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Civil Aircraft Inspection Procedures

Part II - Aircraft

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AIRFRAME

FLYING CONTROLS

CONTROL CHAINS, CHAIN WHEELS AND PULLEYS

1 INTRODUCTION

1.1 The purpose of this Leaflet is to provide guidance and advice on the installation and maintenance of steel roller chains, chain wheels and pulleys used in aircraft control systems.

1.2 Chains provide strong, flexible and positive connections, and are generally used wherever it becomes necessary to change the direction of control runs in systems where considerable force is exerted, e.g. aileron and elevator controls. The change of direction is achieved by the use of chain wheels or pulleys. Chains may be found in, control column installations, aileron controls and elevator controls, and in trim control systems.

1.3 Chains may be used solely in control runs or in conjunction with cable assemblies. In either case, the incorrect assembly of the chains should be rendered impossible by the use of non-reversible chains in conjunction with the appropriate types of wheels, guards and connectors.

1.4 Subject headings are as follows:—

2 SPECIFICATIONS

2.1 Chains used for aircraft purposes are generally of the simple roller type and comply with the requirements of British Standard BS 228: 1984, entitled Specification for Short Pitch Transmission Precision Roller Chains and Chain Wheels. A complete schedule of dimensions and breaking loads for chains is given in this Standard.

NOTE: BS 228 is equivalent to ISO 606 — 1982.

2.2 Chain assemblies are produced to standards prepared by the S.B.A.C. These standards providing a range of chains built up in various combinations with standard fittings, e.g. end connectors with internal or external threads, bi-planer blocks for changing the plane of articulation of a chain through 90° (see Figure 4) and cable spools for connecting chains to cables having eye-splices. Such fittings are illustrated in Figures 1 and 4.

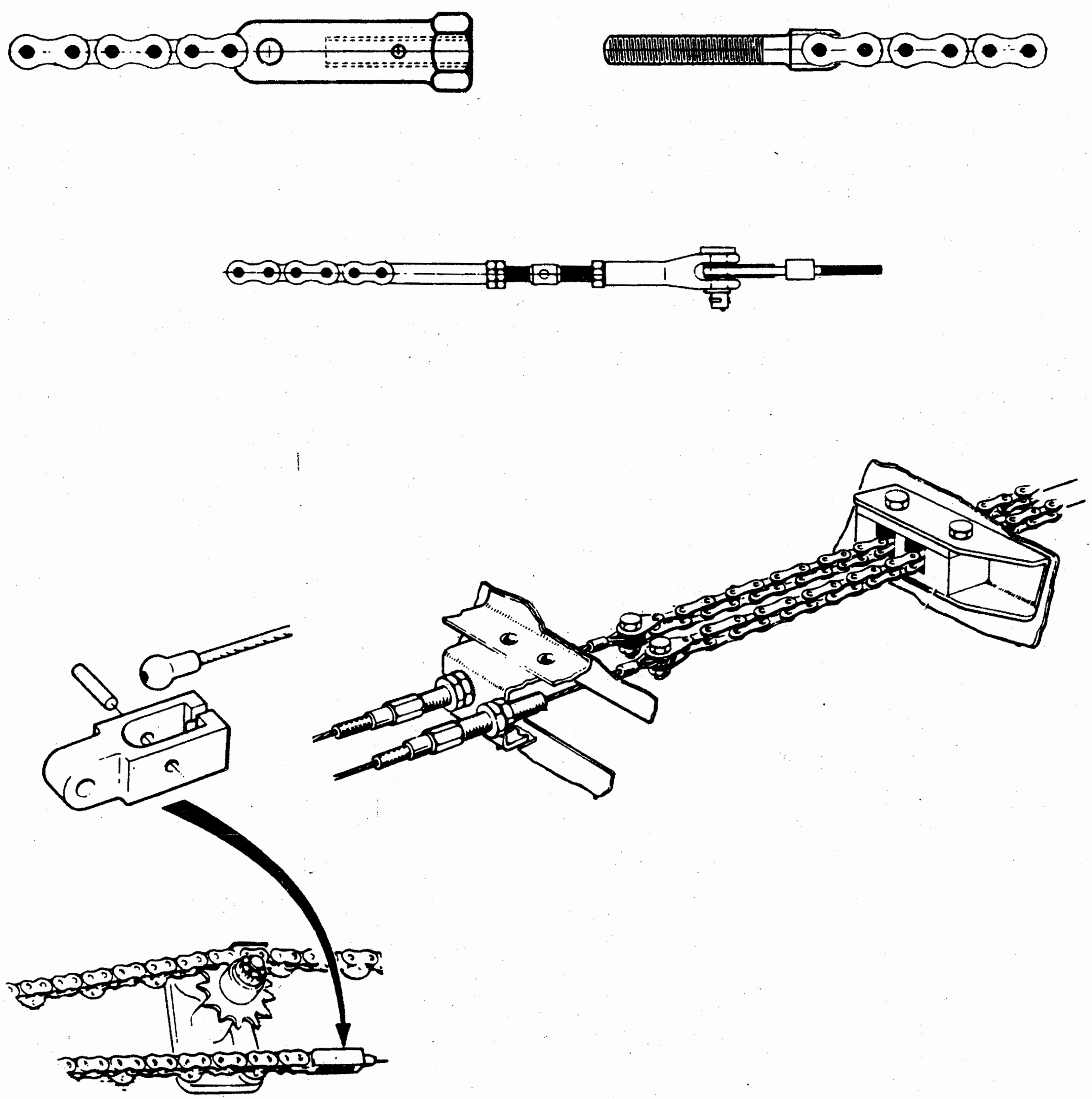


Figure 1 STANDARD CHAIN FITTINGS

3 CHAIN ASSEMBLIES

3.1 A simple roller chain consists of outer and inner plates, rollers, bearing pins and bushes; the component parts are shown in Figure 2(a). The chain has three principal dimensions (known as gearing dimensions since they are related to the size of the wheels on which the chains run), these being pitch, width between inner plates, and roller diameter. The positions at which these dimensions are measured are shown in Figure 2(b).

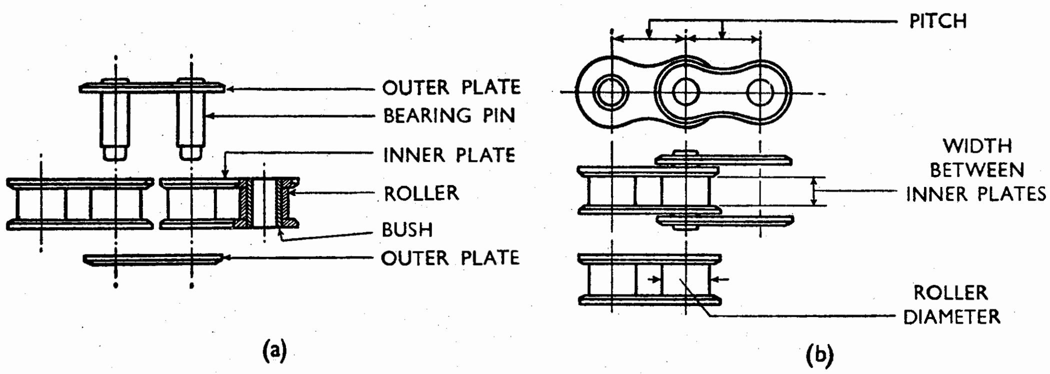


Figure 2 CHAIN DETAILS

3.2 A typical assembly for ⅜ in and ½ in chains, using a standard end connector with an internal thread, is shown in Figure 3.

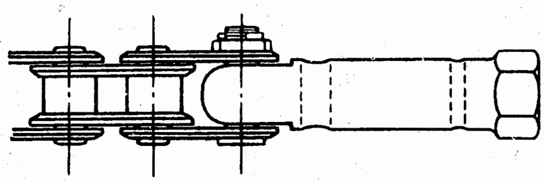


Figure 3 TYPICAL CHAIN END ASSEMBLY

3.3 The pitch of the chain is the distance between the centres of the rollers, and for aircraft purposes, four sizes of chain are standardised by the S.B.A.C., as shown in Table 1. BS 228 prescribes that the proof-load (see paragraph 6.6) for a chain should be one-third of the minimum breaking load; the relevant figures for simple chains are also given in Table 1.

TABLE 1

Chain Pitch	*BS No.*	*Minimum Breaking Load*	*Proof Load (lb)*
8 mm	1	800 lb	267
0·375 in	2	1900 lb	634
0·50 in	4	1800 lb	600
0·50 in	6	3500 lb	1166

3.4 Chain assemblies for aircraft systems should be obtained as complete, proof-loaded units from approved chain assembly manufacturers, and no attempt should be made to break and reassemble riveted links or riveted attachments. If it is necessary to disconnect the chain, this should be undertaken only at the bolted or screwed attachments. Split pins must not be re-used, and this applies also to nuts and bolts which have been peened.

NOTE: The procedure specified by S.B.A.C. standards for securing nut and bolt joints for Class 1 application is to peen the bolt end for 8 mm pitch chain and to split pin the bolts of the remaining standard chains. In all cases the nut is actually a lock nut, since the hole in the loose outer plate is also tapped.

3.5 The use of cranked links for the attachment of the chain to end fittings, etc, is not permitted, thus, when a chain is required to terminate in a similar manner at each end, the length should be an odd number of pitches. For the same reason, an endless chain should have an even number of pitches.

3.6 The use of spring clip connecting links is prohibited, and the attachment of chains to other parts of the system should be effected by positive methods such as pre-riveted or bolted joints.

4 INSTALLATION OF CHAIN ASSEMBLIES

4.1 Figure 4 illustrates typical arrangements of chain assemblies. Figure 4(a) shows the simple transfer of straight-line to rotary motion, Figure 4(b) illustrates how a change of direction of straight-line motion is obtained, whilst Figure 4(c) shows a change of direction of motion in two planes by the use of a bi-planer block.

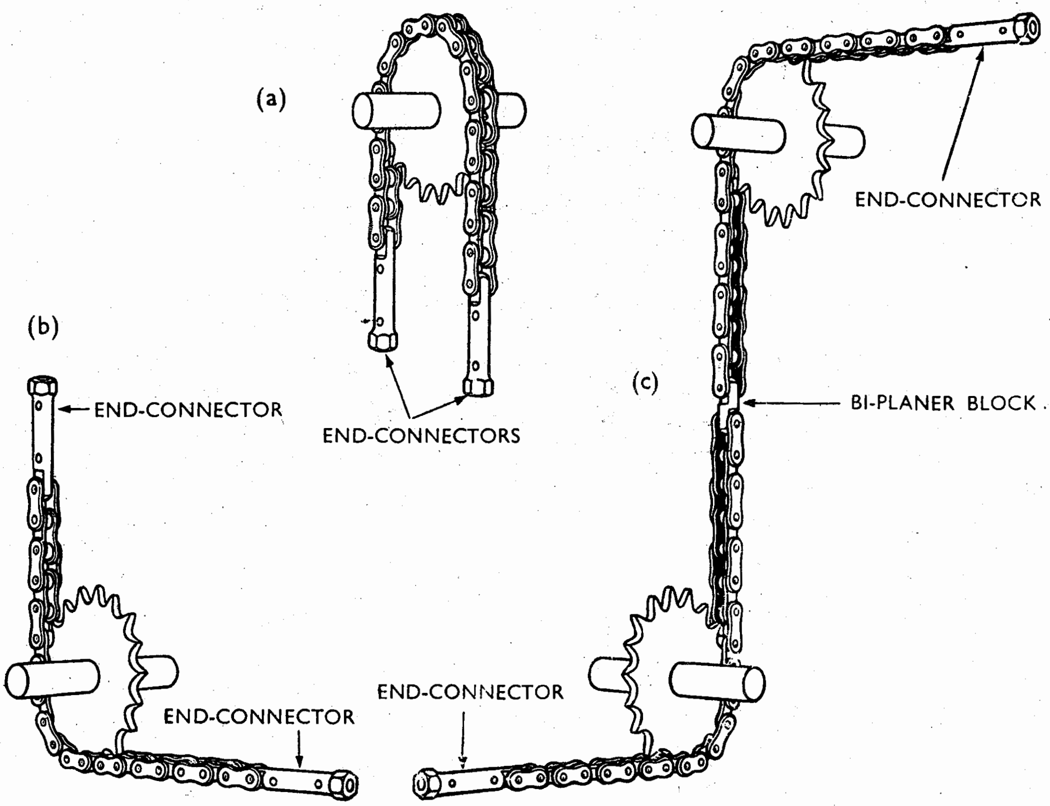


Figure 4 TYPICAL CHAIN ASSEMBLY ARRANGEMENTS

4.2 A range of non-interchangeable end fittings is available as a safeguard against the crossing of controls. However, these connectors do not always prevent the possibility of reversing the chain end to end on its wheel, neither do they prevent the possibility of the chain being assembled to gear on the wrong face where two wheels are operated by the same chain. Such contingencies can be overcome by the use of non-reversible chains.

4.3 **Non-reversible Chains**

4.3.1 Non-reversible chains are similar to standard chains except that every second outer plate is extended in one direction in order to break up the symmetry of the chain. The complete system of non-reversibility involves the use of five features, i.e. the non-reversible chain, the shroud on the wheel, correct positioning of the wheel on its shaft, the chain guard, and non-interchangeable connectors. The shape of the special outer plates and the principle of non-reversible chains is shown in Figure 5.

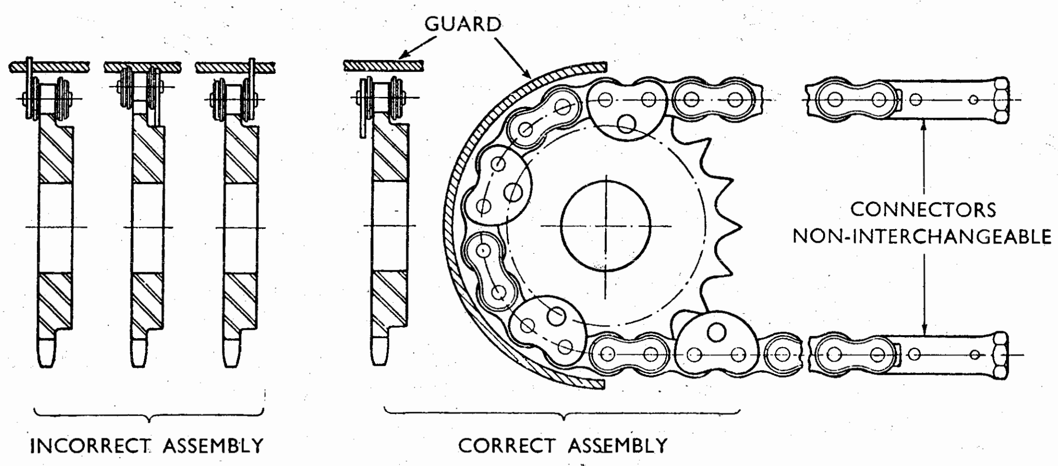


Figure 5 NON-REVERSIBLE CHAIN ASSEMBLY

4.3.2 It will be seen from Figure 5 that by providing a shroud on one side of the wheel and by making use of the chain guard, the reversing of the chain end to end on its wheel is not possible. It should be borne in mind that in practice a special feature, such as an attachment collar, a key, or a flat on the shaft in conjunction with a specially shaped hole, is incorporated in the wheel mounting to ensure that it can be assembled on its shaft in one definite position only.

4.3.3 Figure 6 illustrates an instance where the use of jockeys is necessary or where contra-rotation of the wheels is required; it will be seen that the feature of non-reversibility does not affect the ability of the chain to gear on both sides.

4.4 **Inspection after Assembly**

4.4.1 After installation in the aircraft, the chain should be examined for freedom from twist, particularly in instances where the attachment is made to threaded rods by means of screwed end connectors, or where a twist may inadvertently be applied to the chain during the locking of the assembly. Care should be also taken to ensure that the chain is not pulled out of line by the chain wheel; the chain should engage smoothly and evenly with the wheel teeth and there should be no tendency for the chain to ride up the teeth.

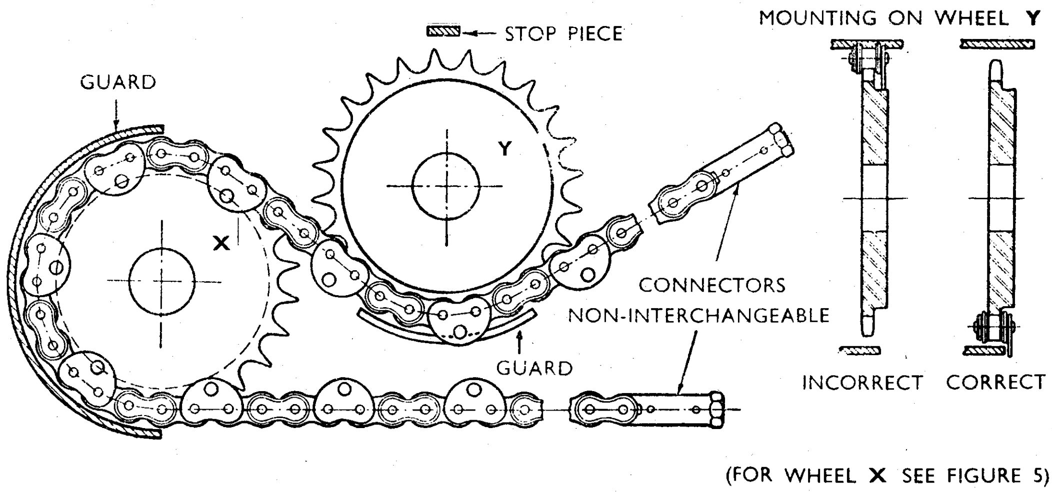


Figure 6 NON-REVERSIBLE CHAIN WITH JOCKEY PULLEY

4.4.2 The pre-tensioning of chains should not be excessive, as this will cause friction, but should be just sufficient to prevent any back-lash in the system.

4.4.3 The guarding should be checked to ensure that jamming could not occur, and that the chain would not come off the wheel should it become slack.

4.4.4 The security of end connections should be checked, care being taken to ensure that the split pins in the chain connecting bolts are correctly locked.

4.4.5 The initial lubricant on new chains should not be removed, and the chains should be further lubricated after assembly by brushing all over, particularly on link edges, with lubricant complying with specification DTD 417A, unless otherwise specified.

4.4.6 The wheel or pulley mountings should be examined to ensure that the wheels or pulleys are firmly secured to the shafts or spindles, that they are correctly located, and are running freely.

5 MAINTENANCE INSPECTION

5.1 Chain assemblies should be inspected for serviceability at the periods specified in the relevant Maintenance Schedule; guidance on the recommended methods of checking chains is given in the following paragraphs.

5.2 The continued smoothness of operation between the chain and the chain wheel or pulley should be checked. If the chain does not pass freely round the wheel or pulley, it should be removed and checked as detailed in paragraph 6.

5.3 The chain should be checked for wear; if it is worn so that the links are loose and can be lifted away from the wheel teeth, it should be removed and checked for excessive elongation as detailed in paragraph 6.3.

5.4 The chain should be checked for damage, cleanliness, adequacy of lubrication and freedom from corrosion. If the inspection shows the chain to be corroded or otherwise defective, it should be removed.

5.5 In instances where it becomes necessary to adjust the tension of the chain in systems incorporating turnbuckles or screwed end connectors, care should be taken to ensure that the chain itself is not twisted during the adjustment. The connectors should be held firmly while the locknuts are being slackened or tightened.

6 INSPECTION OF CHAIN ASSEMBLIES

6.1 Chain assemblies should be removed from the aircraft for complete inspection at the periods specified in the appropriate Maintenance Schedule.

6.2 **Removal.** When it is necessary to disconnect the chains the assemblies must be removed at design breakdown points.

6.3 **Checking Elongation**

6.3.1 If elongation through wear is suspected, the following procedure should be adopted:—

(a) The chains should be cleaned by immersion in clean paraffin and brushing with a stiff brush; after cleaning, the chains should be dried immediately by hot air to ensure that no paraffin remains, otherwise the chains will corrode. The chains should be measured when clean but before any oil is applied.

(b) The chains should be placed on a flat surface and stretched by the application of a tensile load. Table 2 indicates the load applicable to the various sizes of chains. The length should then be measured between the centres of the bearing pins, elongation being calculated by the formula given in paragraph (c).

TABLE 2

Chain Pitch	*BS No.*	*Tensile Load (lb)*
8 mm	1	12
0·375 in	2	16
0·50 in	4	28
0·50 in	6	28

(c) The percentage extension over the nominal length should be calculated by the following formula:

$$\text{Percentage extension} = \frac{M - (X \times P)}{X \times P} \times 100$$

where

M = Measured length under load in inches.
X = Number of pitches measured.
P = Pitch of chain in inches.

6.3.2 If the extension is in excess of 2% on any section of the chain the whole run of chain should be replaced. Should localised wear be likely to occur in a chain run, additional checks should be made on such sections, and the percentage extension ascertained from the formula given in paragraph 6.3.1(c). If the extension in such sections is in excess of 2%, the chain should be rejected.

6.3.3 The chain should be checked for kinks and twists by suspending it freely and sighting along the length; if kinks or twists exist the chain should be rejected.

6.4 **Checking Articulation.** The chain should be checked for tight joints by articulating each link through approximately 180°. The most suitable method being to draw the chain over a finger. Tight joints may be caused by foreign matter on the bearing pins or between the inner and outer plates; this may be remedied by cleaning as described in paragraph 6.3.1(a). If cleaning is not successful, the end of the bearing pin may be very gently tapped with a light hammer, but if this does not clear the joint, the chain should be rejected. Tightness may also be caused through lack of clearance between the inner and outer plates due to damage; if this is so, the chain should be rejected.

6.5 **Checking for Deterioration.** The chain should be examined for damage, cracks and wear to plates and rollers, and for evidence of corrosion and pitting.

NOTE: It is not permissible to break down or attempt to tighten a riveted link in a run of chain.

6.6 **Proof Loading.** It is not necessary to proof load a chain after removal for routine examination. However, if it is desired to replace a portion only of the assembly, proof loading of the complete assembly is necessary. The proof load (Table 1) should be evenly applied, and unless this can be assured, it is considered preferable to fit a complete new assembly.

6.7 **Protection and Storage.** After the chain has been cleaned, inspected and found to be acceptable, it should be thoroughly soaked in an appropriate oil, time being allowed for the lubricant to penetrate to the bearing surfaces. If not required for immediate use, the chain should be laid on a flat surface, carefully coiled, and wrapped in greaseproof paper, care being taken to ensure the exclusion of dirt, and the prevention of distortion, during storage.

7 INSTALLATION OF CHAIN WHEELS AND PULLEYS

7.1 During installation, chain wheels and pulleys should be checked to ensure that they are attached in the manner and method specified by the relevant drawings. The correct positioning of chain wheels is of particular importance when non-reversible chains are used (see paragraph 4.3). During maintenance, chain wheels should be checked for security and wear on the teeth. Pulleys should be checked for damage and excessive wear on the walls and on the chain guide section. The continued efficiency of ball races should also be ascertained.

AL/3-6

Issue 1.

15*th November*, 1974.

AIRCRAFT

SYSTEMS AND EQUIPMENT

LANDING GEAR

1 INTRODUCTION This Leaflet gives general information on the different types of landing gear used on aircraft, the various components employed, and the maintenance practices normally recommended. Because of the wide variety of landing gear designs, this Leaflet should be read in conjunction with the appropriate aircraft Maintenance Manual and the approved Maintenance Schedule. The Leaflet does not deal with the specialised methods of operating on water, snow and ice.

1.1 Information on associated subjects will be found in the following Leaflets:—

BL/6-15 Manufacture of Rigid Pipes

AL/3-13 Flexible Pipes

AL/3-14 Installation of Rigid Pipes in Aircraft

AL/3-18 Tyres

AL/3-19 Wheels and Brakes

AL/4-1 Hydraulic Systems—Installation and Maintenance

2 GENERAL The functions of a landing gear are to support an aircraft during ground manoeuvres, dampen vibration, and absorb landing shocks; when required, it also performs the functions of steering and braking. These objectives are achieved by many different designs, depending on the type of aircraft to which the landing gear is fitted and the degree of sophistication required. A landing gear usually takes the form of two or more main undercarriage units in the wings or fuselage, and an auxiliary undercarriage unit at the nose or tail which carries only a small proportion of the total load and is used for steering purposes.

2.1 With slow, light aircraft, and some larger aircraft on which simplicity is of prime importance, a fixed (non-retractable) landing gear is often fitted; the reduced performance caused by the drag of the landing gear during flight is offset by the simplicity, reduced maintenance and low initial cost. With higher performance aircraft, drag becomes progressively more important, and the landing gear is retracted into the wings or fuselage during flight; there are, however, penalties of increased weight, greater complication and additional maintenance.

2.2 The landing gear of an aircraft may receive harsh treatment throughout its installed life, being subject to frequent landing shocks and in regular contact with spray, ice, dirt, and abrasive grit. Regular washing, servicing and lubrication are required, therefore, to guard against corrosion, seizure of mechanical parts and failure of electrical components.

3 FIXED LANDING GEAR There are three main types of fixed landing gear; those which have a spring steel leg, those which employ rubber cord to absorb shocks, and those which have an oleo-pneumatic strut to absorb shocks. Exceptions include aircraft with rubber in compression, spring coil, and liquid spring struts.

3.1 **Spring Steel Legs.** Spring steel legs are usually employed at the main undercarriage positions. The leg consists of a tube, or strip of tapered spring steel, the upper end being attached by bolts to the fuselage and the lower end terminating in an axle on which the wheel and brake are assembled.

3.1.1 **Maintenance.** Spring steel undercarriages should be inspected regularly for damage and corrosion. The aircraft should be jacked up periodically, so that all load is taken off the wheels, and the security of each undercarriage checked by attempting to move it against the restraint of its attachments to the airframe structure. If there are signs of looseness, the bolts should be removed for detailed inspection and the bolt holes should be checked for cracks or fretting. Axle fittings should be similarly inspected, and all nuts and bolts should be tightened to the specified torque.

3.2 **Rubber Cord.** When rubber cord is used as a shock-absorber, the undercarriage is usually in the form of tubular struts, designed and installed so that the landing force is directed against a number of turns of rubber in the form of a grommet or loop.

3.2.1 Rubber cord is colour coded to indicate the date of manufacture and the specification to which it conforms, by replacing some of the fibres in the outer cotton covering with coloured threads wound in a spiral. Details concerning the significance of the colour coding may be obtained from British Standards F16, F51, F70 or F71 as appropriate.

3.2.2 **Maintenance.** The undercarriage should be examined for damage, corrosion, wear or cracks at the pivot points, and bent pivot bolts, and should be lubricated as specified in the approved Maintenance Schedule. The rubber cord should be inspected for chafing, necking, or other deterioration, and it is advisable to replace it if it is more than five years old, regardless of its external condition.

3.3 **Oleo-pneumatic Struts.** Some fixed main undercarriages, and most fixed nose undercarriages, are fitted with an oleo-pneumatic shock-absorber strut. The design of individual struts varies considerably, and reference should be made to the appropriate Maintenance Manual for a particular type, but operation and maintenance procedures for a typical design are covered in the following paragraphs.

3.3.1 **Construction.** Figure 1 shows the construction of a simple oleo-pneumatic strut, in this instance a nose undercarriage which also includes a steering mechanism. The outer cylinder is fixed rigidly to the airframe structure by two mounting brackets, and houses an inner cylinder and a piston assembly, the interior space being partially filled with hydraulic fluid and inflated with compressed gas (air or nitrogen). The inner cylinder is free to rotate and move up and down within the outer cylinder, but these movements are limited by the torque links, which connect the inner cylinder to the steering collar. The steering collar arms are connected through spring struts to the rudder pedals, and a shimmy damper is attached to the steering collar.

3.3.2 **Operation**

(i) Under static conditions the weight of the aircraft is balanced by the strut gas pressure and the inner cylinder takes up a position approximately midway up its stroke.

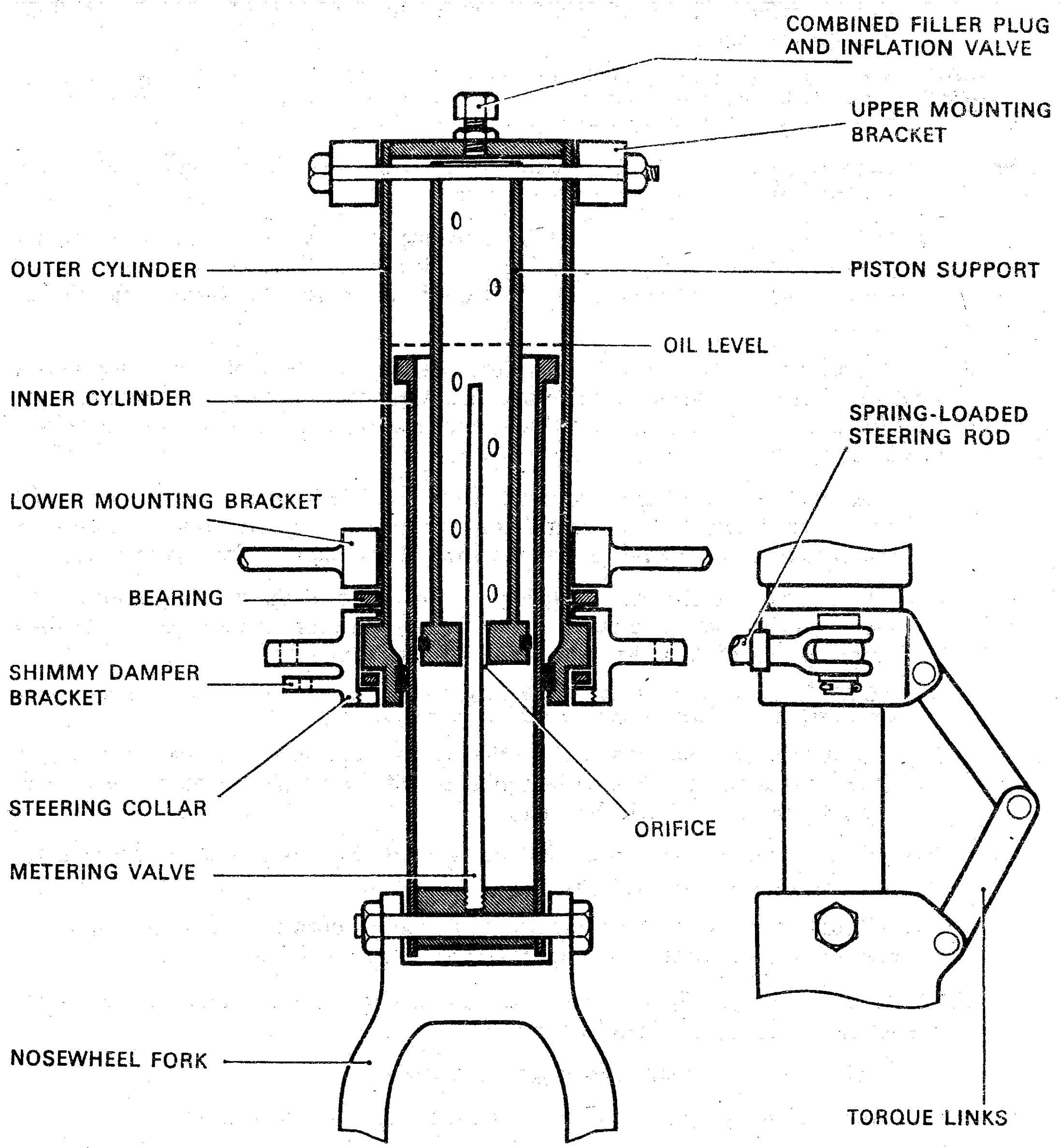


Figure 1 OLEO-PNEUMATIC STRUT

(ii) Under compression (e.g. when landing), the strut shortens and fluid is forced through the gap between the piston orifice and the metering rod, this restriction limiting the speed of upward movement of the inner cylinder.

(iii) As the internal volume of the cylinders decreases, the gas pressure rises until it balances the upward force.

(iv) As the upward force decreases, the gas pressure acts as a spring and extends the inner cylinder. The speed of extension is limited by the restricted flow of fluid through the orifice.

NOTE: On some struts an additional valve is fitted to the piston or inner cylinder, to further restrict the flow of fluid during extension, and prevent violent extension of the strut if upward force is suddenly released, such as when a bounce occurs.

(v) Normal taxying bumps are cushioned by the gas pressure and dampened by the limited flow of fluid through the orifice.

(vi) Movement of the rudder pedals turns the nose wheel to facilitate ground manoeuvres, the spring struts being provided to allow for vertical movement of the nose wheel, and prevent shocks from being transmitted through the rudder control system.

3.3.3 **Maintenance.** Oleo-pneumatic undercarriages should be subjected to inspections similar to those recommended for spring leg and rubber cord types, such as examinations for cracks or damage to mounting structure, corrosion, and wear at pivot points. In addition, the following maintenance is necessary:—

(i) Machined surfaces of the strut inner cylinder should be wiped free of dust or dirt at frequent intervals, to prevent damage to the lower cylinder seals. A lint-free cloth, soaked in the fluid used in the strut, should be used for this purpose.

(ii) The extension of the inner cylinder, i.e. the length of the visible portion of the inner cylinder, should be checked frequently against the centre of gravity/loading graphs provided in the approved Maintenance Manual.

NOTE: Because of the tightness of the sealing glands in the strut, it may be necessary to rock the aircraft to free the inner cylinder and obtain the true extension.

(iii) The strut should be inspected frequently for fluid leaks. If leaks are due to faulty glands the glands may be replaced, but if they are due to a scored inner cylinder, the strut should be changed.

(iv) Torque links, steering arms, and damper attachments should be checked for security, and for cracks, wear or any other damage.

(v) All moving parts of the undercarriage should be lubricated on assembly, and at the intervals specified in the approved Maintenance Schedule.

3.3.4 **Servicing Struts.** When it becomes necessary to check the fluid level in a strut, the following procedure should be carried out:—

(i) Jack up aircraft to take the weight off the strut.

(ii) Remove inflation valve cap and release air pressure completely.

(iii) Remove valve housing.

(iv) Compress strut and check fluid level is at bottom of filler hole; if not, top-up with the approved fluid.

(v) Extend and compress strut several times to expel any trapped air, then repeat (iv).

(vi) With strut compressed, replace valve housing and inflate strut to specified gas pressure, checking that the leg extends completely.

NOTE: It is usually recommended that a new seal is fitted when replacing the valve.

(vii) Lower aircraft and check that extension of the inner cylinder is in accordance with the tables or graphs supplied by the manufacturer, for the particular aircraft weight and centre of gravity position.

3.4 **Shimmy Dampers.** Most nose and tail wheels are fitted with shimmy dampers to prevent rapid oscillation during ground manoeuvres.

3.4.1 A simple damper consists of two friction discs, one connected to a fixed part of the undercarriage and the other connected to the oscillating part. The discs are held in contact by spring pressure and resist relative movement between the parts to which they are connected.

3.4.2 A type of damper commonly found on light aircraft is illustrated in Figure 2; the piston rod is connected to the steering collar and the cylinder attached to a fixed part of the strut. The cylinder is completely filled with fluid, and small holes in the piston allow a restricted flow of fluid when force is applied to the piston rod. Movement of the nose undercarriage is therefore slowed down, and oscillations damped.

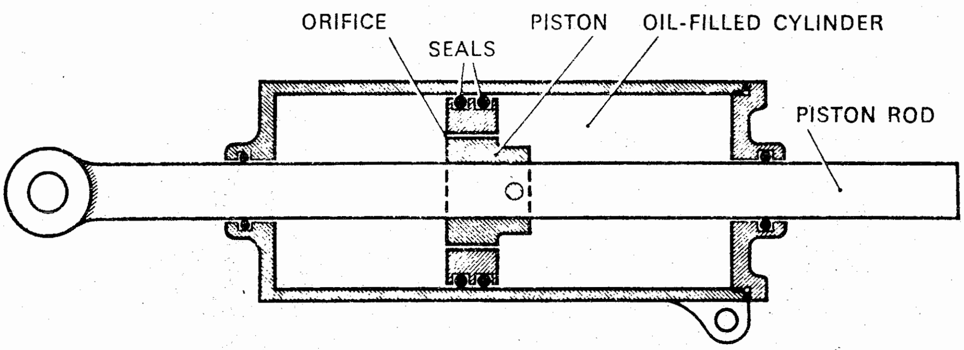


Figure 2 DAMPER STRUT

3.4.3 **Maintenance.** Friction disc dampers should be inspected for security, damage, and wear of the friction material. Piston type dampers will not operate satisfactorily if air is present in the cylinder, and should be inspected frequently for oil leaks; they should be removed at the periods specified in the approved Maintenance Schedule, and the oil level checked.

4 RETRACTABLE LANDING GEAR The majority of modern transport aircraft, and an increasing number of light aircraft, are fitted with a retractable landing gear, for the purpose of improving aircraft performance. Retraction is normally effected by a hydraulic system, but pneumatic or electrical systems are also used. In some instances power is used for retraction only, extension being effected by gravity and slipstream. Retractable landing gear is also provided with mechanical locks to ensure that each undercarriage is locked securely in the retracted and extended positions; devices to indicate to the crew the position of each undercarriage; and means by which the landing gear can be extended in the event of failure of the power source. In addition, means are provided to prevent retraction with the aircraft on the ground, and to guard against landing with the landing gear retracted. Undercarriage wells are normally sealed by doors for aerodynamic reasons, but one particular aircraft type employs inflatable rubber bags to seal the main undercarriage wells.

4.1 Retractable undercarriages normally consist of an oleo-pneumatic shock-absorber strut, similar to the one shown in Figure 1 but supported in a trunnion bearing which is fixed to a spar or strengthened box section in the wings or fuselage; the strut is braced longitudinally by drag struts, and laterally by sidestays. In some designs the drag strut or sidestay is in two parts, and hinges about the centre point to provide a means of retraction, while in others the retraction jack operates on an extension of the shock-absorber strut housing. Figure 3 shows a typical retractable undercarriage unit which is hydraulically operated in both directions and locked by means of a geometric (over-centre) lock.

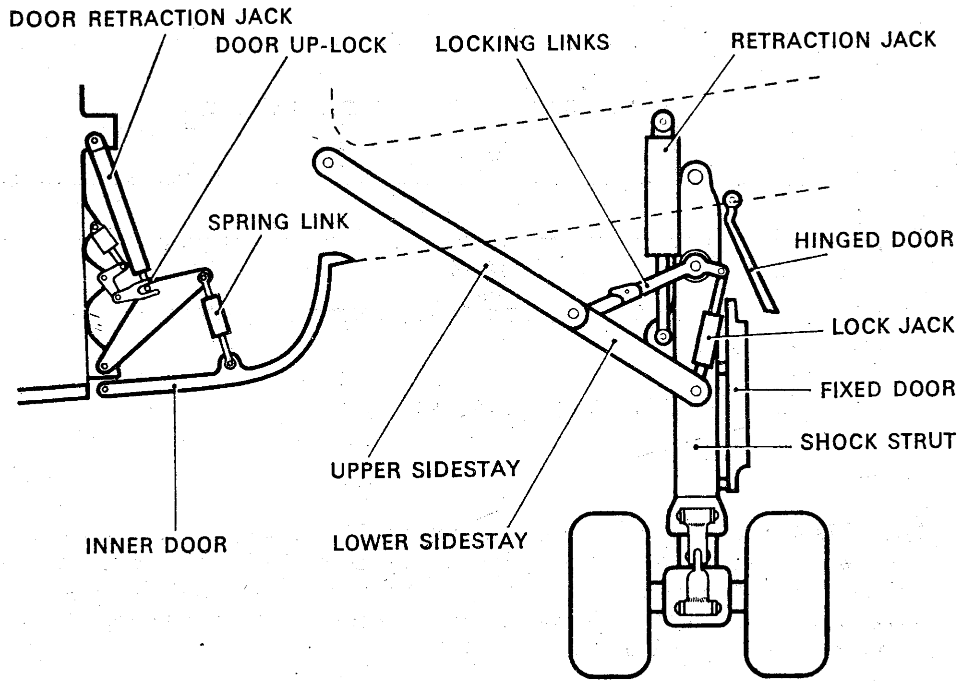


Figure 3 TYPICAL UNDERCARRIAGE UNIT

4.2 **Hydraulic Retraction System.** A hydraulic system for retracting and extending a landing gear normally takes its power from engine driven pumps, alternative systems being available in case of pump failure. On some light aircraft a self-contained 'power-pack' is used, which houses a reservoir and selector valves for the landing gear and flap systems; an electrically driven pump may also be included, or the system may be powered by engine driven pumps. This type of system normally provides for powered retraction of the landing gear, extension being by 'free-fall', with the assistance of spring struts.

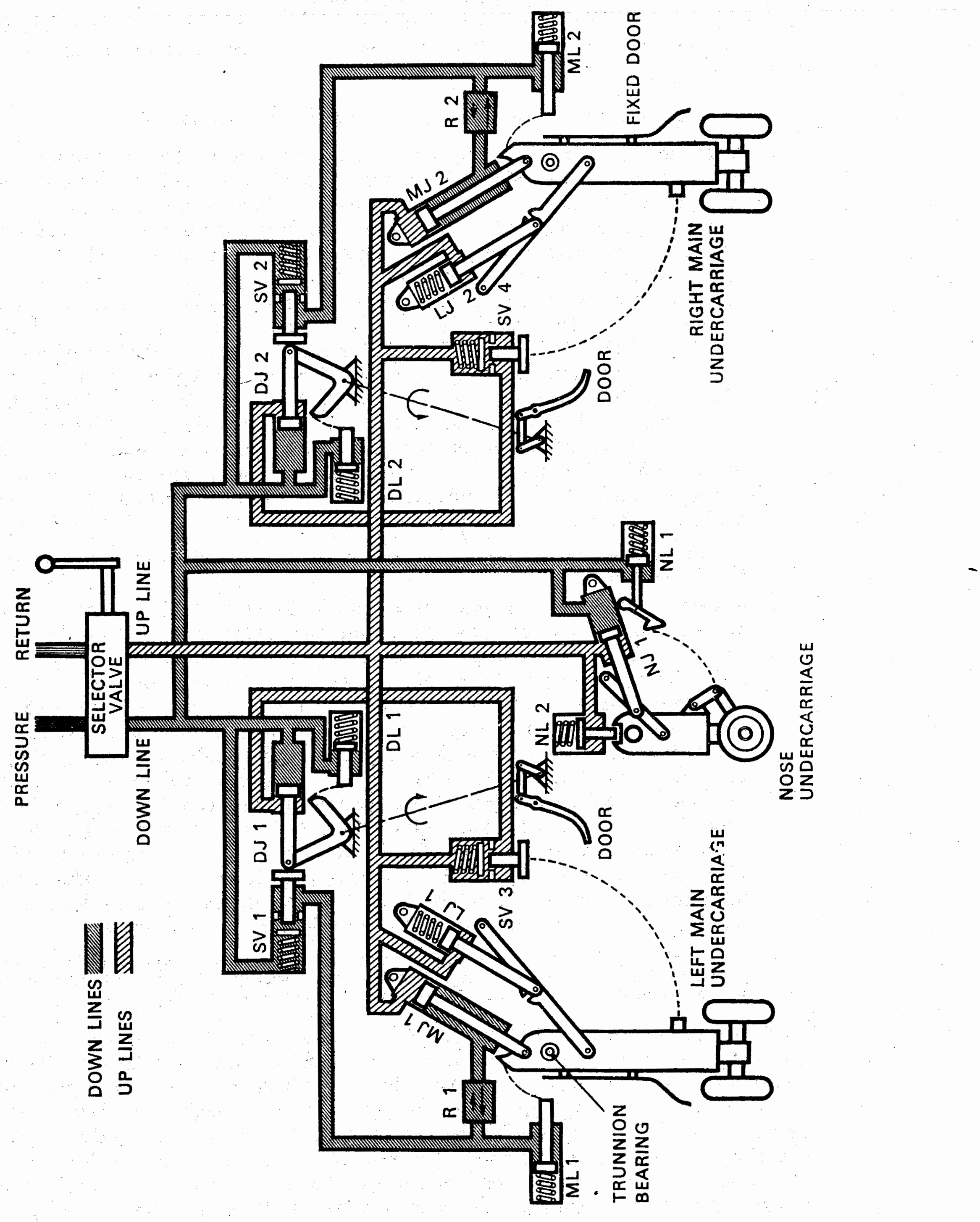


Figure 4 SIMPLE HYDRAULIC RETRACTION SYSTEM

4.2.1 Figure 4 is a schematic diagram of a simple hydraulic retraction system. The various components shown illustrate operation of this system, but are not intended to represent a typical design; actual components often operate in a different manner, but their purpose is the same.

4.2.2 Operation of the system illustrated in Figure 4 is as follows:—

(i) **Retraction.** When the landing gear selector is moved to the 'up' position, fluid under pressure is directed to the 'up' line and fluid from the 'down' line is directed back to the hydraulic reservoir. Fluid flows to the sequence valves (SV3, SV4), retraction jacks (MJ1, MJ2, NJ1), main undercarriage down-lock jacks (LJ1, LJ2), and nose undercarriage down-lock (NL2); it cannot pass the sequence valves, which are closed, but operates the retraction jacks and down locks. The locks operate first, releasing the landing gear and allowing the retraction jacks to raise each undercarriage, the nose undercarriage engaging its spring-loaded up-lock (NL1) first, because of the jack's smaller size. At the end of upward travel of the main undercarriage units, a striker on each leg contacts the plunger of its associated sequence valve (SV3, SV4), and opens the valve, allowing fluid to flow to the door jacks (DJ1, DJ2). The main undercarriage engages the up-locks (ML1, ML2) and the doors close, engaging locks DL1, DL2. Fluid in the 'down' lines returns to the reservoir, flowing unrestricted through the restrictor valves (R1, R2) and overcoming the small restriction of the spring loading of the sequence valves (SV1, SV2).

NOTE: The nose undercarriage doors are operated mechanically by linkage to the nose shock-absorber housing.

(ii) **Extension.** When the landing gear selector is moved to the 'down' position, fluid under pressure is directed to the 'down' line, and fluid from the 'up' line is directed back to the reservoir. Fluid flows to the sequence valves (SV1, SV2), door jacks (DJ1, DJ2), door locks (DL1, DL2), nose undercarriage retraction jack (NJ1) and the nose undercarriage up-lock (NL1). The sequence valves are closed, so fluid pressure releases all the door locks and the nose undercarriage up-lock, and the doors and nose undercarriage extend, the nose undercarriage engaging its down-lock (NL2) at the end of its travel. When the doors are fully open, the door jacks strike the plungers of their associated sequence valves (SV1, SV2) and open the valves, allowing fluid to flow through the restrictor valves (R1, R2) to the main undercarriage up-locks (ML1, ML2) and retraction jacks (MJ1, MJ2). These locks are released, and the retraction jacks lower the main undercarriage fully, the spring-loaded lock-jacks (LJ1, LJ2) imposing a geometric lock on the sidestays. Main undercarriage doors are held open by fluid pressure.

NOTE: Restrictor valves are normally fitted to limit the speed of lowering of the main undercarriage units, which are influenced in this direction by gravity. The nose undercarriage often lowers against the slipstream and does not need the protection of a restrictor valve.

4.3 **Pneumatic Retraction System.** Operation of a pneumatic retraction system is similar to that of a hydraulic system, except that pressure in the return lines is exhausted to atmosphere through the selector valve. Pressure is built up in a main storage cylinder by engine driven air pumps, and passes through a pressure reducing valve to the landing gear selector valve. Operation of the selector valve to the 'up' position directs pneumatic pressure through the 'up' lines to the retraction rams, and opens the down line to atmosphere. Operation of the selector valve to the 'down' position directs pneumatic pressure through a second pressure reducing valve and the down lines, to the up-lock rams and retraction rams. A simple pneumatic system is illustrated in Figure 5.

NOTE: A low pressure is used for landing gear extension, for the same reason that restrictor valves are used in hydraulic systems, which is to prevent damage occurring through too-rapid extension of the undercarriage units.

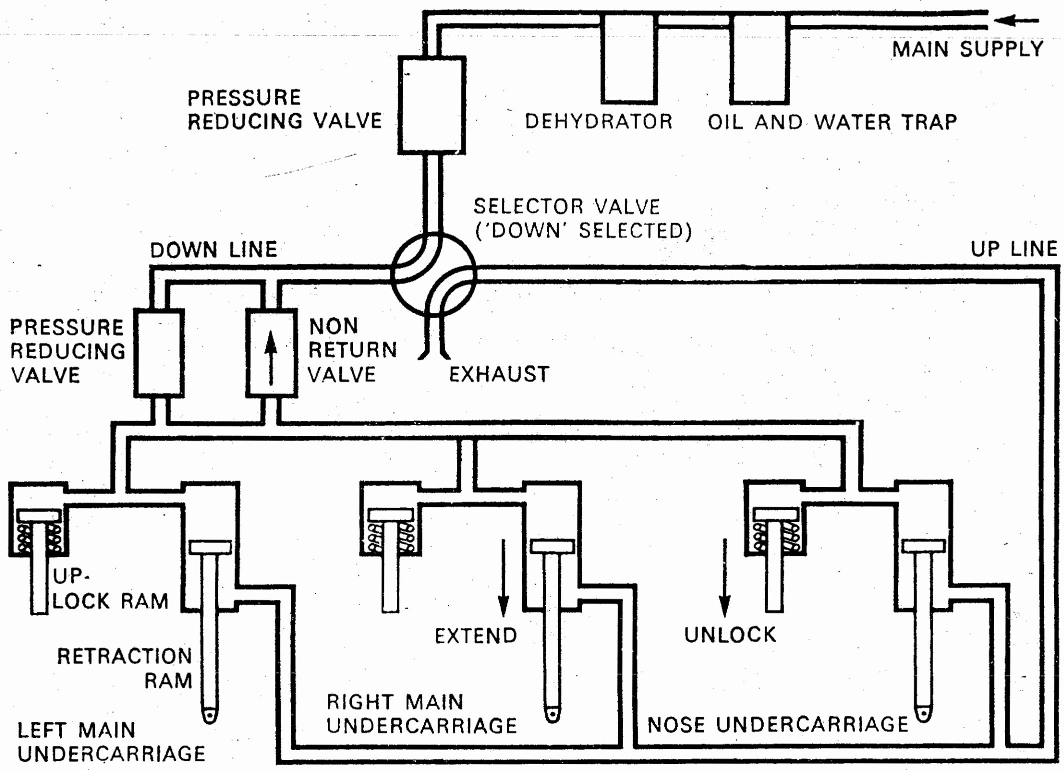


Figure 5 SIMPLE PNEUMATIC RETRACTION SYSTEM

4.3.1 Retraction rams are usually damped to prevent violent movement. The hollow piston rod is filled with oil or grease, which is forced through the annular space between the inner surface of the piston rod and a stationary damper piston whenever the ram extends or retracts, thus slowing movement.

4.3.2 Up-locks and down-locks are similar to those used with hydraulic systems, the geometric down-locks being imposed by over-centering of the drag strut at the end of retraction ram stroke, and the up-locks by spring-ram operated locks. Down-locks are released by initial movement of the retraction rams during retraction, and up-locks are released by pneumatic pressure in the spring-rams during extension.

4.3.3 Undercarriage doors are operated mechanically, by linkage on the shock-absorber housing.

4.4 **Electrical Retraction System.** An electrical retraction system is often fitted to light aircraft which do not otherwise require the use of a high pressure fluid system. The main and nose undercarriage units are similar to those used in fluid retraction systems, but push and pull forces on the retraction mechanism are obtained by an electric motor and suitable gearing. Figure 6 illustrates a typical system, in which a single reversible electric motor provides the power to retract and extend the landing gear.

4.4.1 The motor operates a screw jack, which provides angular movement to a torque tube; a push-pull rod from the torque tube acts on the drag strut of the nose undercarriage, and cables and rods from the torque tube act on the main undercarriage sidestays, rubber cord being used to assist extension of the main undercarriage units.

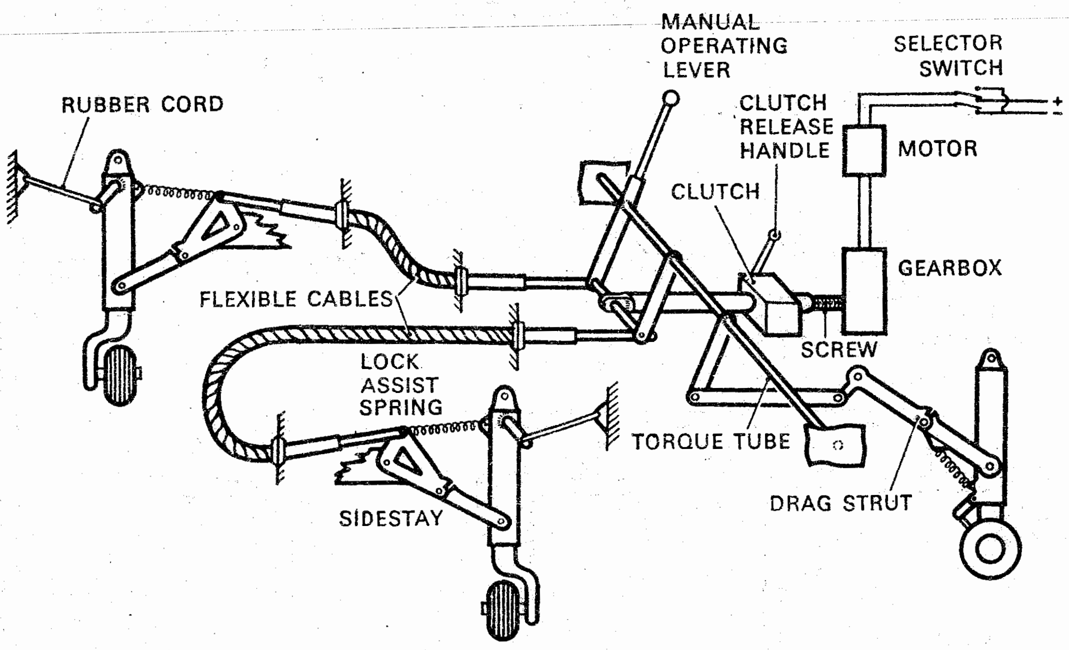


Figure 6 SIMPLE ELECTRICAL RETRACTION SYSTEM

4.4.2 Down-locks are imposed by over-centering of the drag strut and sidestays during final movement of the operating mechanism, with the assistance of springs. Limit switches on the drag strut and sidestays cut off electrical power and brake the motor when the down-locks have engaged, while a limit switch on the torque tube stops and brakes the motor when the landing gear is fully retracted.

4.4.3 Undercarriage doors are operated by linkage to the shock-absorber housings.

4.5 **Position Indication.** Although the landing gear, when selected down, may be visible from the crew compartment, it is not usually possible to be certain that each undercarriage is securely locked. An electrical indicating system is used to provide a positive indication to the crew of the operation of the locks and of the position of the landing gear. The system usually consists of microswitches on the up-locks and down-locks, which make or break when the locks operate, and which are connected to a landing gear position indicator on the instrument panel. A mechanical indicator may also be provided, to show that the landing gear is down and locked when the electrical system is inoperative. On British manufactured aircraft, the electrical undercarriage indicating system operates in such a manner that a green light is displayed when the undercarriage is locked down, a red light is displayed when the undercarriage is in transit, and no lights are visible when the undercarriage is locked up; bulbs are usually duplicated to avoid the possibility of false indications as a result of bulb failures. On other aircraft, similar indications may be obtained by the use of magnetic indicators or lights, but on some light aircraft a single green light indicates that all undercarriages are locked down, and an amber light indicates that all undercarriages are locked up.

On some transport aircraft, provision is also made for the crew to examine the locks during flight in the event of failure or incorrect operation of the indicating system. Whichever indicating system is used, it is important that the microswitches are adjusted so that operation of the lights coincides with the corresponding position of the landing gear.

4.6 **Safety Features.** Since the correct operation of the landing gear is of the utmost importance, a number of safety features are included in the retraction system to ensure its correct operation under all conditions.

4.6.1 **Nose-wheel Centering.** To avoid damage to the airframe structure, the nose wheel must always be aligned in a fore and aft direction during retraction, and a number of methods are used to ensure that this happens automatically. One method utilizes a cam and cam track between the inner and outer cylinders on the shock-absorber. The cam is fixed to the top of the inner cylinder, and the track to the bottom of the outer cylinder. As the strut extends under internal gas pressure after take-off, the cam engages the track and centres the nose undercarriage before it retracts. A second method is the use of a peg located at the top of the shock-absorber strut, which engages a track fixed to the strut housing or in the wheel bay, and this device centres the undercarriage as it retracts. Hydraulic nose wheel centering on aircraft with powered steering is discussed in paragraph 5.

4.6.2 **Selector Lock.** To prevent inadvertent retraction of the landing gear when the aircraft is resting on its wheels, a safety device is incorporated which prevents movement of the selector lever; mechanical ground locks are also provided for servicing purposes. The safety lock consists of a spring-loaded plunger which retains the selector in the down position and is released by the operation of a solenoid. Electrical power to the solenoid is controlled by a switch mounted on the shock-absorber strut; when the strut is compressed the switch is open, but as the strut extends after take-off, the switch contacts close and the electrical supply to the solenoid is completed, thus releasing the selector lever lock and allowing the landing gear to be selected up. A means of overriding the lock, such as a separate gated switch to complete the circuit, or a mechanical means of avoiding the locking plunger, is provided for emergency use and for maintenance purposes.

4.6.3 **Warning Devices.** To guard against landing with the landing gear retracted or unlocked, a warning horn is incorporated in the system and connected to a throttle-operated switch. If one or more throttle levers are less than approximately one third open, as would be the case during approach to land, the horn sounds and the red warning lamp illuminates if the landing gear is in any position other than down and locked. A horn isolation switch is often provided to allow certain flight exercises and ground servicing operations to be carried out without hindrance.

4.6.4 **Emergency Extension.** A means of extending the landing gear and locking it in the down position is provided to cater for the eventuality of main system failure. On some aircraft the up-locks are released manually or by means of an emergency pneumatic system; the landing gear 'free-falls' under its own weight and the down locks are engaged by spring jacks. On other aircraft the landing gear is extended by an emergency pressure system which often uses alternative pipelines to the jacks. Pressure for the emergency system may be supplied by a hydraulic accumulator, a hand pump, a pneumatic storage cylinder, or an electrically powered pump.

4.7 **Maintenance.** The landing gear performs an important function and every care should be taken to ensure that the instructions for its inspection and maintenance contained in the relevant Maintenance Manual and approved Maintenance Schedule are correctly carried out.

4.7.1 **General Precautions.** The following precautions are relevant to most types of landing gear, and will help ensure the safety of personnel and correct operation of the system.

(i) Ground locks should be fitted whenever the aircraft is out of service, and the appropriate circuit breakers tripped, or fuses removed, when work is carried out on the system.

(ii) Replacement or adjustment of components in the retraction system should be followed by a retraction test.

(iii) Components should never be removed while the system is under pressure, i.e. by hydraulic accumulator or pneumatic supply bottle.

(iv) When components are removed, the open pipelines should be properly blanked; rags or masking tape must not be used for this purpose.

(v) New components should be inspected for cleanliness before installation, and it is usually recommended that components containing fluid should be completely filled before installation, or primed and bled after installation.

(vi) Care should be taken to ensure that the fluids used for topping up the hydraulic system or shock-absorber strut are perfectly clean. Funnels and containers must be kept clean and should be rinsed in clean fluid before use.

(vii) Fluid bled or drained from the system, or used for flushing, must be discarded.

(viii) Care should be taken to prevent spillage of fluid, which may have a detrimental effect on paint, rubber, cable insulation, etc. Some fluids are also irritant to the skin and eyes.

(ix) Air pressure should be released slowly, particularly in confined spaces.

(x) Ground equipment used for replenishing fluids, or for providing hydraulic power or air pressure, should be kept scrupulously clean and should be serviced at stipulated intervals.

(xi) Unless otherwise specified, components should usually be installed using the appropriate lubricant or anti-seize compound on mating surfaces.

(xii) Only the recommended lubricants and fluids should be used, and any tests necessary should be carried out strictly in accordance with the relevant Maintenance Manual.

4.7.2 **Routine Servicing.** At the periods specified in the approved Maintenance Schedule, the landing gear should be lubricated and the relevant inspections carried out. The appropriate inspections detailed in paragraph 3 are also applicable to retractable landing gear, and, in addition, the retraction mechanism should be inspected for security, damage, wear of moving parts, fluid leaks and chafing of pipelines and electrical cables. Doors and wheel bays should be inspected for damage resulting from debris thrown up by the wheels, or witness marks from the tyres indicating faulty adjustment or damaged linkage. Minor damage may usually be blended out and the part re-protected as appropriate, but cracks, kinks in pipelines, or wear beyond the limits specified in the Maintenance Manual are not acceptable. Some leakage from the components of a pneumatic system is usually permissible, since the operating medium is replaceable, but serious leaks could affect operation of the system. Leakage from a hydraulic system may sometimes be corrected by cleaning and re-making a connection, but a component with a persistent leak should be replaced.

4.7.3 **Component Installation.** Whenever a new component is installed in the retraction system, it should be carefully adjusted to prevent physical damage and ensure correct operation. A common method of adjusting components and linkage after installation is to jack-up the aircraft, install ground locks on the undercarriages not being worked on, make the system electrically safe, and operate the individual retraction jack using a hand pump rig. This ensures slow, controlled operation, and allows individual adjustments to be made to the mechanism in accordance with measurements quoted in the relevant Maintenance Manual. After adjustment, the system should be reconnected and bled, and retraction tests carried out.

4.7.4 **Retraction Tests.** Retraction tests should be carried out following replacement of a faulty component, whenever incorrect operation is reported or suspected, and after a hard or overweight landing. The sequence of operations will depend on the particular installation and type of retraction system concerned, and full details should be obtained from the relevant Maintenance Manual. The following procedure is applicable to most retractable landing gears.

(i) Raise the aircraft so that the wheels are clear of the ground, and lock the lifting jacks. Ensure that no ground equipment or personnel are in the vicinity of the undercarriages and doors.

NOTE: In some aircraft the arc described by the wheels during retraction brings them nearer to the ground, and additional ground clearance must be allowed in these instances.

(ii) Connect electrical power and external hydraulic or pneumatic servicing equipment as appropriate.

(iii) Carry out several retractions and extensions, initially at low power to ensure slow operation, and using both the normal and emergency systems, and check the following:—

(a) Undercarriages for proper operation.

(b) Doors for correct operation and fit.

(c) Clearance in the wheel bays with the landing gear retracted, making due allowance for the effects of centrifugal force on tyre diameter.

(d) Linkage for correct operation and adjustment.

(e) Locks, switches, warning devices and mechanical indicators for correct operation.

(f) Freedom from fouling during retraction or extension, especially of flexible pipes.

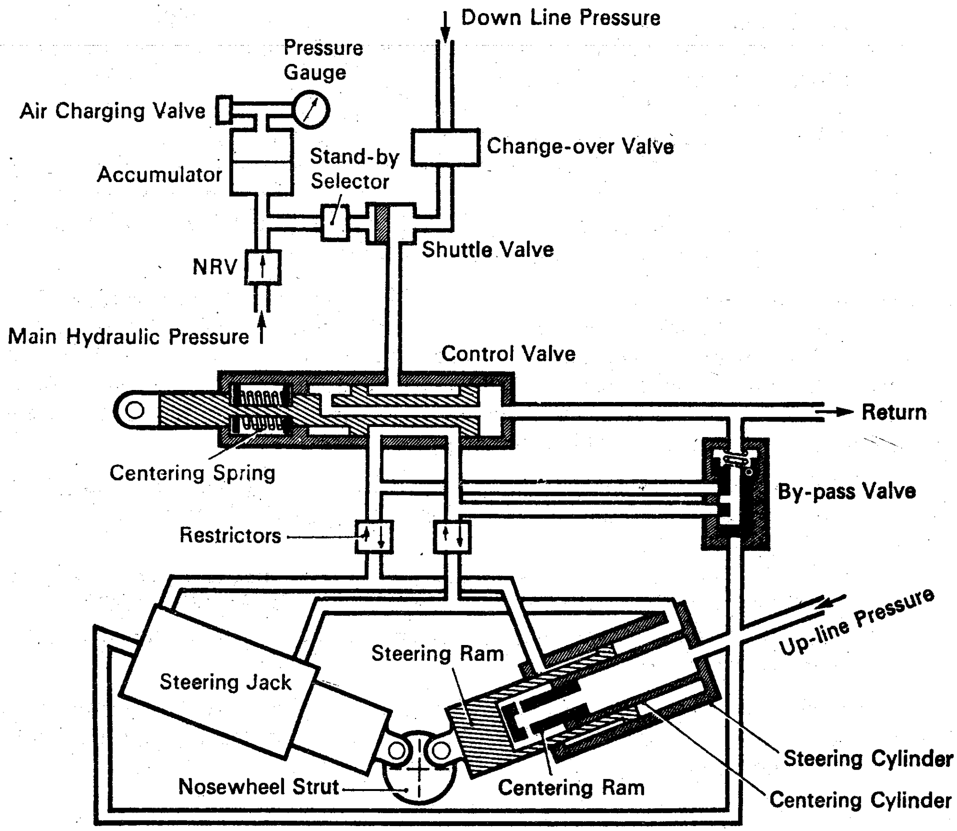
(g) General smooth operation of the mechanism.

NOTE: Retraction tests following initial assembly, replacements or significant adjustments, should be carried out with the wheel doors disconnected from their operating struts, and, if necessary, the sequence valves operated by hand; loose operating rods should be guided clear of structure. This procedure will permit direct inspection for clearance and alignment, and will also permit adjustment of mechanical stops, sequence contact points, up and down locks, and over-centre linkage.

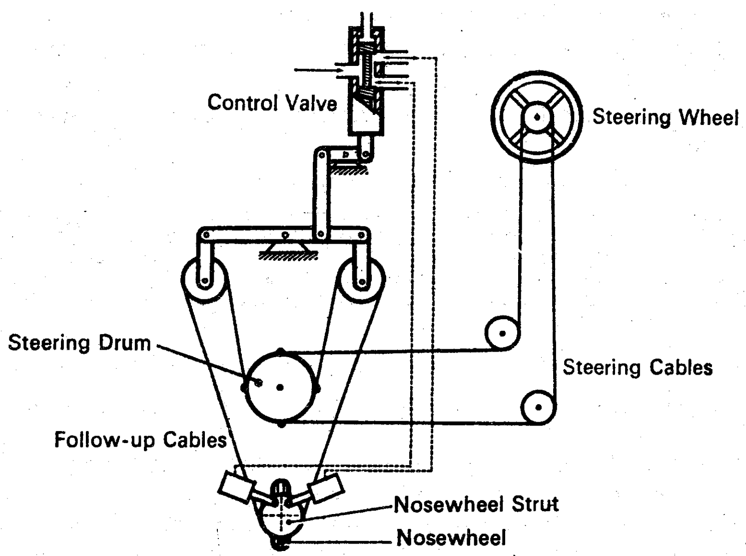
(iv) Remove servicing equipment, lower aircraft and fit ground locks.

(v) Finally tighten and lock any equipment installed immediately prior to the test.

5 POWERED STEERING Light aircraft generally employ a simple steering system, in which the nose wheel is mechanically linked to the rudder pedals. Larger aircraft require powered steering arrangements, in which the nose wheel is turned by hydraulic, pneumatic, or electrical power. A powered steering system generally includes a cockpit steering wheel or tiller, a control valve, steering cylinders to actuate the nose undercarriage, a follow-up device to hold the nose wheel at the correct angle, and a power source. A typical hydraulically operated system is described below, and illustrated in Figure 7.



HYDRAULIC SYSTEM



MECHANICAL LINKAGE (IN CASTORING POSITION)

Figure 7 POWERED STEERING SYSTEM

5.1 **Hydraulic Steering System.** Main operating pressure is derived from the undercarriage 'down' line, and a limited emergency supply is provided by a hydraulic accumulator. In the system shown in Figure 7, hydraulic pressure passes through a changeover valve, which ensures that the steering system is only in operation when the nose undercarriage is down.

5.1.1 **Steering Operation.** Pressure is directed through the control valve to the steering jacks, which retract or extend to rotate the nose shock-absorber strut within its housing. Movement of the steering wheel is transmitted through mechanical linkage to the control valve, in accordance with the amount and direction of turn required. Follow-up linkage from the nose undercarriage gradually resets the control valve as the nose wheel turns, and when the selected angle is reached a hydraulic lock is formed between the control valve and the steering jacks, preventing further movement. When the steering wheel is released, the control valve returns to neutral under the action of its centering springs, and the nose wheel is free to castor.

5.1.2 An inner cylinder in each steering jack is connected to the landing gear 'up' line and is supplied with fluid under pressure when the landing gear is selected up. The steering jacks extend equally to centralise the nose wheel before pressure is applied to the nose retraction jack, and the by-pass valve allows fluid from the steering jacks to flow to the return line.

5.1.3 **Castoring.** Whenever the control valve is in its neutral position, fluid is free to flow between the steering jacks, thus allowing the aircraft to be towed, or the nose wheel to return to the central position after a turn has been initiated with the steering wheel. Angular movement of the nose wheel during towing will be transmitted through the follow-up linkage to the steering wheel. Some form of quick-release pin is often provided to enable the steering jacks to be disconnected so that the nose wheel may be turned through large angles during ground servicing.

5.1.4 **Damping.** Restrictors in the pipelines between the control valve and the steering jacks, provide damping for the nose undercarriage.

5.2 **Maintenance.** The lubrication and inspection requirements of the steering system are broadly similar to those detailed in paragraph 4.7 for retractable landing gear. Installation and adjustment of the mechanical linkage, and functional testing of the system are described in the following paragraphs.

5.2.1 **Mechanical Linkage.** Proper adjustment of the mechanical linkage is most important, since slackness or faulty installation could lead to incorrect operation of the steering system. To facilitate installation of components, rigging pins are usually inserted through jig-drilled holes in the steering wheel, drum assembly and follow-up linkage (see Figure 7) in order to fix their positions. The nose wheel can then be centralised, and the cables and rods fitted and adjusted, accordingly. Cables should be tensioned using a tensionmeter, and rods adjusted so that the connecting pins and bolts can be easily fitted. When new pulleys or cables are fitted, it is usually recommended that they are 'bedded-in' by operating the steering wheel a number of times over its full range of travel; cables should then be re-tensioned.

5.2.2 **Functional Test.** The following test is applicable to the system illustrated in Figure 7 and contains the basic essentials for tests on similar steering systems. The hydraulic installation on a particular aircraft may necessitate additional operations, and these will be fully described in the appropriate Maintenance Manual.

(i) Ensure that the shock strut is correctly serviced.

(ii) Jack the aircraft so that the wheels are clear of the ground and ensure that no ground equipment or personnel are in the vicinity of the landing gear.

(iii) Depressurize the main hydraulic system and check that the nose wheel has freedom of movement over the full castoring range.

(iv) Connect a hydraulic test rig and ground electrical power, and set controls and switches for normal hydraulic operation.

(v) Operate the steering wheel over its full range, and check that the nose wheel follows smoothly and stops at selected positions.

(vi) Set the nose wheel a few degrees to one side and select the landing gear up, checking that the nose wheel centres before the down-lock breaks.

(vii) Lower landing gear and repeat operation (vi) with the nose wheel displaced in the opposite direction.

(viii) Carry out further retractions to check that the steering is only operative when the nose undercarriage is down.

NOTE: Operations (vi), (vii), and (viii) could lead to extensive damage if malfunction occurs, and should be performed with the test rig adjusted to give a slow rate of operation of the retraction system.

(ix) Check that the stand-by accumulator is correctly charged with air pressure and operate the test rig to pressurise the accumulator.

(x) Select stand-by steering and check that the nose wheel can be steered satisfactorily. This check may involve a specified number of turns before the accumulator is exhausted or the stand-by system low pressure warning lights illuminate.

(xi) Set the stand-by selector to off, and disconnect the test rig and external electrical power.

(xii) Lower the aircraft and finally lock any components installed prior to the test.

6 BOGIE UNDERCARRIAGES On heavy aircraft, the need to spread the weight over a large area has resulted in the use of multiple wheel undercarriages. A typical four-wheeled bogie is illustrated in Figure 8, but a larger number of wheels are used on some undercarriages.

6.1 The undercarriage unit normally consists of a shock-absorber strut, at the lower end of which a bogie beam is pivoted, and the axles are attached to each end of the beam. On some aircraft the rear pair of wheels swivels on the bogie beam, and castors when the nose wheel is turned through a large angle; on others, the upper torque link member is replaced by a pair of hydraulic jacks, which, when nose wheel steering is applied, rotates the whole bogie. Castoring or steering prevents excessive torque on the undercarriage leg and minimises tyre scrubbing during turns. For normal operation, the swivelling pair of wheels is locked in line with the fixed pair. Brake torque at each wheel is transmitted through compensating rods to the shock-absorber strut, thus preventing excessive loads on the bogie beam.

6.2 On retractable landing gear a levelling strut or 'hop damper' provides a means of positioning the bogie beam at suitable angles for retraction and landing; this strut is usually connected into the hydraulic system to prevent retraction if the bogie is not at a suitable angle, and combines the functions of hydraulic ram and damper unit.

6.3 **Maintenance.** In addition to the lubrication, testing and maintenance of landing gear described in previous paragraphs, particular care and higher standards of workmanship are necessary with bogie undercarriages. Since this type of undercarriage is fitted to heavy aircraft, the materials used are of very high strength, and great care is

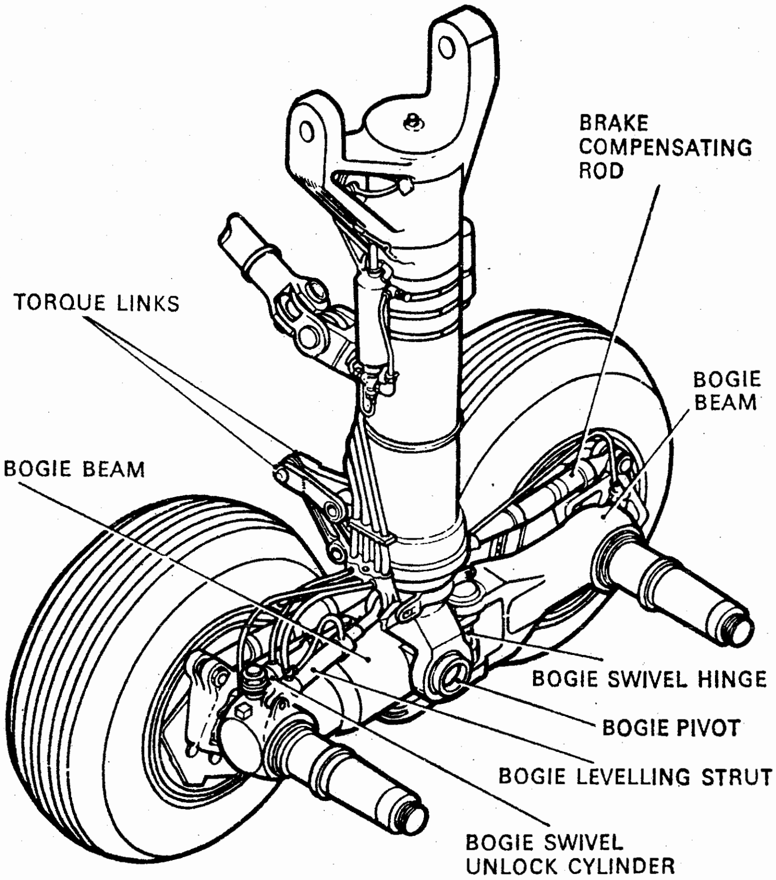


Figure 8 TYPICAL BOGIE UNDERCARRIAGE

taken in the manufacture, heat treatment and finish of the components. However, these materials are usually more susceptible to failure from scratches, indentations or corrosion, than materials of lower strength. All servicing functions should, therefore, be carried out with special care, particularly with regard to lubrication, the lack of which could result in corrosion or hydrogen embrittlement. If any surface damage is found during inspection, it should be repaired strictly in accordance with the instructions and limitations specified in the manufacturer's manuals, or, if no adequate guidance is given, in accordance with an approved repair scheme.

6.3.1 When changing wheel or brake assemblies, the axle should be fitted with a protective sleeve to prevent damage, and the surface and threads should be inspected for damage and corrosion before re-assembling the wheel or brake.

6.3.2 When carrying out retraction or steering tests, operation of the levelling strut and locking/unlocking of the swivelling wheels should be checked in accordance with the appropriate Maintenance Manual.

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AIRCRAFT

SYSTEMS AND EQUIPMENT

CONTROL SYSTEMS

1 INTRODUCTION This Leaflet gives general guidance on the inspection procedure for control systems which are either manually operated, power assisted or power operated. The Leaflet should be read in conjunction with the relevant approved drawings and manuals for the aircraft concerned.

2 CONTROL SYSTEMS A control system is defined as a system by which the flight attitude or the propulsive force of an aircraft is changed (BCAR, Chapter A5–3).

2.1 For the purpose of duplicate inspection (see paragraph 2.2) the flight control system includes the main control surfaces, lift and drag devices and trim and feel systems, together with any flight control lock systems, and the associated operating mechanisms and controls. In the case of rotorcraft, the flight control system includes the mechanisms used by the pilot to control collective pitch, cyclic pitch and yaw. The engine control system includes the primary engine controls and related control systems (e.g. throttle controls, fuel cock controls, oil-cooler controls) and the mechanisms used by the crew to operate them.

2.2 **Duplicate Inspection.** A duplicate inspection of a control system is defined as an inspection which is first made and certified by one qualified person and subsequently made and certified by a second qualified person.

2.2.1 Components or systems subject to duplicate inspection must not be disturbed or re-adjusted between the first and second parts of the inspection, and the second part of the inspection must, as nearly as possible, follow immediately after the first part.

2.2.2 In some circumstances, due to peculiarities of assembly or accessibility, it may be necessary for both parts of the inspection to be made simultaneously.

3 INSPECTION OF CONTROL SYSTEM COMPONENTS

3.1 Control system components, the parts of which are concealed during bench assembly before installation, shall be inspected in duplicate on assembly during manufacture, overhaul or repair.

3.2 Both parts of the duplicate inspection and the results of any tests made during and after final assembly shall be certified on the Inspection Record for the part concerned.

4 DUPLICATE INSPECTION OF CONTROL SYSTEMS

4.1 A duplicate inspection of the control system in the aircraft shall be made (a) before the first flight of all aircraft after initial assembly, (b) before the first flight after the overhaul, replacement, repair, adjustment or modification of the system. The two parts of the duplicate inspection shall be the final operations, and as the purpose of the inspection is to establish the integrity of the system, all work should have been completed. If, after the duplicate inspection has been completed, the control system is disturbed in any way before the first flight, that part of the system which has been disturbed shall be inspected in duplicate (paragraph 2.2) before the aircraft flies.

4.2 In some instances it may not be possible after complete assembly of the aircraft to inspect all parts of the system because some sections of the system may get progressively 'boxed in' and sealed during assembly operations. In such cases the condition and security of any section which is liable to be sealed must be established to the satisfaction of the persons named in paragraph 5 before the section is sealed and the related Inspection Record endorsed accordingly.

NOTE: Inspection Records should be carefully prepared to ensure that any duplicate inspection required at an early stage during assembly operations is clearly indicated, thus avoiding unnecessary dismantling at later stages.

4.3 The correct functioning of control systems is at all times of vital importance to airworthiness, and it is essential that suitably licensed aircraft engineers and members of approved inspection organisations responsible for the inspection or duplicate inspection should be thoroughly conversant with the systems concerned. The inspection must be carried out systematically to ensure that each and every part of the system is correctly assembled, and is able to operate freely over the specified range of movement without risk of fouling. Also that it is correctly and adequately locked, clean and correctly lubricated, and is working in the correct sense in relation to the movement of the control by the crew.

5 PERSONS AUTHORISED TO CERTIFY DUPLICATE INSPECTIONS

5.1 Persons authorised to make the first and second parts of the duplicate inspection of control systems in accordance with Chapter **A5—3** of BCAR are as follows:—

(a) Aircraft engineers appropriately licensed in Categories A, B, C and D.

(b) Members of an appropriately approved Organisation who are considered by the Chief Inspector competent to make such inspections, in accordance with Airworthiness Notice No. 3.

(c) For minor adjustments to control systems when the aircraft is away from base, the second part of the duplicate inspection may be performed by a pilot or flight engineer licensed for the type of aircraft concerned.

5.2 **Certification.** It is recommended that the certification of the duplicate inspection be in the following form:—

Duplicate inspection performed in accordance with the requirements of BCAR, Chapter A5—3.

1st inspection .... **signature**

.... **authority**

2nd inspection .... **signature**

.... **authority**

Date ....

6 GENERAL

6.1 JAR 25.671(b) states that, in relation to aeroplanes, each element of each control system must be designed, or distinctly and permanently marked, to minimise the probability of incorrect assembly that could result in the malfunction of the system. The interpretive material in ACJ.671(b) states that for control systems which, if incorrectly assembled would hazard the aeroplane, the design should be such that at all reasonably possible breakdown points it is mechanically impossible to assemble elements of the system to give an out-of-phase action, reversed controls or interconnection between two systems which was not intended; only in exceptional circumstances should distinctive marking be used.

6.2 Section G of BCAR, in respect of rotorcraft, specifies that the physical features of the control system elements shall be such that it is mechanically impossible to assemble any system with reversed connections or to confuse the connections between systems.

6.3 These requirements are satisfied in practice in a number of ways, e.g. by the use of end fittings having different diameter threads for different cables, by the use of different diameter pins in correspondingly different diameter holes in end fittings, by staggering the positions of breakdown points so that cross-connecting, etc., is impossible.

6.4 The above requirements do not, however, minimise the necessity of thorough end-to-end inspection of each control run. Cases are on record of control cables being crossed and re-crossed so that the relative movements of the controls and the control surfaces were correct.

7 SCHEDULE OF INSPECTION A schedule of all inspections and functioning checks applicable should be compiled to ensure that no part of the system is overlooked. The schedule should include as a minimum sufficient instructions to enable the following to be completed:—

(a) The duplicate inspection of parts of components which will be concealed during bench assembly.

NOTE: Where such work is the subject of a sub-contract order, instructions regarding inspection and duplicate inspection should be stated on the order, and incoming release documentation should be endorsed to the effect that such inspections have been completed.

(b) The duplicate inspection of the internal locking and critical assembly features the correctness of which cannot be proved during final inspection or functioning tests with the assembly installed in the aircraft.

(c) The duplicate inspection of parts of the control system which may subsequently be obscured by the erection of further structure.

(d) The duplicate inspection, functioning and checking for correct relative movement of the complete system.

(e) The final inspection of the complete system to ensure that all covers, guards, etc., are correctly fitted.

(f) The recording of control surface movements and the serial numbers of components.

NOTE: In considering the instructions to be included in a Schedule of Inspection, it should be noted that the term "control systems" includes (for the purpose of this Leaflet) all power-operated or power-assisted controls together with their attachments and operating mechanism which in any way change the flight attitude or propulsive power of the aircraft. Only when other controls, such as an engine auto-stabiliser or an automatic control unit or parts of these units are interconnected with the control system in such a way that they cannot be instantly over-ridden by the crew in flight, are they considered as part of the control system.

8 POWERED CONTROLS

8.1 **Power-assisted Controls.** In this type of control part of the force needed to move the control surface is provided by a power system and part by the physical effort of the pilot. The pilot's 'feel' is thus provided by the control surface loads.

8.1.1 Initial movement of the pilot's controls produces (by mechanical connection) a small movement of the control surface which operates a control valve causing the control jack to follow-up, thus providing the bulk of the force to permit the movement of the control surface. As the control surface reaches the position appropriate to the position of the pilot's control, the valve is closed and the system comes to rest.

8.1.2 In the event of power failure or faults in the power system, satisfactory control can be maintained by manual means. A disconnecting mechanism is usually provided to prevent interference from the power system when it is not in use.

8.1.3 The trim control of power-assisted control systems is usually provided by conventional trailing-edge tabs, as for manually-operated flying control systems.

8.2 **Power-operated Controls.** In this type of system the whole of the force needed to operate the control surfaces is provided by power systems independent of each other but working in parallel.

8.2.1 Movement of the pilot's control operates a valve controlling an appropriate mechanism which operates the control surfaces until they reach the position appropriate to that of the pilot's control, when the valve is closed and the system comes to rest. It is not inherent in the system that the pilot's 'feel' should have any direct connection to the force on the control surface, and this, together with the self-centring of the controls, is achieved by artificial means. The two most common methods of providing feel are (a) constant load for a given control position imposed by a spring strut and (b) a variable loading related to airspeed and applied by a 'q' system, i.e. a force mathematically proportional to the square of the speed of the aircraft.

8.2.2 To provide for the event of power failure or faults in the power-operating mechanism, manual reversion might be provided, or there may be two or more systems, each with its own independent hydraulic system having additional pumps to safeguard against failure of their own pressure sources. In controls incorporating three power systems, where the servo unit is attached to the main structure and the jack rams move to control the aerofoil surface, a seizure of the unit selector valve could cause a hydraulic lock in the jack concerned. In this unlikely event the combined pressure of the two other jacks is designed to cause a safety relief valve in the defective unit to open, thus maintaining normal power control. The independent systems may operate one at a time, requiring manual changeover if a fault develops, or may be operating all the time in harmony, with a device to cut out (by manual selection or automatically) the system which fails to operate correctly.

8.2.3 Since power-operated controls are irreversible, it is not usual to make use of the conventional trailing-edge trim tab, and trim is often obtained by adjusting the zero position of the artificial feel mechanism. However, balance tabs are sometimes fitted to assist in maintaining hinge and servo loads to within the design values.

9 INSTALLATION OF FLYING CONTROLS The flying controls must be installed in accordance with the requirements prescribed in the relevant approved drawings and documents associated with the drawings, or with the requirements of the relevant manual. All parts used in the installation (e.g. electrical, hydraulic and pneumatic parts of the system) must bear evidence of prior inspection and, where applicable, duplicate inspection. It must be ensured that the highest standards of workmanship and cleanliness have been observed, and that no parts have been damaged or subjected to distortion during assembly.

9.1 **Pulleys and Sprockets.** All pulleys and sprockets must be aligned to provide a satisfactory 'run' for the cables and chains so preventing riding on the flanges of the pulleys and sprockets and chafing against the guards and covers.

9.1.1 The pulley and sprocket bearings should be examined to ensure that they are properly lubricated, rotate freely, and are free from dirt, swarf and paint spray, etc.

9.1.2 Non-metallic pulleys should be examined for freedom from embedded foreign matter and metal pulleys for freedom from roughness and sharp edges.

9.2 **Guards and Covers.** Pulleys and sprockets must be guarded to prevent jamming of cables and chains. The guards and covers must be so fitted and locked that they cannot foul the controls in any position and are held positively against rotation about the pulley or sprocket axis. Where a guard forms an integral part of a removable panel, adequate precautions must be taken to check the controls and the correct positioning of the guard after the panel has been replaced.

9.2.1 Glands, gaiters, etc., intended to prevent the escape of lubricant, ingress of foreign matter or loss of cabin pressure where controls pass through pressurised areas, must be undamaged and correctly and securely attached.

9.2.2 When longitudinally-split rubber seals are fitted at pressure bulkheads to seal the apertures through which control cables pass, care must be taken to ensure that the assembly is such that the seal will not be chafed as this could result in the seal being broken permitting the retaining rings to come off and ride along the control cable, possibly causing jamming of a pulley. Care must also be taken to ensure that the retaining rings are installed correctly into the groove in the seal to prevent a similar occurrence.

9.3 **Levers and Fairleads.** All levers and fairleads should be aligned to give the required run without chafing. After installation the levers should be checked for free and unrestricted movement.

9.4 **Chains.** Information on the assembly, testing and installation of chains is given in Leaflet **AL/3—2** and should be read in conjunction with this Leaflet.

9.5 **Cables.** Information on the assembly and testing of spliced and swaged cables is given in Leaflet **BL/6—24.**

9.5.1 Before installing a cable which has an identification tag affixed other than as shown in British Standards SP53, SP54, SP105 and SP106, the tag should be removed and, for future identification purposes, the particulars on it should be entered in the Aircraft Log Book.

9.5.2 Where applicable the protective treatment specified should be applied to the cables. However, where the cables pass through or over fairleads, any excess greasy substance should be removed to prevent these parts collecting abrasive dust which would wear the cables.

NOTE: In order to improve the wear and fatigue life of control cables, British Standards require a lubricant to be applied during spinning of the cable. It is important, therefore, when cleaning cables not to wash out the lubricant by saturating the cable with a grease solvent.

9.5.3 The cables should be free from broken wires or other defects, e.g. kinks and 'bird-caging', which would affect their strength.

9.5.4 It is important that the cables should be correctly tensioned and this can be helped by having the control surface locks in position during tensioning to support the weight of the control surfaces. During tensioning, adjustment should be made equally on all turnbuckles, otherwise circuits which incorporate a number of pulleys and fairleads and/or where the cables have to negotiate several bends may be difficult to tension evenly.

9.5.5 Where the tension is specified in the drawing or manual, this should be checked by means of a tension meter specified for the weight of cable concerned, due allowance being made for temperature. To obtain a true reading the tension meter should be placed in the position on the cable indicated in the drawing or manual. In the absence of a position being specified it should be placed away from fairleads and pulleys.

NOTE: Where long cable runs are concerned, drawings and manuals often detail the tensions required over a range of ambient temperatures.

9.5.6 Where the tension is not specified it should be ensured that the cable run is not too slack or too taut but has a satisfactory 'feel' over the whole range of travel of the controls.

9.5.7 Turnbuckles should be locked (using wire of the gauge and specification quoted in the relevant drawing or manual) using any of the methods illustrated in Figures 1 to 3. Prior to locking, it should be ensured that the end-fittings are 'in safety' (i.e. the internal fitting extends past the inspection hole in the external fitting) by attempting to pass a hardened pin probe through the inspection hole. Locking wire must not be used more than once.

NOTE: Some turnbuckles are designed so that they can be locked by special locking devices (e.g. spring locking clips to MS21256). Instructions regarding their assembly and use should be obtained from the relevant manual.

9.5.8 With the larger type of control cables (i.e. cables from 45 to 120 cwt), it has been found that tension loads tend to straighten out the helically-wound cable resulting in a torque action sufficient to break the locking wire or release lock nuts on turnbuckles or similar assemblies. To overcome this 'unlocking' action a tube fitted over the turnbuckle assembly and drilled to accommodate three bolts is often specified. This provides a positive means of preventing independent rotation of any part of the assembly.

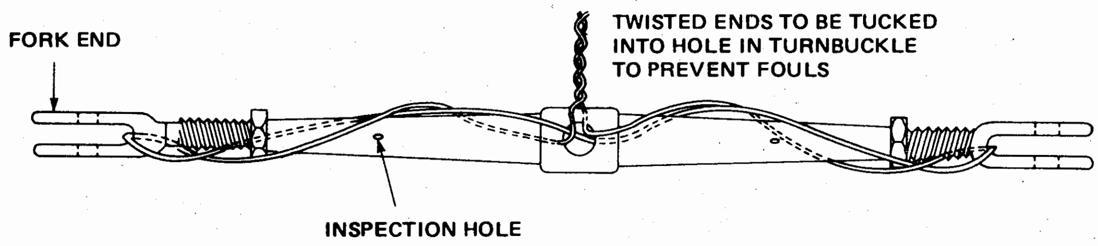

Figure 1 WIRE-LOCKING OF TURNBUCKLE WITH FORK END-FITTINGS

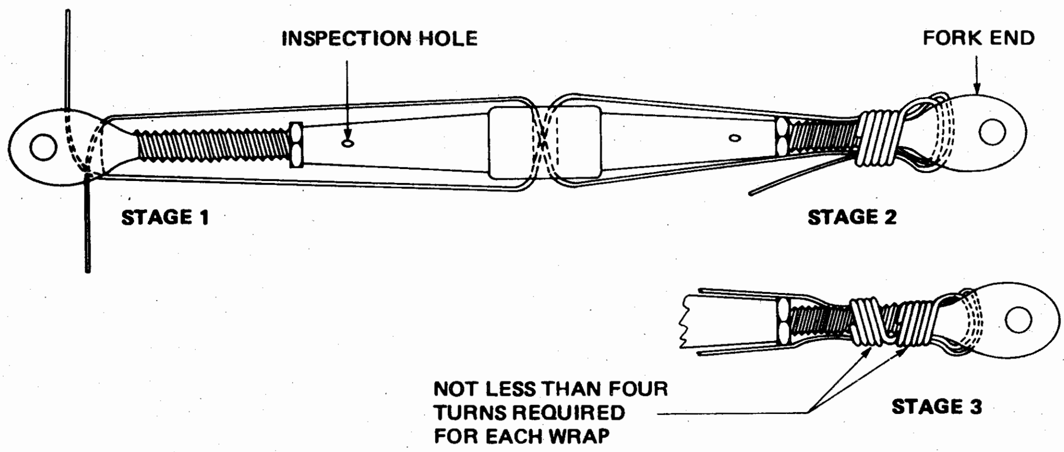

Figure 2 ALTERNATIVE METHOD OF WIRE-LOCKING TURNBUCKLE WITH FORK END-FITTINGS

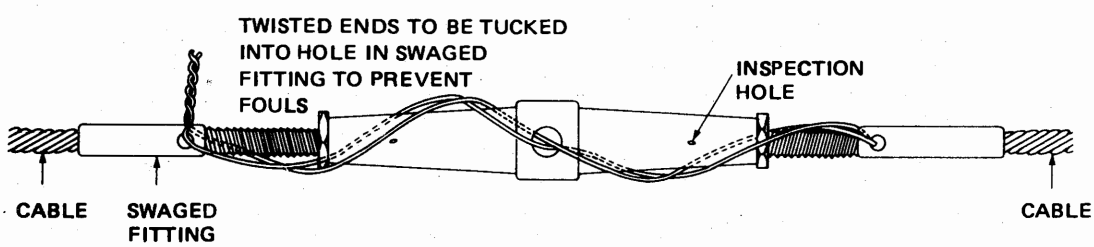

Figure 3 WIRE-LOCKING OF TURNBUCKLE WITH SWAGED END-FITTINGS

9.5.9 The adjustable end-fitting shown in Figure 4 may be attached, for example, to a swaged cable, a chain or a tension rod. The threaded end must be in safety and the locknut adequately tightened. The screwed portion (A) must not abut the fitting (B) in the fork end as this would impose an additional strain on the fitting, the joint would lack flexibility and there would be no provision for further adjustment.

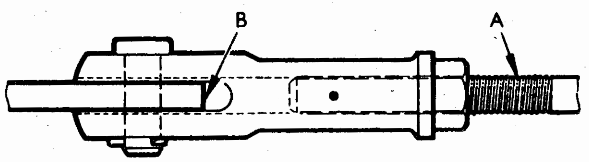

Figure 4 ADJUSTABLE FORK END-FITTING

9.6 **Control Rods.** Control rods should be perfectly straight (unless designed to be otherwise) when fitted, and bell-cranks, etc., to which they are attached, should be checked for freedom of movement before and after assembly of the control rods. The assembly as a whole should be checked for correct alignment.

9.6.1 Where self-aligning ball-races are fitted, free rotational movement of the rods must be obtained in all positions.

9.6.2 There have been cases of control rods with self-aligning bearings becoming disconnected because of failure of the peening retaining the ball-races in the rod end housings, thus allowing the rods to become detached from the ball-races. This can be obviated if the control rods are assembled so that the abutment flange of the rod end housing is interposed between the ball-race and the anchored (as opposed to the free) end of the attachment pin or bolt (see Figure 5). Alternatively, a washer having a larger diameter than the hole in the abutment flange may be required under the retaining nut on the end of the attachment pin.

9.7 **Gearboxes and Torque Tubes.** Where this type of equipment is installed in the system, it should be ensured that the gearboxes are correctly mounted, that the torque tubes are not bowed and run freely in their guides, that universal joints are correctly fitted and give the correct degree of angular transmission throughout a complete rotation of the torque tube, and that only the lubricant specified by the aircraft manufacturer is used in the gearbox.

9.8 **Control Surfaces, Tabs, etc.** The method of attachment varies with each type of aircraft, but it must be ensured that the component is assembled to the aircraft without strain and that adequate clearance exists between adjacent control

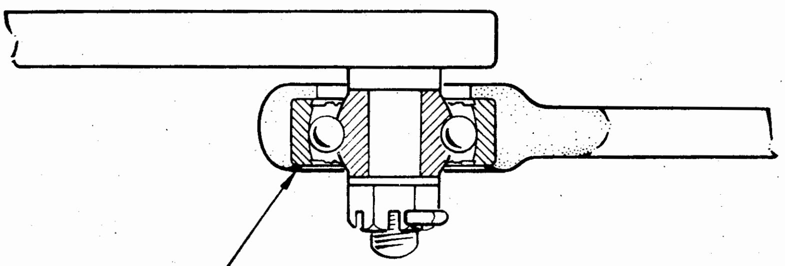

Figure 5 SELF-ALIGNING BEARING

surfaces, or between the control surface and adjacent structure and shrouds, throughout the full range of movement. There must be no slackness in linkage which may cause collective backlash and introduce control flutter.

9.9 **Rotor Blades.** Rotor blades are particularly susceptible to damage and sensitive to its effects. Particular care is necessary, therefore, when handling and assembling rotor blades to prevent them becoming dented or scored. The attachment of rotor blades must be inspected in duplicate as must the re-securing of the blades after unfolding.

9.10 **Locking.** All connections of components and parts in the control system must be positively secured and locked in accordance with drawing requirements (see Leaflet **BL/6—13**).

9.11 **Lubrication.** All moving parts should be lubricated with the specified lubricant during assembly. Proprietary bearings, such as those of the oil-retaining variety, should receive lubrication only when recommended by the manufacturer.

9.12 **Placarding.** A check should be made to ensure that all placards and notices relating to the functions, direction of movement and operational positions of controls, levers, handles, etc., are clearly and correctly applied in accordance with drawing requirements and are in their specified positions.

NOTE: It is important that all placards and labels should be maintained in a clean and legible condition.

9.13 **General.** During installation, care must be taken to avoid any possibility of the controls jamming or fouling against adjacent structure, or cables rubbing together or chafing against other fixed or moving parts throughout their range of movement. Where clearances are not stated on drawings and there is some doubt about their adequacy, the guidance of the approved Design Organisation should be sought. The system should be protected against corrosion and deterioration and should be effectively bonded (see Leaflet **EEL/1—6**).

10 CONTROL SETTINGS

10.1 **Manually operated.** The manual operation of the system should be witnessed whilst the controls are operated throughout their full range. This should be carried out in quiet conditions as some mechanical defects can be detected by an unusual noise. The primary systems should be checked for static friction, using a spring balance. The CAA recommends that the forces on the control column or wheel and rudder pedals necessary to overcome static friction should not exceed the values given in Table 1. In the case of systems incorporating cables, these conditions should be met with the cables rigged at the stipulated tensions.

TABLE 1

Maximum Weight of Aeroplane kg(lb)	Maximum Static Force on Control N(lbf)		
	Elevator	Aileron	Rudder
5700 kg (12,500 lb) or less	17·79 N (4 lbf)	8·89 N (2 lbf)	26·68 N (6 lbf)
22 680 kg (50,000 lb) or more	44·48 N (10 lbf)	35·59 N (8 lbf)	44·48 N (10 lbf)
Linear variation should be assumed between these weights.			

10.2 The full and synchronised movement of the controls should be checked to the relevant rigging diagrams, and the limit stops adjusted as necessary to the relevant rigging diagram requirements. The stops should be relocked. It is important that the pilot's controls and control surfaces contact their stops in the correct sequence.

NOTE: When checking the range of movement of the control surfaces, it is important that the controls should be operated by the pilot's controls and not by handling the control surfaces. It should be ensured that all obstructions, such as trestles, are out of the way of control surfaces.

10.3 During the checking of settings it should be ensured that collective backlash in the system does not exceed permitted limits and, when controls are in the 'full-travel' position and against their respective stops, that chains, cables, etc., have not reached the limit of their travel. Where dual control facilities are provided, it should be ensured that they are correctly synchronised and function satisfactorily when operated from both positions.

10.4 Where components or control systems are interconnected it should be ensured that they are correctly co-ordinated in accordance with drawing requirements.

10.5 Where friction devices are employed it should be ensured that the selected degree of friction is applied to the controls throughout the range of movement.

10.6 Trim tabs and other tabs should be checked in a similar manner to the main control surfaces, it being ensured that any devices for indicating the position of the tabs function correctly. When screw jacks are employed to actuate the tab, care must be taken to ensure that they are not out of safety when in the fully extended position.

10.7 Where spring devices are fitted in the control system, these should be checked for correct tension, cleanliness and adequate lubrication.

10.8 Guidance on control functioning checks for aeroplanes and rotorcraft is given in paragraph 11.

10.9 **Powered Controls.** The rigging of powered controls varies with each type of aircraft, therefore, it is impracticable to attempt in this Leaflet to define a procedure; it is essential to follow the manufacturer's requirements in this respect. However, reference can be made to the nature of the precautions which should be taken when rigging such systems.

10.10 It is of the utmost importance that each system should be correctly adjusted and all means of adjustment correctly locked. Where cables are used in powered control systems, it is essential that they are correctly tensioned to prevent malfunctioning of the actuating units. The tensioning requirements, the type of tension meter to be used, and the positions where readings are to be taken will be prescribed in the relevant manual for the aircraft concerned. To compensate for structural flexing and changes in temperature, cable-tension compensator-units are sometimes incorporated in the control circuit; these compensators should be pre-set and the system adjusted as prescribed in the relevant manual. To simplify the adjustment, compensator units may be provided with scales or datum holes to indicate when the adjustment is correct.

10.11 It is important during initial setting that jacks do not bottom, unless the relevant manual so specifies, as this may result in over-stressing of parts of the unit which could lead to failure in service.

10.12 Pins, usually 'rigging' pins (which must have a red warning flag permanently attached), are sometimes required to simplify the setting of such parts as pulleys, levers, hydraulic control units, etc., in their neutral positions by inserting the pins in the alignment holes provided. This arrangement also simplifies the correct alignment and tensioning of the various control systems. When rigging pins are not provided, the neutral positions may be checked by means of alignment marks, by the use of special templates or by taking linear measurements; these procedures will be clearly defined in the relevant manuals.

NOTE: To prevent damage to the control system, if by error rigging pins were left in position, some rigging pins are designed to have a maximum shear value and only those designed for the system concerned should be used, but in general, the accuracy of diameter and correct fitting are the important considerations. Ground locking devices should never be used in lieu of rigging pins.

10.13 If the final alignment and adjustment of the system is correct it should be possible to withdraw the rigging pins easily. Any undue tightness of the pins in the rigging holes indicates incorrect tensioning or malalignment of the system.

NOTE: All rigging pins or centralising devices must be removed immediately after the rigging operation is completed and before operating the power systems, otherwise damage may result. This precaution must be made part of the control system clearance procedure. Similarly, precautions should be taken to ensure that all obstructions, such as trestles, are out of the way of control surfaces.

10.14 When static friction tests are prescribed for the control circuits, these should be done with a spring balance or suitable test rig in the manner prescribed and must not exceed the limiting values permitted. In some power-assisted systems, excessive friction could upset the feel of the system to the detriment of the handling qualities of the aircraft.

NOTE: In some instances it may be necessary to disconnect the 'feel' spring struts in order that the true friction value can be obtained. It may also be necessary to check spring-strut break-out forces following the static check.

10.15 Since the hydraulic systems are independent of each other, a check should be made to ensure that the routeing of all pipelines and electrical cables does give the necessary isolation. In addition, pipelines and electrical cables should be checked for signs of chafing while the systems are functioning.

10.16 It is essential that all control functioning checks and tests are carried out strictly in accordance with the manufacturers' publications complying with Chapter **A6–2** of BCAR.

NOTE: It must be ensured that test rigs contain the correct fluid and are provided with the same standard of filtration as is provided on the aircraft.

10.17 The correct engagement and disengagement of control locks should be checked at the same time as a check on the correct functioning of the associated warning devices.

10.18 The range of movement of the controls and control surfaces should be checked in both directions from the neutral position. If the range does not meet the rigging tolerances, the necessary adjustments should be made and the duplicate inspection completed.

10.19 Where components in control systems are interconnected their operation should be correctly co-ordinated in accordance with drawing requirements. Where friction devices are employed, it should be ensured that the selected degree of friction is applied to the controls throughout the range of movement.

10.20 When testing the system all hydraulic equipment and pipe-lines should be checked for leaks. The appropriate filters should be checked for cleanliness and freedom from damage, and particular care should be taken to follow the instructions given in the relevant manual, as a broken or disintegrated filter may cause a valve to jam. Where 'tell-tale' indicators are incorporated in filters these should be checked at the periods specified. After checking for cleanliness, all air should be expelled from the systems.

10.21 **Engine Ground Run Test.** As some parts of the hydraulic systems are not tested with the hydraulic test rig the controls should be operated during a convenient ground test run to ensure that all engine pumps operate satisfactorily over the speed range of the pumps. Where part of a hydraulic system has been disconnected, e.g. to change an engine or pump, precautions should be taken to expel any air which may have entered the system and the operation of the system should be rechecked.

11 CONTROL FUNCTIONING The final functioning checks on control systems is of the greatest importance and it is essential that they should be completed systematically. The checks should be carried out after thorough cleaning and only when all other work on the system has been completed.

11.1 **Aeroplanes**

11.1.1 The functioning checks must include verification that full, free and correct movement of the controls is obtained throughout the system relative to the movement of the crew controls.

11.1.2 A list of all controls and the salient checking points should be drawn up in a suitable sequence and in duplicate.

11.1.3 A person competent to certify a duplicate inspection should operate the controls in the cockpit, maintaining the sequence specified in the checking list. Another person competent to certify the duplicate inspection should check on the control movements in the same sequence. For the second part of the inspection the two persons should exchange positions and repeat the checks in identical sequence.

11.1.4 The relative movements of the control surfaces in relation to the pilot's controls should be carefully checked to the manufacturer's instructions.

NOTE: Where 'free operating control surfaces' are installed the relative movements of controls are affected. For example, if the control column is moved back, the elevator does not move at all, but the tab of the elevator moves downwards causing the elevator to move upwards in flight. This type of control system requires a special checking technique and the manufacturer's instructions must be closely followed.

11.1.5 The movement of wing-flaps and slats should be checked for synchronisation and a check should be made to ensure that the relevant surface position indicator accurately registers the position of the surfaces throughout their range of movement.

(a) A check should be made (where applicable) to ensure that the wing-flap or slat asymmetric control device is functioning correctly.

(b) Where wing-flaps are interconnected with leading-edge flaps or slats, the installation should be checked for correct operation during extension and retraction of the wing-flaps.

11.1.6 Where spoilers/speed brakes are interconnected with the aileron control system, their correct operation in relation to the ailerons should be checked.

11.1.7 Where an aerodynamic feel simulator is connected into the main control systems, its correct operation should be checked with the aid of a suitable pitot system test rig.

11.1.8 It should be ensured that when operational time limits are specified for certain controls, e.g., flaps, spoilers or speed brakes, these are within permitted limits.

11.2 **Rotorcraft**

11.2.1 A list of all controls affected, and the salient checking points, should be drawn up in a suitable sequence and used as indicated in the relevant parts of paragraph 7.

11.2.2 The nature of the functioning checks necessary will vary with the system concerned, but where applicable the following should be checked:—

(a) That the direction of movement of the main and tail rotor blades or other related controls in relation to the movement of the pilot's controls is correct.

(b) That the operation of interconnected control systems (e.g. engine-throttle and collective-pitch controls) are co-ordinated in accordance with drawing requirements.

(c) That the range of movement and neutral positions of the pilot's controls (i.e. cyclic-pitch control columns, collective-pitch levers and yaw pedals) are as specified in the relevant drawings.

(d) That the maximum and minimum pitch angles of the main rotor blades, in both fore-and-aft and lateral cyclic-pitch, are within drawing requirements.

(e) That the maximum and minimum pitch angles of the main rotor blades in collective pitch are within drawing requirements.

(f) That, in the case of multi-rotor aircraft, the rigging and the movement of the blades of the rotor are in correct synchronisation.

(g) That the tracking of the main rotor blades is satisfactory.

(h) That, when tabs are provided on main rotor blades, these are correctly set.

(j) That the neutral, maximum and minimum pitch angles and coning angles of the tail rotor blades are in accordance with drawing requirements.

(k) That, when dual controls are provided, these function correctly and in synchronisation when operated from both positions.

(l) That, to comply with Chapter **G4—2** of BCAR, the static operating loads of the system are not excessive and, when specified, do not exceed drawing requirements.

11.2.3 **Tracking Checks.** When the main rotors do not 'cone' by the same amount during rotation, they are said to be 'out of track', and this may result in excessive vibration at the control column. Tracking checks should be carried out at the prescribed engine operating conditions, if possible in still air. Where it is not possible to obtain still-air conditions, the rotorcraft should be faced into a wind not exceeding 10 knots and it should be free from gusts.

11.2.4 **Tab Setting.** The setting of the tabs on main rotor blades (if provided) should be checked to eliminate out-of-balance moments which will apply torque to the rotor blades. The tab setting should be checked for correctness by running the rotor at the prescribed speed and ensuring that the cyclic-pitch control column remains stationary. Out-of-balance moments impart a stirring motion to the column.

11.2.5 **Checking Blade Angles.** Before checking blade angles it must be ensured that the rotorcraft and, where applicable, the rotorhead, is set up in the correct lateral and longitudinal position. The blades must be set in the specified position for the check. The blade angle should be checked on each blade in turn and, when specified, the angles of the subsidiary blades on the main rotor must agree with those of the master blade within the prescribed limits. When it is necessary to adjust the initial blade rigging in order to obtain correct tracking or acceptable flight characteristics, the rigging should be re-checked after test flying has been completed to ensure that it is within permitted limits.

11.3 **Control Locks.** A check should be made on internal ground control-locking systems to ensure they are positive in action, engage fully in the 'locked' position and have adequate clearance in accordance with drawing requirements in the 'unlocked' position. There should be no possibility of interference between the locks and the controls over the full range of movement of the latter.

11.4 **Inspection after Functioning.** When the functioning checks have been completed, all checking equipment should be removed from the aircraft and a final inspection made to ensure that the systems are free from all foreign matter which might cause jamming (e.g. nuts, bolts and small tools). All access panels should be replaced, care being taken to make sure that securing screws are the correct length not to foul the controls and that chains and cables retaining the access panels are correctly fitted.

12 AUTOMATIC-PILOT INSTALLATIONS The information in this paragraph does not apply to any particular type of installation of automatic-pilot but gives general guidance on essential points which relate to the flying control system. Any moving parts of the automatic-pilot that constitute integral parts of the normal control system, whether the automatic-pilot is 'in' or 'out', should be regarded as part of the flying control system and should be inspected in accordance with the procedure given in this Leaflet.

12.1 When the automatic controls are disengaged, the normal controls should function satisfactorily, e.g. the resistance offered by the automatic-pilot motors, where applicable, should not affect the control of the aircraft.

12.2 A check should be made on the means provided for disconnecting the automatic-pilot from the normal controls to ensure it is possible to do so at all positions of the controls and that the manual override of the automatic-pilot is satisfactory.

12.3 The interconnecting mechanism between the automatic-pilot and the normal controls should give the required range of travel and should be correctly aligned and smooth and positive in operation. The clearance should be in accordance with drawing requirements.

12.4 Operating cables, where applicable, should be checked for tension in the manner applicable to the particular installation.

13 GROUND TEST—AFTER OVERHAUL OR MAJOR DISMANTLING

13.1 All rigging pins or retaining devices should have been removed from the controls. Where control locks are not provided, it may be necessary to support the control surfaces until the system is functioning. The control surfaces should be checked for freedom from obstruction and the automatic-pilot should be disengaged.

13.2 If any one of the independent systems has been disturbed, a complete series of checks required to test that system should be made. Where any rectification affects more than one system or where there is any possibility of the functioning of all systems being affected, then the complete series of checks to test all systems should be made.

14 PERIODIC INSPECTIONS Periodic inspections on the complete flying control systems should be carried out in accordance with the requirements of the Maintenance Schedule or constructor's Manual.

AL/3-8

Issue 2.

December, 1979.

AIRCRAFT

SYSTEMS AND EQUIPMENT

FIRE—GENERAL PRECAUTIONS

1 INTRODUCTION This Leaflet deals with fire precautions during maintenance and engine running, and indicates some of the maintenance and inspection procedures concerned with fire prevention. Some general information on the causes of aircraft fires is also included. The Leaflet should be read in conjunction with the relevant manuals for the aircraft concerned, the Factories Act and any local regulations concerning the prevention of fire.

1.1 Guidance on the installation and maintenance of airborne fire detection and extinguishing equipment is given separately in Leaflets **AL/3-9** and **AL/3-10.**

1.2 Leaflet **BL/10-2** gives guidance on the methods of testing aircraft furnishing materials in order to ensure compliance with BCAR, Chapter **D4-3.**

1.3 CAP 74* gives guidance on the fire prevention measures which should be taken when fuelling and de-fuelling aircraft.

2 PREVENTION OF FIRE ON THE GROUND Personnel engaged in the maintenance, overhaul and repair of aircraft, should be fully conversant with the operation of fire protection equipment provided and the action to be taken in the event of discovering a fire. Supervisors should satisfy themselves that all reasonable safety precautions are taken and that all apparatus is completely serviceable. Personnel should not wear footwear with exposed iron or steel studs, nails or tips in hangars, fuelling and de-fuelling areas, and aircraft movement areas, and it is recommended that matches or other means of ignition should not be carried.

2.1 **Fuelling Operations.** Personnel concerned with fuelling should be fully conversant with the guidance material in CAP 74, with local aerodrome instructions and with the safety precautions detailed in the relevant aircraft Maintenance Manual. Fuelling should only be carried out at a site approved by the aerodrome authority, and the precautions outlined in paragraphs 2.1.1 to 2.1.7 should be observed.

2.1.1 **Fuelling Zones.** Fuelling zones should be established before fuelling commences. These zones should be regarded as extending at least 6 m (20 ft) radially from the filling and venting points on the aircraft and fuelling equipment. Within this zone, smoking, the use of naked lights and the operation of switches which are not of an approved pattern should be forbidden.

(a) Unless fuelling takes place in a designated no smoking area, "No Smoking" signs should be displayed not less than 15 m (50 ft) from the fuelling equipment and aircraft tank vents.

***CAP 74 is available from Printing and Publication Services, Greville House, 37 Gratton Road, Cheltenham, Glos., GL50 2BN.**

(b) Auxiliary Power Units (APUs) which have an exhaust discharging into the zone should, if required to be in operation during fuelling, be started before filler caps are removed or fuelling connections made. If an APU is stopped for any reason during a fuelling operation it should not be started again until fuelling has ceased and there is no danger of igniting fuel vapours.

(c) Ground Power Units (GPUs) should be located as far as practical from aircraft fuelling points and vents, and should not be connected or disconnected while fuelling is in progress.

(d) Fire extinguishers should be located so as to be readily accessible.

2.1.2 **Precautions Prior to Fuelling.** Before the transfer of fuel commences, the following procedure should be carried out:—

(a) The aircraft should be connected to an effective earthing point and to the fuelling equipment.

(b) When overwing fuelling, the nozzle of the hose should be bonded to the aircraft structure before removing the tank filler cap. When fuelling from hand-operated equipment, including pumping from cans or drums, similar precautions should be taken to bond the pumping equipment, hose nozzle and containers. If funnels are used they too should be bonded to the nozzle or can and to the aircraft. If a chamois leather filter is used, the funnel, and all metal parts securing the leather, should be included in the bonding circuit.

(c) When pressure fuelling, the fuel tank pressure relief valves should, if possible, be checked for correct operation, and the bonding lead on the fuelling hose should be connected to the receptacle, located adjacent to the fuelling point, before connecting the nozzle.

2.1.3 **Precautions During Fuel Transfer**

(a) When overwing fuelling, the amount of fuel required should be determined and the quantity of fuel delivered should be regulated so that no overflow occurs. Fuel should not be splashed nor allowed to run into the aircraft structure.

(b) When pressure fuelling, any fuel levelling devices between tanks should be operated as necessary. The correct sequence of operations is essential to avoid damage to tanks and subsequent leakage of fuel or vapour.

2.1.4 **Precautions After Fuelling.** When the transfer of fuel is completed, the bonding wires should not be removed until the filler caps have been refitted or the pressure fuelling hose disconnected, as appropriate.

NOTE: Any cables, clips and plugs used for bonding or earthing, should be maintained in good condition and should be regularly tested for continuity.

2.1.5 **Work on Aircraft During Fuelling.** Whilst fuelling is in progress, servicing, maintenance, test and repair activities within the fuelling zone should be closely controlled.

(a) All ground equipment such as trestles, jacks, steps, etc., should be moved clear of the aircraft, to prevent damage to the aircraft as it settles because of the weight of fuel being uplifted.

(b) The main aircraft engines should not be operated.

(c) Only those electrical circuits essential to the fuelling operation should be switched on, except that some operators may permit certain specified maintenance work to be carried out during kerosene fuelling. The maintenance permitted is usually restricted to the replacement of complete unit assemblies. Testing and functioning of defined systems and equipment may be continued unless fuel spillage occurs or fuelling equipment becomes defective. No maintenance work may be permitted on aircraft using fuels which present a higher degree of fire hazard.

(d) Strobe lighting should not be operated.

(e) The engines of vehicles normally employed for servicing aircraft, including those on electrically powered vehicles, should not be run within the fuelling zone unless they have been designed for the purpose. All vehicles, their engines and equipment, should be subjected to regular inspection and maintenance to preserve their safety characteristics.

(f) All connections between ground equipment and an aircraft should be made before fuelling equipment is connected, and should not be broken until fuelling has been completed.

(g) Battery trolleys may be used within the fuelling zone provided that connection is made to the aircraft before fuelling equipment is connected. The circuit should remain unbroken until fuelling has ceased.

(h) Vehicles operating in the fuelling zone should not pass under or park beneath an aircraft unless specifically required to do so for maintenance or fuelling purposes. A clear exit path should be maintained.

(j) Aircraft combustion heaters should not be used.

(k) Maintenance work which may create a source of ignition should not be carried out in the vicinity of tanks or fuelling equipment.

(l) All hand torches and inspection lamps, and their cable connections, used within the fuelling zone, should be of certified 'flameproof' or 'intrinsically safe' type.

(m) Only authorised persons and vehicles should be permitted within the fuelling zone and the numbers should be kept to a minimum.

2.1.6 **Special Hazards**

(a) Aircraft should not be fuelled within 30 m (100 ft) of radar equipment under test, or in use in aircraft or ground installations.

(b) When any part of an aircraft landing gear, i.e. the wheels, tyres and brakes, appears overheated, the Aerodrome Fire Service should be called and fuelling should not take place until the heat has dissipated (see also Leaflet **AL/3-19**).

(c) Extreme caution should be exercised when fuelling during electrical storms. Fuelling should be suspended during severe electrical disturbances in the vicinity of the aerodrome.

(d) The use of photographic flash bulbs and electronic flash equipment within 6 m (20 ft) of the filling or venting points of aircraft or fuelling equipment, should not be permitted.

2.1.7 **Spillage of Fuel.** The actions to be taken in the event of a spillage of fuel will depend on the size and location of the spillage, the type of fuel involved, and prevailing weather conditions.

(a) If, despite care, fuel is inadvertently spilled in the aircraft structure, it should be cleared before the main aircraft engines are started. Lowering the flaps may accelerate drainage in some cases. Flight should be delayed to permit the evaporation of spillage, and air blowers should be utilised as necessary.

(b) In the case of a minor spillage of fuel on the ground, all liquid should be mopped up and the area allowed to dry out before starting any aircraft or vehicle engines in the vicinity.

(c) In the case of a major spillage of fuel (i.e. covering an area greater than 5 m^2 (55 ft^2)), action should immediately be taken to stop the flow of fuel, to evacuate all persons from the area and to notify the Aerodrome Fire Service.

(d) Fuel should not be washed into drains or culverts, but if such contamination does occur, large-scale water flushing should be carried out and the local water authority notified. Absorbent cleaning agents or emulsion compounds should be used to absorb spilled fuel, the contaminated absorbents being placed in suitable containers and removed to a safe location for disposal. The selection of tools and equipment to be used in removing spilled fuel and disposing of contaminated materials should have regard to minimising the risk of ignition.

2.2 **Work in Hangars.** Before commencing any inspection, overhaul or repair work involving the use of possible ignition sources in the vicinity of the fuel tanks, all tanks should be drained. De-fuelling should be carried out in the open air, by means of a fuel tanker utilising the pressure-fuelling/de-fuelling connections on the aircraft, or by draining the tanks into suitable containers. In either case, adequate bonding preacutions should be taken, the tanker or containers being bonded to the aircraft and the ground before draining commences. Care should be taken to avoid spilling fuel onto the ground, and containers should be sealed immediately after filling. To avoid danger from sparking between containers and ground contacts, the aircraft should normally be moved from the site first.

NOTE: If fuel tests (e.g. calibrations, flows, etc.) or draining become necessary inside hangars, then additional precautions are required. Adequate notices should be displayed and fire-fighting personnel should be in attendance. It should be noted that for calibration checks aircraft are usually on jacks to maintain a known datum and could not, therefore, be towed away in the event of a fire.

2.2.1 The draining of fuel tanks does not render them free from fire risk, as they will contain fuel vapour. It is therefore necessary to purge tanks of vapour before subjecting them to inspection or repair involving the use of heat, electrical equipment or other sources of ignition. The safety precautions applicable to the inspection and repair of tanks are included in Leaflet **AL/3-15**.

2.2.2 Special care is necessary during fuel flow testing, and foam or CO_2 type extinguishers should always be available whilst this work is in progress. The use of an enclosed flow test rig, similar to that described in Leaflet **AL/3-17**, is recommended (see paragraph 2.2 NOTE).

2.2.3 Electrical equipment used during maintenance work, e.g. portable lighting equipment, electric drills, soldering irons, etc., should be maintained in good condition to avoid generating sparks, and in any case this equipment should not be used when flammable vapours are present in the atmosphere. For work in areas where heavy fumes are present, e.g. inside fuel tanks, flameproof torches must be used. Care should be taken that no flammable fluid is splashed on naked bulbs or other hot surfaces as spontaneous ignition may follow. Low voltage electrical supplies for inspection lamps, etc., are advantageous.

2.2.4 As far as possible only non-flammable cleaning fluids and paint strippers should be used, but if the use of solvents giving off flammable vapours is unavoidable, they should be handled with care and if spilt, should be wiped up immediately. During the use of such fluids the aircraft electrical system should be made inoperative with, for preference, the aircraft batteries removed.

2.2.5 In certain aircraft, special battery lead stowages are embodied. These should be utilised in accordance with the appropriate instructions contained in the Maintenance Manual.

2.2.6 The spraying of large surfaces with dope or paint should be carried out in a properly constructed and equipped spray shop. When touching up small areas, all electrical apparatus worked from a mains supply should be switched off or removed from the vicinity.

2.2.7 Open containers of dirty oil, fuel, dope or solvents should not be stored in aircraft hangars and should be removed from the vicinity of aircraft as soon as possible, otherwise accumulations of flammable vapour may result.

2.2.8 Magnesium and titanium swarf should be completely removed after drilling or machining operations. Special dry powder extinguishants, which are usually known by a trade name, should be used on fires of these combustible metals; water must not be used. The extinguishants form a crust or skin over the burning metal and thus exclude air.

2.2.9 Before permitting the refitting of floor panels or inspection covers, inspectors should ensure that the bays are clean and free from all foreign matter, that all drains are unobstructed, and all applications of primers, sealing compounds, etc., in the boxed up area are dry. In addition, all electrical connections, fuse box covers, etc., should be checked, and the systems functioned, and if the bay houses part of the flying control system duplicate inspection of the flying controls should be carried out before fitting the covers or panels.

NOTE: Fire precautions specified in the Factories Act, and in other governmental or local regulations for industrial premises, should always be strictly observed.

3 MAINTENANCE AND FIRE PREVENTION The following recommendations give guidance on maintenance practices which will reduce the risk of fires occurring in flight or when ground running engines.

3.1 **Power-Plant.** Faulty assembly or mechanical failure of engines or power-plant components can cause fire, and careful inspection is therefore essential to ensure that fractures, cracks or leaks are detected and rectified.

3.1.1 Attention should be given to main engine and APU starter systems, and, in particular, to ignition harnesses and to high energy igniter plugs and leads in turbine engines. Maintenance instructions must be carefully carried out in accordance with the engine Maintenance Manual.

3.1.2 Pipes carrying flammable fluids are routed by design as far from exhaust systems and electrical apparatus as the installation permits, and, if disturbed, should be re-installed so that the original distances from such sources of ignition are not reduced. Great care must always be exercised to ensure that pipes are in good condition, are appropriately colour coded, are adequately clipped and bonded, and that unions are correctly secured so that leaks cannot occur, and that drains are clear. Guidance on the inspection of flexible and rigid pipes is given in Leaflets **AL/3-13** and **AL/3-14**, respectively (see also paragraph 3.1.12).

3.1.3 It is most important to trace the source of any flammable fluid leakage and to rectify it immediately. Kerosene, lubricating oil, gasolene and most hydraulic fluids will ignite spontaneously if in contact with hot surfaces, such as exhaust pipes, combustion chambers, jet pipes and overheated brakes. Gasolene at ambient temperatures and kerosene at elevated temperatures will vapourise and form a combustible mixture with air, which may be ignited by sparks from electrical equipment or accumulations of static electricity. Fuel and oil drains should be checked for blockage and the routeing of the pipes must be clear of cowlings and brake systems. Cowlings should be kept clean to obviate accumulations of flammable fluids, greases and dirt.

3.1.4 The flame traps or shutters of air intake systems must always be in good condition. Flame traps will burn if combustible sludge is allowed to accumulate on the gauze.

3.1.5 Grommets or flash plates used to seal openings in firewalls must always be refitted carefully and renewed if damaged. Gaps through or around a firewall are not permitted. Seals must be securely fixed in position, approved sealants should be renewed as necessary, and distorted or damaged cowlings must be repaired or renewed.

3.1.6 The power plant bonding system is an important safeguard against fire and all bonding connections should be inspected frequently according to the recommendations of Leaflet **EEL/1-6.**

3.1.7 A major failure, such as the fracture of a cylinder or induction manifold on a piston engine (particularly a supercharged engine) is a serious matter, as air/fuel vapour mixture may be discharged and contact a hot surface in the power plant area, where ignition could occur. Careful visual examination may reveal minor defects before the danger of a complete breakdown arises.

3.1.8 Shortage of coolant in liquid-cooled piston engines will result in over-heating with a grave risk of mechanical failure of the engine causing a fire. It follows that careful maintenance of cooling systems is an aid to fire prevention.

3.1.9 Cracked exhaust manifolds, pipes, ejectors, or turbine-engine combustion chambers may allow hot gases or torching flame to impinge on vulnerable parts of the power plant installation, either causing fire directly or giving rise to mechanical failure which may start a fire. Exhaust systems and combustion chambers should therefore receive very careful examination.

3.1.10 Engine vibration is generally an indication of a serious defect and can also result in the cracking of pipes or leaking of high pressure hoses and loosening of pipe connections.

3.1.11 It is most important that all the appropriate fire precautions are taken during the operation of auxiliary power units whilst the aircraft is on the ground. Intakes and exhausts must be free from obstruction. Temperature and warning indicators should be observed and action taken accordingly.

3.1.12 A contributory cause of fires in engine bays is the saturation of flexible-pipe lagging by flammable liquids. This can occur when the outer covering (e.g. sleeving of neoprene or rubber) has been damaged or has deteriorated, allowing seepage into the lagging. This condition can be detected by blistering or a soggy feel, as distinct from the hard feel of unsaturated pipes. If pipes are in a saturated condition they should be renewed.

3.2 **Airframes.** Leakage of fuel, hydraulic, de-icing or lubricating fluids, can be a source of fire in aircraft, and this should be noted when inspecting aircraft systems. Minute pressure leaks of these fluids may be dangerous, as they could quickly produce an ignitable mixture.

3.2.1 Fuel tank installations should always be carefully examined for signs of external leaks. With integral fuel tanks, the external evidence of a leak may occur at some distance from where the fuel is actually escaping, particularly with kerosene which has particular penetrating properties.

3.2.2 Hydraulic fluids are generally flammable and should not be allowed to accumulate in the structure. Lagging and sound-proofing materials may be rendered highly flammable if soaked with oil of any kind and should be renewed.

3.2.3 All oxygen system equipment must be kept absolutely free from traces of oil, grease or flux, as these substances will ignite spontaneously in contact with pressurised oxygen. Oxygen servicing cylinders should be clearly marked so that they cannot be mistaken for cylinders containing Air, CO_2 or Nitrogen, as explosions and fatal accidents have resulted from these errors during maintenance operations.

NOTE: When a form of lubricant is necessary (e.g. because of a binding thread) the approved or recommended lubricant must be used. Lubricant should be used sparingly to ensure that it does not enter the oxygen system.

3.2.4 Any spillage or leakage of flammable fluid in the vicinity of combustion heaters is a serious fire risk, particularly if any vapour is drawn into the heater and passed over the hot combustion chamber. All safety devices, such as NO-HEAT or OVER-HEAT switches should be inspected at the intervals prescribed in the relevant Maintenance Schedule.

3.2.5 Hot air de-icing and other heating systems should be carefully inspected, particularly on turbine-engined aircraft, where high initial air temperatures exist, to ensure that the ducting and lagging are free from defects.

3.2.6 Pyrotechnical equipment such as signal cartridges, should be renewed if defective in any way. Stowages should not be located in high temperature zones.

3.3 **Smoking Compartments.** In these compartments, furnishing materials must be flame-resisting, and must be approved in accordance with CAA Specification No. 8 (see Leaflet **BL/10-2**). It is important that any gaps or crevices in the flooring and at the free edges of panelling should be sealed and this should be checked at regular intervals. Furnishing materials should also be inspected for grease or oil stains which may tend to propagate a fire, and loose covers which have been laundered or dry-cleaned should be re-proofed as necessary. Ash trays must be fitted and a hand-held fire extinguisher of an approved type must be installed (see Leaflet **AL/3-10**).

NOTE: The use of highly toxic extinguishants such as methyl bromide or carbon tetrachloride is prohibited in either crew or passenger compartments. However, in the case of a fire occurring during servicing or maintenance, the toxicity of the extinguishant may be less important, particularly if it is possible to direct the extinguisher through an open door or window into the fuselage.

3.4 **Electrical Equipment.** As faulty electrical equipment can provide a source of ignition by generating sparks or becoming over-heated, attention should be given to the following points:—

(a) Overheating and eventual destruction of cables can be caused by over-loading a circuit. To prevent this, particular care should be taken when installing new fuses or cables to ensure that the design standards as shown on the relevant drawings or manuals are maintained.

(b) Overheating of equipment can be caused by poor ventilation. Gauzes may become choked and cooling ducts damaged or disconnected.

(c) Electrical sparks from bad commutation in generators or motors, and arcing at relays and loose connections, are particularly dangerous. Terminal ends and cover bands must be torque loaded in accordance with the Maintenance Manual and securely locked.

NOTE: There have been cases of short-circuits at terminal positions and special care is necessary to prevent inter-action between circuits at these positions, particularly after any re-orientation of cables and looms. Care is also necessary to prevent arcing and tracking across terminal blocks through the ingress of moisture.

3.4.1 Deterioration of cable insulation can be caused by exposure to fluids such as fuel, hydraulic fluid, oil, etc., or their vapours. Heat and sunlight also have deleterious effects and if exposure is severe or continuous the insulation may eventually break down. Faulty insulation on cables may be the cause of arcing, particularly on heavy duty cables which are attached to movable components or parts, e.g. adjustable lamps, portable apparatus and leads to control columns. Particular care should be taken to ensure that these cables are correctly installed and tested for insulation resistance and freedom from chafing at the prescribed intervals, in accordance with the relevant Maintenance Manual.

3.4.2 Bearing failure in engine-driven rotating equipment may result in friction that could generate sufficient heat to destroy the component and create a serious fire risk.

4 ENGINE RUNNING PRECAUTIONS Fires during engine starting and running can be avoided by observing the correct drill given in the relevant Manuals for the aircraft and engine concerned. General guidance on some important points is given in the following paragraphs:—

(a) Whilst engines are being started and ground run, fire extinguishing apparatus, preferably of the CO_2 trolley type with extending applicator and under the control of trained and experienced personnel, should be positioned near the aircraft. Additionally, a good communication system should be arranged between the cockpit and ground.

(b) Persons in control of engine ground running should be familiar with the approved ground running instructions in the appropriate Manuals and with the correct fire drill procedure.

4.1 **Piston Engines**

4.1.1 Care should be exercised when priming piston engines preparatory to starting, particularly when an electrical priming pump is used or when priming is carried out by pumping the throttle (to operate the carburettor accelerator pump). Overpriming can cause an excess of fuel in the engine, and could result in an intake fire.

4.1.2 When excess-fuel conditions exist and an engine fails to start (a common occurrence when engines are hot), the fuel cock should be turned OFF (or the fuel cut-out closed) and the throttle should be fully opened. After ensuring that all ignition switches including booster coil switches are OFF, the engine should be turned. Most types of engines can be turned in the running direction by the propeller or starter, but when this has been done, precautions should be taken to dispel any accumulations of fuel in the exhaust system. On some small engines the propeller can be used to turn the engine in the reverse direction of rotation to expel the over-rich fuel-air mixture through the air intake.

4.1.3 If an air intake fire occurs before the engine picks up, a previously agreed signal should be made to the person at the controls, who should immediately turn off the appropriate engine fuel cock; it is often recommended to continue to motor the engine on the starter so that the burning fuel is drawn into the engine. If the engine picks up and runs, an air intake fire will probably cease without further action, in which case the fuel may be turned on again. Consideration should then be given to any damage which may have been caused to the intake filters by the intake fire.

4.1.4 If an intake fire persists or appears to be serious, a ground CO_2 type fire extinguisher should be discharged into the air intake. Outside action will also be necessary if burning fuel runs from the intake or exhaust on to the ground.

NOTES: (1) The ideal fire extinguishants to use are CO_2 or BCF which will cause no harm to the engine. If CO_2 or BCF have been drawn into an engine no harm should result provided the engine is run or turned over adequately within the next few hours. However, if an extinguishant such as methyl bromide is allowed to remain in the engine, particularly at temperatures below 4°C when it is in a liquid state, it will be necessary to strip the engine to ensure that corrosion has not occurred. If foam has been drawn into an engine the danger of corrosion can be greater. Mechanical foams can leave deposits which may be cleared by hot engine running. Chemical foams can leave deposits which require engine stripping.

(2) Mechanical foam is an extinguishant formed by mixing air, water and foam-making liquid.

4.1.5 Should an engine fire occur whilst ground running, the drill given in the appropriate Manual should be followed. To help the person in charge of the ground fire-fighting equipment, any other operating engines should be shut down.

4.1.6 Any practice which promotes accumulation of flammable fluid or vapour inside engine cowlings should be avoided. Exhaust systems must give complete sealing; flanges, gaskets and air intake sealing must be regularly examined and maintained. In shutting-down, engines should first be cooled by running at low power for a short period, and fuel cut-outs (if fitted) should be used strictly in accordance with the engine manufacturer's operating instructions.

4.2 **Gas Turbine Engines.** The most frequent cause of fire during starting is the accumulation of fuel in the engine and jet pipe following an earlier 'wet start' (i.e. an unsuccessful attempt to start in which the fuel has failed to ignite and has been distributed throughout the engine and jet pipe and drained into the lower combustion chambers and drain system). It is necessary to ensure that the drain system operates correctly, and to drain the vent tank (which has a limited capacity), as advised by the manufacturer. It is normal practice to carry out a 'dry run' (i.e. motor the engine through the starting cycle with the fuel and ignition turned off) after a wet start, before making another attempt to start an engine.

4.2.1 As kerosene spreads readily and does not evaporate quickly, a very slight leak is significant and must be remedied. Fuel which may have collected in cavities, cowlings, etc., should be wiped up after maintenance operations before any attempt is made to start the engines.

4.2.2 If there is any indication of an internal engine fire when an engine is not running, the fuel cocks should immediately be turned OFF and every attempt made to localise the fire. An outside assistant should discharge a CO_2 or BCF extinguisher into the intake or jet pipe if necessary.

4.2.3 When starting and running gas turbines, particular note should be taken of the jet pipe temperature. If this exceeds the manufacturer's limitations, a serious risk of mechanical failure followed by fire may result.

4.2.4 The recommendations of paragraph 4.1.5 apply equally to gas turbine engines.

4.3 **Engine Nacelle Fire Extinguisher Doors.** These engine nacelle doors (British Standard C.6), when fitted, should be maintained strictly in accordance with the aircraft Maintenance Manual. It is important that the doors operate freely inwards, and that the beads or lips on the doors will not restrict the removal of the extinguisher nozzle.

AL/3-9

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AIRCRAFT

SYSTEMS AND EQUIPMENT

FIRE DETECTION EQUIPMENT

1 INTRODUCTION This Leaflet gives guidance on the installation and maintenance of fire, overheat and smoke detection systems. Detection systems in current use are designed to give indication of fire, smoke or hydraulic mist at various locations in an aircraft by the illumination of warning lamps and, in the case of fire, by audible warning devices. Guidance on the maintenance and testing of the associated electrical system is given in the relevant paragraphs of Leaflet **EEL/2-1.**

1.1 This Leaflet should be read in conjunction with the manufacturers' data sheets for the equipment concerned and with the Maintenance Manuals and Schedules for the aircraft in which the equipment is installed.

1.2 Information on general fire precautions is given in Leaflet **AL/3-8** and on extinguishing equipment in Leaflet **AL/3-10.**

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet **ML/2-2,** issue 2, dated 1st November 1964.

2 REQUIREMENTS REGARDING THE PROVISION OF FIRE AND OVERHEAT DETECTION EQUIPMENT Chapters D5—8 and K5—8 of British Civil Airworthiness Requirements prescribe the conditions under which fire and overheat detection equipment should be fitted to aircraft. Fire detectors must be fitted in the Designated Fire Zones of all power plants except those of low-powered piston engined aircraft with a maximum authorised weight of 12 500 lb or less.

NOTE: A Designated Fire Zone is a region where a potential fire risk may exist following failure or leakage of any component, equipment or part of the power plant.

2.1 Detection systems must be capable of providing rapid detection of a localised fire or overheat condition and indication of the area in which some corrective action is required. Detectors must not automatically operate main power unit extinguishers although they may, in certain circumstances, be used to shut down an auxiliary power unit.

2.2 The construction and installation of fire detectors and the design of the system must be such that:—

(i) Indication of fire is given immediately it occurs and continues for the duration of the fire; it is recommended that indication that the fire has been extinguished should also be given with the minimum of delay.

(ii) So far as is practicable, the failure of any component is more likely to render the system inoperative than to cause it to function spontaneously.

(iii) The functioning of any associated electrical circuit may be checked by the flight crew.

2.3 The main power plant fire detection system should contain an audible warning device to supplement the visual indications. The audible warning may be isolated during critical flight conditions, but if a manual cancelling facility is also provided, this should reset automatically when the warning signal has ceased.

3 DETECTION SYSTEMS On most civil transport aircraft the engine compartments are divided into two or more fire zones. The actual engine, where the likelihood of fire is most probable, is protected by fire warning and extinguishing systems, while other zones, such as around the jet pipes, may be fitted with overheat warning systems but not necessarily fire extinguishing systems. Overheat warnings result from the leakage of hot gases which, although they may not result in fire, may cause other damage to the engine bay or airframe structure.

3.1 In addition to warnings originating in the main engine compartments, potentially dangerous overheat or fire situations in other parts of the aircraft may be notified to crew members by separate warning systems.

3.1.1 The presence of smoke or hydraulic mist in equipment bays or baggage compartments is sometimes indicated by special detectors, particularly when these compartments are not accessible in flight. To permit visual inspection of these compartments, louvres are sometimes mounted in the roof, through which a periscope may be inserted.

3.1.2 Structure adjacent to high pressure hot air ducting such as is normally used on turbine powered aircraft for supplying air for cabin pressurisation, de-icing and air conditioning systems, is normally protected by excess temperature detectors placed at strategic positions near the ducts, normally close to pipe joints.

3.1.3 Auxiliary power units (A.P.U.s) are used on many large aircraft and these are protected by a system similar to that applied to the main engines. In this case, however, the warning system may also operate the normal shut-down system to stop the A.P.U. automatically in the event of a fire or overheat condition on the ground.

3.2 Signals received from any of these detectors are used to illuminate appropriate warning lamps on the flight deck. The control units of main engine fire detection circuits are also sometimes used to operate a 'trend indicator', which continuously indicates temperature conditions in the engine bay, and may also be used to operate, at the warning temperature, an alarm bell or other audible warning device.

3.3 Test facilities, which will completely test the continuity and operation of the circuit, are normally provided in all detection systems. Alternatively, some circuits may be fitted with warning lamps which incorporate a press-to-test facility.

4 TYPES OF DETECTORS Both 'unit' and 'continuous' type detectors are in use, the 'unit' type being situated at the points most likely to be affected by fire, whilst the 'continuous' type are routed to provide maximum coverage in the fire zone. Detectors of either type may be used separately, or together in a combined fire warning and engine overheat system. Detectors or control units of any one type may have alternative temperature settings and the part number marked on the case is the only positive means of identification of the warning temperature.

4.1 **Unit Type Detectors.** These include the following types, although some are now fitted only on older types of aircraft and are not considered further in this Leaflet.

4.1.1 **Melting-link Switches.** These switches consist of a pair of contacts held apart by a mechanism which is released when a fusible compound melts. At a predetermined temperature the compound melts, allowing the contacts to come together and complete the circuit to a warning lamp.

4.1.2 **Thermo-couple Detectors.** These units are used to operate a sensitive relay or electronic circuit when a predetermined temperature is exceeded.

4.1.3 **Differential Expansion Switch.** This type of unit detector is often used in engine installations and combustion heater zones. The switches operate on the principle of the difference in the coefficients of expansion of dissimilar metals, and reset automatically when the ambient temperature is reduced below the warning level.

4.2 **Continuous Type Detectors.** To ensure efficient detection of fire a considerable number of unit detectors may be necessary in some installations, and in such cases continuous type detectors are normally used.

4.2.1 **Continuous Wire Type Detectors.** These detectors operate on either of two principles, the mode of operation depending on the type of control unit fitted to the system. Detector elements are manufactured in various lengths and may be joined together to form a continuous detector loop which is routed round the installation as required. An element consists of a stainless steel or inconel tube, with one or two centre electrodes insulated from the tube by a temperature sensitive material. In certain circumstances elements are enclosed in a perforated armoured sheath which gives protection from random damage.

(i) **Resistance Type.** The resistance of the insulating material decreases with an increase in temperature until, at the warning temperature, sufficient current passes to operate a warning circuit. The element is fed with a current which is passed through a control box for operation of the warning system.

(ii) **Capacitance Type.** The element forms a capacitor, the capacitance of which increases with increased temperature. The central electrode is fed with half wave alternating current which it stores and returns to a control unit during the second half of the cycle. The stored charge increases with the temperature and, when the warning temperature is reached, the back current is sufficient to operate a relay in the warning circuit. The main advantage of the capacitance system is that a short circuit grounding the element or wiring does not result in a false fire warning.

4.2.2 **Liquid Type Detector.** This detector consists of a tube and expansion chamber filled with liquid. If a short length of the tube undergoes a sudden rise in temperature, the liquid expands and builds up a pressure differential across an orifice leading to the expansion chamber. A Bourdon tube is thereby deflected to close a pair of electrical contacts.

4.2.3 **Pyrotechnic Flame Switch.** This consists of a metal capillary housing a pyrotechnic cord which will ignite if sufficient heat or flame touches any part of the capillary length. If this occurs pressure is generated within the capillary and operates a switch mechanism.

4.3 **Smoke Detectors.** Freight holds, baggage compartments and equipment bays in the fuselage are often fitted with smoke detectors. Air from the compartments is arranged to flow through a smoke detector either by mounting a detector in the roof of each compartment or by passing air from all compartments through a single detector. In the latter case cabin differential pressure is used to circulate air through the detector and a separate visual indicator shows which compartment is affected. Alternatively, when only a visual indicator is fitted, air may be drawn through the system by means of an external venturi. It should be noted that this type of system may not continuously monitor the compartments concerned and frequent checks may need to be carried out during flight by switching on the indicator lamp.

4.3.1 **Photo-electric Cells.** There are two types of detectors which use photo-electric cells to give warning of the presence of smoke.

(i) In the single cell detector a divergent beam of light is directed towards a photo-electric cell but direct illumination is prevented by an opaque screen. When smoke is present the light is scattered round the screen and falls on the cell, increasing the cell's electrical conductance. Cell output is amplified to operate the warning relay.

(ii) In the double cell detector, detecting and balancing cells, located in separate compartments but affected by a single projector lamp, are connected in a bridge circuit which is adjusted to pass no current under normal conditions. When smoke is introduced in the detection cell chamber, the smoke causes increased light scatter and a current flows in the bridge circuit. This causes operation of a sensitive relay which in turn energises a power relay and results in illumination of the warning lamps.

4.3.2 **Alpha Particle Detector.** A third type of detector is used on some aircraft and depends on the absorption, by smoke, of alpha particles. It consists of a small d.c. operated unit embodying a double balanced ionisation chamber containing radium coated strips, and a special cold cathode tube. One chamber is protected from sudden atmospheric changes by partial enclosure and the other is open to cabin air. When smoke enters the open chamber the alpha particles are absorbed with a consequent decrease in ionisation current. This initiates discharge of the cold cathode tube and so operates the alarm. A part from periodic checks for security and damage no maintenance is required with this type of detector. A test switch on the signal panel verifies the correct sensitivity and functioning of the equipment.

4.3.3 **Visual Smoke Indicators.** Although visual smoke indicators provide the only means of smoke detection on a few aircraft, they are usually installed to verify that warnings given by an automatic detector are genuine, or as a means of locating the smoke source. Smoke present in any particular compartment will be drawn past the appropriate indicator window and will be rendered visible when automatic operation of the smoke detector results in illumination of a lamp in the indicator. A switch is provided to illuminate the lamp for test purposes and a pilot window in the indicator is available to check lamp serviceability. A device is also provided in the indicator to show that air is flowing through it, even though no smoke is present.

4.3.4 **Carbon Monoxide Detectors.** Certain aircraft of American manufacture are equipped with systems for detecting concentrations of carbon monoxide (CO). Although primarily intended to indicate contamination of cabin air (samples of which, taken from air flowing from the engine blowers, and cabin heaters, are automatically analysed by a cyclic device) a warning of excess CO would probably be associated with a fault involving increased fire risk.

5 INSTALLATION AND MAINTENANCE The efficiency of any detection system depends on the suitable positioning of the detectors and on the proper maintenance of all components within the system. For details of particular installations reference should be made to the relevant manuals for the aircraft concerned but the following paragraphs discuss the servicing requirements of the most common aircraft fire detection systems and indicate the faults which may be found.

5.1 **General.** Fire detection equipment is located around and adjacent to the engines where maintenance operations are comparatively frequent, and is therefore susceptible to damage from actions unconcerned with the maintenance or testing of the fire detection system. The detectors, whether unit or continuous, and the associated wiring, are attached to the engine or cowlings and are affected by engine vibration and by leakage or spillage of fluids used in the engine. When work is being carried out in an area fitted with fire detection equipment extreme care is necessary to prevent damage or contamination of the system since a spurious fire indication or failure to detect an actual fire could result.

5.2 **False Fire Warnings.** Investigations into the incidence of false fire warnings have emphasised the need for correct installation and proper maintenance. Some of the probable causes of false warnings or failure to operate on test are:—

(i) **Ingress of Moisture.**

(a) Incorrect assembly of sealing washers or glands on detectors or associated wiring accessories.

(b) Premature removal of transit caps or seals when fitting new items.

(c) Inadequate tightening of connectors (a torque loading is usually specified).

(d) Failure to fit new crushed metal sealing washers (if fitted) when fitting a replacement unit.

(e) Cracked or chafed elements.

(ii) **Faulty Installation.**

(a) Detection elements too close to heat shields or other surfaces which may attain a temperature high enough to operate the detector.

(b) Short circuiting of electrical wiring by chafing against structure.

(c) Damage to detection components through carelessness during routine maintenance of adjacent unrelated equipment.

(d) Inadequate support, more particularly of continuous element detectors, with consequent damage from chafing or fracture through vibration.

(e) Clip bushes of a material unsuitable for the environment, resulting in damage to a continuous element at clipping positions.

(f) Incorrect racking of printed circuit cards in fire detection modules, possibly resulting in spurious warnings.

(iii) **Lack of Cleanliness.**

(a) Dirt, swarf or other foreign matter in electrical connections causing short or open circuit.

(b) Oil or other fluids penetrating connections, either prior to tightening or through incorrect torque loading, and resulting in failure of the insulation.

5.3 **Continuous Element Detector Systems.** Except for the types which are enclosed within an armoured sheath, continuous elements are vulnerable to rough handling and it is essential that every precaution is taken to maintain the integrity of the system and to check its function at frequent intervals. A typical system is shown in Figure 1.

5.3.1 **Installation.**

(i) There are several types of element, each type being manufactured in a variety of lengths and suitable for either fire detection or overheat warning. Before fitting a new element the part number should be checked, the element inspected for cleanliness or damage, and an electrical check carried out to ensure that continuity and insulation resistance are within the limits quoted in the relevant Maintenance Manual. Testing should be carried out at normal room temperature since an elevated temperature would result in different readings being obtained.

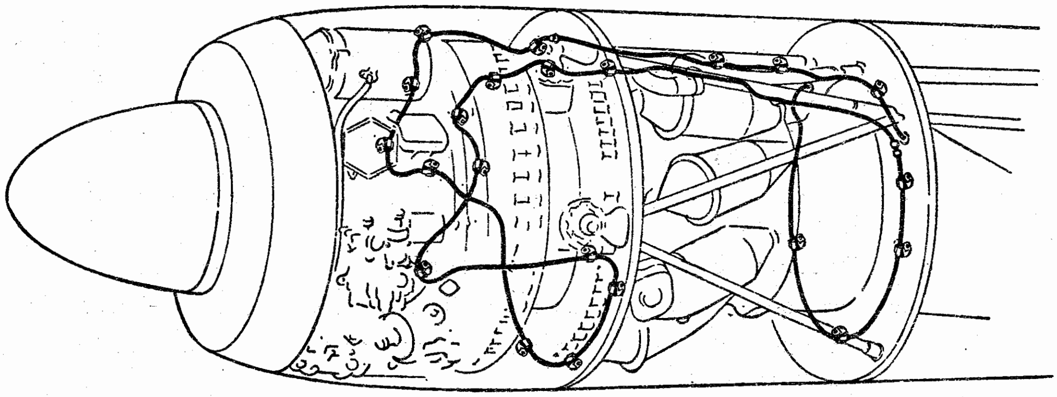

Figure 1 TYPICAL CONTINUOUS ELEMENT INSTALLATION

(ii) The manner in which the element is attached to the structure is most important. It is clipped 4 inches from end fittings and at approximately 6 inch intervals along its length, and the clips, which are often of the quick-release type, must be positioned so that no damage can be caused to the element by rubbing or vibration. Installation details are normally shown pictorially in the relevant Maintenance Manual.

(iii) Care is also necessary when bending the element and curves should be kept smooth and not less than the minimum radius quoted by the manufacturer. Clip bushes should be correctly positioned at each clip and care taken to eliminate strain on the element. Excessive bending could result in work-hardening of the capillary, so that kinks or bends which are within the specified limits should be left and not straightened. Elements vary slightly in length and any excess should be spread throughout the run.

(iv) The end fittings of each element, and of the other components in the system, are protected by caps during storage. These caps should only be removed for testing purposes or immediately before coupling up. New sealing washers must be fitted whenever a connection is broken and all parts must be perfectly clean and dry. Coupling nuts should be torque tightened to the appropriate values, using two spanners to prevent twisting the capillary.

(v) Different types of control unit are often identical in appearance and care must be taken to ensure that the correct types are fitted. Electrical connections to the units may be by terminal posts, plugs and sockets, edge connectors or contact buttons, and whichever type is used care must be taken to ensure that the contacts are clean. Where electrical connection (between the control unit and its mounting base) is by spring-loaded contact buttons, operation of the buttons should also be checked.

(vi) When installation has been completed, operation of the system should be checked by use of the appropriate test switch. If this test proves satisfactory all nuts which have been re-connected should be wire locked.

5.3.2 **Inspection**

(i) **Acceptance Checks.** All components should be examined externally for damage which may have occurred in transit, and sealing caps should be removed to ensure that the threads are clean and internal parts of connections are undamaged. Control units can be bench-checked by means of a special test set, all other components being tested for continuity and insulation resistance. Procedures for the electrical checks vary between installations and reference should be made to the relevant Maintenance Manual for details of the test for a particular component.

(ii) **Function Test.** Test circuits are usually arranged to simulate fault conditions by either grounding the centre electrode of the element (resistance type), or introducing additional capacitance into the circuit (capacitance type). By this means the system is completely checked; provided the visual and audible warnings function when the test switch is operated and cease to function when it is released, the system may be considered serviceable. It should be noted that on some aircraft the engine fire warning lamps are held on by a magnetic relay and are extinguished by moving the test switch to the 're-set' position. On other aircraft, operation of the audible warning may be dependent on throttle or flap position, or aircraft altitude. These variations will be fully described in the appropriate Maintenance Manual.

(iii) **Periodic Checks**

(a) At the intervals prescribed in the approved Maintanence Schedule all components should be examined, in situ, for security, damage, corrosion or deterioration. Any damage found on elements should be compared with the limits laid down in the manufacturer's manual and components replaced as necessary. Parts with acceptable physical damage should be given an electrical check to ensure that insulation resistance remains satisfactory. The dressing of dents, gouges, kinks, etc., is not permitted.

(b) When required by the Maintenance Schedule, the detector elements should be removed from the aircraft so that all components can be properly cleaned and inspected. Particular attention should be paid to the centre pin and ceramic insulation of connections and to those parts of the element which were not accessible for visual examination in the aircraft. Control units should be given a thorough electrical check in accordance with the relevant manual, a special test set normally being used for this purpose. When the components are re-installed, new sealing washers must be fitted and every precaution taken to keep connections clean and dry.

NOTE: The time interval between these checks varies considerably and is based on experience gained with each particular aircraft installation. On some aircraft, detector elements are only removed when they become unserviceable.

5.3.3 **Cleaning.** Cleanliness of all components in the system is essential. Dry foreign matter in end fittings and couplings should be removed with a camel hair brush, but if oil or other liquids are present they should be removed by brushing with a small quantity of approved cleaning fluid. The part should then be allowed to dry for at least 10 minutes or blown out with dry bottled air or nitrogen to remove all traces of liquid. Normal compressed air supplies are unsuitable for this purpose since they normally contain moisture or oil.

5.4 **Unit Detector Systems.** These are normally simple d.c. circuits in which a number of unit detectors are connected in parallel so that actuation of any one detector will complete the circuit through a warning lamp. In some circuits the detectors are connected between two wiring loops, either of which may be supplied through a magnetic circuit breaker. A short circuit in the energised loop results in operation of the magnetic circuit breaker and the supply is then routed to the second loop, thus preventing a spurious indication of fire. A typical installation is shown in Figure 2.

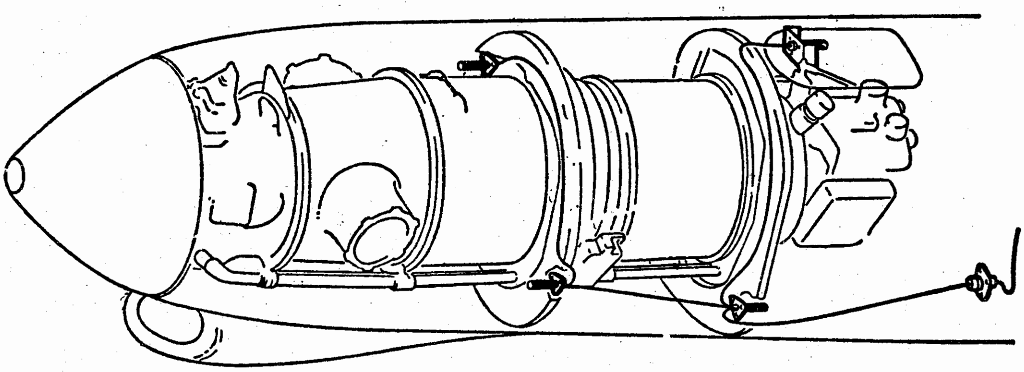

Figure 2 TYPICAL UNIT DETECTOR INSTALLATION

5.4.1 **Installation.** The operating temperature of any particular unit detector depends on its position in the engine bay and care is necessary to ensure that the correct type is fitted at each position. Details of temperature settings are contained in the relevant Maintenance Manual and the setting of a particular detector is sometimes included in its part number.

(i) The detector units are rigidly mounted in position and are of comparatively robust design, although severe blows could upset the temperature setting. Installation of the electrical wiring, however, requires considerable care, since if not adequately supported and clipped it may chafe on the surrounding structure and eventually cause a system failure. Contact with excessive heat, moisture, oil or grease could also cause deterioration of the insulation, and cables should be routed to avoid any form of contamination.

5.4.2 **Inspection**

(i) **Function Test.** Operation of this type of detection system is checked by use of a test switch which simulates operation of a detector. This completes the warning circuit and, if the warning lamp lights, proves the continuity of the associated wiring.

(ii) **Periodic Inspection.** At the intervals prescribed in the relevant Maintenance Schedule all parts of the system should be examined for security or damage, particular attention being paid to the condition of the electrical cables and their connection to each detector. Continuity of the cables, and insulation resistance between the shell and leads of each detector, should be checked with suitable test equipment.

(iii) **Detectors.** Thermo-couple type detectors should normally be removed and subjected to a bench test whenever it is necessary to verify their operation. This is not always necessary with thermal expansion type detectors however and apparatus is often recommended which enables testing to be accomplished in situ. With this equipment a heating probe is attached to the detector, and the temperature obtained by the detector is recorded on an associated temperature gauge. The temperatures at which the detector operates and resets must be within the limits laid down by the manufacturer.

5.5 **Smoke Detector Systems.** These systems vary considerably due to the differences in layout between various aircraft. Most transport aircraft are fitted with a photo-electric detector and visual indicator system through which air flows under cabin differential pressure. On some aircraft photo-electric detectors are fitted in each compartment, while in others only a visual indicator may be used and airflow induced by an externally mounted venturi. A typical system is shown in Figure 3 and described below.

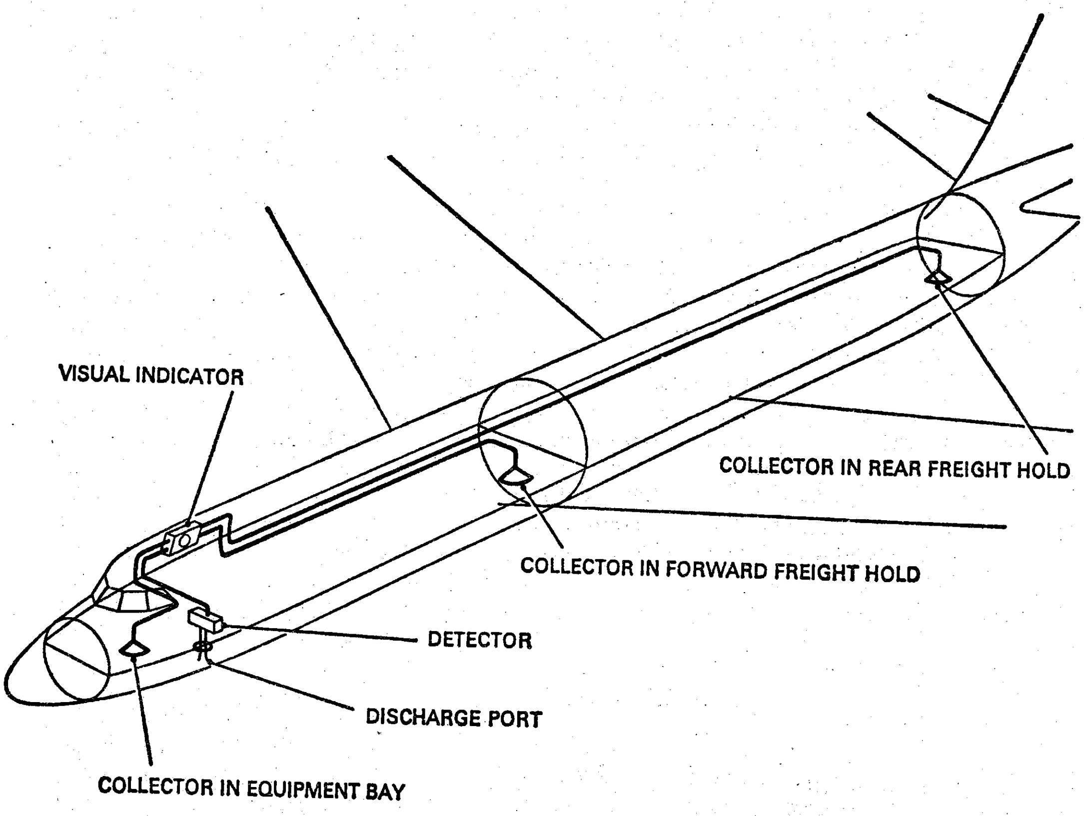

Figure 3 TYPICAL SMOKE DETECTION SYSTEM

5.5.1 **System Function Check.** Operation of the test/re-set switch on the flight deck illuminates a test lamp in the photo-electric detector, thus causing light to fall on the detector cell. This results in operation of a sensitive relay and illumination of the smoke warning lamp. At the same time a lamp in the visual smoke indicator is illuminated and becomes visible as a green light in the pilot window and a red light in each of the indicator windows. The red lights are not visible when air is flowing through the indicator (i.e. in flight). Once the test/re-set switch has been moved to the 'test' position the sensitive relay in the detector is held on by a small magnet; by moving the switch to the 're-set' position a coil in the relay is energised to overcome the magnet and break the circuit to the warning lamps. An additional test/re-set switch is fitted to some detector units and operation of this switch should be checked during servicing operations.

5.5.2 **Inspection.** The complete system should be inspected periodically for security and signs of damage. Particular attention should be paid to electric cables, pipe-lines and detector units, especially when these are located in freight compartments and liable to damage from loading and unloading operations. Air outlets from the monitored compartments must not be obstructed by furnishings, insulation, etc., and there must be a free flow of air through the louvres in the detector unit casings. Individual components should be checked for satisfactory operation as follows:—

(i) Detectors having two cells in a bridge circuit (para. 4.3.1 (ii)) are provided with a number of switches and adjusters for use during servicing. A test/re-set switch is used as described in para. 5.5.1; a 'zero' switch cuts out a resistor in the circuit to the projection lamp, thus increasing voltage to that produced with engines running; an adjusting screw alters the position of a shutter over the balancing cell, and a pointer is fitted to the sensitive relay to measure current flowing in the bridge circuit. The pointer should register zero under normal conditions, and this is set, with the 'zero' switch held on, by turning the shutter adjusting screw. If, during this check, excessive adjustment is required to zero the pointer (i.e. more than two turns per indicated micro-amp), a defective cell is indicated and the unit should be changed.

(ii) Detectors having a single cell (para. 4.3.1 (i)) are fitted with a label showing the obscuration at which that particular detector should operate its warning signal. This may be checked with a suitable meter attached to test sockets in the detector case. With the test/re-set switch set to 'test' the calibrate volts (i.e. the difference between the amplifier output volts and the signalling volts) are measured, and the figure compared with the marking on the label. The result gives the percentage obscuration at which the warning signal is actually given and this should be within the range prescribed in the relevant Maintenance Manual.

(iii) **Visual Indicator.** This component requires little attention apart from replacing an unserviceable lamp. However, since air is passing through the unit whenever the aircraft is operating, dust or dirt may obscure the viewing windows and obstruct internal passages, particularly when oil mist or moisture are present. Indicators should be removed for overhaul and cleaning at the prescribed intervals and whenever contamination becomes apparent during a routine functional test.

(iv) **Pipelines.** Operation of a smoke detection system in which the detector or indicator is connected to all the monitored compartments, is dependent on the free flow of air from those compartments through the detector and/or indicator to atmosphere. It is necessary, therefore, to ensure that pipelines are free from obstruction or leaks, and checks are specified at regular intervals in the relevant approved Maintenance Scheaule. The application of either pressure or suction may be recommended.

(a) **Flow and Pressure Test.** Each pipe run should be disconnected at the ends, and air pressure applied to one end by means of an air test set. When free air flow from the opposite end is evident, that end should be blanked off and air pressure allowed to increase to the recommended test pressure (normally about 10 lb/in^2). With the air supply turned off the test pressure should be maintained for one minute. If leaks are apparent a non-corrosive leak-detecting fluid should be applied to all connections in the pipe run, while air pressure is maintained at test pressure. Leaks should be rectified when found and a further test carried out. Leak detection fluid must be washed off and the components thoroughly dried before re-connection and locking.

(b) **Flow and Suction Test.** This test is similar to the flow and pressure test except that the pipe run is required to withstand a negative pressure (usually 1 lb/in^2) for one minute, and this is applied by means of a suction rig. The flow check and application of leak detecting fluid should still be carried out with positive pressure applied to the pipe.

5.6 **Hot Air Ducting.** Air ducted from combustion heaters and engine compressors for use in the cabin air conditioning system may be of sufficiently high temperature to cause structural damage. To prevent damage caused by hot air leaks, thermal expansion type unit detectors are often placed adjacent to hot air ducts and coupled to a warning lamp in the flight compartment. A press-to-test facility incorporated in the lamps ensures that the circuit continuity can be checked, while functioning of the system can be verified during servicing operations by shorting the detector leads and ensuring that the appropriate warning lamp lights. Whenever it becomes necessary to change a detector, it is important that the replacement has the correct temperature setting, since warnings are required at different temperatures from different locations.

6 STORAGE With the exception of certain types of control units, all components in fire and smoke detection systems may be stored indefinitely provided that adequate precautions are taken to prevent the ingress of moisture. Sealing caps must be fitted to the end connections of all detector elements, and all equipment should be wrapped in greaseproof paper and packed inside suitably padded cartons. Heat sealed polythene bags should be added in tropical climates. Smoke detectors should preferably be retained in the packaging supplied by the manufacturers so that the photo-electric cells are not subjected to light during the storage period. A label should be attached to each component showing details of type, serial number, date of last overhaul, hours flown, reason for removal, etc. as applicable in each case.

6.1 **Storage Conditions.** Components should be stored on shelves which allow free circulation of air, shielded from direct sunlight and protected from moisture or corrosive fumes.

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1*st February*, 1974.

AIRCRAFT

SYSTEMS AND EQUIPMENT

FIRE EXTINGUISHING EQUIPMENT

1 INTRODUCTION This Leaflet gives brief details of operating principles and guidance on the installation and maintenance of the equipment embodied in typical aircraft fire extinguishing systems. The information is of a general nature and should be read in conjunction with the Maintenance Manuals for the equipment concerned and the aircraft in which it is installed. Reference should also be made to approved Maintenance Schedules, drawings, test schedules and to the following Leaflets which contain information closely associated with that covered by this Leaflet:

AL/3-8 Fire—General Precautions
AL/3-9 Fire Detection Equipment
EEL/1-6 Bonding and Circuit Testing
EEL/1-7 Fire Detection and Extinguishing Systems—Electrical Tests on Systems.

1.1 The conditions under which extinguishing systems should be fitted to aircraft are prescribed in Chapters **D5-8** and **K5-8** of British Civil Airworthiness Requirements.

2 TYPES OF SYSTEMS The extinguishing systems in general use are the fixed system, the portable system and the mixed system. The term 'fixed' refers to a permanently installed system of extinguishant containers, distribution pipes and controls provided for the protection of power plants and, where applicable, auxiliary power units. In some types of aircraft, fixed systems may also be provided for the protection of landing gear wheel bays and baggage compartments.

2.1 A portable system refers to the several hand-operated fire extinguishers provided to combat any outbreaks of fire in flight crew compartments and passenger cabins.

NOTE: The performance requirements for hand-operated fire extinguishers, methods of installation and markings which should appear on them, are specified in British Standard M 29.

2.2 A mixed system is one used in some aircraft for the protection of baggage and service compartments. The distribution pipeline and spray system is fixed in the appropriate compartment and is coupled to adaptor points to which a hand-operated extinguisher may be plugged in.

3 TYPES OF EXTINGUISHANT The extinguishants in general use are described in the following paragraphs.

3.1 **Methyl Bromide (M.B.).** This extinguishant boils at 4·6°C and is commonly used in fixed systems, particularly for the protection of power plants. Because of its toxicity, Methyl Bromide should not be used in confined spaces, flight crew compartments or passenger cabins. The effects of breathing the vapours may not be immediately apparent, but serious or even fatal after-effects may be sustained at a later stage.

3.2 **Bromochlorodifluoromethane (B.C.F.).** This semi-toxic extinguishant is particularly effective against electrical and flammable liquid fires. It is used in power plant systems, and for the protection of auxiliary power units in some aircraft; it is also used in certain types of portable extinguisher. It becomes gaseous at normal temperatures and condenses to liquid at –4°C (25°F), and can be stored and discharged at moderate pressures. It has little or no corrosive effect, although halogen acids will be formed if its products which have been decomposed by fire come into contact with water, e.g. condensation caused by fire. In contact with fire, B.C.F. volatilises instantly, giving rapid flame extinction with little or no deleterious effect on metallic, wooden, plastic or fabric materials.

3.3 **Carbon Dioxide (CO_2).** This gas extinguishant is also effective against electrical and flammable liquid fires and is used principally in portable fire extinguishers. It is non-corrosive and if the concentration needed to extinguish a fire is excessive it can have appreciable toxic effects. When discharged in a confined space, the vapour cloud can reduce visibility temporarily.

3.4 **Water.** In many aircraft, certain of the portable fire extinguishers in passenger cabins are of the water type, designed for combating fires involving ordinary combustible material such as paper, fabric, etc., where the quenching and cooling effects of water are of prime importance. These extinguishers are not suitable against electrical fires. An anti-freezing agent is normally included to permit operation at temperatures as low as –20°C. Typical examples are the water/glycol extinguisher with 38 per cent of inhibited ethylene glycol, and the 'wet-water' extinguisher with glycol, wetting agents to reduce surface tension, and inhibitors to impart anti-corrosive characteristics.

3.5 **Bromotrifluoromethane (B.T.M.).** This semi-toxic extinguishant is used in fixed systems for the protection of power plant and auxiliary power units. It is also widely used in cargo compartment fire suppression systems of some types of aircraft.

3.6 **Dry Chemical.** Dry chemical extinguishant takes the form of a non-toxic powder, e.g. potassium bicarbonate, and is used in portable fire extinguishers fitted in certain types of aircraft. It is very effective against fires involving flammable liquids and free-burning material such as wood, fabrics and paper. Use of the extinguishant against fires in electrical equipment is not recommended, since it could render contactors and switches unserviceable which may otherwise be functioning correctly in adjacent equipment. It does not have a quenching effect and thereby the dangers of distortion or explosion when used on hot surfaces, such as overheated wheel brakes, are minimised. Some dry chemical powders have a corrosive effect on some metals (including aluminium) which may require special attention when cleaning-up after the discharge of an extinguisher. Dry chemical extinguishers should not be used in flight crew compartments or passenger cabins where visibility would be seriously affected both during the discharge of powder and also as a result of its deposition on transparencies and instruments.

4 TYPICAL FIXED SYSTEMS In the types of aircraft for which fixed fire extinguisher systems are specified, it is usual for the extinguishant to be stored in the containers under pressure and to be discharged by electrically firing cartridge units within the extinguisher discharge heads. The firing circuits are controlled by switches or fire control handles in the flight crew compartment; in some types of aircraft, control may also be automatic in the event of a crash landing. The layout of a system and the number of components required, depend largely on the type of aircraft and number of power plants, and also on whether fire protection is required for auxiliary power units, landing gear wheel bays and baggage compartments. Figure 1 diagrammatically illustrates a typical arrangement for

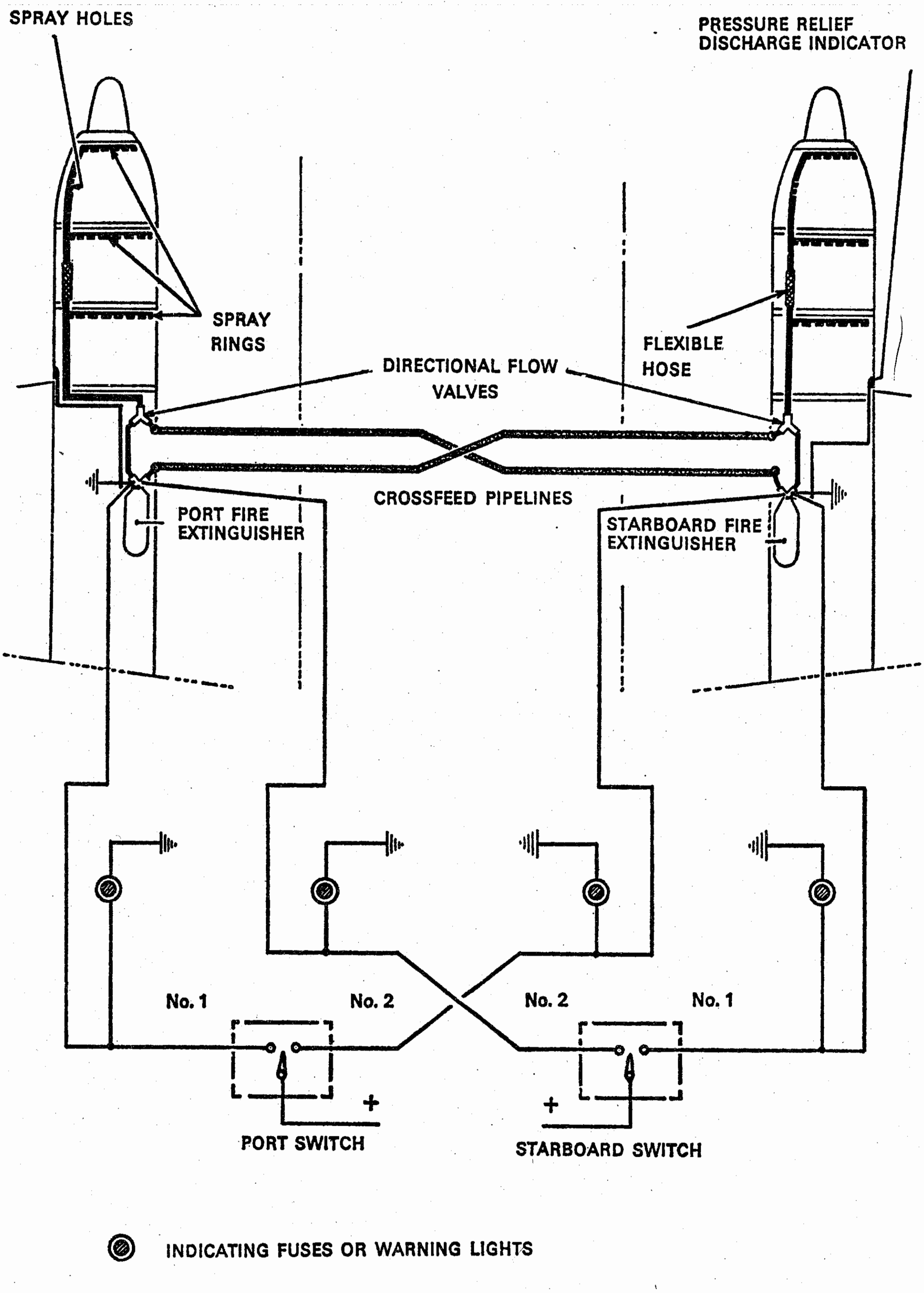

Figure 1 TYPICAL FIXED EXTINGUISHER SYSTEM power plant protection and indicates the components which, in general, form part of any fixed system. It also indicates the discharge control method normally adopted for multi-engine fire protection and known generally as the 'two-shot system'. In this system the fire extinguishers for each power plant are interconnected, so permitting two separate discharges of extinguishant into any one power plant. In some aircraft incorporating crash switches (see Leaflet EEL/1-7 paragraph 3.3), the system may be so arranged that operation of the switches will cause an adequate and simultaneous discharge of extinguishant to each power plant. Brief descriptions of the principal components of a fixed fire extinguishing system are given in the following paragraphs. For precise technical details reference must be made to the manuals for the relevant aircraft and components.

4.1 **Extinguishers.** Extinguishers vary in construction but are normally comprised of two main components: (i) the steel or copper container and (ii) the discharge or operating head. A sectioned view of an extinguisher widely used in a two-shot system is shown in Figure 2. The container is in the form of a steel cylinder and has an externally threaded neck to which the discharge head is screwed and soldered. The discharge head contains two annular machined diaphragms, each bearing an externally-threaded spigot on which a hollow charge plug is screwed to form an annulus between its inner end and its respective diaphragm. Each annulus is connected by a 'flash' hole to a port containing the appropriate cartridge unit. Below, and concentric with each diaphragm and charge plug, is a radially adjustable light-alloy hollow junction box fitted with a union to which an extinguisher discharge pipe is connected. The lower end of the junction box is closed by a cap which embodies a discharge indicator pin. (See paragraph 4.3.1). A banjo coupling is fitted in the main body of the operating head and serves as a connection for a pressure discharge indicator. (See paragraph 4.3.1 (i)).

4.1.1 When either of the cartridge units is fired, sufficient pressure is created in the adjacent annulus to rupture the associated diaphragm. The spigot and charge plug assembly is thereby detached and forced down the hollow junction box beyond the outlet union and discharge pipe through which the extinguishant then flows to the spray pipes or rings.

4.2 **Directional Flow Valves.** These valves are a special form of non-return valve designed for use in two-shot systems to allow the contents of one or several extinguishers to be directed into any one power plant. The methods of connection may vary between different aircraft systems, but the one shown in Figure 1 is typical and also serves to illustrate the two-shot operating sequence generally adopted. The extinguishers are controlled by individual firing switches each having three positions; No. 1, OFF and No. 2. When the port extinguisher switch is selected to the No. 1 position, the relevant cartridge unit in the port extinguisher is fired and the extinguisher is discharged to the port power plant. If the fire has not been extinguished, selection of the No. 2 position then causes the starboard extinguisher to be discharged also into the port power plant via the crossfeed line and port directional flow valve, the latter preventing extinguishant from entering the empty extinguisher of the port system. In order to extinguish a fire in the starboard engine, the starboard extinguisher switch is selected to its No. 1 position, and the relevant cartridge unit is fired so that extinguishant is discharged to the starboard power plant. If selection of the No. 2 position of the starboard extinguisher switch becomes necessary, then the port extinguisher will also be discharged into the starboard power plant via the appropriate crossfeed line and the starboard directional flow valve, which prevents charging the empty starboard extinguisher.

NOTE: In some types of aircraft, the cross connecting of selected extinguishers between engines is accomplished by means of transfer switches which are additional to the normal firing switches.

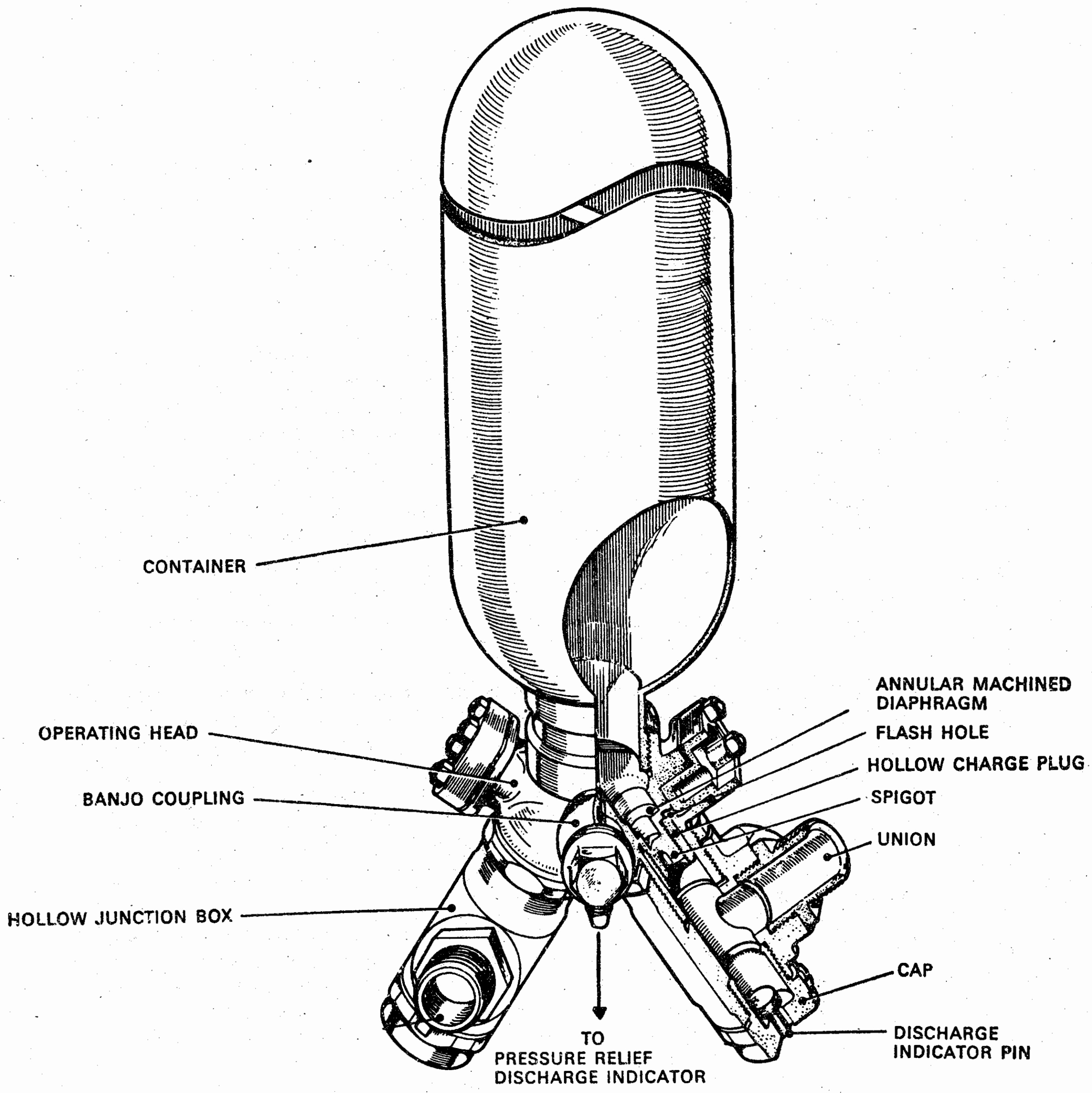

Figure 2 FIXED TYPE OF EXTINGUISHER

4.3 **Discharge Indicators.** In fire extinguisher systems of the fixed type, provision is made for positive indication of extinguisher discharge as a result of either (a) intentional firing, or (b) inadvertent loss of contents, i.e. pressure relief overboard or leakage. The methods adopted are generally mechanical and electrical in operation.

4.3.1 **Mechanical Indicators.** Mechanical indicators are, in many instances, fitted in the operating heads of extinguishers (see Figure 2) and take the form of a pin which under normal conditions is flush with the cap of the hollow junction box. When an extinguisher has been fired, and after the charge plug has been forced down the hollow junction box, the spigot of the plug strikes the indicator pin causing it to protrude from the cap, thereby providing a visual indication of extinguishant discharge. In the extinguishers employed in some types of aircraft, mechanical type pressure gauges are embodied in the containers and these serve to indicate extinguishant discharge in terms of pressure changes and, in addition, serve as a maintenance check on leakage.

(i) Protection against bursting of a fire extinguisher as a result of build-up of internal pressure under high ambient temperature conditions, is provided by a disc which fuses at a specific temperature, or a disc which bursts when subjected to bottle over-pressure. The disc is located in the operating head and when operated, the extinguishant discharges overboard through a separate pressure relief line. In order to indicate that discharge has taken place, a disposable plastic, or metal, disc is blown out from a discharge indicator connected to the end of the relief line exposing the red interior of the indicator. Discs are generally coloured red, but in certain types of indicator, green discs are employed. Discharge indicators are mounted in a structural panel, e.g. a nacelle cowling, and in a position which facilitates inspection from outside the aircraft.

NOTE: In some aircraft, indicators of similar construction but incorporating a yellow disc, are provided to indicate discharge by normal firing.

4.3.2 **Electrical Indicators.** Electrical indicators are used in several types of aircraft and consist of indicating fuses (see Leaflet **EEL/1-7**), magnetic indicators and warning lights. These are connected in the electrical circuits of each extinguisher so that when the circuits are energised, they provide a positive indication that the appropriate cartridge units have been fired. In some aircraft, pressure switches are mounted on the extinguishers and are connected to indicator lights which come on when the extinguisher pressure reduces to a predetermined value. Pressure switches may also be connected in the discharge lines to indicate actual discharge as opposed to discharge initiation at the extinguishers.

4.4 **Pipelines.** Extinguishants are discharged through a pipeline system which, in general, is comprised of light-alloy pipes outside firezones and stainless steel rings inside firezones, which are perforated to provide a spray of extinguishant in the relevant zones. In some cases, extinguishant may be discharged through nozzles instead of spray rings. Flexible fireproof hoses are also used, e.g. between a nacelle firewall and spray rings secured to an engine.

5 PORTABLE EXTINGUISHERS The portable extinguishers in common use are of the CO_2 type and the water type. Extinguishers containing extinguishant B.C.F. (see paragraph 3.2) are also used in some aircraft. The type of extinguisher installed in a particular location is chosen to be appropriate to the nature of the possible fires in the compartment in which it is installed. Extinguishers are located in accessible positions and installed in suitable attachment brackets with quick-release metal straps. Brief descriptions of their construction and operation are given in the following paragraphs for general guidance.

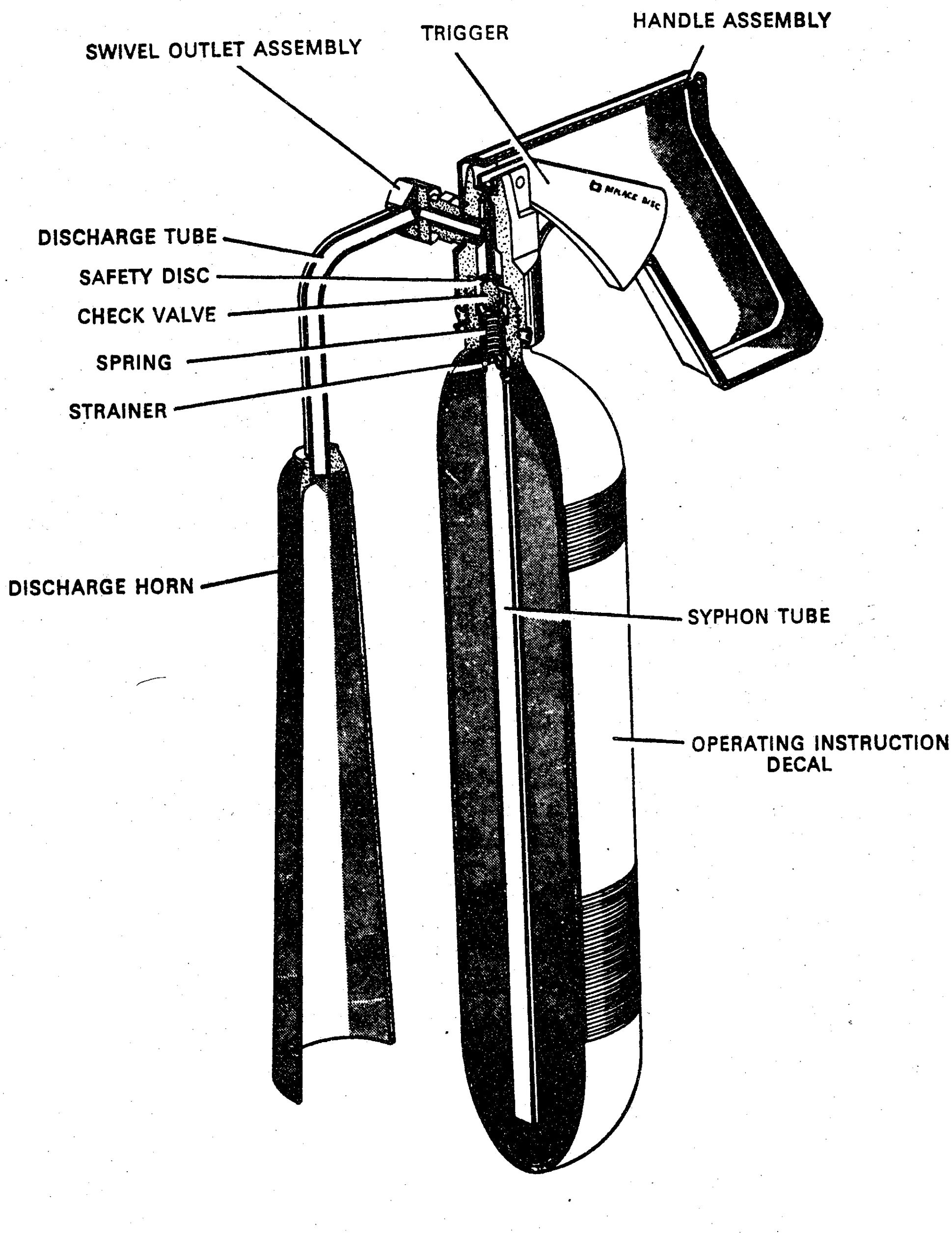

Figure 3 TYPICAL PORTABLE CO_2 EXTINGUISHER

5.1 **CO_2 Extinguishers.** A typical extinguisher (see Figure 3) comprises a steel cylinder and an operating head incorporating a pistol-type firing mechanism, check valve assembly and discharge horn which characterises CO_2 extinguishers generally. When the trigger is pressed, a lockwire and seal are broken and the spindle of the check valve assembly is forced downward, thereby removing the valve from its seat. This allows the extinguishant to flow up the siphon tube, through the centre of a safety disc, to discharge from the discharge horn. Releasing of the trigger allows the valve to reseat and seal off the flow. The purpose of the safety disc is to permit the release of extinguishant in the event of excessive internal pressures. When a safety disc bursts, the trigger of the firing mechanism springs downward and exposes the instruction 'REPLACE DISC' engraved on the side of the trigger.

5.2 **Water Extinguishers.** A typical extinguisher incorporating an anti-freeze agent is shown in Figure 4. It comprises a cylinder and a valve body which houses a lever-operated check valve assembly and a nozzle. A cartridge holder containing a cartridge of CO_2 is secured to the valve body, and, in addition to its main operating function, serves as a hand-grip. When the cartridge holder is twisted the cartridge is punctured causing the CO_2 to be released into the cylinder, thereby pressurising it. Depression of the check valve assembly lever moves the valve from its seating at the top of a syphon tube, allowing the extinguishant to be forced up the tube and to discharge through the nozzle. When the lever is released, the valve is returned to its seating under the action of a spring, and the flow of extinguishant is sealed off.

5.2.1 Some water extinguishers have a plastic head which contains an operating trigger and plunger mechanism, and screws into a threaded boss on the metallic container. The complete assembly is sealed by a rubber sealing ring. When the trigger is squeezed, the plunger mechanism breaks a seal within the operating head and thereby releases the extinguishant. The discharge is subsequently controlled by maintaining or releasing pressure on the trigger. In some cases, the containers are expendable and scrapped after discharge, and only the operating heads are subject to inspection and overhaul procedures.

6 INSTALLATION AND MAINTENANCE The methods of installing the principal components of fire extinguishing systems, and carrying out relevant maintenance procedures vary between types of aircraft. Certain aspects are, however, of a common nature and the information given in the following paragraphs is intended only as a general guide. For precise details of particular installations, reference must be made to the approved manuals and schedules for the aircraft concerned. Reference should also be made to Leaflets **AL/3-13** and **AL/3-14** which deal with the installation of flexible and rigid pipes in aircraft, and to Leaflet **EEL/1-7** for guidance on the testing of the electrical control circuits of fire extinguishers.

6.1 **Fixed Systems**

6.1.1 **Extinguishers**

(i) Before installation, the following checks and inspections should be carried out:—

(a) Containers should be inspected for signs of leakage, dents, corrosion, scoring and chafing. If one or more of these faults exist, or there is any other condition indicating weakness of a container, the extinguisher must not be installed.

(b) Weight check and, where appropriate, a pressure check (see paragraph 6.3) to determine whether any loss of extinguishant has occurred.

(c) Pin-type discharge indicators should be checked to ensure that they are flush with the cap of the operating head junction box.

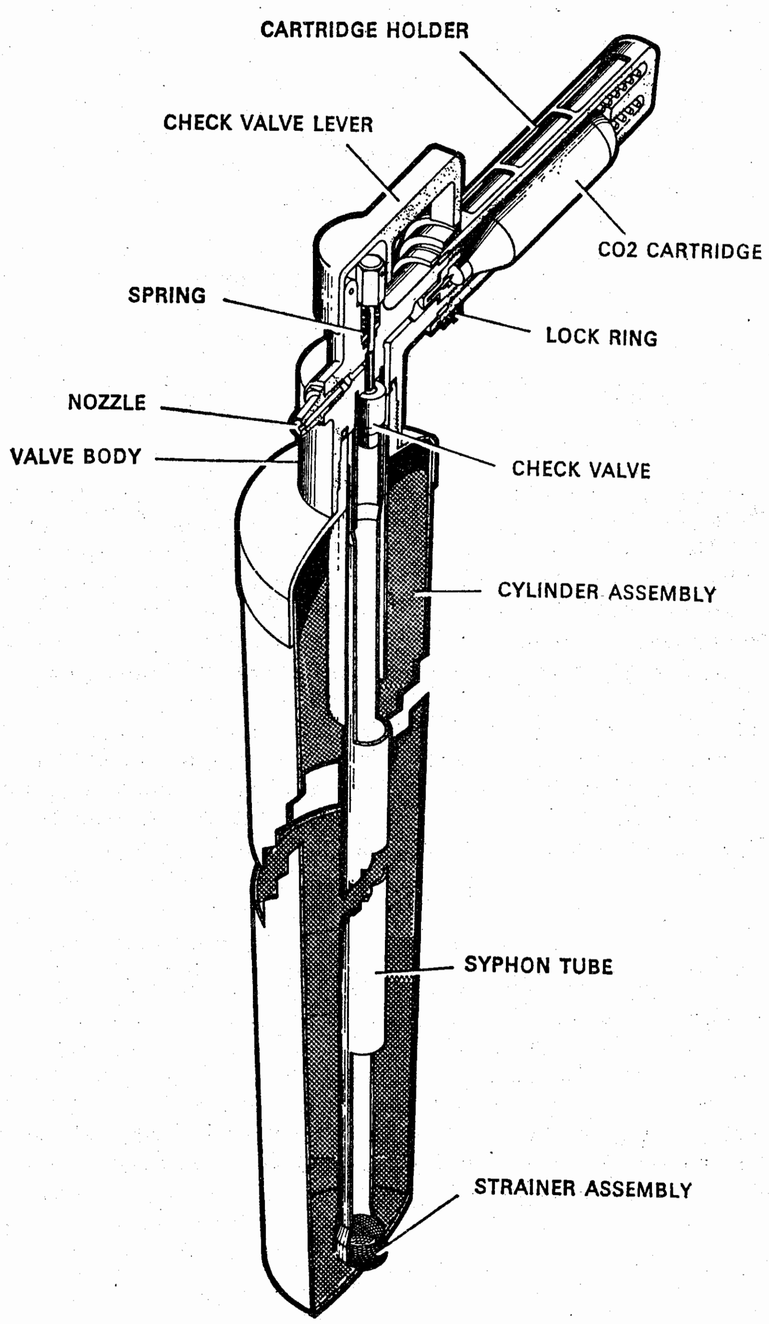

Figure 4 TYPICAL WATER EXTINGUISHER

(d) The threads of all unions and studs should be inspected for damage. Where specified, operating head junction boxes should be removed and the threads lightly smeared with an approved lubricant, e.g. Barium Chromate grease to specification DTD 369. The junction boxes should be refitted leaving the locknuts finger-tight until after an extinguisher has been installed and all connections finally made.

NOTE: In certain types of extinguishers, removal of the operating or discharge head exposes the main discharge diaphragm. To prevent damage to this diaphragm and injury to personnel, protective caps must always be fitted to the extinguisher container outlet.

(e) Before securing cartridge units to extinguishers, they should be inspected for signs of distortion, corrosion, chafing or other damage. The date of manufacture stamped on a unit should be checked to ensure that the cartridge life has not exceeded that specified in the appropriate Maintenance Manual. Checks on the insulation resistance, continuity and resistance of the fuse element should also be carried out (see Leaflet **EEL/1-7**).

NOTE: Cartridge units contain gunpowder and should, therefore, be handled with extreme care at all times to prevent inadvertent operation. In some cases, conductive rubber plugs known as shunts are provided, and these must be fitted to the electrical connectors when the appropriate cartridge unit is detached from its extinguisher, or the system supply cable is disconnected.

(ii) When installing extinguishers, it must be ensured that they are properly positioned in their support brackets and secured by straps or mounting bolts as appropriate to the type of extinguisher. Where locking pins are necessary, e.g. on securing straps, a check must be made to ensure that they are in a serviceable condition and correctly assembled to the straps.

NOTE: Extinguishers should be handled carefully during installation, and bumping against adjacent parts of the aircraft structure should be avoided. Accidental discharge of an extinguisher may cause injury to personnel.

(a) Operating head junction boxes and discharge outlet unions must be correctly aligned with their respective pipelines and the appropriate connections secured in the manner specified in the relevant manuals.

(b) Before connecting power supply cables to cartridge units, the discharge circuits should be tested for correct functioning (see Leaflet **EEL/1-7**). On satisfactory completion of the functional tests, the circuit breakers of the relevant extinguishing system should be tripped, and the cables connected and secured to the cartridge units appropriate to the type of unit. The system circuit breakers should be re-set after ensuring that the extinguisher operating switches are in the off position.

6.1.2 **Pipe Systems.** Before installation, the bore of pipes and spray rings should be checked for freedom from obstruction, by blowing through with clean, dry compressed air or with nitrogen. A check should also be made on pipes and spray rings to ensure freedom from corrosion, cracks, dents and other deformation. The mating surfaces and connections must also be clean and free from damage.

NOTE: To prevent enlargement or deformation of spray holes and jets, they should be cleaned out only by the methods specified in the relevant manuals.

(i) Metal pipes must be properly secured to the airframe structure at the specified attachment points, and there must be adequate clearance between all pipes and structural parts to avoid chafing during flight.

(ii) The minimum bend radii of pipes should comply with the dimensions specified in relevant manuals and installation drawings.

(iii) End connections should be tightened to appropriate torque values. When tightening flexible pipe connections, care must be taken to ensure that pipes do not become twisted.

(iv) After installation of a section of pipe, a pressure test of the system should be carried out. Precise details of pressure test procedures are given in relevant Maintenance Manuals and test schedules, and reference must be made to these documents. In general, however, a test requires that the pipeline from the extinguisher outlet to the spray rings should be disconnected at both ends. One end should then be blanked, and compressed air applied at the other end to check whether the pipeline will retain a given pressure over a given period.

(v) When pipes are removed from an aircraft, blanks should be fitted to the end connections and all other exposed connections in the system. Support clamps should be returned to their original positions as soon as a pipe has been removed to ensure their correct re-location.

6.1.3 **Valves.** The following points should be observed when installing and maintaining valves:—

(i) They should be inspected for cleanliness, signs of damage and freedom of movement.

(ii) Care should be taken to ensure their correct location with respect to the required flow of extinguishant.

(iii) Attachment to their respective mountings should be securely made.

(iv) Where appropriate, new sealing rings should be fitted between valve and pipe end connections.

6.1.4 **Discharge Indicators.** The fittings of disc-type discharge indicators are normally permanently fixed to the appropriate parts of the aircraft structure and it is, therefore, only necessary to check that the discs are in position and that discharge pipe connections are securely made. In certain types of indicator it is also necessary to check that a sealing plug is in position within the discharge outlet.

6.2 **Portable Extinguishers.** The pre-installation checks, installation procedures and inspections of portable extinguishers may vary between types but, in general, the following points are common to all:—

6.2.1 Before installing extinguishers in their appropriate stowage brackets, they should be inspected for general condition and signs of fluid leakage, and their weight should be checked against that specified for the type. (See paragraph 6.3).

6.2.2 The expiry dates of extinguishers should be checked against the date of manufacture to ensure that they are within the specified service life. Extinguishers having expendable containers should be fitted with new containers at the time expired date. Other extinguishers should be removed for re-charging and replaced by serviceable units.

(i) Dates of manufacture are given on some types of extinguishers in the form of a code. For example, months are represented by letters A to M (excluding I), years are indicated by the last figure of the year number, and weeks are given by figures 1–5 beneath the month and year codes. Thus $\frac{\text{E–3}}{2}$ marked on an extinguisher would indicate that it was manufactured in the second week of May 1973 and, assuming a life of five years, the expiry date of the extinguisher would be May 1978.

6.2.3 In certain types of water extinguishers, safety pins are provided to lock the triggers when the extinguishers are in transit. Such pins must be removed before installation of the extinguishers.

6.2.4 Lockwire and seals should be checked to ensure that they are intact. If the wire and seal of an extinguisher have been broken it must be withdrawn from service for a weight check.

(i) In the case of water extinguishers employing a CO_2 cartridge, a broken seal wire could indicate that the cartridge has been fired. The cartridge should therefore be removed and its weight checked. If the cartridge has been fired, the extinguisher is in a pressurised condition and it should be withdrawn and replaced by a serviceable unit. If the cartridge is serviceable, and the extinguisher weight is in accordance with that specified, the cartridge should be refitted and a new seal wire attached.

6.2.5 Where a dust cap is provided on the discharge nozzle of an extinguisher, a check should be made to ensure that the cap is free to be forced off should the extinguisher be used. If necessary, the nozzle should be smeared with a light application of silicone grease.

6.3 **Weight and Pressure Checks.** The fully charged weight of an extinguisher should be checked at the periods specified in the approved Maintenance Schedule, and before installation, to verify that no loss of extinguishant has occurred. The weight, including blanking caps and washers, but excluding cartridge units, is normally indicated on the container or operating head. For an extinguisher embodying a discharge indicator switch, the weight of the switch cable assembly is also excluded.

NOTE: The provision of discharge indicators in fixed extinguisher systems does not alter the requirement for periodic weighing which is normally related to calendar time.

6.3.1 The date of weighing and the weight should, where specified, be recorded on record cards made out for each type of extinguisher, and also on labels for attachment to extinguishers. If the weight of an extinguisher is below the indicated value the extinguisher must be withdrawn from service for recharging.

6.3.2 For extinguishers fitted with pressure gauges, checks must be made to ensure that indicated pressures are within the permissible tolerances relevant to the temperature of the extinguishers. The relationship between pressures and temperatures is normally presented in the form of a graph contained within the appropriate aircraft Maintenance Manuals.

6.3.3 In certain types of portable extinguishers, a check on the contents is facilitated by means of a disc type pressure indicator in the base of the container. If the charge pressure is below the specified value, the disc can be pushed in by normal thumb pressure.

7 STORAGE Extinguishers should be shielded from direct sunlight, stored in an atmosphere free from moisture and corrosive fumes and be located on shelves which allow free circulation of air. Transit caps, sealing plates and transit pins, where appropriate, must remain fitted during storage.

7.1 The weights of extinguishers should be checked annually during storage, which, in general, is limited to five years from the date of manufacture or last overhaul. At the end of this period, extinguishers must be withdrawn for overhaul.

NOTE: The storage limiting period may vary between types of extinguishers. Reference must, therefore, always be made to the relevant manuals.

7.2 Cartridge units must be stored in sealed polythene bags in a moisture-free atmosphere and kept away from sources of heat. A label quoting the life expiry date which, in general, is five years from the date of manufacture of last overhaul, should be attached to each bag. If a cartridge unit is removed from its bag, the life expiry date is two years from the date of removal, provided the expiry is within the normal five year period.

7.2.1 Defective or time-expired cartridge units must be disposed of in accordance with regulations relating to the handling of gunpowder.

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AIRCRAFT

SYSTEMS AND EQUIPMENT

LIFEJACKETS

1 INTRODUCTION This Leaflet gives guidance on the inspection and maintenance of lifejackets, which are required to be carried in certain aircraft operating under conditions specified in the Air Navigation Order. Owing to the wide variety in detail of lifejackets, the information is of a general nature and does not apply to any particular make or type of lifejacket. The maintenance and servicing of the less common types of survival equipment are very similar to the single inflation chamber type covered by this Leaflet.

NOTE: The Requirements for the design and manufacture of lifejackets are covered in CAA (Airworthiness Division) Specification No. 5.

2 GENERAL Lifejackets are designed as lightweight items of equipment and as such should be treated with care. Lifejackets are normally packed in specially made fabric valises or containers for ease of handling, and these also protect the lifejacket; they also help to keep the lifejacket correctly folded, to facilitate donning. However, care should be taken not to drop a packed lifejacket or to place loads upon it. Manufacturers often recommend that a lifejacket which has been subjected to such abuse or has been immersed in sea water, should be rejected for further operational use.

2.1 The necessary instructions for fitting lifejackets are displayed in the aircraft and, in many instances, these instructions are repeated in safety pamphlets for distribution to individual passengers. Similar information may also be given on the lifejacket by means of special adhesive labels or stencilling on the surface of the jacket.

2.2 Normally, lifejackets are stowed under passengers' seats and in easily accessible positions for crew members. Stowages should be kept clean and dry, and the stowage retaining device should be checked periodically for security and ease of release.

2.3 Lifejackets which have been used for demonstration by crew members should be returned for inspection as if they were time expired. To ensure that this is always done, the demonstration lifejackets should be kept out of the normal stowage and a suitable warning label should be attached.

3 LIFEJACKETS—GENERAL DESCRIPTION There are several types of lifejackets in use, and all are basically similar. Buoyancy is obtained by inflating the jacket with carbon dioxide (CO_2) gas, which is stored under pressure in a small cylinder and released by means of a manually operated mechanism. A standby mouth inflation valve is also provided in case the CO_2 system is inoperative, or if it is necessary to 'top-up' the pressure after a long period of immersion. To assist rescue operations, lifejackets are

equipped with an identification light and battery, and a whistle is also provided. Certain types of lifejackets may also carry additional equipment such as fluorescent sea marker dye, shark repellent products and special signalling devices.

NOTE: Care should be taken to avoid unintentional operation of the inflation mechanism. The mechanism cannot be used to stop the gas flow, which will inflate the lifejacket in a few seconds. However, if the lifejacket is inadvertently inflated, means are provided for deflation. This can be effected on some lifejackets by depressing the non-return valve in the mouthpiece, by means of a deflation key stowed next to the mouth inflation valve and secured to the lifejacket by an attachment cord, or by inserting the extension piece moulded on to the side of the valve protection cap.

3.1 Most lifejackets are of the single inflation chamber type as illustrated in Figure 1, but there are others which have more than one inflation chamber, gas cylinder and mouth inflation facility; some aircraft may also carry baby flotation survival cots.

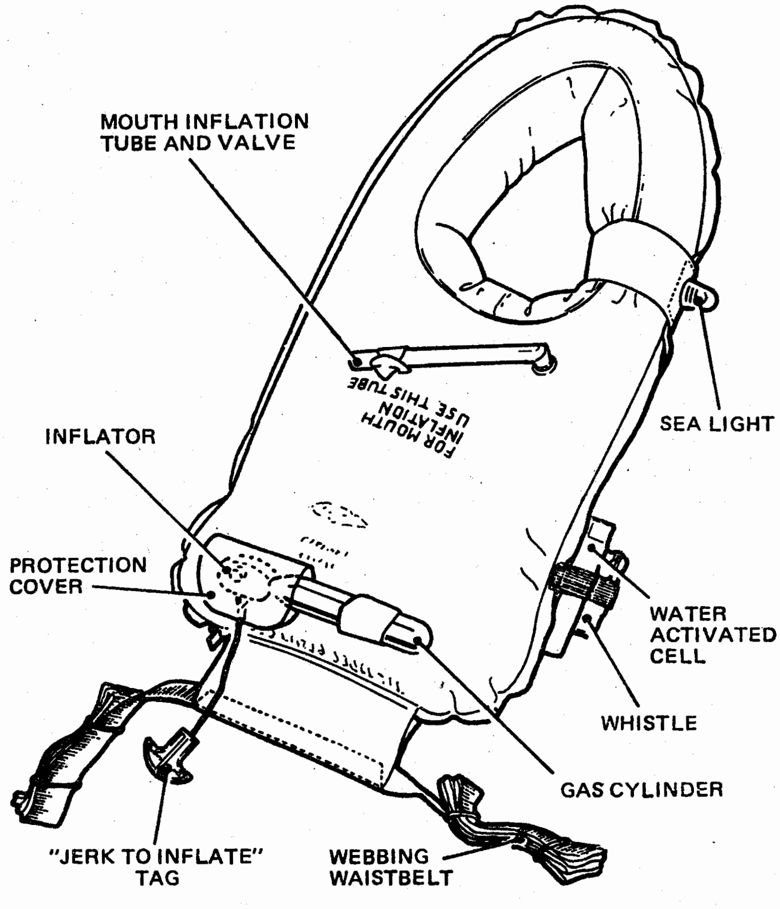

Figure 1 TYPICAL LIFEJACKET

3.2 The material used for fabricating lifejackets is generally either rubberised cotton or polyurethane coated nylon (coated on either one or both sides), the panels being joined by the use of an adhesive or by welding.

3.3 A light unit is attached to a lifejacket in such a way as to ensure that, when the lifejacket is in use, the lamp assembly will be in a prominent position. The bulb is connected by means of a plastic covered lead to a battery, which is usually water activated and located below the water line. Operation of the battery is achieved by the ingress of water into the cell.

3.4 The operating mechanism into which the CO_2 cylinder is fitted consists of a housing containing a piercing pin which, when pushed forward by a cam-type operating lever, pierces a sealing disc in the neck of the cylinder, allowing gas to flow past a non-return valve into the lifejacket. The piercing pin is actuated by pulling a red knob or tag, which is attached by a cord or chain to the operating lever.

4 MAINTENANCE REQUIREMENTS The appropriate manufacturer's publication will stipulate the periods at which inspections and related tests are required and will also give full details of the inspection and test operations involved. It may stipulate inspection after every six months of service life, with a more comprehensive inspection after every 18 months, or it may stipulate a yearly inspection only. Similar information will also be given regarding accessories, such as CO_2 mechanisms, identification lights, inflation valves, etc. The lifejacket and some of the accessories (e.g. CO_2 cylinder), will also have a maximum service or storage life, stipulated in years, which must not be exceeded. All work should be carried out in accordance with the relevant publications and the lifejacket and inflation equipment manufacturers' Service Bulletins, etc. All details of a particular lifejacket, including modifications and inspections, and the Inspector's stamp or signature, should be recorded on an Inspection Record kept at the maintenance base.

4.1 Inspections and tests should be carried out in clean premises kept at stable room temperature. To avoid damage through puncture or abrasion, the inspection tables should have smooth, well finished surfaces free from any wood splinters or sharp corners, and the working surfaces should be kept thoroughly clean. Precautions should be taken to avoid any contact with oil, grease or acid.

4.1.2 A rack should be provided from which lifejackets under inflation test can be suspended, and a method of referencing should be adopted to relate each lifejacket with the time of inflation and the duration of the test period. The rack should be kept away from direct sunlight or radiated heat.

NOTE: All inflation tests must be carried out under stable temperature conditions.

4.1.3 To trace leaks in lifejackets which have failed to maintain the required test pressure, an immersion tank containing clean water is often used. In other instances, the suspected area is smeared with an acid-free soap solution, all traces of which should be thoroughly removed by rinsing with lukewarm water immediately after test.

4.1.4 Laboratory type scales having an accuracy of 0·1 gramme should be available for cylinder gas-charge checks.

5 INSPECTIONS AND TESTS

5.1 **Lifejacket.** The lifejacket should be withdrawn from its valise, unfolded, and such equipment as the CO_2 cylinder, identification light assembly and whistle removed. A check of the serial number marked on the lifejacket and that on the related Inspection Record should be made. All instructions stencilled or labelled on the lifejacket should be examined for legibility. Such information as date of manufacture, modifications embodied, etc., must agree with the Inspection Record.

NOTE: In some instances it may be necessary to clean the lifejacket before inspection. This should be done with lukewarm water and the cleaning agent recommended by the manufacturer.

5.1.1 **Inspection.** The proofed fabric should be inspected for slits, tears, holes, adhesion of seams and general deterioration. Deterioration is seldom immediately apparent and can easily be overlooked. It is vitally important, therefore, that a careful inspection for any of the following signs should be made:

(a) Discoloured areas (not due to surface dirt which can be washed off).

(b) Sticky areas.

(c) Hard or stiff areas.

(d) Shiny areas.

(e) Wrinkled or crazed areas.

5.1.2 Webbings, elastics and cordages should be inspected for discoloration, deterioration and security of attachment (e.g. condition of stitching and security of knots).

5.1.3 Metal and plastics components should be inspected for cleanliness, damage or deterioration and security (e.g. adhesion of components to fabric where applicable).

5.1.4 **Inflation Tests.** Inflation tests are required to check a lifejacket for leaks and may be carried out after repairs have been made, to check the buoyancy chamber, or after the gas cylinder has been inspected and reassembled, to check the complete jacket. The lifejacket is inflated using a test rig, which may be connected either to the mouth inflation valve or to the operating head (with the gas cylinder removed), depending on the reason for the test.

NOTE: Before tests are commenced the test equipment should be checked for leaks, especially at the connections.

5.1.5 The initial test consists of inflating the lifejacket to a given pressure and allowing the pressure to stabilise with the air supply disconnected. After a given time, the pressure is checked to ensure that it has not dropped below a specified figure.

NOTE: The lifejacket should not be touched whilst on test as the pressure reading may be affected.

5.1.6 If the initial test is satisfactory, the lifejacket is re-inflated and allowed to stand for a longer test period, after which the pressure should not have dropped below a second stipulated figure.

5.1.7 Whilst the lifejacket is inflated a visual examination should be made for any signs of distortion or damage not revealed before inflation.

5.1.8 If any stage of the test proves unsatisfactory, leakage may be traced by either of the methods outlined in paragraph 4.1.3, when air bubbles will indicate the position of the leaks. Local repairs may often be carried out, but where damage exceeds limits specified in the relevant manual, the lifejacket should be returned to the manufacturer (see paragraph 6).

5.1.9 The mouth inflation valve will also require pressure testing for leaks, either by placing a small amount of water in the mouthpiece or by immersing the valve unit in water and checking for the presence of bubbles. A valve functioning test may be specified; this is done by applying air pressure to the mouthpiece, and ensuring that the valve opens at a specified pressure below the working pressure of the lifejacket. If the valve should leak, or if it fails to open at the functioning pressure specified, the following actions should be taken depending on the type of valve:

(a) With the type of valve which can be disassembled, this should be done and the valve should be cleaned and its seat checked for deterioration or dirt, and then lubricated with a silicone grease specified by the manufacturer. After re-test, if the valve still leaks it should be replaced by a new assembly and again tested.

(b) With the type of valve which cannot be disassembled, it should be renewed in accordance with the instructions contained in the relevant Overhaul Manual.

5.2 **Light Unit.** The life of the light unit is often indefinite, provided that periodic inspections and tests prove satisfactory.

5.2.1 **Inspection.** The battery should be inspected for any signs of damage or deterioration, or for signs of chemical reaction indicated by the presence of a white powdery deposit or bulging of the battery case.

5.2.2 It is also important to ensure that no activation has taken place due to the ingress of moisture. Depending on the design of the battery it is often possible to check for activation visually. With some types this may be done by holding a source of light at the base of the battery case and looking through the water holes at the top. It should be possible to see clearly through the holes but if any activation has taken place the holes will be obstructed.

5.2.3 When fitting water-activated batteries into stowages on the lifejackets, care is necessary to ensure that the instructions regarding the removal of the water sealing plugs or other sealing devices are carefully followed, as they will vary with the type of battery used.

5.2.4 **Electrical Tests.** Electrical tests for the water-activated type of battery are usually prescribed. They often consist of testing with a standard aircraft insulation resistance tester connected across the battery terminals to obtain a specified reading in megohms (e.g. 1 megohm minimum). A milli-voltmeter test is also often acceptable; with the milli-voltmeter across the battery terminals, no voltage should be registered.

NOTE: When testing with a milli-voltmeter, an initial test should be made at a higher scale reading to obviate damage to the meter should the battery be active.

5.2.5 The electrical circuit and the bulb should be checked for electrical continuity and functioning using a slave battery of the correct voltage.

5.3 **Gas Cylinders.** The CO_2 cylinders should be carefully inspected for any signs of damage such as dents, scores or corrosion, which would weaken the cylinder and render it unserviceable and possibly dangerous. The cylinder threads should also be checked for obvious signs of damage.

5.3.1 With the operating mechanism removed, the CO_2 cylinder should be checked for correct gas charge by weighing. Some cylinders are marked with the empty weight and the weight of the gas charge is given in the appropriate publication; later cylinders are marked with the total (charged) weight, e.g. TW. 146. Should the cylinder be found to be outside the weight limitations it should be replaced by a fully charged one.

5.3.2 All CO_2 cylinders are 'lifed' and should be returned to the manufacturer for inspection and test when their life has expired. A code representing the date of manufacture, or the actual date of manufacture of a cylinder, is stamped on its base, and this should be checked during inspection.

5.4 **Operating Mechanism.** With the CO_2 cylinder removed, the inspection instructions usually stipulate a functioning check to ensure the correct travel of the piercing pin, and in some cases the mechanism is disassembled and all parts cleaned and inspected at specified intervals. Damaged or corroded metal parts and seals or rubber washers showing any signs of deterioration should be renewed if permitted by the manufacturer.

5.4.1 On some lifejackets the operating mechanism is mounted on a rubber base and the unit is bonded to the lifejacket; no attempt should be made to separate this bond. Care is therefore necessary to avoid damage to the attached lifejacket when work is carried out on the operating mechanism.

5.4.2 After reassembly of the operating mechanism a final check should be made to ensure that the operating lever is in the correct position (i.e. cocked) and that the safety retaining device (e.g. break thread or spring clip) has been properly fitted.

5.4.3 In the event of the mechanism having been immersed in sea water, it should be disassembled, checked for corrosion and then thoroughly cleaned to remove all traces of salt deposit.

6 **REPAIRS** The parts of a lifejacket which are made from proofed fabric are liable to suffer from damage or deterioration, and repair schemes and instructions are often contained in the relevant Overhaul Manual. In the case of lifejackets which are joined by an adhesive, extensive repairs are often permissible within limits specified by the manufacturer, but in the case of lifejackets which are joined by welding, only minor patch repairs are usually permitted. This is because the machine settings have to be predetermined for each tool and type of weld and it is unlikely that a lifejacket servicing facility other than the manufacturer could carry out satisfactory welded repairs.

6.1 **General.** Repairs are carried out by patching with a material identical to or compatible with that used in the original lifejacket, using a self-vulcanising solution as the adhesive. Repairs may usually be carried out within the following limitations:

(a) Minor damage (i.e. cuts, tears, abrasions and deterioration extending to less than 100 mm (4 in) in length or diameter), provided it is not within 25 mm (1 in) of a seam, can be repaired by applying an external patch.

(b) Minor damage within 25 mm (1 in) of a seam but not affecting the internal seam reinforcing strip can be repaired by applying internal and external patches.

(c) Minor damage affecting the reinforcing strip can be repaired by applying internal and external patches and renewing the damaged portion of reinforcing strip.

(d) Damage exceeding 100 mm (4 in) in length or diameter can be repaired by renewing a complete panel or part of a panel.

(e) If damage is sustained to a panel which already has two repair patches, the panel should be renewed.

NOTE: The damage limits of (d) and (e) would only be applicable to lifejackets joined by an adhesive.

6.1.1 Patches should be circular, or rectangular with rounded corners, and should overlap any damage by at least 25 mm (1 in). Reinforcing strip should overlap the existing strip by at least 25 mm (1 in) and exterior tape should overlap by 50 mm (2 in).

6.1.2 The repair solution is supplied as a kit, and contains a number of ingredients which must be mixed strictly in accordance with the manufacturer's instructions. Once mixed the solution must be used within a few hours, as it soon becomes unstable.

6.1.3 All tools and utensils used when carrying out repairs, e.g. roller, brushes and spatula, should be kept scrupulously clean and free from abrasions.

6.1.4 In some cases it may be recommended that a test piece should be prepared using the fabric and adhesive used for the repair, in order to check the progress of vulcanisation. At the end of the vulcanising period (2 to 4 days) a portion of the test piece should be peeled apart and a few drops of an appropriate solvent applied to the surface. If vulcanisation is complete the liquid will spread quickly and be absorbed, but if not it will be absorbed slowly and the surface will be tacky.

6.2 **Repair Procedure.** Because of the different methods of manufacture of lifejackets, damage could be caused by using inappropriate repair procedures. As an example, some fabrics are proofed on the outside only, whilst others are proofed on the inside only; abrading the former is an essential part of the repair procedure, whereas abrading the latter would weaken the fabric and cause further damage. It is essential, therefore, that the manufacturer's instructions concerning the repair of a particular lifejacket are carefully followed and any related safety precautions are observed.

6.2.1 After repairs have been carried out the lifejacket should be tested as outlined in the Overhaul Manual.

7 FINAL ASSEMBLY After all the inspections, repairs and tests have been satisfactorily completed and before the lifejacket is folded, a careful check should be made to ensure that all the related equipment has been correctly assembled and fitted to the lifejacket in accordance with the instructions for the type concerned.

7.1 **Folding.** The folding instructions will vary in detail with different types of lifejacket, or in some instances with similar types fitted with different equipment. Care is necessary to ensure that all air has been expelled from the lifejacket before folding.

NOTE: On some lifejackets a deflation key is fitted to the mouth inflation valve to ensure that all air is expelled; this key must be removed before the lifejacket is folded.

7.1.1 After inspecting the valise or container for cleanliness and damage, the lifejacket should be inserted and the closure secured.

7.1.2 A tie-on label giving the serial number of the lifejacket and the date of the next inspection due should be attached, or when a pocket is provided in the valise, a card giving similar information should be inserted.

NOTE: When a tie-on label is used, the quality of the label and the attaching cord should be such that they cannot be damaged or become detached whilst the lifejacket is in service. Some instances have arisen, where lifejackets have been transferred from one aircraft to another and the label(s) have become detached. This has necessitated unpacking and checking against the base Inspection Record to ensure that the inspection date had not expired.

8 STORAGE Leaflet BL/1-7, Storage Conditions for Aeronautical Supplies, gives guidance on acceptable conditions for the storage of lifejackets.

AL/3-13

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AIRCRAFT

SYSTEMS AND EQUIPMENT

HOSE AND HOSE ASSEMBLIES

1 INTRODUCTION This Leaflet gives guidance on the installation and maintenance of hose and hose assemblies in aircraft, and should be read in conjunction with the relevant manuals for the aircraft concerned.

NOTE: In this Leaflet the term "hose" is used to describe a flexible tube which may be used on its own in some locations, and the term "hose assembly" is used to describe the hose complete with end fittings. Some manufacturers use the terms "flexible pipe" and "flexible pipe assembly" to describe the same parts.

1.1 Factors which affect the service life and reliability of hose and hose assemblies include the conditions prevailing in the area in which they are installed, the care with which they are installed and maintained, and the pressures, temperatures and externally applied loads to which they are subjected in service. The need for scrupulous cleanliness at all stages during the lives of the hoses and hose assemblies cannot be over-emphasised.

1.2 Paragraphs 2 to 9 of this Leaflet deal with rubber and synthetic material hose assemblies. Metallic hose assemblies differ considerably with regard to manufacture, installation and maintenance, and are dealt with separately in paragraph 10.

1.3 Guidance on the manufacture of rigid pipes is given in Leaflet **BL/6-15,** and on the installation of rigid pipes in Leaflet **AL/3-14.**

2 GENERAL Hose assemblies for use in high-pressure fluid systems are usually supplied by the manufacturers complete with end fittings which, in most cases, cannot be dismantled or altered in any way. However, there are some types of hose assemblies on which the end fittings may be changed, if necessary, and these are dealt with in paragraph 9.

2.1 **Hose Assemblies.** Modern high-pressure, metal-reinforced rubber or synthetic material hose assemblies are designed for the widest possible application in aircraft and engine construction. The tube or lining of the hose is manufactured from material such as synthetic rubber, which is specially compounded to withstand the deleterious effects of high pressures, high temperatures, oils, solvents, fuels and other fluids. The hose is considerably strengthened by the incorporation of high tensile steel wire braiding or spiral lay, which provides maximum resistance to bursting, together with minimum dimensional alterations when the hose assembly is subjected to high internal pressure. Hose assemblies are generally designed either for specific functions or for a limited range of functions only, and it is essential to ensure that only the hose specified on the appropriate drawing or in the approved parts catalogue is fitted in any particular system and location.

2.1.1 One material which is widely used for the manufacture of hose for engine and hydraulic systems is polytetrafluoroethylene (PTFE). This material is chemically inert, is unaffected by the synthetic oils and fluids used in aircraft systems, operates satisfactorily at high fluid and ambient temperatures, and normally has an unlimited shelf life. PTFE hose is, however, more susceptible to damage from careless handling than rubber hose, and great care is required during removal, installation and inspection.

2.1.2 The operating conditions under which a hose assembly may have to function vary considerably. Fluids may have to be conveyed at very high pressures at altitude where the ambient temperature may be in the region of −55°C; on the other hand high ambient temperatures in the region of jet engines may affect the same hose assembly. Hose assemblies required to function in designated fire zones or adjacent to fireproof bulkheads must possess fire-resistant properties, and are usually fitted with a protective sleeve; these sleeves are usually made from woven asbestos, are covered with asbestos-impregnated synthetic or silicone rubber, and may be secured to the hose assembly by clips.

2.1.3 In addition to the pressures and temperatures to which hose assemblies are subjected, vibration, and in some cases appreciable angles of flexing, may have to be accommodated. It is, therefore, essential that the lives specified for these assemblies in the approved Maintenance Schedule should not be exceeded.

2.2 **Construction of High-pressure Hose Assemblies.** A typical high pressure hose assembly (Figure 1) consists of an inner tube or lining covered by one or two closely-woven wire braids, either moulded or sandwiched between the synthetic rubber of the tube, or woven on the surface of the tube. The whole may be enclosed by an outer cover, the purpose of which is to provide protection for the other parts of the hose, to resist abrasion and the effects of weather and environmental fluids and chemicals, and, in some cases, to provide a degree of fire resistance. In some cases cotton braid is introduced between the wire braids and the rubber inner and outer tubes, and a thin rubber layer may be interposed between layers of wire braid.

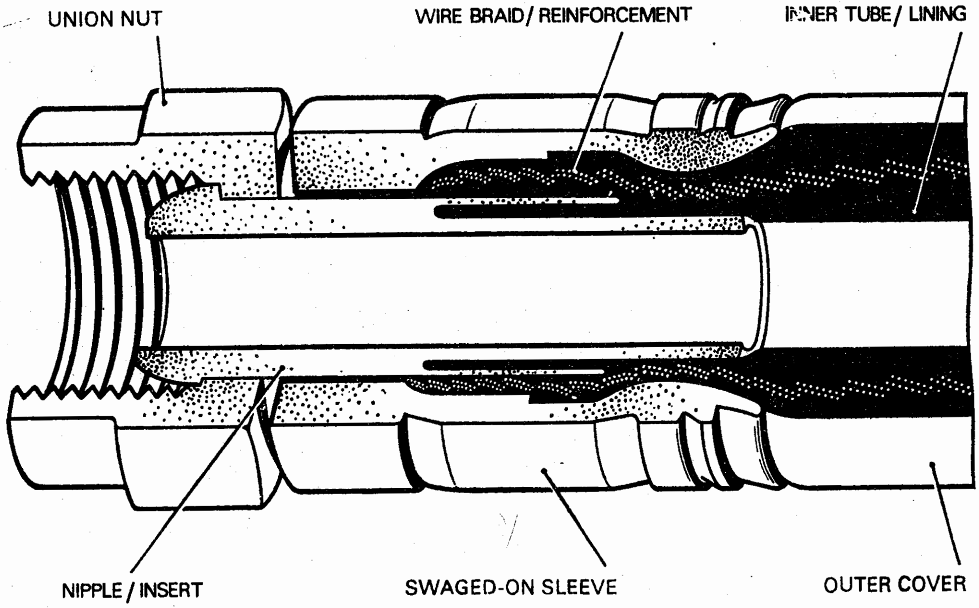


Figure 1 HIGH PRESSURE HOSE ASSEMBLY

2.2.1 The end fittings on a hose assembly are made of steel or light alloy, depending on the application, and they are designed to exert a grip on both the tubes and wire braids so as to resist high pressure, twisting and vibrating loads, and to provide an electrical bond throughout the assembly.

2.3 **Measurement of Length.** The length of hose assemblies with straight end fittings is taken as the distance between the extremities of the two nipples. In the case of elbowed end fittings the length is taken from the centre of the bore (see Figure 2).

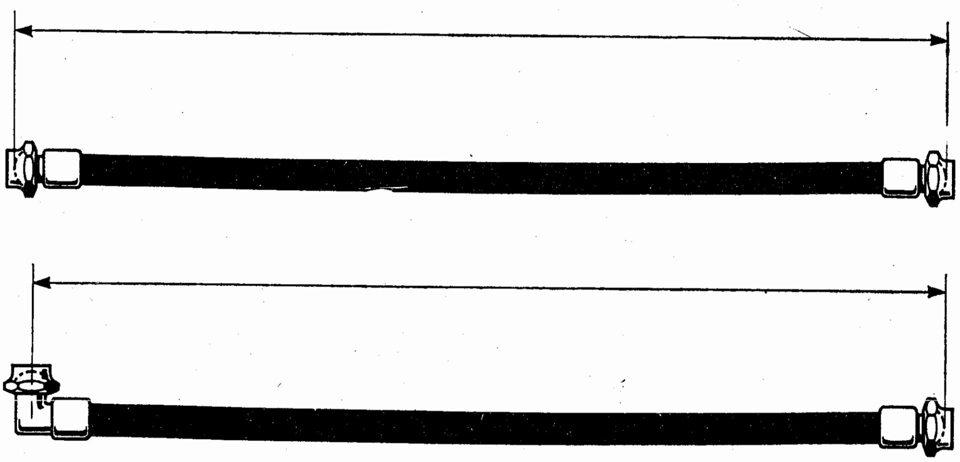


Figure 2 MEASURING HOSE ASSEMBLIES

2.4 **Low-pressure Hose.** There are many types of low-pressure hose used on aircraft, e.g., the thin-walled textile-reinforced type used for instrument lines (especially for instruments mounted on panels equipped with vibration isolators) and the rubber or canvas spirally-corrugated hose having a spiral of spring steel embedded in the corrugations, which is often used for systems where there are negative pressures.

2.4.1 With low-pressure hose it is important to ensure that bends are not too acute, since this may result in kinking of the hose or flattening of the cross-sectional area at the bend. Where sharp bends cannot be avoided an internal support coil may be included in the design.

3 STORAGE OF HOSE AND HOSE ASSEMBLIES PTFE hose does not normally have a specified storage life, but rubber or synthetic rubber hose normally has a storage life, depending on the formulation of the material, of between three and five years. The storage details relevant to a particular hose or hose assembly should be obtained from the appropriate Maintenance Manual or manufacturer's manual, and any instructions relating to the inspection and testing of hose or hose assemblies while in storage or prior to installation should be carefully observed. The storage life of hose supplied in bulk is calculated from the cure date, and the storage life of hose assemblies is calculated from the date of manufacture or assembly.

3.1 **Storage Conditions.** Bulk supplies of hose are generally stored in coils of large diameter, but hose assemblies should be stored flat and relieved of stress. Hose and hose assemblies should be stored away from strong light and running electric motors, and air should be permitted to circulate freely about the parts unless they are contained in plastics envelopes. The temperature should be controlled between 10°C and 26°C.

3.1.1 Preformed hose assemblies and PTFE hose assemblies which are being stored after removal from an aircraft system must be stored in such a way that the required or assumed shape is maintained; no attempt should be made to straighten or bend these hoses. A length of locking wire may be attached between the end fittings to prevent the hose from straightening.

3.2 **Sealing Blanks.** During storage, the correct sealing blanks should be fitted. Plugs and caps conforming to appropriate AGS and AS Specifications are usually suitable, but in instances where the standard blanks cannot be used, blanks should be so designed that they cannot enter the end fitting or be left in position when the assembly is connected. It is also important to ensure that the material used for blanking will not "pick-up" or otherwise tend to leave small particles inside the end fitting after long periods of storage. Tape or rag must not be used for blanking purposes.

3.3 **Rotation of Stock.** Strict rotation of issue from stores must be observed to ensure that older stock is issued first.

3.4 **Bore Protection.** In some special cases, to prevent deterioration of the bore or inner lining of the hose, it may have to be stored filled with the liquid which it is intended to contain in service; special instructions concerning such assemblies will normally be attached by the manufacturer. If a hose assembly is issued in an airtight plastics envelope, this should not be removed until the part is fitted. Should the envelope become damaged during handling, any desiccant contained within should be checked for condition and the envelope should be re-sealed or renewed.

4 MARKINGS ON HOSE AND HOSE ASSEMBLIES There are many ways in which the date of manufacture is marked on hoses and hose assemblies, varying according to the type and construction of the item. The date may be stencilled on the external surface, or impressed on a tab or band secured to the hose; in instances where the external surface is of cotton braid some of the 'strands' are woven in black and some are coloured to indicate the month and year of manufacture.

4.1 In addition to the date of manufacture, hose assemblies are marked with the drawing number or part number, inspection stamp, 'test' stamp and name of manufacturer.

4.2 Most hose assemblies are marked along their length with one or more continuous thin lines to indicate any twist which may occur on installation. Some manufacturers use these lines also for construction identification (see Figure 4), e.g. a hose having a single high-tensile wire braid would be indicated by a single line, while a hose having a double wire braid would be indicated by a double line.

5 PRE-INSTALLATION CHECKS Before a hose assembly is fitted to an aircraft it should be examined for damage and corrosion, and for cleanliness. The part number, date of manufacture and date of last test should also be ascertained. Where specified by the manufacturer, hose assemblies should be pressure tested before installation (see paragraph 8).

5.1 Where possible, every hose assembly should be examined internally to ensure that the bore is free from obstruction or damage. Straight hose assemblies may be examined by looking through them with a light positioned at the opposite end, but preformed hose should be checked by means of a ball test (paragraph 9.4.2 (a)).

5.2 If the end fittings have been welded, brazed or silver soldered, they should be examined for any corrosion which may have developed during manufacture. An Introscope or similar inspection instrument should be used in cases where direct viewing is impractical.

5.3 The hose bore should be examined for cleanliness, blown through with clean, dry compressed air as necessary and, when recommended by the manufacturer, flushed with clean fluid of the type used in the system to which the hose assembly is to be fitted.

6 INSTALLATION When installing a hose assembly, it should be ensured that there is adequate clearance between the hose and other parts of the aircraft structure, so as to prevent chafing or electrolytic corrosion. It must be borne in mind that hose may flex when internal pressure is applied, and considerable 'whip' may occur under surge conditions; the force exerted when a hose 'whips' may be sufficient to cause damage to the hose assembly and to surrounding components.

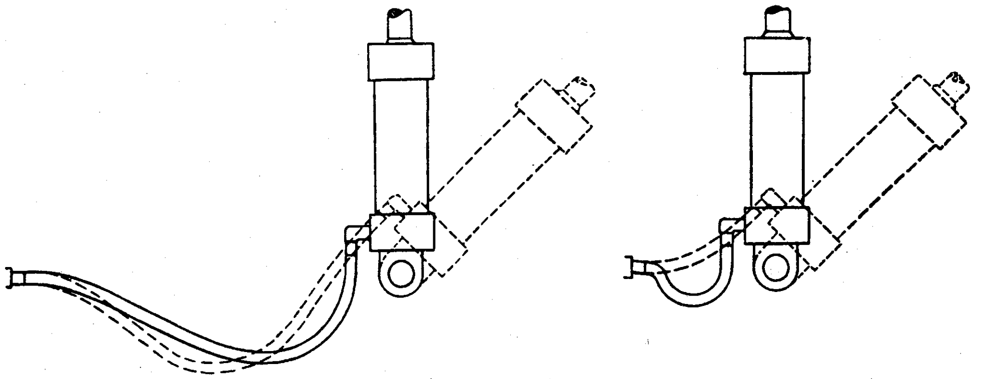
6.1 The serviceability and life of a hose assembly is considerably affected by the degree of bending of the hose. There may be some variation in the connecting angle and distance between fittings for a particular hose assembly in similar installations, and a check should be carried out to ensure that the bend radius is not less than the minimum specified by the manufacturer.

6.1.1 There are two classes of minimum bend radii recommended by hose manufacturers for each hose diameter. The minimum bend radii recommended for hose in locations where there is no relative movement, are smaller than those recommended for hose in locations where there is relative movement between end fittings, e.g. a hose assembly connected to a flap actuator would have a larger radius bend than a hose assembly connecting two rigid couplings at different angles. The flexing radius should, in general, be twice the bend radius of a static installation. It should also be noted that the recommended minimum bend radii for PTFE hose may vary from those recommended for rubber hose.

6.1.2 It is important to ensure that the bend radius of hose fitted to moving parts is never less than the recommended minimum, throughout the range of movement of the parts. Correct and incorrect methods of installation are shown in Figure 3, where the different alignment of the hose assemblies resulting from movement of the attached parts is illustrated.

6.2 To allow for shrinkage, vibration, movement of parts and 'whip', all straight hose assemblies should be at least 3 per cent longer than the maximum distance between the fittings to which they are connected. In no circumstances may a hose assembly be under any form of tension (see Figure 4 (B)).

6.3 Sharp bends in a hose adjacent to an end fitting must be avoided, as this can cause considerable local strain and rapid failure of the hose (see Figure 4 (D)). When fitting hose assemblies with different types of end fittings, the correct method of installation should be observed.



(A) CORRECT (B) INCORRECT

Figure 3 CORRECT AND INCORRECT INSTALLATIONS

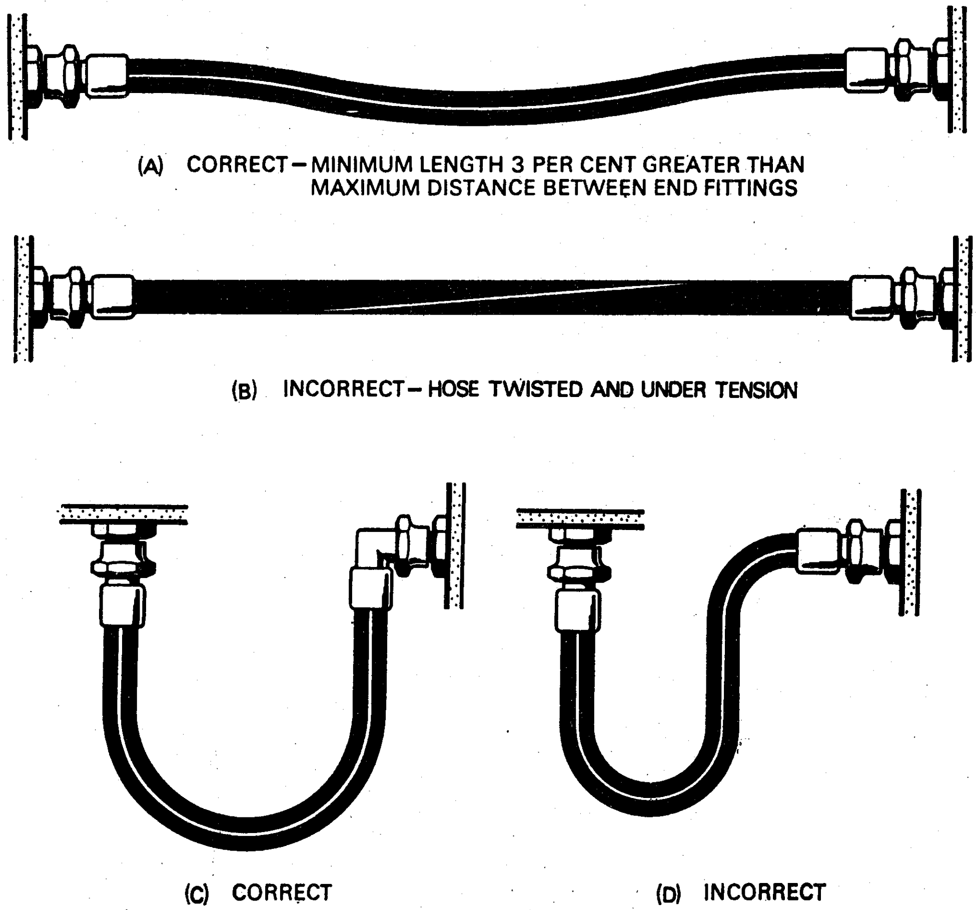


Figure 4 CORRECT AND INCORRECT INSTALLATIONS

6.4 **Lubrication of Couplings.** If the lubrication of coupling threads is specified to avoid 'picking up', it is essential to use the lubricant specified by the manufacturer, and to ensure that it does not enter the bore of the hose assembly; this can be done by applying lubricant to the external threads only. For connections in oxygen systems, where the presence of oil or grease is very dangerous, only specified lubricants may be used. Because of the sensitivity of oxygen to many substances, it is essential that the instructions given in the relevant manual are followed when applying these lubricants.

6.5 **Tightening of Couplings.** When fitting a hose assembly, it is most important to prevent it from twisting when the connections are tightened. The union nuts at each end should be fitted finger-tight and then, while holding the hose portion firmly as near to the coupling as possible, the union nuts should be tightened with a spanner. On some hose end fittings, flats are provided for holding the hose with a second spanner while tightening the union nuts.

6.5.1 The continuous coloured line which some hose assemblies have on their outer cover will assist in detecting any twist in an installed hose (see Figure 4(B)). In the case of hose with a metal braided outer cover, twist may be detected by distortion of the braid pattern in a helical direction, but careful tightening or loosening of the union nuts is the only safe way of avoiding twist and strain in the hose assembly.

6.5.2 Care must be taken when tightening union nuts or banjo bolts, to avoid damage to the nuts, bolts or threads. Spanners should be of the correct size and in good condition, and the bolts and nuts should be tightened to the appropriate torque as specified in the relevant manual.

6.6 **Support Guides.** In many installations, a hose is supported or retained by large 'U' fittings or guides fitted to the adjacent structure to guide the movement of the hose in a particular plane, and to prevent it fouling or catching other moving parts of the aircraft installation. These support guides are usually encased in synthetic rubber to prevent damage to the hose. It is important to check the positioning of these support guides in relation to the angular movement of the hose to ensure that the hose movement is not restricted at extreme angles.

6.6.1 **Clipping.** In some installations, where there is no relative movement of the hose assembly, the hose is clipped to give support and minimise vibration. It must be ensured that, where clips are fitted, the hose is not distorted by overtightening or poor positioning of the clip.

6.6.2 **Taping.** Where taping of a hose is considered necessary as a protection against fouling, this should be reduced to a minimum, since, apart from restricting the hose flexibility, deterioration of the hose under the tape often occurs. On no account should leather be used for this purpose, since acid from the leather will corrode any metal parts with which it comes into contact.

6.6.3 **Movement of Hose Assemblies.** Where a hose assembly is connected to a moving part, it is important to ensure that the hose can only move in the plane or planes intended in the design.

(a) In the case of a hose assembly having movement in more than one plane, torsional loads will be imposed on the hose at the end fittings. If such movement is the design intention, a hose which has no metal braid or wire spiral in its construction is generally used, otherwise the torsional effect would result in early deterioration. In such instances special attention should be given to the locking of end fittings.

(b) Each moving hose should be observed during the functioning tests of the component to which it is connected so that it can be checked throughout its travel for evidence of chafing, binding, tight bends and other deleterious effects. An important application of these checks is to brake hose assemblies, which may appear to be of adequate length when the aircraft is resting on its wheels, but may be too short when the undercarriage strut is fully extended. It should be borne in mind, however, that an excessively large loop in the hose may be hazardous during retraction of the undercarriage.

6.6.4 **Tests after Installation.** After installation of a hose assembly, the associated system should be tested for flow, pressure and bonding as specified on the appropriate drawing or in the relevant aircraft manuals. During tests, freedom from leaks and excessive movement under pressure should be verified.

NOTE: In positions where the hoses cannot be seen with the system in operation, every possible precaution must be taken to ensure safety in the known most adverse condition of operation.

7 MAINTENANCE The life of a hose assembly varies largely according to environmental and operating conditions, but may also be affected by storage conditions and the care taken during its installation. The life is assessed from experience with a particular installation, and it may be specified in a number of ways. Some hose assemblies are given a definite life after which they are scrapped regardless of their apparent condition, some are given an overhaul life which usually coincides with the aircraft overhaul periods, and some are renewed only "on condition"; the life applicable to a particular hose assembly will be specified in the approved Maintenance Schedule. Apart from the replacement of time-expired or unserviceable hose assemblies little maintenance is possible, except in some cases, the replacement of end fittings and protective sleeves, but regular inspections of the condition of the assembly should be carried out, and care should be exercised during its service life to prevent deterioration through abuse.

7.1 **Inspection.** The inspection of hose assemblies should normally be carried out in situ, at the intervals specified in the approved Maintenance Schedule. During each inspection the date of manufacture of hose should be checked to ensure that its prescribed life will be valid until the next inspection, and the assembly should be examined for defects as outlined in paragraphs 7.1.1 to 7.1.9.

7.1.1 **General Condition.** General deterioration of a hose may be recognised by discoloration, flaking, hardening, circumferential cracking or crazing of the outer cover (Figure 5). These defects do not render the hose unserviceable unless the cracks penetrate to the braid.

7.1.2 **Installation.** The installation of a hose assembly should be checked to ensure that it is not twisted, stressed, or bent through too sharp an angle, and that any clips or supports are correctly fitted and not chafing or imposing stress on the hose.

7.1.3 **Chafing and Cuts.** Light chafing and cuts in the outer cover are generally acceptable if the braiding is not exposed, but the reasons for the damage should be ascertained and corrected. In the case of hose assemblies which have no outer covering over the braid, any damage to the braid will normally entail rejection, but some manufacturers permit the acceptance of isolated broken strands. Chafing which occurs under clips may entail changing both the hose and the clips.

7.1.4 **Kinks.** This defect is usually caused by incorrect installation or by mishandling. It shows up as a sharp increase in radius at one point in a bent hose, and is usually easy to detect visually unless the hose has a protective cover; finger pressure should be used to check this type of hose. Any kinked hose must be considered to be permanently damaged and must be scrapped.

Figure 5 AGEING CRACKS

7.1.5 **Corrosion.** Hose assemblies with corroded wire braid, or end fittings which are corroded (other than very lightly and locally) must be scrapped.

7.1.6 **Contamination.** Contamination of a hose with an outer rubber cover will show up as swelling, sponginess, hardening or disintegration of the surface, and is not acceptable. Hose which is contaminated should be rejected and renewed.

7.1.7 **Overheating.** The overheating of rubber covered hose is apparent as scaling, crazing, or discoloration of the surface. Hose with an outer wire braid may assume an overall golden brown colour when exposed to normally high temperature, and this is acceptable; patches of discoloration caused by overheating are not acceptable.

7.1.8 **Blisters.** Blisters may form on the outer synthetic rubber cover of hoses, but these do not necessarily affect the serviceability of the hoses provided they are able to withstand the applicable test described in (a) or (b). Certain factors must be taken into consideration, however, e.g. if the hose is exposed to spray from the tyres, puncturing of the outer cover may allow corrosive elements to attack the wire braiding.

(a) **Hose Assemblies in Pneumatic Systems**

(i) Remove the hose assembly from the aircraft and puncture the blister with a needle having a chisel point. The needle should be inserted parallel with the outer cover of the hose so that it penetrates the outer cover only. The blister should then collapse.

(ii) Pressurise the hose at 1½ times working pressure under water.

(iii) When the hose is pressurised, the air supply should be turned off. Bubbles will appear from air trapped beneath the outer cover but eventually disappear, and if no further bubbles appear, the hose is serviceable.

(iv) A constant flow of air bubbles indicates a leak and can be observed as a pressure drop on the pressure gauge. A leaking hose must be scrapped.

(b) **Hose Assemblies in Hydraulic Systems.** Remove the hose from the aircraft and puncture the blister as outlined in (a). If fluid emerges from the pin hole the hose must be scrapped; if air only emerges the hose should be pressurised with fluid at 1½ times its maximum working pressure for a period of two minutes and, if no fluid leakage occurs, it can be regarded as serviceable.

7.1.9 **Leaks.** A hose assembly should be checked for leakage with pressure in the associated system. A leak may be detected by the presence of fluid on the hose, end fittings or adjacent structure, or by the appearance of blisters on the hose (paragraph 7.1.8). When a protective sleeve is fitted, stains may appear on the sleeve or fluid may emerge from the ends of the sleeve, but if the leak is small and no fluid is visible, the presence of fluid may sometimes be detected by squeezing the sleeve. Hose assemblies in pneumatic systems may be checked by applying, externally, a non-corrosive soapy water solution, by the use of special test equipment, or by carrying out a leak rate check (Leaflet **AL/3-22**). If there is any doubt the hose assembly should be removed from the aircraft and subjected to a pressure test (paragraph 8). A leaking hose must be scrapped.

8 PRESSURE TESTS When specified in the approved Maintenance Manual or Schedule, or whenever the serviceability of a hose assembly is in doubt, a pressure test should be carried out.

8.1 **Test Equipment.** Before pressure testing a hose assembly the following points should be verified: (a) that the test equipment available is adequate for the proposed tests, and located in such a position as to preclude cross-contamination with dissimilar fluids, (b) that the test medium is clean and suitably protected against the ingress of dirt, (c) that the test equipment and instruments are checked at regular intervals, and a record kept of these checks, and (d) that before any tests are made, either in the aircraft or on separate components, the test figures are ascertained from the appropriate drawings or manual.

8.1.1 To prevent injury to personnel in the event of a hose failure during the pressure testing of a hose removed from an aircraft, the hose should be located behind a heavy plastics screen. For tests using air as the test medium the hose should also be submerged in water.

8.2 **Test Medium.** Pressure tests are usually made with a fluid similar to that which the hose will carry in service. However, there are some exceptions, for example, paraffin is usually recommended for testing petrol hoses as it is safer and more searching. Pneumatic and oxygen hoses are usually tested with water then thoroughly dried out with a warm air blast. This is followed by a further test with clean, dry air, in which pressure is limited to maximum system pressure.

8.2.1 Oxygen pipes must not be contaminated with oil, and should not be connected to a compressor for test purposes.

8.3 **Hose Flexing.** When under test, the hose should be restrained to approximately the shape it assumes in service.

8.3.1 If the hose is non-flexing in service it should be flexed approximately 15° from its normal shape several times each way and the pressure should be maintained for at least two minutes. Low pressure non-flexing hoses used in regions of high ambient temperature should be regarded as exceptions and should not be subjected to flexing during pressure testing, since such hoses, having been subjected to extremes of heat during service, will automatically be rendered unserviceable if treated in this manner.

8.3.2 Hoses which are subject to flexing in service should be tested in a similar manner but, in addition, should be flexed through their normal flexing angle plus 15° each way.

8.3.3 No leakage or malfunction should occur during any of these tests.

8.4 **Test Pressures.** Unless otherwise stated on the appropriate drawing or in the relevant manual, hoses should be pressure tested to 1½ times their maximum working pressure.

8.4.1 In some instances hose assemblies are tested in situ, in which case one end should be connected to a universal type of inflation adapter gauge and the other shut off or blanked as required. For information on the universal type of adapter and gauge see Leaflet **AL/3-14**.

9 RE-USABLE END FITTINGS The purpose of re-usable end fittings on hose assemblies is to save the cost of renewing a complete assembly when only the hose portion is unserviceable. An end fitting consists basically of two or more components; a socket fits tightly over the hose, and a tapered nipple (or insert), when screwed into the hose bore, expands the hose and clamps it firmly against the socket. This is the most common method and is known as a 'compression seal' (Figure 6 (A) and (B)), but a somewhat different method of attachment, known as a 'lip seal' (Figure 6 (C)), is used by some manufacturers; the nipple in this case has a cutting spur or separate collar which separates the inner hose from the braid during the assembly operation. The re-use of end fittings is satisfactory if precautions are taken to ensure that no damage is caused to the hose bore during the assembly operation and the manufacturer's instructions are followed with regard to both assembly and testing. A brief description of a typical assembly technique is given in the following paragraphs and illustrated in Figures 6, 7 and 8, but reference should always be made to the aircraft or hose manufacturer's manuals for specific instructions on measurement, assembly, lubricants, tools, etc.

9.1 **Hose.** The new hose must first be carefully measured and cut to length with a fine-tooth hacksaw or specialised cutting equipment, ensuring that the cut-ends are square and smooth. It should then be thoroughly cleaned and blown out with dry compressed air.

9.1.1 To minimise fraying when cutting off hose which has a cloth or metal sheath, it is advisable to wrap the hose with masking tape and saw through the tape.

9.1.2 High pressure hose usually has a metal braid sheath and, when this has a protective rubber cover, the cover must often be removed to enable the hose to enter the socket. Using a sharp knife, the cover should be cut off to the depth of the socket and the exposed braid carefully cleaned with a wire brush. Care must be taken to avoid damage or displacement of reinforcement wires.

9.2 **Fitting Sockets.** Sockets usually have a form of coarse left-hand internal thread to grip the outside of the hose, and threads at the outer end of the bore which mate with threads on the nipple.

9.2.1 To prevent the ingress of moisture on hoses which have a metal braid sheath, it is sometimes recommended that a sealant is applied to the braid and socket bore before assembly.

9.2.2 Large bore hoses are quite rigid and, to facilitate entry of the nipple, it is often recommended that the hose is slightly flared and its bore carefully chamfered before assembly into the socket. Except where a sealant is specified, lubrication of the outer surface of large diameter hose will also ease its assembly into the socket.

9.2.3 Actual assembly of the hose and socket is carried out by holding the socket firmly in a vice and screwing the hose into the socket until it bottoms.

NOTE: Some manufacturers recommend that, after screwing the hose fully into the socket, it should be unscrewed a quarter turn to allow for expansion when the nipple is inserted.

9.2.4 After assembly of the hose to the socket it is recommended that the hose is marked with a grease pencil, paint or tape, at the point where it enters the socket, in order to provide a means of checking that the hose is not forced out of the socket during subsequent insertion of the nipple.

(A)

(B)

(C)

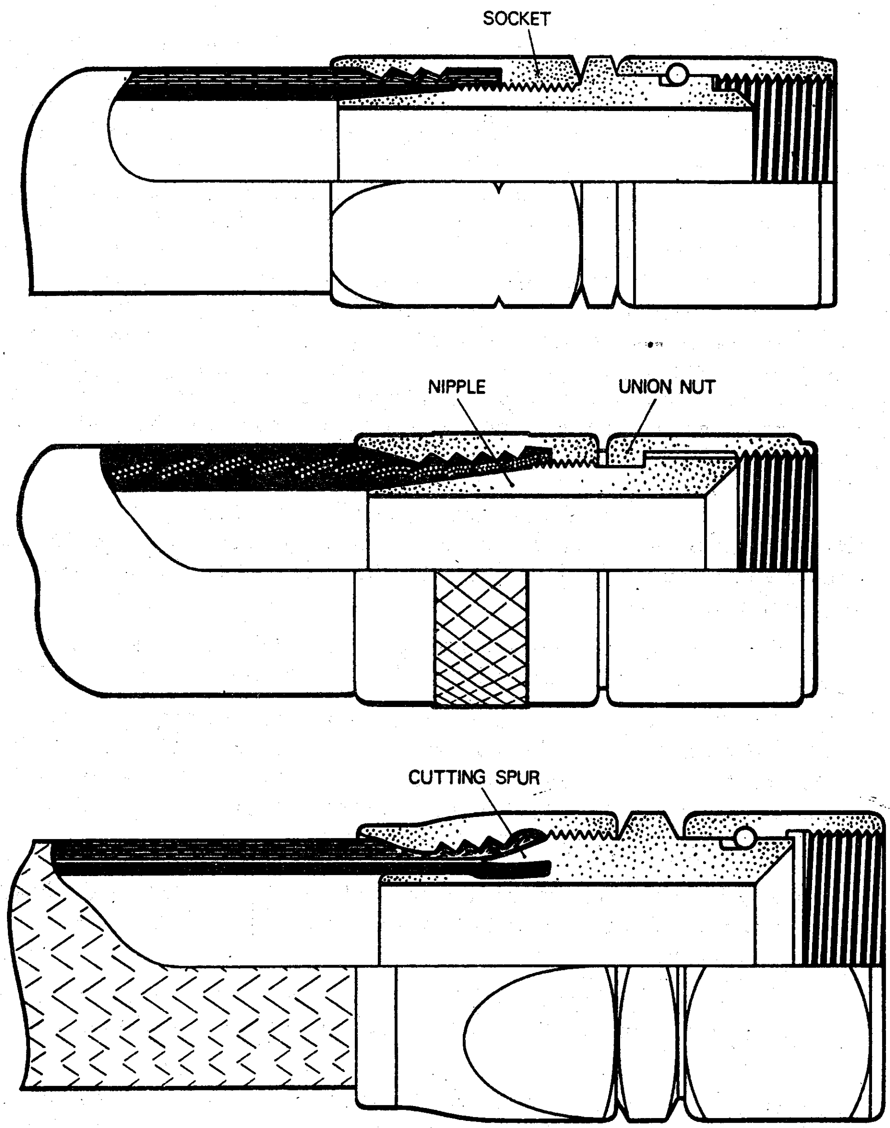


Figure 6 TYPICAL RE-USABLE END FITTINGS

9.3 **Fitting Nipples.** To complete the hose assembly, nipples must be screwed into the previously assembled hose and socket. This operation must be carried out with extreme care, as misalignment of the nipple could easily result in its tapered end cutting into the hose wall; slices of rubber dislodged in this way have been known to cause malfunction of associated components.

9.3.1 Nipples are usually tapered over approximately half their length and are often provided with a plain pilot extension to guide the nipples accurately into the hose (Figure 7). When the nipple does not have a pilot extension, an assembly mandrel should be used and should extend at least 6 mm (¼ in) beyond the end of the nipple. The assembly mandrel also acts as a means of turning a nipple which does not have an integral hexagon or flats.

NOTE: Because of their design, lip seal fittings do not require the use of an assembly mandrel.

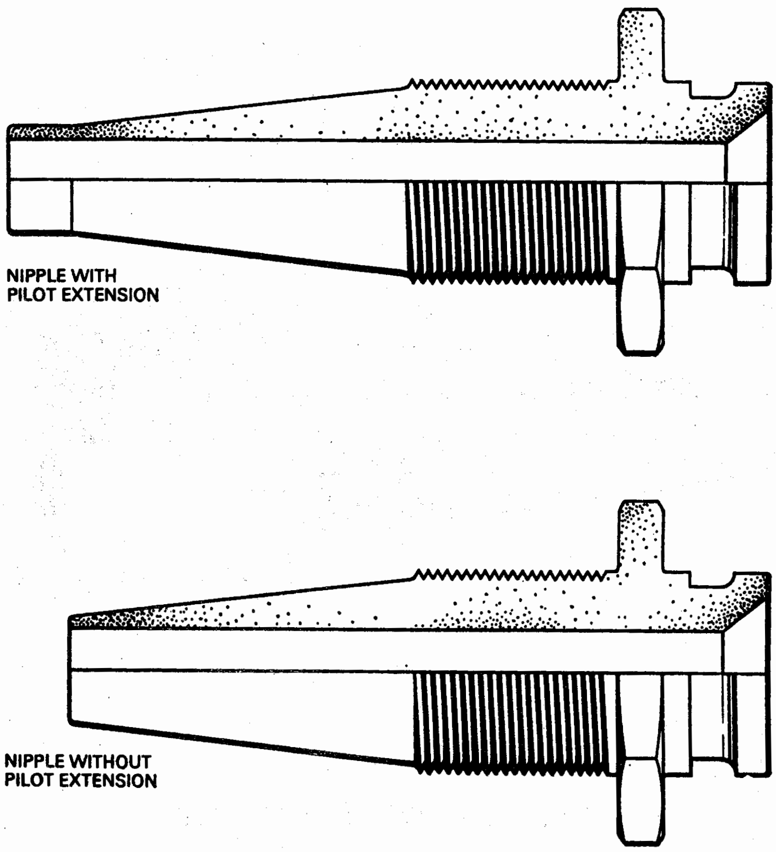


Figure 7 NIPPLE CHARACTERISTICS

9.3.2 Angled nipples are always provided with a pilot extension because an assembly mandrel cannot be used, but some manufacturers recommend that a straight nipple should be partially inserted first, to ensure that a concentric thread is started in the hose bore.

9.3.3 To assemble a nipple, the hose and socket should be held in a vice and, where appropriate, the nipple screwed onto a mandrel of the correct size (Figure 8). The hose bore and nipple should then be liberally lubricated with the recommended lubricant and the nipple screwed carefully by hand into the hose and socket until the threads on the nipple engage with those in the socket. The nipple should then be screwed fully home by use of a spanner or tommy bar as appropriate. With the lip seal type of fitting the hose should be pressed firmly into the socket during this operation and particular care taken when engaging the socket threads.

9.3.4 Check by reference to the mark applied to the hose (paragraph 9.2.4) that the hose has not been pushed out of the socket during insertion of the nipple.

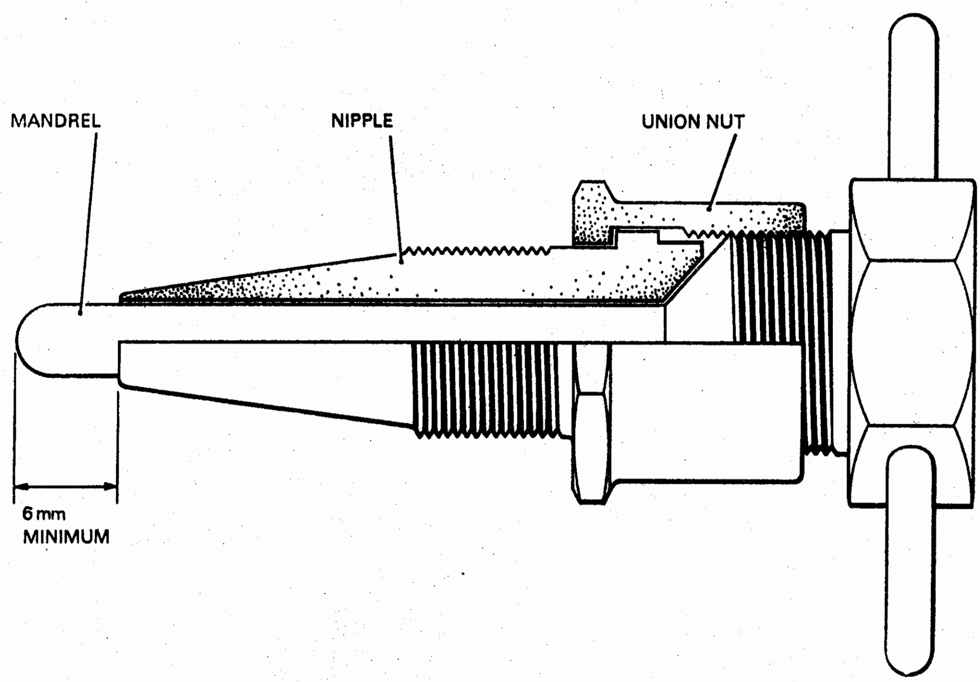


Figure 8 ASSEMBLY MANDREL

9.4 **Inspection.** Sockets and nipples which have been removed from an unserviceable hose should be inspected for damage and corrosion, and any traces of hose adhering to the threads must be removed. Before re-using a lip-seal type of nipple all traces of rubber should be removed from under the lip and, subject to limitations laid down by the hose manufacturer, the lip should be restored to its original profile. After the hose assembly has been made up it should be thoroughly cleaned and dried, examined and pressure tested to 1½ times maximum system pressure, to ensure that it will withstand the pressure existing in the system with which it is to be used.

9.4.1 **External Inspection**

(a) Check all metal parts for signs of damage, particularly of the union nuts and cone faces.

(b) Check that the union nuts turn freely.

(c) Check that the gap between the socket and union nut (or integral hexagon) is within limits.

(d) Check the hose for damage at its point of entry into the socket.

9.4.2 **Internal Inspection.** Internal bulges and flaps can often be detected by looking through the hose with a light held at the opposite end, but a more satisfactory examination can be made using normal inspection equipment (e.g. an Introscope). Hoses which have straight nipples may be readily examined, and hoses which have one angled nipple may be examined from the opposite end. Hoses which have an angled nipple at both ends, however, present difficulties, and although radiological examination would show if the nipple had been assembled eccentrically it might not reveal damage to the hose bore, and would in any case defeat the object of using re-usable fittings. In these cases either a ball test or a flow test is recommended.

(a) **Ball Test**

(i) With the hose assembly suspended from one end, a ball should pass freely through the assembly under its own weight and without lubrication. The check should be repeated from the opposite end, and if the ball fails to pass through the hose in either direction the hose must be rejected as unserviceable.

NOTE: Precautions must be taken to ensure that a hose in which a ball has become lodged is not introduced into service; the hose should be cut immediately and the ball extracted.

(ii) The diameter and material of the ball are specified by the hose manufacturer and vary with the design of the hose, but a steel ball having a diameter of approximately 90% of the bore of the end fittings is generally used.

NOTE: It is sometimes recommended that a rod should be used on small diameter hoses.

(b) **Flow Test.** In some instances a ball test may be considered to be inadequate and it may be required to be demonstrated that the assembly is capable of passing a given quantity of fluid in the time and under the conditions specified.

9.4.3 **Pressure Test.** Hose assemblies with re-usable end fittings should be given pressure tests identical to those described in paragraph 8 for normal hose assemblies.

9.4.4 **Bonding Test.** Where hose assemblies have metal wire braid reinforcing or embody any form of metal in their construction (such as a wire spiral) a bonding test will be specified. An approved type of bonding tester should be used, and the resistance recorded should not exceed 0·050 ohm or 0·025 ohm per foot length, whichever is the greater.

10 FLEXIBLE METALLIC HOSE ASSEMBLIES This type of flexible hose is made entirely of metal, mainly stainless steel, and must, therefore, be treated separately from the synthetic rubber and metal composite flexible hoses dealt with in the previous paragraphs.

10.1 **Construction.** Flexible metallic hose is constructed from an annular or spirally convoluted, seamless, flexible inner tube, reinforced by an exterior covering of one or more layers of stainless wire braid.

10.1.1 **Reinforcing Overbraid.** Unless restrained by some means, the effect of internal pressure on the convoluted tube would cause elongation, and the convolutions would tend to flatten out. Such elongation is prevented by means of a layer, or layers, of wire braid, which is braided upon, or slipped over the inner tube and securely anchored at the end fittings. Special attention is given during the manufacture of the hose to braid tension, pitch angle and final diameter to ensure that change of length of the assembly under pressure is kept to a minimum. This practice obviates the possibility of premature fatigue failure induced by excessive 'panting' and, in addition, 'fretting' on the convolution crests is avoided.

10.1.2 **Function.** The wire overbraid counteracts any tendency of the inner tube to elongate under pressure by containing the end loads thus produced between the fittings. The overbraid also performs other important functions, such as providing protection against damage for the inner tube, and by the exertion of a considerable damping influence on the inner tube when the assembly is under the effects of vibration and pressure impulse.

10.2 **End Fittings.** Various types of steel end fittings are available and are designed to effect a pressure-tight seal at the end of the hose. The seal is achieved by mechanical means or by brazing, silver soldering or welding the fitting to the tube. The end fitting also provides an anchorage for the wire braid to take the end loads caused by internal pressure.

10.3 **Storage.** Assemblies which are to be stored should preferably be left in the boxes in which they are received, but in any case they should have their sealed plastics envelopes intact. Under these conditions, the assemblies have no life limitations, provided that normal steps have been taken to prevent corrosion due to atmospheric conditions, physical damage, etc. It is also important in the event of the plastics envelope having been removed or damaged, to fit approved blanks; adhesive tape or rag should not be used.

10.4 **Identification.** Each assembly has a tag, brass band or adhesive label attached to it on which appears the part number of the assembly, the date of manufacture, the manufacturer's name and inspector's stamp.

10.5 **Pre-installation Check.** Before a hose assembly is fitted, the following checks should be made:—

(a) Verify the part number is correct to the drawing or the appropriate manual.

(b) Remove the blanking plugs or caps and ensure that the end fittings are undamaged and free from corrosion. Special attention should be given to the seating faces.

(c) As far as possible, examine the bore for corrosion.

(d) Carry out the pre-installation pressure test, according to the instructions given on the drawing or in the manual.

NOTE: Prior to fitting, cleanliness of the assembly is imperative.

10.6 **Installation.** When 'offering-up' the hose assembly, particularly if considerable manipulation is required to fit it within a confined space, care must be taken to ensure that the minimum bend radius is not less than that specified. Flexible metallic assemblies comprise thin-section, highly-stressed metal components and it is imperative that they are not stressed beyond their elastic limits.

10.6.1 Union nuts at the end fittings should be hand-tightened at both ends and the hose should lie in a natural manner before the union nuts are finally tightened. Due to its construction, metallic hose will always tend to lie in its natural manner, but care is required to ensure that no twist is applied to the hose during final tightening.

(a) Where provision is made for the use of two spanners, one on the end fitting and one on the union nut, a spanner should always be used on the end fitting to steady the assembly and prevent twisting of the hose on final tightening.

(b) Where no provision is made for the use of a spanner on the end fitting, the hose should be firmly gripped by hand as near the end fitting as possible while the union nut is finally tightened.

(c) After tightening of the union nuts, a hose assembly should always be checked to ensure freedom from twist and tension. It must also be ensured that the end fittings are relieved of the weight of the hose and its contents by suitable supports.

(d) Thread lubricants should only be used if specified on the appropriate drawing or in the relevant manual (see paragraph 6.4).

10.6.2 **Flanges.** In the case of assemblies incorporating 'Vee' band flanges, the correct type of 'O' ring should be carefully positioned in the flange groove, and the inner flange brought into alignment before placing the clamping device in position. This type of flange is produced both with and without means of positive lateral positioning —in the former case care must be exercised in engaging the spigot portion provided for the purpose.

10.6.3 **Supports.** Support clips, which may be either of the close-fitting type and support the hose positively, or of the loose guide type which will allow movement of the hose while containing it in a specific space, must be placed as prescribed on the appropriate drawing.

NOTE: Wire locking of union nuts should be made in the approved manner as described in Leaflet BL/6-13.

10.6.4 **Bonding.** After installation, a bonding check should be made between the assembly end fittings and between the end fittings and the components to which they are connected. The resistance should not exceed 0·050 ohm.

10.7 **Inspection.** When carrying out a visual inspection of flexible metallic hose assemblies installed on an aircraft, any of the following would be cause for rejection:—

(a) Signs of distortion or damage of the wire braiding, or of the braiding being pulled away from end fittings.

(b) Leakage around end fittings.

NOTE: The hose should also be examined for signs of leakage at the lowest points in its run.

(c) Abrasion of the hose caused by contact with adjacent components.

(d) Signs of twisting of the assembly, generally visible as a distortion of the regular pattern of the overbraid in a helical direction.

(e) Corrosion of the external surfaces of the hose end fittings.

(f) Visible cracks or other damage pertaining to the end fittings.

NOTE: When hose assemblies are adjacent to the power plant, a careful examination should be made for any discoloration caused by hot gas leaks which may occur at the shroud ring, exhaust cone or other parts of the engine.

10.7.1 Assemblies should be removed for detailed examination at the periods stated in the Maintenance Schedule or at any time the hose assembly becomes suspect. They should be immersed in a clean non-chlorinated solvent and thoroughly agitated to loosen any oils or deposits on internal and external surfaces and to assist in flushing any deposits clear of the convoluted bore and other parts such as elbow fittings, etc. After cleaning, the assemblies should be inspected as indicated in (a) to (f).

NOTE: It is important not to use any form of internal brushing such as the type used for rifle or tube bore cleaning, as this may cause damage to the inner diameter of the convolutions when the rod or brush is pushed into the bore.

(a) Examine the end fittings for corrosion and damage.

(b) Examine all welded or brazed joints for damage, cracks or corrosion.

(c) Examine all threads for wear.

(d) Check that all mating surfaces (nipple faces) are undamaged.

(e) Examine the wire braid for chafing, dents, and for looseness at end fittings.

(f) Examine the hose for corrosion and discolouration due to overheating.

10.7.2 **Testing.** Assemblies which are considered satisfactory after examination as above should be pressure tested at room temperature using the following procedure:—

(a) Lay the assembly in a free position on a bench, and couple it to a controlled pressure supply of a suitable test fluid, as defined by either manufacturer's requirements or hose usage. After washing through thoroughly, blank off the open end of the assembly. Unless otherwise stated on the appropriate drawing or in the relevant manual, it is usual to pressurise to 1½ times the system maximum working pressure. When the correct pressure has been reached, the pressure supply should be cut off, and there should be no indication of a drop on the pressure gauge after a period of five minutes.

(b) If the hose assembly is part of a pneumatic or air conditioning system, it should be connected to a suitably controlled pressure supply of clean dry air, and immersed in clean water or other suitable liquid at a temperature of about 26°C. Air pressure should be applied slowly up to 1½ times the maximum working pressure of the system in which the assembly is used. The pressure should be maintained for five minutes and the assembly checked for any signs of bubbles indicating a leak.

NOTES: (1) Water at this temperature assists in the dispersion of any air bubbles trapped under the wire braiding, but the assembly should also be agitated.

(2) In the case of hose assemblies with mechanically-attached end fittings, no attempt must be made to seal off a leak by further tightening of the fitting.

(c) **Pressure Test Observations.** During operation (a) and (b) above, the assembly should be checked for the following:—

(i) Signs of leakage.

(ii) Tube distortion under pressure.

(iii) Movement of the wire braiding adjacent to its attachment to the end fittings.

(d) After the assembly has been uncoupled from the test rig and allowed to remain unconfined for at least one hour, a length check should be made with reference to the length tolerances given on the appropriate drawing or in the relevant manual. There may be a slight elongation, but if this is beyond acceptable limits, the assembly should be rejected and returned for investigation to the manufacturing organisation concerned.

(e) **Ball Test.** A ball test should be carried out as detailed in paragraph 9.4.2 (a), but where this is not possible a flow test should be made in accordance with the design requirements for the particular hose.

(f) **Drying.** To avoid corrosion, assemblies which have undergone the tests mentioned in this paragraph (10.7.2) must be thoroughly dried by placing them in a forced-draught, hot-air oven for 30 minutes with the air temperature controlled at 100°C to 105°C, and the longitudinal axes of the hoses in line with the air flow. However, if paraffin was used as the pressure testing medium, it is sufficient to vibrate and drain the hoses until dry.

(g) **Test Identification.** Upon completion of testing, a further identification band or tag should be affixed to the assembly bearing the date of test and the inspection stamp. It is also recommended that an appropriate reference be made in the log book or other records.

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AIRCRAFT

SYSTEMS AND EQUIPMENT

INSTALLATION AND MAINTENANCE OF RIGID PIPES

1 INTRODUCTION This Leaflet gives guidance on the installation and maintenance of rigid pipes in aircraft, and should be read in conjunction with the relevant manuals and the installation drawings for the aircraft concerned.

1.1 Guidance on the manufacture of rigid pipes is given in Leaflet **BL/6–15,** and on the installation and maintenance of hose and hose assemblies in **AL/3–13.** Additional information on hydraulic systems, pneumatic systems, pitot-static systems, thermal de-icing systems and fuel systems, is given in Leaflets **AL/3–21, AL/3–22, AL/10–1, AL/11–2** and **AL/3–17** respectively.

1.2 Information on the identification marking of system pipes is given in British Standard M23, entitled "Identification Scheme for Aircraft Pipe Lines".

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet ML/3-2, Issue 2, dated 15th February, 1961.

2 GENERAL Certain requirements are general to the installation of all types of fluid systems, e.g. the need to avoid 'U' bends, the relief of pressure which may increase as the result of a temperature rise, the isolation of fuel pipes in certain areas and the need to reduce the possibility of incorrect assembly. All these factors are taken into consideration in the design of a fluid system, but maintenance personnel should also be thoroughly acquainted with the system on which they are working and aware of the problems associated with rigid pipes and their connections, so that any necessary inspection, maintenance or repair, can be carried out in a satisfactory manner.

2.1 Since fluid systems vary widely in purpose and design, it is essential that any work on a particular system is carried out strictly in accordance with the relevant Maintenance Manual.

3 INSTALLATION OF RIGID PIPES

3.1 **Pre-installation Checks.** Before a pipe assembly is fitted into an aircraft, it should be checked to establish that it is of the specified type and that there is evidence of prior inspection and testing. The inspector's stamp should normally appear adjacent to the part number.

3.1.1 A pipe should be inspected for damage to the pipe itself, the end fittings and the protective treatment, for correct forming of the flared ends (or correct preset on flareless couplings), and for signs of external corrosion. If damage or deformation is suspected the pipe should be pressure tested or the roundness of the bore checked (as applicable) as outlined in Leaflet **BL/6–15.** Such checks are extremely important, since dented or otherwise damaged pipes may cause a restriction to fluid flow which could have serious consequences. Where permitted in the Maintenance Manual, light external corrosion may be blended out and the protective treatment re-applied. Internal or deep corrosion would be causes of rejection of the assembly.

3.1.2 Dirt, swarf, dust, etc., introduced by fitting pipes which have not been adequately cleaned, may not only affect the various services of which the pipe system forms a part, but may increase the wear of the various components in the system and thus cause a malfunction. It is of the utmost importance, therefore, that adequate precautions are taken at all times to ensure the scrupulous cleanliness of individual pipes and the complete pipe system. Prior to assembly, all pipes should be blown out with clean, dry air and, where applicable, flushed with clean, filtered fluid of the type to be used in the particular system in which the pipes are to be installed. For pipes used in oxygen systems an additional approved degreasing process should also be used, since oil or grease in contact with oxygen under pressure may cause an explosion.

3.1.3 If a pipe is not to be installed immediately, its ends should be blanked following pre-installation inspection and tests, using the blanks fitted during storage or suitable alternatives. Plugs and blanks to standard specification are generally suitable for this purpose, but in instances where standard blanks cannot be fitted it must be ensured that the blank used is so made that it cannot be left in position when the pipe is installed. Rag, tape or paper should not be used for blanking purposes.

3.2 **Installation.** When transporting or carrying pipe assemblies, or moving them into position on the aircraft, care should be taken, particularly with long pipes of small diameter, not to damage them and to support them adequately so as to prevent distortion and kinking. Pipes should be loosely fitted into position in the supporting clamps (paragraph 3.2.1) and adjusted so that the connections meet correctly (paragraph 3.2.2). The connections should be completed, the clamps tightened and bonding attached as specified.

3.2.1 **Pipe Supports**

(a) Multiple pipe clamps are used to support groups of pipes running adjacent to one another. These clamps are often made of red fibre, aluminium alloy, moulded rubber, nylon or other materials. The two halves of the clamps are usually joined together by bolts, which also serve to secure them to the aircraft structure. It is important to ensure that the semi-circular recesses in each half of a clamp mate correctly, do not have sharp edges and are of the correct size for the pipes they support.

(b) In instances where packing is required between the pipes and clamps, the material used should be that specified in the relevant manual or drawing. Typical packing materials are cork sheet, tinned copper or stainless steel gauze and various types of tape or low-friction liners, but leather should not be used since it may cause corrosion of the pipes.

(c) To ensure electrical continuity, some pipe clamps are self-bonding, but in other cases the use of metal gauze between the pipes and clamp may be specified. Bonding strips which bridge pipe connections are often used and should be assembled as specified in the relevant manual or drawing.

(d) Where individual pipes require support, standard clips are usually specified and usually have a moulded rubber lining which obviates the need for packing. Where individual pipes run close together a double type of 'P' clip is often used to avoid contact between the pipes and to provide support.

(e) A minimum clearance of 6 mm (0·25 in) from fixed structure, of 18 mm (0·75 in) from control rods and rigid moving parts, and of 25 mm (1·0 in) from control cables, must be maintained, otherwise vibration and movement may cause chafing. Particular care is necessary to ensure that adequate clearance is maintained between pipes and moving parts, and tests should be carried out to ensure that clearance is satisfactory throughout the full range of movement of the associated part. Consideration should also be given to effects which it may not be possible to simulate, such as an increase in tyre diameter due to centrifugal force, or in width due to ageing.

3.2.2 Connection of Pipes

(a) When connecting pipes with standard brazed, flared or flareless couplings the following points should be verified:—

(i) That union nuts rotate freely, and can be withdrawn from the pipe end without being impeded by bends or other obstructions.

(ii) That all loose parts such as nipples, non-metallic glands, washers, etc., which form part of the coupling, are of the correct type and are correctly located.

(iii) That the pipe ends align correctly with their mating parts. Pipes should never be forced into position, since this may introduce considerable stress into the connection, and result in subsequent leakage or fatigue damage.

(iv) That the pipes are not drawn into position by their union nuts, since this would impose a strain on the flare of a flared coupling or the sleeve of a flareless coupling, and cause deformation of the pipe.

(b) With pipes which have the compressed rubber gland type of coupling, the pipe end must be hard against the shoulder of the recess in the union adaptor before any attempt is made to tighten the union nut.

(c) Where flexible hose is used to connect rigid pipes, it is essential that the correct type of hose is used, since some may not be compatible with the system fluid.

(i) It should be ensured that all sharp edges have been removed from the pipe ends, and that, where specified, the pipe ends have been protected against corrosion.

(ii) A gap of 6 to 12 mm (0·25 to 0·5 in) should exist between the pipes to prevent contact when flexing occurs.

(iii) Hose clips should be of the correct size and type, and should provide an adequate degree of adjustment for subsequent tightening. Care should be taken to ensure that clips are fitted on the side of the beading remote from the pipe ends, and are accessible when all other systems have been installed.

(iv) If a hose proves difficult to assemble, it may usually be lubricated by system fluid. Care must be taken to ensure that pieces of hose are not cut or broken off during assembly and left in the pipe bore.

(d) Two spanners should always be used when tightening (or disconnecting) a pipe coupling; one to hold the sleeve or adaptor and one to turn the union nut. Overtightening should be avoided since many standard pipe couplings are made of aluminium alloy, which can easily be strained. Any special tightening techniques or tightening torque values specified in the relevant publication should be carefully observed.

(e) If lubrication of threads is specified to avoid 'pick-up', it is essential that the correct lubricant is used and that it does not enter the bore of the pipe. This is particularly important with couplings used in oxygen systems, where dry film lubricants requiring special application procedures are usually specified.

4 TESTS AFTER INSTALLATION All pipes will have been pressure tested following manufacture, but it is usually necessary to carry out pressure and flow tests after installation of a pipe, to ensure that there are no leaks from the pipe and its connections and that, where essential to the correct operation of the associated system, the required flow rate is obtained.

4.1 Power for carrying out the tests may be provided by the aircraft engine-driven pumps or by an external test rig suitable for the system concerned. The tests should be carried out strictly in accordance with the relevant Maintenance Manual. Guidance on typical procedures is also given in the appropriate CAIP Leaflets. Special note should also be taken of any precautions specified for the safety of personnel or the prevention of damage to the aircraft or its systems.

4.2 While the associated system is pressurised, and while the services are being operated, the pipelines should be inspected for flexing or displacement to ensure that the required clearances are maintained. The pipe supports should also be checked for security of attachment and the pipes for local distortion at the clamping points.

4.3 Leakage from pipes in liquid systems (e.g. hydraulic systems) can usually be detected by careful visual inspection, and leakage from gas systems (e.g. pneumatic systems) can usually be detected aurally or, after painting the pipes and connections with a solution of water and acid-free soap, be detected by the appearance of bubbles. If the soap solution is used it should be washed off immediately after the test.

4.4 If leakage from a connection is apparent, the connection may be tightened, but should not be over-tightened in an attempt to cure the leak. Leaks are often caused by solid particles at the mating faces of a joint, by misalignment of a nipple, or by damage to one of the components in the joint. Loosening and re-tightening of a coupling will often cure a leak but if it does not do so, the coupling should be disconnected and the cause of the leakage ascertained.

4.5 After all tests have been completed satisfactorily, it is important to ensure that any liquid which may have leaked or been spilled on the airframe structure or components, is removed. In addition to any fire hazard, aircraft liquids may also have deleterious effects on some of the alloys and compounds with which they come into contact.

4.6 When the work of installing and testing a pipe is complete, the connections should, where applicable, be locked in the appropriate manner (see Leaflet **BL/6-13**).

5 MAINTENANCE OF RIGID PIPES The maintenance of these components should be in accordance with the relevant Maintenance Manual, but the factors outlined in paragraphs 5.1 to 5.5 should be taken into account.

5.1 **General**

5.1.1 Pipes which are attached to the structure of an airframe may often be in a shielded position and will not normally be subject to accidental damage, but other pipes are located in exposed positions where they may be highly susceptible to damage or corrosion. Pipes located in a wheel bay, or attached to an undercarriage leg, could easily be damaged by stones, mud or detached rubber thrown up from the tyres or corroded by regular contact with water. In other positions pipes may be subject to abuse from carelessly performed, unrelated servicing activities. Special care must, therefore, be taken when inspecting pipes in exposed locations.

5.1.2 Chafing may occur under pipe clamps and clips, particularly where vibration is present. Pipes which have sharp bends and which are subject to high pressure pulsations tend to develop an oval section at the bend, which may eventually develop into a crack. The possibility of damage from both these causes should be considered when inspecting pipes in any location.

5.2 **Leaks.** The presence of a leak from a pipe connection in a liquid system will often be shown by the presence of liquid or an accumulation of dust or dirt on the outside of the pipe or connection. Leakage from a gas system may only be detected by the loss of system pressure, but the position of the leak may usually be detected as outlined in paragraph 4.3. The actions described in paragraph 4.4 should be taken to cure a leak, but if these are not effective the pipe assembly should be renewed.

5.3 **Damage.** Reference should be made to the relevant Maintenance Manual when assessing damage, since the acceptability may vary with particular materials and particular systems.

5.4 **Corrosion.** Corrosion may affect pipes of any material, particularly in exposed locations and in the areas of clips and supports, where moisture may be trapped. Corrosion products should be removed and the depth of any pits should be checked (see Leaflet **BL/4-2**). Pipes which have corroded areas which cannot be blended out within the limits specified in the relevant Maintenance Manual should be renewed. If the corrosion can be removed satisfactorily, protective treatment should be re-applied to the affected areas.

5.5 **Rubber Hose Couplings.** Rubber hose couplings can be affected by expansion, contraction, vibration and heat, and should be inspected regularly for deterioration and freedom from oil and grease. When couplings are removed from pipe ends it is essential that damage to the pipe be avoided; if the hose is stuck to the pipe it should be carefully cut axially with a sharp knife and peeled off.

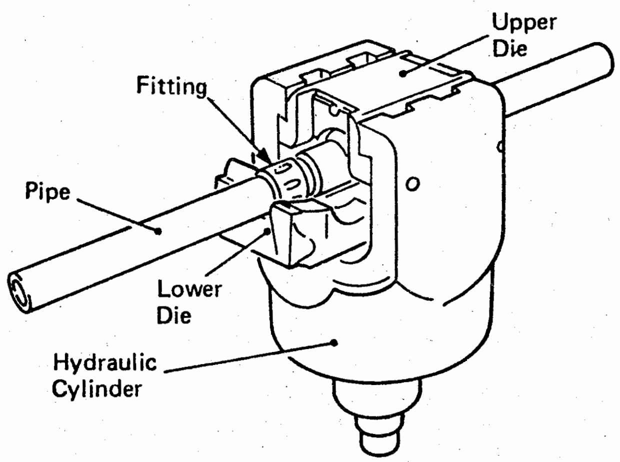
5.5.1 Hose clips have a tendency to loosen subsequent to initial installation, due to compression of the rubber, and may need to be re-tightened when they have been in service for a short period.

6 REPAIR OF RIGID PIPES Damage to rigid pipes which is outside the specified limits for acceptable damage, will usually necessitate the removal of the affected pipe and the fitting of a new or reconditioned item. However, in some cases repairs may be permitted, either by the insertion of a new portion of pipe or by the insertion of a coupling, depending on the extent of the damage. After repairs, the inspections and tests detailed in paragraph 4 should be carried out.

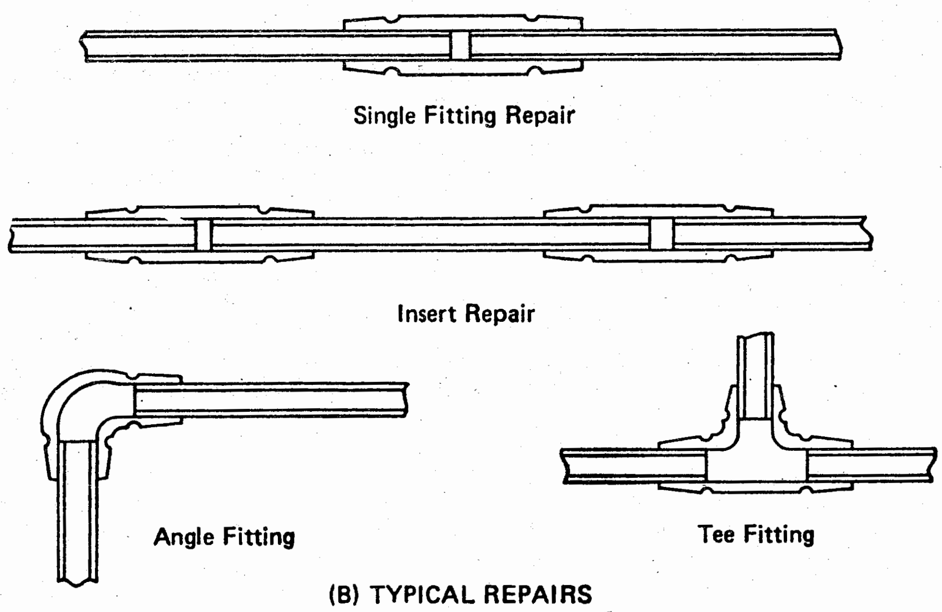
6.1 **Repairs using Standard Couplings.** These repairs will normally involve removal of the damaged pipe, since the pipe ends will have to be flared or flareless couplings fitted, and will usually be applied only to straight sections of pipe. However, the addition of a pipe coupling could change the resonant frequency of that portion of pipe, and this could lead to vibration and fatigue; these repairs should thus only be used when specified in the relevant Maintenance Manual.

6.1.1 A circumferential crack or deep score may be repaired by cutting out the small damaged section of pipe and inserting a union body and two connections. Care should be taken to ensure that the final length of pipe is correct and that the couplings will not foul parts of the structure when installed. The pipes should be thoroughly cleaned after preparation of the ends, and pressure tested before re-installation.

6.1.2 If the damage is in excess of that which could be repaired as outlined in paragraph 6.1.1, the damaged portion of pipe should be cut out and a new section inserted, using two new union bodies and connections, or, if the damaged portion includes one existing end fitting, by replacing that fitting and joining the new section to the old with a union body and two connections. The precautions outlined in paragraph 6.1.1 should also be observed.



(A) HYDRAULICALLY-OPERATED SWAGING TOOL



(B) TYPICAL REPAIRS

Figure 1 TOOLS AND TYPICAL REPAIRS FOR EXTERNAL SWAGING PROCESS

6.2 **Repairs Using Swaged Fittings.** Some manufacturers specify the use of swaged fittings for carrying out in situ repairs to pipelines. Full details of the processes and of the type of swaged fittings to be used in a particular case are given in the relevant Maintenance Manual, and all repairs should be carried out strictly in accordance with those instructions.

6.2.1 **External Swaging Process.** The damage which can be repaired by this process is broadly as outlined in paragraphs 6.1.1 and 6.1.2, and the repair consists of a tubular fitting which is swaged over a pipe joint. The gap between the pipe ends can be up to 8 mm (0·3 in), thus permitting a degree of latitude when replacing a damaged portion of pipe. Typical repairs are illustrated in Figure 1.

(a) The equipment necessary for carrying out externally swaged repairs is available in three kits, each covering a range of pipe diameters and comprising a hydraulically operated swaging tool with pairs of dies to cover the range of pipe diameters, a ratchet pipe cutter and a deburring tool. Various marking gauges are also provided to enable fittings to be correctly positioned, and GO/NO GO gauges enable checking of the swaging operation to be carried out.

(b) The method of operation of the process is briefly as follows:—

(i) Release pipe supports sufficiently to enable the repair to be carried out.

(ii) Select the repair kit appropriate to the pipe diameter.

(iii) Fit and operate the ratchet cutter to remove the damaged portion of pipe.

(iv) Using the deburring tool (which incorporates a rubber plug to prevent swarf being trapped in the pipe), remove the burrs and chamfer the pipe ends.

(v) Clean the pipe ends, then, using the appropriate gauge, mark the pipe so that the swage fitting can be correctly located.

(vi) Select and fit the appropriate fitting and position it over the ends of the pipes being joined.

(vii) Select the appropriate dies, fit them to the swaging tool, position the tool over the fitting and operate the tool in accordance with the manufacturer's instructions to complete the swaging operation.

(viii) Remove the swaging tool and dies, and visually inspect the fitting for cracks. Check that the swaging operation is satisfactory by use of the GO/NO GO checking gauge provided.

6.2.2 **Internal Swaging Process.** The components used in this process are a male externally threaded fitting and a female fitting with either a separate or an attached union nut. This process can be used for repairing the type of damage outlined in paragraphs 6.1.1 and 6.1.2, or for repairing leaking or damaged couplings, using a special repair fitting with an extended barrel. The tools used, and some typical repairs, are illustrated in Figure 2.

(a) Swaging equipment is provided for each pipe diameter and wall thickness, and consists of an expander, a die set, a holding collar and a set ring for checking the expander setting.

(b) The method of operation of the process is briefly as follows:—

(i) Release the pipe supports sufficiently to enable the repair to be carried out.

(ii) Remove the damaged portion of the pipe using a chipless cutter, then deburr the pipe ends using the tool provided. Clean the pipe ends.

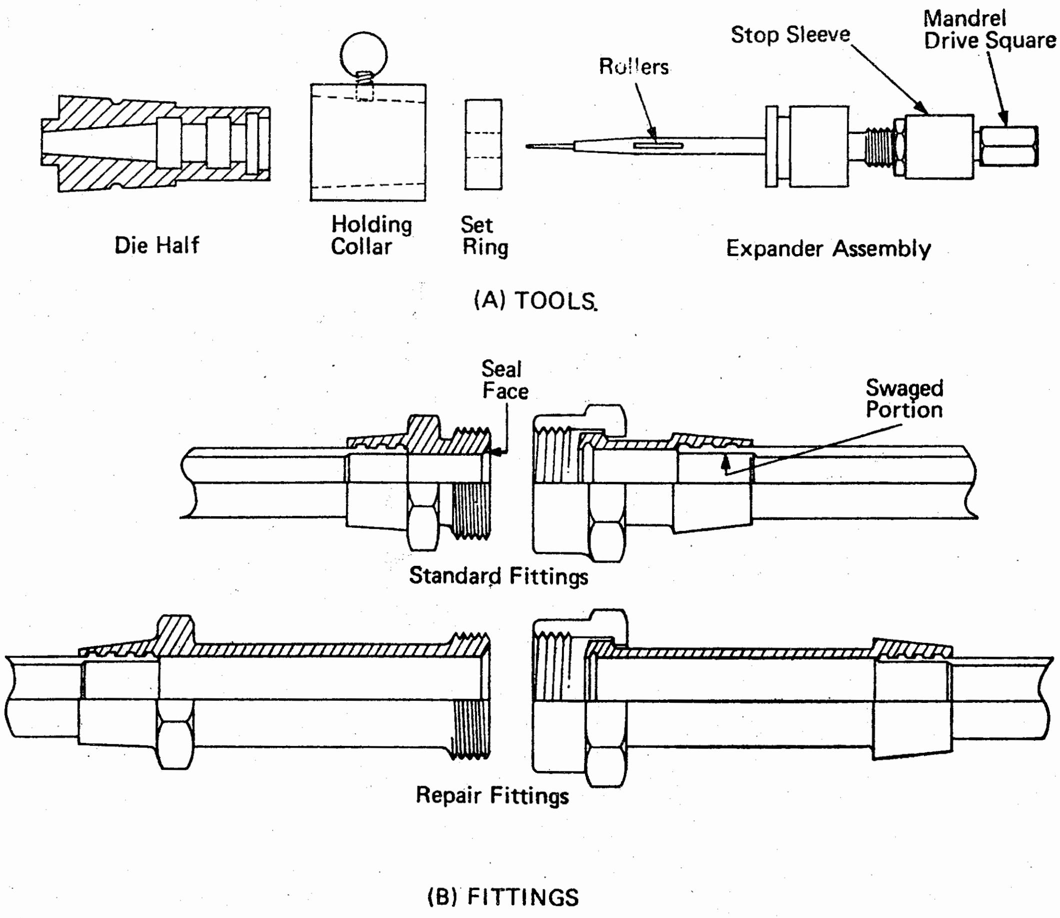


Figure 2 TOOLS AND TYPICAL REPAIRS FOR INTERNAL SWAGING PROCESS

(iii) Select the appropriate tools, check the fit of the holding collar and die set, and check the setting of the expander with the associated set ring.

(iv) Position the pipe in the fitting and ensure that it butts against the fitting shoulder. Mark the pipe at the end of the fitting for future reference (see 6.2.2 (b) (ix)).

(v) Insert the expander into the pipe with the mandrel retracted and place the assembly in one die half. Push in the mandrel until it stops, then rotate it until finger tight.

(vi) Fit the other die half and secure with the holding collar.

(vii) Rotate the mandrel with a wrench or rotary tool until the mandrel contacts the stop sleeve, then rotate it a further 10 turns to complete the swaging operation.

(viii) Loosen the mandrel and remove the swaging tools from the pipe.

(ix) Visually inspect the fitting for damage and check the marking on the pipe to ensure that the fitting is correctly positioned. Measure the internal diameter of the swaged portion of the pipe to ensure that it is within the tolerance specified in the relevant manual.

AL/3-15

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AIRCRAFT

SYSTEMS AND EQUIPMENT

TANKS

1 INTRODUCTION This Leaflet gives guidance on the construction, installation, and maintenance of the various types of tanks used in aircraft systems. This Leaflet should be read in conjunction with the relevant Maintenance Manual and approved Maintenance Schedule for the aircraft concerned.

1.1 The Civil Aviation Authority's requirements applicable to tanks are prescribed in British Civil Airworthiness Requirements; the requirements for fuel tanks are in **Section D,** Chapter **D5-2, Section G,** Chapter **G5-2,** and **Section K,** Chapter **K5-2,** respectively, and those for oil tanks, are in **Section D,** Chapter **D5-3, Section G,** Chapter **G5-3,** and **Section K,** Chapter **K5-3,** respectively.

1.2 The following Leaflets contain information on related subjects, and should be referred to as appropriate:—

BL/1-6	Stores and Approved Release
BL/4-1	Corrosion - Its Nature and Control
BL/4-2	Corrosion - Removal and Rectification
BL/4-3	Corrosion - Methods of Protection
BL/6-4	Oxy-acetylene Welding
BL/6-5	Arc Welding
BL/6-8	De-greasing - Trichloroethylene
BL/6-16	Resistance Welding - Seam Welding Procedure
BL/6-29	Riveting
AL/3-8	Fire - General Precautions
AL/3-17	Fuel Systems
AL/3-21	Hydraulic Systems
EEL/1-6	Bonding and Circuit Testing

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet ML/3-3, Issue 2, dated 15th February, 1961.

2 GENERAL There are three types of tanks in use; rigid or shell tanks, flexible tanks, and integral tanks (tanks which are formed by sealing part of the structure). Rigid tanks are generally used for oil, de-icing fluid, hydraulic fluid, water, and, in some cases, fuel, whilst flexible and integral tanks are used almost exclusively for fuel, so as to make full use of the available space, and to save weight. The construction, installation and maintenance procedures peculiar to each type of tank, are described separately in paragraphs 3, 4 and 5, and the procedures common to all types are described in paragraphs 6 and 7.

3 RIGID TANKS Rigid tanks are normally used in engine oil systems, water systems, and the fuel systems of some light aircraft. Tanks which are contained within the airframe structure are generally manufactured from aluminium alloy, and may be either riveted or welded. Some tanks, such as coolant header tanks, may be constructed from sheet brass or similar alloy, and others, which have to withstand high temperatures or corrosive fluids, may be made from stainless steel. External fuel tanks are sometimes made from non-metallic materials such as glass fibre.

3.1 **Installation.** Rigid tanks are often mounted on suitably shaped bearers, and secured by means of padded metal straps, which are joined and tightened by turnbuckles. On some wing fuel tanks, however, the lower surface of the tank is also the wing skin, and is secured to the surrounding structure by screws. In instances where the tank skin or the tank bay closing panel provides a load-bearing surface, the wing must be suitably supported before the tank is removed, and the supports must remain in position until the tank is re-installed and secured.

3.1.1 Before a tank is installed, the tank bay should be examined for cleanliness, damage and corrosion, and to ensure that there are no projections such as bolts, screws, or fasteners, which could chafe or damage the tank when it is in position. Any rectification necessary should be carried out, and protective treatment should be applied and allowed to dry. The tank bay area should then be thoroughly cleaned, fuel pipe and vent connections should be prepared to receive the tank, and electrical power to any tank connections should be isolated. Blanks fitted to the pipes should be left in position as long as possible, in order to prevent the ingress of foreign matter and moisture.

3.1.2 The tank which is to be fitted should be inspected for damage, all traces of inhibitor should be removed from it, and any components required for the tank, such as contents transmitters and booster pumps, should be installed in accordance with the appropriate Maintenance Manual. Any filters should be inspected for cleanliness and security, and the filler cap, where fitted, should be checked for effective sealing. Vents should be checked to ensure they are properly connected and unblocked. All fittings should be locked in the appropriate manner.

3.1.3 Care is necessary when installing a tank, since there is often very little clearance between the tank and tank bay, and access holes may permit only a limited view. Careless installation could result in damage to the tank, which may lead to subsequent leakage.

3.1.4 Connections should be made without bending or stretching the pipes, and, when required by the manufacturer, installation alignment tolerances should be checked. The introduction of a low point in a feed or vent pipe run could result in the collection of water at that point, which could lead to a blockage if the water were to freeze.

3.1.5 Straps should be tightened sufficiently to prevent the tank from moving, but over-tightening must be avoided. It is important that all straps are tightened equally, to permit even distribution of strain.

3.1.6 Overboard drain and vent pipes should be checked after tank installation, to ensure they do not discharge in such a manner that combustible fluids could leak into the structure or passenger compartments, and create a fire hazard.

3.1.7 The bonding of tanks which are not connected directly to the structure is most important, and all bonding strips and cords should be securely attached. After installation of the tank, bonding should be checked as described in Leaflet **EEL/1-6**.

3.1.8 The tank should then be filled, while the contents gauge is checked, as described in Leaflet **AL/10-3**, and the tank should be inspected for leaks.

3.2 **Inspection**

3.2.1 **Installed Tanks.** All applicable panels in the aircraft skin adjacent to the tank should be removed, and the tank should be inspected for security, correct adjustment of straps and slings, contamination, corrosion, superficial damage, cleanliness, chafing, distortion, and evidence of leakage from pipe connections, drains, and the tank itself. Leakage from connections may often be corrected in situ, by draining the tank and re-making the connection, but a damaged tank must, in most cases, be removed for repair.

3.2.2 **Removed Tanks.** Tanks must be drained before being removed for inspection, and other associated tanks should be isolated by means of their supply cocks, so that only the tank being removed is drained. Vent pipes must be clear, to prevent the tank from collapsing as the fuel drains out. When necessary (see paragraph 3.1), the wing structure should be supported, access covers should be removed, pipes and vents should be disconnected and blanked, and electrical services should be isolated and disconnected. The tank should be released from its mountings, then carefully removed, and laid in a suitable cradle. The tank should then be thoroughly flushed and cleaned to remove all traces of fluid, sediment and gummy substances, and the following inspections should be carried out as appropriate:—

(a) The external surfaces of the tank should be examined for evidence of leakage and corrosion, and for any other damage which may have resulted from factors such as chafing, vibration, and incorrect adjustment of mounting straps.

(b) The condition and security of all pipe adaptors, anchor nuts, and external fittings should be checked.

(c) The internal surfaces of the tank should be examined for defects such as corrosion, contamination, and, where applicable, the looseness or flaking of the internal protective treatment. All internal fittings, such as pumps, baffles, and de-aerating devices, should be examined for security, damage and corrosion

3.3 **Repairs.** Leakage from the joint surfaces of components and access panels may usually be cured by renewing gaskets or sealant, as appropriate. When the tank itself is leaking, the method by which it should be repaired will depend on its mode of construction.

3.3.1 Tanks which are constructed by riveting are normally repaired from inside. Small tanks are sealed by 'slushing' with an approved sealant, and large tanks are usually provided with access holes of sufficient size to permit entry into the tank and to facilitate the application of sealant to particular areas. The affected areas must be thoroughly degreased, and the sealant must be mixed and applied strictly in accordance with the manufacturer's instructions.

3.3.2 Welded tanks may usually be repaired by argon arc or gas welding. All traces of combustible fluid must be removed before welding is commenced, by flowing steam or water through the tank for approximately 1 hour, then drying with warm air. During welding, the use of 'dry ice', as a depressant to combustion, is often recommended (see also paragraph 7 for additional safety precautions). After welding, all traces of flux must be removed from the tank, in accordance with the manufacturer's instructions.

3.3.3 Tanks which are constructed from glass fibre may usually be repaired by replacing the damaged material. These repairs should be carried out strictly in accordance with the manufacturer's instructions, and by persons who have received proper training.

3.3.4 Tanks should be pressure tested after repairs have been carried out (see paragraph 6), and should be re-painted as necessary.

4 FLEXIBLE TANKS Flexible tanks are manufactured from rubber or plastics sheet, which is reinforced with nylon or fabric. They are tailored to fit a particular location in the wing or fuselage, and are supported by means of buttons or cords, to ensure that they maintain their shape and enable accurate contents indications to be obtained. Filler necks, pumps, vents, feed pipes and contents units, are each connected to the tank by means of a moulding at the tank aperture; the moulding being squeezed between an internal and external fitting. A controlled compression joint is often used, to prevent damage to the moulding through overtightening of the attachment bolts.

4.1 **Installation.** Tank bays for flexible tanks are designed with smooth, flat surfaces, to provide maximum support for the tank. Any projections, such as rivet heads or skin joints, are covered with tape or rubber strip, to prevent chafing of the outer surface of the tank. Before a tank is installed, the tank bay should be inspected to ensure that the protective strips are secure, that the tank bay is free from foreign objects, rags, etc., and that there are no projections or loose swarf likely to damage the tank.

4.1.1 A flexible tank should always be inspected before installation, to ensure that no damage has been sustained during transit, or through faulty storage. If damage is found, it must be repaired in accordance with the appropriate Manual, before the tank is installed. It is important also to check any life limitations before installation.

4.1.2 The tank must, generally, be folded in the manner prescribed in the appropriate Maintenance Manual, and inserted into the tank bay through an access hole; in some cases, a manhole large enough to permit entry into the tank is provided, to facilitate both installation and internal repairs. The edges of the access hole should be padded, in order to prevent damage to the tank, and, after the tank has been inserted, it should be carefully unfolded and slid into position. The use of french chalk is often recommended to assist in moving the tank into position.

NOTE: To ensure that the tank is sufficiently flexible, some manufacturers specify a minimum temperature for installation and removal.

4.1.3 When the tank fittings have been positioned, the tank securing studs or cord should be attached, using an approved lubricant to ease installation, and the tank walls should be smoothed out to eliminate creases. Where entry into the tank is necessary, soft, rubber-soled canvas shoes must be worn, and a protective rubber mat should be laid on the floor of the tank.

4.1.4 All internal fittings should then be secured, care being taken not to overtighten the attachment bolts. All servicing equipment should be removed, and the tank should be thoroughly cleaned.

4.1.5 External fittings should then be attached, and the access hole covers and manhole cover should be replaced.

4.1.6 When installation of the tank is complete, vent and drain pipes should be checked for positioning, and a bonding test should be carried out as described for rigid tanks. The tank should then be filled while the contents gauge is checked, as described in Leaflet **AL/10-3,** and the tank should be inspected for leaks.

4.2 **Inspection.** It is generally only possible to make a superficial examination of a tank after it has been installed in an aircraft, since only small parts of the external surface will be visible. With all adjacent skin panels removed all visible parts of the tank and the tank bay should be inspected for damage and damp patches. External connections should be examined for leakage. The inside of the tank should be inspected for damage, corrosion of any metal fittings, contamination, and deterioration of the lining. This inspection should be carried out using a mirror and flame-proof lamp inserted through the filler orifice or other suitable aperture. Whenever a thorough examination is required removal of the tank is usually specified in the approved Maintenance Schedule.

4.2.1 In order to remove the tank for inspection, it should be drained, and all external pipes should be disconnected and blanked. The manholes and handholes which are attached to the aircraft structure, and any items, such as booster pumps, which may hinder withdrawal of the tank, should be removed. After checking that the tank interior is free from loose articles and debris, the tank fastenings should be released, and the tank should be folded in a prescribed manner, and carefully withdrawn through the access hole. Handling straps are sometimes provided to assist in withdrawal, but external fittings must not be used as handles. Some tanks are too inflexible to be folded, and in these cases the access is sufficiently large to permit withdrawal without folding. Any sharp edges or projections should be padded prior to withdrawal of the tank, in order to prevent damage to the exterior surface. When removed, the tank should be laid on a rubber sheet, ready for inspection.

4.2.2 Any fuel which may be on the outside of the tank should be wiped off, and the following external inspections should be carried out:—

(a) Examine the tank for cuts, punctures, chafing, lifting of seams, and security of fittings.

(b) Examine all metal fittings, for security, corrosion, and evidence of leakage.

(c) Examine the tank for stains, and check whether they are the result of fuel leakage.

NOTE: A damp patch on the tank surface may not necessarily mean that the tank itself is leaking. Fuel may have leaked from, for example, a pipe connection, and have drained into the tank bay. If the tank appears to be satisfactory after it has been removed, a check should be made for leaks elsewhere in the system.

4.2.3 All inspection covers must be removed, and the tank must be freed from fuel vapour, before an internal inspection is carried out. The safety precautions detailed in paragraph 7 must be implemented, and the following inspections should be carried out:—

(a) Examine all joints, seams, and reinforcing patches, for lifting, and for signs of bubbles resulting from lack of adhesion of the lining.

(b) Examine the lining for creases, and for deterioration resulting from exposure to air.

(c) Examine any baffles or supporting pillars which may be fitted, for security and buckling.

(d) Examine all internal fittings for security, damage, corrosion and contamination.

4.2.4 Any damage, lack of adhesion, or bubbles, which are likely to result in leakage, should be repaired, and a pressure test should be carried out before the tank is returned to service.

4.3 **Repairs.** The materials used for the repair of a particular tank, will depend on the materials used in its manufacture. Tanks may usually be identified by their overall colour, and by the markings placed on the outside by the manufacturer. These markings indicate the type of construction, thickness of materials used, and any other details relevant to the particular tank; this information is essential for the carrying out of a satisfactory repair in accordance with the Repair Manual.

4.3.1 All damage should be assessed to ensure that it is within the limits permitted for repair. If the damage is outside these limits, the tank should be returned to the manufacturer for overhaul.

4.3.2 There are two methods for repairing flexible tanks. One method involves the use of cold-curing cement and cured patches, sheet, or strips; the other involves the use of repair solution and uncured materials, which are subsequently vulcanised. The materials required, and the methods to be used for a particular repair, will be stated in the relevant Repair Manual. Atmospheric conditions are important to the satisfactory adhesion of the repair; the repair shop should be maintained at a temperature of 15°C to 27°C (60°F to 80°F), and at a humidity of approximately 50%.

4.3.3 A typical repair to a flexible tank, using cold-curing cement, may be carried out as follows.

NOTE: The types of materials to be used, the methods of mixing and applying the cement, and the drying times during repair, must be strictly in accordance with the manufacturer's instructions.

(a) Clean the tank with warm water or gasolene, as recommended by the manufacturer, and dry it thoroughly.

(b) Support the tank around the damaged area, and trim off any loose material. If the damage is in the form of a slit, a hole should be punched at each end to prevent it from elongating.

(c) Prepare patches of repair material. The interior patch should overlap the damage by 50 mm (2 in) all round, and the exterior patch should overlap the damage by 60 mm (2·5 in) all round. For some large repairs, an additional patch of reinforced material is required to cover both internal and external patches, and this additional patch should overlap the larger by 35 mm (1·5 in) all round. The edges of all patches should be skived or feathered.

(d) Roughen the under surface of the exterior patch and the exterior surface of the tank in an area slightly larger than the patch, using an abrasive wheel or fine emery cloth.

(e) Prepare the cement for use. Some cement is supplied in twin-pack form, and the entire contents of both containers must be mixed in order to provide the correct proportions. Once the cement has been mixed, its application life is limited to a few hours. The application life of single part cement is also limited, once the container is opened.

(f) Clean the roughened areas with a lint-free cloth moistened with solvent, and, when dry, apply a coat of cement to the roughened area of the tank and to the inner face of the patch. In some instances a number of coats of cement may be specified, and each coat should be allowed to dry before the next coat is applied.

(g) When the cement has become tacky, centre the patch over the damage and roll it down with a hand roller, taking care to exclude all air. If a hole has been cut in the tank skin, a sheet of cellophane may be placed inside the repair, in order to prevent the patch from sticking to the opposite side of the tank.

(h) Apply the internal patch and, where required, reinforcing patches, as described in (d), (e), (f) and (g).

(j) Paint over the patches with cement and, when this has dried, apply paint or varnish, as appropriate, to the exterior surface of the repair.

(k) The tank should be left for 24 hours before it is handled, and for 72 hours before pressure tests are carried out.

4.3.4 Minor damage affecting only the outer covering, such as chafing and blistering, should be repaired by cementing any loose material, applying a fabric patch over the area, and painting as required.

4.3.5 After repairs have been carried out, the tank should be pressure tested as described in paragraph 6.

4.3.6 When tanks which have been in use for some time are removed for inspection or repair, they tend to shrink slightly on drying out. This shrinkage could cause difficulties in re-fitting, and could cause the tank lining to be strained. Although refuelling the tank will restore it to its original size, some manufacturers treat the tank with a plasticizer during repair and overhaul. This treatment may also be applied by a person carrying out repairs, but it must be carefully controlled and applied strictly in accordance with the manufacturer's instructions. The tank must be treated with plasticizer after repairs and pressure tests have been carried out, and it must be installed and refuelled within eight hours of the treatment.

5 INTEGRAL TANKS Integral tanks are often formed by sealing the whole of the wing torque box during manufacture. Chordal diaphragms both divide the wing into a number of compartments, or tanks, and also prevent surge; external or internal pipes connect the tanks into the fuel system. A number of methods are used for sealing the structure, including the use of sealant as a faying compound between mating surfaces, and the use of a filleting compound at the edges. The interior of the tank is then further protected by tank coatings, which may be applied by slushing, brushing or spraying. Any or all of these methods may be used on a particular aircraft, and may be accompanied by special paint schemes, which are designed to minimise microbiological attack. A suitable number of large access panels, hand holes, and tank connections, are included in the structure at strategic positions; the covers are normally made fuel tight by using seals or sealant at the mating surfaces.

5.1 In some cases, corrosion inhibitor cartridges are fitted in integral tanks. Typically, these cartridges consist of strontium chromate or calcium chromate tablets contained in a linen bag. It is a requirement with such cartridges that the linen bag should be thoroughly wetted with water before installation, and after tank repair operations.

5.2 **Inspection.** At the periods specified in the approved Maintenance Schedule, the fuel tanks should be inspected for leaks, corrosion or damage to internal components, freedom of operation of non-return and anti-surge valves, and microbiological contamination. Particular attention should be paid to areas of stress concentration, and holes which have been formed in the spar webs or structure for the purpose of mounting booster pumps or other heavy components, to ensure that no cracks have developed.

5.2.1 To check for leakage, the tanks should be filled to maximum capacity, and a whitening solution (e.g. dye penetrant developer) should be applied over all joints, rivets, and bolts, which may be likely sources of leaks. After a soaking period (4 to 12 hours), the external surfaces should be inspected for drips, and for any staining of the developer. If leaks are found they should be marked with a soft crayon, and should subsequently be categorized and repaired, as necessary. The developer should be removed with a soft bristle brush, and the tank should be washed off.

5.2.2 Microbiological contamination is more easily visible when it is wet, and, when access is provided in the top skin, the tanks need only be drained sufficiently to permit removal of a suitable hand hole cover. The interior surfaces which are visible through the handhole, should be inspected, using a flame-proof torch, for signs of brown, slimy deposits. This inspection should be carried out, initially, on the tanks which have been found by experience to be the most critical (usually the inboard wing tanks), but, if contamination is found, the remaining tanks must be checked. Any contamination must be removed (see paragraph 8).

5.2.3 An examination for corrosion of internal metallic parts is best carried out when the tanks are empty, so that entry into the tanks may be effected. The safety precautions outlined in paragraph 7 must be observed, and particular care must be taken not to damage the tank sealant. In some large aircraft the tanks must be drained in a prescribed order, or the aircraft must be jacked when individual tanks are drained. The treatment of corrosion in aluminium structures, is described in Leaflet **BL/4-2.**

5.3 **Removal of Components.** It may be necessary to partially or fully drain a tank to remove a particular component, but some components, such as booster pumps, which require regular attention, are often enclosed within an isolation chamber to eliminate the need for draining. The isolation chamber may be provided with flap valves which, when open, provide free flow from the tank to the component. When it is necessary to remove the component, the chamber is sealed by turning an external screw, which closes the flap valves.

5.3.1 The joint faces of components are normally sealed with sealing rings or gaskets, and these should always be renewed when the components are replaced. The faces should be thoroughly cleaned with a dry, lint free cloth, before making the joint.

5.3.2 Where jointing compound or sealant is specified at joint faces, it should be applied sparingly, and should not be allowed to contact the sealing ring or bolt threads. If too much sealant is applied, it could form droplets at edges, and these may later become detached and cause malfunction of fuel system components.

5.3.3 Attachment bolts should be tightened progressively, and evenly, to the torque specified by the manufacturer.

5.4 **Repairs to Sealant.** Whenever a leak is found in a tank, either during a routine leak test (paragraph 5.2) or during normal service, it must be categorised, and, if necessary, repaired in accordance with the instructions detailed in the relevant Maintenance Manual. In some cases, special repair methods are necessary, because of the method of construction, but, generally, the procedures outlined in this paragraph will apply.

5.4.1 **Categorisation of Leaks.** A leak may be broadly classified as a stain, seep, or run. In general, a stain, where leakage merely results in the staining of a small area of skin, does not require repairing, but the area should be inspected regularly to check whether the rate of leakage has increased. A seep, which may be regarded as a leak which results in the spreading of the stained area, but does not produce drips of fuel, must be repaired at the next major inspection, or when the tank is opened up for any other reason; it should also be inspected frequently to check whether the leakage rate has increased. A run, in which fuel is dripping from the tank, must be repaired immediately, or, as a temporary measure, action should be taken to reduce the leakage rate to that of a stain or seep.

5.4.2 **Temporary Repairs.** Temporary repairs are usually permitted to enable an aircraft to be flown to a maintenance base, where permanent repairs may be carried out. A temporary repair usually consists of plugging the leak at the exterior skin joint, rivet or seam, then covering the plug with sealant and a fabric patch. Only those materials recommended by the manufacturer should be used.

5.4.3 **Location of Leak Source.** The position of an external leak may not correspond to the point at which the tank sealant has failed, and investigation may be necessary to trace the leak source. The position of the external leak should be marked with soft crayon, the tank should be defuelled by stages, and the fuel level at which leakage ceases should be noted. Any seams between this fuel level and a position on the inner tank wall corresponding to the position of the external leak should be carefully examined for signs of cracking or poor adhesion of the sealant. If no evidence of a faulty seal can be found, the tank should be completely drained; the suspect area on the inside of the tank should be degreased with a suitable solvent, and a non-corrosive soap solution should be applied. A jet of dry air at a pressure of approximately 35 kN/m² (5 lbf/in²) should then be applied to the position of the external leak, and the interior surface should be examined for the appearance of bubbles. The position of the leak source should be marked with a soft crayon, and all traces of soap solution should be washed off, using a water-dampened, lint-free cloth; the affected area should then be de-greased and dried.

NOTE: The use of air pressures in excess of the maximum permitted by the manufacturer could damage serviceable sealant and must be avoided.

5.4.4 **Permanent Repairs.** The adhesion of sealant to the inner surface of a tank depends on the cleanliness of the surface, and on the proper mixing and application of the sealant. Sealants are, generally, supplied in 'twin-pack' form, the quantities of sealant and accelerator being correct when the entire contents of each container are mixed. Once mixed, the compound must be used within a prescribed time, and must be 'tack-free' before a second coat is applied, and completely cured before the tank is refuelled. Application times, tack-free times, and curing times, vary between different products, and the recommendations of the particular manufacturer must be observed. In addition, sealants are normally subject to a shelf-life, and packages which have been in stock longer than this, must be discarded. Procedures for the repair of leaks in integral tanks may vary, but the following paragraphs describe a typical repair. Any variation from this method will be detailed in the relevant Maintenance Manual.

(a) The tank should be completely drained and ventilated, and the area to be repaired should be cleaned with solvent and thoroughly dried. The safety precautions detailed in paragraph 7 must be observed.

(b) The faulty fillet of sealant should be removed, and the fillet should be cut back to a position where adhesion is satisfactory. The edges of the fillet should be chamfered, and the exposed sealant and skin should be cleaned and dried.

NOTE: The tools used for cutting and removing sealant should be made from a material which will not damage the tank structural surfaces.

(c) In cases where leakage has occurred round rivets or bolts, these should be removed, and replacement items should be wet-assembled, using the specified sealing compound. It is usually recommended that the holes are drilled out, and oversize items fitted.

(d) Filleting sealant should be applied with a gun, and the fillet should be smoothed with a fairing tool. Care must be taken to prevent the inclusion of bubbles, and surplus sealant should be removed while it is still wet.

(e) When the filleting sealant has become tack-free, the primary sealant should be brushed on to the new section of fillet, and over any exposed rivet or bolt heads. A number of coats should be used to build up sealant to the original contour.

(f) Where applicable, two coats of top coat lacquer should be applied over the new sealant so as to overlap the original lacquer.

(g) Splashes of sealant or lacquer should be wiped off, and all debris should be removed.

(h) When the sealant has cured, the tank access covers should be replaced, the tank should be refuelled, and a check should be made for leakage as described in paragraph 5.2.1.

6 PRESSURE TESTS After repairs have been carried out on rigid and flexible tanks, a pressure test is usually specified to ensure that the leaks have been cured. Pressure testing of integral tanks is not normally required, but flow tests may be specified (Leaflet AL/3-17).

6.1 In order to apply pressure to a tank, leakproof blanks must be fitted to all apertures, and one blank must include a fitting suitable for the attachment of a dry air supply. A pressure gauge (normally a water manometer) should be fitted in the pressure line.

6.2 Rigid tanks may be pressure tested by filling with a few gallons of kerosene, and applying a mixture of whiting and methylated spirit to all seams, joints and other possible sources of leaks. When the mixture has dried, an air pressure of approximately 10 kN/m^2 (1·5 lbf/in^2) is applied to the inside of the tank, which is then rotated to distribute kerosene over the whole surface. Leaks will be indicated by staining of the whiting. After the test, the whiting should be washed off, the kerosene should be drained, and the tank, if not required for kerosene, should be flushed with the appropriate system fluid. As an alternative, the test described in paragraph 6.3.2, using dry air pressure and soap solution, may be used.

6.3 Flexible tanks may be pressure-tested in a number of ways; by the free test method, by the use of pressure rigs, or by a chemical method.

6.3.1 The free test method is similar to the test used for rigid tanks. The tank is filled with a few gallons of kerosene, and an air pressure of not more than 2 kN/m^2 (0·25 lbf/in^2) is applied in order to shape out the tank. The tank is then rotated in order to distribute the kerosene, and any leaks will be indicated by the presence of kerosene on the exterior surfaces.

6.3.2 The pressure rig method is carried out with the tank contained within a frame, which is designed to support the tank. The frame consists of a welded steel structure inlaid with a wide mesh screen, which permits inspection of all seams and fittings; each frame is designed for use with a particular tank. The tank is carefully located in the frame, and an air pressure of approximately 7 kN/m^2 (1 lbf/in^2) is applied to the tank. A soap solution is brushed over the tank skin, and if a leak is present, it will be indicated by the appearance of bubbles. After the test, the soap solution should be washed off, the tank should be drained, and, where necessary, the tank should be flushed with system fluid.

6.3.3 In the chemical method, a rag soaked in ammonia is inserted into the tank, which is then sealed and inflated to a pressure of 4 kN/m^2 (0·5 lbf/in^2). A large cloth is then soaked in an indicator solution containing 2·25 litres (0·5 gal) of water, 2·25 litres (0·5 gal) of ethyl alcohol and 40g of phenolphthalein crystals, wrung out, and spread over an area of the tank to be checked. Leaks will be indicated by the appearance of red spots on the cloth, and should be marked on the tank with a silver coloured pencil. The cloth should again be soaked in the indicator solution, and wrung out before checking a different area on the tank.

NOTE: Rubber gloves should be worn by all personnel involved in the handling of chemicals in this process.

7 SAFETY PRECAUTIONS Whenever it is necessary to enter a tank, in order to make an inspection, or to carry out repairs, certain precautions must be taken because of the flammability and toxicity of fuel and oil vapours. Defuelling and ventilating operations must be carried out in an open area, and no flame or spark producing equipment may be operated in the vicinity of such operations, or when fuel tank covers are open. Adequate and properly manned fire-fighting equipment must be provided, and suitable placards should be prominently displayed. The aircraft, and any ground equipment used, should be electrically earthed to a satisfactory earthing point.

7.1 After a tank has been defuelled and drained, it must be ventilated, by removing all access covers and circulating dry, filtered air, through the tank, until all fumes have been removed. The period of ventilation will vary according to ambient conditions, but must be continued until the tank walls are completely dry. Interconnecting feed and vent pipes must be blanked or isolated, in order to prevent any liquid or vapour in adjacent tanks, from contaminating the purged tank.

NOTE: Some manufacturers recommend the use of a combustible gas indicator to ensure that the tank is safe to enter, and where this is the case the readings which indicate an acceptable level of safety will be specified in the relevant Maintenance Manual. It should be noted, however, that these instruments may not be satisfactory with all types of fuels, and the manufacturer's recommendations, regarding their use, should be followed.

7.1.1 Battery cables should be removed and stowed, to prevent inadvertent sparking of electrical tank units.

7.1.2 Only spark-proof tools and explosion-proof torches may be taken into the tank, and only air-operated vacuum cleaners may be used for removing debris.

7.1.3 All tools required for a particular operation, should be cleaned and placed in a shallow open-topped box, so as to limit the movement of personnel through the access hole, and to minimize the possibility of the tank becoming contaminated with dirt and grit. A check list should be kept of all tools and equipment taken into the tank, and items should be checked off this list as they are removed, before the final inspection of the interior and the replacement of the tank covers.

7.1.4 The edges of holes through which entry is to be made, and the edges of passageways in internal formers, must be protected from damage, and protective mats must be placed on the bottom of the tank.

7.2 Personnel working in a tank must wear an air-fed respirator, and a supply of fresh air should be circulated through the tank. Protective clothing should be worn, and this should include canvas shoes, clean cotton overalls (which should be free from exposed metal buttons, buckles or fasteners), and clean cotton head covering. Goggles and rubber gloves should also be worn when solvents and sealants are to be handled.

7.2.1 Particular care must be taken when working inside water/methanol tanks, since methanol may be absorbed through the skin. For such work the protective clothing should cover the whole body.

7.2.2 A lifeline should be attached to a person who is working inside a tank, and a second person should be stationed outside the tank, to maintain contact with, and to be responsible for, the safety of the first person. Where there is an alternative access hole this should be opened, in case the person inside the tank should require assistance.

8 MICROBIOLOGICAL CONTAMINATION Microbiological contamination of fuel can cause inaccurate fuel contents indications, blockage of filters, and corrosion of aluminium alloy fuel tanks. This type of contamination does not normally occur in aviation gasoline, but is common in kerosene-type fuels. The contamination is usually in the form of a fungus (Cladosporium resinae), the spores of which are present in most kerosene-type fuels and are too small to be completely filtered out. In order to grow, these spores require a temperature of 25°C to 35°C (77°F to 95°F) and the presence of free water in the fuel. Temperatures favouring the growth of spores are quite often obtained in aircraft standing in strong sunlight or in heated hangars, and the water may result from condensation and precipitation, and may also be introduced during refuelling. Fungal growth commences at the boundary of a water droplet, and may eventually fill the water droplet, and release further spores into the fuel. Any imperfections or weak points in the tank coating will be penetrated by the fungus, and corrosion pitting or intergranular corrosion over a larger area may result. Fungal attack can also be a contributory cause of stress corrosion cracking. Careful monitoring of bulk fuel storage facilities, and regular inspections of the aircraft tanks, are necessary to guard against the effects of microbiological contamination.

8.1 Modern integral fuel tanks are designed to provide fuel flow across the bottom of the tank, and to minimize the risk of water collecting in stagnant areas. However, even with the best possible drainage, when water droplets have wetted a surface, they will often remain attached to it, and be held by surface tension. Upward facing surfaces are most likely to be affected, and the worst contamination is usually found at the lower inboard end of each tank, and below natural drip points, such as bolts and stringer runouts in the tank roof.

8.2 **Prevention.** The use of a fungicidal additive to the fuel is often recommended by aircraft manufacturers, particularly when the aircraft is operating in areas where fungus has been encountered, or where temperatures favouring its growth are likely to be experienced. There are two main types of additives, which may be used to sterilize the fuel tanks on a continuous or non-continuous basis.

8.2.1 **Ethylene Glycol Monomethyl Ether (EGME).** EGME is widely used as an anti-icing additive, and is also a biocide. It must be thoroughly mixed with the fuel before being introduced into the aircraft tanks; for this special injection equipment is normally necessary. EGME may be used as a biocide in a concentration of 0·15% by volume, and ideally, should be used on a continuous basis. EGME is not frequently used in civil aircraft, because of the difficulties in mixing, and the fact that it cannot be air freighted in large quantities.

8.2.2 **Biobor.** Biobor may be used as a biocide, on a continuous basis at a maximum concentration of 135 parts per million (ppm), or on a non-continuous basis (e.g. once every two months) at a maximum concentration of 270 ppm. Biobor mixes easily with fuel, and may be pre-mixed in storage, mixed in the refuelling vehicle, or poured directly into the aircraft tanks. For non-continuous use, sufficient treated fuel should be introduced into each tank to cover likely areas of contamination (approximately $\frac{1}{8}$ of tank capacity), and should be left as long as possible (ideally 3 or 4 days) to achieve maximum effect. It is important that this fuel is diluted before being burned in the engines, and the manufacturer's instructions regarding the running of engines on fuel treated with Biobor should be carefully followed. It is usually recommended that the fuel filters are checked at frequent intervals after biocidal treatment, to prevent contamination from microbiological debris.

8.3 Fungal growth is more easily discernible in a tank which contains fuel, and will generally appear as patches of a brown slimy deposit on upward-facing surfaces. Corrosion resulting from fungal attack, although not often visible, may appear as white spots through the fungus. Fungus may be difficult to see on a background of sealant, but will be easily visible on light-coloured coatings; it will usually be concentrated at the lowest point in a tank.

8.3.1 The inspection should be made through a suitable access hole, using a flame-proof torch. If the fuel vapour concentration is high, an air-fed respirator should be worn.

8.4 **Fungus Removal.** If any fungus is found in a tank its position should be noted, and it should be removed as soon as possible. The decontamination process may vary between different aircraft manufacturers, but will normally follow the procedures outlined in (a) to (e).

(a) Drain out and isolate all fuel, and ventilate the tank to permit entry. Some manufacturers may recommend the removal of booster pumps, contents units and other equipment, to avoid damage, to allow better access, and to facilitate inspection.

(b) Wash the tank with detergent and water, using a bristle brush to aid the removal of fungus.

(c) Thoroughly rinse the tank with clean water to remove the detergent, using a hose fitted with a spray nozzle.

(d) Apply a biocidal rinse to the tank to kill any remaining spores. This rinse is usually either 5% chromic acid or 50% methanol in water, and is left in the tank for a short period.

(e) Thoroughly flush out the tank with clean water to remove the rinse, mop up any pools, and dry it with warm air.

NOTE: Protective clothing and goggles must be worn by personnel mixing or applying the biocidal rinse (see also paragraph 7). A spray should not be used to apply the solution, since splashes may be harmful to unprotected personnel.

8.5 **Corrosion Removal.** After the fungus has been removed, the tanks should be carefully inspected for corrosion and damaged sealant, particularly in those areas where fungus was found. It will usually be necessary to remove sealant and protective coatings from these areas in order to investigate the extent of the corrosion. All visible corrosion should be removed by mechanical methods (Leaflet **BL/4-2**), leaving a smooth, shallow depression, and the affected area should be inspected for cracks, using a penetrant dye process. If the reduction in skin thickness resulting from corrosion removal is within the limits laid down by the manufacturer, the protective coating should be re-applied, and any areas from which sealant was removed should be re-treated (see paragraph 5.4.4). Frequent checks should subsequently be carried out, to ensure that all corrosion has been eliminated. If the reduction in skin thickness is outside the acceptable limits, an approved repair scheme must be carried out.

8.5.1 After repairs have been carried out, all debris should be removed with a vacuum cleaner, and the tank should be thoroughly cleaned before the pumps, any other components which have been removed, and the tank access panels are replaced. Filters should be checked for debris after initial engine runs, and at frequent intervals thereafter.

9 STORAGE Rigid and flexible tanks should be retained in their original packing until they are required for use, and they should be re-packed in a similar manner after removal from the aircraft for transportation or storage.

9.1 **Rigid Tanks.** Rigid tanks are normally inhibited prior to storage; all openings are sealed, and the external surface is sprayed with a strippable lacquer. The tanks are then secured to a suitably shaped, padded cradle, and installed in a crate to prevent physical damage. During storage, these tanks should be inspected occasionally for signs of corrosion on the external surface.

9.2 **Flexible Tanks.** Flexible tanks made from rubber should normally be stored in a cool, dry place, at a temperature of not more than 15°C. Different temperatures may be recommended by the manufacturers for tanks made from plastics materials.

9.2.1 A fully flexible tank should be carefully folded, with identification marks on the outside, and corrugated cardboard should be placed between the folds to prevent chafing. The tank should then be sealed inside a strong polythene bag, and placed in a cardboard carton or crate of suitable size.

9.2.2 A flexible tank containing rigid formers or fragile contents units may be transported or held in short-term storage in an air-inflated condition. Air inflation is not suitable for long-term storage however, and attachment loops are usually fitted to the tank, adjacent to internal fittings, so that the tank can be securely located in a crate, in its normal shape.

9.2.3 Tanks which have a heavy protective coating are essentially self-supporting, and, for storage purposes, generally only require to have their openings sealed and to be contained within a carton or crate.

9.2.4 Rubber tanks should be checked to confirm any shelf life storage limitations.

9.3 **Integral Tanks.** Normal storage requirements do not generally apply to these tanks, but if an aircraft is out of service for a long period, a small quantity of fuel (usually 10% of tank volume) should be retained in the tanks, so as to prevent drying out and deterioration of the sealant. This fuel should be treated with biocide to discourage fungal contamination.

AL/3-17

Issue 1.

14*th November*, 1975.

AIRCRAFT

SYSTEMS AND EQUIPMENT

FUEL SYSTEMS

1 INTRODUCTION This Leaflet gives general guidance on the operation, installation and maintenance of fuel systems in aircraft. Since there are considerable differences between the fuel systems fitted to different types of aircraft, this Leaflet should be read in conjunction with the Maintenance Manual and Maintenance Schedule for the aircraft concerned.

NOTE: This Leaflet contains the relevant information previously published in Leaflet **PPL/2-1,** Issue 3, dated 15th December 1965.

1.1 The following Leaflets contain information on related subjects, and should be referred to as appropriate:—

AL/3-13 Flexible Pipes

AL/3-14 Installation of Rigid Pipes in Aircraft

AL/3-15 Tanks

AL/10-3 Engine Instruments

EEL/1-6 Bonding and Circuit Testing

2 FUELS There are two main types of fuel used in aircraft, aviation gasolene, which is used in piston engines, and aviation kerosene, which is used in turbo-jet and turbo-propeller engines. It is most important that the correct type and grade of fuel, as indicated in the appropriate Maintenance Manual, should be used.

2.1 **Gasolene.** Aviation gasolene (AVGAS) is the lighter of the two fuels, having a relative density of approximately 0·72. The only grade of AVGAS generally available is grade 100L, which has an octane rating of 100 and a low lead content. Where different grades of fuel were previously specified for use in a particular engine, the use of AVGAS 100L may necessitate additional checks and maintenance to be carried out. Automobile fuel must not be used instead of non-leaded aviation fuel (Airworthiness Notice No. 70 refers).

2.1.1 Gasolene has powerful solvent properties, and it is essential that it does not come into contact with certain components such as transparent panels and tyres. Personal contact may also result in skin infections, and it should be noted that some of the additives used in gasolene are poisonous.

2.2 **Kerosene.** The fuel generally used in civil turbo-jet and turbo-propeller engines is known as AVTUR (Specification D Eng. RD 2494). It has a relative density of approximately 0·8, a high flash point, and does not give off easily-ignitable vapours at normal ground temperatures. In many instances the use of AVTAG (Specification D Eng. RD 2486) is permitted in civil aircraft, but this fuel is lighter, and has a lower flash point; the 'wide-cut' formula for this fuel includes gasolene, and it should, consequently, be treated as highly flammable.

2.3 **Fuel Quality Control.** The quality of the fuel delivered to an aircraft must be carefully controlled. Engines will operate satisfactorily when a small amount of water and dirt are present in the fuel, but the quantities must be strictly limited.

2.3.1 Bulk storage tanks should frequently be checked for contamination. Fuel is usually drawn from these tanks through a floating suction, which ensures that the contents of the lower part of the tank, where contaminants may have collected, are not drawn off.

2.3.2 After a refuelling vehicle has been filled from a storage tank, it should be left to stand for at least ten minutes, then approximately one gallon of fuel should be drawn from the sump in order to check its quality. If sediment is found, further samples should be taken, until the result is satisfactory. Suspended water in kerosene will give the fuel a cloudy appearance, and free water may often be readily visible, but in any case, a chemical water detection method should be used. If water is found, the vehicle should be driven a short distance, left to stand for a further period, and another sample taken. This process may be repeated until a clean sample is obtained. During normal use, fuel samples should be taken daily. The refueller delivery line should contain a 5 micron filter, and all equipment should be kept scrupulously clean. Nozzle caps should be removed immediately prior to refuelling, and replaced immediately after refuelling.

2.3.3 Hydrant installations are often used for direct refuelling of aircraft, and the associated tanks are generally fitted with a floating suction and a water separator. Samples should be taken from the storage tank sumps, pipelines and dispenser unit daily, and should be checked for water, sediment, and other contamination.

2.3.4 If signs of microbiological contamination are found in a sample, the storage tank should be checked for contamination. Contaminated tanks must be cleaned before being used to refuel aircraft. Leaflet **AL/3-15** describes the causes of microbiological contamination, its effect on aircraft fuel tanks, and the precautions which can be taken.

3 GENERAL A simple fuel system may consist of a gravity feed tank, a filter, a shut-off valve, and suitable rigid and flexible pipes between these components and the engine. The tank would be vented to atmosphere, and a means of indicating the fuel quantity, would be provided. This type of system is adequate for a single piston-engined, high wing aeroplane, and is often used. However, larger, multi-engined aircraft, particularly those fitted with turbo-propeller or turbo-jet engines, require a more sophisticated system, with facilities to enable transfer of fuel, electronic control of refuelling and defuelling, and controls and indicators for many functions not necessary in a simple system.

4 FUEL SYSTEMS FOR SMALL AIRCRAFT Figure 1 illustrates a simple fuel system such as may be used on a modern light aircraft. A rigid aluminium alloy tank, or a flexible tank, is housed in each wing, and feeds fuel to a selector valve, the control for which is located in the cabin. From this point fuel is fed through a filter and booster pump to the engine carburettor.

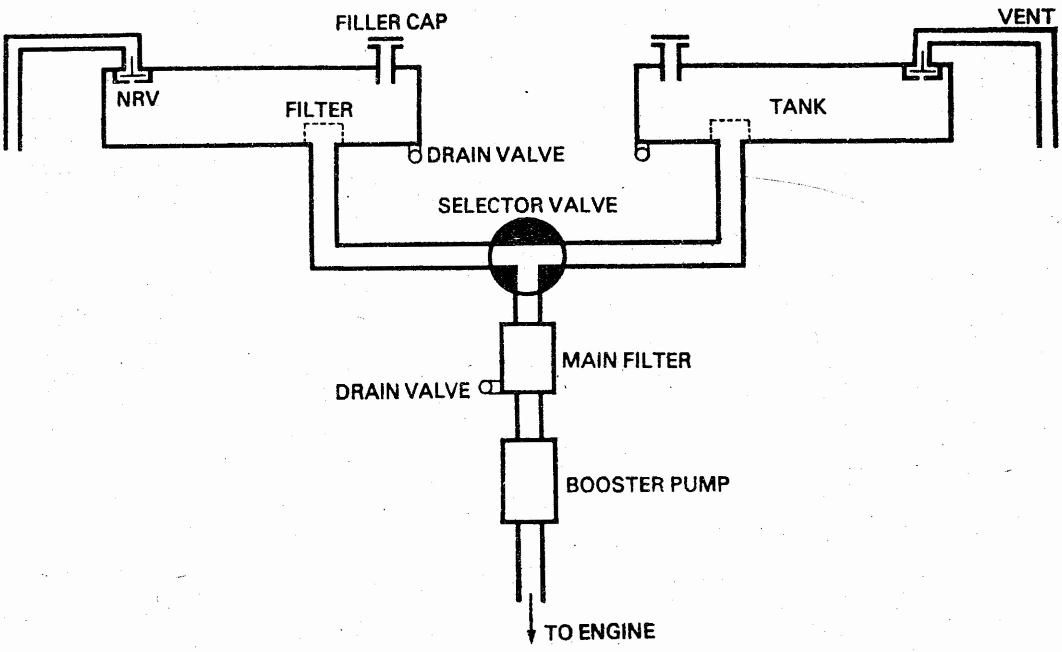


Figure 1 SIMPLE FUEL SYSTEM

4.1 Each fuel tank is fitted with a vent pipe, which has its open end outside the wing structure, in order to ensure that atmospheric pressure is maintained in the tank. A non-return valve (NRV) in the tank prevents fuel from syphoning through the vent pipe, and a bleed hole in the NRV prevents the build-up of pressure as a result of fuel expansion, when the NRV is closed. Coarse mesh filters are generally fitted at the filler openings, and at the outlet pipes, in order to prevent large objects from passing into the system. A drain valve, fitted to the lowest point in each tank, is used to drain off fuel and any water which may have collected through condensation, or have been introduced during refuelling. The fuel tanks of light aircraft should be filled as soon as possible after a flight, to minimize condensation; a small quantity of liquid should be drained off through the tank and main filter drain valves before flight, in order to remove any water which may have accumulated. Tanks are fitted with a contents gauge, which may be a float operated mechanical unit, a float operated electrical unit, or an electrical capacitance type unit (see Leaflet **AL/10-3**).

4.2 The selector valve enables the engine to be fed from individual tanks, or both tanks together, and an OFF position is also usually provided to enable the supply to be turned off. This latter position is particularly important with those high wing aeroplanes which have engines fitted with float chamber carburettors, since a small leak past the float valve could result in complete loss of fuel when the aircraft is parked; it is also essential to be able to turn off the fuel supply in the event of an engine fire. Selector valves are usually rotary valves, and the operating lever may be mounted directly on the valve, or located remote from the valve and connected to it by mechanical linkage. In either case it is important that the operating lever is accurately aligned with the valve, and represents the true position of the valve at all selected positions; a detent at each position assists proper selection.

4.2.1 In some systems an additional valve may be fitted in the fuel feed line, to isolate the tanks for maintenance purposes. This valve will usually be wire locked to the ON position for normal operations.

4.3 The main fuel filter is usually fitted to the lowest point in the system, so that water and sediment, being heavier than fuel, will collect at this point. The filter is designed to remove both water and dirt from the fuel by trapping them in the sediment bowl. The sediment bowl is attached to the body of the filter by a quick-release fitting, thus assisting easy removal for cleaning and examination of the filter element.

4.4 The booster pump is electrically operated, by direct current, and is fitted to ensure a positive fuel supply to the engine for starting, take-off, climb, high altitude, flight through turbulence, and landing, and to safeguard the engine in the event of engine-driven pump failure. Pumps are usually of the centrifugal type, and are sometimes fitted with two speed controls, the higher speed being used for emergency operation. Pumps are often mounted in the bottom of the fuel tanks, but in some cases are located in the fuel lines as illustrated in Figure 1.

4.4.1 Seals are fitted between the pump and its motor to prevent fuel and vapour from leaking into the motor. However, any slight leakage which does occur is drained overboard, and some motors are vented by passing air through the casing.

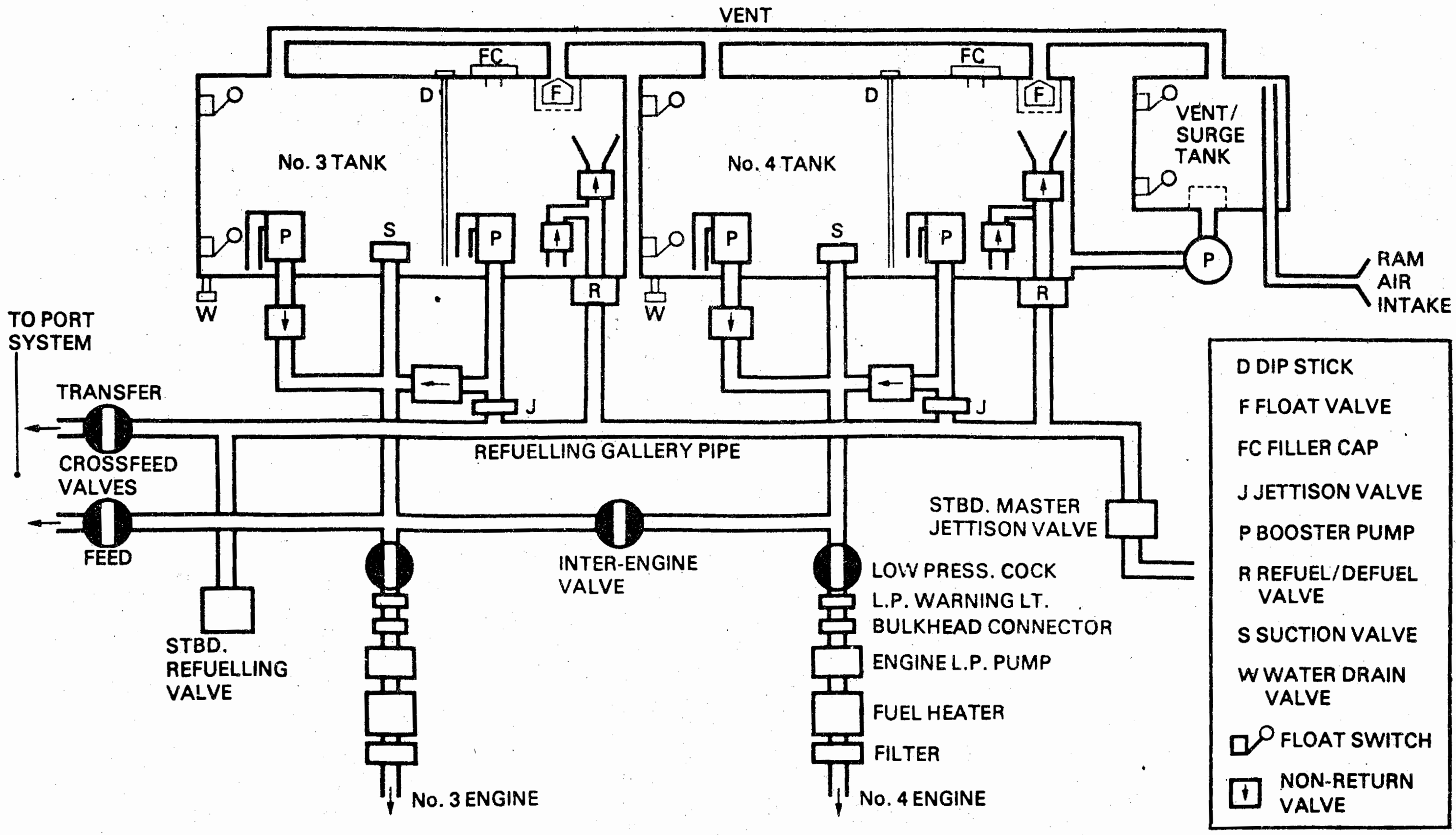
4.4.2 Different types of pumps are used in some instances, but the inherent advantages of centrifugal pumps, are that they separate fuel and vapour, thus providing a vapour-free fuel supply, and they do not require pressure relief or by-pass valves.

4.5 Pipelines aft of the firewall in light aircraft fuel systems are generally made from aluminium alloy, and are joined by standard aircraft couplings; because of the modest fuel requirements of small piston engines, the pipelines are seldom larger than 25 mm (1 in) diameter. Fuel pipelines in British aircraft (except those inside the tanks) are labelled, for recognition purposes, in accordance with British Standard M23. The marking consists of an adhesive label wrapped around the pipe at intervals, with the word FUEL in black, on a red background, and a symbol in the form of a black four-pointed star on a white background. In addition, the word FLAM (flammable) and the purpose of the pipe (e.g. VENT) may be added.

4.6 Fuel tanks are marked, adjacent to the filling point, with the type of fuel required and the usable tank capacity. The filling points of other systems are also marked, in order to prevent a system from being filled with the incorrect fluid.

5 FUEL SYSTEMS FOR MULTI-ENGINED AIRCRAFT A fuel system for a typical multi-engined aircraft is illustrated in Figure 2. The basic requirements for the system are the same as those described in paragraph 4, but the multiplicity of engines necessitates additional tanks, piping, valves and pumps. In addition, different venting and refuelling systems are necessary, and additional functions such as fuel jettisoning, fuel heating, cross-feeding, and instrumentation have to be provided for.

5.1 **Fuel Feed.** In modern turbine-powered aircraft, the fuel is usually contained in a number of integral tanks (Leaflet **AL/3-15**), in the wings and centre section, and, occasionally, in the fin. Individual engines are usually fed from an associated tank, or group of tanks, but cross-feed and inter-engine valves may be provided to enable the engines to be fed from any desired group of tanks, and also to permit fuel transfer between tanks. Fuel supplies for auxiliary power-units and combustion heaters, where fitted, are normally taken direct from a suitable tank or from a feed line.



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FEED
REFUELLING GALLERY PIPE
STBD. MASTER
JETTISON VALVE
STBD.
REFUELLING
VALVE
INTER-ENGINE
VALVE
LOW PRESS. COCK
L.P. WARNING LT.
BULKHEAD CONNECTOR
ENGINE L.P. PUMP
FUEL HEATER
FILTER
No. 3 ENGINE
No. 4 ENGINE
D DIP STICK
F FLOAT VALVE
FC FILLER CAP
J JETTISON VALVE
P BOOSTER PUMP
R REFUEL/DEFUEL
VALVE
S SUCTION VALVE
W WATER DRAIN
VALVE
FLOAT SWITCH
NON-RETURN
VALVE

5.1.1 **Pumps.** In the fuel system illustrated in Figure 2, two booster pumps are fitted in each tank. These pumps are designed for continuous operation, and either pump can supply the needs of any one engine. In the event of failure of both pumps in a tank, fuel is drawn from that tank by the associated engine-driven, low-pressure pump, via the suction valve, but in some cases this may be inadequate to provide full engine power at high altitude, and operating limitations may be imposed. The booster pumps are electrically operated, but, unlike the pumps fitted to light aircraft, may be operated by alternating current. They vary considerably in design, but are usually powered by induction motors, and may include a two stage impeller. In some instances the motor is of the flooded type, in which the motor runs submerged in fuel, thus obviating the need for seals. Overheat protectors are usually fitted, which cut off power to the motor when the pump temperature rises above a predetermined value. Pumps are often fitted in isolation chambers within the fuel tank, which enables them to be removed and re-fitted without draining the tank.

5.1.2 **Valves.** Low-pressure valves, cross feed valves and inter-engine valves, are usually ball-type, full-flow valves, and may be either mechanically or electrically operated. A typical valve is illustrated in Figure 3; in this type a form of pressure relief is provided, to bleed off excess pressure which may occur, through variations of temperature downstream of the valve, when the valve is closed. This is a two position valve only, and either internal or external mechanical stops are provided, to limit movement to 90°; a visual indication of valve position is also provided. When the valve is electrically operated, a reversible electric motor, equipped with an electro-magnetic brake, is mounted on the valve casing, and drives the valve through a gear train. Limit switches cut off power to the motor at the fully-open and fully-closed positions, and the brake operates automatically as the motor is de-energised; the brake is magnetically released when a reverse selection is made. The limit switches may also be used to operate position indication lights or magnetic indicators in the crew compartment.

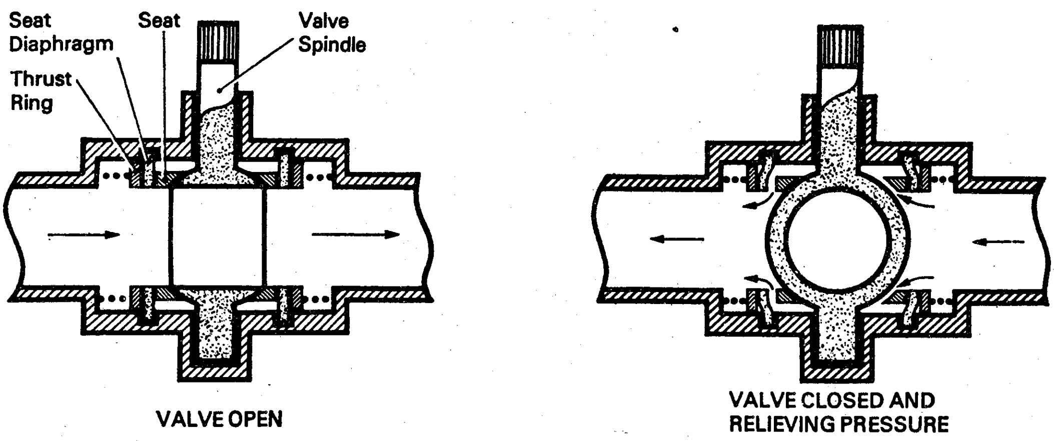

Figure 3 BALL-TYPE VALVE

5.1.3 Suction valves are fitted to enable fuel to be drawn from the tanks by the engine-driven pumps; they are closed when booster pumps are operating normally. A suction valve is illustrated in Figure 4; it is a simple flap type valve, which closes when a pressure exists in the pipeline, and opens when suction is applied to the pipeline.

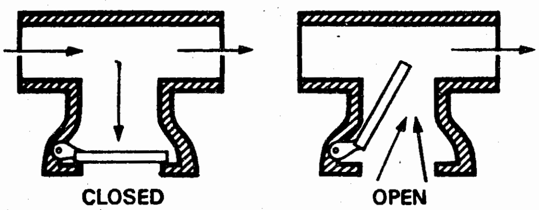

Figure 4 SUCTION VALVE

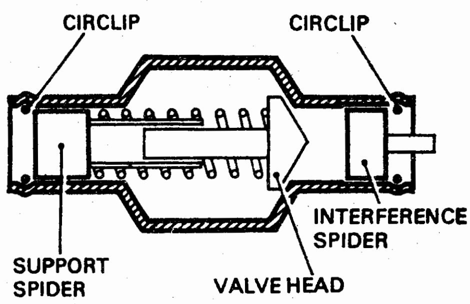

Figure 5 NON-RETURN VALVE

5.1.4 Non-return valves may be fitted in several places in the fuel system, to provide flow in one direction only. A typical non-return valve is illustrated in Figure 5. The casing is marked with an arrow to show the direction of flow, and, in the valve illustrated, an interference spider is fitted to the inlet side, in order to prevent the valve from being fitted the wrong way round.

5.2 **Venting.** The tank venting system provides positive venting of the tanks during flight. A ram air intake maintains a slight positive pressure in the vent system, thus decreasing fuel vaporization, and preventing negative pressures in the tanks through changes in aircraft attitude and fuel usage. In some aircraft, the vent system also prevents the building up of dangerous pressures in the tanks during refuelling, should the automatic cut-off fail, by dumping excess fuel. Generally, there are two vent pipes in each tank, the inboard vent is open-ended, but the outboard vent is fitted with a float valve, the purpose of which is to minimize fuel transfer both between tanks and into the vent/surge tank during changes of aircraft attitude. Fuel which is spilled into the venting system, collects in the vent/surge tank. On some aircraft the vent/surge tank drains under gravity into the main tanks, but on other aircraft an automatic pumping system is used. The pumping system may operate on a continuous basis, using 'jet' pumps, or on an intermittent basis using float switches and a separate electrically-operated pump. In a jet pump, output from a normal booster pump passes through a jet nozzle, which is contained within a concentric pipe leading from the vent/surge tank. The flow of fuel through the jet nozzle automatically draws fuel from the vent/surge tank. With an intermittent system, a high-level float switch switches the transfer pump on, thus transferring fuel from the vent/surge tank to a main tank, and a low-level float switches the transfer pump off. A time-delay may be incorporated in the pump circuit, to prevent intermittent operation as a result of fuel surge.

5.2.1 Vent valves are generally either a caged cylindrical float which itself acts as a valve to close the vent, or a simple lever-type flap valve; typical examples are shown in Figure 6.

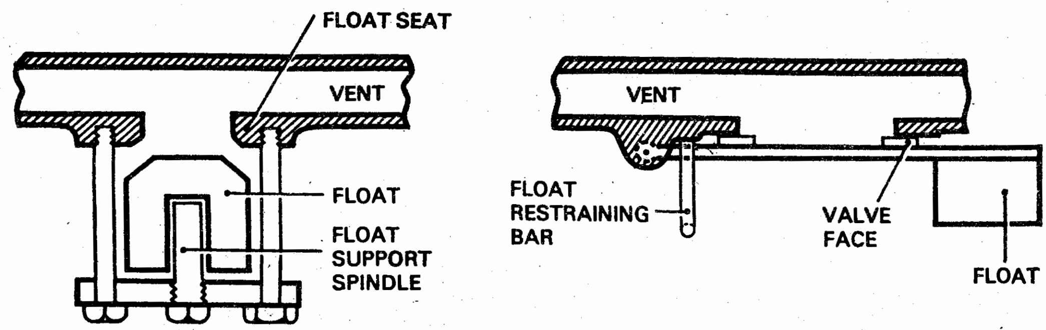

Figure 6 VENT VALVES

5.2.2 Float-operated switches are often of a magnetic type, similar to the one shown in Figure 7, and are designed to isolate the electrical mechanism from the fuel tank, for safety reasons. Upward movement of the float brings the armature closer to the magnet, and, at a pre-determined fuel level, it has sufficient influence to attract the magnet, which results in operation of the micro-switch. As the fuel level and the float fall, the attraction of the armature is eventually overcome by the combined forces of the counterweight and the micro-switch spring, and the counterweight falls, changing the micro-switch circuit.

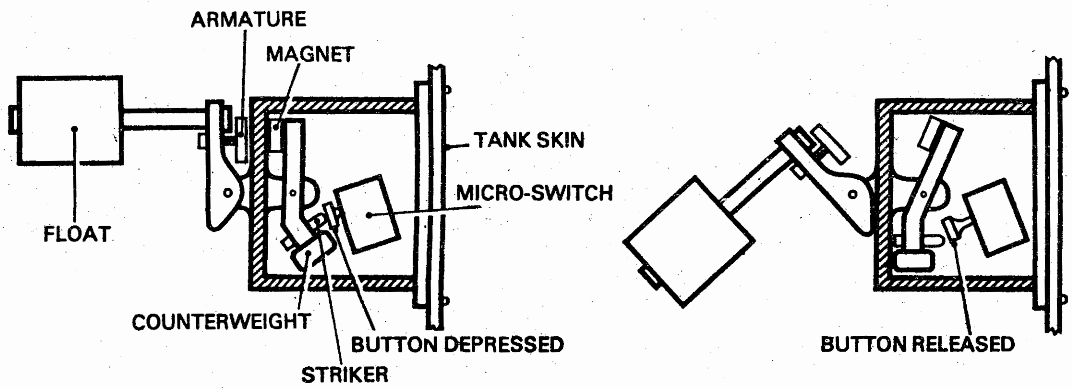

Figure 7 FLOAT SWITCH

5.3 Compartments in which rigid or flexible tanks are contained, and bays or conduits through which fuel system pipes pass, are usually ventilated and drained to prevent the build-up of vapour pressure, and to release condensation or fuel which may have leaked into them. These regions are invariably sealed to prevent vapour leakage into crew and passenger compartments, and pressure tests are normally required at specified intervals, and after repairs have been carried out or components have been replaced.

5.4 **Refuelling/Defuelling.** Light aircraft fuel tanks are usually filled through over-wing filler caps, and drained by means of suitable cocks or plugs in the tanks or pipelines. These features are often retained on large transport aircraft for emergency refuelling and for draining individual tanks, but as these methods are very slow, refuelling and defuelling are normally carried out through pressure refuelling connections situated in the lower wing or fuselage surfaces. Using a tanker or hydrant, and delivery pressures of up to 350 kN/m² (50 lbf/in²), refuelling rates of up to 1,000 gal/min (4500 litres/min) may be achieved; defuelling is carried out using the same system, but suction is then applied to the pressure connections. The system includes the pressure connections, individual refuel/defuel valves for each tank, a load control panel, and suitable pipelines and tank valves as illustrated in Figure 2. In systems fitted with electrically-operated refuel/defuel valves, the refuel/defuel valves are opened by selector switches on the load control panel, but may be closed by these switches, by the float switches in the tanks when the tanks are full, or by electronic controls on the load control panel when complete refuelling is not required. In systems fitted with mechanically-operated refuel/defuel valves, the valves are opened manually, and closed either manually, or by means of pressure operated valves in the tanks. The refuelling discharge pipes in the tanks are usually fitted with a diffuser, the purpose of which is both to prevent any erosion of, or damage to, the sealant, which may result from a high pressure jet, and also to prevent static discharge within the tank.

NOTE: Refuelling points should be marked with the type of fuel to be used, and overwing filling points should also be marked with the capacity of each tank. Similarly, refuelling/defuelling containers and storage vehicles should be identified as to the type of fuel they contain.

5.4.1 A typical load control panel, suitable for the system illustrated in Figure 2, is shown in Figure 8; it is in the form of a 'mimic' diagram of the relevant parts of the fuel system, and includes a master switch, automatic/manual selector switch, switches for each refuel/defuel valve, a function (refuel/defuel) switch, contents indicators for each tank, and magnetic indicators to show the position of each refuel/defuel valve.

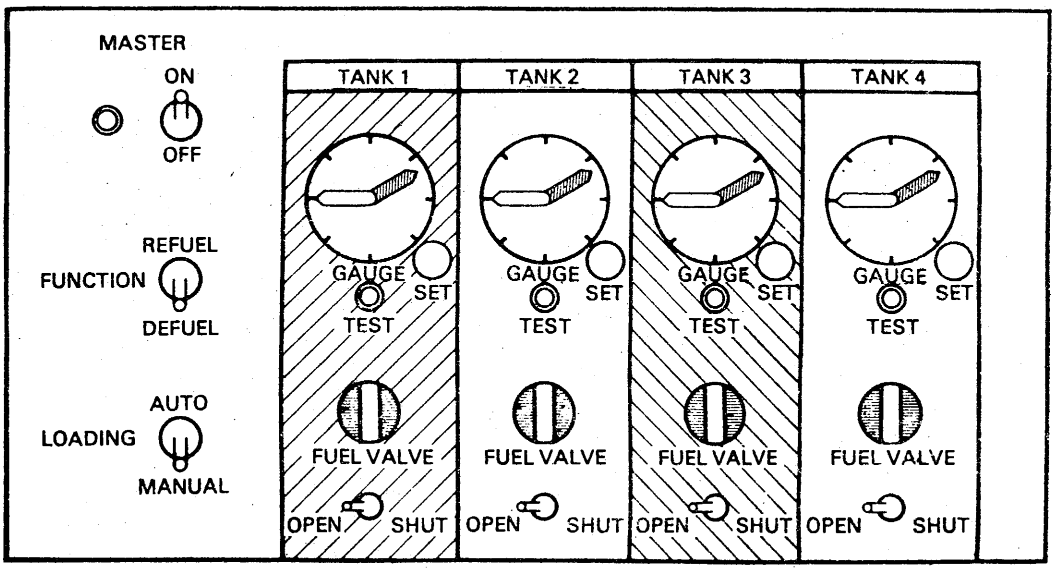

Figure 8 LOAD CONTROL PANEL

5.4.2 A typical refuel/defuel valve is illustrated in Figure 9; it is actuated by either of two solenoids, one for refuelling and one for defuelling. When the refuel solenoid is energised, the associated plunger opens the passage from the inner cylinder to the exhaust port, and fuel pressure at the refuelling inlet opens the valve. When this solenoid is de-energised, the passage is closed, and pressure builds up on the inner face of the piston; the area of the piston is greater than that of the valve, so the valve closes. When the defuel solenoid is energised the inner cylinder is open, via the by-pass duct, to the refuelling inlet side of the valve, and suction applied to this side of the valve will create a pressure differential across the piston, moving the piston inwards and opening the valve. When the defuel solenoid is de-energised, the by-pass is closed, and fuel enters the inner cylinder by leakage past the piston; pressure builds up on the inner face of the piston and this pressure, assisted by the spring, closes the valve. Any pressure which builds up in the refuelling inlet line when the valve is closed, is relieved via the non-return valve and spring-loaded refuel solenoid plunger, to the tank.

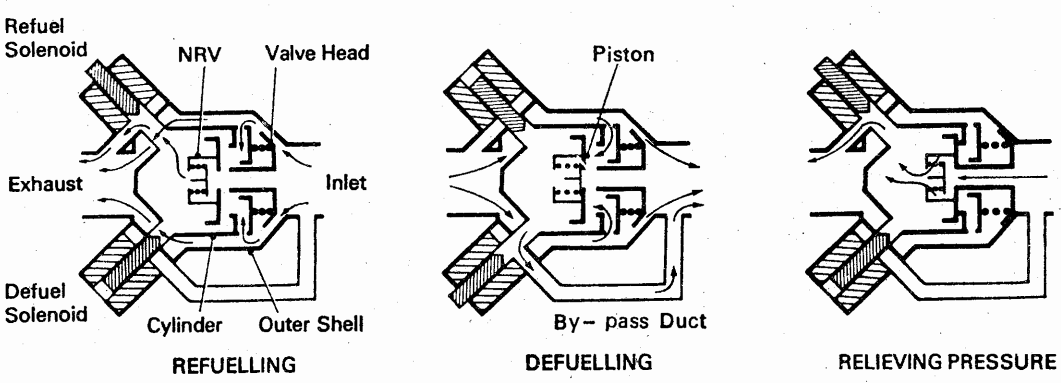

Figure 9 REFUEL/DEFUEL VALVE

5.4.3 The fuel contents gauges on the load control panel are dual pointer instruments. One pointer indicates actual tank contents, and the other pointer is used for pre-selecting the required quantity, whether refuelling or defuelling (automatic load control system). The pre-selector mechanism includes two micro-switches, one connected to the refuel solenoid of the refuel/defuel valve and the other connected to the defuel solenoid of the refuel/defuel valve. Pre-selection of a quantity greater than the actual tank contents will operate the micro-switch controlling the refuel solenoid, and pre-selection of a quantity smaller than the actual tank contents will operate the micro-switch controlling the defuel solenoid. When the pre-selected fuel quantity is obtained, the appropriate micro-switch circuit is broken and the refuel/defuel valve closes.

5.4.4 When refuelling using the automatic load control system, the master switch is selected 'on', the function switch to 'refuel', and the loading switch to 'auto'. The contents indicator pre-selector pointers are set to the amount of fuel required in each tank, and the refuel/defuel valve selector switches moved to 'open'. The circuits to the refuel/defuel valves are now complete, and the valves open as pressure is applied. When the quantity of fuel pre-selected for a particular tank has been uplifted, the pointers on that indicator coincide, the appropriate micro-switch circuit is broken, and the associated refuel/defuel valve closes.

5.4.5 Manual refuelling is carried out by selecting 'on', 'refuel', and 'manual' on the appropriate switches, and filling the tanks individually by use of the refuel/defuel valve selector switches; the appropriate selector switch should be tripped as each tank contents indicator pointer reaches the fuel quantity required.

5.4.6 Defuelling is carried out in a manner similar to that described in paragraphs 5.4.4 and 5.4.5 for refuelling, except that the function switch is selected to 'defuel'. The system functions in the same way as for refuelling, the refuel/defuel valves being tripped either by the indicator micro-switch, or by the selector switches, when the excess fuel has been off-loaded.

5.5 **Fuel Jettisoning.** Many transport aircraft are equipped with a means of jettisoning excess fuel in an emergency. Fuel is pumped or drained from each tank through a stand pipe, which ensures that a pre-determined quantity of fuel remains. One type of system makes use of the refuelling gallery pipe, which is extended outboard to a position near each wing tip, and terminates in a large diameter open-ended pipe at each trailing edge. One of the booster pumps in each tank, which may be run at a higher speed for the jettisoning operation, is used to off-load the fuel, and the fuel feed to the engines is protected by non-return valves. Individual jettison valves are located at selected tank outlets, and a master jettison valve is located adjacent to each discharge nozzle; this type of system is illustrated in Figure 2. In another type of system, fuel is jettisoned through a pipe in each wing, the pipe being lowered into the airstream by an electrically-operated actuator. A short manifold is fitted between the main tanks in each wing, and a jettison valve controls flow from each tank into the manifold; auxiliary tanks are fed into the main tanks by the normal transfer valves, the transfer pumps being inter-connected with the circuits operating the jettison valves. When the jettison pipe is in the retracted position it forms a seal at the manifold, and acts as a master jettison valve; the circuits to the jettison valves are not armed until this pipe is locked in the extended position. Both types of systems are controlled from a special panel at the crew station, which contains switches for the pumps and valves, and warning lamps or magnetic indicators to show the positions of the valves and the jettison pipes.

5.6 **Controls and Indicators.** All controls and indicators for the main fuel system, are grouped together on a fuel control panel in the crew compartment. To simplify control and management of the system, the various components are arranged in the form of a mimic diagram as in Figure 10 which shows a fuel control panel suitable for use with the system illustrated in Figure 2. The operation, installation and maintenance of the instruments shown in Figure 10 are described in Leaflet **AL/10-3,** and reference should also be made to the appropriate Maintenance Manual for details of the particular installation. In addition to the fuel quantity gauges fitted to the fuel control panel and load control panel, most large aircraft are also provided with a means of physically checking the quantity of fuel in each tank, during maintenance. For the methods described below, the aircraft must be levelled both laterally and longitudinally to obtain accurate readings.

5.6.1 A 'dip stick' is a rod with a screwed fitting at the top, which screws into a mating fitting in the top skin of the tank. It protrudes into the tank and is calibrated to indicate the contents of the tank between certain limits. When unscrewed, the fuel level is indicated by the limit of fuel-wetting on the rod.

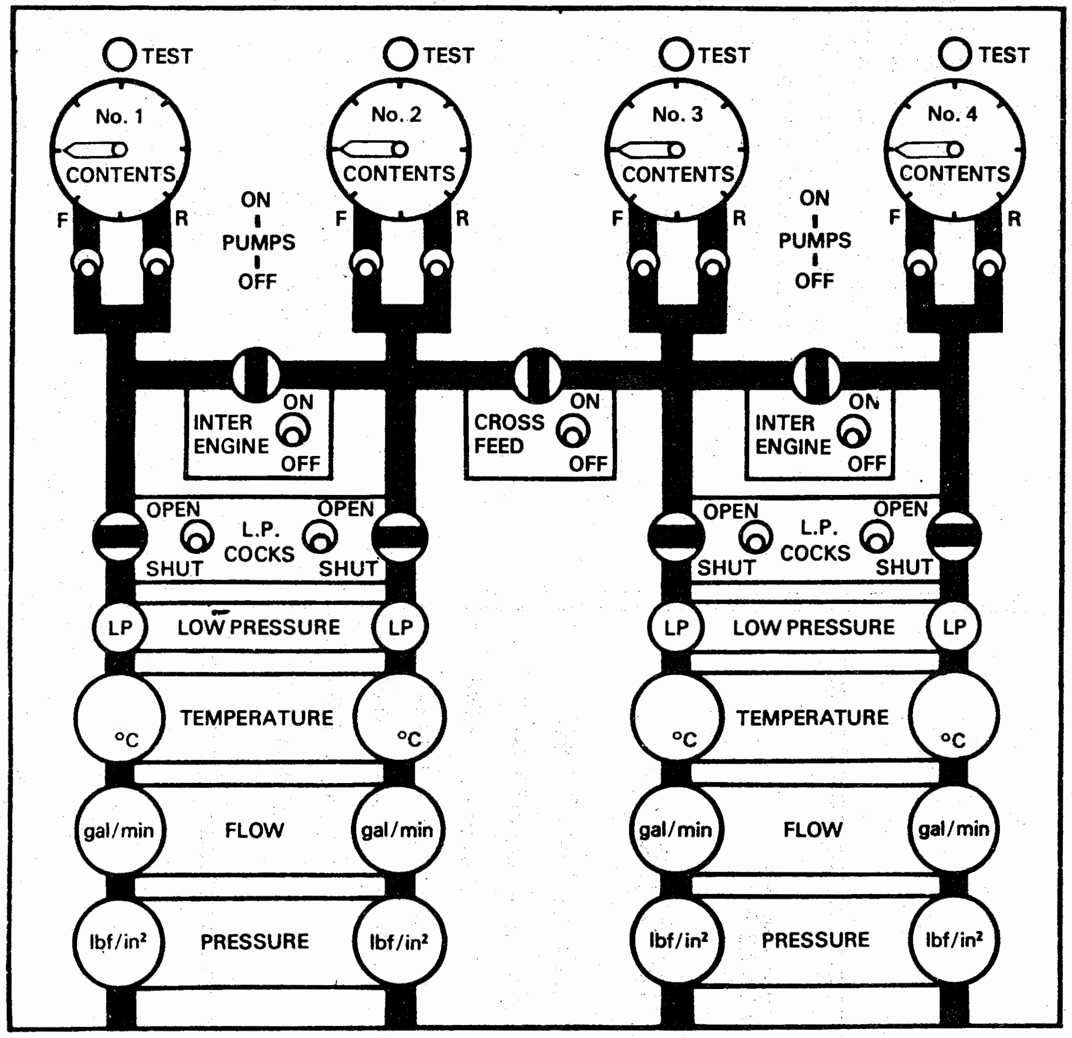

Figure 10 FUEL CONTROL PANEL

5.6.2 A 'drip stick' consists of a short outer tube, which is attached to an adaptor in the lower wing skin and protrudes upwards into the tank, and a long inner tube (calibrated in gallons or inches), which slides in the outer tube, and is secured to the adaptor by a bayonet fitting. The gap between the tubes is sealed against fuel leakage. To check fuel contents, the inner tube is unlocked and slowly withdrawn downwards; when the top of this tube falls below the fuel level, fuel will flow through it, and drain out of a hole in its base. The length of tube protruding from the adaptor, will indicate the tank contents. The volume of fuel, in gallons, may be obtained from tables provided in the aircraft Maintenance Manual.

5.6.3 A 'magnetic level indicator' is similar to a drip stick, but the top of the outer tube is sealed. A magnet mounted on a float which surrounds the outer tube rises and falls with the fuel level. A magnet is also mounted inside the top of the inner tube, and when this tube is unlocked, it may be carefully withdrawn downwards until the magnetic fields coincide. At this point the inner tube will be magnetically supported, and the contents will be indicated in the same way as with a drip stick.

5.7 **Fuel Heating.** Water may enter the fuel system during refuelling, or as a result of condensation in the tanks, and, when the fuel temperature falls below 0°C, the suspended water droplets may freeze. These frozen droplets collect at the low pressure filters, and may restrict or block fuel flow to the engines. To prevent this, a filter by-pass and blockage indicator may be fitted, or a de-icing additive such as methyl alcohol may be used in the fuel. However, in most large aircraft provision is made for heating the fuel before it enters the filters.

5.7.1 Fuel heaters are usually heat-exchangers, and may utilize engine oil, or air tapped from the engine compressors, as the heating medium. On some aircraft the engine oil coolers, which are in continuous use, are oil/fuel heat exchangers, and serve the additional purpose of heating the fuel. A heat exchanger operated by hot compressor air may be used in addition to the oil cooler, or may be used by itself for the purpose of heating the fuel. Oil/fuel heat exchangers are automatic in operation, oil flow being thermostatically controlled, but air/fuel heat exchangers may be either manually or automatically controlled.

5.7.2 A manually controlled fuel heating system usually consists of a pressure differential switch on the fuel filter, which operates a warning lamp in the crew compartment, and an electrically-operated valve on the heat exchanger, which is controlled by a switch adjacent to the warning lamp; a second warning lamp may also be included, to signify that the heating valve is open. When fuel flow through the filter becomes restricted by ice, the differential pressure across the filter increases, until it is sufficient to operate the icing warning lamp. The heat-exchanger valve should then be opened to admit hot compressor air to the heat-exchanger and to warm the fuel. Fuel temperature on the outlet side of the filter is indicated by an instrument on the fuel control panel. With this type of system, the period and frequency of operation of the heat exchanger may be limited.

5.7.3 An automatically controlled fuel heating system consists of a thermostatically controlled air inlet valve on the heat exchanger, which progressively opens and closes to maintain fuel outlet temperature within pre-set limits above 0°C. Actual fuel temperature is indicated on an instrument on the fuel control panel, but no action is required by the crew.

5.8 **Pipelines and Couplings.** Pipelines in aircraft fuel systems are not subjected to high pressures, and rigid pipes are generally manufactured from aluminium alloy tubing, although fire resistant and fireproof materials, such as stainless steel or titanium, must be used forward of the engine bulkhead and in other specified areas. Pipe ends are flared or beaded to accept the specified type of coupling. Some vent and jettison pipes are built into the structure, and in certain cases are of square section for ease of manufacture. Standard AGS or AS pipe couplings (Leaflet **BL/6-15**) are available in sizes up to 2½ in. diameter, and these are often used in aircraft fuel systems; however, where flexibility is required in joints, because of flight loads and temperature variations, specially designed couplings may be employed. A number of non-standard couplings are described and illustrated in the following pages.

5.8.1 **Flexible Couplings.** Two types of flexible coupling are illustrated in Figure 11. Sketch (A) shows a coupling which has provision for a certain amount of misalignment, as well as both angular and axial movement of the pipes. The pipe ends are beaded, and the surfaces within the joint are smooth and polished, so that the seals may slide freely over the pipes. A split retainer encloses the beads. When the coupling nut is tightened on the body, the O-rings are squeezed between the gland washers and the split retainer, and expand to form a seal between the body and the pipes. Sketch (B) shows a coupling which is less flexible, but which has provision for a limited amount of misalignment and movement. When the inner and outer sleeves are screwed together pressure is applied to the split collars, and the rubber seal is squeezed out to form a seal between the inner sleeve and the pipe beads.

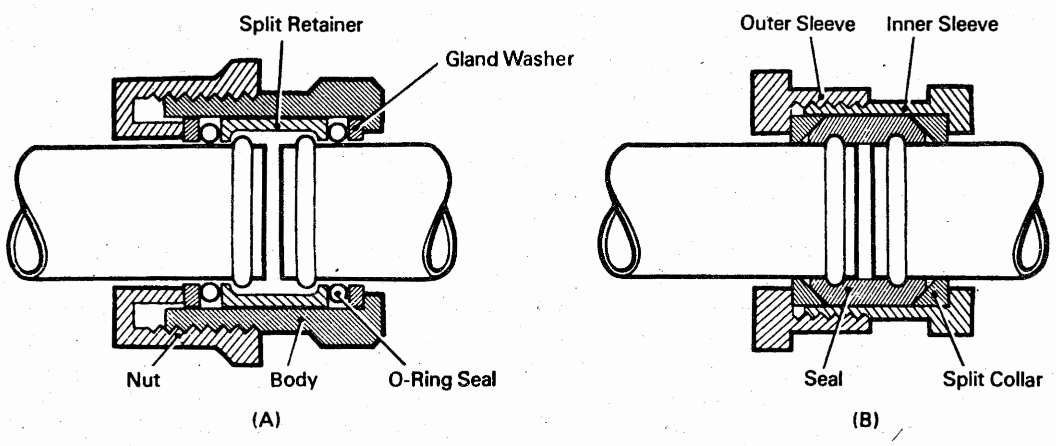

Figure 11 FLEXIBLE COUPLINGS

5.8.2 **Vee-clamp Couplings.** Figure 12 illustrates a typical Vee-clamp coupling. With this coupling a special fitting is welded to each pipe end, and the two fittings are held together by a pair of vee-section, semi-circular clamps. The seal is formed by an O-ring, which is located in a groove in one fitting, and is pressed against the face of the other fitting when the clamps are tightened. In some instances, fail-safe links are fitted to the clamps.

5.8.3 **Sliding Couplings.** Where only air or vapour passes through a pipe, a sliding coupling (Figure 13) may be used. As with vee-clamps, a special fitting is welded to each pipe end. An O-ring forms the seal, and the coupling is assembled by sliding the inner sleeve into the outer sleeve, so that the O-ring is located centrally.

5.8.4 Bonding of fuel system pipes is very important, since many of these are contained within the fuel tanks, and static electricity must be prevented from causing sparks in this explosive atmosphere. Bonding strips or cables are used to form a conducting path across couplings, and between pipes and adjacent structure. A typical bonding installation is included in Figure 14.

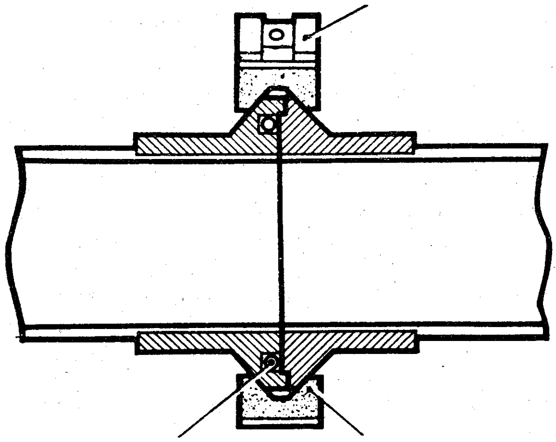

Figure 12 VEE-CLAMP COUPLING

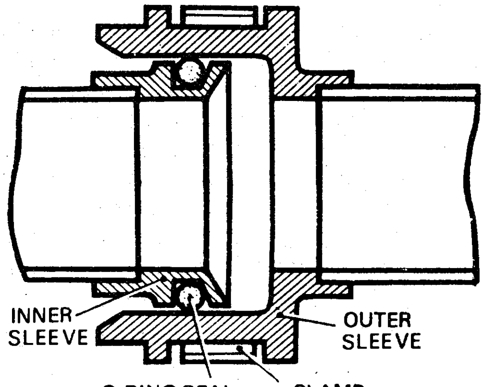

Figure 13 SLIDING COUPLING

5.8.5 In certain positions in the aircraft, couplings may be enclosed in drip shields, or heat shields, for safety reasons. Draining facilities are often provided on these shields, and a typical installation is shown in Figure 14.

5.8.6 Pipes are marked for identification purposes (see paragraph 4.5).

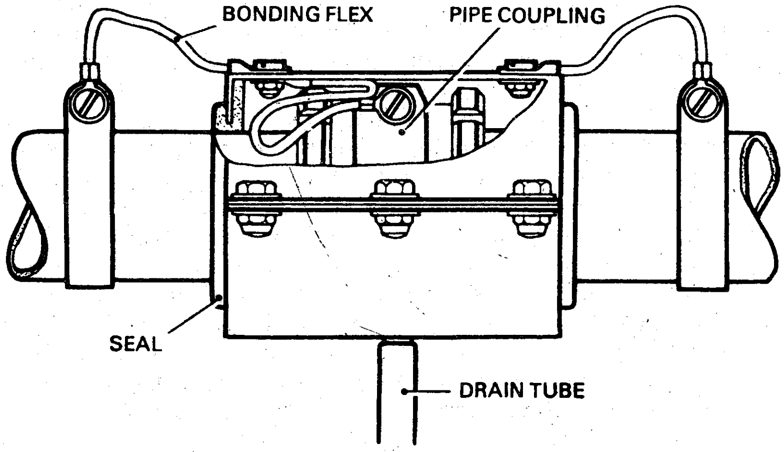

Figure 14 DRIP SHIELD, SHOWING BONDING CONNECTIONS

6 MAINTENANCE The fuel system is very important to the safe and efficient operation of an aircraft, and particular care must be taken to ensure that the instructions and precautions contained in the relevant manuals, schedules, and servicing instructions, are properly carried out.

6.1 **Safety Precautions.** The flammability of a fuel depends to a large extent on its flash point, and the different types of fuel vary considerably in this respect. Kerosene is far safer to handle than gasolene, but, regardless of the type of fuel used in a particular system, it is essential that precautions are taken to prevent the combustion of fuel vapours during servicing operations. In addition, precautions must be taken to prevent the harmful effects to health which may result from handling fuel or inhaling fuel vapour. The following general precautions should be observed whenever the fuel system is being worked on, and the relevant manuals should be consulted for any requirements which are applicable to a particular aircraft or fuel system. The special safety precautions necessary when entry into a tank is to be made, are detailed in Leaflet **AL/3-15.**

(a) The aircraft should be electrically earthed, and any ground equipment or containers should be earthed to the aircraft.

(b) Suitable and adequately manned fire-fighting equipment should be available, and suitable warning notices should be prominently displayed.

(c) Aircraft electric supplies should be switched off, and no live electrical cables should be left disconnected.

(d) Only spark-proof electrical equipment should be operated in the vicinity of the aircraft.

(e) Explosion-proof lamps and torches should be used.

(f) When draining fuel, any precautions detailed in the relevant Maintenance Manual regarding centre-of-gravity movement or maximum permitted jack loads, must be observed.

(g) To prevent undue spillage of fuel, tanks and pipes should be drained or isolated as appropriate, before breaking a connection or removing a component.

(h) Air-fed respirators should be worn in areas of high vapour concentration, e.g. near an open tank access hole.

6.1.1 **Refuelling/Defuelling.** When the aircraft is to be refuelled or defuelled, precautions must be taken to provide a path to earth for any static electricity which may be present, or which may build up as a result of the fuel flow. Refuelling and defuelling should normally be carried out in the open air, and suitable fire extinguishing equipment should be available and adequately manned. Both the aircraft and the refuelling vehicle should be earthed to a point which is known to be satisfactory, and an 'escape route' for the refuelling vehicle should be kept clear. When the aircraft is to be pressure refuelled the earthing wire on the refuelling pipe should be connected to the earth point provided on the aircraft, before connecting the refuelling pipe, and when the aircraft is to be refuelled through the over-wing filler port, the earthing wire on the refuelling pipe should be connected to the earth point provided on the aircraft before removing the filler cap and inserting the nozzle. The earthing wire should remain in position until after the refuelling pipe is disconnected, or the filler cap replaced, as appropriate. Similarly, when defuelling, the earthing wire should be connected first and disconnected last. No radio or radar equipment should be operated while refuelling or defuelling is taking place, and only those electrical circuits concerned with these operations should be switched on.

NOTE: Since pressure refuelling rates are high, the failure of an associated float switch or fuel level shut-off valve could cause a rapid build-up in pressure, and possibly serious damage to the tanks. Persons refuelling an aircraft should be prepared to shut off the supply instantly, should the automatic cut-off system fail to operate.

6.1.2 **Fuel Leakage.** When leakage or spillage of fuel has occurred, care must be taken to ensure that all traces of fuel and vapour are removed. Where lagging has become contaminated with fuel in areas adjacent to passenger cabins and crew compartments, the lagging should be removed and cleaned, and any residual fuel should be mopped up. Where fuel has leaked into a compartment which is vented and drained, the venting and drainage arrangements should be checked to ensure that they are functioning correctly, and that there is a flow of air through the compartment. It is sometimes specified that a check of the venting system of such a compartment should be carried out with the cabin pressurised. In the event of a gross leakage, consideration should be given to the effects that fuel may have on other materials and components, such as cable insulation, seals, transparencies and bearings.

6.2 **Cleanliness.** Scrupulous cleanliness is essential for correct and safe operation of an aircraft fuel system. This applies not only to the installed fuel system, but also to any ground equipment (e.g. test rigs, containers, refuelling vehicles and storage tanks) used in connection with it; a check for contamination in ground equipment should be carried out on a regular, planned basis. Foreign matter or contaminants in an aircraft fuel system can cause serious corrosion or damage to tanks and components, and may result in engine malfunction.

6.2.1 Whenever an orifice or a connection in a fuel system has unavoidably to be left open, protection against the entry of foreign matter must be provided, by the use of blanks or specially designed covers; these blanks or covers must remain in place until the orifice or connection is finally closed. The blanking of all openings in components removed from a fuel system is equally important, especially when the components are being returned for investigation; any foreign matter retained in the component may provide a clue as to the cause of the failure or malfunction.

6.2.2 In many cases, standard AGS blanks, made from rubber, plastic or metal, may be suitable for use in a fuel system, but many components have non-standard connections, and these necessitate the use of blanks which are specially designed for the purpose, and made from a material which is compatible with the fuel. No material from which particles are easily detached (e.g. cotton, paper, wood and cork) should be used for blanking purposes. Blanks must be designed so that it is impossible to re-connect the attaching component with a blank in place.

6.2.3 When jointing compound is used during installation or assembly of a component, care must be taken not to use an excessive amount, otherwise surplus compound may enter the system, and block or damage components such as valves, pumps and filters. Surplus compound should be wiped off whilst still wet.

6.2.4 The tanks, filters, and the lowest points in a number of feed and vent pipes, are fitted with drain valves, by means of which fuel samples may be taken after refuelling, and at the periods specified in the approved Maintenance Schedule. Fuel samples are normally collected in a glass jar, and should be inspected for the presence of free water, sediment and microbiological contamination. If excessive free water or sediment is found in the samples, all fuel should be drained from the system, and the tanks should be partially filled with clean fuel. This fuel should then be drained through the drain valves until samples are satisfactory. If microbiological contamination is found in the samples, the tanks should be visually inspected for fungal deposits, which, if present, must be removed (Leaflet **AL/3-15**). After removal of fungus, the fuel feed system must be flushed through to remove microbiological debris. Whenever excessive contamination of any sort has been found, the system filters should be inspected, and cleaned or replaced as necessary.

6.3 **Component Removal and Installation.** In order to remove a component (except for those in the top of a tank) it will usually first be necessary to drain some, if not all, of the fuel in a tank, or to close the low pressure, transfer, or servicing valves, so as to isolate part of the system. The normal defuelling system should be used to remove large quantities of fuel, but small quantities may be drained into suitable containers, using the water drain valves. The fire and safety precautions detailed in paragraph 6.1 should be observed when defuelling and when working on the fuel system. Actual procedures for removing or installing components should be obtained from the appropriate Maintenance Manual, but the following general points should be taken into account.

6.3.1 **Removal**

(a) Any electrical circuits which have to be disconnected, should first be isolated by removing the associated fuse, or by tripping the associated circuit breaker, as applicable.

(b) Care should be taken not to twist or strain the pipes, when removing union nuts; the use of two spanners is recommended wherever possible.

(c) In order to remove a component, it may be necessary to remove adjacent pipe clips in order that pipes may be withdrawn without damage. Care must be taken not to dent or score pipe flares or mating surfaces when removing the associated component.

(d) Provision should be made for the collection of any fuel which may drain from the pipes when they are disconnected. Any spillage should be mopped up.

(e) Any nuts and washers which are removed should be retained, but seals and gaskets should be discarded.

(f) Blanks or covers should be installed on openings and pipe ends, including those on the component which was removed.

6.3.2 **Installation**

(a) A component which is drawn from stores for installation on an aircraft, should be checked to ensure that it is the correct part, is to the required modification standard, and has the appropriate test and inspection markings; the remaining life of any seals or rubber components should also be checked. An inspection should be made for any damage or corrosion which may have occurred during storage. Any position indicators on the component should be checked for correct setting. Components such as valves, which have adjustable stops, should be checked to ensure that the stops are adjusted to the correct position of the valve.

(b) Any component which is treated with inhibiting oil, should be thoroughly flushed with system fluid, and dried with a lint-free cloth.

(c) New seals and gaskets should be fitted, blanks should be removed, and the component should be installed in position. Care should be taken not to damage associated joint faces, pipes, or threads. Mating parts should be checked for alignment and fit; they should not be forced into position.

(d) Modern aircraft fuel system components are so designed that it should be impossible to install them incorrectly. However, when fitting physically reversible units, or components with adjacent unions of similar size, care should be taken to ensure that the pipes are correctly connected.

(e) Where recommended, anti-seize compound should be applied to threads. To prevent contamination of the system, the compound should be applied sparingly, and should only be applied to the male thread on a pipe union. Seals should normally be lubricated with mineral jelly or an approved alternative; joint gaskets are normally fitted dry, but use of a sealant or jointing compound may be recommended in some instances.

(f) Nuts, bolts and pipe unions should be tightened to the recommended torque values, and the bonding wires and clips which were removed from adjacent parts should be replaced as originally installed.

(g) Any electrical connections to the component should be made before re-connecting the supply, and the unit should, where appropriate, be checked for full and free movement in the correct sense.

(h) Manual controls on valves should be checked to ensure that the valve operates in the correct sense, and reaches its stops before the associated control; the clearance between the control and its stops should be checked and adjusted to within the limits specified in the relevant manual. Controls should be locked after adjustment.

(j) The operation of limit switches on electrically-operated mechanisms, should be checked against the position of the component, and should be adjusted as necessary.

(k) Any indicators in the crew compartment, such as magnetic indicators and warning lamps, which are associated with the component being installed, should be checked for correct operation.

(l) Bonding should be tested as described in Leaflet **EEL/1-6.**

(m) When installation is complete a flow test and/or pressure test should be carried out.

6.4 **Refuelling.** Although there may be occasions when weight and centre-of-gravity considerations will limit the fuel load, light aircraft fuel tanks are normally completely filled before flight. With transport aircraft, however, the carriage of fuel not actually required for a particular journey would mean limiting the payload; only the quantity of fuel actually required (plus safety reserves) is therefore carried, and the tanks are seldom completely filled. Fuel gauges are normally compensated for changes in fuel density (Leaflet **AL/10-3**), and therefore indicate fuel weight, but it is general practice to check the tank contents by means of the dip sticks (paragraph 5.6), and since these indicate fuel level only, corrections must be made for the actual Specific Density of the fuel and the aircraft attitude. Some aircraft are fitted with an aircraft attitude indicator, and charts and tables are provided in the aircraft Maintenance Manual, by means of which correction factors may be applied to the dip stick readings obtained, when checking the fuel load.

6.5 **Filters**

6.5.1 A light aircraft fuel filter normally consists of a housing, a filter element, a sediment bowl, and a drain valve. Water and sediment may be drained from the bowl prior to flight, and the bowl should be removed periodically for cleaning and inspection of the filter element. These filters are often placed in the suction line to the pump and, when replacing the bowl, care should be taken to ensure that it forms a good seal with the housing; a leak could result in inadequate fuel supply to the engine.

6.5.2 The main filters fitted to turbine engined aircraft are usually fitted to the engine, and consist of a housing, a felt or paper filter element, a filter case, and a drain valve; in some aircraft the housing incorporates a differential pressure switch, which operates an icing warning lamp in the flight compartment. The drain valve may be used to take fuel samples (paragraph 6.2.4), but precautions may need to be taken to avoid the need to bleed the engine fuel system; these precautions normally include closing the high pressure fuel cock, opening the low pressure fuel cock, and using the tank booster pump to discharge the fuel sample. New filter elements should be fitted at the periods specified in the approved Maintenance Schedule, and whenever breakdown, repairs, or contamination of the system have taken place. To remove a filter element, the high and low pressure fuel cocks should be closed, the associated electrical services should be isolated, and the element and case should be removed; any debris should be examined, and the source located. Before fitting a new filter element, the case should be washed out with kerosene or trichloroethylene, and old seals or gaskets should be replaced; it is usually recommended that seals are lubricated with kerosene or petrolatum prior to installation. After fitting a filter element, it is usually necessary to run the associated engine, and to check the system for satisfactory operation and freedom from leaks.

7 PRESSURE TESTS Pressure tests are normally required at regular intervals, after repairs, modifications, and replacement of components, and whenever leakage is suspected. In those vent systems which utilise part of the wing structure (e.g. top hat sections) to form the vent duct, vent pressure tests may also be required after structural repairs. The tests required will be specified in the relevant Maintenance Manual, and should be carefully carried out. Test rigs, capable of supplying fuel or air under pressure, are required, and should include an accurate pressure gauge, a relief valve, and, in the case of a fuel pumping rig, a flowmeter. All test rigs should be clearly identified with the certification (or re-certification) date. In addition, special blanks, plugs, cover plates, and dummy components may be required. The vent, feed, and transfer systems are usually tested separately since different test pressures are generally prescribed.

7.1 **Vent System Pressure Test.** For this test, the vent system on each side of the aircraft should normally be tested separately. All vent openings should be blanked, and it will often be necessary to gag float-operated valves, or to replace them with dummy components. Alternative means of venting the tanks during the tests should be provided. Air pressure should be applied to the system either through a water drain valve, or through an adaptor fitted to one of the blanks, and the pressure should be slowly raised to the test pressure quoted in the relevant Maintenance Manual. When the air pressure supply cock is turned off, any decrease in pressure will indicate leakage, and the drop in pressure over a prescribed time should be noted. The source of any leakage in excess of that permitted should be traced and rectification action should be taken.

7.2 **Feed System Pressure Test.** The feed system from a tank to its associated engine should be tested individually. Cross-feed and inter-engine valves should be closed, and the low-pressure cock should be opened. On some aircraft the feed systems are pressurized by switching on both pumps in the tank concerned, whilst on others the booster pumps are replaced by dummy components, and fuel pressure is applied by means of an external test rig. In some systems (see Figure 2) there will be flow through the bleed hole in the suction valve, and this must be within prescribed limits. Rates of flow indicated on the test rig flowmeter, which are in excess of these limits, will be indicative of either an internal or external fuel leak. All pipes, connections, and valves should be checked visually for signs of leakage under pressure; no leakage is normally permitted.

NOTE: In systems in which drip shields or heat shields are fitted to some couplings, the test pressure must be applied for a sufficient length of time to enable any leakage to collect and flow through the drain. Alternatively, a separate pressure test of the drip shield may be specified, or the shield may be required to be removed for the test.

7.3 **Transfer System Pressure Test.** The pipes and couplings in the fuel transfer system may be pressure tested in a similar manner to the feed system. Pipes should be disconnected and blanked at the positions specified in the relevant Maintenance Manual, and fuel pressure should be applied by means of the transfer pump, or by use of an external test rig, supplying fuel through a dummy pump. No leaks should be evident, and no fuel flow should be recorded on the test rig flowmeter.

7.4 **Additional Pressure Tests.** A number of other pressure tests may be specified, in order to ensure that there is no leakage which could prove hazardous, or prevent proper operation of the fuel system. One example is the pressure testing of conduits which pass through the fuel tanks, and house electrical cables. These conduits are usually sealed by means of a pressure bung or pressure seal, and are tested by applying air pressure to the inside, through a drain pipe, or special adaptor. When the air supply is shut off, there should be no drop in pressure over a prescribed period of time. If leakage is evident at the pressure bung, it is usually permissible to apply sealant to seal the bung and the holes through which the cables pass.

8 FLOW TESTS Flow tests should be carried out in accordance with the relevant Maintenance Manual, as and when required by the approved Maintenance Schedule, or when necessitated by repairs, replacements or modifications. The tests are designed to ensure that the system will provide a fuel flow to each engine which is in excess of the requirements of the engine when it is operating at maximum power, and at a pressure suitable for proper operation of the carburettor or engine-driven pump, as appropriate. For all tests the aircraft should be levelled laterally and longitudinally, and the fuel tanks should contain the minimum quantity of fuel (i.e. unusable fuel plus sufficient for the test only); tank vents should be clear, and overwing filler caps should be fitted. All equipment used should be bonded and electrically earthed.

8.1 **Full Flow Test.** A full flow test is normally only required after initial installation or major breakdown of the system. Fuel flow test rigs are required for the test, and should be located adjacent to each engine, with the test rig pump at the same level as the engine-driven pump. The rig inlet hose is usually connected to a self-sealing coupling on the engine bulkhead, and the outlet directed to a suitable container. An external electrical supply should be connected to the aircraft, in order to operate the fuel system valves and to check operation of the associated warning lamps and indicators. The test includes suction feed operation (using the test rig pump), pressure feed operation (using the aircraft booster pumps), and all possible combinations of cross-feeding, to ensure that fuel flow is satisfactory under all flight conditions. The schedule of test operations, and the flow rates and pressures which should be achieved, are detailed in the relevant Maintenance Manual.

8.1.1 For the suction test, the test rig pump is used to draw fuel from the tanks. Valve selections should be made according to the test schedule, and the flow rates and pressures obtained at each stage of the test should be recorded. These results should be within the limitations prescribed for the suction test.

8.1.2 For the pressure test, the aircraft booster pumps should be used to pump fuel from the tank. The test rig pump is switched off, and its by-pass opened. Selections of pumps and valves should be made in accordance with the test schedule, and the flow rates and pressures obtained at each stage of the test should be recorded. These results should be within the limitations prescribed for the pressure test.

8.2 **Limited Flow Test.** A limited flow test is often considered as a satisfactory method of checking a fuel system after a component has been changed; only that part of the system affected by the component change needs to be tested. The fuel feed pipe is disconnected at the engine, or, in some instances, a drain pipe is connected to a special drain valve at the engine, and a suitable container is positioned to catch the drained fuel.

8.2.1 The appropriate low pressure cock should be turned on, and the flow rates should be checked with the associated pumps operating separately and together. For each part of the test, when the fuel flow is free from bubbles, it should be directed into a calibrated container, and the time taken to pump a given quantity of fuel should be recorded. These figures should be converted to flow rates, which should not be less than the minimum flow rates specified in the relevant Maintenance Manual.

8.3 **Gravity Feed Test.** To check a gravity feed system such as is fitted to some light aircraft, the feed pipe should be disconnected at the carburettor, and a suitable container should be positioned below the engine. With the fuel outlet positioned at the same height as the carburettor, and the fuel valve turned on, the fuel should be checked for freedom from bubbles and for full-bore flow, then directed into a calibrated container. The time taken to drain a given quantity of fuel should be recorded, and the equivalent flow rate should not be less than the minimum flow rate specified in the relevant Maintenance Manual.

9 STORAGE Components should be stored as detailed in Leaflet **BL/1-7.** Further particulars regarding the storage of tanks may be obtained from Leaflet **AL/3-15.**

Issue 2.

June, 1979.

AIRCRAFT

SYSTEMS AND EQUIPMENT

TYRES

1 INTRODUCTION This Leaflet gives general guidance on the care and maintenance of aircraft tyres. It should be read in conjunction with the manufacturer's manuals for the tyres concerned, since minor variations may occur between the various manufacturers' products. The topics discussed are as follows:—

Para.	**Topic**
1	Introduction
2	General
3	Tyre Markings
4	Fitting Tubed Tyres
5	Fitting Tubeless Tyres
6	Wheels Suitable for Tubed or Tubeless Tyres
7	Inflation after Fitting
8	Testing
9	Tyre Creep
10	Maintenance of Tyres
11	Removing Tyres
12	Inspection of Tyres and Tubes Removed from Aircraft
13	Repair of Tyres and Tubes
14	Remoulding Tyres
15	Storage
16	Records

1.1 Information on the maintenance and overhaul of wheels and brakes is given in Leaflet **AL/3-19.**

1.2 The high take-off and landing speeds of most transport aircraft have resulted in tyres being operated under increasingly severe and intensive loading conditions, therefore a high standard of maintenance and inspection is essential at all times to ensure the continued serviceability of the tyres. The CAA recommends that, in all cases where doubt exists regarding the condition of aircraft tyres, the tyres should be changed and the tyre manufacturer's representative should be consulted.

2 GENERAL

2.1 **Tubed Tyres.** Tubed aircraft tyres consist of two component parts, i.e. inner tubes and outer tyres. The general construction of a typical tyre is shown in Figure 1, but the detailed construction varies considerably according to the manufacturer and the duties for which the tyre is intended.

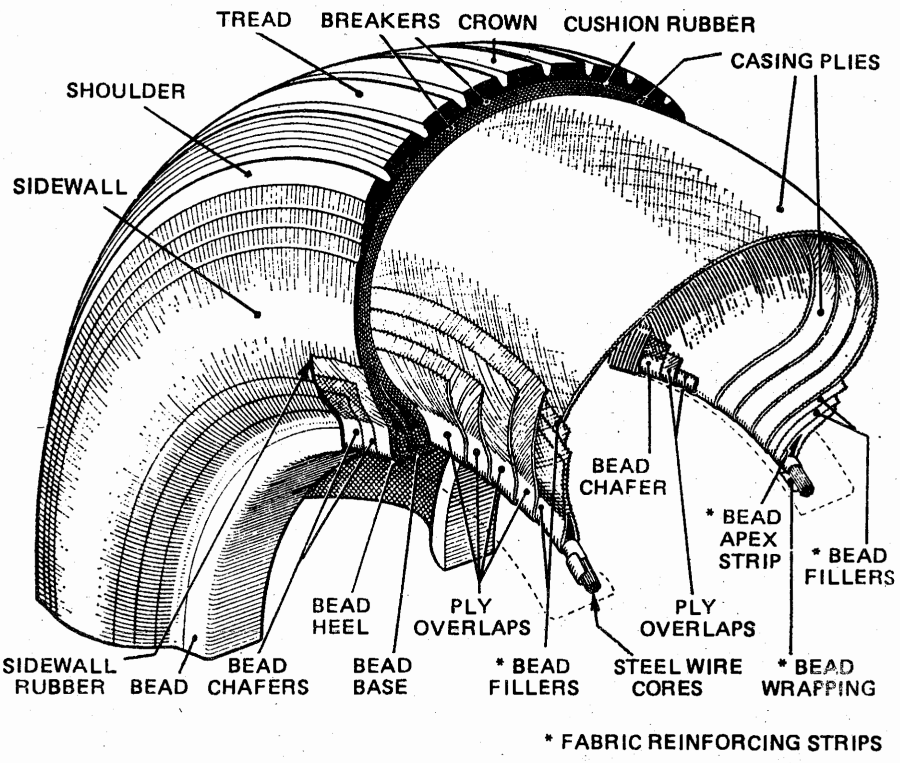

Figure 1 CONSTRUCTION OF TYPICAL TUBED TYRE

2.2 **Tubeless Tyres.** Basically a tubeless tyre is identical to a tubed tyre except that the tube is replaced by an air-retaining inner lining and the beads are designed to prevent air leakage at the rim of the wheel. Some of the advantages derived from the use of tubeless tyres include about 7½% saving in weight compared with using a tyre and tube, a reduction in permeability losses, cooler running by about 10°C, less danger of deflation due to puncture, and the elimination of tube troubles. Because it is necessary to keep the bead areas in good condition, tubeless tyres are not fitted to well-base wheels.

2.3 **High Pressure Tyres.** Some aircraft tyres are inflated to pressures of 1400 kN/m² (200 lbf/in²) or more. Because of their strength and rigidity, such tyres, whether tubed or tubeless, are normally fitted only to divided or detachable-flange wheels. Special precautions are necessary to protect personnel from injury during initial inflation (paragraph 7.1).

2.4 **Tyre Venting.** During manufacture all tubeless tyres are provided with vents by partially piercing the rubber covering with an awl (of approximately 1·5 mm (0·0625 in) diameter) at several places, usually around the tyre immediately outside the area of the wheel flanges, but, in some instances, also on the crown and shoulder areas. These vents are provided as a means of releasing air under pressure from the tyre casing, and are marked with a green or grey spot. Such air may be residual air in the casing cords after manufacture, which is compressed to a high pressure on inflation of the tyre, or air which accumulates in the casing by normal permeation through the inner lining. If a free passage of air were not provided, the residual or permeating air could cause looseness or lifting of rubber on the tread or sidewalls of the tyre. Aircraft tyres to which tubes are fitted, are vented through the complete casing at the bead position in order to allow air trapped between the tube and tyre to escape.

2.5 **Tread Patterns.** The tread pattern on a tyre is usually designed to suit specific operating conditions, aircraft weights, and aircraft take-off and landing speeds.

2.5.1 Ribbed (i.e. circumferentially grooved) tread tyres are probably used more than any other types, and there are a number of variations on the basic pattern such as the number of ribs and the width of grooves. A ribbed tread provides a good combination of long tread wear, good traction, and directional stability, particularly on hard surfaced runways.

2.5.2 Diamond pattern (or 'all-weather') tyres are also widely used and give good performance on all types of surfaces. They are particularly suitable for unpaved (e.g. turf or packed earth) airfields.

2.5.3 Plain tread was at one time very common, particularly on British aircraft, but has gradually been replaced by ribbed and diamond pattern treads. It is, however, still used on some light aircraft and helicopter tyres.

2.5.4 Some nosewheels are fitted with tyres having twin-contact tread, i.e. a tread consisting of a large circumferential rib at each side of the crown, which is designed to assist in preventing shimmy.

2.5.5 Some nosewheel tyres are also fitted with a water deflector (or 'chine') on the upper sidewall, to deflect water away from rear-mounted engines. This deflector may be on one side for twin-wheel installations or on both sides for single-wheel installations.

2.5.6 Water dispersing treads, which have many small holes incorporated in the crown and shoulder rubber, are also fairly common as a means of helping to prevent aquaplaning.

3 TYRE MARKINGS Tyres have certain markings imprinted on their sidewalls for identification purposes. These markings vary according to the manufacturer but usually include size, part number, serial number, date of manufacture, tubed/tubeless, speed rating, ply rating, and the type and number of retreads carried out. These markings are explained in paragraphs 3.1 to 3.7.

3.1 **Size.** Tyres are identified for size in the following way:—

Example: 26 × 10·00-18.

The first number (26) indicates the outside diameter (A in Figure 2) in inches.

The second number (10·00) indicates the width (C in Figure 2) in inches.

The third number (18) indicates the bead diameter (B in Figure 2) in inches.

It will be found that some tyres do not specify all three dimensions. Some tyres of American manufacture may quote only the outside diameter (e.g. 26) but otherwise the tyre width will always be stated, either preceded by the outside diameter (e.g. 26 × 10·00) or followed by the bead diameter (e.g. 10·00-18).

NOTE: Dimensions (A) and (C) may, alternatively, be quoted in millimetres.

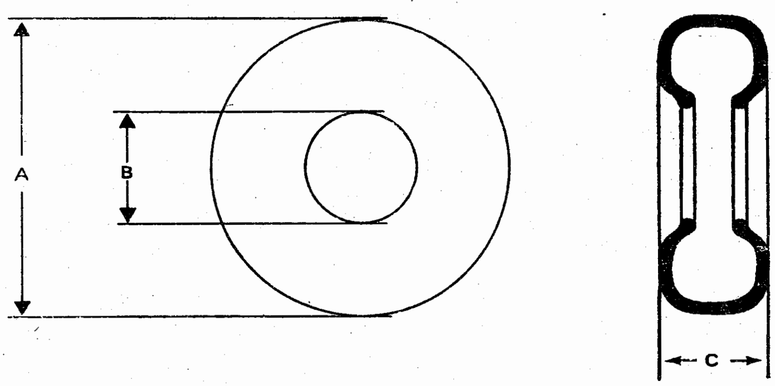

Figure 2 TYRE DIMENSIONS

3.2 **Part Number.** The part number usually includes the manufacturer's identification, the drawing to which the tyre is manufactured, and letters to indicate the tread type, and whether it is tubed or tubeless. The part number is the only positive means of identifying a tyre, and size markings alone should not be used for this purpose. Example: DR 7153 T.

3.3 **Serial Number.** The serial number is usually marked in conjunction with the date of manufacture, which may be in the form of a code indicating the day, week, or month, and the year.
Example: 2283 Nov 72 or 23202283.

3.4 **Ply Rating.** The term 'ply rating' is used to identify a tyre with its maximum recommended load and pressure. It is the index of the tyre strength and does not necessarily represent the number of cord plies used in its construction. The marking may be imprinted in full, e.g. 10 PLY RATING, or abbreviated, e.g. 10PR.

3.5 **Speed Rating.** Most high speed tyres (i.e. those which may be used at speeds over 160 mile/h) have the speed rating imprinted on the tyre to indicate the maximum speed for which they are designed, e.g. 200 mile/h.

3.6 **Other Markings.** Other markings which may be found on new tyres include the following:—

(a) Military Stores Reference Number.

(b) Green or grey spots indicating the positions of the awl vents.

(c) A red spot or triangle indicating the light part of the tyre.

3.7 **Retreads.** Retreaded tyres are usually marked in accordance with a system peculiar to each manufacturer. The markings usually include the tyre part number, the name of the retreader, the number and date of the last retread, and in the case of retreads in which the sidewalls are covered with new rubber, the tyre serial number, manufacturer, speed, size and ply rating.

4 FITTING TUBED TYRES The successful fitting of tyres is not difficult provided that a suitable procedure is employed and the correct type of tool is used for each operation. However, careful attention to detail is essential throughout the process, since visual inspection after the tyre is fitted is obviously limited.

4.1 When a new tyre is required on those aircraft fitted with tubed tyres, it is advisable to fit a new tube since any stretching or local thinning present in the original tube may result in the formation of wrinkles during refitting, leading to early failure of the tube. If it is decided to refit the original tube it should be carefully examined for signs of damage or defects before refitting.

4.2 Care should be taken to ensure that the tyre and tube are of the correct size, and of types authorised for use on the particular wheels of the particular aircraft. It is also important to ensure that the correct type of valve cap is fitted, since an incorrect type of cap may foul the airframe structure when the landing gear is retracted.

4.3 **Tyre Balance.** The balance of tyres and tubes is checked and brought within specified limits by the tyre manufacturer (often by the addition of a balancing patch). Where balance is not perfect the lighter side of the tyre is marked with one or two circular or triangular spots above the bead heel and the heavier side of the tube is marked with a red or yellow band approximately 10 mm (0·375 in) wide; fitting the tyre and tube with these markings together will achieve the best state of balance.

4.4 **General Fitting Precautions.** When fitting tyres and tubes to any type of wheel, the following general precautions should be observed:—

(a) Care must be taken to ensure that nothing is left inside the tyre, e.g. labels, paper or tools, and that the rim of the wheel is clean, free from oil and grease and from damage which, apart from other considerations, might be harmful to the tyre or affect its form.

(b) Wheels should be rested on rubber or felt mats to prevent damage during assembly.

(c) The outer surface of the tube and the inner surface of the tyre should be dusted with French chalk, any excess being shaken off.

(d) Tyre and tube balance marks (paragraph 4.3) should be aligned during assembly.

(e) After fitting a tube into a tyre, the tube should be smoothed out with the hand to remove any creases; this will help to prevent the trapping of air inside the tyre during inflation.

(f) Care should be taken to ensure that valves of the correct part number are fitted. The inflation valves for all high pressure tyres should have hexagonal valve caps and should be fitted with cores having stainless steel springs.

4.5 **Well-base Wheels**

4.5.1 **Preparation for Fitting.** When fitting a tyre to this type of wheel, all air should be expelled from the tube before it is fitted into the tyre. This should be done by removing the core from the valve and rolling the tube tightly until it is completely deflated; the core should then be refitted.

4.5.2 **Fitting the Lower Bead.** The tyre should be inclined to the wheel and the lower bead pushed on by hand to just over half-way, ensuring that the bead enters the well. The fitting of the bead should be completed in a series of small 'bites' with the appropriate lever, using water or an approved bead lubricant to facilitate fitting.

4.5.3 The tube should be placed on top of the tyre so that the position of the valve stem corresponds to the valve hole in the wheel. The valve-bearing portion of the tube should then be pushed into the tyre, the valve inserted into the valve hole and loosely secured with the valve cap or extension piece. Finally, the remainder of the tube should be pushed into the tyre and, after ensuring it is clear of the bead seat, inflated gently until it adopts its correct contour, so that it can be checked for freedom from twisting or creasing. While it is inflated, the position of the valve should be checked to ensure that it is concentric with the hole.

4.5.4 **Fitting the Top Bead.** The top bead should be fitted with the appropriate lever, ensuring that the bead section adjacent to the valve is the last to be fitted and using a lubricant as before. Care must be taken to ensure that the bead enters the well without nipping the tube.

4.5.5 After the tyre has been fitted it should be inflated to a pressure sufficient to position the beads on the bead seats. The tube should then be slowly deflated, care being taken not to disturb the bead positions, and slowly re-inflated and tested as outlined in paragraphs 7 and 8 respectively. The purpose of deflation is to ensure that the tube adopts a position free from creases, and that the minimum amount of air is trapped between the tyre and tube.

4.6 **Divided Wheels**

4.6.1 **Preparation for Fitting.** The wheel should be dismantled by removing the nuts, collars, locking plates and bolts, and then the upper half of the wheel should be lifted off.

4.6.2 **Fitting the Tyre.** The tube should be placed in the tyre and then inflated until it just adopts its correct contour. Great care is necessary when fitting tyres to this type of wheel, since if the tube is not sufficiently inflated it may become trapped between the two halves of the wheel; conversely, if the tube is over-inflated, the halves of the wheel will not meet. The tyre, with the tube inflated as described above, should be placed on the lower half of the wheel, with the valve in alignment with the valve hole.

4.6.3 The upper half of the wheel should then be fitted, two opposite bolts being inserted to guide it into position; care should be taken to ensure the valve is centrally positioned in its hole. On pressing the two halves of the wheel together, a metallic noise should be heard when they meet; this is a good indication of whether or not the tube has been nipped. When it is ensured that the tube is not trapped, the remaining bolts should be inserted and the nuts fitted, but not tightened at this stage since tightening may cause the wheel to turn in the tyre and so damage the valve stem.

4.6.4 The tyre should now be inflated to a pressure sufficient to position the beads on the bead seats, and as soon as one bead grips the wheel, the bolts should be progressively tightened, taking opposite bolts in a sequence similar to that shown in Figure 3. The final tightening should be in the order and to the torque values recommended by the manufacturer.

NOTE: If the tyre has fitting lines on its walls just above the wheel rim, these should be used as a guide to the correct fitting of the tyre.

4.6.5 The nuts should then be locked, as appropriate, and the tyre inflated and tested as outlined in paragraphs 7 and 8 respectively.

4.7 **Detachable Flange Wheels**

4.7.1 **Preparation for Fitting.** The lock-ring and loose flange should be removed from the wheel, the method of removing the lock-ring depending on the type fitted.

(a) To remove the split type lock-ring, a screwdriver should be inserted in the slot and, after the flange has been pushed inward and clear of the lock-ring, the lock-ring should be gently prised from the groove. Lock-rings of the coil type can be removed with the fingers.

(b) When the flange has been removed, the wheel should be laid flat on a block to allow the tyre to drop to the full depth of the wheel.

4.7.2 **Fitting the Tyre.** The tube should be placed inside the tyre and inflated to shape, after which the tyre should be positioned on the wheel, care being taken to ensure that the valve is correctly positioned in relation to the valve slot.

4.7.3 The loose flange should be placed in position and pushed down clear of the lock-ring groove in the wheel; the lock-ring should then be fitted. If the lock-ring is of the split type, care must be taken to ensure that the collar, if fitted, is correctly positioned in the notches in the wheel and the flange. Coil type lock-rings must be fitted by hand. Finally, the tyre should be inflated and tested as outlined in paragraphs 7 and 8 respectively.

5 FITTING TUBELESS TYRES Prior to fitting the tyre, the wheel should be examined for scratches and other damage in the flange, bead seat and rim areas. Any damage should be blended out within the limits permitted by the relevant Maintenance or Overhaul Manual. The beads and inner liner of the tyre should be checked for damage, and the wheel sealing ring should be checked for defects such as deformation, permanent set and ageing. The precautions outlined in paragraph 4.4 should be observed, as applicable.

5.1 **Fitting the Tyre**

5.1.1 The seal spigot joint faces of divided wheels and seal register area, should be cleaned and lightly lubricated with a preparation recommended by the manufacturer. The seal should then be stretched evenly onto the wheel, ensuring that it is seating correctly in its location groove.

5.1.2 The tyre bead and wheel bead seat areas should normally be kept dry, but some manufacturers permit or recommend the use of a bead lubricant to facilitate mounting. The tyre should be positioned on the wheel with the balance mark on the tyre in alignment with the balance marks (if any) on the wheel. When the wheel has no balance marks, the tyre balance mark should be aligned with the valve location.

NOTE: It is important that the tyre beads should not become contaminated with wheel grease.

5.1.3 With divided wheels, the bolt threads should be lightly lubricated with a grease recommended by the manufacturer and the bolts progressively tightened, in a sequence similar to that shown in Figure 3, to the recommended torque value. Wet assembly of the bolts may be specified by the manufacturer.

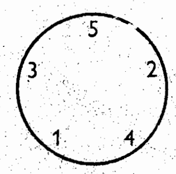

Figure 3 TIGHTENING SEQUENCE

5.1.4 With the valve core removed to permit the maximum flow of air, the tyre should be inflated as rapidly as possible to spread the tyre walls until the beads seat on the rim. Once this condition has been achieved, inflation should be discontinued immediately. If inflation cannot be effected, as a result of, for instance, tyre distortion caused by storage or transit, the assembly should be stood vertically and a load applied to the crown.

5.1.5 When the beads are correctly seated, the valve core should be refitted, and the tyre should be inflated and pressure tested as outlined in paragraphs 7 and 8 respectively.

5.2 **Sidewall Valves.** Some tubeless tyres are fitted with a sidewall valve (Figure 4) which is in the form of a rubber self-sealing insert in the tyre wall. A central aperture in this insert permits the insertion of a servicing needle for inflation and deflation purposes. Before inflating a tyre of this type, the servicing needle must be inspected for cleanliness and lubricated with the felt pad contained in its sheath.

NOTE: Servicing needles should be inserted and removed using a twisting motion.

6 WHEELS SUITABLE FOR TUBED OR TUBELESS TYRES Detachable flange wheels are available to which either tubeless tyres or tubed tyres can be fitted. This is effected by means of special adaptors which permit an inflation valve assembly to be used for both purposes. For tubeless tyres the special adaptor is secured by a nut and washer, and is made leakproof by a rubber 'O' ring clamped between the washer and the outer chamfered seating of the adaptor housing, as illustrated in Figure 5(A). For tubed tyres the adaptor is integral with the inner tube and is similarly secured by a nut and washer, but in this instance an additional rubber 'O' ring is fitted between the head of the adaptor and the inner chamfered seating of the adaptor housing, as shown in Figure 5(B).

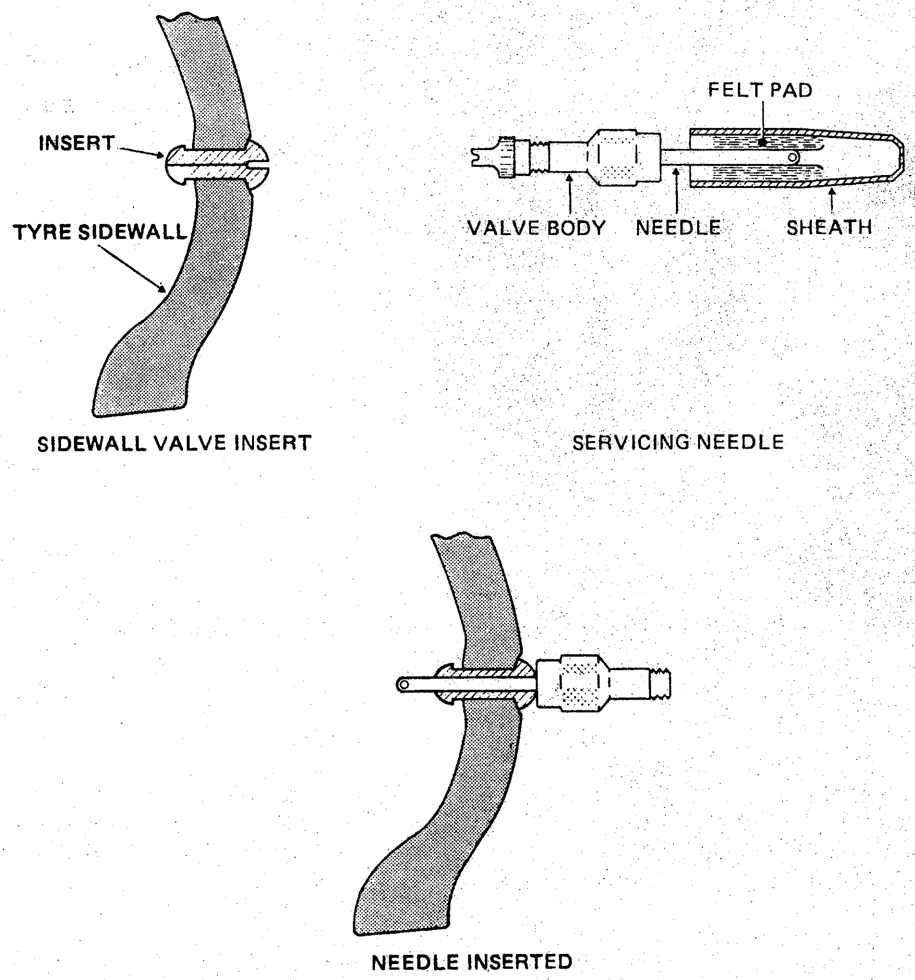

Figure 4 SIDEWALL VALVE

6.1 **Fitting Tubeless Tyres.** If the adaptor has been removed, ensure that its sealing face and also the sealing face of the wheel are not damaged or corroded. The adaptor should be placed in position, and the outer 'O' ring should be lightly lubricated with an approved grease and carefully passed over the adaptor threads. The assembly should be secured to the wheel with the washer and nut, and the adaptor should be wirelocked to its retaining nut. The tyre should be fitted as recommended in paragraph 5.1, and should be pressure tested as indicated in paragraph 8. If the duration pressure test (paragraph 8.2) is employed, the efficiency of the outer 'O' ring and the inflation valve seal should be checked by the local application of an acid-free soapy water solution (prepared with non-corrosive soap). After this test the solution must be washed off with clean water and the part thoroughly dried.

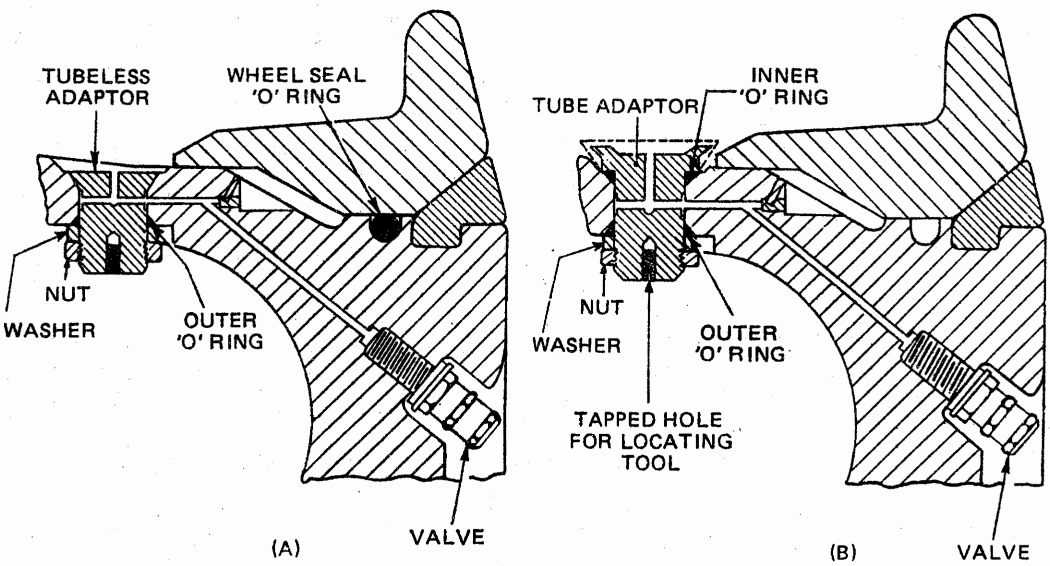

Figure 5 ADAPTORS FOR COMBINATION SCHEME

6.2 **Fitting Tubed Tyres.** The tube must be fully deflated (paragraph 4.5.1) before it is fitted into the tyre. The inner 'O' ring should be lightly lubricated with an approved grease and carefully passed over the adaptor threads until it seats around the shoulder adjacent to the tube.

6.2.1 The end of a special adaptor locating tool should be screwed into the end of the adaptor, and the tyre should be placed on the wheel, aligning the adaptor with its housing.

6.2.2 The locating tool should be passed through the adaptor housing in the wheel and, after re-checking the alignment, the tyre should be fitted, ensuring that the adaptor remains located in its housing. Finally, the wheel should be assembled, but in this instance the 'O' ring between the loose flange and the wheel (Figure 5(B)) should not be fitted.

6.2.3 **Assembling the Wheel.** The wheel should be placed with the fixed flange uppermost, and the adaptor should be pulled carefully into position. The outer 'O' ring should be greased and threaded over the locating tool, followed by the washer and nut, after which it should be passed carefully over the adaptor threads. The adaptor should be secured by finger-tightening the nut, and the locating tool should be removed. The special retaining tool should be used to compress the inner 'O' ring, after which the adaptor nut should be fully tightened. The loose flange should then be fitted (paragraph 4.7.3).

6.2.4 **Inflation and Testing.** The tyre should be inflated (paragraph 7) and pressure tested (paragraph 8), and on completion of the test, the tightness of the adaptor nut should be rechecked, after which it should be wirelocked. The sealing efficiency of the outer 'O' ring should be checked by applying an acid-free soapy water solution over the crevices between the wheel, lock-ring and flange. The gap between the ends of the lock-ring should be blocked with rags or paper to prevent the solution draining into the wheel.

NOTE: This test on the inner 'O' ring should not be carried out until at least one hour after inflation in order to allow air trapped between the tyre and tube to escape first.

7 INFLATION AFTER FITTING After fitting, both tubed and tubeless tyres should be inflated to the test pressure specified in the relevant manual.

7.1 A suitable supply of dry air or nitrogen should be connected to the valve; nitrogen is preferred, but air may be used provided that the moisture content, measured in the expanded condition, is less than 0·02 g/m³. A screw-on type of connector should be used on tyres which are to be inflated to a pressure in excess of 700 kN/m² (100 lbf/in²), and the tyre and wheel assembly should be contained within a safety cage to prevent injury to the operator.

7.2 All tyres should be inflated slowly, and this is particularly important with tubed tyres. With tubed tyres, inflation to 140 kN/m² (20 lbf/in²) should take at least two minutes, and further inflation to full test pressure should take at least another four minutes. This procedure will reduce the possibility of trapping air between the tyre and tube.

8 TESTING The testing of either tubed or tubeless tyres should normally be by means of a duration pressure test, but an immersion test may sometimes be permitted on tubeless tyres when insufficient time is available. Pressure loss will occur on most tyres during a test, because of tyre stretch, and will be most apparent during the first 12 hours; the figures quoted for the duration pressure test take account of this loss.

8.1 **Venting.** With a tubeless tyre, venting from the awl vents (paragraph 2.4) occurs in three stages. The first stage of venting results from residual air in the casing and may be fairly rapid, but virtually ceases after 20 minutes. The second stage is a slow seepage of residual air from the casing and may last for several hours. The third stage is a continuing process and results from normal permeation through the inner lining. Tubeless tyres should, therefore, be tested after the first stage of venting has ceased, or misleading results could be obtained.

8.2 **Duration Pressure Test.** This test should normally be carried out as follows:—

(a) The valve cap should be removed and the valve checked for leakage.

(b) The actual tyre pressure should be checked and recorded.

(c) The assembly should be left for 12 hours, and the pressure should again be checked and recorded.

(d) If the loss in pressure from that originally recorded exceeds 10% the assembly should be rejected. If the loss in pressure is less than 10% the tyre should be re-inflated to the original pressure.

(e) The assembly should be left for a further 12 hours, and the pressure again checked and recorded.

(f) If the pressure loss is more than $2\frac{1}{2}\%$ the assembly should be rejected, but if less than $2\frac{1}{2}\%$ the assembly may be considered serviceable and returned to service.

NOTE: When recording tyre pressures allowance should be made for changes in ambient temperature. A temperature change of 3°C will result in approximately a 1% change in pressure. Application of the tyre pressure gauge will also result in a slight loss of pressure.

8.3 **Immersion Test.** After the first stage of venting, i.e. 20 minutes after inflation, the wheel and tyre should be mounted on a suitable bar and suspended in a tank of water so that the water covers the lower cross-section of the tyre and valve, but does not reach the wheel bearings. The wheel should then be slowly rotated and checked for leakage from the beads seats, seal area, valve, fusible plugs (see Leaflet **AL/3-19**) and wheel hub. A continuous stream of bubbles from any of these areas is cause for rejection. After testing, the wheel and tyre assembly should be thoroughly dried, using a jet of compressed air.

8.4 After tests have been satisfactorily carried out, the pressure should be reduced to 20% of unloaded inflation pressure for storage and transit, and the valve cap should be refitted and tightened to the specified torque value.

9 TYRE CREEP When wheels are first fitted to an aircraft, the tyres tend to move slightly as they settle down on the rims, the initial movement varying according to load, pressure, braking, shimmy and outside diameter of the tyre in relation to rim diameter. After the settling down period, circumferential movement may continue gradually and, if this extends beyond a certain limit, the valve may be torn from the tube.

9.1 In order that creep may be detected, marks are moulded into the lower wall of most tyres. The marks usually consist of two arrows, spaced 25 mm (1 in) apart on tyres up to 600 mm (24 in) nominal outside diameter and 38 mm (1·5 in) apart for all larger tyres. The marks usually commence at the wheel rim and extend outward, the surface between being knurled.

9.2 The knurled surface should be painted white, the paint mark being carried down on to the rim. The width of this mark represents the maximum circumferential movement permitted with tubed tyres, and if the tyre creep mark becomes out of alignment with the mark on the wheel by more than the width of the mark the wheel should be removed and the tyre and tube taken off and reassembled; before reassembly, the valve should be checked to ensure that it is undamaged. In the case of tubeless tyres, creep is not considered to be detrimental provided that bead condition is satisfactory and any pressure loss is within limits.

9.3 When tyre replacements are made, the old marking on the wheel should be removed with a suitable solvent and a new creep mark applied.

10 MAINTENANCE OF TYRES Unsatisfactory tyre maintenance can significantly affect tyre performance and reliability, and jeopardise aircraft safety. Serious accidents and incidents have occurred when engine, airframe and aircraft systems have suffered damage as a result of neglected or incorrect tyre maintenance. Various studies indicate that a significant number of tyre failures and premature removals could have been prevented by careful attention to recommended tyre maintenance procedures and practices.

NOTE: Where removal of a tyre is recommended in this paragraph, it should be understood that this implies removal of the tyre and wheel assembly from the aircraft.

10.1 **Tyre Pressures.** The importance of keeping tyres inflated to the correct pressure cannot be overstated. Under-inflated tyres may creep to such an extent that the valve could be torn out, causing the tyre to deflate rapidly, whilst over-inflation can cause excessive vibration when taxying, uneven tyre wear and high pressure bursts. In addition, where two wheels and tyres are mounted on the same axle, unequal tyre pressures will result in one tyre carrying a greater share of the load than the other, with possible operation above its rated capacity; the undercarriage may also be subject to additional stress.

10.1.1 Tyre manufacturers specify a rated inflation pressure for each tyre, which applies to a cold tyre not carrying any load. The pressure to which a tyre should be inflated when it is subject to aircraft weight, is determined by adding a pressure allowance (normally 4%) to the rated inflation pressure. A tolerance of 5% to 10% above the loaded inflation pressure is generally specified, and tyre pressures up to this maximum are permitted and may benefit tyre reliability. The loaded inflation pressures for the tyres on a particular aircraft may be specified in the relevant Maintenance Manual as the maximum and minimum pressures permitted, or in the form of a graph with pressure being a function of aircraft weight.

10.1.2 After an aircraft has landed, or has been subject to prolonged taxying, individual tyre pressures may vary because of the absorption of energy by the tyre and heat transfer from the brake units, and a pressure rise of up to 10% can be expected. This pressure should not be reduced to normal working pressure as this could result in under-inflation at normal temperatures.

10.2 **Inflation Procedures.** Dry air or nitrogen should be used for inflating all tyres, and the applicable precautions outlined in paragraph 7 should be observed. The particular gas specified by the aircraft manufacturer should always be used, and should not be mixed with the alternative unless specifically authorised. If a dial-type gauge is used, the required inflation pressure should register in the centre of the dial; all gauges should be checked for accuracy at frequent intervals. When using a high pressure storage bottle, a pressure reducing valve must be incorporated in the delivery line.

10.2.1 The normal procedure for inflating a tyre is as follows:—

(a) Check the pressure required by reference to the aircraft Maintenance Manual.

(b) Remove the valve cap and connect the supply to the valve (ensuring that a screw-on connector is used for pressures above 700 kN/m^2 (100 lbf/in^2)).

(c) Adjust the regulator on the inflation trolley to the required pressure.

(d) Slowly inflate the tyre to the required pressure.

(e) Disconnect the supply, check the valve for leakage, then refit the valve cap.

10.2.2 **Cold Tyres.** When checking the pressure of tyres which are at ambient temperature, any tyre which is more than 10% below loaded inflation pressure should be rejected, together with the companion tyre on the same axle. Any tyre which is between 5% and 10% below loaded inflation pressure should be re-inflated to the correct pressure and checked at the next daily check; if the pressure is again more than 5% low the tyre should be rejected.

10.2.3 **Hot Tyres.** It may often be necessary to check the pressures of tyres which are still hot following a landing. The pressure of each tyre should be checked and noted, and compared with the pressures of the other tyres on the same undercarriage leg. Any tyre with a pressure of 10% or more below the maximum recorded on the same leg should be re-inflated to that maximum pressure but should be rejected if a similar loss is apparent at the next check.

10.3 **Examination of Fitted Tyres.** A careful visual examination of tyres should be carried out prior to each flight, rotating the wheels wherever possible to ensure that the whole surface of the tyre is checked. Manufacturers prescribe limits of damage within which a tyre may be kept in service; tyres damaged in excess of these limits should be removed from the aircraft and repaired or scrapped as appropriate. The following paragraphs summarise the actions which should be carried out.

10.3.1 **Embedded Stones, Flints and Glass.** The outer surface of the tyre should be examined for embedded objects and any found should be carefully removed.

10.3.2 **Cuts and Scores.** All cuts should be probed with a suitable blunt tool in order to assess the depth and extent of any damage to the casing. Minor damage may be defined as that which does not affect the casing cord: cuts in both the tread and side rubber, providing they do not expose the casing cord, do not appreciably weaken the tyre. Such defects should be filled with a tyre dough compound, since continued exposure permits the entry of water and grit, which tends to cause chafing and rotting. Tyres damaged beyond the limits described above should be rejected.

10.3.3 **Bulges.** The presence of bulges may indicate a partial failure of the casing, and the tyre should be removed for further examination. If it is obvious that the casing has failed, i.e. if the fabric is fractured, the tyre should be rejected, but if not it should be returned to the manufacturer for possible repair.

10.3.4 **Wear.** The extent to which tread has been removed from a tyre is not always easy to assess and may be either general or local; methods of indicating wear are shown in Figure 6. Local wear may be in the form of a 'flat spot' caused by severe abrasion or skid burns and these may occur as a result of excessive braking, hard touch-downs or aquaplaning. The probability of aquaplaning increases as the depth of tread is reduced. It is recommended that tyres be removed when wear has reached the limits defined below:—

(a) Patterned tread tyres may be used until the tread is worn to the depth of the pattern.

(b) Ribbed tyres with marker tie bars may be used until worn to the top of the tie bars.

(c) Ribbed tyres without marker tie bars may be used until worn to within 2 mm (0·080 in) of the bottom of the wear indicator grooves.

(d) Twin contact tyres may be used until the centre of the crown shows sign of having been in contact with the ground.

(e) Plain tread tyres may be used until either the grey cushion rubber is exposed (on early tyres only), or when the shape of the casing cords can be seen through the cushion rubber.

NOTE: On tyres with reinforced tread, several layers of fabric are moulded into the tread rubber and will become visible during normal use; the threads so exposed should not be confused with the casing cords. These tyres are provided with marker tie bars which should be used to assess the wear as in (b).

10.3.5 **Creep.** Tyre creep should be dealt with as indicated in paragraph 9.

10.3.6 **Sponginess.** Tyres which are only slightly affected by fuel, oil or glycol and which, after being wiped and allowed to dry, show no appreciable signs of swelling or softening, may be considered serviceable; tyres affected beyond this stage should be rejected.

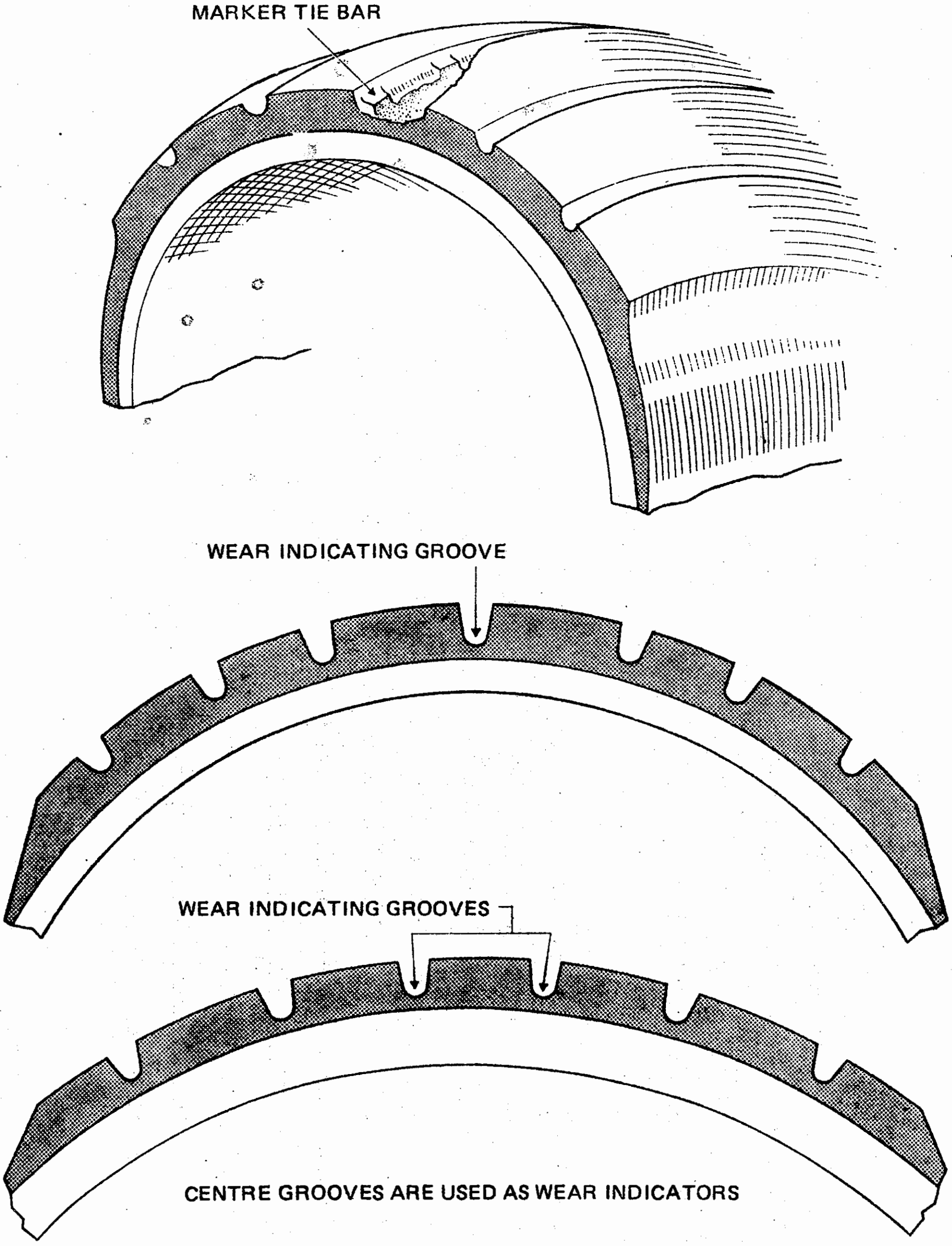

Figure 6 INDICATION OF TYRE WEAR

10.3.7 **Flat Spots on Nylon Tyres.** Tyres having nylon casings may, due to their lack of elasticity, develop a temporary 'flat spot'. This should not be confused with the flat worn on the tread as described in paragraph 10.3.4, but is caused by the local relief of tension in the cords at that section of the tyre and is usually the result of the tyre being subjected to static load for a lengthy period.

(a) Stretch of the nylon cords is considerable and progressive, and when the load is removed the cords do not immediately resume a tension equal to that of the cords in the rest of the casing.

(b) Normally the flat spot works itself out during the period of taxying before take-off, but should this not be the case, the tyre will be out of balance and set up vibration in the aircraft during take-off.

(c) Precautions against the occurrence of flat spots can, however, be taken; these include occasionally moving aircraft which are to be stationary for lengthy periods in order to transfer the load to different sections of the tyres.

(d) If a flat spot has developed, it can normally be remedied by rolling or taxying the aircraft for a short distance.

10.3.8 **Heat Transmission.** On aircraft main wheels, excessive braking may result in the transmission of heat to the beads of the tyres. If this is evident from indications of excessive heat on the wheels (such as discolouration, paint flaking or melting of fusible plugs) the tyres should be carefully examined. The results of overheating are indicated by 'tackiness' of the tyre bead and, in severe cases, a deposit from the tyre will adhere to the wheel flanges and bead seats. Tyres affected in this manner should be rejected.

10.3.9 **Deflated Tyres.** Tyres which have been under load while in a deflated condition should be removed from the aircraft. If the aircraft has taxied with a tyre in this condition, the deflated tyre and its axle companion should be scrapped, but if a single tyre deflates while static (except when deflated for servicing purposes) it should be removed and inspected in accordance with the relevant Maintenance Manual. If more than one of the tyres on a multi-wheel undercarriage are found to have been run in a deflated condition, all the tyres on that undercarriage should be scrapped.

10.3.10 **Rejected Take-offs.** A rejected take-off at high energy levels may have resulted in the overstressing or overheating of all the main wheel tyres, although no evidence of damage may be visible. Reference should be made to the relevant Maintenance Manual for guidance on the action to be taken.

10.3.11 **Replacement Tyres.** New and retreaded tyres have slight differences in external diameters, and replacement tyre and wheel assemblies for twin or multi-wheel undercarriages should be selectively fitted to ensure that both or all tyres take an equal share of the load.

10.4 **Protection.** Tyres must be protected from excessive heat, dampness and bright light, and from fluids such as oil, fuel, glycol and hydraulic fluid, since all of these have a harmful effect on the rubber. If the aircraft is to be parked for any length of time, or if any of the above-mentioned systems are to be drained, an oilskin cover should be placed over the tyre. Any fluid inadvertently spilt or allowed to drip on to the tyre should be wiped off immediately.

11 REMOVING TYRES Defects in tyres, particularly those which would be difficult to find once the air pressure is released, should be marked with wax crayon before the tyre is removed. It is recommended that the tyre pressure should always be reduced before removing a wheel from an aircraft and that a screw-on type deflator is used to deflate a tyre or tube.

11.1 **Tubed Tyres**

11.1.1 **Well-base Wheels**

(a) The tube should be deflated and the valve core removed; the bead should then be unseated by levering it away from the rim of the wheel on the valve side.

(b) The valve should be pushed in and tucked away under the tyre, the bead being levered off by commencing at approximately 60° from the valve and working away from it, using levers lubricated with acid-free soapy water.

(c) The wheel should be turned over and the other bead unseated as in (a). Some difficulty may be experienced in levering the bead from the rim on this side of the wheel, owing to the heat generated by the brakes. In this instance also, the levers should be lubricated with acid-free soapy water.

(d) The tube should be removed by grasping it diametrically opposite the valve and pulling it out of the tyre, the valve being the last part of the tube to emerge.

(e) The bead should be pressed into the well of the wheel and a lever placed between the bead and the wheel flange with its tip positioned at the valve hole. When pressure is applied to the lever, the tyre should come off quite easily.

11.1.2 **Divided Wheels.** Great care must be taken to ensure that the tyre is completely deflated before any attempt is made to remove the loose members. (See also paragraph 11.3.)

(a) The tube should be deflated and the valve core removed; the bead opposite to the valve should be unseated by levering it away from the wheel rim, using acid-free soapy water as a lubricant.

(b) The second bead should be unseated in a manner similar to that used for the first bead and the bolts should be removed from the wheel.

(c) An aligning mark, to assist reassembly, should be placed on both halves of the wheel below the valve, after which the upper half of the wheel should be lifted off and the tyre removed.

(d) If a tyre is not to be fitted to the wheel immediately, the wheel should be re-assembled.

11.1.3 **Detachable Flange Wheels.** Great care must be taken to ensure that the tyres are completely deflated before any attempt is made to remove the loose members. (See also paragraph 11.3.)

(a) The tube should be deflated and the valve core and flange locking device removed; the detachable flange may then be levered away from the tyre bead. The wheel should be turned over and the second bead loosened, after which the tyre and tube should be removed from the hub, care being taken to ensure the tube valve is not damaged in the process.

(b) If a tyre is not to be fitted to the wheel immediately, the wheel should be re-assembled.

11.1.4 **Wheels Embodying Combination Adaptor Scheme.** Deflate the tyre by removing the valve cap and core, but before attempting to remove the flange and locking device, remove the adaptor nut, washer and outer 'O' ring. The adaptor should be pushed well into the tyre with a blunt wooden probe to avoid the possibility of damage to the adaptor during dismantling. The wheel and tyre assembly may then be dismantled as outlined in paragraph 11.1.3.

11.2 **Tubeless Tyres.** The tyre should be deflated and the valve core removed, or, where a sidewall valve is used, deflated by removing the core from the servicing needle and inserting the needle in the valve insert. The valve core and cap should be refitted or the servicing needle removed as appropriate. The beads should be unseated from the taper bead seat by means of a special tyre removal machine which exerts an even pressure circumferentially round the wheel on both sides of the tyre. Sharp tools or tyre levers must not be used to unseat the beads as this may impair the sealing properties of the tyre and wheel. Finally, the wheel assembly should be dismantled according to its type and the rubber sealing rings removed.

11.3 **High Pressure Tyres.** During deflation of these tyres the valve stem may become blocked with pieces of ice. The use of probing devices to remove the ice is unnecessary, since the ice formation will break down under normal ambient temperatures, permitting the further passage of air. However, it must be noted that blockage of the valve by ice may take place several times during deflation, and it is essential to allow sufficient time to elapse between the removal of the valve core and the commencement of dismantling to ensure that the air has been completely exhausted.

12 INSPECTION OF TYRES AND TUBES REMOVED FROM AIRCRAFT Paragraph 10 details the checks to be made on tyres during running maintenance; at the periods specified in the Maintenance Schedule, the tyres should be removed from the aircraft and examined as described in the manufacturer's Service Manual. Guidance on inspections and typical defects is given in this paragraph.

12.1 **Tyres**

12.1.1 **Fractures.** The inside of the tyre should be examined for fractures caused by fatigue or concussion. The latter defect may be caused by heavy impact on a protrusion, e.g. striking a stone during touch-down. External detection of the fracture may be difficult, but a dark stain on the tyre, or a very slight smooth bulge, may be visible where the rubber is bruised.

(a) If a fracture has occurred, internal inspection will reveal a diagonal line or a 'star', dark in colour, at the point where the impact occurred.

(b) The interior examination of a large tyre may be facilitated by rolling it along the floor and observing closely the area which is flattened by contact with the ground, since this tends to open the fracture.

(c) Tyres so damaged should be scrapped and labelled accordingly.

12.1.2 **Bead Failure.** Tyres showing any signs of bead chafing or break-up of the bead should be returned to the manufacturer for assessment of possible repair.

12.2 **Tubes.** The base of the tube, i.e. that part of the tube which has been in contact with the tyre, on the brake side, should be examined for evidence of thinning of the rubber caused by heat generated during normal braking operations.

12.2.1 Tubes which have thinned at the base, are perished or cracked, have 'grown' or stretched unduly, or show bad creases, must be discarded.

12.2.2 Valve stems should be examined for bending, cracks or damaged threads, and, if damaged beyond local repair, the tube should be rejected. Valve cores with bent pins or damaged threads, or showing signs of corrosion, should be renewed.

12.2.3 Cuts in tubes may be repaired by a vulcanising process, except where they occur in the region of the valve. Vulcanising is a specialised process and should only be done by trained personnel using suitable equipment.

12.3 **Tubeless Tyres.** The tyre should be thoroughly cleaned with clean water, and inspected for damage, paying particular attention to the inner lining and the entire bead area. It is essential that the beads should be clean and free from grease.

13 REPAIR OF TYRES AND TUBES Tyres and tubes which have been removed from aircraft because of damage which is considered to be in excess of the limits defined in paragraph 10, may still be repairable locally provided the necessary tools and vulcanising equipment are available. These repairs must not exceed the limits laid down in the manufacturers' Repair Manual and must be carried out by personnel having the specialised knowledge and experience necessary and using only those materials specified by the manufacturer. The method of repair is to remove the damaged rubber and replace it with unvulcanised sheet rubber repair compound which is then vulcanised to the existing rubber by heat and pressure. During the vulcanising process the repair compound is converted into a material with properties almost identical to the surrounding rubber. A typical procedure for carrying out a repair is summarised in the following paragraphs.

13.1 **Classification of Damage.** The tyre or tube should be carefully inspected and all damage marked. A probe should be used to ascertain the depth and extent of cuts.

13.1.1 Minor damage to tyres is damage to tread or sidewall rubber not affecting the casing cords, up to a maximum of 38 mm (1·5 in) diameter. Numerous repairs of minor damage may be carried out.

13.1.2 Damage involving cut cords may be repaired in the tread area only, provided that not more than 20% of the cord layers or a total of four are damaged.

13.1.3 Small holes in tubes may be plugged with compound and larger damaged areas may be repaired up to an area of 50 mm × 50 mm (2 in × 2 in). Both types of repair must be vulcanised.

13.1.4 Tyres or tubes which are damaged beyond these limits should be returned to the manufacturer for possible repair.

13.2 **Repairs to Tyres.** For all types of repair, the tyre should be mounted on a wheel and inflated to a pressure of 140 to 210 kN/m² (20 to 30 lbf/in²) for crown and shoulder repairs, 70 to 140 kN/m² (10 to 20 lbf/in²) for sidewall repairs. A chalk line should be drawn round the damaged area to indicate the extent to which the rubber is to be removed.

13.2.1 The rubber is removed within the chalk circle by using a hollow drill, rotary rasp or knife as appropriate to the area affected, bevelling the edges at 45° and taking care not to damage the cords.

13.2.2 Where cords are damaged, the gap between the cord ends should be treated with tyre repair solution and filled with a suitable piece of tyre repair compound well rolled down.

13.2.3 The walls of the cavity and surrounding rubber should now be roughened with a rotary wire brush, and the rubber remaining on the cord surface removed to expose the cords. The roughened rubber surface and exposed cords should now be given two coats of the tyre repair solution, the first coat being brushed well in and allowed to become tacky before lightly applying the second coat.

13.2.4 The repair area should now be built up with successive layers of tyre repair compound, each layer being well rolled down to exclude any air bubbles. When the level of the repair is slightly higher than the surrounding rubber, the surplus compound should be removed with a sharp knife (lubricated with water as necessary), leaving a slightly raised crown in the centre. The surface should then be cleaned, dried and dusted lightly with French chalk.

13.2.5 The pre-heated vulcanising unit, fitted with a suitably-shaped base plate, should now be clamped centrally over the repair and left in position for a period of time appropriate to the thickness of the repair as specified by the manufacturer. The temperature is controlled automatically at approximately 150°C (300°F).

13.2.6 After removal of the vulcanising unit, the repair should be tested by probing with a blunt pencil point; if the pencil springs back the repair is correctly vulcanised, but if an indentation is left in the rubber the vulcanising unit should be replaced for a further 15 minutes.

13.2.7 The final stage of repair is the replacement of the tread pattern, which should be re-cut using either a hollow drill or knife.

13.3 **Repairs to Tubes**

13.3.1 **Solution.** The solution used for repairing tubes is prepared by cutting thin strips of tube repair compound, covering them with the solvent specified by the manufacturer and leaving them for 24 hours in a sealed container. The liquid thus obtained is then stirred and thinned down with solvent to the consistency of thin paint. Only small quantities of solution should be prepared as it is highly volatile and deteriorates quickly.

13.3.2 **Small Holes.** The hole should be roughened right through and the adjacent area cleaned with solvent and treated with solution. The plug should be made from a strip of tube repair compound, fed through the hole and trimmed off slightly proud of the surrounding material. The repair is completed by rolling down the plug and vulcanising for a period of time specified by the manufacturer.

13.3.3 **Large Holes.** A circular hole should be cut round the damaged area using a pair of curved scissors. Holding the scissors flat against the tube and working in a clockwise direction will ensure that the edge of the hole is correctly bevelled. The edges of the hole and surrounding area should now be roughened with a wire brush and cleaned with a muslin cloth dipped in solvent.

13.3.4 To prevent the repair from sticking to the opposite wall of the tube, a thin piece of paper, slightly larger than the hole, should be inserted through the hole and located centrally. The solution should then be applied on top of the paper and the roughened tube area, and rubbed well in. When the solution has reached a dry, tacky, state the repair should be built up and vulcanised in the same manner as described for tyres in paragraphs 13.2.4 and 13.2.5, but using a flat base plate on the vulcanising unit and working on a suitable flat bench.

14 REMOULDING TYRES Most aircraft tyres, when worn beyond safe, usable limits, may have their useful life extended by replacement of the tread rubber; this operation may, however, only be carried out by the original manufacturer or by an approved specialist organisation. The term 'retread' is normally used where the crown and shoulder rubber is replaced and cured in a specially designed mould. The term 'remould' is normally used where the tyre is similarly processed, but is cured in a mould similar to that in which the tyre was originally made; the new tread is therefore cured, and the sidewall rubber re-cured without being renewed. Tests have shown that the strength of a tyre casing does not deteriorate appreciably throughout its life; up to 10 remoulds have been carried out on specific tyres with only a 1% decrease in strength. The casing life for almost all aircraft tyres is therefore determined by initial tyre quality and the exercise of proper maintenance practices while the tyre is in service. One exception to the general rule is the case of the high performance aircraft where skin friction temperatures in continuous high-speed flight could result in prolonged high wheel-bay temperatures and consequently a diminished tyre life.

14.1 On new aircraft types the first few tyres are returned after service for a thorough examination by the manufacturer. If this examination is satisfactory the next few tyres are used to develop a remoulding technique and to evaluate the tyre's structural life. On successful completion of these tests the tyre is approved for one remould life. From this stage the process is repeated until a particular type of tyre can be released for its optimum number of remoulds.

14.2 **Initial Inspection.** The initial inspection of a tyre received by a manufacturer for repair or remould is carried out by personnel with a wide experience in the manufacture and servicing of tyres. The degree of damage which can be allowed depends on the use for which the tyre was designed and the aircraft type to which it is to be fitted. The inspector must take account of every type of deterioration to which the tyre has been subjected throughout its service life. Even though individual damage may be repairable, the general condition of a tyre often results in its rejection. The various types of damage which can occur are cracking, skin burns, oil contamination, excessive wear, tread separation, cuts, ply separation and damaged cords, The most highly stressed portion of the tyre is the bead area where only very minor damage is permitted.

14.3 **Buffing.** Depending on the extent of remoulding approved for a particular tyre the required amount of rubber is removed on a buffing machine. This operation also provides the opportunity for a further inspection of the tyre, as many defects such as cuts and broken cords, can only be seen when the tread is removed.

14.4 **Remoulding Process.** After the original rubber is removed, the casing is treated with a layer of cement and the complete new tread carefully rolled on under pressure. The whole assembly is then mounted in the appropriate mould, where heat and pressure are applied until vulcanising is complete. The vulcanising time and temperature are pre-determined by the manufacturer for the type, size and ply rating of the tyre.

14.5 When the remoulding process has been completed the tyre is balanced and re-inspected before being finally released for further service.

15 STORAGE Excessive light and heat will cause cracking and general deterioration of rubber, therefore tyres and tubes should be stored in a darkened room having a dry temperature of from 10 to 27°C (50 to 80°F). and should be kept away from radiators, steam pipes, electric motors or other sources of heat. It should be ascertained that the possibility of contamination from oil or grease does not exist, since this would also cause rapid deterioration of the rubber.

15.1 **Tyres.** Preferably, tyres should be stored vertically in special racks embodying support tubes, so that each tyre is supported at two points. Two-thirds of the tyre should be above the support tubes and one-third below. By this method, the weight of the tyre is taken by the tread, and distortion is reduced to a minimum. The tyres should be turned to a new position every two or three months.

15.1.1 Where space does not permit the use of the above method, tubed tyres may be stored horizontally in stacks on a level floor. The height of stacks should be limited to four tyres so that the weight does not cause distortion of sidewalls and tread on the lower tyres which could lead to failure in service. Staggering the tyres in piles tends to distort the bead wires and casing. If possible a stack of tyres should be graded so that the largest tyre is at the bottom and the smallest at the top. This method of storing should not be used for tubeless tyres, as the beads could be pressed close together and make mounting and inflation more difficult.

15.1.2 Where tyres are delivered in bituminised hessian wrappers, the wrappers should be left on during storage.

15.2 **Tubes.** Tubes should preferably be stored in their original wrapping; if they cannot be stored in this manner they should be slightly inflated and stored inside tyres of appropriate size.

15.3 **Assembled Wheels.** The tyres on assembled wheels not required for immediate use should be inflated to a pressure of 140 to 210 kN/m^2 (20 to 30 lbf/in^2) for storage and shipment.

15.4 **Shelf Life.** Provided that the ideal storage conditions are maintained, tyres and tubes may be kept in storage for up to seven years from the date of manufacture, without deterioration. It is recommended, however, that stocks be limited to a quantity which will ensure that a storage life of four years is not exceeded. This will ensure that the most advantage is taken of improvements in design and manufacturing techniques. After seven years in storage, tyres should be returned to the manufacturer for assessment.

16 RECORDS When required by the Maintenance Schedule, a record should be kept of the number of landings for each tyre on the aircraft.

AL/3-19

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AIRCRAFT

SYSTEMS AND EQUIPMENT

WHEELS AND BRAKES

1 INTRODUCTION This Leaflet gives guidance on the installation and maintenance of aircraft wheels and brakes. It should be read in conjunction with the relevant approved Maintenance and Overhaul Manuals and Maintenance Schedule, from which details of the construction and maintenance requirements of the particular components may be obtained.

1.1 Information on hydraulic systems is contained in Leaflet **AL/4—1,** on pneumatic systems in Leaflet **AL/5—1,** on flexible pipes in Leaflet **AL/3—13,** on rigid pipes in Leaflet **AL/3—14** and on tyres in Leaflet **AL/3—18.**

NOTE: This Leaflet incorporates the relevant information previously published in Leaflets **AL/8—2,** Issue 2, and **AL/8—3,** Issue 2, published 16th October, 1961.

2 GENERAL Aircraft wheels and wheel brakes are often subjected to severe conditions of operation, including shock loading and exposure to high temperatures, and the utmost care is necessary during installation and maintenance to ensure that their condition remains satisfactory during service. Owing to the risk of explosion caused by heat generated by friction in the brakes during landing and taxying, special safety precautions may be necessary when handling or servicing brake, wheel, and tyre assemblies, particularly in an extreme situation such as immediately after an abandoned take-off, when the components may be overheated.

2.1 On light aircraft, where aircraft weight and landing speed are low, single wheels are fitted at all landing gear positions. Wheel brakes on older types of aircraft are often of the expanding shoe type, similar to conventional automobile practice, and may be operated by cables or by a simple independent hydraulic system. In these systems a single hand brake lever may be used to apply both brakes together, or each brake may be operated individually from a pedal attached to the rudder bar. Modern high performance light aircraft are more usually fitted with hydraulically operated disc brakes.

2.2 With larger and modern types of aircraft, where aircraft weight and landing speed are high and aerodynamic drag is low, multiple wheels are generally used at all undercarriage positions, to spread the aircraft weight over a greater area and facilitate stowage in the airframe structure. Some older types of medium sized aircraft are fitted with large single wheels and pneumatically actuated drum brakes, but most modern transport aircraft are fitted with twin nose wheels and twin wheels or a four-wheel bogie arrangement at each main undercarriage position. Brakes are of the multiple disc type and are operated from the normal aircraft hydraulic system.

3 WHEELS

3.1 **Construction.** Wheels are usually made from aluminium or magnesium alloy forgings or castings and are of three main types (Figure 1), known as well-base, detachable flange and split hub. Well-base wheels are only fitted on light aircraft and are normally used in conjunction with tubed tyres. Nose wheels which do not house brake units, are usually of simpler construction than main wheels, but in some instances all wheels on an aircraft are interchangeable for ease of provisioning.

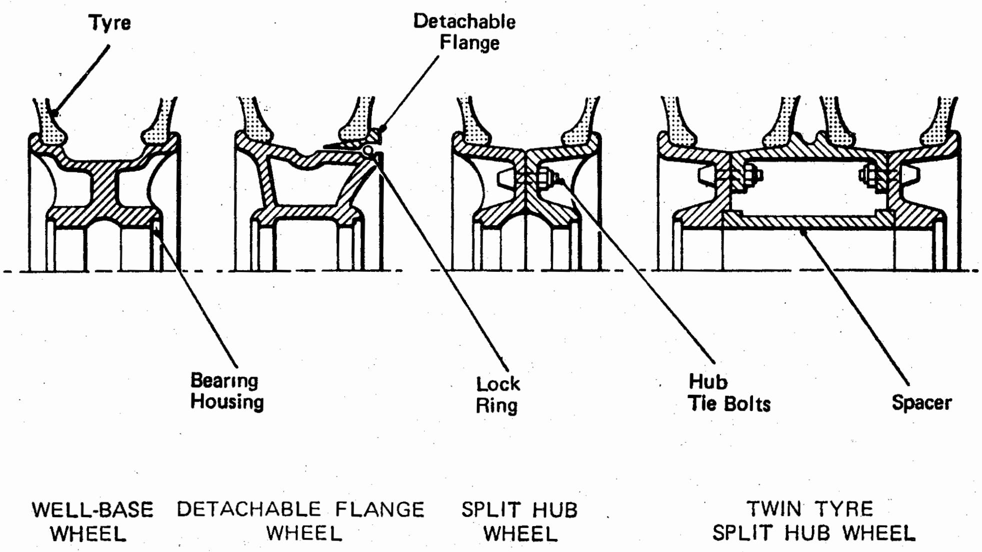

Figure 1 WHEEL TYPES

3.1.1 Heat generated by braking action is dissipated by radiation and conduction through the wheel and tyre, and every effort is made to keep heat transference to a minimum. Wheels are designed to permit optimum ventilation, and cylindrical stainless steel heat shields may be installed around the brake unit. On some aircraft, an electric motor mounted within the axle, or a series of motors installed in the brake housing, drive fans which provide a forced draught through the wheel and relieve the build-up of heat.

3.1.2 To prevent the danger of tyre explosion, the main wheels of many modern aircraft are fitted with fusible plugs which melt at a predetermined temperature (approximately 150°C), allowing a piston to be blown out of the plug bore and thus deflating the tyre.

3.1.3 Some aircraft wheels are also fitted with a pressure relief valve, the purpose of which is to prevent over-inflation of the tyre.

3.1.4 In general wheels are mounted on ball or roller bearings which fit directly on to the axle, or on to a bearing sleeve which is keyed to the axle. In some cases, nose wheels are mounted rigidly on to a "live" axle, which itself rotates within bearings in the nose wheel leg.

3.2 **Removal.** Before removing a wheel, the aircraft must be prepared and jacked up in accordance with the approved Maintenance Manual. These preparations may be very simple, such as chocking the opposite wheels and lifting the wheel which is to be removed by means of a bottle jack, but on large transport aircraft additional procedures, such as fitting ground locks to the landing gear, landing gear doors and steering mechanism, may be necessary. In some cases one wheel of a twin wheel arrangement may be lifted clear of the ground by running the other wheel up an inclined block. On aircraft with multi-disc brakes it is usual to set the brakes on before removing the wheel in order to keep the rotating discs in alignment with the driving keys in the wheel hub; on aircraft with drum brakes, however, application of the brakes would prevent removal of the wheel and they should be released.

3.2.1 A typical removal procedure is described below:—

(i) Prepare aircraft for jacking in accordance with the appropriate aircraft Maintenance Manual.

(ii) Raise axle or bogie, as appropriate, until the tyre is clear of the ground.

(iii) Deflate tyre or reduce pressure to a low value.

NOTE: During release of tyre pressure, icing of the valve may occur and give a false indication of complete deflation. Sufficient time must elapse after the air flow has ceased to ensure that any ice has melted and that the tyre is sufficiently deflated.

(iv) Where applicable, remove cooling fan or hubcap assembly.

(v) Remove axle nut locking device.

(vi) Remove axle nut and install thread protector.

(vii) Position wheel trolley and remove wheel carefully so as not to damage the axle.

NOTE: On some aircraft it is recommended that an approved extractor is used when removing the wheel.

(viii) Remove grease seals and bearings.

(ix) Install axle protector.

(x) Fit protective cover over the brake assembly if the wheel is not to be re-fitted immediately.

3.3 **Installation.** Before installing a wheel and tyre, the general condition of the wheel, tyre and bearings should be checked (paragraph 3.4 and Leaflet **AL/3—18**). The axle should also be checked for corrosion, scores and other damage, particularly in the bearing support area and, if an axle sleeve is fitted, this should be checked for allowable wear at the bearing area and correct fit on the axle. Bearings on new or replacement wheels may be packed with storage grease, and this should be cleaned out and replaced by grease specified for service use.

3.3.1 A typical installation procedure is described below:—

(i) Grease inner bearing and seal with the specified grease, and install on axle.

(ii) Slide wheel into position on axle, using the appropriate aligning fixture as necessary to line up the brake disc driving keys in the wheel hub with the slots in the rotating discs.

(iii) Grease and install the outer bearing and seal.

(iv) Remove thread protector and lubricate axle threads.

(v) Install axle nut and tighten to the recommended initial torque, rotating the wheel as the nut is tightened.

(vi) Slacken axle nut then, again rotating the wheel, tighten to the specified final torque and fit the locking device.

(vii) Replace cooling fan or hub cap assembly.

(viii) Check tyre pressure and tyre growth clearance, retracting landing gear where necessary to facilitate this check, then lower the aircraft and remove the ground locks installed to prevent operation of the steering mechanism or landing gear doors.

3.4 **Maintenance.** A superficial inspection and minor repairs may be carried out with the wheel installed on the aircraft. A more detailed inspection is made when the wheel is removed for tyre replacement following operation with a deflated tyre (or with the companion tyre deflated on a twin wheel arrangement), and at the intervals specified in the approved Maintenance Schedule. Some wheels may require overhaul after a specified number of landings.

3.4.1 **Installed Wheels**

(i) The wheel should be examined for cracks, corrosion, distortion, dents and scores, particular attention being given to the wheel flanges. Small dents on the outside of the flanges may usually be blended within specified limits, but in general no damage is permissible where the flange is in contact with the tyre. When a dent or abrasion is blended out, the exposed metal should be closely inspected for cracks and the protective treatment renewed. It is particularly important to give prompt attention to protective treatments following repairs to magnesium alloy wheels.

(ii) Wheel hub tie bolts and nuts, inflation valves, balance weights and, where visible, the axle nut locking device, should be inspected for security and damage. If any tie bolt is found defective, the wheel should be removed and the complete set renewed.

(iii) The wheel, brake and tyre should be examined for signs of overheating, such as blistered or discoloured paint, distortion, and leakage of grease from the wheel bearings.

NOTE: If a fusible plug is found to be blown out, the tyre should be scrapped and all fusible plug seals renewed, but the wheel may be satisfactory subject to certain checks (paragraph 3.4.2).

(iv) Periodically the wheels should be raised clear of the ground in order to check for free rotation and end float in the bearings.

3.4.2 **Wheels Removed from Aircraft**

(i) The tyre must be completely deflated before any attempt is made to dismantle a wheel or remove a tyre.

(ii) Dismantled wheels should be thoroughly cleaned in a suitable cleaning fluid and then examined for cracks, corrosion, distortion or other damage.

(iii) Some manufacturers require that paint should be completely removed from wheels before checking for cracks. Where chemical paint strippers are used it is essential that the chemical is removed by thorough washing.

(iv) A careful examination should be made for cracks around bolt holes, in the radius at the base of the wheel flange (tyre bead seat) and at other highly stressed points or changes of section. These examinations are normally made using ultrasonic or eddy current methods.

(v) Light surface corrosion can be cleaned off, and damage blended out within specified limits, but deep corrosion, scores, dents or cracks beyond these limits will render the wheel unserviceable.

(vi) Brake drums should be examined for signs of distortion, wear, scores and cracking and there should be no evidence of drum movement relative to the wheel. With disc type brakes the drive blocks in which the discs are tenoned should be checked for security, damage, wear and hammering.

NOTE: The braking surface of bi-metal brake drums is subject to crazing; this condition is acceptable until it advances beyond the limits specified in the relevant manual.

(vii) Wheels should also be inspected for distortion and concentricity, by mounting the wheel on a mandrel in vee-blocks and checking at the flange with a dial test indicator. Distortion may also be checked using large calipers. After this check the wheel should be statically balanced.

(viii) Wheels which may have been damaged by overheating but which are not found to be distorted and are otherwise serviceable, may be required to be given a check for material hardness. When this check is specified, the method and the acceptable range of hardness numbers will be found in the approved Maintenance Manual.

(ix) Bearings may sometimes be inspected in position, but they must often be removed (using an extractor where necessary) in order that they may be thoroughly cleaned and inspected. They should be cleaned in a solvent such as white spirit and examined for corrosion, brinelling of the races, chipped balls or rollers, retaining cage condition, roughness and discolouration. If serviceable, bearings should be packed with approved grease immediately after inspection, and protected from dust and dirt.

(x) Tie bolts, i.e. those used for clamping the two halves of a split hub, should be checked for corrosion, distortion, cracks and condition of threads. Any damage found on these bolts will necessitate their replacement. In some instances, self-locking nuts which are found to have a satisfactory locking torque may be re-used, but the manufacturer may require all stiffnuts to be discarded after disassembly.

(xi) Wheels should be painted and reassembled in accordance with the manufacturer's recommendations, and particular care should be paid to the sequence of assembly and torque tightening of the tie bolts. It is usually recommended that new seals should be fitted during re-assembly.

(xii) When a tyre is assembled on a wheel, the complete unit should be statically balanced.

4 DRUM BRAKES Although used extensively on earlier aircraft, drum brakes have largely been superseded by hydraulically operated disc brakes, on most modern high performance aircraft. Pneumatically operated drum brakes may still be found in service, however, and the construction, operation and maintenance of a typical brake unit of this type is described in the following paragraphs.

4.1 **Construction.** The main components of the brake unit are the back plate, brake drum, expander tube (pressure bag) and brake linings (Figure 2).

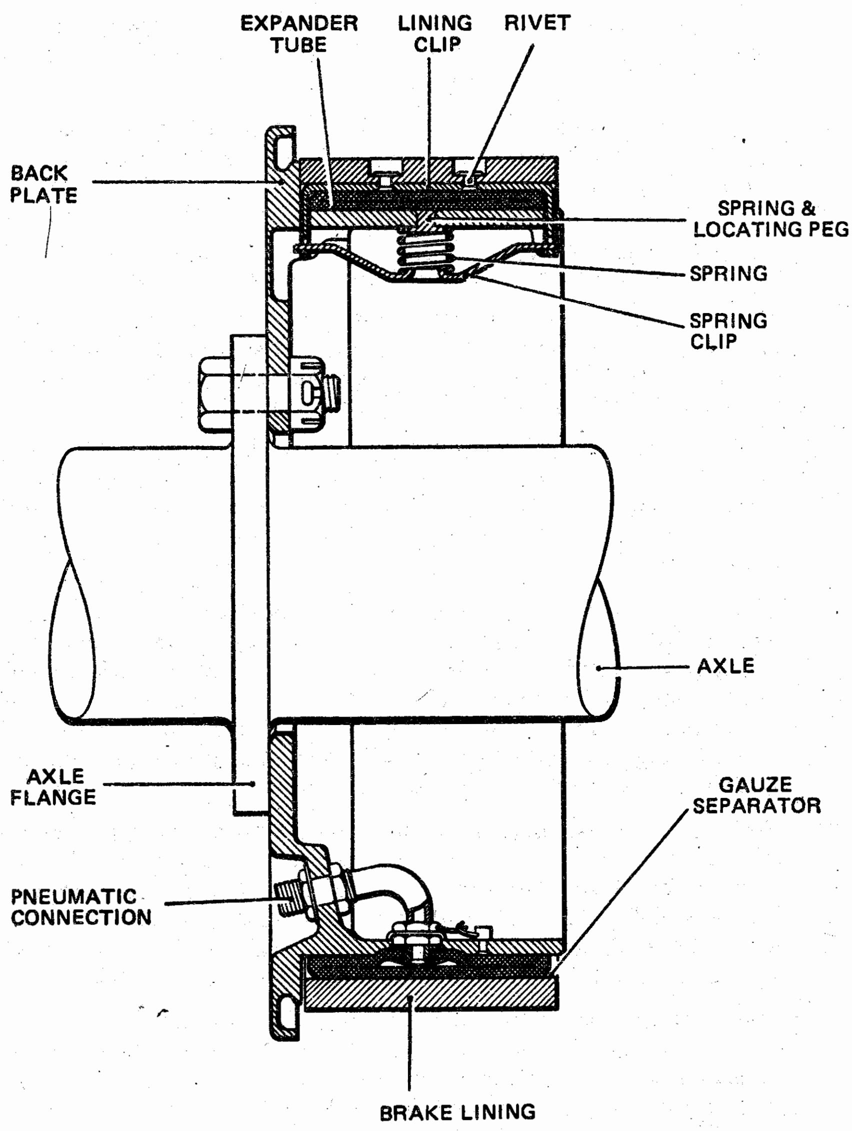

Figure 2 DRUM BRAKE

4.1.1 **Back Plate.** This unit is cylindrical in shape and is attached to a flange on the axle. It houses the expander tube, brake linings and pneumatic connections.

4.1.2 **Expander Tube.** This is a circular, reinforced rubber tube of flat cross-section, and is fitted around the back plate. It has a pneumatic connection leading through the back plate to the aircraft pneumatic system.

4.1.3 **Brake Linings.** The complete brake lining assembly is made up of a number of segments of heat-resisting friction material which form a ring around the expander tube and are shaped to conform to the inside radius of the brake drum. Each segment is bonded or riveted to a metal fitting, which protrudes through the back plate and is secured by a spring clip.

4.1.4 **Separators.** Phosphor-bronze gauze separators are fitted between the ends of the brake lining segments to reduce heat penetration to the expander tube and to exclude carbon particles.

4.1.5 **Brake Drum.** The brake drum is a heavy steel cylinder, attached to and rotating with the wheel, and against which the brake lining segments expand to produce the braking action.

4.2 **Operation.** When the pilot's control is operated, air pressure is applied to the inside of the expander tube, which expands and forces the brake linings against the brake drum. When air pressure is released the expander tube collapses and the brake linings are withdrawn from the brake drum by the action of the return springs.

4.3 **Removal/Installation.** Before attempting to work on the brake system or to remove a wheel, it is important to ensure that all air pressure is exhausted from the system. Disconnecting a pipe joint containing air pressure is a dangerous practice, and, if a wheel is removed with the brake system connected and pressurised, inadvertent operation of the brake could cause the expander tube to burst and possibly damage other parts of the system. In many pneumatic systems a pressure maintaining valve is used to safeguard the brake pressure in case of a leak elsewhere or failure of the compressor, so that lack of pressure in the brake system must be confirmed from the brake system pressure gauge and not by reference to the general system pressure.

4.3.1 When the wheel has been removed, the brake unit can be removed by disconnecting and blanking the air pressure connection and removing the bolts attaching the back plate to the axle flange.

4.3.2 When installing a new brake drum, the protective treatment applied for storage purposes should first be removed with a suitable solvent such as methylated spirits; petrol or paraffin should not be used.

4.3.3 When installing the brake unit, care must be taken to ensure that oil or grease do not come into contact with the linings; operators should also avoid handling the linings as the natural oils from the skin may have an adverse effect. If brake linings do become contaminated they must be considered unserviceable; no attempt should be made to clean the surface with solvents.

4.4 **Inspection**

4.4.1 Drum brakes are not normally accessible for visual inspection when installed on the aircraft. During a pre-flight inspection the back plate and wheel should be examined for signs of overheating, and the flexible pneumatic hose between the brake units and the landing gear leg should be checked for damage, security or leaks. Operation of the brakes may be checked by means of the brake pressure gauge and also by checking that air is discharged from the brake relay valve (Leaflet **AL/5—1**) when the brakes are released.

4.4.2 At the times specified in the approved Maintenance Schedule, and whenever unsatisfactory operation is suspected, the brake unit should be removed for inspection and overhaul. Disassembly, which should be carried out on a rubber or felt covered bench, is normally straightforward, but reference should be made to the approved Maintenance Manual for details of any special procedures or tests required. It may be found that the expander tube is stuck to the back plate and extreme care is necessary to prevent damaging the tube; the careful use of smooth, broad tyre levers is sometimes recommended. The assembly position of each brake segment should be marked so that, in the event of their being suitable for further service, they can be returned to their original positions.

(i) Brake segments should be examined for wear by measuring the thickness of the remaining material, the minimum thickness permitted for replacing the linings being stipulated in the approved Maintenance Manual. Any carbon deposits which may have been formed should be removed with a stiff bristle brush.

(ii) The back plate should be examined for distortion, damage or corrosion, and elongation or cracking at bolt holes and lining clip slots. Protective treatment should be renewed as necessary.

(iii) The expander tube should be examined for signs of overheating, which is usually indicated by hardening or flaking of the rubber. The connection threads and nuts should also be in good condition.

(iv) The brake lining rivets should be examined for security, and the lining clips for cracks or damage, particularly at the corner radii.

(v) The brake drum should be checked for cracks, corrosion and distortion. The friction surface should be free from deep scoring which is likely to cause excessive lining wear, and any trace of grease or dirt should be removed with a suitable solvent. If any grease or oil is found on the drum, the cause should be investigated to prevent a recurrence.

(vi) New separators should be fitted when the brake is reassembled.

4.4.3 **Test After Reassembly.** Following reassembly the complete brake unit should be installed in an appropriate sized test brake drum, and submitted to pressure tests as prescribed by the manufacturer. No leakage should occur, and the linings should return to the "off" position as soon as air pressure is released. The most suitable means of detecting a leak in the expander tube connection is by applying a solution of non-corrosive soapy water which, subsequently, must be washed off. Bubbles will indicate the position of a leak.

5 DISC BRAKES Most modern aircraft are fitted with hydraulically-operated disc brakes (also known as plate brakes). Light aircraft generally have a single-disc type and larger aircraft a multi-disc type.

5.1 **Single-disc Brake Units.** A simple single-disc brake unit is shown in Figure 3 and is of a type found on many light aircraft. A single operating cylinder is shown but two or three are often used for increased braking performance, and larger aircraft may have brakes using five or six cylinders. The brake unit consists basically of a light alloy torque plate shaped for attachment to the landing gear leg or axle flange, housing a caliper-type hydraulic jack unit and a pair of friction pads. A steel disc is slotted into the wheel and rotates between the friction pads. When the brakes are operated, fluid pressure is applied to the cylinder and forces the operating piston towards the disc, thus squeezing the disc between the operating and fixed friction pads and thus resisting wheel rotation. When the brakes are released the disc is free to rotate between the friction pads.

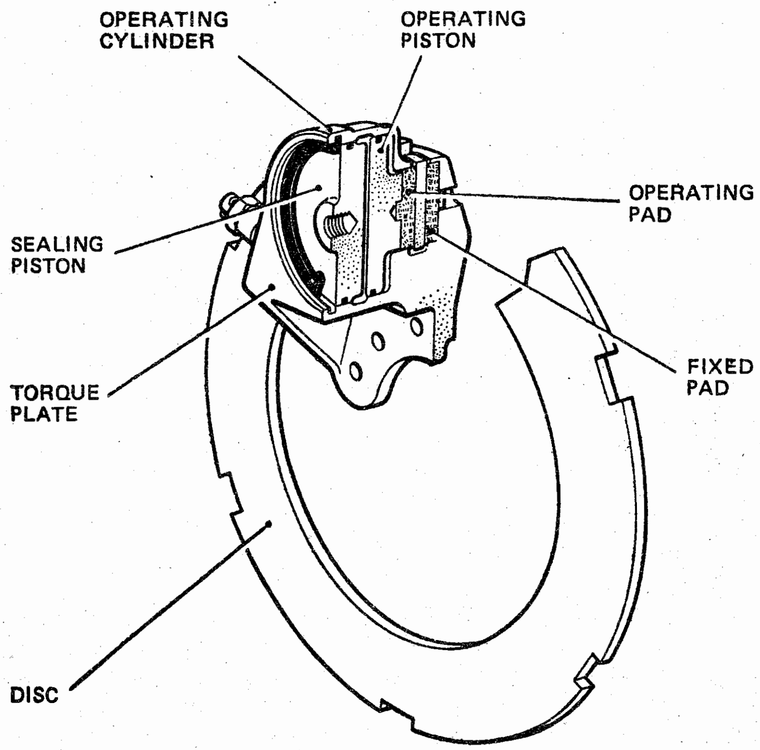

Figure 3 SINGLE DISC BRAKE

5.1.1 The brake unit should be examined periodically for fluid leaks, damage or corrosion, the friction pads for wear and the disc for scoring or pick-up of surface plating. The single discs used on light aircraft brakes are prone to corrosion and pitting during periods of idleness, and this may lead to rapid wear of the friction pads. Discs in poor condition should be replaced or machined to give a clean surface as appropriate. Replacement of worn pads is normally a very simple procedure once the wheel has been removed, and often does not necessitate breaking down the hydraulic system. The servicing and repair procedures discussed in paragraph 5.2 are also applicable to single disc brakes but reference should be made to the approved Maintenance Manual for details of any particular limitations, procedures, tests or special tools recommended by the manufacturer.

5.2 **Multi-disc Brake Unit.** Multi-disc brakes are designed to provide increased friction surfaces for braking purposes. The general arrangement is basically similar to the single-disc brake, but the single disc is replaced by a stack of alternate stationary and rotating discs, and a number of operating cylinders are equally spaced around the torque plate. The friction elements are normally in the form of pads attached to either side of the stationary discs, but on some types the rotating discs have sintered surfaces or pads. This type of brake is operated from the aircraft's main hydraulic system, through valves connected to the pilot's rudder pedals.

5.2.1 **Construction.** A typical multi-disc brake unit is shown in Figure 4. In this unit a torque plate and torque tube assembly fits over the axle and is bolted to a flange on the axle; alternative designs are often similarly mounted but prevented from rotating by means of a torque arm attached to a suitable fixture on the landing gear leg or bogie. A number of cylinders are spaced around the torque plate, connected to the hydraulic brake system and house pistons which apply load to the pressure plate. The disc pack (also known as the heat pack) contains alternate stationary and rotating discs, the stationary discs being keyed to the torque tube and the rotating discs being keyed to drive blocks in the wheel hub. In this unit the stationary discs house the brake pads and the rotating discs are segmented to prevent heat distortion and brake drag. Correct working clearance in the disc pack is maintained by means of adjuster assemblies (paragraph 5.3). Pins attached to the pressure plate and protruding through the torque plate on this brake unit, indicate the amount of wear which has taken place in the disc pack.

5.2.2 A further type of multi-disc brake is known as a trimetallic brake. Construction is similar to the brake described in paragraph 5.2.1, except that the rotating discs have a metallic compound sintered to their faces, and steel segments, known as wear pads, are riveted to the faces of the stationary discs. Alternatively, the faces of both sets of discs may be sintered, or the stationary discs may be plain.

5.2.3 **Operation.** When the brakes are selected "on", hydraulic pressure is admitted to the cylinders and moves the operating pistons against the pressure plate. The disc pack is clamped between the pressure plate and thrust plate, and the friction loads generated between the stationary and rotating members provide the required braking action. When the brakes are released, springs in the adjuster assemblies move the pressure plate back to maintain a working clearance in the disc pack and permit free rotation of the wheel.

5.2.4 **Maintenance.** Contamination of the friction surfaces of a brake unit by fluids used in aircraft servicing operations is highly detrimental to brake operation. It is essential, therefore, to protect brakes from contamination by fuel, oil, grease, paint remover, de-icing fluid, etc., when operations involving their use are undertaken, and the condition of the brake units should subsequently be confirmed by inspection.

5.2.5 Installed disc brakes may be inspected for signs of fluid leakage, external damage, corrosion, disc pack wear and overheating, and the associated hydraulic pipes for security, distortion, chafing or leaks. Brake disc pack wear can be checked by measuring wear pin protrusion, the limits being specified in the approved Maintenance Manual.

5.2.6 In some installations a worn disc pack may be exchanged after removing the wheel and thrust or back plate, and without disconnecting the hydraulic system, but in order to carry out a detailed inspection the brake unit must be removed from the axle.

5.2.7 At the periods specified in the approved Maintenance Schedule the brake unit should be removed for inspection and overhaul. The wheel should first be removed (paragraph 3.2) and the hydraulic pipe couplings should be disconnected at the brake and fitted with suitable blanks. In some cases fluid will drain from these pipes and bleeding will be necessary (paragraph 5.4) after re-connection, but in other cases connection is by self-sealing couplings which isolate the hydraulic system from the brake unit. The brake unit attachment bolts (and, where fitted, the torque link) should then be removed and the unit carefully withdrawn.

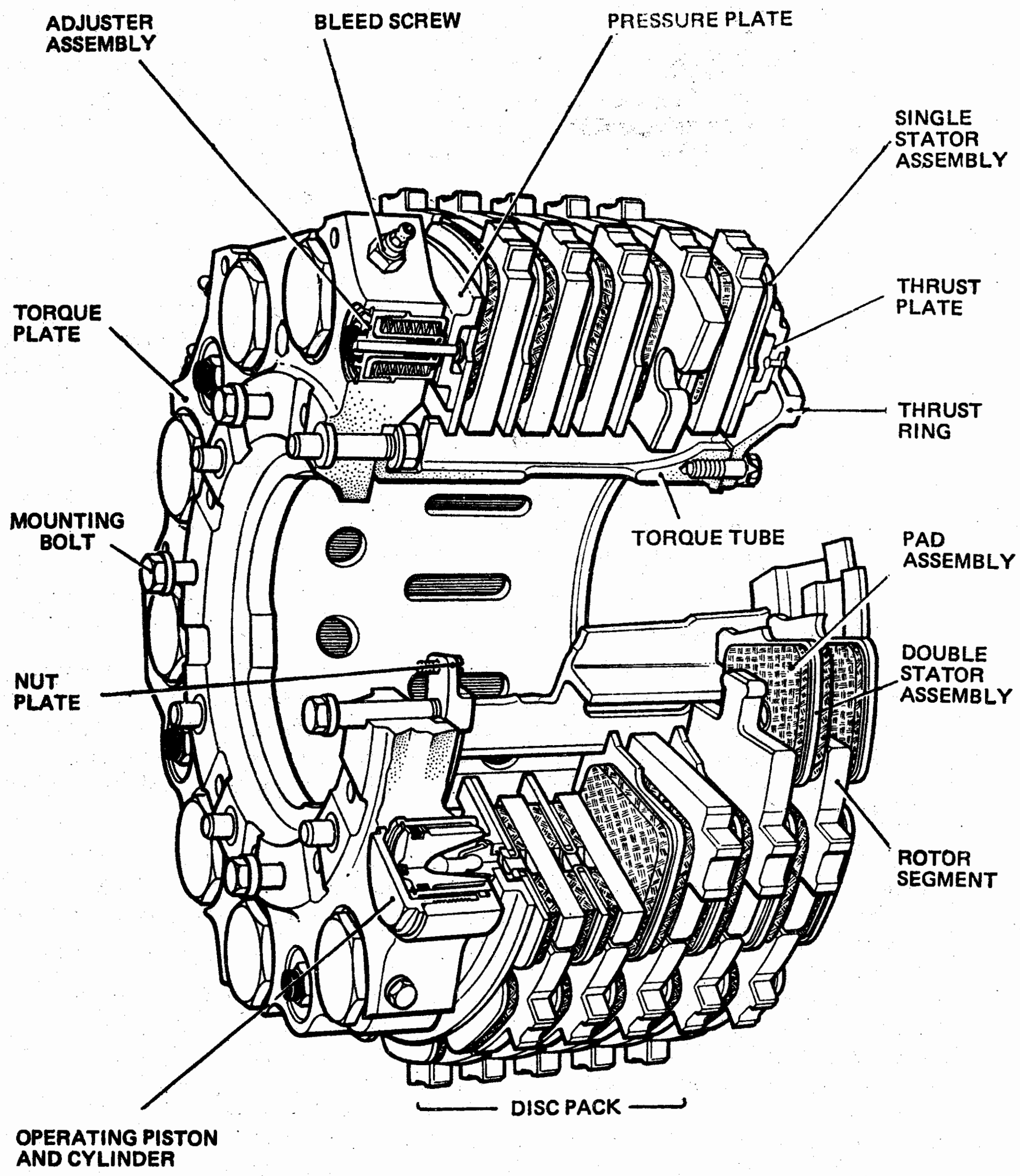

Figure 4 MULTI-DISC BRAKE

5.2.8 Following its removal, the brake unit should be dismantled, cleaned and inspected. All metallic components should be thoroughly cleaned and dried; if chemical solvents are used they must not be allowed to come into contact with the elastomeric seals. Inspection of components should be related to any limitations or repair schemes specified by the manufacturer and will normally include the following:—

(i) Rotating discs should be checked for excessive scoring, corrosion, distortion and wear on the friction surfaces and driving slots. Light surface damage which would not cause excessive wear of the friction pads may be acceptable, but deep scores or corrosion should be ground out within prescribed limits. Heat damage may cause surface cracking and, if present, must be within limits specified by the manufacturer for the disc to be re-used.

(ii) Brake friction pads should be inspected for excessive wear (normally checked by measuring individual pad thickness and weighing the complete pack), burning, flaking, cracking, security of attachment to the stationary disc and contamination by oil or grease. It is normally specified that, if any pad is damaged or worn beyond limits, or contaminated with oil or grease, the complete set should be changed. In some instances it is also specified that the rotating discs should be changed. If part-worn pads are to be re-used they must be reassembled in their original location.

(iii) The torque plate, torque tube and thrust plate should be examined for cracks, corrosion, distortion and damage, particular attention being paid to bolt holes and other highly stressed areas. Cylinders and pistons should be inspected for scores or other damage, and springs inspected for corrosion and given a load/compression test as specified by the manufacturer.

(iv) Operation of the self-adjusting mechanism should also be checked, and the friction force applied to the retraction pin measured (Figure 5).

5.2.9 Protective treatment should be applied as necessary to the metal components, and the brake unit reassembled and tested for leaks and correct operation. It is normally specified that new seals, gaskets and self-locking nuts should be used for reassembly, and all fasteners torque loaded in accordance with the manufacturer's recommendations. The unit should be primed with hydraulic fluid, and blanks fitted to all connections.

5.2.10 When re-installing the brake unit on the axle, care must be taken not to spill fluid on the disc pack. Jointing, sealing or anti-seize compounds should be used where specified, and all fasteners and pipe connections should be torque loaded and locked to the manufacturer's requirements.

5.3 **Adjuster Assemblies.** The diagrammatic arrangement of a typical adjuster assembly is shown in Figure 5. At least two adjuster assemblies are fitted to the majority of disc brakes, their purpose being to maintain a suitable running clearance in the brake pack. In a single-disc brake the retraction pins are often attached directly to the operating pistons but on multi-disc brakes they are usually attached to the pressure plate. In operation, movement of the piston or pressure plate is transmitted via the retraction pin and friction bush to compress the adjuster spring and move the guide until it abuts the torque plate. When the brakes are released the adjuster spring pulls the guide back until it contacts the spring housing, the clearance between the guide and torque plate being the designed running clearance. As wear takes place in the discs the pressure plate has to move further forward, thus pulling the retraction pin through the friction bush by an amount equal to disc wear, but maintaining the design clearance when brakes are released. On some brake units wear may be assessed by measuring the protrusion of the retraction pin.

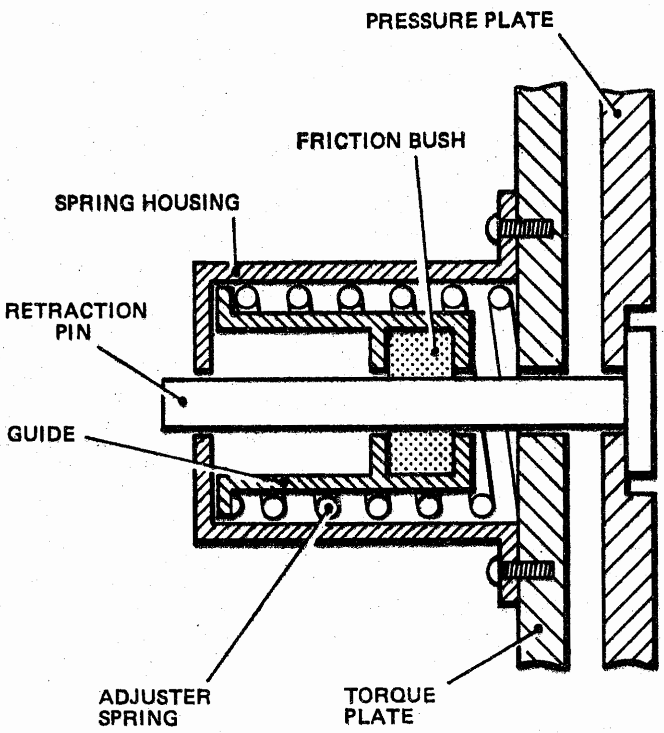

Figure 5 ADJUSTER ASSEMBLY

5.3.1 On initial assembly of the adjuster a special tool is used to position the retraction pin at the position of maximum protrusion through the friction bush. The pin takes up its initial operating position when the brakes are first pressurised.

5.3.2 On some types of disc brakes a conical friction bush is used, and friction is adjusted by torque loading the retaining nut to a specified value, whilst on others, provision is made for manual adjustment of the working clearance.

5.3.3 Correct operation of the adjuster assemblies must be checked whenever the brakes are tested, and should result in free rotation of the wheel when brakes are released.

5.4 **Bleeding the Brakes.** The presence of air in the hydraulic brake system will degrade the performance of the brakes, and must be removed after initial installation and whenever brake response becomes sluggish.

5.4.1 The exact method of bleeding the brakes will depend to a large extent on the particular aircraft system, and reference should be made to the approved Maintenance Manual for the aircraft concerned. However, the normal method of bleeding is to pressurise the brake system and open the bleed screws fitted to the brake units, allowing hydraulic fluid to flow through the system until bubble-free fluid is discharged; the bleed screws are then closed and brake operation tested. Bleed fluid should be piped to a suitable container, and must not be allowed to come into contact with the disc pack.

5.4.2 On low pressure systems fluid is forced through the brake unit by slowly pumping the appropriate brake pedal. Care must be taken to ensure that the reservoir is kept topped up during this operation, since further air might be introduced if the fluid level is allowed to fall too low.

5.4.3 On high pressure systems the associated hydraulic accumulator is pressurised, and as the brake pedal is depressed, fluid is forced out of the bleed screws under pressure. In this type of system it is sometimes recommended that only a specified quantity of fluid is discharged, and it may be necessary to bleed other parts of the system such as, where fitted, the servo system from the brake pedals to the control valves, or the normal and emergency accumulators, before bleeding the brakes. After bleeding, the appropriate reservoir should be topped up as necessary.

5.5 **Testing the Brakes.** Brakes are normally tested after overhaul, and after installation on an aircraft, while the aircraft is still jacked up. The brakes should be applied several times then released; there should be no leakage and the brakes should restrain wheel movement when pressurised and permit wheel rotation when released (free rotation is important, because binding brakes can cause overheating and increase take-off ground-run distance). Operation of the emergency and parking brake controls should be checked and, on completion, a full brake sense check should be carried out in a manner which will ensure correct brake operation for any brake application. Special care should be taken to ensure that the hydraulic systems are correctly connected and in particular that the main system, and not the emergency system, is connected through the anti-skid device.

6 BRAKE TEMPERATURE MONITORING SYSTEM On some aircraft, in order to inform the pilot of excessive build-up of heat in the wheel brakes, a brake temperature monitoring system is fitted. A typical system includes a temperature sensor at each wheel, which supplies information to a central monitor and warning unit on the flight deck. The monitor contains a temperature gauge and a selection button for each wheel. The gauge normally records the temperature at the hottest brake, and a button illuminates when the associated brake temperature exceeds a predetermined amount. When any button is pressed, the gauge records the temperature at the associated brake.

6.1 For testing purposes, operation of a test switch on the control unit will cause all buttons to illuminate and the gauge to read within a test signal range when all circuits are serviceable.

6.2 Installations vary considerably between aircraft, and trouble-shooting charts are normally included in the appropriate Maintenance Manual to enable faults to be traced. Routine maintenance should include inspection of the sensors and associated wiring for security and damage, and functional tests of the system using the appropriate test switches.

7 SKID CONTROL The braking systems of most modern aircraft are provided with a means of preventing the wheels from skidding on wet or icy surfaces and of ensuring that optimum braking effect can be obtained under all conditions, by modulating the hydraulic pressure to the brakes. Anti-skid units sense the rate of change of wheel deceleration, decreasing the hydraulic pressure applied to the brakes when a high rate of increase in deceleration (i.e. consistent with an impending skid) occurs, and restoring it as the wheel accelerates again. A modulator is often fitted in conjunction with the anti-skid unit, to restrict the flow of fluid to the brakes after initial brake application and to conserve main system pressure. There are basically two types of anti-skid systems in use, the mechanically controlled and the electronically controlled.

7.1 **Mechanical System.** The anti-skid unit is mounted either on the brake unit torque plate or within the axle bore, and is connected into the brake hydraulic circuit at the brake unit. The anti-skid unit consists of a valve assembly connected to a flywheel, which is driven by the associated wheel.

7.1.1 **Operation.** During normal braking action (i.e. when no skid is present) the flywheel rotates at the same speed as the drive and the valve is closed, allowing maximum hydraulic pressure to be applied to the brake operating pistons. When the rotational speed of the wheel decreases rapidly, as when a skid begins to develop, the inertia of the flywheel alters its angular relationship with the drive shaft and, through the action of a cam and push rod arrangement, the valve opens to relieve the pressure applied to the brake, thus reducing braking action and allowing the wheel to increase its rotational speed. As the wheel accelerates, the angular relationship between flywheel and drive returns to normal, and the valve closes, increasing pressure to the brake. If the wheel bounces clear of the ground after brakes are applied, the adjustment of the anti-skid unit allows the brake to be completely released for a sufficient period of time to ensure that the brake is off when the wheel contacts the ground again.

7.1.2 **Installation.** The mounting details of the various types of mechanical units vary considerably, and reference should be made to the appropriate Maintenance Manual for details of any particular installation. An external unit is driven by means of a rubber tyre surrounding its flywheel housing and engaging in a track on the landing gear wheel. The whole unit is spring-loaded, or the mountings shimmed, to maintain satisfactory driving contact with the track. The tyre loading is normally checked after installation by measuring the flat produced on the rubber tyre at its point of contact with the track. An axle mounted unit is driven by means of a shaft, which is splined into the anti-skid unit at one end and into a drive housing bolted to the wheel hub, at the other. All types of units are marked with the correct direction of rotation, and this must be checked before installation.

(i) Bleeding of the anti-skid unit is normally achieved when bleeding the main brake system but independent bleeding may be necessary after installing a unit. This is accomplished by fitting a drain pipe at the exhaust connection, rotating the drive smartly in the direction of rotation, then bringing it to rest. Each time rotation is stopped fluid will be discharged from the exhaust port, and bleeding should be continued until the discharged fluid is free from air, then the pipe connections remade.

7.1.3 **Inspection.** At the periods specified in the approved Maintenance Schedule the anti-skid unit should be inspected as follows:—

(i) The unit should be cleaned and inspected for security, signs of corrosion, external damage, and cracks.

(ii) With brakes applied, the unit should be checked for signs of external leakage of hydraulic fluid.

(iii) The pipelines should be checked for damage or distortion and the connections for security of attachment.

(iv) The driving tyre and wheel track should be inspected for correct loading and alignment, and the tyre for excessive wear.

NOTE: It is possible to lock the spring-loaded type units out of contact with the wheel track by inserting a pin in the mounting stud. This is normally done to facilitate wheel removal, but it is recommended that a red streamer should be attached to the pin as a visual reminder that the anti-skid unit is out of operation.

7.1.4 At the end of its overhaul life an anti-skid unit should be returned to the manufacturer or an approved firm for overhaul. Testing after overhaul requires the use of specialised equipment which is not normally held by operators. After removal, all fluid connections and orifices should be properly blanked, the fluid being retained as a guide to the internal condition of the unit. Packing should be suitable for the method of transit and the destination.

7.2 **Electronic System.** The system comprises a wheel speed transducer, a control unit and an anti-skid valve in the brake pressure line, together with associated switches, and check-out and warning lamps. The wheel speed unit may supply either d.c. or a.c. depending on the type of system used. Operation is basically similar to the mechanical system but the use of sophisticated logic circuits in the later types of electronic control units enables much finer control to be exercised. Further refinements such as strut oscillation damping circuits, touch-down protection and locked wheel protection, may also be incorporated, and some systems automatically de-activate at low speed to prevent interference with normal taxying manoeuvres.

7.2.1 The method by which the wheel speed signal is processed in the control unit varies from type to type, but all operate on the basis that if any brake produces more torque than can be supported by the friction between the tyre and ground for the existing wheel load, the resulting impending skid will produce a smaller rotational velocity signal from the affected wheel. This reduced signal is detected by the anti-skid control circuits, which send a signal to the anti-skid control valve, causing brake pressure to be reduced sufficiently to correct the skid condition. Brake pressure will be re-applied to a level just below that which caused the skid, and will then increase at a controlled rate.

7.2.2 Control units normally contain circuits which provide warning of failure in the system, and a self-test facility which enables the serviceability of the various components to be checked. Controls for the operation and testing of the anti-skid system are contained in the control unit and in the flight compartment.

7.2.3 Some systems operate by providing a continuous bleed from the brake pressure line, and in these cases the parking brake operates a cut-off valve in the brake return line.

7.2.4 **Maintenance.** The inspection, testing and maintenance of any particular anti-skid system will vary considerably between different installations, and details should be obtained from the approved Maintenance Manual. However, the self-test facility normally enables complete testing of the system to be carried out and the test circuit is designed to facilitate location of faulty components. A visual inspection of the system should include the following:—

(i) The various components should be examined for damage, security, and, where appropriate, fluid leaks.

(ii) Pipelines should be examined for security, chafing and fluid leaks, particularly at connections.

(iii) Electrical cables should be examined for security, chafing and damage by fluids or heat.

7.2.5 The removal and installation of components in the anti-skid system often requires the observance of certain safety precautions. These precautions are detailed in the approved Maintenance Manual and normally include the fitting of landing gear ground locks and door locks, and depressurising the appropriate hydraulic system.

8 LOW PRESSURE BRAKE SYSTEMS Most light aircraft are fitted with an independent hydraulic system for each brake, similar to that shown in Figure 6. On some aircraft a handbrake system is connected to each brake through a shuttle valve, while on others a parking brake control applies a mechanical lock to the footbrake linkage when brakes are applied. The main components in each system are a fluid reservoir and master cylinder, connected mechanically to the brake pedals and hydraulically to the brake operating cylinder.

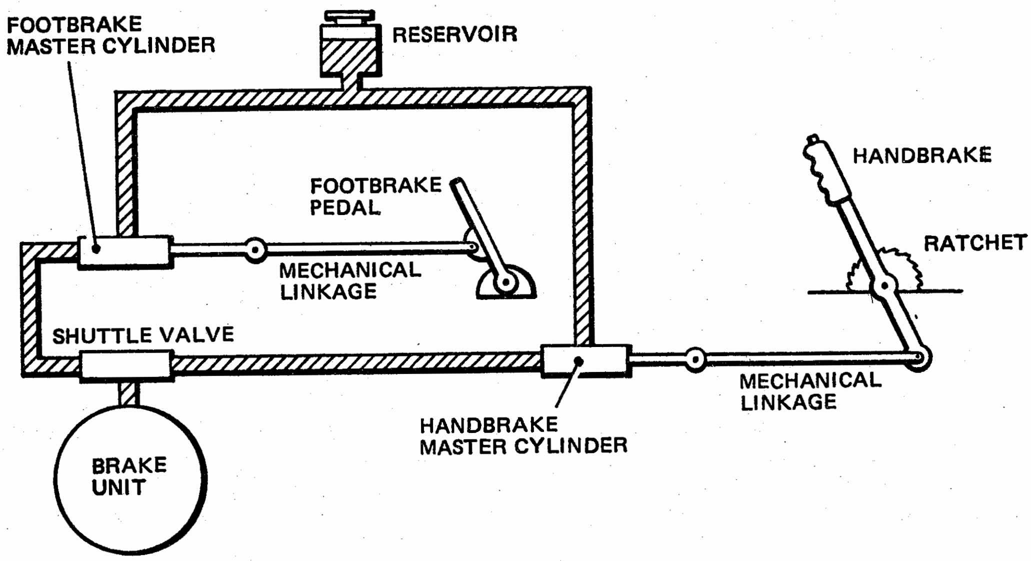

Figure 6 SIMPLE LOW-PRESSURE BRAKE SYSTEM

8.1 **Operation.** As the brake pedal is pressed, a piston in the master cylinder forces fluid through the pipelines to the brake operating cylinder, the braking force depending on the force exerted on the brake pedal. When the pedal is released, a return spring in the master cylinder returns the piston to its original position, and pressure is relieved. Handbrake operation is similar except that the shuttle valve moves to allow pressure to the brake unit and close off the port from the footbrake master cylinder; brakes are held on by a ratchet device in the handbrake mounting. With the alternative parking brake system, the brake should be set by applying pressure with the footbrake, then the parking brake operated to lock the footbrake linkage; subsequent footbrake application will release the locking catch.

8.2 **Bleeding and Testing.** After installing the braking system and whenever faulty system operation is suspected, the aircraft should be jacked up and the following procedure carried out, subject to specific instructions contained in the approved Maintenance Manual.

(i) Ensure that the brake fluid reservoir is topped up.

(ii) Undo the bleed screw in the brake unit and position a container to catch draining fluid. It is usually advisable to fit a tube between the bleed screw and container, to avoid contaminating the brake pads.

(iii) Pump the brake pedal slowly until bubble-free fluid issues from the bleed screw, topping up the reservoir as necessary, then tighten the bleed screw.

(iv) Apply the footbrake and ensure that the brake is operating, then release the brake and ensure that the wheel rotates freely.

(v) Hold the footbrake fully on for 30 seconds and check for hydraulic leaks. The brake should still be applied, with no apparent pedal movement, at the end of this time.

(vi) Repeat (v) using the handbrake or parking brake as appropriate.

8.3 **Maintenance.** Little maintenance is required with this type of brake system except for ensuring that the reservoir is kept topped up to the required level with the specified fluid. Use of the correct fluid is most important, since the piston and shuttle valve seals are often manufactured from a material which is compatible with a limited range of fluids and might deteriorate rapidly if a different fluid were introduced. Cleanliness is also an important aspect and every care should be taken to prevent the introduction of dust and dirt into the system when topping up the reservoir.

8.3.1 The components and pipelines should be inspected periodically for security, fluid leakage and correct operation. Flexible pipes are often fitted between the brake unit and landing gear leg, and it should be confirmed that the pipes are secure and have freedom of movement throughout the range of movements of the landing gear.

8.3.2 Spongy operation of the brakes may be caused by air in the system, which should be bled as described in paragraph 8.2. Fluid bled from the brakes should not be replaced in the system.

8.3.3 Loss of brake pressure, or inability to hold the brakes on, may be due to faulty or worn seals in the master cylinder or shuttle valve. Extreme care is necessary when replacing these seals, as they usually have to be expanded over the valve or piston. The use of an assembly tool is often recommended and the seals should be lubricated with system fluid before fitting. Cleanliness is of the utmost importance since dirt and grit could prevent proper sealing and possibly score the piston or cylinder surfaces.

9 HIGH PRESSURE BRAKE SYSTEMS High pressure braking systems use the normal aircraft hydraulic system to provide fluid, under pressure, to the brake units. A brake system accumulator stores energy in the brake system for use in the event of normal system pressure not being available, and an emergency pneumatic system is frequently included to safeguard brake operation in the event of complete hydraulic failure. A simplified system is shown in Figure 7.

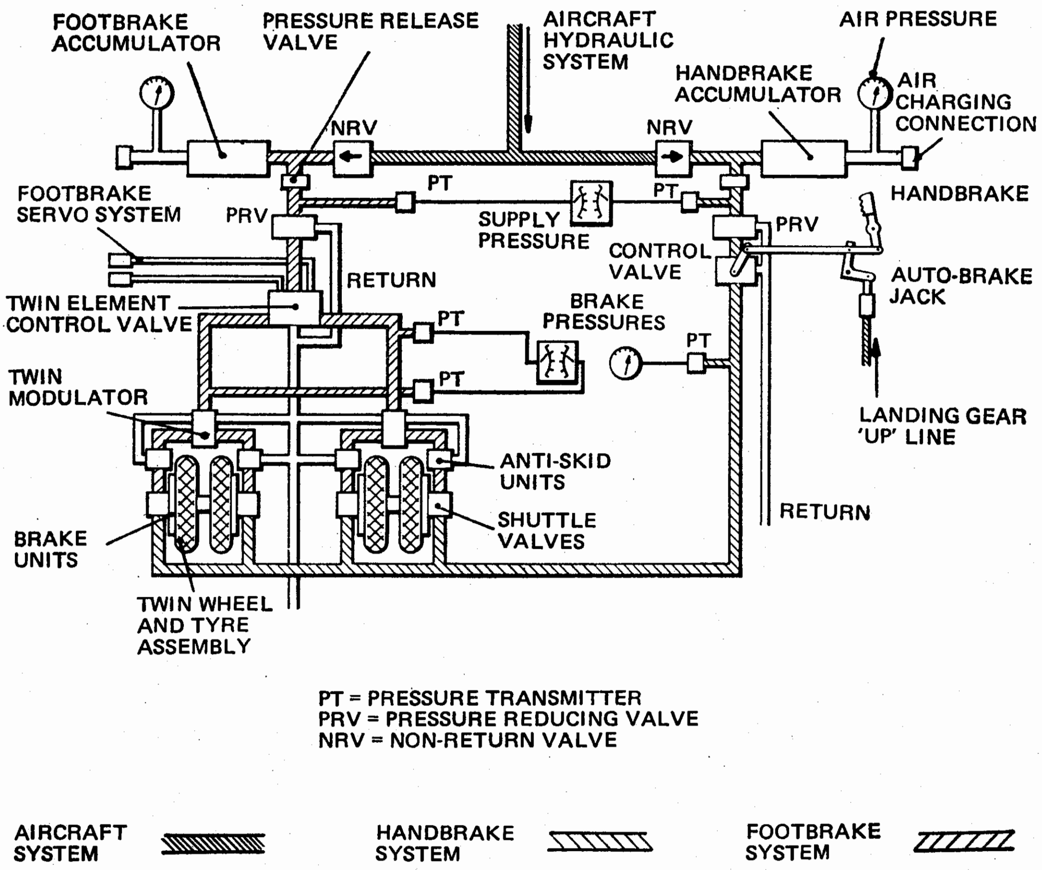

Figure 7 SIMPLE HIGH-PRESSURE BRAKE SYSTEM

9.1 Operation of the brakes can be controlled from either pilot's position, by brake pedals attached to the rudder bar. Application of left or right pedals at either pilot's station causes operation of the associated left or right brakes.

9.2 The brake pedals are linked through a system of levers and cables, or a hydraulic servo system, to a control valve (normally located adjacent to the main wheel bays to minimise the length of pipe run) which controls hydraulic pressure according to the position of the brake pedals. This pressure is often reduced through a pressure reducing valve, and modulated by an anti-skid valve, before being applied to the brake cylinders.

9.3 **Adjustment.** The accurate setting-up of the mechanical linkage between the rudder pedals and control valve is very important since it controls the brake pressure in relation to pedal movement and must be identical in both left and right braking systems. Details of the setting-up procedure for a particular aircraft system will be found in the approved Maintenance Manual, but in a normal system, levers and bellcranks are locked in position by the insertion of rigging pins and the connecting rods and cables adjusted to fit these fixed locations. Alternatively, graduated quadrants may be fitted to show the angular positions of particular levers so that the connecting components may be correctly adjusted. Cables should be tightened to the tension quoted in the Maintenance Manual.

9.4 **Bleeding.** Bleeding of the hydraulic braking system is normally carried out using an approved hydraulic servicing rig connected into the aircraft system at selected quick-release couplings. It is normal practice to bleed the main hydraulic system first to ensure the fluid passing to the brakes is free from air. A typical procedure would be as follows:—

(i) Install landing gear ground locks and door locks, and chock wheels.

(ii) Release parking brake.

(iii) Connect hydraulic servicing rig to aircraft system and adjust to normal operating pressure.

NOTE: Cleanliness of the rig connections and fluid are most important and every precaution must be taken to prevent the ingress of foreign matter into the aircraft system.

(iv) Apply and release brakes several times.

(v) Set hydraulic pressure to a low value (as specified in the Maintenance Manual) and slowly pump the brake pedals to discharge the brake accumulator, then set the parking brake.

(vi) Release brake unit bleed screws and bleed until bubble-free fluid is discharged, then close bleed screws.

(vii) Reset hydraulic pressure to normal system pressure and release parking brake.

(viii) Operate foot brakes several times and check operation and release of brakes by observing movement of the disc return springs.

(ix) Remove servicing rig, check level of fluid in hydraulic reservoir and restore aircraft to normal.

9.5 **Testing.** Operation of the wheel brakes may be checked by operating the brakes normally and visually observing the action of the disc return springs, and their efficiency may be assessed during taxying. When a full functional check is required however, such as after initial installation or following major component change, a more detailed procedure must be followed. This will normally entail the installation of landing gear ground locks and door locks, or jacking the aircraft, and carrying out the following operations:—

(i) Install a suitable pressure gauge at each brake unit bleed fitting.

(ii) Provide hydraulic power (by connection of a hydraulic test rig or by running an aircraft hydraulic pump).

(iii) Check operation of brake system warning lights and gauges by reference to the relevant Maintenance Manual.

(iv) Fully depress each brake pedal in turn, note the pressure recorded at each pressure gauge and check brake operation.

(v) Release brake pedals, visually or physically check that the brakes are off and check that the readings on the pressure gauges are zero or less than a specified maximum pressure.

(vi) Repeat checks with parking brake and, where fitted, the alternative hydraulic system.

NOTE: On some aircraft which are fitted with an automatic brake system to stop the wheels during landing gear retraction, the test may also include selecting the landing gear up and carrying out a function check.

9.6 **Maintenance.** The main items of maintenance common to all modern aircraft with high pressure braking systems are the checking of fluid levels and accumulator gas pressures, followed by replenishment as necessary. When recharging the gas in accumulators the system hydraulic pressure should be fully released, and when topping up a hydraulic reservoir it must be ensured that all the hydraulic rams are in their appropriate positions. The various components and pipelines should also be inspected at frequent intervals for chafing, security, satisfactory bonding and freedom from leaks.

NOTE: High pressure air or nitrogen charging cylinders should be fitted with relief valves, and extreme care taken to ensure that specified accumulator gas pressures are not exceeded.

9.6.1 The procedure necessary for the replacement of components in a braking system will be found in the approved Maintenance Manual, and particular attention should be given to the prescribed safety precautions. In particular, since a high pressure braking system contains a pressurised accumulator, the system will always be under pressure whether the normal aircraft hydraulic system is operating or not, and this pressure must be released before a disconnection is made. The normal method is to slowly pump the brake pedals until the accumulator is discharged, and this also provides a means of checking internal leakage in the system by observing the number of full brake applications available.

10 OVERHEATED BRAKES The action of braking converts kinetic energy into heat and the temperature of brake units will, therefore, rise during use. There is a limit to the amount of heat which can be absorbed and dissipated by a brake and wheel unit, and excessive use of the brakes, such as during a rejected take-off or prolonged periods of taxying, can lead to overheating and combustion and, in extreme cases, result in rupture of a wheel assembly.

10.1 One of the main problems associated with overheated brakes or brake fires, is how to cool the wheel without inducing uneven contraction of the metal. This could cause fracture of the wheel and explosive release of the air in the tyre. Serious, and sometimes fatal, accidents have been known to occur as the result of the application of an incorrect extinguishant to a brake fire.

10.2 A small fire, due perhaps to combustion of grease on the wheel, would probably cause less damage in burning itself out than might be caused by attempting to extinguish it. A short period should be allowed, therefore, to check the progress of the fire before attempting to put it out. In some cases however, such as when the fire is fed by leaking hydraulic fluid, immediate action will be necessary; some aircraft wheels are made from magnesium alloys which, once ignited, burn fiercely and are difficult to extinguish.

10.3 Tests have shown that the safest extinguishant to use is a dry chemical agent, and this must be used whenever possible. It should be applied by an operator standing in line with the tyre's rolling path and at a safe distance; an overheated wheel should never be approached in line with the axle.

10.4 If a wheel fire has to be extinguished and no dry chemical is available, CO_2 or foam may be used but extreme caution is necessary. The extinguishant should be applied as lightly as possible from a distance of at least 20 feet to reduce the likelihood of uneven cooling, and the area should be kept clear after the fire has gone out, until such time as the wheel and brake are completely cooled.

AL/3-20

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AIRCRAFT

SYSTEMS AND EQUIPMENT

CARBON MONOXIDE CONTAMINATION

1 INTRODUCTION This Leaflet describes the nature and effects of carbon monoxide (CO), and outlines the main causes of this type of contamination. It gives only general guidance on the inspections, tests and repairs which should be carried out in order to minimise the dangers of such contamination to crew and passengers, and must, therefore, be read in conjunction with the relevant aircraft Maintenance Manuals.

1.1 The harmful effects of contaminants in the air breathed by crew and passengers are recognised in British Civil Airworthiness Requirements. It is stipulated in the Requirements that CO should not be present in occupied compartments in quantities exceeding 50 parts/million by volume, for any period exceeding five minutes: maximum allowable concentrations are also prescribed for other noxious substances such as fuel, oil, de-icing and hydraulic fluids, fire extinguishing agents, and the fumes given off by other materials when they are heated. Airworthiness Notices Nos. 40 and 41 deal specifically with CO contamination.

2 THE NATURE AND EFFECTS OF CARBON MONOXIDE Carbon monoxide is a gas which is colourless, odourless, and tasteless, and is therefore impossible to detect by the senses. It is a product of the incomplete combustion of carbonaceous materials, and is found in varying amounts in the smoke and fumes emanating from the exhaust systems of aircraft engines and combustion heaters.

2.1 If a person breathes air contaminated by CO, the CO will combine with the haemoglobin in the blood and cause oxygen starvation in the body and brain, thus reducing the person's normal ability to reason and make decisions. Exposure to even small amounts of CO over a period of several hours can be as dangerous as a short exposure to much larger amounts. At altitude, with a smaller quantity of oxygen in the atmosphere, the susceptibility to CO poisoning is correspondingly increased.

2.2 The presence of CO in the air may often be assumed from the smell of exhaust fumes, and from the onset of symptoms such as mild tiredness, a feeling of warmth, and tightness across the forehead. These symptoms cannot, however, be relied upon to give adequate warning of CO contamination, and a person's judgement may become impaired by levels of CO in the blood lower than that at which the symptoms normally appear.

3 CAUSES OF CARBON MONOXIDE CONTAMINATION Carbon monoxide may enter the interior of an aircraft in a number of ways. Defective cabin heating systems of the type which use the engine exhaust pipe as the heat source, and combustion heaters which are independent of the aircraft engines, may introduce CO directly into the fuselage through the cabin heater outlets, while the engine and heater exhaust gases may enter from the outside, either on the ground or during flight. Exhaust gas leaking from any part of the engine exhaust system through cracks, or faulty slip joints, gaskets or muffs, can find its way into the aircraft through ineffectively sealed bulkheads, access panels or skin joints, and in some cases, particularly during starting, ground-running and taxying, the gas discharged from the engine exhaust pipes may enter through open windows or cabin fresh-air intakes. During flight, any poorly sealed doors or windows can result in reduced cabin pressure, encouraging exhaust gas to be drawn into the cabin through the lower fuselage or wing roots.

4 ROUTINE INSPECTIONS The physical inspection of all exhaust system and cabin heating components, of bulkheads and of access panels in the fuselage, should be carried out at the intervals prescribed in the Maintenance Schedule.

4.1 All parts of the engine exhaust system should be inspected for security, warping, dents, cracks, and evidence of gas leakage (i.e. overheating or smoke traces) particularly at clips, slip-joints, clamps, expansion joints and heater jackets. Repair or replacement should be carried out in accordance with the manufacturer's instructions.

4.2 Exhaust pipes under heater jackets should be inspected very carefully at the prescribed intervals, and whenever CO contamination is suspected. In some cases the heater jacket is detachable, and can be completely removed to enable a thorough visual inspection of the exhaust pipe for signs of gas leakage. In cases where the jacket is integral with the exhaust pipe, it is recommended that a pressure test should be carried out by blanking the outlet from the heater jacket and applying air pressure, via a suitable non-return valve, through the inlet; there should be no leakage when the air supply is turned off.

NOTE: The maximum test pressure prescribed in the appropriate Maintenance Manual should not be exceeded, since excessive pressure may damage the jacket and increase the likelihood of crack propagation.

4.3 The procedures for ensuring the serviceability of combustion heaters are outlined in Airworthiness Notice No. 41, and detailed in the appropriate manufacturer's and aircraft manuals. The heater exhaust system should be inspected for the defects listed in paragraph 4.1 and the ducting carrying the heated fresh air from the combustion heater to the cabin should be examined for signs of exhaust contamination. Overhauls of heaters should normally be carried out at the prescribed intervals (normally not exceeding two years). In some instances the combustion chambers are required to be pressure-tested at half the overhaul life.

4.4 Engine bulkheads and the bulkheads isolating combustion heaters, are designed to prevent the transmission of flame, heat or gas to the airframe structure or cabin. Any joins or openings for controls, pipes, or fittings, are sealed with heat-resistant material. All bulkheads should be examined for cracks, damage, ineffective sealing, and signs of smoke or overheating.

4.5 Access panels, particularly those fitted in the underside of the fuselage or giving direct access to the cabin, are generally sealed with a rubber or elastomeric gasket between the panel and the fuselage skin. These gaskets prevent the entry of exhaust gases into the fuselage and are thus important in preventing CO contamination. The fasteners and gaskets of access panels should be examined for security and effectiveness whenever the panels are removed.

4.6 Lap joints and butt joints in the exterior skin of an aircraft are often sealed by the use of a liquid sealant when the skins are riveted during manufacture. When modifications or skin repairs are carried out the same methods should be used to prevent the entry of exhaust gas, and an inspection should be made to ensure that the sealing is effective.

4.7 Cabin windows and windscreens are usually secured to the metallic structure of the aircraft by means of rubber sealing channels or strips. Poor sealing of these glazed panels could allow exhaust gas into the fuselage, and the seals should be examined for security, condition and fit.

4.8 On twin-engined aircraft, exhaust gas may enter the wheel wells or flap shrouds and flow along the leading and trailing edges of the wings into the fuselage. The sealing in these areas, and the landing gear doors, should be checked for effectiveness.

5 TESTS FOR CO CONTAMINATION When doubt exists as to the extent of contamination of the air in the crew or passenger compartments, a test should be carried out to determine the CO concentration. This test is usually carried out by a sampling process, detection being based on the colour reaction of CO with iodine pentoxide, selenium dioxide and fuming sulphuric acid. A typical apparatus and test are described in paragraph 5.1.

5.1 The apparatus usually consists of a hand-operated bellows, which is used to draw a specified volume of air through a sampling tube, the presence of CO being indicated by the staining of crystals in the indicating portion of the tube.

5.1.1 The sampling tube is a sealed glass capsule containing crystals which are white on one side of a datum line and pigmented with the reagent on the other side of the datum line. The white (indicating) part of the tube has two scales marked on the outside of the glass, one graduated for small CO concentrations and the other graduated for large CO concentrations, the units used generally being parts per million (ppm).

5.1.2 When carrying out a test the ends of a sampling tube should be broken to expose the chemicals, and the indicating end of the tube should be inserted in the air intake opening of the bellows assembly. The bellows should then be fully compressed, and when released will expand under internal spring pressure to draw a specified quantity of air through the sampling tube. The number of times the bellows is operated depends on which scale is being used, and this information should be obtained from the manufacturer's published literature. The presence of CO in the air drawn through the sampling tube will result in a green-brown staining of the indicator crystals, the extent of staining depending on the quantity of CO in the sample. The CO concentration can then be read directly from the appropriate scale, at the dividing line between the white and stained crystals.

5.2 Tests should be carried out with the engine(s) running and the cabin heater turned on, both on the ground and during flight, to take account of varying conditions of airflow around the aircraft.

6 REPAIR OR REPLACEMENT OF PARTS The repair or replacement of parts may have to be carried out if it is discovered that CO is entering the crew or passenger compartments in quantities sufficient to cause concern. The procedures relevant to particular components are outlined in paragraphs 6.1 to 6.5.

6.1 **Exhaust Pipes and Heater Jackets.** Renewal of damaged parts is generally preferable to repair, and new gaskets or seals should always be fitted when replacing a component. Damage may often be repaired by welding, but when making such repairs it is important to comply with any specific instructions which may be contained in the relevant Maintenance Manual. Extreme care should be taken to maintain the original contour, since any disruption to the smooth flow of exhaust gas will result in a hot spot and lead to early failure at that point. It is also important to ensure that the materials used in a repair are the same as, or compatible with, the original material. Pre-heating may be necessary in some cases to prevent cracking, and it may be recommended that, after welding, parts are heat-treated in accordance with a prescribed procedure or normalised to reduce grain size in the weld area. Pressure tests are generally required after welding operations. Advice on gas and arc welding is contained in Leaflets **BL/6-4** and **BL/6-5** respectively.

6.2 **Combustion Heaters.** Combustion heaters should be maintained in accordance with an approved Maintenance Schedule, using only those procedures detailed in the relevant manuals produced by the aircraft constructor or the equipment manufacturer; any repairs or replacements which become necessary should be carried out in accordance with these instructions. If burning or traces of smoke are found in the cabin heater ducting the cause should be ascertained and the defective parts repaired or renewed as necessary. Damage to the cabin heater ducting, which is generally made from glass-cloth, nylon or silicone rubber, and supported by a steel coil, is generally not repairable, and the affected parts should be renewed.

6.3 **Bulkheads.** Cracked or otherwise damaged bulkheads should be repaired in accordance with the procedures laid down in the relevant Repair Manual, and using only those materials specified for the particular repair. At the same time that repairs are carried out, all sealing material applied to the bulkhead should be examined for condition and effectiveness, and renewed as necessary.

6.4 **Access Panels.** Access panels may become distorted with use and allow contaminated air to enter the aircraft. If a panel is found to be in this condition it may sometimes be repaired by, for example, adding a stiffener, or by adjustment or replacement of the fasteners, but replacement with a new panel may often be necessary. Damaged or incorrectly fitted rubbing strips or seals in an access panel aperture may also result in air leakage, and should be repaired or renewed in accordance with the relevant manuals.

6.5 **Doors and Windows.** Poorly fitting or ineffectively sealed cabin doors and windows on aircraft can allow the entry of contaminated air. Although hinges and locks are adjusted during installation to provide a good aerodynamic fit and to ensure the safety of the locking mechanisms, the effects of air loads and wear may result in the need for re-adjustment from time to time, and this should be carried out strictly in accordance with the manufacturer's instructions. Door seals may be of the solid or inflatable type, and are usually attached to the door surround with a suitable adhesive; if damaged or loose they may usually be repaired, but special procedures and materials are usually required. Information concerning the repair or replacement of door and window seals should be obtained from the relevant Maintenance Manual.

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AIRCRAFT

SYSTEMS AND EQUIPMENT

HYDRAULIC SYSTEMS

1 INTRODUCTION This Leaflet gives guidance on the operation and maintenance of hydraulic systems in aircraft. There are wide variations in the hydraulic installations of different aircraft, and no attempt is made, in this Leaflet, to describe any particular system in detail; it is important, therefore, that this Leaflet should be read in conjunction with the relevant manuals for the aircraft concerned.

1.1 Information on associated subjects will be found in Leaflets **BL/6-15**—Manufacture of Rigid Pipes, **BL/6-30**—Torque Loading, **AL/3-13**—Flexible Pipes, and **AL/3-14**—Installation of Rigid Pipes in Aircraft.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet **AL/4-1**, Issue 3, 15th February 1961.

2 GENERAL PRINCIPLES Hydraulics is a method of transmitting power through pipes and control devices, using liquid as the operating medium. For certain applications hydraulic systems are used in preference to mechanical or electrical systems for a number of reasons, among which are ease of application of force, ability to increase the applied force as necessary, ease of routeing of pipelines, and elimination of backlash between components.

2.1 Liquids are, for most practical purposes, incompressible, and this fact enables movement to be transmitted through pipelines, over great distances, without loss of time or motion. However, liquids will expand or contract as a result of temperature changes, and a relief valve is necessary, to prevent damage from excessive pressures, in any closed system which may be subjected to large changes of temperature.

NOTE: In systems using very high pressures, the compressibility of the liquid and the elastic yield of the system components may become important. In design calculations a value of 0·07%/MN/m² (0·05%/1000 lbf/in²) is often used for the combined effects of these factors, compressibility of the liquid amounting to approximately 0·05%/MN/m² (0·035%/1000 lbf/in²).

2.2 In a closed static system, pressure exerted on a liquid is transmitted equally in all directions. Figure 1 shows a simple arrangement of pistons, cylinders and pipes, which uses this principle to obtain mechanical advantage. The area of piston A is 10 mm², and the force applied to it is 10 N. The pressure in the liquid is, therefore, 1 N/mm², which is transmitted undiminished to piston B. The area of piston B is 100 mm², and the force exerted upon it is thus 100 N, representing a mechanical advantage of 10:1. This advantage is obtained at the expense of distance, however, because the area of piston B is 10 times that of piston A and piston B will move only one tenth the distance of piston A.

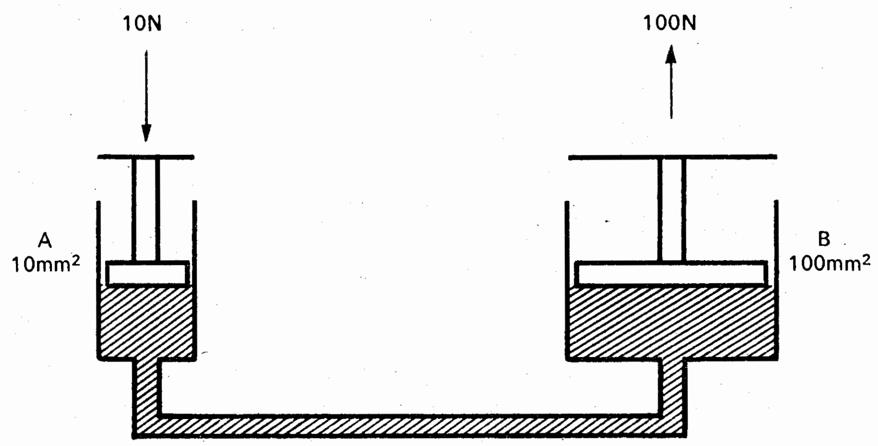


Figure 1 MECHANICAL ADVANTAGE BY HYDRAULIC MEANS

2.3 When liquid is in motion, its dynamic characteristics must also be taken into consideration. Friction exists between the molecules of a liquid, and between the liquid and the piping through which it flows; this friction increases with any increase in viscosity or velocity of the liquid. Friction results in some of the power available from a pump being transformed into heat, and in a reduction in pressure throughout the pipelines.

2.4 Any restriction in a pipeline will increase liquid velocity and produce turbulence, resulting in reduced pressure downstream of the restriction. This fact is often exploited in system design and a restrictor is also used to limit the rate of liquid flow, and thus the rate of movement of components such as the landing gear or flaps.

3 HYDRAULIC FLUIDS Almost any sort of liquid could be used in a hydraulic system, but the special requirements of aircraft systems have resulted in the use of vegetable, mineral and synthetic-based oils (known as hydraulic fluids) which have the following properties:—

(a) They provide good lubrication of components.

(b) Their viscosity is low enough to minimise friction in pipelines and to allow high-speed operation of motors and pumps, but high enough to prevent leakage from components.

(c) They prevent internal corrosion in the system.

(d) They have a wide operating-temperature range.

Fluids are coloured for recognition purposes, and fluids to different specifications must never be mixed; fluids to the same specification, but produced by different manufacturers, may be mixed when permitted by the appropriate Maintenance Manual. Use of a fluid which is not approved for a particular system may result in rapid deterioration of seals, hoses and other non-metallic parts, and may render the system inoperative.

3.1 Vegetable-based fluid is normally almost colourless, and must be used with pure rubber seals and hoses. It is used in some braking systems, but is not often found in hydraulic power systems.

3.2 Mineral-based fluid is normally coloured red, and must be used with synthetic rubber seals and hoses. It is widely used in light aircraft braking systems, hydraulic power systems, and shock-absorber struts.

3.3 Phosphate ester based fluid is widely used on modern aircraft, mainly because of its fire-resistance and extended operating-temperature range. It may be coloured green, purple or amber, and must only be used with butyl rubber, ethylene propylene or teflon seals and hoses.

3.3.1 This fluid requires extreme care in handling as it is irritant to the skin and eyes. A barrier cream should be applied to the hands and arms, and fluid resistant gloves should be worn, whenever servicing operations on the hydraulic system are carried out. In addition, goggles should be worn whenever there is the possibility of fluid being splashed into the eyes, such as when pressure-testing or bleeding components.

3.3.2 Spillage of fluid should be avoided, but, if it does occur, the area affected should immediately be wiped with a dry rag, and thoroughly washed with soap and hot water.

3.4 In view of the incompatibility of different fluids, it is important that any containers, or test rigs, used for servicing aircraft, are clearly marked with the type of fluid they contain.

4 PUMPS Most modern aircraft are fitted with either fixed volume or variable volume, multi-piston type hydraulic pumps, driven from the engines. Other types of pumps, such as gear or vane positive displacement pumps, may be found in some installations, but these are generally used for powering emergency systems. Hand pumps, where fitted, are often of the double-acting type.

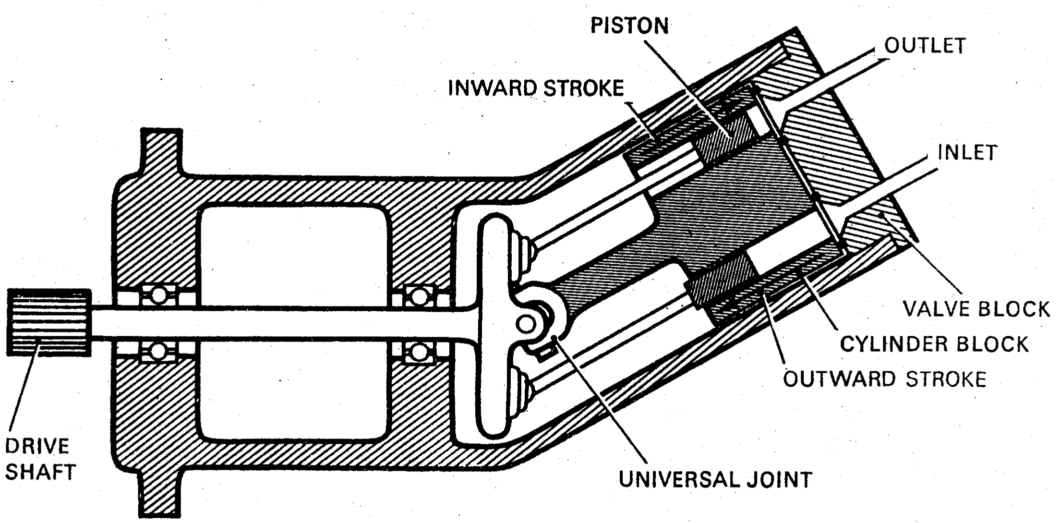


Figure 2 AXIAL PISTON PUMP

4.1 **Fixed Volume Pumps.** These pumps deliver a fixed quantity of fluid into the system at a particular speed of rotation, regardless of system requirements, and means must be provided for diverting pump output when it is not required in the system. These means are discussed in paragraphs 5 and 6.

4.1.1 One type of fixed volume multi-piston pump is illustrated in Figure 2. The cylinder block and drive shaft rotate together, and because of the angle between the cylinder block and shaft axes, each piston moves into and out of its cylinder once each revolution. The stationary valve block has two circumferential slots leading to the top of the cylinder block, which are connected to the fluid inlet and outlet ports, and are arranged so that the pistons draw fluid into the cylinders on the outward stroke, and expel fluid into the system on the inward stroke.

4.1.2 Another type of fixed volume pump is illustrated in Figure 3. In this pump the cylinders are arranged radially around an eccentric crankshaft, so that when the crankshaft is rotated, a piston moves up and down in each cylinder once per revolution. Fluid is drawn into the pump body, and enters each cylinder, through ducting in the cylinder block, whenever the associated piston is at the bottom of its stroke. As a piston moves outwards into its cylinder, it covers the inlet port, and forces fluid out of the top of the cylinder, past a delivery valve, to the pump outlet connection.

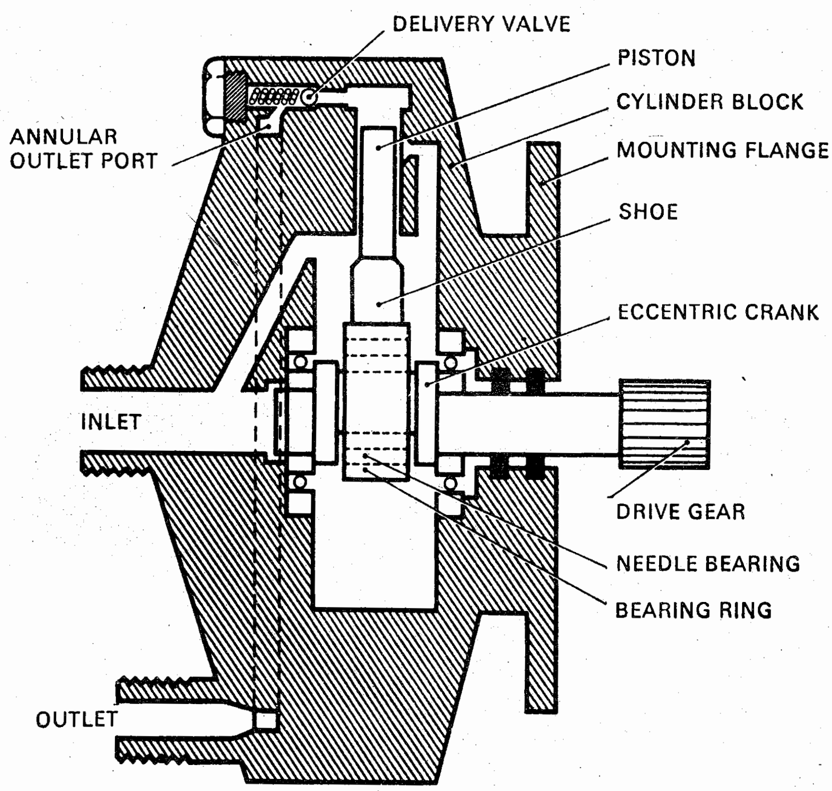


Figure 3 RADIAL PISTON PUMP

4.2 **Variable Volume Pump.** This type of pump is similar in construction to the fixed volume pump described in paragraph 4.1.1, but the cylinder block and drive shaft are co-axial. The pistons are attached to shoes which rotate against a stationary yoke, and the angle between the yoke and cylinder block is varied to increase or decrease pump stroke to suit system requirements. Figure 4 shows the operation of the pump. When pressure in the system is low, as would be the case following selection of a service, spring pressure on the control piston turns the yoke to its maximum angle, and the pistons are at full stroke, delivering maximum output to the system. When the actuator has completed its stroke, pressure builds up until the control piston moves the yoke to the minimum stroke position; in this position a small flow through the pump is maintained, to lubricate the working parts, overcome internal leakage and dissipate heat. On some pumps a solenoid-operated depressurising valve is used to block delivery to the system, and to off-load the pump.

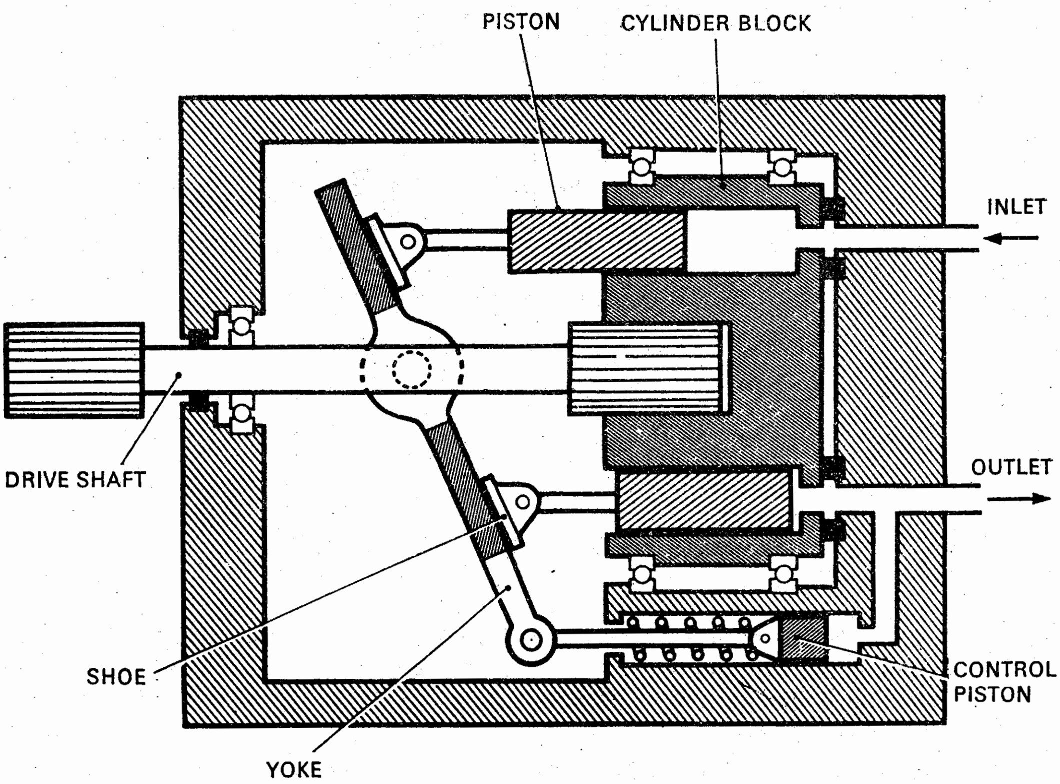


Figure 4 VARIABLE VOLUME PUMP

4.3 **Hand Pumps.** A hand pump is included in some aircraft installations, for emergency use and for ground servicing operations. Figure 5 illustrates a double-acting hand pump (i.e. a pump which delivers fluid on each stroke). As the piston moves upward in the cylinder, fluid is drawn in through a non-return valve (NRV) at the inlet connection into the cylinder; at the same time fluid above the piston is discharged through a non-return valve in the outlet connection. As the piston moves downwards, the inlet NRV closes and the transfer NRV opens, allowing fluid to flow through the piston; since the area below the piston is larger than the area above the piston, part of this fluid is discharged through the outlet port. When pressure in the outlet line exceeds the relief valve setting, discharged fluid is by-passed back to the pump inlet.

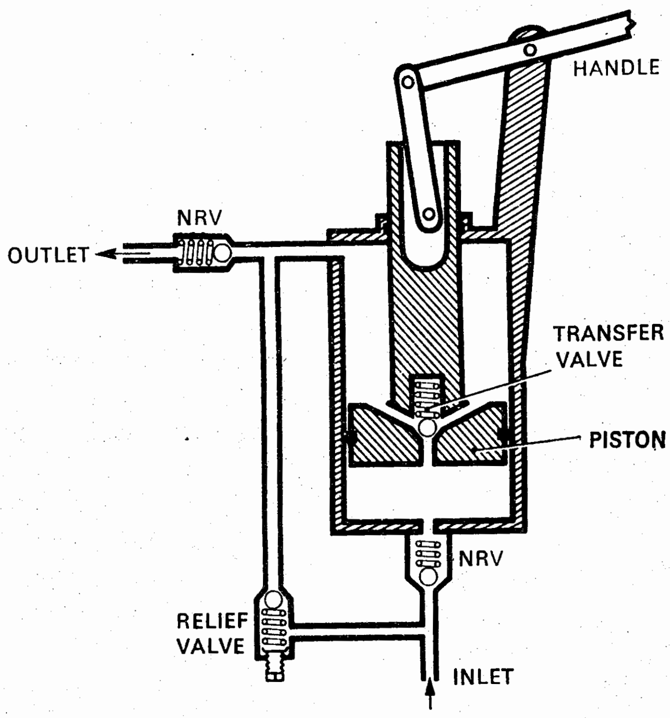
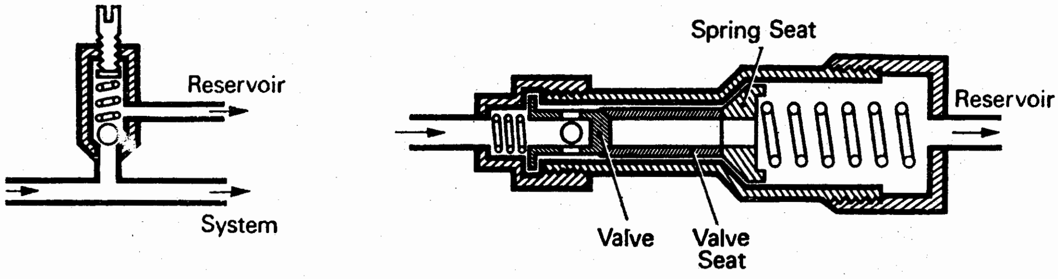


Figure 5 DOUBLE-ACTING HAND PUMP

5 PRESSURE CONTROL Maximum system pressure is often controlled by adjustment of the main engine-driven pump, but a number of other components are used to maintain or limit fluid pressures in various parts of a hydraulic system, and these sometimes have additional functions.

5.1 **Relief Valves.** A relief valve is the simplest form of pressure limiting device, and may be used by itself, or within larger components. A relief valve is frequently used as a safety device, e.g. a thermal relief valve, in which case it is adjusted to blow-off at a pressure slightly higher than normal system pressure, and is normally designed to relieve only a small quantity of fluid. In some systems a full-flow relief valve is fitted downstream of the pump, to by-pass full pump output to the reservoir in the event of failure of the cut-out valve, or of blockage elsewhere in the system. A simple ball-type relief valve and full-flow relief valve are shown in Figure 6.



BALL-TYPE RELIEF VALVE   FULL-FLOW RELIEF VALVE

Figure 6 RELIEF VALVES

5.2 **Cut-out Valves.** A cut-out valve is fitted to a system employing a fixed volume pump, to provide the pump with an idling circuit when no services have been selected. An accumulator is essential when a cut-out is fitted, since any slight leakage through components, or from the system, would result in operation of the cut-out, and in frequent loading and unloading of the pump.

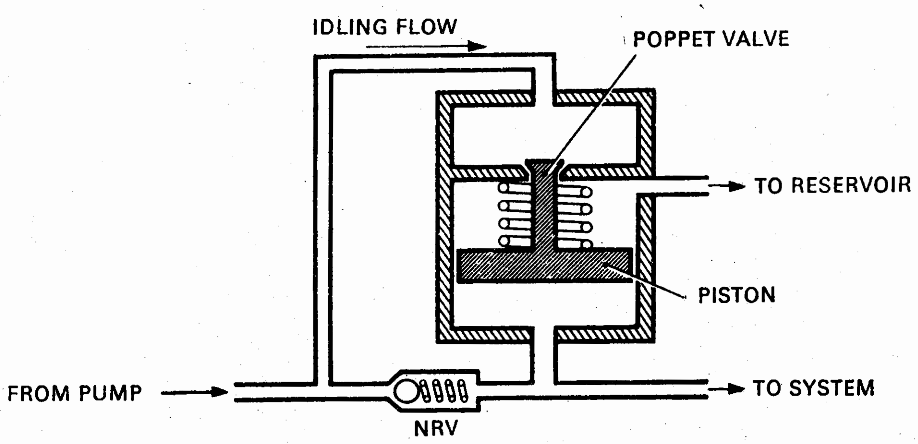


Figure 7 CUT-OUT VALVE

5.2.1 Figure 7 shows the operation of a cut-out valve. When a service has been selected and the pump is delivering fluid to the system, the NRV is open and equal pressure is applied to the poppet valve and piston; the force of the spring combined with the pressure on the poppet valve, is greater than the force on the piston, so the valve is closed and the return line to reservoir is blocked. When the service selected has completed its travel, pressure builds up in the delivery line to the system until the force applied to the piston is sufficient to lift the poppet valve off its seat; this results in a sudden drop in pressure on the pump side of the poppet valve which snaps the poppet valve open and the NRV closed. Pressure in the return line drops to a low value and the load on the pump is removed. Pressure in the system is maintained by the accumulator until a further selection is made; when pressure drops, and the force on the cut-out piston becomes less than the spring force, the poppet valve closes and pump output is again directed into the system.

5.3 **Pressure Maintaining Valves.** A pressure maintaining valve, or priority valve, is basically a relief valve which maintains the pressure in a primary service at a value suitable for operation of that service, regardless of secondary service requirements. When main system pressure exceeds this pre-determined value, the spring load is overcome, and the valve opens to allow main system pressure to reach the secondary service. A pressure maintaining valve is generally used to safeguard operation of important services such as flying controls and wheel brakes. Figure 8 shows a valve in the open position, pressure being sufficient to move the piston against spring pressure and connect the main supply to the sub-system.

5.4 **Pressure Reducing Valves.** A pressure reducing valve is often used to reduce main system pressure to a value suitable for operation of a service such as the wheel brakes. Figure 9 illustrates a pressure reducing valve, which also acts as a relief valve for the service operating at reduced pressure. Fluid enters the inlet port, and flows through the valve to the sub-system; when the fluid pressure exceeds the spring-loading on the valve, the valve is lifted and gradually covers the inlet port until sub-system pressure reaches the specified value. If sub-system pressure increases for any reason, the valve is lifted further and uncovers the return port to relieve excess pressure.

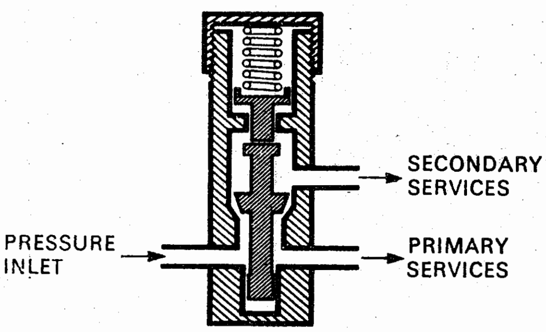


Figure 8
PRESSURE MAINTAINING VALVE

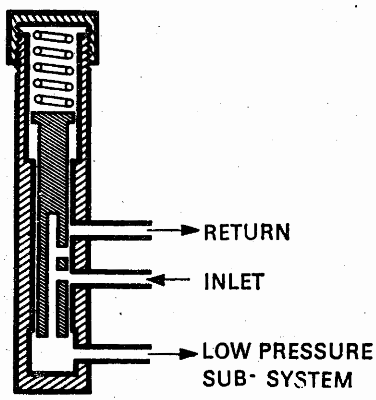


Figure 9
PRESSURE REDUCING VALVE

5.5 **Brake Control Valves.** A brake control valve is essentially a variable pressure reducing valve, which controls pressure in the brake system according to the position of the pilots' brake pedals. The valve usually contains four elements, one pair for the brakes on each side of the aircraft, to provide duplicated control. Figure 10 illustrates a single element, in this case operated by a slave servo from the brake pedal.

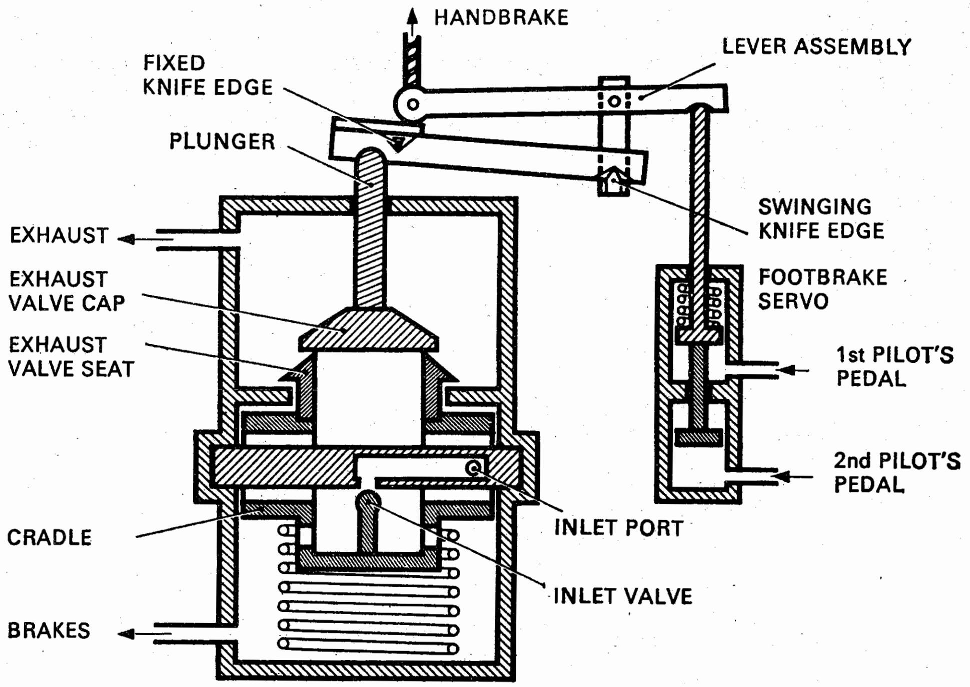


Figure 10 BRAKE CONTROL VALVE

5.5.1 When either pilot's brake pedal on the appropriate side is depressed, or the hand brake is operated, the servo piston applies load to the linkage on the control valve, which, via the lever assembly and plunger, presses down the exhaust valve cap. This action initially closes the gap between the exhaust valve cap and the exhaust valve seat, then moves the cradle down to open the inlet valve, and to direct fluid to the brakes. Pressure builds up in the brakes and valve, until it is sufficient, assisted by the spring, to overcome the inlet pressure, to force the cradle and exhaust valve seat against the exhaust valve cap, and to close the inlet valve. An increase in the load applied to the valve linkage will be balanced by increased delivery pressure, and a decrease in the load applied will be balanced by relief of delivery pressure past the exhaust valve. When the brake pedals are released, the exhaust valve cap lifts, and exhausts pressure from the brakes to the reservoir.

6 FLOW CONTROL The components described in this paragraph are used to control the flow of fluid to the various services operated by the hydraulic system.

6.1 **Non-return Valves.** The most common device used to control the flow of fluid is the non-return valve, which permits full flow in one direction, but blocks flow in the opposite direction. Simple ball-type non-return valves are included in Figure 5, but design may vary considerably. When a non-return valve is used as a separate component, the direction of flow is indicated by an arrow moulded on the casing, in order to prevent incorrect installation.

6.2 **Restrictor Valves.** A restrictor valve may be similar in construction to a non-return valve, but a restrictor valve is designed to permit limited flow in one direction and full flow in the other direction; the restriction is usually of fixed size, as shown in Figure 11. A restrictor valve is used in a number of locations, in order to limit the speed of operation of an actuator in one direction only. It may, for instance, be used to slow down flap retraction or landing gear extension.

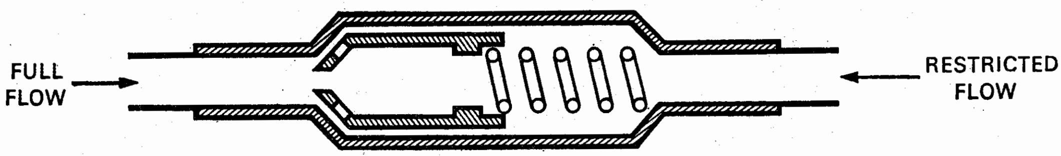


Figure 11 RESTRICTOR VALVE

6.3 **Selectors.** The purpose of a selector is to direct fluid to the appropriate side of an actuator, and to provide a return path for fluid displaced from the opposite side of that actuator. Many selectors are simple four-way valves, connecting the pressure and return lines to alternate sides of the actuator, without a neutral position, but selectors in open-centre systems (see Figure 22) often lock fluid in the actuators while providing an idling circuit for the pump. Selector valves are generally manually operated, and some typical examples are illustrated in Figure 12.

6.3.1 It is sometimes necessary to be able to hold the actuator in an intermediate position. On some aircraft this is achieved by using a selector which blocks both lines to the actuator when it is in the neutral position, the selector being manually returned when the desired actuator position is reached. However, as this could be distracting for the pilot at a critical stage of flight, a feed-back mechanism is often used, which automatically returns the selector to neutral whenever a selected position is reached. Figure 13 shows, diagrammatically, a method which is used in a flap circuit to enable any intermediate position to be held; the selector would normally operate in a gated quadrant.

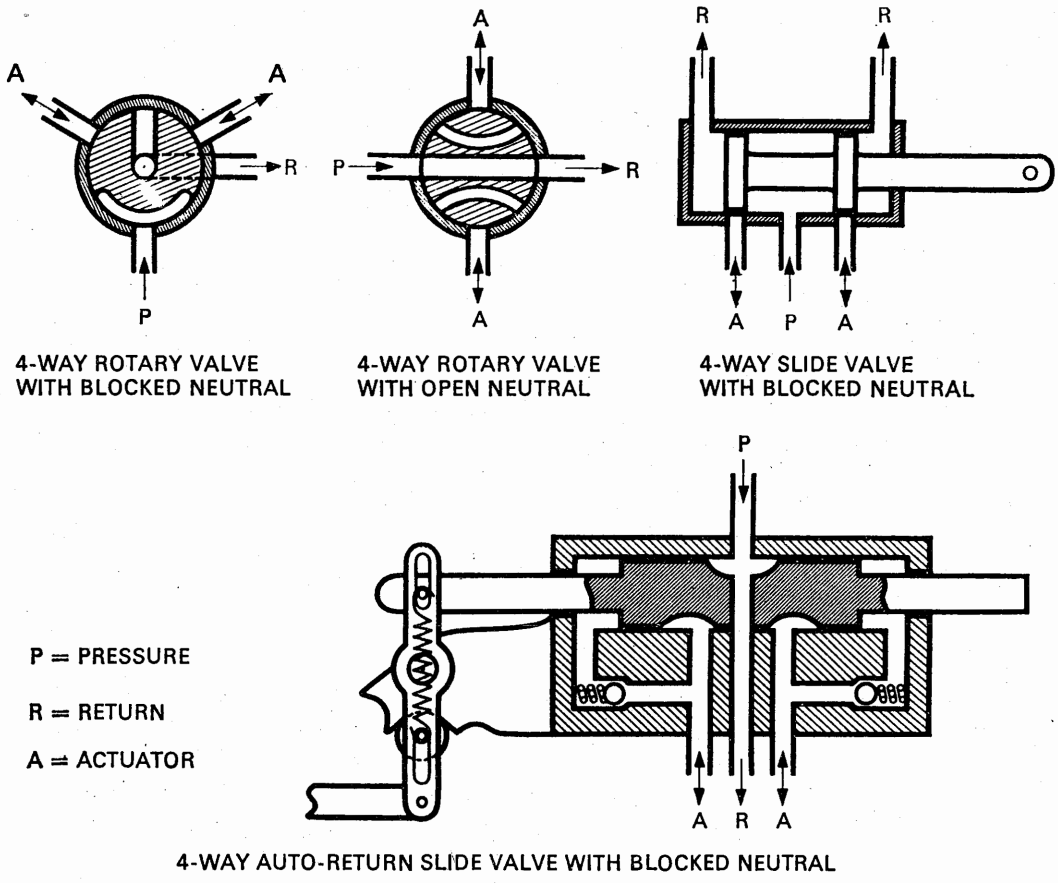


Figure 12 MANUAL SELECTOR VALVES

6.3.2 **Electrically-operated Selectors.** It is sometimes convenient to locate a selector valve at a position remote from the crew compartment, and to eliminate the need for extensive mechanical linkage the selector is normally operated electrically. The selector shown in Figure 14 is a typical electrically-operated two-way valve, which may be used, for example, for emergency operation of the flaps or landing gear. With the solenoid de-energised, the pilot valve is spring-loaded against the return seat, and fluid from the emergency system passes to both sides of the slide valve. Since the right hand end of the valve is of larger diameter than the left, the valve moves to the left and fluid passes to the actuator to extend its ram; fluid from the opposite side of the actuator passes through the selector to the return line. With the solenoid energised, the pilot valve is held against the pressure seat, and supply pressure acts on the left hand side of the slide valve only, the right-hand side being open to return; the slide valve moves to the right, and directs fluid to retract the actuator ram, the opposite side of the actuator being open to return.

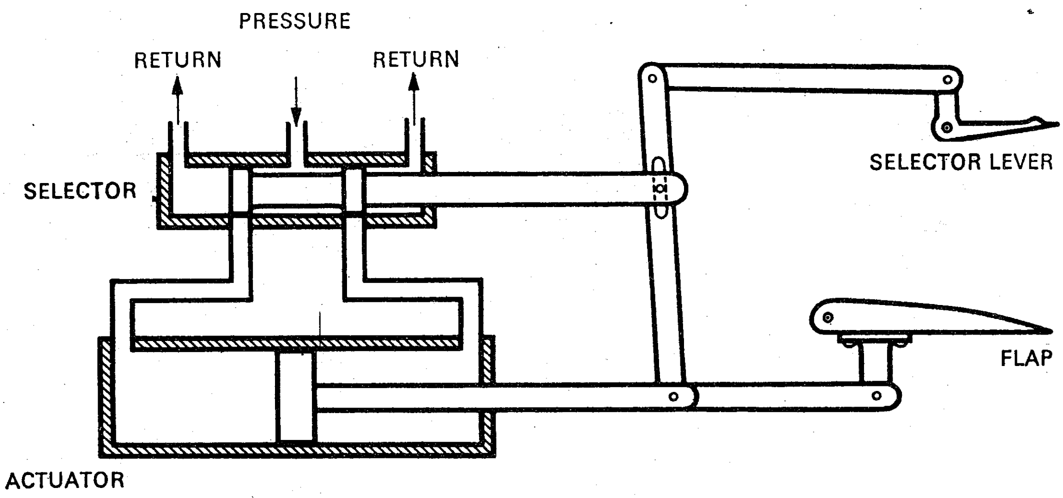


Figure 13 FOLLOW-UP LINKAGE

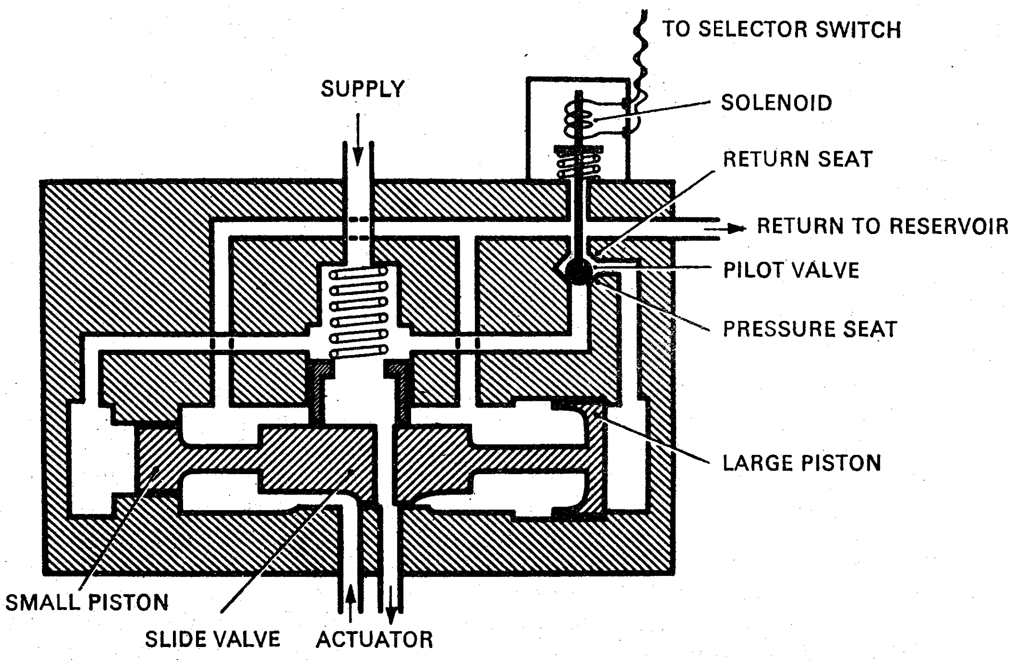


Figure 14 ELECTRICAL SELECTOR VALVE (2-way)

6.4 **Shuttle Valves.** These are often used in landing gear and brake systems, to enable an emergency system to operate the same actuators as the normal system. During normal operation, free flow is provided from the normal system to the service and the emergency line is blocked. When normal system pressure is lost and the emergency system is selected, the shuttle valve moves across because of the pressure difference, blocking the normal line and allowing emergency pressure to the actuator. A typical shuttle valve is shown in Figure 15.

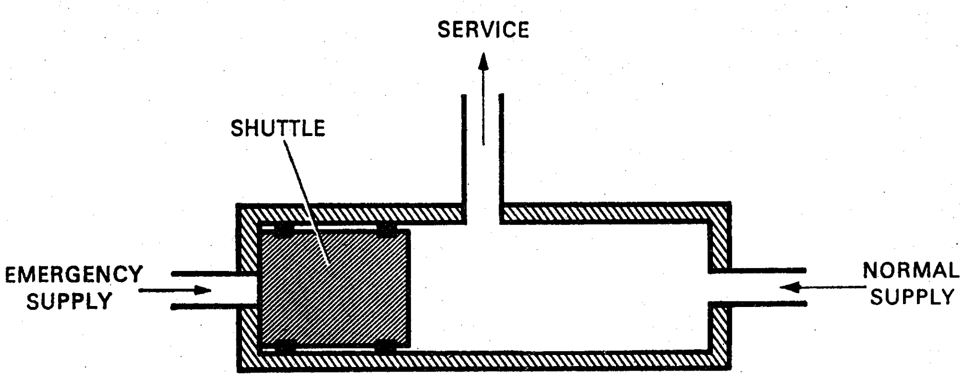


Figure 15 SHUTTLE VALVE

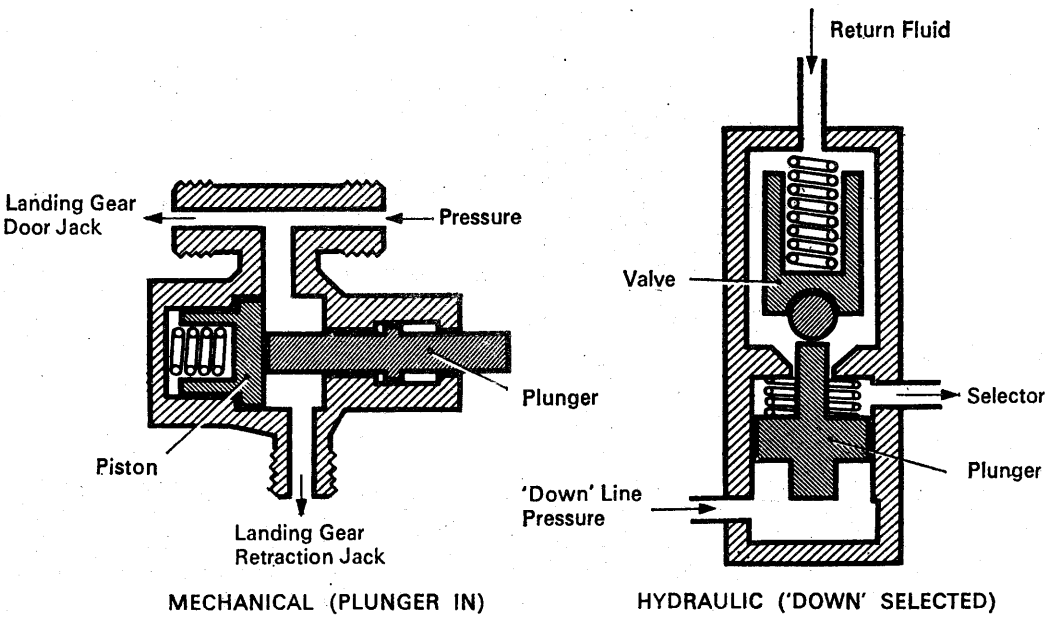


Figure 16 SEQUENCE VALVES

6.5 **Sequence Valves.** Sequence valves are often fitted in a landing gear circuit to ensure correct operation of the landing gear doors and jacks. Examples of mechanically operated and hydraulically operated sequence valves are illustrated in Figure 16.

6.5.1 Mechanically operated sequence valves ensure that the landing gear does not extend until the doors are open, and that the landing gear is retracted before the doors close. Completion of the initial movement in the sequence results in part of the mechanism operating the plunger of the sequence valve, and allowing fluid to flow to the next actuator.

6.5.2 During extension of the landing gear, pressure in the 'up' lines could exceed pressure in the 'down' lines, because of the force of gravity acting on the landing gear, and thus result in partial closing of the doors. This is prevented by fitting a hydraulically operated sequence valve in the 'up' line, which blocks return flow until down line pressure, acting on the plunger, is sufficient to overcome the spring and open the valve. The ball valve is virtually a non-return valve, which does not significantly restrict flow when the landing gear is selected up.

6.6 **Modulators.** A modulator is used in conjunction with the anti-skid unit in a brake system. It allows full flow to the brake units on initial brake application, and thereafter a restricted flow. Figure 17 shows a modulator, the swept volume of which would be equal to the operating volume of the brake cylinders. During initial operation of the brake control valve, the piston is forced down the cylinder against spring pressure, and the brakes are applied. Subsequent fluid feed to the brakes, necessitated by anti-skid unit operation, is through the restricting orifice, and is very limited. This limited flow allows the anti-skid unit to completely release the brakes when necessary, and conserves main system pressure. When the control valve is released, the piston returns to its original position under the influence of the spring and the return fluid.

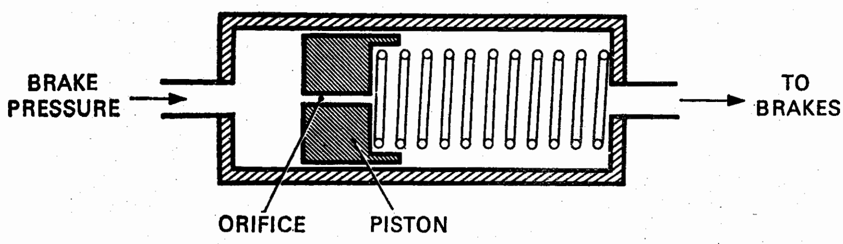


Figure 17 MODULATOR

6.7 **Flow Control Valves.** A flow control valve may be fitted in a hydraulic system to maintain a constant flow of fluid to a particular component; it is frequently found upstream of a hydraulic motor which is required to operate at a constant speed. A typical flow control valve is shown in Figure 18, and consists of a body and a floating valve. Flow through the valve head is restricted by an orifice, which creates a pressure drop across the valve head. At normal supply pressure and constant demand, the pressure drop is balanced by the spring and the valve is held in an intermediate position, the tapered land on the valve partially restricting flow through the valve seat, and maintaining a constant flow through the outlet. If inlet pressure rises, or demand increases, the pressure differential across the valve head also increases, and moves the valve to the left to reduce the size of the aperture and maintain constant flow. The spring loading is increased by the valve movement, and again balances the pressure drop. Similarly, if inlet pressure drops or demand decreases, the valve takes up a new position, slightly further to the right, so as to maintain a constant flow.

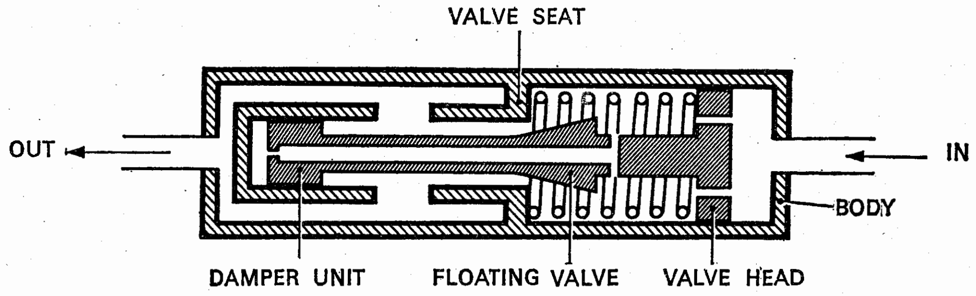


Figure 18 FLOW CONTROL VALVE

7 ACCUMULATORS An accumulator is fitted to store hydraulic fluid under pressure, to dampen pressure fluctuations, to allow for thermal expansion, and to provide an emergency supply of fluid to the system in the event of pump failure. A non-return valve fitted upstream of an accumulator, prevents fluid from being discharged back to the reservoir.

7.1 Three different types of accumulator are illustrated in Figure 19, but many other types are used. Accumulators of the type shown in (a), in which the gas is in contact with the fluid, are seldom used on modern high-pressure systems, as there is a possibility that the gas may be dissolved into the fluid, and thus introduced into the system. For this reason the accumulators shown in (b) and (c) are most commonly used.

7.2 The gas side of the accumulator is charged to a predetermined pressure with air or nitrogen. As hydraulic pressure builds up in the system, the gas is compressed until fluid and gas pressures equalise at normal system pressure. At this point the pump commences to idle, and system pressure is maintained by the accumulator. If a service is selected, a supply of fluid under pressure is available until pressure drops sufficiently to bring the pump on line.

7.3 The initial gas charge of the accumulator is greater than the pressure required to operate any service, and the fluid volume is usually sufficiently large to operate any service once; except that brake accumulators permit a number of brake applications.

7.4 The gas side of an accumulator is normally inflated through a charging valve, which may be attached directly to the accumulator, or installed on a remote ground servicing panel and connected to the accumulator by means of a pipeline. The charging valve usually takes the form of a non-return valve, which may be depressed by means of a plunger in order to relieve excessive pressure.

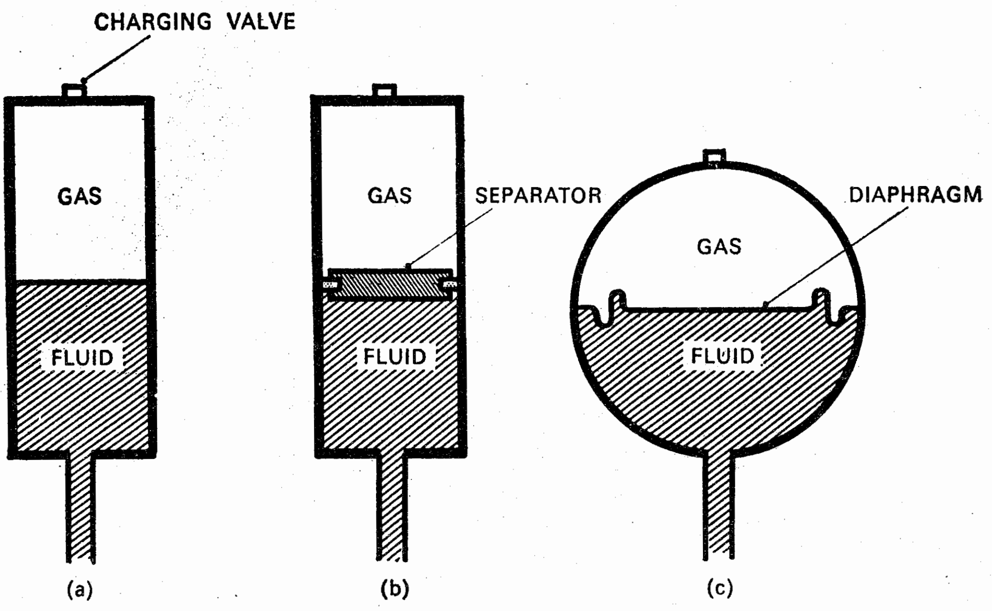


Figure 19 ACCUMULATORS

8 **RESERVOIRS** A reservoir provides both storage space for the system fluid, and sufficient air space to allow for any variations in the volume of fluid in the system which may be caused by thermal expansion and actuator operation. Most reservoirs are pressurised, to provide a positive fluid pressure at the pump inlet, and to prevent air bubbles from forming in the fluid at high altitude. On modern jet aircraft, air pressure is normally supplied from the compressor section of an engine, but it may be supplied from the cabin pressurisation system. Air entering the reservoir is filtered, and, in some cases, provision is also made for the removal of moisture.

8.1 A reservoir also contains a relief valve, to prevent over-pressurisation; connections for suction pipes to the pumps, and return pipes from the system; a contents transmitter unit and a filler cap; and, in some cases, a temperature sensing probe. In systems which are fitted with a hand pump, the main pumps draw fluid through a stack pipe in the reservoir. This ensures that, if fluid is lost from that part of the system supplying the main pumps, or supplied solely by the main pumps, a reserve of fluid for the hand pump would still be available.

9 **ACTUATORS** The purpose of an actuator is to transform fluid flow into linear or rotary motion. Figure 20 illustrates three types of simple linear actuator, which are used for different purposes in an aircraft hydraulic system. Numerous refinements to the simple actuator will be found in use, and these may include such features as internal locking devices, auxiliary pistons and restrictors, each designed to fulfil a particular requirement. Details of a particular actuator should be obtained from the appropriate Maintenance Manual.

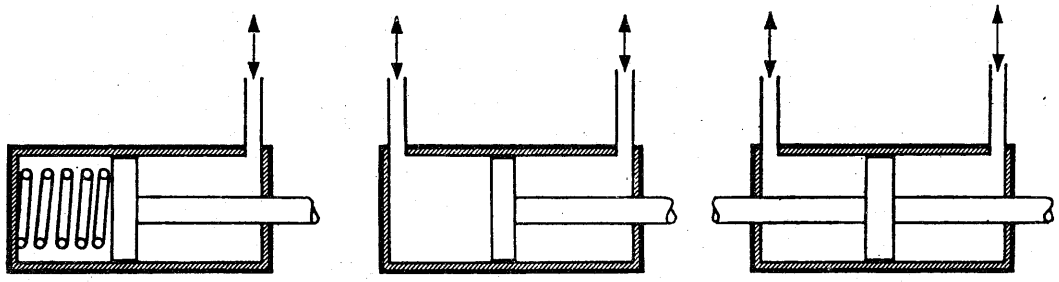


Figure 20 ACTUATORS

9.1 The single acting actuator is normally used as a locking device, the lock being engaged by spring pressure and released by hydraulic pressure. A typical application is a landing gear up-lock.

9.2 The double-acting actuator is used in most aircraft systems. Because of the presence of the piston rod the area of the top of the piston is greater than the area under it. Consequently, more force can be applied during extension of the piston rod. Therefore, the operation which offers the greater resistance is carried out in the direction in which the piston rod extends; for example, in raising the landing gear.

9.3 A balanced actuator, in which equal force can be applied to both sides of the piston, is often used in applications such as nose-wheel steering and flying control boost systems. Either one or both sides of the piston rod may be connected to a mechanism.

9.4 Hydraulic motors are a form of rotary actuator, and are sometimes connected through gearing to operate a screw jack, or to drive generators or pumps. In some aircraft they are used for driving a hydraulic pump unit, thus enabling power to be transferred from one hydraulic system to another without transferring fluid. The construction of a hydraulic motor is generally similar to the construction of a variable volume multi-piston pump. Hydraulic pressure directed through the inlet port forces the pistons against the angled yoke, causing rotation of the cylinder block and drive shaft. A starter valve is used to initiate rotation in the correct direction, and a governor, driven from the cylinder block, meters fluid to a control piston, altering the angle of the yoke according to the load placed upon the motor.

10 FILTERS Main filters are fitted in both suction and pressure lines in a hydraulic system, in order to remove foreign particles from the fluid, and to protect the seals and working surfaces in the components. In addition, individual components often have a small filter fitted to the inlet connection. Main filters usually comprise a filter head containing inlet and exhaust valves, and a sump which houses the filter element. Installation of the sump normally opens the valves, and removal of the sump normally closes them, so that the filter element can be removed without the need for draining the complete system.

10.1 Some filters are fitted with a device which senses the pressure differential across the filter element, and releases a visual indicator, in the form of a button, when the pressure differential increases as a result of the filter becoming clogged. False indication of element clogging, as a result of high fluid viscosity at low temperature, is prevented by a bi-metal spring which inhibits indicator button movement at low temperatures. Other filters are fitted with a relief valve, which allows unfiltered fluid to pass to the system when the element becomes clogged; this type of filter element must be changed at regular intervals.

10.2 Paper filter elements are usually discarded when removed, but elements of wire cloth may usually be cleaned. Cleaning by an ultrasonic process is normally recommended, but if a new or cleaned element is not available when the element becomes due for check, the old element may be cleaned in trichloroethylene as a temporary measure.

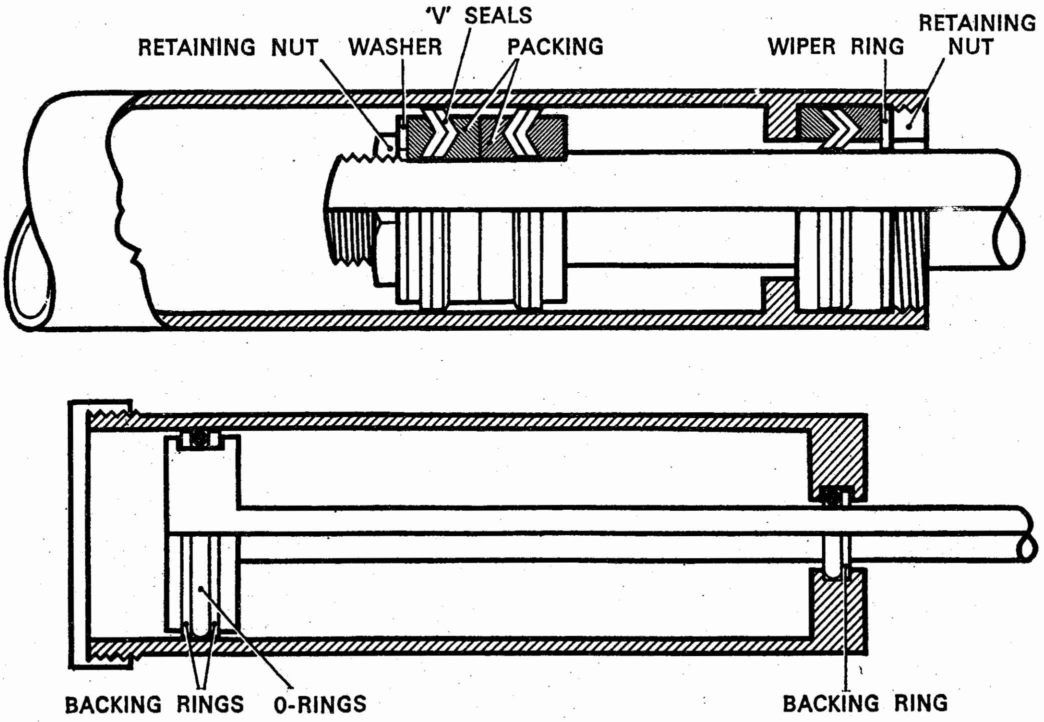


Figure 21 TYPICAL INSTALLATION OF SEALS

11 **SEALS** Seals perform a very important function in a hydraulic system, in preventing leakage of fluid. Static seals, gaskets and packing are used in many locations, and these effect a seal by being squeezed between two surfaces. Dynamic seals, fitted between sliding surfaces, may be of many different shapes, depending on their use and on the fluid pressures involved. 'U' and 'V' ring seals are effective in one direction only, but 'O' rings and square section seals are often used where pressure is applied in either direction.

Dynamic seals require lubrication to remain effective, and wetting of the bearing surface, or a slight seepage from the seals, is normally acceptable. Where high pressures are used, an 'O' ring is normally fitted with a stiff backing ring, which retains the shape of the seal and prevents it from being squeezed between the two moving surfaces. Seals are made in a variety of materials, depending on the type of fluid with which they are to be used; if a seal of an incorrect material is used in a system, the sealing quality will be seriously degraded, and this may lead to failure of the component. Typical seal installations are shown in Figure 21. Seals are easily damaged by grit, and a wiper ring is often installed on actuators to prevent any grit that may be deposited on the piston rod from contaminating the seals.

12 BASIC HYDRAULIC SYSTEMS There are two main types of system in use, the open-centre system and the closed system. The former is frequently found on light aircraft, and the latter, or a combination of the two, is found on most large aircraft.

12.1 **Open-centre System.** The main advantage of this system is its simplicity, and the main disadvantage is that only one service can be operated at a time. When no services are being operated, the pressure in the system is at a low value, pump output passing directly to the reservoir. Figure 22 shows a simple open-centre system which contains all the components necessary for operation. It should be noted, however, that when the actuator reaches the end of its travel, pressure will build up and remain at the relief valve setting until the selector is returned to neutral. This imposes a high load on the pump, which is normally overcome by fitting automatic-return selectors.

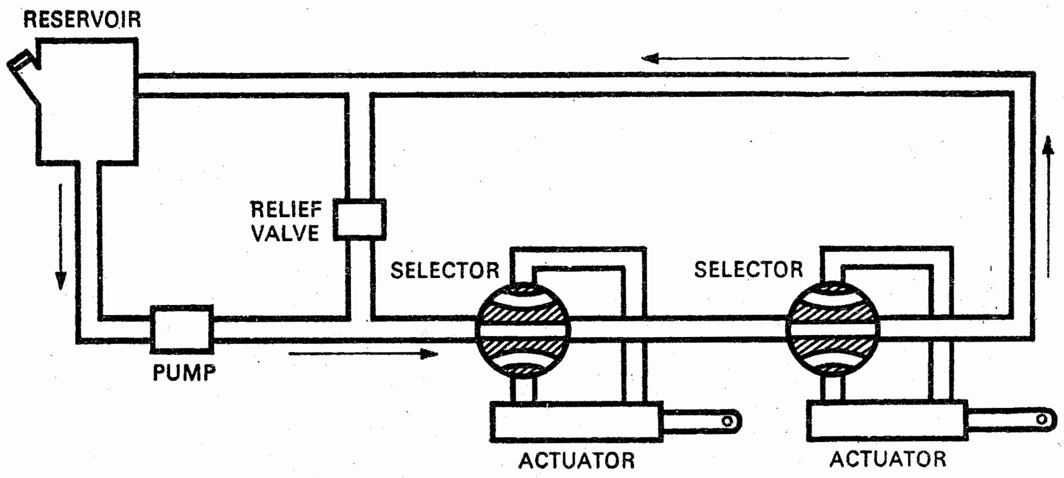


Figure 22 OPEN-CENTRE SYSTEM

12.2 **Closed System.** With this type of system, operating pressure is maintained in that part of the system which leads to the selector valves, and some method is used to prevent over-loading the pump. In systems which employ a fixed volume pump (Figures 2 or 3), an automatic cut-out valve is fitted, to divert pump output to the reservoir when pressure has built up to normal operating pressure. In other systems a variable volume pump (Figure 4) is used, delivery being reduced as pressure increases, whilst in some simple light aircraft systems, operation of an electrically-driven pump is controlled by a pressure-operated switch. A simple closed system is illustrated in Figure 23.

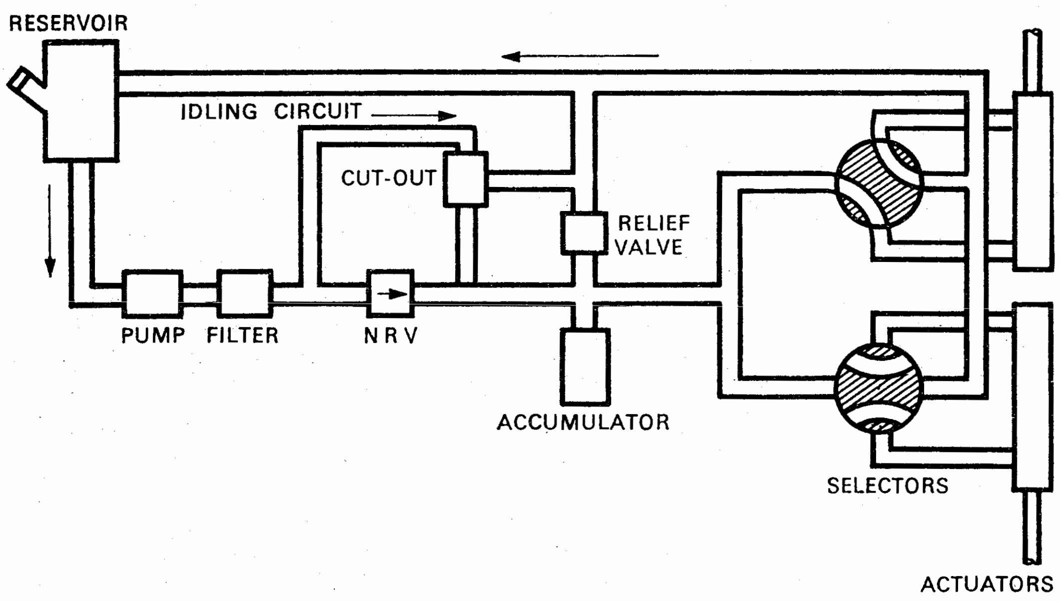


Figure 23 CLOSED SYSTEM

12.3 **Power Packs.** A power pack system is one in which most of the major components, with the exception of the actuators, and, with some systems, of the pumps, are included in a self-contained unit. The system may operate on either the open-centre or the closed system principle, and is widely used in light aircraft.

12.3.1 Figure 24 shows a simple power pack used for raising and lowering the landing gear. Power is provided by the accumulator, which is automatically re-charged by operation of the electrically-operated pump. When a selection is made, pressure in the accumulator drops and the plunger is raised until its collar contacts the trip switch arm, providing electrical power to the pump motor. As pressure builds up in the system, the accumulator plunger lowers until it contacts the switch arm and cuts off power to the pump motor. Pressure is constantly maintained between the pump cut-in and cut-out pressures, and power is constantly available for operation of the landing gear.

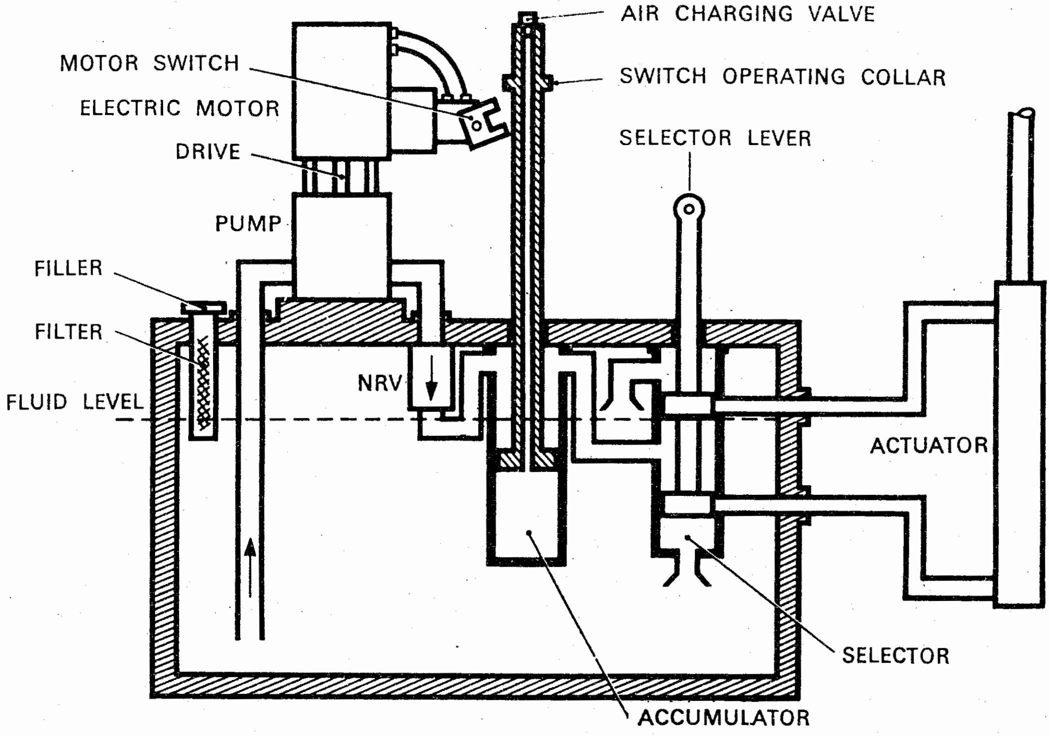


Figure 24 POWER PACK

13 AIRCRAFT INSTALLATIONS Light aircraft are often fitted with a power pack, or provided with a single hydraulic system of the open circuit type, which is powered by an engine-driven or electrically-driven pump. A hand pump is fitted to enable the flaps to be lowered in the event of main pump failure; landing gear up-locks are manually released to enable the landing gear to free-fall and lock down under its own weight. If a power-operated brake system is fitted, sufficient pressure is available in the accumulator to enable a landing to be made. Multi-engined transport aircraft usually have two or more self-contained hydraulic systems, each system providing power for the flying controls and some of the remaining services; in addition, facilities are provided for transferring power from one system to another following failure of a main pump. Alternative pumps, operated by a.c. or d.c. electrical power, or air turbines, are often provided for use in emergency. A cut-off valve is sometimes provided for each system, and this may be operated by use of the fire control handle.

13.1 Since weight is an important factor with aircraft, modern hydraulic systems tend to use very high pressures, thus enabling smaller diameter piping and jacks, and less fluid, to be used. Tubing in parts of the system containing fluid at maximum pressure is usually made from stainless steel, but tubing providing return flow only, or subjected solely to air pressure, is often made from aluminium alloy. Tubing used in the hydraulic system is labelled for recognition purposes in accordance with British Standard M23. This marking consists of a label with the word "HYDRAULIC" in black on a white, or blue and yellow, background, and a symbol in the form of a black circle on a white background. In addition, the sub-system, e.g. "LANDING GEAR", and the direction of flow may be added.

13.2 In most modern aircraft, a number of the major components such as accumulators, electrically-operated pumps, reservoirs, filters, drain valves, charging valves, and associated instruments, are grouped together in a hydraulic service bay, which is easily accessible for routine servicing operations.

13.3 **Instrumentation.** In many light aircraft, there is often no indication, in the cabin, of hydraulic system operation. Incorrect operation will, therefore, only become known to the pilot when a service is selected. However, an aircraft fitted with a power pack, as described in paragraph 12.3, will normally have a combined warning lamp/master switch on the instrument panel, which will indicate when the pump motor is operating, and will enable correct operation of the system to be determined. Larger aircraft normally have a hydraulic services panel in the crew compartment, which contains indicators covering parameters such as fluid quantity, pressure and temperature, and switches to control operation of emergency pumps and valves. The instruments and switches for each separate hydraulic system are normally grouped together, and the panel may be marked with a mimic diagram to assist the crew in transferring hydraulic power, or in overcoming an emergency situation. The components normally used are described in paragraphs 13.3.1 to 13.3.6.

13.3.1 **Quantity Indicators.** A clear window fitted in the reservoir provides a means of checking fluid level during servicing, but the reservoir may also be fitted with a float-type contents unit, which electrically signals fluid quantity to an instrument on the hydraulics panel in the crew compartment.

13.3.2 **Pressure Relays.** A pressure relay is a component which transmits fluid pressure to a direct reading pressure gauge, or to a pressure transmitter which electrically indicates pressure on an instrument on the hydraulics panel. In some cases both types of indication are provided, the direct reading gauge being fitted in the hydraulic equipment bay, adjacent to the relay. A typical pressure relay is shown in Figure 25. During normal operation the piston acts as a separator, transmitting fluid pressure to the gauge side. If a leak develops on the gauge side, the piston moves to the gauge end of the cylinder, and the valve seats in the cylinder head, thus preventing leakage from the system. The valve also permits bleeding when a new gauge, or gauge line, is fitted.

13.3.3 **Pressure Gauges.** Electrically operated pressure gauges are fitted on the hydraulics panel, to register main and emergency system pressures. Direct reading gauges are often fitted to the accumulators and reservoirs, to enable servicing operations to be carried out. Operation and maintenance of pressure gauges is dealt with in Leaflet **AL/10—3,** Engine Instruments.

13.3.4 **Pressure Switches.** Pressure switches are often used to illuminate a warning lamp, and to indicate loss of fluid pressure, or loss of air pressure in a reservoir. Such switches contain a diaphragm, which flexes under fluid or air pressure, this movement being transmitted to a micro switch, which, at the appropriate pressure, makes or breaks contact with the warning lamp.

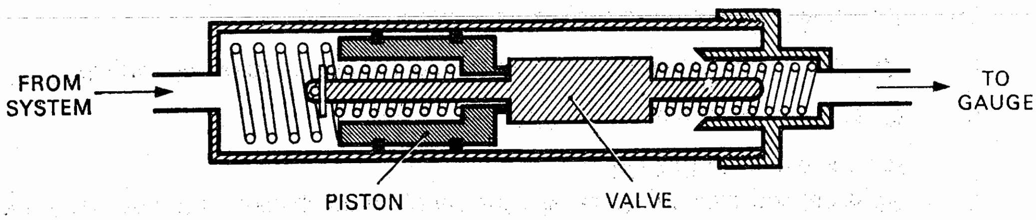


Figure 25 PRESSURE RELAY

13.3.5 **Flow Indication.** A flow indicator valve is often fitted in the outlet line from a pump, and is used to provide warning of pump failure. The valve comprises a body, a spring-loaded plunger connected to an actuator arm, and a micro-switch. During normal operation, fluid pressure overcomes spring pressure, and the plunger moves to allow full flow through the valve. If pump output decreases below a predetermined minimum, the spring loading overcomes fluid pressure, moving the plunger and actuator arm, and closing the micro-switch contact to illuminate the warning lamp.

13.3.6 **Temperature Indication.** Warning of fluid overheating is normally provided by a temperature sensing element in the reservoir. Warning of overheating of electrical motors which are used to operate emergency pumps, is normally provided by fitting a similar element in the motor casing. The sensing element takes the form of a bi-metal strip or rod arrangement, which operates a snap-action switch when the warning temperature is reached. Operation of the switch closes the contacts to an associated warning lamp.

13.4 **Components for Servicing Purposes.** A number of components are included in the hydraulic system specifically to facilitate servicing. These components are normally located in the hydraulic equipment bay.

13.4.1 **Quick-disconnect Couplings.** In positions where it is necessary to frequently disconnect a coupling for servicing purposes, a self-sealing, quick-disconnect coupling is fitted. The coupling enables the line to be disconnected without loss of fluid, and without the need for subsequent bleeding.

13.4.2 **Pressure Release Valves.** Pressure release valves are fitted to enable pressure to be released from the system for servicing purposes. The valves are manually operated, and consist of a valve body with an inlet and outlet port, the passage between the two being blocked by a spring-loaded valve. Operation of an external lever opens the valve against spring pressure, and allows fluid to flow from the accumulator to the reservoir.

13.4.3 **Drain Cocks.** Drain cocks are generally simple manually operated spherical valves, and are located in the hydraulics bay at the lowest point in the system. They are marked to indicate direction of flow, and are used to drain the system, when it is necessary to do so, in order to replace the fluid, or, in some systems, to change certain components.

13.4.4 **Fluid Sampling Points.** Fluid sampling points are suitably positioned in the suction and pressure lines, to enable samples of fluid to be removed for analysis. The component is usually a T-piece adaptor, the two main connections being connected in the system pipeline, and the third connection being fitted with a bleed screw.

13.4.5 **Ground Servicing Couplings.** These components are included in most hydraulic systems, and enable the system to be tested using a ground test rig. The coupling is self-sealing, and is similar to the quick-disconnect coupling, one half being located in the aircraft and the other on the test rig. When not in use the coupling is sealed by a dust cap.

14 POWERED FLYING CONTROLS Because of the high loads imposed on the flying control surfaces, modern transport aircraft are provided with power-operated or power-assisted controls. Because of the importance of the flying control system, hydraulic power to each control surface is provided by at least two independent hydraulic systems (sometimes using separate actuators) plus an emergency system operated by electrical power or by ram air turbines. In addition, some systems allow for reversion to manual operation of the control surfaces, or tabs, in the event of all hydraulic systems failing.

14.1 A hydraulic sub-system for the operation of the flying controls, is often fed through a priority valve, which ensures that fluid under pressure is always available; the sub-system may also have a separate accumulator.

14.1.1 The unit which moves a control surface is a combined selector valve and actuator, usually known as a servo-control unit, the selector being connected by cables and rods to the pilots' controls. A typical servo-control unit is illustrated in Figure 26. With hydraulic power available, operation of a pilot's control moves the spool in the selector, thus directing fluid to one side of the actuator and opening a return path from the other side. Movement of the actuator operates the control surface, and at the same time moves the selector back towards the neutral position. When control surface movement corresponds to the deflection of the pilots' control, the selector is in the neutral position, and fluid is locked in the actuator. When no hydraulic pressure is available, the interconnecting valve opens under spring pressure and the actuator is free to move. The control may then be operated by alternative servo-control units, or by manual linkage, depending on the particular installation.

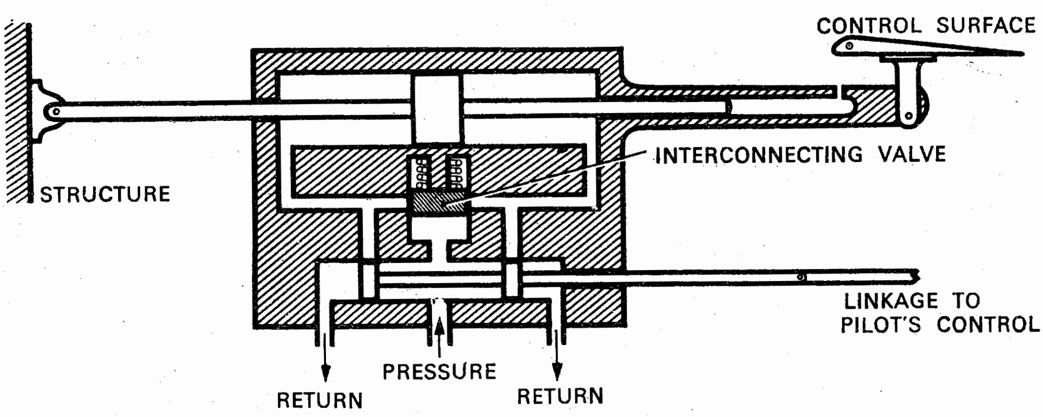


Figure 26 SERVO-CONTROL UNIT

14.2 An alternative method of operating the flying controls is by means of self-contained powered flying control units (PFCU's). Control surfaces are divided into sections, and each section is operated by a separate PFCU, thus providing duplication to guard against failure of a unit. Each unit is controlled by mechanical linkage from the pilots' controls, and some units also accept electrical inputs from the auto-pilot and auto-stabilizer. The mechanical input rod to each unit is telescopic and spring loaded, so that failure of one PFCU will not prevent operation of the associated control system. In the event of failure, or when a unit is inoperative, the actuating ram is mechanically locked in the neutral position, thus preventing movement of the associated section of the control surface. Actual operation is basically similar to that of the servo-control unit described previously, but each PFCU is a self-contained hydraulic system, and is not connected with the main hydraulic system, or with other PFCU's. The main body of each PFCU acts as a reservoir, and houses all the components necessary for operation of the unit, including electrically driven pumps and hydraulic actuator.

15 INSTALLATION AND MAINTENANCE Aircraft installations vary considerably, and the appropriate Maintenance Manual should be consulted before any work is carried out on the hydraulic system of any particular aircraft. Failure to observe the precautions detailed by the manufacturer could lead to damage to the aircraft, and, possibly, to physical injury. Even when the aircraft pumps are stationary, high pressures are maintained in parts of the system by the accumulators, and no disconnections should be made while the system is pressurised. Any specific instructions regarding the isolation of electrical circuits, or the fitting of hydraulic safety locks during servicing, should be carefully followed.

15.1 **Cleanliness.** With a modern hydraulic system cleanliness is of the utmost importance. The filters fitted in the aircraft system will normally protect the components from the effects of particle contamination, but it is important that any ground equipment used for servicing purposes is kept scrupulously clean, and that the fluid is filtered to a similar standard. Contamination from other fluids must also be avoided, and provision is usually made for taking fluid samples. Whenever a connection is broken, or a component is removed, precautions must immediately be taken to prevent the ingress of foreign matter or moisture. If it is necessary to top-up the system, fluid should be poured directly from a new fluid container into the reservoir, or a sealed dispensing rig should be used. When the system is topped-up from a can, any unused fluid should be discarded.

15.2 **Sampling.** Samples of the system fluid should be taken at the periods specified in the approved Maintenance Schedule, and whenever contamination is suspected. If a fluid sampling kit is available it should be used strictly in accordance with the manufacturers' instructions, but, if such a kit is not available, the sample should be sent to a laboratory for examination.

15.2.1 The bottle into which the fluid is drained must be scrupulously clean, to avoid adding to any contamination that may already be present in the sample. The bottle should be washed with soap and water to give a clean, bright finish, rinsed in clean water, then in filtered alcohol, and dried with clean dry air. It is usually recommended that plastic sheet is interposed between the bottle and the cap, to prevent the formation of loose particles when the cap is screwed on.

15.2.2 When taking a sample, a suitable service should be operated to circulate the fluid, and a small quantity should be drained from the sampling point before filling the sample bottle. Every precaution should be taken to prevent contamination of the sample, and any instructions contained in the Maintenance Manual, or in the test kit, should be carefully followed.

15.2.3 The action which it is necessary to take following the testing of a sample of fluid, will depend on the degree of contamination found. The parameters to be tested are—acidity, specific gravity, viscosity, water content, and particle contamination, and acceptable values are specified in the appropriate Maintenance Manual. If slight contamination is present, the fluid should be circulated by operation of the services, and a further sample taken. If heavy contamination is found, the affected system should be flushed or drained, and re-filled with clean fluid.

15.3 **Flushing.** Flushing is normally required after extensive removal and replacement of pipelines or components, and is carried out by operating the particular service a number of times, so that any particle contamination may be trapped by the filters. When it is necessary to flush the main system, the filters should be changed and the fluid should be circulated by operating the largest hydraulic jacks a number of times. Either an auxiliary pump, or an external hydraulic test rig, may be used for flushing, but, if an auxiliary pump is used, it is normally recommended that it is subsequently removed and inspected for possible damage.

15.4 **Draining the System.** The hydraulic system should be drained whenever components which are not provided with self-sealing couplings have to be removed, and also when overheating or mechanical failure of a pump, or the introduction of extraneous fluids or foreign matter, has resulted in contamination of the system.

15.4.1 It is common practice to disconnect the engine-driven pump from the system before commencing draining, so as to prevent the formation of air locks in the pump and to maintain lubrication when the pump is rotated.

15.4.2 The hydraulic system should be made electrically safe (by the tripping of circuit-breakers or the removal of fuses, as appropriate), the hydraulic pressure should be released by operating one of the services, and the air pressure should be released from the accumulators and reservoir. The reservoir filler cap should be removed, and fluid should be drained into a clean container of suitable capacity, by means of the system drain cock. Drained fluid should be returned, in appropriately identified containers, for reclamation by an approved process.

15.4.3 If fluid contamination is the reason for draining, it will also be necessary to remove the filters, and to clean or replace the filter elements as appropriate. Cleaning is usually by an ultrasonic cleaning process, but washing in trichloroethylene may also be permissible as a temporary measure.

15.5 **Filling the System.** Following initial installation, and whenever the fluid has been drained, the system should be filled and primed. Filling may be carried out through the reservoir filler neck, or through a priming connection in the ground servicing bay, using an external priming rig. The system is pressurised for priming purposes by using either an aircraft electrically-operated pump, or an external hydraulic test rig.

15.5.1 To ensure correct operation of the system, all air must be removed from the pipelines and components. Some components are bled by slackening the pipe connections, allowing fluid to escape, then retightening; some components are fitted with bleed valves, and others are purged by operating the service and forcing any trapped air to return to the reservoir.

15.5.2 The aircraft should be jacked in accordance with the relevant Maintenance Manual, and the accumulators should be charged with air or nitrogen, as appropriate. Ground electrical power should be connected, and the appropriate fluid and pump overheat warning lamps should be tested.

15.5.3 The reservoir filler cap should be removed, the system should be completely filled with fluid, and the quantity indicators should be checked. The system should be pressurised to normal system pressure, using the electrically operated pump or test rig as appropriate, and one of the services should be operated until the reservoir fluid level has stabilised. Trapped air should be released from the reservoir, and fluid added to keep the level at maximum. This process should be repeated for each service, bleeding being carried out where appropriate, and careful watch being kept on the pump and fluid temperatures. Fluid bled or drained from components must not be returned to the system.

15.5.4 After each service has been primed, the fluid level should again be checked. In some systems the fluid level depends on the positions of various actuators, and, before checking the fluid level, it is necessary to make the appropriate selections, and to ensure that all accumulators and reservoirs are fully charged.

15.5.5 When filling and priming are completed, all connections should be checked for tightness, and locked. Electrical power (and the hydraulic test rig, if used) should be disconnected, and the aircraft should be lowered to the ground. Engines should be run to check correct operation of the hydraulic services.

15.6 **Replacement of Components.** Before removing any components in the system, fluid pressure should be released by operating an appropriate service a number of times, and gas pressure should be released by means of the accumulator gas charging valve and the reservoir filler cap. Care should be taken to release gas pressure slowly. In addition, it may be necessary to electrically isolate some components by tripping the associated circuit-breaker, or by removing a fuse, making due note of the circuits disconnected, for reference when re-assembling. Electrical isolation is preferable, in order to avoid any possibility of inadvertent selection, whether or not power is available at that time. Some components, such as the engine-driven pumps, are connected into the system by quick-release couplings, so that they may be removed without disturbing the rest of the system, but it may be necessary to drain the system in order to remove other components. In instances where a component, such as a pump, has to be removed because of mechanical failure, the fluid may have been contaminated by metal particles, and it will be necessary to clean the filters, drain the old fluid, and flush the system with clean fluid.

15.6.1 Care should be taken not to spill any fluid drained from the system, and pipes should be blanked immediately they are disconnected. Blanks should not be removed until immediately prior to fitting the new component.

15.6.2 **Installation.** Replacement components must be checked to ensure that they have the correct part number, that they are to the correct modification standard, and that storage life has not been exceeded. The age of replacement seals is particularly important. If the components are filled with storage oil, they should be drained and flushed, then filled with system fluid before installation. Care should be taken, when fitting the pipes, to ensure that the connections meet properly; flexible pipes should not be allowed to twist when the end fittings are tightened, and the associated mechanism should be operated to ensure that the pipes are not stretched or kinked, and do not foul any adjacent structure. Any adjustments to sequence valves, micro-switches and linkage, should be carried out in accordance with the relevant Maintenance Manual, to ensure correct operation of the service and its associated signalling and warning systems. Where necessary, the system should be filled and primed, and all connections should be tightened to the specified torque, and locked, as appropriate.

15.6.3 Actuators usually have a range of movement slightly greater than that of the service they operate. This both ensures that the actuator piston will not bottom in its cylinder before operation of the service is complete, and allows for vibration and flexing of the structure. Adjustable actuators are often used to operate the over-centre linkage on a landing gear, and these are initally adjusted so that the attachment pins are an easy fit; they are then lengthened by one turn of the eye-end, to make sure that the actuator piston will not bottom and inadvertently release the over-centre lock. After adjustment, the eye-end should be checked to ensure that it is still in safety, i.e. that the thread can be seen in the hole provided in the piston rod for this purpose. Another example of an adjustable actuator, is the single acting actuator used as a locking device, although in this case, the actuator cylinder may be adjustable for length. These actuators are adjusted in a similar way, to ensure that the lock is always under spring pressure.

15.6.4 **Testing.** In order to carry out functional tests, the system must be full, accumulators must be charged with air or nitrogen to the correct pressure, and the electrical circuits must be re-connected. Power for operation of the system may be provided by an engine-driven pump, by an aircraft electrically-operated pump, or by an external hydraulic test rig. All hydraulic controls and switches should be set to their appropriate operating positions, and the system should be checked for correct operation, service operating times, and signs of fluid leakage. Both the normal and emergency systems should be operated, and all gauges, instruments and warning lights should be checked for correct operation, according to the particular aircraft system. Full normal functioning tests should be carried out after testing the emergency systems, to ensure that shuttle and emergency valves are returned to their normal positions.

15.7 **Routine Maintenance.** The procedures outlined below are applicable to most aircraft hydraulic systems, but the detailed requirements for a particular system should be obtained from the approved Maintenance Schedule.

15.7.1 Lubrication of pivots and linkages should be carried out at the specified intervals.

15.7.2 Filters and chip detectors should be removed for examination and cleaning, and fluid samples should be taken and sent for analysis whenever contamination is suspected. Filter sumps should be cleaned, and a new gasket or seal should be fitted when changing the filter element.

15.7.3 Exposed actuator rods should be cleaned, and wiped with a lint-free cloth moistened with system fluid.

15.7.4 The fluid level in the reservoirs should be checked and topped-up as necessary. A certain amount of fluid may be lost through heating and seepage past seals, but the amount lost should remain fairly constant. If the level is unusually low, the system should be checked for leakage.

15.7.5 The gas pressure in the accumulators should be checked, and the cause of any excessive loss of pressure should be investigated. Internal leakage past the separator or diaphragm, may introduce gas into the fluid, and external leakage would reduce the effectiveness of the accumulator.

15.7.6 All system components should be examined for damage, corrosion, leaks and security. Pipes should be examined for kinks, dents, chafing, leaks, and security.

15.8 **Checks for System Deterioration.** Sluggish or erratic operation of a hydraulic system may be caused by external leakage from components or joints, or by internal leakage resulting from erosion, or faulty seals. A small amount of external leakage may not seriously affect system operation, and some Maintenance Manuals specify acceptable limits. Temperature indicators installed in some aircraft hydraulic systems will, since flow produces heat, give some warning of incipient failure; but internal leakage tests are generally only conducted at specified intervals, or when faulty system operation is reported. Depending on the type of system installed, either flow rate or leak rate checks are carried out, an external hydraulic test rig usually being connected to the aircraft, and the hydraulic system usually being prepared for normal operation.

15.8.1 **Flow Rate Check.** This check is carried out with a flow indicator installed in line with the external test rig, the hydraulic services being systematically operated in the manner prescribed in the relevant Maintenance Manual, and the flow rates being recorded. Flow through a particular component may be checked by comparing the flow reading at various actuator positions, but some aircraft are fitted with a maintenance hydraulic power system, which uses separate pipelines and isolation cocks to facilitate flow rate checks. Components with internal leakage greater than the maximum permitted, should be removed for investigation.

15.8.2 **Leak Rate Check.** For this check, the system should be pressurised to normal operating pressure, then the test rig should be quickly turned off and the time taken for system pressure to decay by a prescribed amount, should be recorded. If the leakage rate is excessively high, parts of the system may be checked individually, by blanking appropriate connections and recording the leakage rate through particular components, or groups of components. In some cases, leakage through a component, such as an actuator, may be checked by disconnecting one pipeline, applying system pressure to the opposite connection, and measuring the quantity of fluid discharged through the open port over a specified time. Components showing excessive leakage should be removed for examination and possible replacement of seals.

15.9 **Seals.** When it becomes necessary to remove a component with a gasket or static seal fitted to the joint face, or to disassemble a component containing static or dynamic seals, the old gaskets or seals should be discarded, and new ones should be fitted. A new seal should be checked to ensure that it is the correct size, and of the correct material for the type of fluid in the system, and to ensure that the shelf-life, where applicable, has not been exceeded.

15.9.1 Extreme care must be exercised when handling and fitting a seal, and a suitable assembly tool or guide should be used where necessary; a tubular guide should be used when passing a seal over a thread. Scratches and nicks must be avoided, and the seal must not be stretched excessively; it is particularly important to check 'O' rings after assembly to ensure that they are not twisted. Seals should normally be lubricated with system fluid before assembly, and in some instances it is recommended that they should be soaked in fluid for a specified time.

15.9.2 In some cases a number of seals are used together, or in an assembly with backing rings or wiper rings. It must be ensured that these components are fitted facing in the correct direction, and in the correct sequence, otherwise leakage and failure of the component may result.

15.9.3 Backing rings of nylon or similar material may be supplied uncut. The join should be cut at 45°, and the ends should be trimmed to produce the gap specified in the appropriate Maintenance Manual.

15.9.4 Rings made from polytetrafluoroethylene (PTFE) require particular care during assembly, as undue stretching or kinking could result in permanent damage. A tapered mandrel should normally be used during assembly, to minimize stretch, with the larger diameter the same size as the land over which the ring must pass. It is recommended that the component to which the ring is fitted should not be assembled for 30 minutes, to enable the ring to relax.

16 STORAGE Hydraulic components are normally packed in sealed containers or plastic bags, and should not be unpacked until required for use. They should be stored in conditions which are dry and free from corrosive fumes.

16.1 Assemblies containing seals, or other non-metallic parts, are normally filled with system fluid or storage oil, and all connections are securely blanked to prevent leakage or ingress of dirt or moisture. Pipes are usually blanked and stored in a dry condition, and care must be taken to ensure that flexible pipes are stored in the shape in which they have been manufactured or which they have assumed during use. Particular care should be taken with pipes manufactured from PTFE, which has a low structural strength, and which may become permanently kinked if bent.

16.2 Storage life of assemblies is determined by the life of the non-metallic parts, and depends on the material from which those parts are made. The life of rubber components is dependent upon storage conditions, and may be limited, but the life of PTFE parts may be indefinite. The date of packing, and the storage life, should be marked on the container, but storage life may also be checked by reference to the appropriate Maintenance Manual.

16.3 Components removed from storage should be checked, before installation, for damage and corrosion. Components which have been stored dry, or have been filled with storage oil, should be flushed with system fluid, and every precaution should be taken to prevent the ingress of dirt or moisture.

Issue 1.

18*th May*, 1978.

AIRCRAFT
SYSTEMS AND EQUIPMENT
HIGH PRESSURE PNEUMATIC SYSTEMS

1 INTRODUCTION This Leaflet gives guidance on the operation and maintenance of high-pressure pneumatic systems in aircraft, and no attempt is made to describe any particular system in detail. Any maintenance work on an aircraft or system should be carried out in accordance with the procedures defined by the manufacturer, and the Leaflet should, therefore, be read in conjunction with the relevant manuals for the aircraft concerned.

1.1 Information on associated subjects will be found in Leaflets **BL/6-15**—Manufacture of Rigid Pipes, **BL/6-30**—Torque Loading, **AL/3-13**—Flexible Pipes, **AL/3-14**—Installation of Rigid Pipes in Aircraft, and **AL/3-19**—Wheels and Brakes.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet **AL/5-1**, Issue 2, 15th June, 1962.

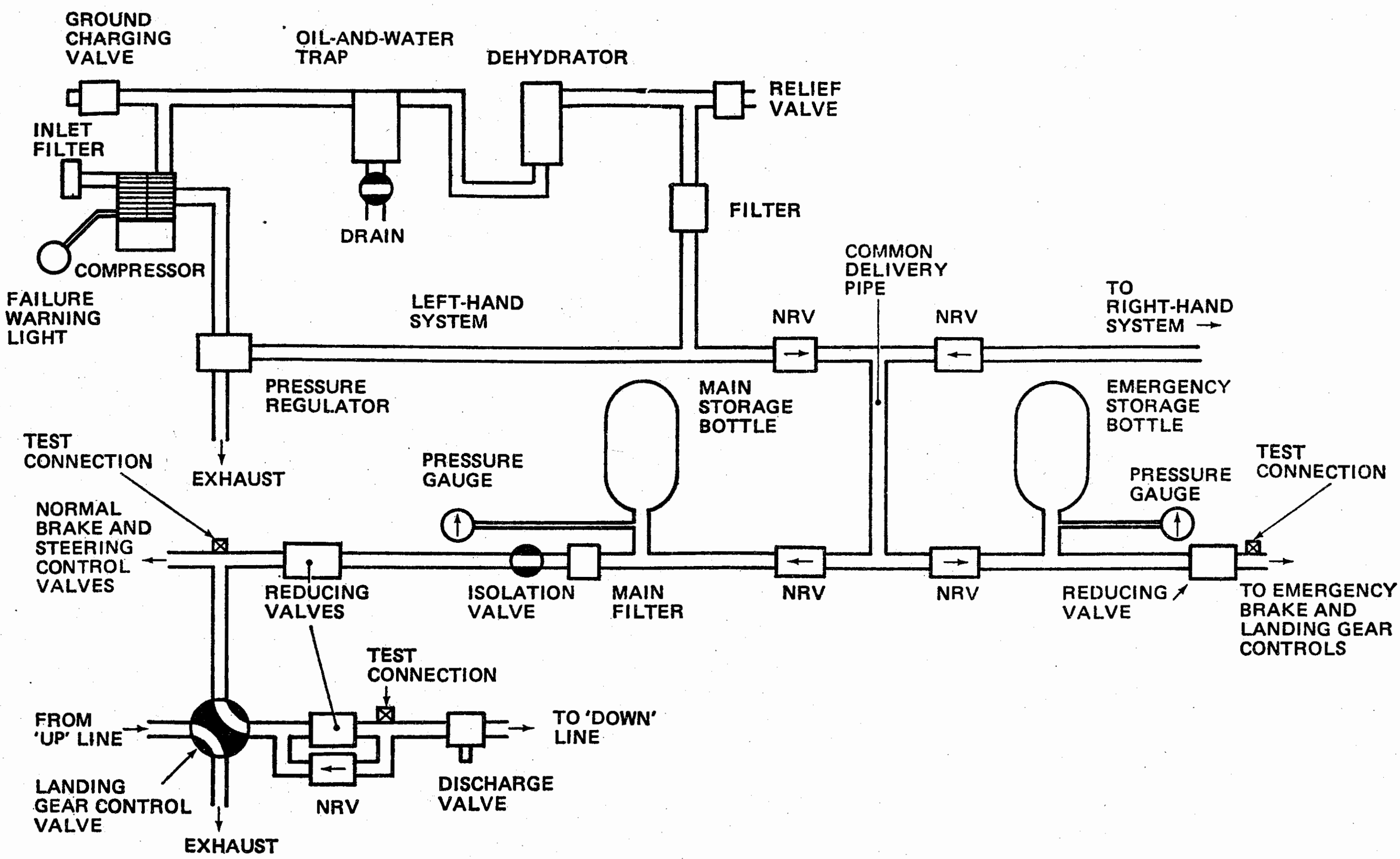
2 GENERAL The use of a compressed-air system to operate an aircraft's services usually represents a saving in weight compared to a hydraulic system, since the operating medium is freely available, no return lines are necessary, and pipes can be of smaller diameter. Systems having operating pressures of up to 24 MN/m^2 (3,500 lbf/in^2) are in use, and provide for the rapid operation of services when this is required. However, compressed air is generally not suitable for the operation of large capacity components, leaks can be difficult to trace, and the results of pipeline or component failure can be very serious.

2.1 Extensive high-pressure pneumatic systems powered by engine-driven compressors are generally fitted on the older types of piston-engined aircraft and are used to operate services such as the landing gear, wing flaps, wheel brakes, radiator shutters and, at reduced pressure, de-icing shoes. There are some modern aircraft which also use a high-pressure pneumatic system, however, and there are many aircraft which use pneumatic power for the emergency operation of essential services; the latter type of system is usually designed for ground-charging only.

2.2 Low-pressure pneumatic systems such as are used on most turbine-engined aircraft for engine starting, de-icing, and cabin pressurization, are supplied with compressed air tapped from the engine compressor and are not dealt with in this Leaflet.

3 TYPICAL SYSTEM This paragraph describes both a typical high-pressure pneumatic system, and the types of components which could be used.

3.1 The system illustrated in Figure 1 contains two separate power circuits, each of which is supplied by a four-stage compressor driven from the gearbox of one main engine, and a common delivery pipe to the high-pressure storage bottles and system services. A multi-stage cooler attached to each compressor cools the air between each of the compression stages, and a means is provided for off-loading the compressor when the system is not being used.


GROUND
CHARGING
VALVE
OIL-AND-WATER
TRAP
DEHYDRATOR
RELIEF
VALVE
INLET
FILTER
DRAIN
FILTER
COMPRESSOR
FAILURE
WARNING
LIGHT
COMMON
DELIVERY
PIPE
LEFT-HAND
SYSTEM
NRV
NRV
TO
RIGHT-HAND
SYSTEM
PRESSURE
REGULATOR
MAIN
STORAGE
BOTTLE
EMERGENCY
STORAGE
BOTTLE
TEST
CONNECTION
EXHAUST
PRESSURE
GAUGE
PRESSURE
GAUGE
TEST
CONNECTION
NORMAL
BRAKE AND
STEERING
CONTROL
VALVES
REDUCING
VALVES
ISOLATION
VALVE
MAIN
FILTER
NRV
NRV
REDUCING
VALVE
TO EMERGENCY
BRAKE AND
LANDING GEAR
CONTROLS
TEST
CONNECTION
FROM
'UP' LINE
TO 'DOWN'
LINE
LANDING
GEAR CONTROL
VALVE
NRV
DISCHARGE
VALVE
EXHAUST

3.2 Air is drawn through an inlet filter into each compressor, and is discharged through an oil-and-water trap, a chemical dehydrator, a filter and a non-return valve, to the main storage bottle and system. Overall control of main system pressure is provided by means of a pressure regulator, but pressure relief valves are included to prevent excessive pressures in the system, which may be caused by regulator failure or by an increase in temperature in the pipelines and components. Pressure reducing valves are used to reduce the pressure supplied to some components.

3.3 A storage bottle for the emergency system is pressurized through a non-return valve from the main system supply, and maintains an adequate supply of compressed air to enable the landing gear and flaps to be lowered, and the brakes to be applied a sufficient number of times to ensure a safe landing.

3.4 Isolation valves are fitted to enable servicing and maintenance to be carried out without the need to release all air from the system, and pressure gauges are provided to indicate the air pressure in the main and emergency storage bottles.

4 COMPONENTS The types of components used in a high-pressure pneumatic system will vary considerably between aircraft, but the examples considered in this paragraph are typical of the components which may be found in current use.

4.1 **Compressors.** A positive-displacement pump is necessary to raise the air pressure sufficiently for the operation of a pneumatic system, and a piston-type pump is generally used. Some older types of aircraft are fitted with a single-cylinder piston pump, which provides two stages of compression and raises the working pressure to approximately 3 MN/m² (450 lbf/in²). To obtain higher working pressures further compression stages are required. The compressor described in paragraphs 4.1.1 to 4.1.3 is capable of raising air pressure in four compression stages to 24 MN/m² (3,500 lbf/in²).

4.1.1 The compressor illustrated in Figure 2 has two stepped cylinders, each of which houses a stepped piston; a plunger attached to the head of No. 2 piston operates in a small cylinder bored in the head of No. 2 cylinder. The reciprocating motion of the main pistons is provided by individual cranks and connecting rods, the cranks being rotated by a common drive gear, and rotating in the same direction. Air passing between each compression stage is routed through an integral cooler, and lubrication is provided by an oil feed connection from the main engine lubrication system.

4.1.2 Compression depends on the volume of each successive stroke being smaller than the stroke preceding it; the induction strokes for each cylinder and the four compression strokes are accomplished during each revolution of the cranks. Operation of the compressor is as follows:—

(a) On the downward stroke of No. 1 piston, air is drawn into the cylinder head through a filter and non-return valve (NRV).

(b) On the upward stroke of No. 1 piston, air is compressed in the cylinder, opens a NRV in the cylinder head, and passes to the annular space formed between the steps of the cylinder and piston.

(c) The next downward stroke of No. 1 piston compresses air in the annular space in this cylinder and forces it through a NRV into the annular space formed between the steps of No. 2 cylinder and piston. No. 2 piston is approximately 90° in advance of No. 1 piston, and is moving upwards as No. 1 piston approaches the bottom of its stroke.

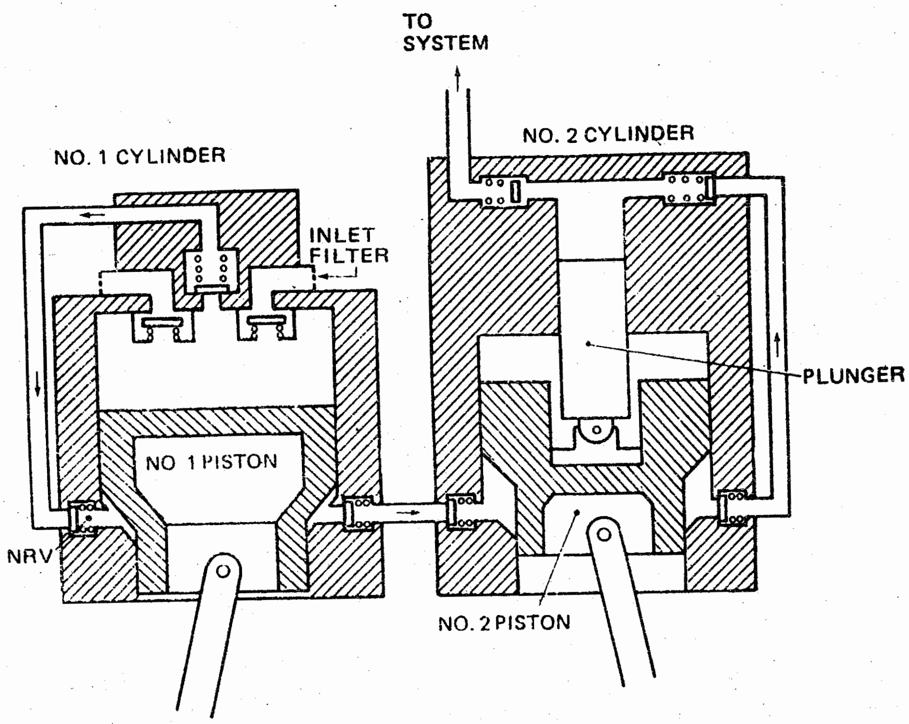


Figure 2 AIR COMPRESSOR

(d) On the downward stroke of No. 2 piston, air is compressed in the annular space at the bottom of the cylinder, and passes through a NRV into the small cylinder formed in No. 2 cylinder head.

(e) On the upward stroke of No. 2 piston, the plunger attached to it also moves upwards, further compressing the air in the small cylinder and passing it through a NRV to the system.

4.1.3 A pressure warning transmitter is fitted at the second-stage outlet, and third-stage pressure is connected to the pressure regulator (paragraph 4.2).

4.2 **Pressure Regulator.** The pressure regulator is fitted to control the maximum pressure in the system and to off-load the compressor when the system is idle. With the regulator illustrated in Figure 3, system pressure is fed to the top connection and acts on a piston, the lower end of which is in contact with the ball of a spring-loaded ball valve. At the predetermined maximum system pressure, the air pressure on the piston overcomes spring pressure and the ball valve is opened, releasing third-stage compressor pressure to atmosphere and allowing the pump to operate at second-stage pressure only. If any pneumatic services are operated, or a leak exists in the system, the air pressure trapped in the storage bottle and pipelines will drop, and the ball valve in the pressure regulator will close. The compressor will thus be brought back on line until the maximum system pressure is restored.

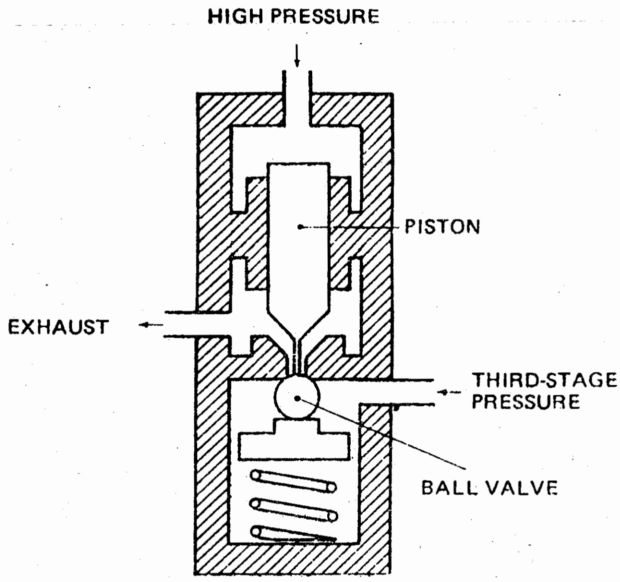


Figure 3 PRESSURE REGULATOR

4.3 **Oil-and-Water Trap.** The oil-and-water trap is designed to remove any oil or water which may be suspended in the air delivered by the compressor. It consists of a casing with inlet and outlet connections at the top and a drain valve in the bottom. Air entering the trap does so through a stack pipe, which includes a restriction and a baffle to prevent the air flow stirring up any liquid or sediment in the bottom of the container. Air leaving the trap also passes through a stack pipe, to prevent liquid or sediment entering the system during aircraft manoeuvres.

4.4 **Dehydrator.** To protect pneumatic systems from malfunctioning due to moisture freezing in the components and pipelines, the compressed air may be dehydrated by a substance such as activated alumina, or it may be inhibited by a small quantity of methanol vapour. The handling of methanol presents some difficulties, however, and because of its corrosive nature systems must be specially designed for its use; activated alumina is, therefore, more generally used.

4.4.1 Activated alumina is housed in a container through which the compressed air passes after leaving the oil-and-water trap, and which generally contains a filter at the outlet end. The charge of alumina in the container will gradually become saturated with moisture, and should be changed at the specified intervals. The number of flying hours at which the alumina charge is changed is normally determined by the aircraft manufacturer through practical experience.

4.5 **Storage Bottles.** In a pneumatic system the storage bottles provide the reservoir of compressed air which operates all services, the compressors being used to build up system pressure when it falls below the normal level. The volume of the actuators and pipelines determines the size of the bottles required for the normal and emergency operation of the pneumatic services.

4.5.1 Storage bottles are generally made of steel, and may be of wire-wound construction for maximum strength. Bottles are generally mounted in an upright position, and a fitting screwed into the bottom end contains the supply connection and, usually, a connection to an associated pressure gauge, together with a drain valve by means of which any moisture or sediment may be removed. Stack pipes are provided at the supply and gauge connections in the fitting, to prevent contamination passing to the system or pressure gauge. Pressure testing of high-pressure storage bottles is required at specified periods, and the date of testing is usually stamped on the neck of the bottle.

4.6 **Pressure Reducing Valves.** Some services operate at pressures lower than the pressure available in the air bottle, and are supplied through a pressure reducing valve. This low pressure is, in some instances, further reduced for the operation of, for example, the wheel brakes, by the fitting of a second pressure reducing valve.

4.6.1 Figure 4 illustrates the operation of a pressure reducing valve. When pressure in the low-pressure system is below the valve setting, the compression spring extends and, by the action of the bell-crank mechanism, moves the inlet valve plunger to admit air from the high-pressure system. As pressure in the low-pressure system increases, the bellows compresses the spring and returns the inlet valve plunger to the closed position. The inside of the bellows is vented to atmosphere, and the valve thus maintains a constant difference in pressure between the low-pressure system and atmospheric pressure.

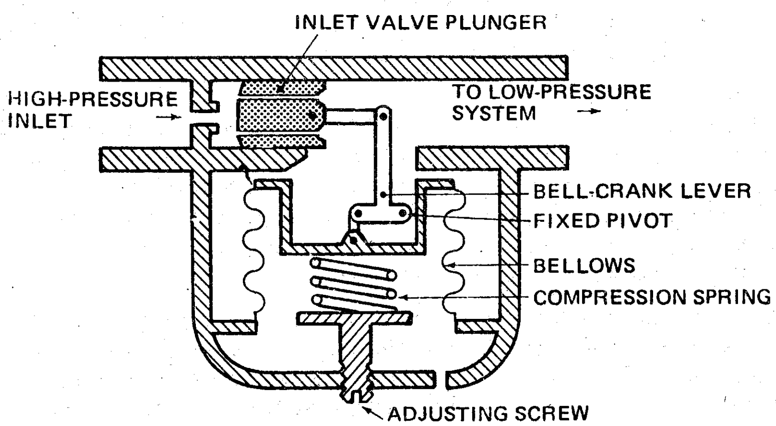


Figure 4 PRESSURE REDUCING VALVE

4.7 **Pressure Maintaining Valve.** A pressure maintaining valve is designed to conserve air pressure for the operation of essential services (e.g. landing gear extension and wheel brake operation), in the event of the pneumatic system pressure falling below a pre-determined value.

4.7.1 Figure 5 illustrates the operation of a typical pressure maintaining valve. Under normal circumstances air pressure is sufficient to open the valve against spring pressure and allow air to flow to the non-essential services. Should the pressure in the storage bottle fall below a value pre-set by the valve spring, however, the valve will close (as shown) and prevent air passing to the non-essential services.

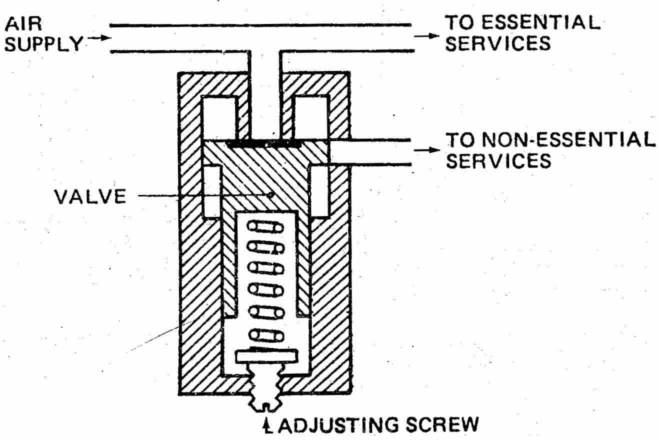


Figure 5 PRESSURE MAINTAINING VALVE

4.8 **Control Valves.** Compressed air stored in the bottle is distributed to the various pneumatic services, and directed to the various types of actuators by means of control valves, which may be manually or electrically operated. Examples of several types of control valves are described in paragraphs 4.8.1 to 4.8.3.

4.8.1 **Electrically-operated Control Valve.** The electrically-operated control valve for a pneumatic landing gear retraction system is illustrated in Figure 6. Selection of the landing gear position is made by either of two push-buttons (marked 'up' and 'down') which are mechanically interconnected to prevent operation of both buttons at the same time. These buttons, when depressed, supply electrical power to the 'up' or 'down' solenoid as appropriate. Actuation of this solenoid lifts an attached pilot valve, supplying compressed air to the cylinder at the bottom of the associated valve; the piston moves downwards, and the valve guide attached to it opens the inlet valve, admitting compressed air to the appropriate side of the landing gear actuators. At the same time the beam attached to the extension of this piston transfers movement to the valve guide in the opposite valve, allowing air from the opposite side of the actuators to exhaust to atmosphere.

4.8.2 **Manually-operated Control Valve.** The valve illustrated in Figure 7 is a simple two-position valve, and may be used as an isolation valve in some systems. The sleeve valve is operated by a cam, and is spring-loaded to the 'off' position; linkage from the cam spindle connects the valve to an operating lever. When used as an isolation valve the operating lever would normally be wire-locked in the 'on' position, and would only be used to permit servicing operations to be carried out.

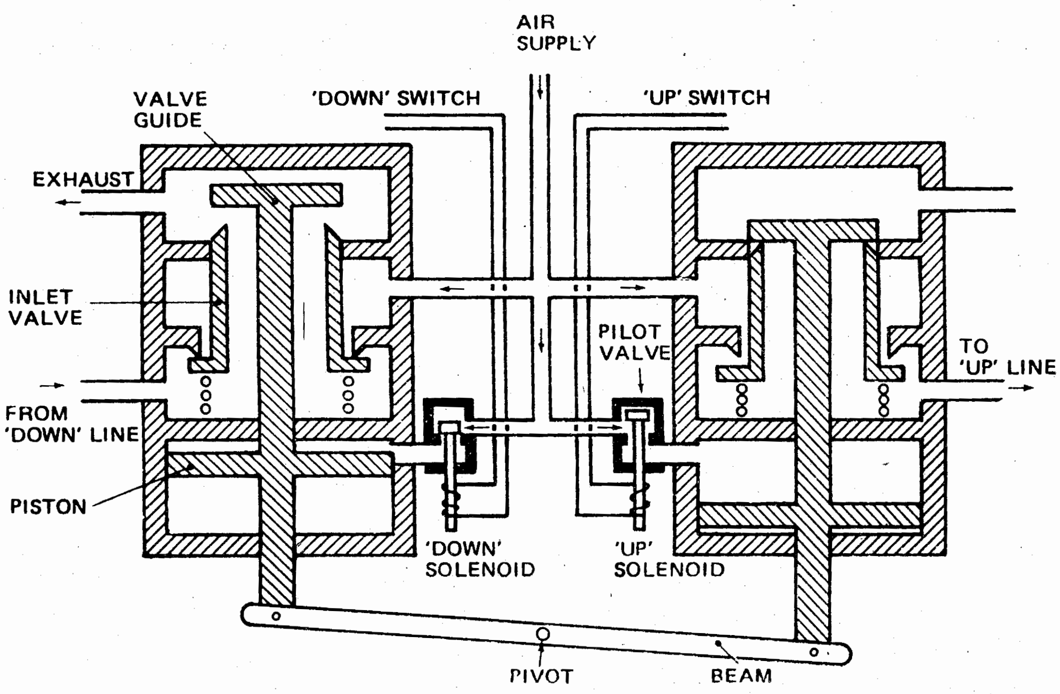


Figure 6 ELECTRICALLY-OPERATED CONTROL VALVE

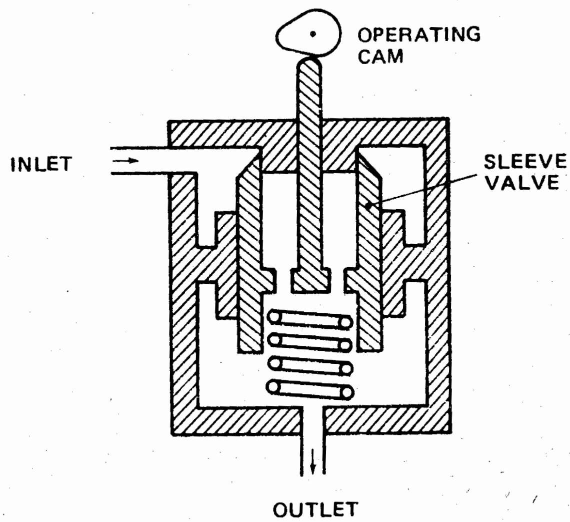


Figure 7 MANUALLY-OPERATED CONTROL VALVE

4.8.3 **Brake Control Valve.** Some older types of aircraft may be fitted with a type of brake control valve (known as a dual-relay valve) by means of which total brake pressure is applied by the operation of a single hand-control, and distribution to either or both brakes is effected by means of a mechanical connection to the rudder bar. The type of brake control valve illustrated in Figure 8 is used on some modern aircraft, and is operated by linkage from brake pedals attached to the rudder bar; separate valves supply compressed air to the brake units on each wheel. Operation of the valve is as follows:—

(a) In the 'off' position (as illustrated) the inlet valve is closed and pressure in the brake line is connected to the exhaust port.

(b) Pressure applied to the associated brake pedal is transmitted via the brake linkage to the valve sleeve, which moves up to close the exhaust valve. Further pressure applied through the valve sleeve and lower spring tends to open the inlet valve, and air pressure in the brake line combined with the force exerted by the upper and centre springs tends to close it. This produces a balanced condition in which any increase in the force applied to the valve sleeve results in a higher air pressure in the brake line, and a decrease in the force applied to the valve sleeve results in opening of the exhaust valve and a reduction in the air pressure in the brake line.

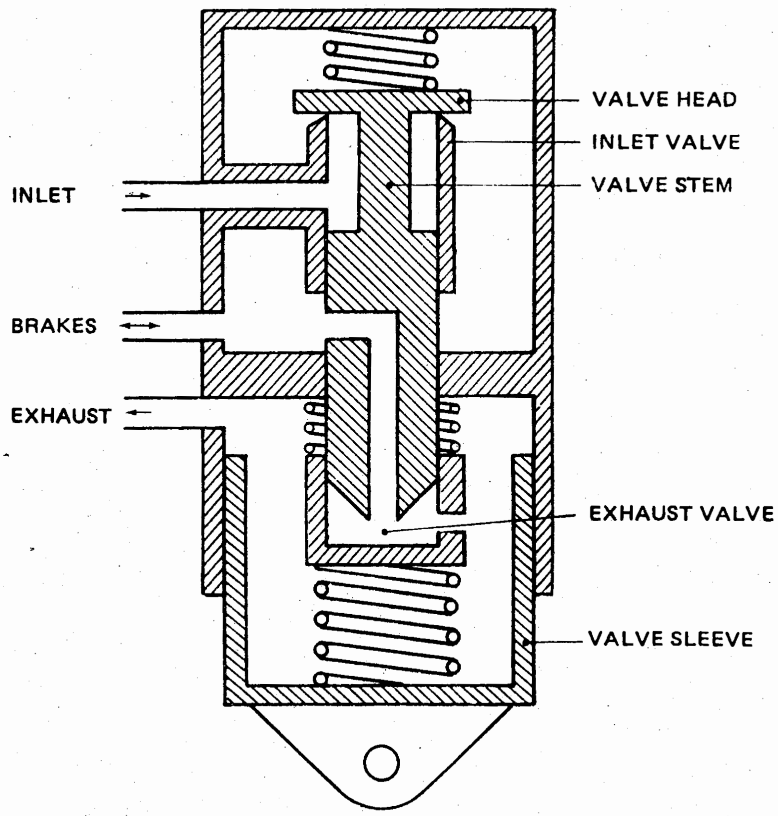


Figure 8 BRAKE CONTROL VALVE

4.9 **Actuators.** The purpose of an actuator is to transform the energy of the compressed air into linear or rotary motion. Actuators in pneumatic systems are normally of the linear type, and are similar in construction and operation to those described in Leaflet **AL/3-21** for hydraulic systems. Because of the nature of the operating medium, however, actuators in pneumatic systems are often damped to prevent violent operation of the services. A typical damped actuator is illustrated in Figure 9, the damping in this case being obtained by forcing grease through the annular space between the inner wall of the piston rod and a stationary damper piston; an orifice and plate valve in the damper piston provide less damping action when the piston rod retracts than when it extends. This type of actuator could be used, for example, to operate the landing gear and to restrict the rate of extension.

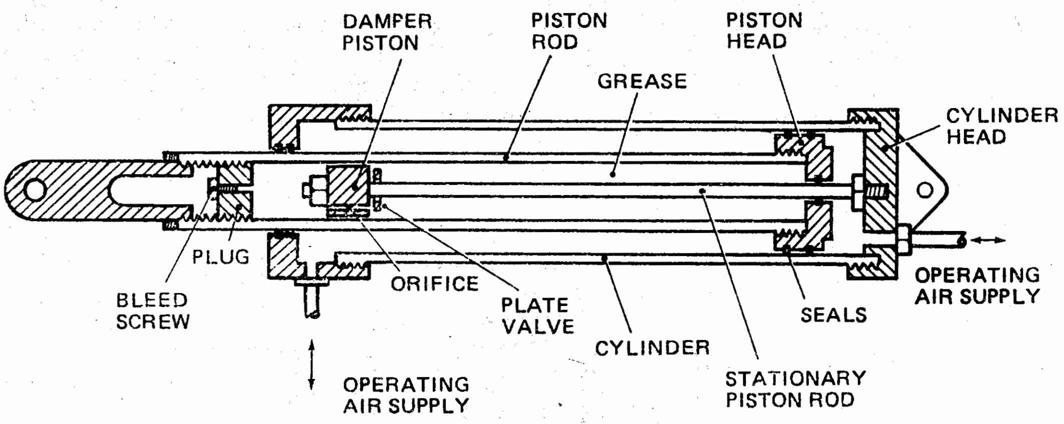


Figure 9 DAMPED ACTUATOR

5 REMOVAL AND INSTALLATION Aircraft pneumatic installations vary considerably, and reference should be made to the relevant Maintenance Manual before any work is carried out on a particular aircraft. Failure to observe any precautions detailed by the manufacturer could result in damage to the aircraft and, possibly, in physical injury. High pressures exist in parts of the system even when the aircraft engines are not running, and this pressure must be released before attempting to disconnect or remove any components or pipelines. Rapid operation of the system services is also a feature of pneumatic systems, and care must be taken during any tests to ensure that the services have complete freedom of movement and that the area is clear of personnel.

5.1 **Cleanliness.** The cleanliness of a pneumatic system is of the utmost importance to its correct operation. The filters fitted in the system will, if serviced at the appropriate intervals, protect the system components from contamination during normal use, but whenever a connection is broken or components are removed, the open pipes should be blanked immediately to prevent the entry of dirt and moisture; blanks should be left in position until the component is re-installed or the connection is re-made. Proper blanking caps should be fitted wherever possible, and on no account should rags or masking tape be used. Any external rig which is likely to be used to charge an aircraft system must be kept to the same standards of cleanliness, and the supply line should be blown through before being connected to the aircraft charging point.

5.2 **Removal of Components.** Before removing any components or disconnecting any pipelines, all pressure should be released from that part of the system. In some cases release of all pressure from the storage bottle will be specified by the manufacturer as being necessary; in the typical system shown in Figure 1 this is done by operating the discharge valve, but in other systems it may be necessary to unscrew a connection a quarter turn to release the air. Even those parts of the system protected from storage bottle pressure by a non-return valve or isolation valve may retain sufficient residual pressure to cause damage, and pipe connections should, therefore, be unscrewed slowly, pausing after the first quarter turn of the union nut to ensure that air pressure escapes slowly.

5.2.1 On aircraft which have a pneumatically-operated landing gear retraction system, ground locks should be fitted before releasing air from the 'down' lines in the system, and the landing gear control lever and emergency landing gear selector should be labelled to ensure that they are not operated.

5.2.2 On systems which have electrically-operated control valves it will usually be necessary to electrically isolate the part of the system being worked on, and this may be done by tripping the associated circuit-breakers or removing the associated fuses. Electrical isolation and placarding of controls is advisable in order to avoid any possible inadvertent selection, whether or not power is available at the time. Note should be taken of the disconnected circuits for reference when re-assembling.

5.2.3 Where a component, such as the compressor, has to be removed because of mechanical failure, other parts of the system may have become contaminated by metal particles. Filters downstream of the component which has failed should be checked for contamination, and if this is found, all components and pipes which may have been affected should be removed and cleaned or renewed as necessary.

5.2.4 Immediately after removing a component all openings should be blanked; flexible pipes should be secured to adjacent structure to prevent them from becoming damaged.

5.3 **Installation.** Before installing a new component, it should be inspected for any damage which may have occurred during storage, the part number and modification state should be checked, and it should be ensured that the storage life (paragraph 7) has not been exceeded. The thorough testing of components drawn from stores is not normally required (paragraph 5.4), but it should be ascertained that external moving parts function without binding, and operate in the correct sense. Components which have been removed from an aircraft and are to be re-installed must be thoroughly examined for cleanliness; pipes should be blown through with clean, dry air.

5.3.1 New gaskets should be fitted to all components which require their use, and other protective material such as may be used under straps or clamps, should be inspected for condition before being refitted.

5.3.2 Some components, such as non-return valves, must be fitted the correct way for the system to operate as intended, and are usually designed with different types of fittings at each connection to prevent incorrect installation. In some cases, however, the fittings may be identical, and the direction of flow marked on the component, should be checked.

5.3.3 The male threads on connections should be sparingly lubricated before assembly, as recommended by the manufacturer, and union nuts should be fitted by hand so as to check that the threads are not binding and to ensure that the connections are correctly aligned. All union nuts should be tightened to the torque values specified in the relevant Maintenance Manual, and should be locked in the appropriate manner.

5.3.4 All blanks should be removed from pipes before installation, and it should be ensured that the pipes are correctly installed and free from acute bends and kinks or damaged protective covering, are correctly aligned with mating connections, have adequate clearance between adjacent pipes and structure, and have been correctly identified, locked and supported. Flexible pipes should be checked to ensure that they are not bent, twisted or stretched at the limits of movement of the component to which they are attached, and are adequately supported.

5.3.5 After the installation of a component, any mechanical or electrical connections should be made, and a full functioning test should be carried out.

(a) Mechanical controls should be connected and adjusted so that control lever movement and valve operation are synchronized, and if stops are fitted to the valve the control should be adjusted to ensure that these stops are contacted; full details concerning the rigging and adjustment of the controls for a particular system should be obtained from the relevant Maintenance Manual. Controls should be free from binding over their full range of movement, and should have at least the minimum specified clearance from adjacent structure. After adjustment and checking, all linkage should be locked and lubricated as appropriate.

(b) The circuits to electrically-operated control valves should be checked for correct installation and functioning as described in Leaflet **EEL/1-6.** Micro-switches should be adjusted carefully to ensure that they operate positively without the plunger bottoming, and their mountings should be checked for rigidity and security.

(c) Unless otherwise stated, an actuator should be adjusted so that its piston does not bottom in its cylinder at the ends of its travel, and it should be checked for smooth and correct operation. When required by the relevant Maintenance Manual, actuators should be filled with grease or other specified damping fluid before carrying out a functional check.

5.4 **Testing.** The overhaul and testing of individual components must be carried out in accordance with the manufacturer's Overhaul Manual and requires the use of specially designed test rigs to ensure their correct operation. Dismantling of components should not be undertaken unless suitable test facilities are available, and the aircraft system should not be considered to be an acceptable alternative. Once tested after manufacture or overhaul, components do not normally require further tests to be carried out prior to installation, provided that their storage life has not been exceeded and that there is no superficial damage. System tests should, however, be carried out on new installations, after any part of a system has been adjusted, dismantled, or renewed, and at the periods specified in the relevant Maintenance Schedule. The method of carrying out a test of the pneumatic system is detailed in the aircraft Maintenance Manual, and will normally include the operations outlined in paragraphs 5.4.1 to 5.4.5.

5.4.1 After a system has been exhausted of air pressure, or parts of a system have been isolated from the storage bottles to permit removal and installation of components, certain precautions must be taken to prevent damage to the aircraft or injury to personnel when the system is re-pressurized prior to testing. The electrical circuits to electrically-operated controls should be reinstated by resetting the appropriate circuit breakers or refitting the fuses, and the positions of all controls, including emergency controls, should be checked as corresponding to the positions of the actuators in the pneumatic services. Ground locks should be fitted to the landing gear (unless the aircraft is on jacks), and air pressure should be built up slowly in the relevant parts of the system, either through the charging connection or by opening the isolation valves, as appropriate.

5.4.2 When a compressor has been changed, or whenever a slow build-up in system pressure has been reported, the output of the compressors should be checked; this check is usually carried out by running the appropriate engine(s) on the ground. The engine power setting, initial pressure, and maximum time permitted to build up pressure by a specific amount, are usually quoted in tables provided in the relevant Maintenance Manual; separate tables are often provided for checking new and in-service compressors.

5.4.3 When checking the operation of the various control valves in the system, care should be taken to ensure that the associated services are free to function and that adequate clearance is provided between any moving part and adjacent structure, trestles, etc. The air exhausted from some large components may be capable of causing damage, and warning notices should be positioned before operating these particular services.

5.4.4 The adjustment and correct operation of all locks, actuators, selectors, control mechanisms and indicators should be checked, using the appropriate test connections where necessary, and the operating pressures of the regulators, pressure reducing valves, pressure maintaining valves, brake valves and relief valves should be verified. It should also be ascertained that there is no internal or external air leakage from the valves or connections.

5.4.5 All services should be checked for correct operation, smoothness, and, when specified, speed of operation and system pressure drop. These tests should be carried out using both the normal and the emergency systems, and should be repeated a sufficient number of times to ensure consistency.

6 MAINTENANCE Maintenance of the pneumatic system should be carried out in accordance with the relevant Maintenance Manual and Schedule, and should include replenishment from an external source as necessary, routine inspections for condition, cleaning of filters, replacement of desiccants and checking for leaks.

6.1 **Charging.** A pneumatic system is fitted with one or more charging valves, by means of which the system may be fully pressurized from an external source. These valves also act as, or include, a non-return valve, and are fitted with a dust cap which must be removed when connecting an external supply. Any external supply, whether from high-pressure storage bottles or a mobile compressor, must be fitted with oil-and-water traps, and, preferably, a dehydrator, to ensure that the air supplied is clean and dry. The supply hose should be capped when not in use, and should be blown through with compressed air before being connected to the charging valve, to prevent the introduction of moisture or dirt into the aircraft system. Care should be taken to turn off the external supply and to release air pressure from the supply hose before disconnecting it from the aircraft.

6.2 **Routine Inspection.** The scheduled routine servicing of the pneumatic system should include the following operations:—

6.2.1 **Filters.** Wire-gauze air and oil filters such as may be fitted to a compressor, should be removed for cleaning and inspection at frequent intervals; cleaning in solvent is usually recommended, and the filters should be dried thoroughly before being refitted. The main air filter usually has a paper or felt element, and this should be renewed at the specified periods. This filter should also be drained periodically in order to check for the presence of water or oil, and this is best carried out by unscrewing the drain plug a quarter turn and releasing the trapped air; if moisture is found, the filter housing should be thoroughly dried and the element renewed, and if oil is found the compressor and the oil-and-water trap should be examined. A porous metal filter may also be fitted in some systems, and this is usually cleaned by reverse-flushing with methylated spirits; the filter must be thoroughly dried before replacing it in the system.

6.2.2 **Physical Condition.** All components and pipelines in the system should be examined periodically, for corrosion, cracks, dents and other superficial damage. Minor damage may often be removed and the area re-protected, but some components (e.g. storage bottles) must be considered unserviceable if the damage extends beyond the protective treatments. The components should also be checked for security and locking, and the pipelines for satisfactory clamping, protection and identification. Any leaks found should be treated as outlined in paragraph 6.3.

6.2.3 **Storage Bottles.** Storage bottles should be drained periodically to remove any sediment or moisture which may have accumulated. Draining is best carried out with pressure in the system, but the drain plug should not be unscrewed more than a quarter turn; without pressure in the bottle the drain plug may be completely removed, and it may be necessary to use a thin rod to clear any congealed sediment. After draining, the drain plug should be tightened to the specified torque and re-locked. The pressure testing of storage bottles should be carried out in accordance with, and at the times specified in, the relevant manuals.

6.2.4 **Oil-and-Water Trap.** The oil-and-water trap should be drained daily, or after each flight if freezing conditions exist, to prevent the freezing of water in the pipe from the compressor. Draining should be carried out as soon as possible after flight, and the procedures outlined in paragraph 6.2.3 for storage bottles should be used.

6.2.5 **Dehydrator.** The periods at which the alumina charge or other desiccant should be changed, depend on the weather conditions in general, and may vary considerably; the actual periods should be determined by experience, and should be such that the dehydrating agent never becomes saturated with moisture. In many cases it will be necessary to remove the dehydrator in order to recharge it, and the following procedure should be used:—

(a) Remove residual pressure from the container by means of the drain plug on the oil-and-water trap.

(b) Disconnect the pipe connection on the container, release the securing strap, and remove the container from the aircraft.

(c) Unscrew the end cap from the container and remove the dehydrating agent.

(d) Remove any moisture from the container by passing warm, dry air through it, and clean the outlet filter in methylated spirit. Check the container for corrosion.

(e) Examine any seals for damage or deterioration, and renew as necessary.

(f) Fill the container with a fresh charge of dehydrating agent, then refit and lock the end cap.

(g) Refit the container in the aircraft, and tighten and lock the connections and securing strap.

NOTE: The dehydrating agent is normally delivered in air-tight tins, but if permitted by the manufacturer the old charge may be re-activated, in emergency, by heating to 250°C to 300°C for 4 to 5 hours.

6.2.6 **Lubrication.** Any linkage associated with the control levers and valves in the pneumatic system, should be lubricated in accordance with the relevant Maintenance Manual, at the periods specified in the Maintenance Schedule. Engine oil is generally satisfactory for use on the threads of fasteners and components, but silicone grease may be recommended for use on some components (e.g. the dehydrator end cap), where it may come into contact with rubber seals.

6.2.7 **System Operation.** The operation of the complete system should be checked at the intervals specified in the Maintenance Schedule, whenever components are changed, and whenever faulty operation is reported. The method of testing a system is specified in the relevant Maintenance Manual, and the operations which are usually included are outlined in paragraph 5.4.

6.3 **Leakage.** In high-pressure pneumatic systems some leakage will inevitably occur, and manufacturers usually lay down a maximum permissible leakage rate for a particular aircraft system. Leakage will sometimes become apparent through the slow or incorrect operation of a service, or failure to maintain system pressure, but a small leakage may only be noticed by a drop in system pressure when the aircraft is out of use for a short period (e.g. overnight). The leakage rate is checked by fully pressurizing the system, then re-checking the pressure after a period of 12 hours (or other specified time). The initial and final pressures should be recorded, taking into account the ambient temperature at the time; if this drop exceeds the maximum permitted, a check for leaks should be carried out.

6.3.1 **Checking for Leaks.** Large external leaks can often be traced aurally or by the application of a non-corrosive soapy water solution (bubbles will appear at the position of a leak); all traces of soap solution must be removed after the test, using plenty of clean water, and the parts must be thoroughly dried. Smaller external leaks may not be detectable by these methods, but several types of electronic leak detectors are available which can be used to detect even the smallest leak. These detectors usually operate on ultrasonic principles, or by measurement of the positive ions emitted from the leak after a small quantity of carbon tetrachloride has been introduced into the system; operation of these detectors should be in accordance with the manufacturer's instructions. Internal leakage may be difficult to trace, and a knowledge of the particular system is essential. Leakage past seals and valves may often be found by checking the exhaust pipes, or by removing a connection and substituting a length of hose, the other end of which is held below the surface in a bucket of water; bubbles will indicate leakage from the component upstream of the disconnected pipe.

6.3.2 **Curing Leaks.** Leakage may be caused by a number of faults, such as deterioration of seals, loosening of nuts, splits in pipes, scoring of cylinder walls, or worn valve seats. Leakage from a pipe connection may sometimes be cured by tightening the union nut, but excessive force must not be used; if the leak persists after tightening, new parts should be fitted. Internal leakage from components will often require their removal for overhaul, but the replacement of seals and gaskets is sometimes permitted. Extreme care is necessary when refitting seals, and special tools may be required; any damage to the seal or component caused by careless handling could result in further leaks. When re-assembling components, absolute cleanliness is essential, and the tests specified in the relevant manual should be carried out before installing them in an aircraft.

7 STORAGE Pneumatic components are normally packed in sealed containers or plastic bags, and should not be unpacked until required for use. They should be stored in conditions which are dry, and free from corrosive fumes (see also Leaflet **BL/1-7**). The storage life of assemblies is determined by the non-metallic parts, such as seals, that they contain, and upon storage conditions. The date of packing, record of tests carried out, and storage life of a component should be marked on the container, but storage life may also be checked by reference to the Maintenance Manual.

7.1 Pipes are usually blanked and wrapped for storage, but flexible pipes should always be stored in the shape in which they were manufactured or have assumed during use.

7.2 Components removed from storage for installation on an aircraft should be examined for external damage and corrosion, and the condition of all threads should be checked. Where applicable the components should be blown through with clean, dry compressed air, and every precaution should be taken to prevent the ingress of dirt or moisture.

AL/3-23

Issue 2

September, 1988

AIRCRAFT

SYSTEMS AND EQUIPMENT

PRESSURISATION SYSTEMS

1 INTRODUCTION

1.1 The purpose of this Leaflet is to provide general guidance and advice on the installation, maintenance, and testing of equipment forming part of cabin pressurisation systems. These systems are designed to automatically maintain a selected altitude relationship between cabin and aircraft by controlling the pressure of the air normally derived from an associated air conditioning system (see Leaflet **AL/3-24**).

1.2 The information contained in this Leaflet is of a general nature and not of a particular aircraft type and should, therefore, be read in conjunction with the relevant Aircraft Manufacturers' Maintenance Manuals and Approved Maintenance Schedules.

1.3 Subject headings are as follows:—

1.4 Related CAIP Leaflets:—

AL/3-24 — Air Conditioning
AL/3-26 — Auxiliary Power Units
AL/7-14 — Repair of Metal Airframes
EL/1-3 — Turbochargers
EEL/1-6 — Bonding and Circuit Testing

2 GENERAL

2.1 In order to protect the occupants of transport aircraft from the effects of reduced atmospheric pressure at altitude, it is necessary to pressurise the cabin area. The purpose of pressurisation, is therefore, to maintain a safe cabin altitude relative to the aircraft altitude, and in association with an environmental air conditioning system, provide a comfortable environment when flying at the higher altitudes.

2.2 Cabin Altitude

2.2.1 With an increase in altitude there is a decrease in atmospheric pressure (see Figure 1).

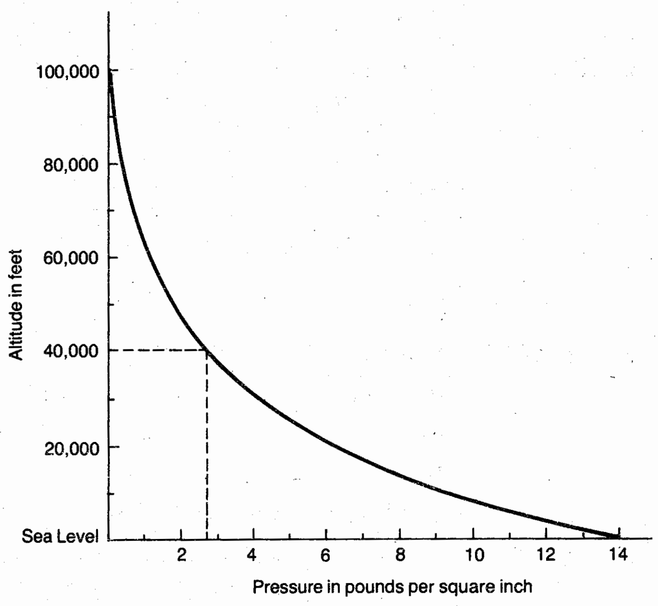


Figure 1 ATMOSPHERIC PRESSURE

2.2.2 From sea level to 7000 ft the oxygen content and pressure of the atmosphere is so sufficient as to maintain all mental and physical functions. At approximately 10,000 ft above sea level, oxygen saturation of the blood is lowered to approximately 90%, and any prolonged exposure to this level of cabin altitude could result in the occupants suffering headaches and fatigue. If the cabin altitude is allowed to rise further to approximately 15,000 ft, disorientation, impaired vision and physical changes may occur. Therefore, the purpose of the pressurisation system is to artificially create a lower altitude within the cabin (cabin altitude) relative to the aircraft altitude using pressurised air (see Figure 2). Design of the pressurisation system will, however, require certain devices to ensure the comfort and safety of the passengers and the structural integrity of the aircraft. These devices are described in the following paragraphs.

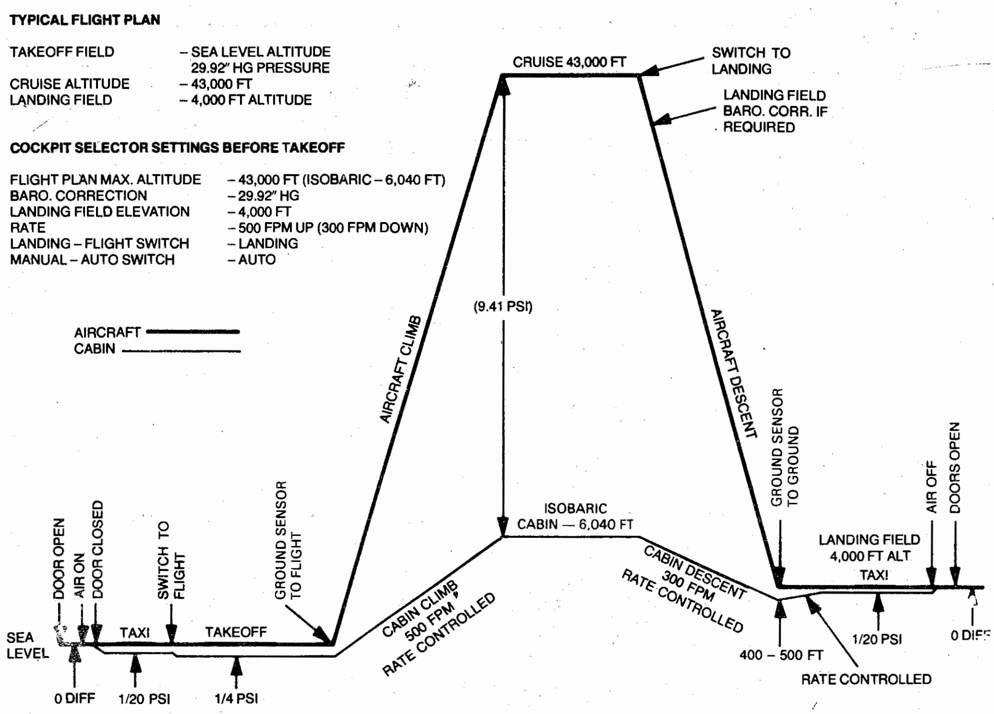


Figure 2 TYPICAL PRESSURISATION SCHEDULE

2.3 The cabin pressure (relative altitude) is controlled by regulating the rate at which air, normally supplied by the air conditioning system, is discharged to atmosphere by one or more discharge valves. In general this is achieved by the pressure controller passing a pneumatic or electrical command signal to the discharge valves (outflow valves) which respond by increasing or decreasing restriction to the flow of air from the cabin to atmosphere (see Figure 3).

2.4 In addition to the basic units which control cabin pressure, pressure limiting valves, inward relief valves, ground depressurisation valves, (of either automatic or manual control), and associated warning systems are provided as part of the pressurisation system to safeguard the occupants and airframe, in the event of a system or component failure.

2.5 Flight deck instrumentation systems and controls include indications of: cabin altitude, differential pressure, and cabin altitude rate of change. These indications can be of either, analogue or digital form, using instruments or cathode ray tube (CRT) displays.

2.6 Normally, visual warning systems also include additional simultaneous audible alarms to alert the crew members of any significant changes taking place, which may require immediate crew action.

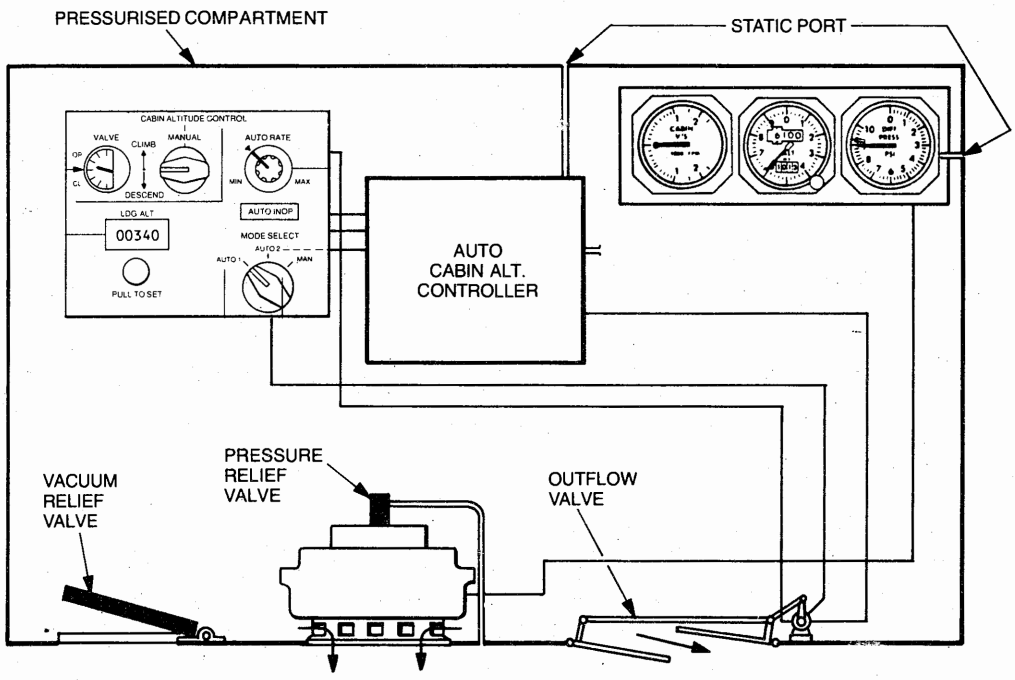


Figure 3 PRESSURISATION SYSTEM SCHEMATIC (ELECTRONIC)

2.7 Brief descriptions of some principal units, controls and instruments which form a typical pressurisation system are given in the relevant paragraphs of this Leaflet. For precise details of specific systems, reference should be made to the relevant Aircraft Maintenance Manual.

3 PRESSURISED AIR

3.1 The source of pressurised air is normally dependent upon the aircraft and engine type. Piston engine aircraft in general, use superchargers or turbochargers which may be part of the induction system or specifically incorporated for the purpose of pressurisation, for further information see Leaflet **EL/1-3**.

3.2 Where aircraft are powered by a turbo-jet engine(s), bleed(s) air from the compressor section of the main engine core is utilised (see Figure 4). However, on smaller aircraft, a system of ram air, supplemented by a small amount of high temperature bleed air for temperature control, may be adopted for air conditioning and pressurisation purposes.

3.3 Where fitted, the auxiliary power unit (APU) is another alternative source of pressurised air for the purpose of pressurisation. However operation is subject to certain operational limitations, for further information see Leaflet **AL/3-26**.

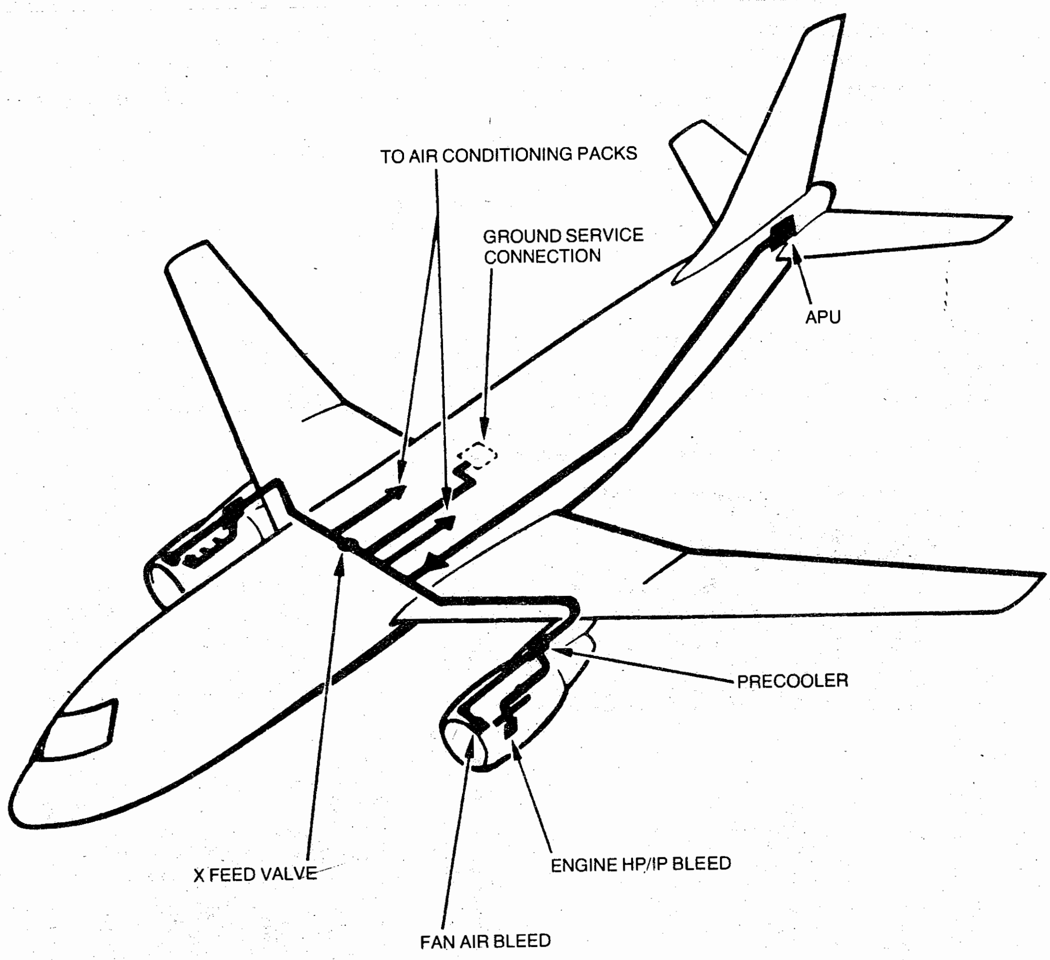


Figure 4 PRESSURISED AIR SCHEMATIC

4 THE PRESSURISATION CONTROL SYSTEM

4.1 **General.** The principal requirements of the pressurisation control system are:—

(a) To control, maintain and monitor the cabin altitude relative to the aircraft altitude within the specified parameters.

(b) To safeguard the occupants and airframe from 'pressure bumps' when ascending to or descending from altitude, by providing a controlled rate of altitude change.

(c) To provide safeguards against total system failure.

4.2 **Pressure Controllers.** Pressurisation control systems vary in their construction and mode of operation. Pneumatically controlled systems in general incorporate the pressure controller as an integral part of the instrumentation and pressurisation selector panel. Electrically controlled systems use remote cabin pressure controllers which amplify command signals from the selector panel to control and modulate the discharge valves (see Figures 5 and 6).

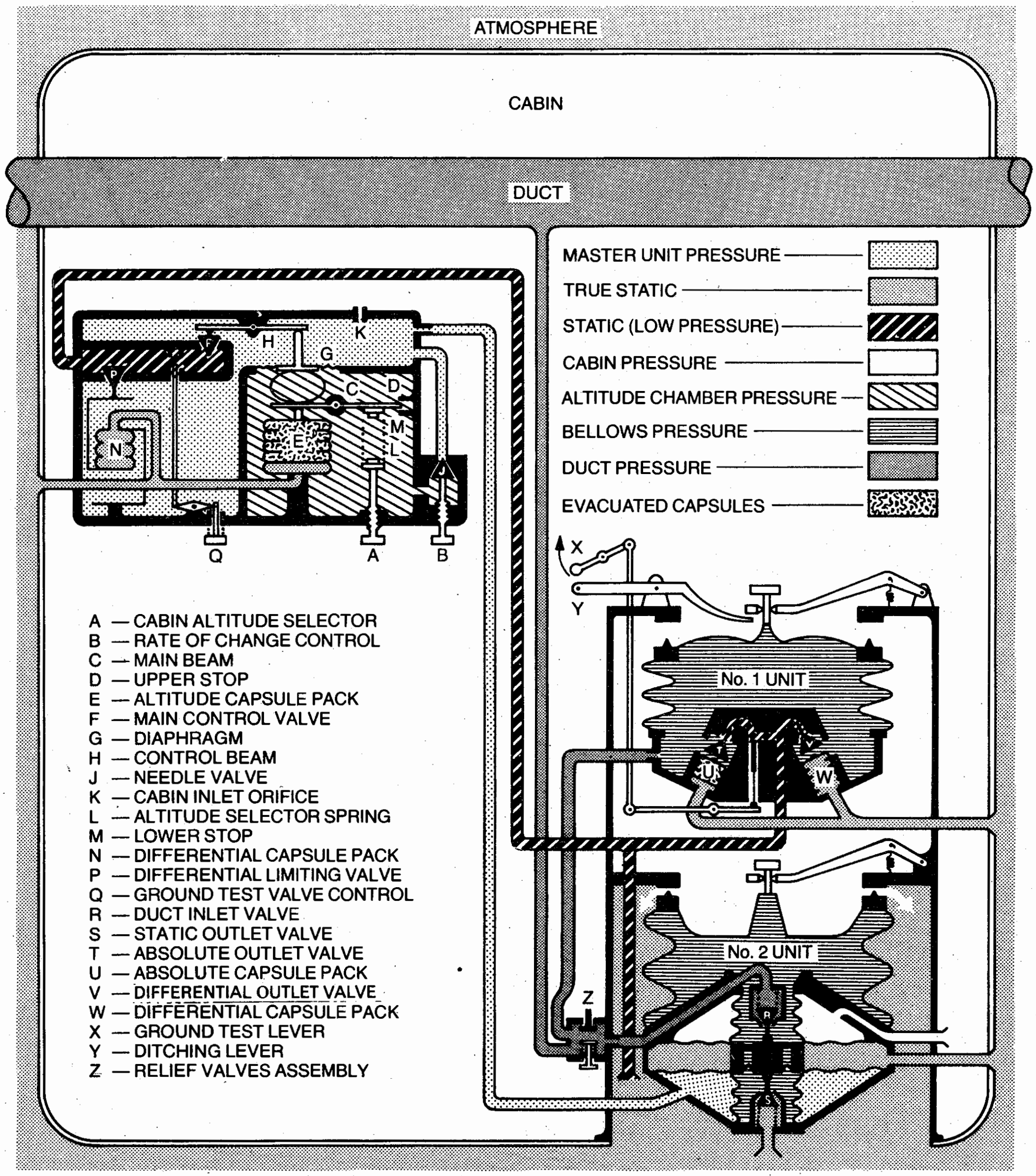


Figure 5 PRESSURISATION CONTROL (PNEUMATIC)

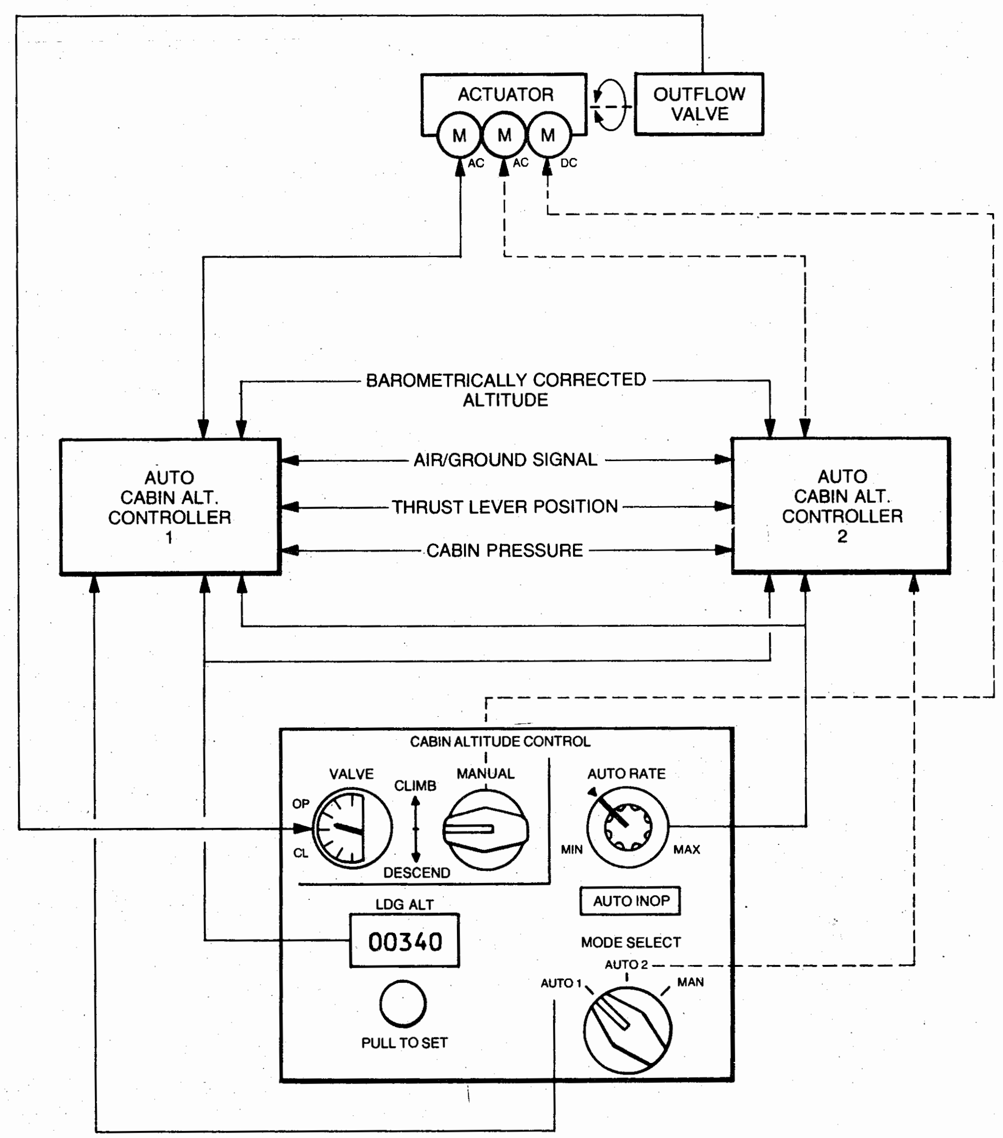


Figure 6 PRESSURISATION CONTROL (ELECTRONIC)

4.3 **Pneumatic Pressure Controllers**

4.3.1 Pneumatic pressure control systems comprise; pressure-sensing capsules and diaphragms which are subjected to both cabin and external pressures, metering valves, and controls for selecting the required cabin altitude and rate of change. With the controls preset prior to flight, the capsules, diaphragms and metering valves assume a datum position which will ultimately establish and maintain the appropriate cabin differential pressure. As the cabin pressure changes, the controller automatically senses the change relative to the external ambient pressure and transmits a pressure signal via a pressure sensing line connected to the discharge valves (outflow valves). The transmitted pressure signal will then open or close the valve to regulate the release of air from the cabin at the pre-selected rate of change, subject to the maximum differential pressure. The following paragraphs describe the function of a typical pressurisation controller and discharge valve of pneumatic operation (see Figure 5).

4.3.2 **Preflight Set-up.** Prior to take off, control knobs (A) and (B) respectively, are set for the required cabin altitude and rate of change. The effect of this, will impose a load on capsule (E) by the spring (L) through the beam (C). The combination of the spring and capsule will then position the main valve (F) through beam (H). The main valve (F) will now open to allow atmospheric pressure into the master unit control chamber and the lower chamber of the No. 2 unit of the discharge valve through the interconnecting pipework. Atmospheric pressure will also enter the altitude chamber through the rate of change needle valve (J), to equalise pressure either side of the diaphragm (G).

4.3.3 **Aircraft Climb.** As the aircraft continues to climb (with the main valve (F) open), the atmospheric pressure within the master unit control chamber will decrease. Pressure within the altitude chamber will also decrease but to a lesser degree because of the restriction imposed by the needle valve (J) on the rate of change control. As a result, pressure below the diaphragm (G) will be greater than the altitude chamber causing the diaphragm to move upwards to close the main control valve (F). As a consequence of the rising cabin pressure entering inlet orifice (K) and the closing of the main control valve (F), pressure within the master unit control chamber will rise. This rise in cabin pressure is also communicated through pipework to the lower chamber of the No. 2 unit. The upper chamber of the No. 2 unit is also subjected to cabin pressure, and between it, and the lower chamber is an additional chamber subject to atmospheric pressure. However, with the greater effective area of the lower chamber diaphragm and the increase in cabin pressure, the diaphragm assembly moves upwards. As a result of this upward movement, duct inlet valve (R) will open to allow duct air from the air conditioning system to enter the interior of the bellows, which expand and consequentially restrict the outflow of cabin air and pressurisation of the fuselage will commence.

4.3.4 **Cruise.** Once the aircraft achieves level flight, any pressure difference on either side of diaphragm (G) will soon equalise. Any further change in cabin pressure, will be sensed by the capsule pack (E), which is sensitive to both static and altitude chamber pressure. The resultant movement of the capsule pack (E) will be transposed through the control beam (H) to open or close the main control valve (F). Movement of the control valve will again create pressure changes within the master control chamber which will be transmitted to the lower surge chamber of the No. 2 unit. These pressure movements will then act upon the diaphragms within the No. 2 unit to either open the duct inlet valve (R), allowing duct pressure into the inner bellows and closing the discharge valve or to open the static outlet valve (S) which will vent duct pressure to atmosphere and subsequently open the bellows of the discharge valve.

4.3.5 Should the aircraft climb to the maximum differential pressure, the differential capsule pack (N) will contract to open the differential limiting valve (P). This will reduce pressure within the master control unit chamber and lower the surge diaphragm of No. 2 unit, subsequently closing the duct inlet valve (R) and opening the static outlet valve (S) allowing the discharge valve to contract and reducing cabin pressure to a safe level. With a reducing cabin pressure the differential capsule pack (N) will expand closing the differential limiting valve (P) returning the control chamber to the conditions of normal operation.

4.3.6 **Aircraft Descent.** Prior to descent, selection of a suitable rate of change, and cabin altitude equal to a landing field height, is required. These selections will reduce the compression load on the altitude capsule pack (E), the result of which, closes the main control valve (F). Therefore, assuming the aircraft cabin is now at the maximum differential pressure because of the low cabin altitude selection, the differential capsule (N) will be in control, as described in paragraph 4.3.5.

4.3.7 As the aircraft descends, the increasing atmospheric pressure, will expand the differential capsule (N) and progressively close the limiting valve (P). This produces a stronger pressure signal to the close discharge valve, subsequently lowering the cabin altitude. When the limiting valve finally closes, the pressure within the altitude chamber rises sharply creating a pressure differential across the diaphragm (G), causing it to deflect and, through the control beam (H), opening the main control valve (F) thus preventing a pressure surge on the lower surge control chamber. The rate of change mechanism will now take control, progressively closing the main control valve (F) and increasing the pressure signal to the discharge valve, at the selected rate of change until the point of cabin altitude and aircraft altitude are of the same value.

NOTE: If in practice the rate of descent of the aircraft is such that it attains the selected altitude before the cabin altitude has reached the same value, the landing of the aircraft must be delayed.

4.3.8 **Emergency Operation.** Under the circumstances of normal operation, the discharge valve No. 1 unit is non-effective in respect of pressurisation control, except to provide a free passage for air to flow into the No. 2 unit.

4.3.9 Whilst the No. 2 unit is in control, the absolute outlet valve (T) vents air from within the bellows of the No. 1 unit to atmosphere. As a consequence, the bellows collapse due to the impingement of cabin pressure on the outer surfaces.

4.3.10 However, should the No. 2 unit fail (open), the consequential decrease in cabin pressure allows the bellows to extend, thereby restricting the flow of air to atmosphere through the failed No. 2 unit.

4.3.11 Pressurisation control is now the responsibility of the absolute capsule pack (U); which is in two parts, and the differential capsule pack (W) with their respective valves, absolute outlet valve (T) and differential outlet valve (V).

4.3.12 As the aircraft altitude climbs or descends, the differential capsule of absolute capsule pack (U) reacts correspondingly, opening or closing absolute outlet valve (T). This results in changing the bellows pressure and the position of the bellows thereby modulating the flow of air and cabin pressure. The changing bellows pressure also effects the absolute portion of the capsule pack (U), which expands or contracts whereby the outlet valve (T) returns to a controlling position.

4.3.13 If there is any tendency for the cabin pressure altitude to exceed that of the preset calibration of absolute capsule pack (U), the resultant increase in bellows pressure will compress capsule pack (W) to open differential outlet valve (V). As a consequence the bellows will compress, discharging the overpressure condition of the bellows and the cabin to atmosphere.

NOTE: With the No. 1 unit in control it is not possible to control the rate of cabin altitude change. However, under normal operational conditions, the change in cabin altitude relative to aircraft altitude should be satisfactory.

4.4 Electronic Pressurisation Control

4.4.1 The operational parameters and requirements of the electronic pressure controller are identical to those of the Pneumatic Controller as described in paragraph 4.3.

4.4.2 The basic differences between, pneumatic and electronic pressurisation control (with reference to Figures 5 and 6), are as follows:—

(a) The automatic cabin altitude controllers are duplicated (Auto 1 and Auto 2), with additional inputs from the landing gear (air/ground signal) and thrust lever positions.

(b) The signal between the automatic cabin altitude controller and the outflow valve (discharge valve) is electrical as opposed to a pneumatic signal.

(c) The cabin altitude control panel is remote from the cabin altitude controller (normally located within the avionics equipment bay) and not an integral part of the controller.

(d) The outflow valve (discharge valve in this description) can be actuated by: either of the two A.C. motors, or for manual or emergency control the D.C. motor.

4.4.3 The electronic pressurisation controller (the cabin altitude controller in Figure 6) is, in basic terms, a shaping and summing network. With information derived from the air data computer, cabin altitude control and various systems within the aircraft, a reference signal is produced by the controller. This reference signal will then be compared by the cabin altitude controller, to the signal produced by the cabin altitude monitor. If a disagreement exists between the two signals, a correcting error signal is produced, which when applied, modulates the outflow valve(s) (see paragraph 5).

4.4.4 As a safeguard against the cabin altitude or rate of change exceeding defined limits within the pressurisation schedule, override circuits constantly monitor the performance of the system in control. If any deviation from the schedule exists, the override circuits will either: automaticallly transfer control to the standby system, (Auto 1 to Auto 2) or de-activate the system completely with the appropriate flight deck indications and aural warnings. The following paragraphs describe the operation of a typical electronic controller.

4.4.5 **Preflight Set-Up.** Automatic electronically controlled cabin pressurisation systems in general terms require the following action prior to take-off:—

(a) Provision of pressurised air from the air conditioning system.

(b) The setting of landing field height (QFE).

(c) Rate of cabin altitude change.

4.4.6 **Prepressurisation.** Where prepressurisation of the cabin prior to take-off is part of the pressurisation schedule, control inputs will be required of the: landing gear (air/ground signal), engine oil pressure, forward throttle position, and the door warning system. The cabin pressure within this part of the schedule is normally only marginally above the ambient atmospheric pressure (i.e. a cabin altitude just below airfield altitude).

4.4.7 **Climb.** Prepressurisation ceases when the aircraft leaves the ground and the landing gear and oleo fully extends (air/ground signal). The cabin altitude climb sequence of the pressurisation schedule will now commence with the cabin altitude rate of change limited to approximately 500 ft per minute.

4.4.8 **Cruise.** With the aircraft maintaining a constant height, the cruise sequence of the pressurisation schedule will commence. Simultaneously, the cabin altitude controller will, for the purpose of originating a datum point for a scheduled descent, and any correction of the cabin cruise altitude, compare the theoretical cabin altitude to that of the selected landing altitude. Any variation to aircraft altitude, in climb, or descent of less than 500 ft, the corresponding cabin altitude will remain unchanged. If, however, the aircraft altitude climbs or descends by more than 500 ft, the cabin altitude controller will enter into an appropriate auto schedule subject to the various controlling parameters i.e. take-off height, landing field height and selected auto rate of change.

4.4.9 **Descent.** The descent sequence of the pressurisation schedule is normally initiated by a descending aircraft altitude of approximately 500 ft and subject to the following criteria:—

(a) The relative aircraft altitude.

(b) The auto rate selected.

(c) The landing field height (QFE).

(d) The maximum cabin to ambient differential pressure limit.

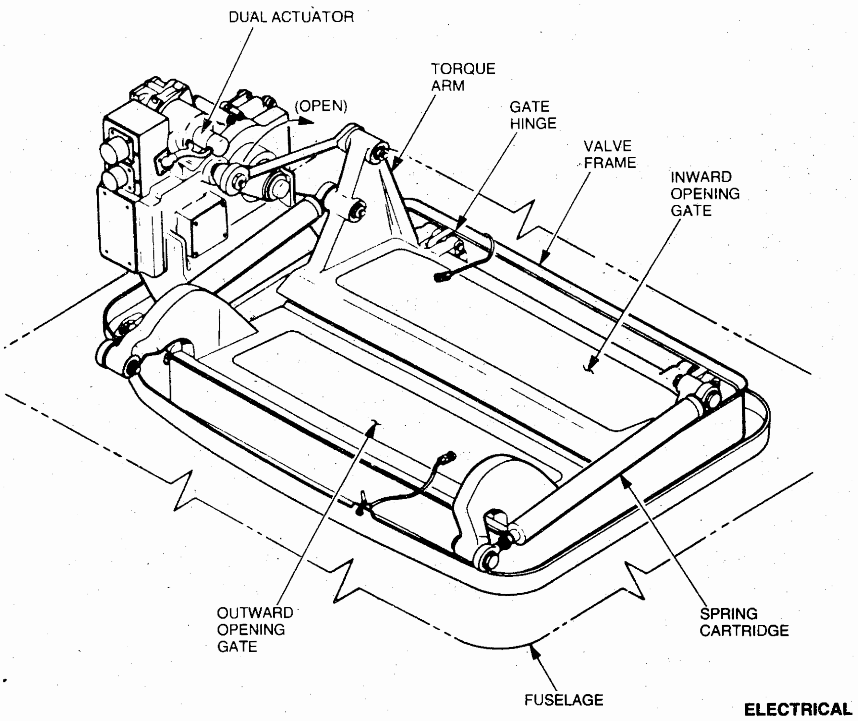
4.4.10 **Landing.** For those aircraft which are designed to land in a pressurised condition, the cabin altitude controller will normally automatically lower the selected landing field by approximately 100 ft height. As a result the cabin will remain pressurised marginally above atmospheric pressure until touch down, where the landing gear air/ground signal takes precedence for controlled depressurisation of the aircraft (see paragraph 7).

4.4.11 **Emergency Operation.** Protection against system failure is provided for by duplication of the control system (see paragraph 4.4.2(a) and (d)). In the event of a system or power failure, control will be automatically transferred to the standby system which is electrically supplied from an alternate source. If total system failure does occur, a reversion to manual control will be required.

5 OUTFLOW VALVES (DISCHARGE VALVES)

5.1 The primary function of the outflow valves is to regulate the discharge of cabin air in response to the pressure signals received from the controller. They vary in design and construction but, in general, there are two main types: those operated by diaphragms, and those by electrical actuation (see Figure 7).

5.2 The size and number of valves required for a particular type of aircraft is governed by the amount of air necessary for pressurisation, and air conditioning. Some types of outflow valve, incorporate safety valves (see paragraph 6.1) and inward (negative) relief valves (see paragraph 6.2) and a means of locking the valve to the closed position in the event of a forced descent on water (ditching).



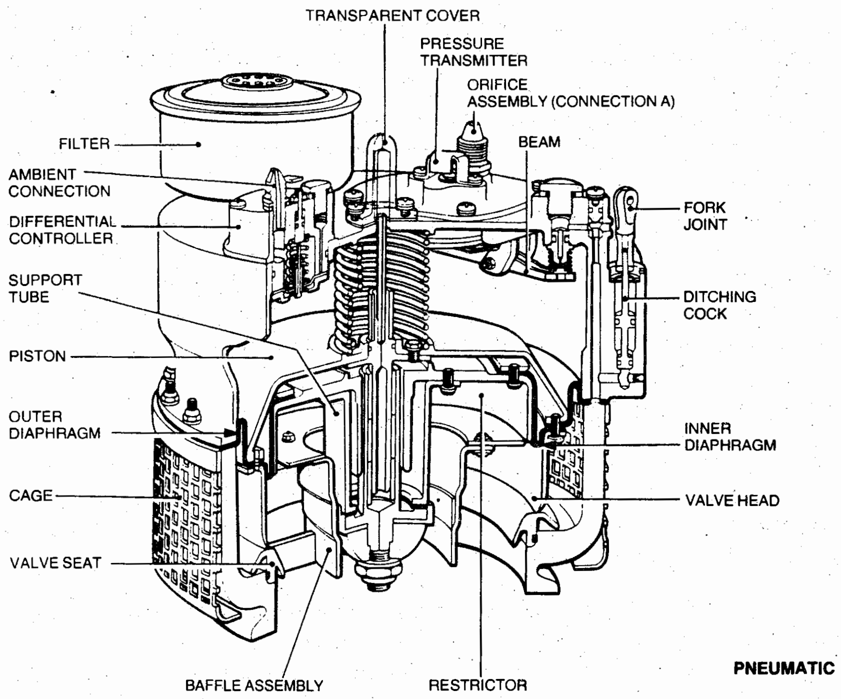
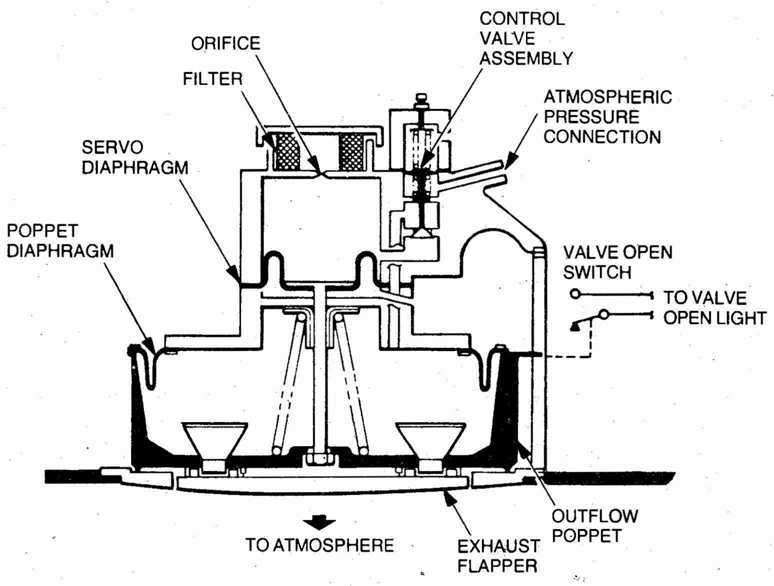


Figure 7 OUTFLOW VALVES (DISCHARGE VALVES)

6 SAFETY VALVES AND INWARD RELIEF VALVES

6.1 **Safety Valves.** Safety valves are provided to relieve excess cabin pressure in the event of a failure of either the pressure controller or discharge valves.



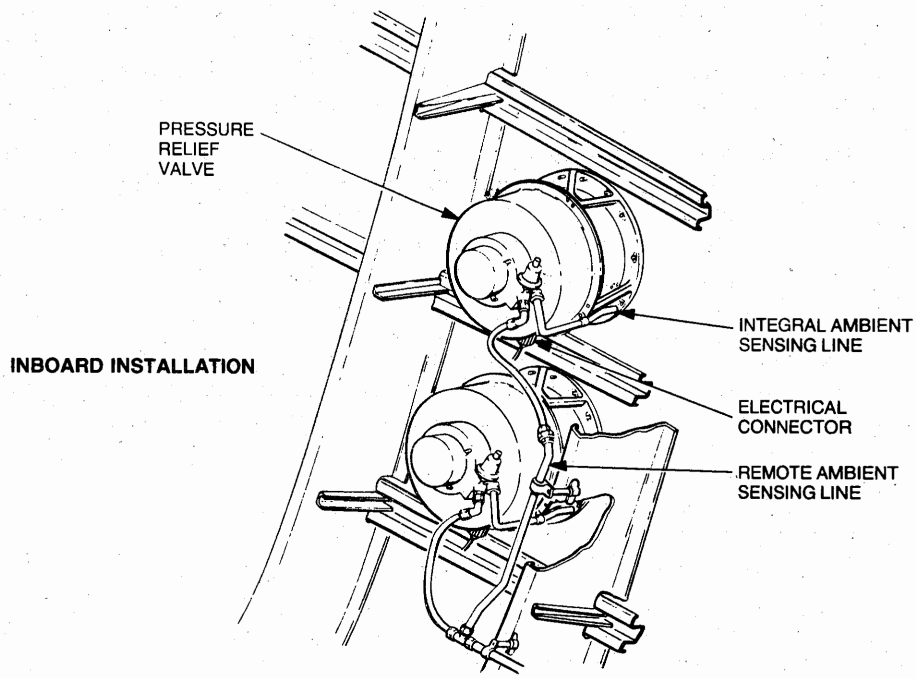


Figure 8 TYPICAL PRESSURE RELIEF SAFETY VALVES

6.2 **Inward Relief Valves.** Inward relief valves are provided to limit any possible negative differential pressure to a safe value. Depending on the system adopted for the particular aircraft type, the valves installed may either be in the form of separate units, single integrated units, or combined with the discharge valves. The valves vary in construction and operation but those most commonly used are of the type utilising diaphragm control (similar to a discharge valve).

7 GROUND AUTOMATIC RELIEF VALVES The ground automatic relief valve is a form of discharge valve used on some aircraft types which is additional to those discharge valves which form part of the pressurisation system. The valve as its title implies, is effectual whilst the aircraft is in a ground mode (i.e. ground/air signal) with the following primary functions:—

(a) To maintain a free flow of ventilating air within the aircraft when parked.

(b) To prevent cabin pressurisation and pressure surges whilst the aircraft is taxiing.

(c) To transmit ground/air signals derived from the landing gear and engine thrust levers, to the cabin altitude controller for controlled prepressurisation and depressurisation of the cabin when respectively the aircraft is taking off or landing (see paragraphs 4.4.5 and 4.4.10).

8 INSTRUMENTS AND INDICATORS

8.1 **General.** The presentation of instrumentation forming part of the pressurisation control system, is largely dependent upon the method of pressurisation control. Pneumatic pressure controllers; as described in paragraph 4.3, have the principal instruments as an integral part of the control panel. Electronic pressure controllers; as described in paragraph 4.4, have instruments which are remote from the controller and generally form part of the cabin altitude control panel.

8.2 **Instruments.** The principal instruments in respect of pressurisation control are, Cabin altitude, Differential pressure, and Rate of Change (vertical speed). These are generally positioned as described in paragraph 8.1, or as a cathode ray tube (CRT) generated display in either digital or analogue (dial and pointer) form in the main instrument panel. Instruments may also be provided to indicate the position of certain valves, e.g. discharge valves.

8.3 **Indicators.** Crew compartment indications, are in general, presented in visual and audio form, i.e. warning light or CRT image with an accompanying sound (bell, chime or horn etc). The factors which will activate those indications, in respect of the cabin altitude control are:—

(a) Excessive cabin altitude.

(b) Discharge valve failure or disagreement.

(c) Inward relief valve operation.

(d) An automatic system changeover.

(e) Excessive differential pressure.

(f) Positive pressure relief valve operation.

9 EMERGENCY CONTROLS In addition to the normal devices which control pressure to the required values, provision is made for the normal operating cabin pressure to be reduced rapidly in the event of, emergency landings, clearing the cabin of smoke or other contaminations, and the rapid reduction of cabin pressure. In all such cases cabin pressure is reduced by the 'dumping' of air. This may be achieved in a number of ways and the methods most commonly adopted include, separate manually operated dump valves, manual override control of a discharge valve or a safety valve, and in some cases manual control of a pressure controller.

10 FILTERS AND AIR DRIERS

10.1 Filters are connected in the cabin air pressure sensing lines to the pressure controllers and discharge valves and normally consist of a casing, housing a replaceable filter cartridge, and fitted with appropriate inlet and outlet connections. In some aircraft installations, air driers are provided to eliminate the possibility of ice forming in the pressure control system and are connected in the cabin air pressure sensing lines to discharge valves, safety valves and inward relief valves.

10.2 There are two types of driers in common use: one utilising the properties of a silica gel drying agent, and the other consisting of a baffle box mounted on the inside of the fuselage skin utilising skin temperature to condense any water vapour present in the cabin air. The moisture deposited in the box eventually drains away through an outlet in the box and aircraft skin.

11 COMPONENT INSTALLATION

11.1 General

11.1.1 Before installing any component of a cabin pressure control system, an inspection should be made to ensure that no deterioration of rubber components, corrosion of metal parts or other damage has occurred during storage or transit. The security of pipe connections, electrical connections, ~~actuators~~, etc., should also be checked and, where specified, pre-installation functioning tests carried out.

11.1.2 Some aircraft pressure controllers' discharge valves and safety valves operate as preset units and must only be used in specific combinations. When renewing or replacing such units it is therefore essential to ensure that their part numbers are correct for the installation.

11.2 Pressure Controllers

11.2.1 It is recommended that where facilities are available, controllers should be bench tested before installation to ensure that the controlling mechanism has not been disturbed during storage or transit. Details of tests peculiar to particular types of controller should be obtained from the relevant Aircraft Maintenance Manual.

11.2.2 When assembling static pressure and reference pressure sensing pipelines, care is necessary to ensure that no obstruction or leakage can occur. Particular care is necessary to ensure that all pipes are correctly assembled. Cabin pressure must not leak into low pressure pipes or chambers as this would unbalance the control characteristics of the system. Where vents to cabin pressure form part of the system, they should not be obstructed by loose trimming or soundproofing materials.

11.2.3 After the installation is completed, functioning tests should be made to prove the correct connection or adjustment of electrical circuits, micro-switches, altitude selectors, rate of change control mechanisms and the pipeline system. Details of tests applicable to particular aircraft installations should be obtained from the relevant Aircraft Maintenance Manual. General guidance on the testing of pressurisation systems is provided in paragraph 12.

11.3 **Discharge Valves and Ground Automatic Relief Valves**

11.3.1 Before installation the valve faces and seating surfaces of discharge valves should be cleaned with a soft lint-free cloth. High pressure air blasts should not be used on discharge valves of the diaphragm-controlled type as damage may be caused to the diaphragms.

11.3.2 To ensure that the joint between discharge valves and appropriate adaptors on the pressure bulkhead or fuselage skin is pressure tight, new mounting gaskets or O-rings should be fitted. Where specified, mounting surfaces should be lightly smeared with the appropriate lubricant as specified in the relevant Aircraft Maintenance Manual.

11.3.3 Pipelines and valve unions should be checked to ensure that they are in correct alignment. Plug and socket connections to electrically actuated discharge valves should be secure.

11.3.4 If ditching cocks are fitted, the ditching control run in the aircraft should be checked before making the connections and locking the cocks to the appropriate discharge valve. Some discharge valves may be closed for ditching purposes by a directly mounted hand control wheel. In such cases the opening and closing of a valve should be checked by rotating the wheel through the requisite number of turns.

11.3.5 After installation of a discharge valve, functioning tests should be carried out to prove the correct connection of pressure sensing pipelines and, where appropriate, the connection of electrical cables to valve actuators. Details of the tests applicable to particular aircraft installations should be obtained from the relevant Aircraft Maintenance Manual.

11.4 **Safety Valves and Inward Relief Valves**

11.4.1 Valves should be cleaned and installed in a similar manner to discharge valves (see paragraph 11.3). Where facilities allow, bellows-type safety valves should be subjected to a leak test before installation in the manner described in the Aircraft or Component Manufacturers's Maintenance Manuals.

11.4.2 In some installations, safety valves are provided with electrical and manual override controls, in such cases functioning checks on the controls must be made after installation (e.g. limit switches of electrical actuators which may need to be adjusted to cut off the power supply when the valve is at the fully open and fully closed positions). Manual controls should be correctly rigged and checked to ensure that the controls and valve move in phase and operate freely over their full range of travel.

NOTES: (1) Limit Switch adjustment is normally carried out when the component is workshop tested.

(2) After carrying out override control system checks, the appropriate controls should be reset to their normal positions.

11.4.3 Some valves incorporate an electrically-operated position transmitter which signals the valve position to an indicator in the crew compartment; checks should therefore also be made to ensure that the indicated positions correspond.

11.5 **Filters and Air Driers**

11.5.1 Before installing a cartridge type of filter unit the cartridge and casing should be inspected for signs of damage and also to ensure freedom from dirt and other foreign matter.

11.5.2 In some unit designs the case is made of rubber and for this reason it may have been stored in French Chalk. Before fitting the cartridge into this type of case, all traces of chalk must be removed by lightly brushing the rubber with a suitable cleaning agent as recommended in the relevant Aircraft Maintenance Manual.

11.5.3 In some installations, air driers are of the type which utilises Silica Gel Crystals as drying media. Before installation, the units should be detached and charged with a fresh quantity of Silica Gel Crystals. After installation, a check should be made to ensure that the inspection windows, where provided, are readily visible.

11.5.4 When installing baffle-type air driers, it must be ensured that the sealant necessary for fixing is of the correct type and is correctly applied to the appropriate area of the fuselage skin and air drier casing.

11.5.5 After installation, the connections between the filters, air driers and all appropriate pressure sensing lines must be securely made and leak-tested in the manner described in the relevant Aircraft Maintenance Manual.

12 TESTING OF PRESSURISATION SYSTEMS

12.1 **General**

12.1.1 Pressurisation systems must be tested to ensure that there are no serious leaks and that pressure control equipment and pressure limiting devices function correctly to maintain the cabin differential pressure within the limits appropriate to the aircraft type. The periods at which functional tests and leak tests should be made are specified in the approved Aircraft Maintenance Schedules. Tests may also be necessary after repairs or modifications which affect the structural strength of a cabin (e.g. Proof Pressure Tests), or after suspected damage to the fuselage. The procedures for carrying out the proof pressure test and precautions to be observed, are also detailed in the relevant approved Structural Repair Manual.

NOTE: General guidance on the repair of metal aircraft is provided in Leaflet **AL/7-14** where attention is drawn to: the accuracy required in skin joints and seams, the necessity for the skin to be free from waves and buckles, and the importance of cleanliness when making airtight joints.

12.1.2 The precise method of carrying out the required tests depends on the type of aircraft and on the nature of its air conditioning and pressurisation system. It is, therefore, essential to make reference to the relevant Aircraft Maintenance Manuals for full details. There are however, certain recommendations, precautions to be observed, and aspects of testing procedures which are of a general nature, and these are summarised for guidance in the following paragraphs.

12.2 **Test Preparation**

12.2.1 The aircraft structure must be complete and fit for flight before attempting to carry out any ground test.

12.2.2 It is recommended that those personnel participating in a pressure test who are stationed within the pressurised area, be certified medically fit. This would include freedom from colds and sinus troubles.

NOTE: Where the pressure differential between the working environment and ambient exceeds 10 p.s.i (20·361 in Hg), medical supervision must be sought.

12.2.3 A minimum of two test operators should be inside the pressurised area during any pressure test where an external ground test unit is used as the air supply source. When using engines for the air supply a third operator to run the engines is required.

12.2.4 When using an external ground test unit as the supply source, intercommunication between test personnel inside the pressurised area and those operating the test unit must be established. (A socket for the connection of an interphone system is normally provided in aircraft for this purpose and is located in an area such as a nose-gear bay.)

NOTE: Warning placards should also be positioned around the aircraft indicating that such testing is being carried out, and only the test personnel should be within, or in the vicinity of the aircraft during testing.

12.2.5 It is necessary to ensure that static pressure and pitot pressure pipelines, within the pressurised area, are complete and connected to their relevant instruments and components such as autopilot coupling units and height lock units. Failure to observe this precaution will result in damage to instruments or units during a pressure test.

NOTES: (1) If it is not possible for a connection to be made, the relevant instrument or unit should be removed and the pipelines blanked off.

(2) Some pressure tests require certain instruments to be removed.

12.2.6 All doors, clear vision windows, emergency exits, etc., should be free to operate, after closing checked for security. If an unusual force is necessary to close any of these items, the cause should be investigated and rectified before the cabin is pressurised.

12.2.7 Where sandwich type windows are fitted, a check for security should be made and, where applicable, services for window de-misting purposes should also be checked to ensure freedom from leaks and obstructions, and for correct venting, i.e. to atmosphere or to the pressurised area dependent upon the design.

12.2.8 During testing, the maximum cabin differential rate of change must not exceed the values specified in the relevant Aircraft Maintenance Manual.

12.2.9 Manometers and other portable test indicators e.g. pressure gauges and vertical speed indicators, required for testing must be checked and calibrated at regular intervals.

12.2.10 Where any disturbance of cabin air ducting has occurred, checks should be made for correct alignment, security and freedom from foreign matter. As necessary, airtightness of the ducting should be checked by blanking local sections and subjecting them to pressure tests.

12.2.11 Any seals, glands or expansion joints should be checked for correct fitting, and where controls pass through the aforementioned they should be lubricated as necessary and in the manner specified in the relevant Aircraft Maintenance Manual.

NOTE: Detachable blanking plates used when testing should not be sealed with jointing compound.

12.2.12 Following the satisfactory completion of tests, the operation of all windows, doors and hatches (including those of galley units) should be checked.

NOTE: Following the conclusion of tests, it must be ensured that cabin pressure has been reduced to the prevailing ambient conditions before attempting to open any doors, windows or hatches.

12.3 Functional Tests

12.3.1 **General.** To perform a full or partial functional test of the pressurisation system reference should be made to the relevant Aircraft Maintenance Manual. Where it is required that the pressurisation system is pressurised, this can be achieved by one of the following methods:—

(a) Running the engines, utilising the bleed air or engine-driven compressors, as appropriate.

(b) Connecting a ground supply unit to the ground service connection point (where fitted) see Figure 4.

(c) Employing bleed air supplied from the auxiliary power unit (APU).

12.3.2 It is however, recommended that functional tests are carried out by running the engines and utilising bleed air or air supplied from engine-driven blowers, as this enables all components to be tested simultaneously.

12.3.3 When carrying out tests, additional test instruments and equipment may be required and reference should be made to the relevant Aircraft Maintenance Manual for precise details of the type and method of connection into the pressurisation system. Generally, a portable vertical speed indicator and mercury manometer or pressure gauge are required, together with a stop watch and a pitot-static test set. The test set is normally used for checking for leaks from pressure controllers, pressure signal and static pressure pipelines, and also for checking the function of discharge valves in response to selected pressure signal settings from pressure controllers.

12.3.4 **Preparation.** Unless otherwise specified in the Aircraft Maintenance Manual, all internal doors or hatches within the pressurised area of the fuselage should be secured in the open position. In all cases, the doors of equipment which could be damaged by differential pressures, e.g. galley cupboards, ovens, should be opened. Unpressurised areas adjacent to the pressure cabin should be vented to atmosphere.

12.3.5 After entering the aircraft, the entrance doors, emergency exits and hatches, toilet servicing connections, sliding and direct vision windows in the crew compartment should all be closed. Where specified in the Aircraft Maintenance Manual, other apertures such as toilet ventilation bleed outlets should be blanked off.

NOTE: Care must be taken to ensure that certain specified fuselage and compartment drains are not obstructed as allowance is made in the leak rates permissible during pressure tests. Reference must always be made to the relevant Aircraft Maintenance Manual for details of drain locations.

12.3.6 **Test.** Electrical power should be switched on and the controls of the appropriate cabin air temperature control system and pressurisation system units selected to the setting specified in the Aircraft Maintenance Manual for functional testing.

12.3.7 When introducing the air supply, the cabin pressure should be controlled in the manner appropriate to the system to ensure that the rate of pressure change (normally given in feet per minute) does not exceed the maximum values specified in the Aircraft Maintenance Manual.

12.3.8 The cabin pressure should be allowed to increase until it stabilises at the maximum working differential pressure for the aircraft type, and a check should be made to ascertain that the pressure remains constant with a temporary increase in air supply. If the differential pressure stabilises at a figure above or below the maximum value, the pressurisation control system should be investigated and rectified as necessary after conclusion of the test. After such rectification, a further test should be made.

12.3.9 Where multiple pressure control units are provided, each unit should be selected in turn and checks made to ensure that the differential pressure builds up and stabilises at the relevant maximum value.

NOTE: Whilst the cabin is pressurised, it may be required that all flying controls are operated to test the efficiency of cable seals etc, therefore reference should be made to the relevant Aircraft Maintenance Manual.

12.3.10 The automatic action of safety valves should also be checked during pressurisation system tests, with the discharge valves isolated from pressure signal sources. Air should be supplied to the cabin at the specified controlled rate and a check made on the pressure at which the valves open. The cabin should then be allowed to depressurise slowly until the valves close and the corresponding pressure noted. The pressures at which valves open and close should be within the limits specified in the relevant Aircraft Maintenance Manual.

NOTE: When checking the operation of cabin safety valves which are set to relieve at the maximum differential pressures permissible for the aircraft type, control of the air supply must be carried out with extreme care to ensure that the pressure never exceeds the maximum value.

12.3.11 If during a pressure test the leak rate increases unduly, as denoted by both a sudden fall in differential pressure and a sudden ascent indication on the cabin vertical speed indicator, the pressure must be released and the fuselage examined for the cause before continuing the test.

12.3.12 When all functional tests are concluded, the air supply should be cut off and the cabin pressure then allowed to fall gradually at a controlled rate. If the pressure is released too rapidly moisture precipitation may occur damaging electrical cables and cabin installations.

12.4 Leak Rate Tests

12.4.1 **General.** Leak rate tests are necessary at specified periods to ensure that no marked deterioration in the sealing standard of the aircraft fuselage has occurred. The tests should also be carried out whenever a component affecting the pressurised area is renewed, refitted or modified, and after a proof pressure test. Before testing, adequate time should be allowed for the drying of any freshly applied sealants. On certain aircraft, leak rate tests may be combined with functional tests; in other cases the tests should be carried out separately. The periods at which the tests and tests methods are to be carried out, are provided respectively in the relevant Approved Maintenance Schedules and Aircraft Maintenance Manuals.

12.4.2 As in the case of functional tests, observers are required inside the aircraft and the instructions given in paragraphs 12.2.2 of this Leaflet equally apply. It is preferable to supply air to the cabin from a ground air supply unit thus eliminating the danger from propellers or jet engine intakes and exhausts to personnel inspecting the outside of the fuselage.

12.4.3 The instructions given in the relevant Aircraft Maintenance Manual for leak rate testing should be closely followed. It is the practice on some aircraft to render the pressure controller inoperative by disconnecting it from the discharge valves, in which case the cabin pressure obtained is at maximum determined by the safety valves. On other aircraft the delivery rate of the air supply is controlled and the air is shut off when the pressure reaches a specified value lower than maximum.

12.4.4 A check should be made on permanent fuselage drain holes, battery compartment vents, hydraulic system reservoir bleeds etc., to cnsure that they are unobstructed.

12.4.5 The air should be introduced to the cabin gradually until the pressure stabilises. In some cases manufacturers recommend that the pressure is raised slightly above the specified values and then allowed to fall to this value before checking the leak rate.

12.4.6 After the pressure has stabilised, the air supply should be shut off and the pressure allowed to fall by normal fuselage leakage. The time taken for the pressure to fall over the range appropriate to the aircraft type must not be less than that quoted in the relevant Aircraft Maintenance Manual.

12.4.7 If the leak rate is excessive, an inspection of the fuselage pressurised area should be carried out with the cabin pressure held to the value specified for the aircraft type. Escaping air may usually be detected by sound, or touch, but a soapy water solution may be used to trace certain leaks and this should be cleaned off after testing. When inspecting the outside of the aircraft for leaks, inspection personnel should exercise caution when entering nose-gear bays or similar breaks in the main pressurised area.

12.4.8 The sealing standard of the fuselage should be improved as necessary and in the manner detailed for the aircraft type, until the leakage rate is within limits.

12.4.9 At the conclusion of the tests the air supply should be shut off and the cabin depressurised ensuring that the rate of pressure change does not exceed the specified value. Before opening doors, windows, or hatches, it must be ensured that cabin pressure has been reduced to prevailing ambient conditions.

12.4.10 Electrical power should be switched off and all blanks and plugs used during tests should be removed.

12.4.11 Where pressure control system components have been removed or isolated for purposes of leak rate tests, they should be restored to their normal operating condition. Leak tests of the system should be carried out with the aid of a pitot-static test set and in the manner detailed in the relevant Aircraft Maintenance Manual.

12.4.12 The fuselage should be examined for obvious damage or distortion, particular attention being paid to the pressure bulkheads, cabin floor members, window and windscreen frames and panels, and suppressed antenna covers. The transparencies should be examined for signs of crazing. All doors, hatches and windows which are intended to open should be fully opened and then closed, to check for free movement and absence of deformation.

13 MAINTENANCE

13.1 **General.** Details of the operations necessary for the inspection and maintenance of pressurisation system components will be found in the relevant Aircraft Maintenance Manuals and Approved Maintenance Schedules, and reference must at all times be made to such documents. The information given in the following paragraphs is intended only as a general guide to the checks normally required on the principal components covered by this Leaflet.

13.2 Pressure Controllers

13.2.1 Functioning tests of the pressure controller, should be made when defective operation of the pressurisation control system is suspected, and at all other times specified in the relevant Approved Maintenance Schedule. Further checks can be carried out where electronic pressure controllers are equipped with Built In Test Equipment (BITE). Adjustments and rectifications which may be made in situ are limited, and therefore the relevant Aircraft Maintenance Manuals appropriate to the type of aircraft and controller should be referred to before any adjustments or tests are carried out. If the results of the functioning tests are unsatisfactory and the pressure controller is found to be defective, it should be removed from the aircraft and tested according to the manufacturer's recommended test schedule and as appropriate, repaired, overhauled or replaced.

13.2.2 At certain specified intervals, some pneumatic pressure controllers are required to be lightly lubricated using only lubricants recommended by the manufacturers. Checks should also be made for security, corrosion or damage, and the associated electrical circuits should be tested as necessary for continuity and insulation resistance (see Leaflet **EEL/1-6**.

13.3 **Discharge Valves and Ground Automatic Relief Valves**

13.3.1 At intervals specified in the Aircraft Maintenance Schedule, the pressure controlling function should be tested. These tests are normally done in situ and in conjunction with the associated pressure controller. The security and functioning of ditching system controls, where fitted, should also be carried out.

13.3.2 Valve faces and seats should be inspected for damage and deposits of dust and nicotine tar which should be removed in the manner specified in the relevant Aircraft Maintenance Manuals. The cleaning fluids used should be of the type recommended by the manufacturers, and on completion of a cleaning operation all traces of fluid should be removed and all surfaces cleaned using a dry, soft, lint-free cloth. High pressure air blasts should not be used to dry the seating surfaces of diaphragm-controlled discharge valves as damage may be caused to the diaphragms. Bonding leads and their attachment points should be inspected for security of attachment and checked for electrical continuity (see Leaflet **EEL/1-6**).

13.3.3 At specified periods, discharge valves should be removed, inspected, and leak tested to ensure that the leak rate is within specified permissible limits. After reinstatement or replacement of a discharge valve a full functional check should be carried out as detailed in paragraph 12.3.

NOTE: On some aircraft types, shims are installed to aerodynamically align the discharge valve, with the fuselage. When removing the valve from the aircraft these shims should be retained in order to maintain that alignment when replacing the valve. (See also paragraph 11.3.2.)

13.4 **Safety Valves and Inward Relief Valves**

13.4.1 Mountings, pipe unions, electrical actuator where fitted, (and its connections) should be checked for signs of damage, deterioration and security.

13.4.2 Leak tests and functioning tests should be made after installation, when the serviceability of valves is suspect, during cabin pressure testing (see paragraph 12), and at the periods specified in the Approved Maintenance Schedule. The requirements for functional testing of inward relief valves is normally restricted to checking freedom of movement.

13.4.3 Valve faces and seats should be inspected and deposits of dust and nicotine tar removed in the same manner as that specified for discharge valves (see paragraph 13.3.2). After cleaning, a check should be made to ensure that valve faces and seats make good contact.

13.4.4 Electrical and manual override controls should be checked for security and tested for correct operation, particular attention being paid to the settings of actuator limit switches, lost motion in linkages, cable tension and static friction. Where specified, moveable parts should be lightly lubricated using only the specified lubricants.

13.4.5 Certain types of safety valves can be adjusted in situ, but before any attempt is made to alter the relief pressure setting it should be established that any error in the pressure at which the valve relieves is not due to a defect in the valve mechanism. After making adjustments to a valve its operation must be checked by repeating the appropriate cabin pressure and functional test as described in paragraph 12.

13.5 **Filters and Air Driers**

13.5.1 The element of cartridge type filter units should be removed and replaced by a new element when necessary. Before fitting the element the filter casing and connecting union orifice should be cleaned with the recommended cleaning agent as prescribed in the relevant Aircraft Maintenance Manual.

13.5.2 Checks should be made on the condition of Silica Gel Crystals and the appropriate air drier containers recharged as necessary. The condition of sealing rings should also be checked.

13.5.3 Baffle type air driers should be checked for security paying particular attention to the condition of the sealant. The filter gauze which is also provided must be free from corrosion and cleaned with the recommended cleaning agent.

AL/3-24

Issue 2

September, 1988

AIRCRAFT

SYSTEMS AND EQUIPMENT

AIR CONDITIONING

1 INTRODUCTION

1.1 The purpose of this Leaflet is to provide general guidance and advice on the installation, maintenance and testing of equipment forming part of aircraft air conditioning systems.

1.2 The information contained in this Leaflet is of a general nature, and should therefore be read in conjunction with the relevant Aircraft Maintenance Manuals and Approved Maintenance Schedules.

1.3 **General**

1.3.1 The air conditioning system of an aircraft is designed to maintain selected temperature conditions within flight crew, passenger and other compartments, and comprises five principal sections: air supply, heating, cooling, temperature control, and distribution. In some aircraft a humidity control section also forms part of the air conditioning system.

1.3.2 In pressurised aircraft, the air conditioning and pressurisation systems are intrinsically linked, and it is the controlled discharge of pressurised and conditioned air, which maintains the selected cabin altitude. For further information on aircraft pressurisation systems and cabin pressure control equipment, see Leaflet **AL/3-23**.

1.4 Brief descriptions of some principal units which form a typical air conditioning system are given in the relevant paragraphs of this Leaflet. For precise details of specific systems reference must be made to the relevant Aircraft Maintenance Manuals.

1.5 The subject headings are as follows:—

1.6 Related CAIP Leaflets and Airworthiness Notices:—

AL/3-8 — Fire — General Precautions
AL/3-23 — Pressurisation Systems
AL/3-26 — Auxiliary Power Units
Airworthiness Notice No. 40
Airworthiness Notice No. 41

2 AIR SUPPLIES

2.1 **General.** The source of air supply and arrangement of essential components depends on the type of aircraft and air conditioning system employed, but in general one of the methods described in the following paragraphs may be adopted.

2.2 **Ram Air.** This method is adopted in certain small types of unpressurised aircraft utilising either combustion heating or engine exhaust heat exchanger systems (see paragraphs 3.2 and 3.3). A typical system is diagrammatically illustrated in Figure 1. Typical locations for a ram air intake are at the nose of an aircraft or in a dorsal fairing at the base of the fin or vertical stabiliser. The air, after circulating through the cabin, is discharged to atmosphere via a spill vent.

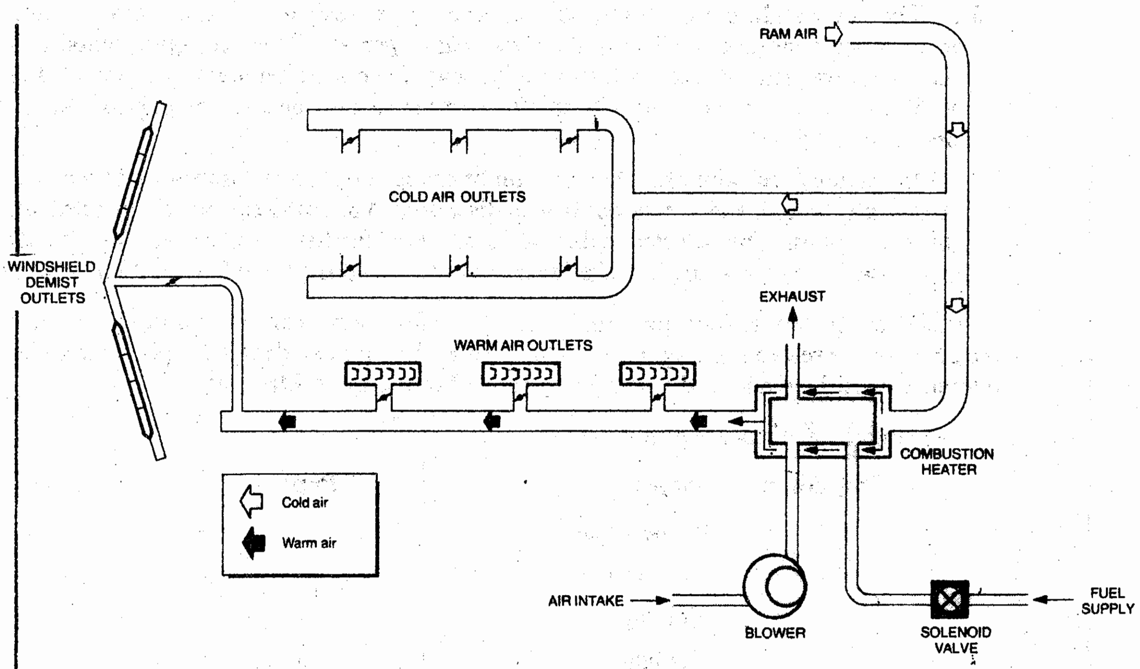


Figure 1 TYPICAL RAM AIR SYSTEM

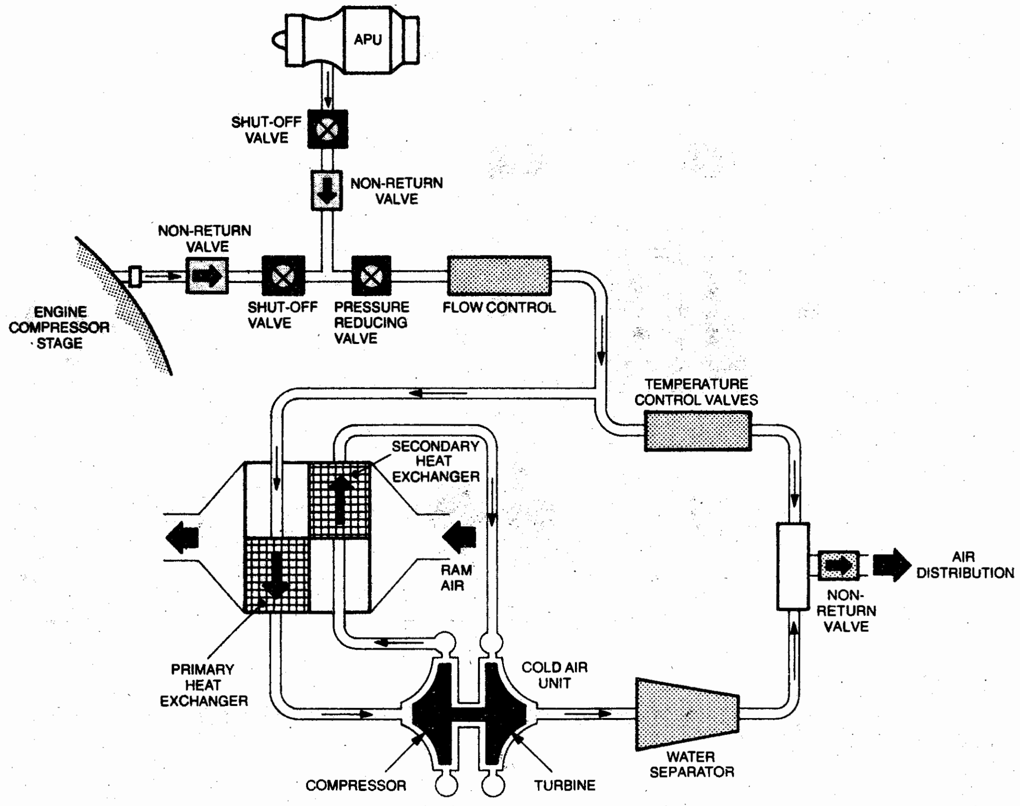


Figure 2 TYPICAL BLEED AIR ('BOOTSTRAP') SYSTEM

2.3 **Engine Bleed Air.** This method is adopted in certain types of turbo-jet aircraft, in which hot air, readily available from main engine compressors is tapped off and supplied to the cabin. Before the air enters the cabin it is passed through appropriate control valves and a temperature control system (see paragraph 5) to reduce its pressure and temperature. A typical bleed air system of the 'bootstrap' type is illustrated diagrammatically in Figure 2.

2.4 **Auxiliary Power Unit (APU).** The auxiliary power unit, where fitted, is an independent source of pressurised air. Operation of the APU is, however, subject to certain limitations, and further information is contained in Leaflet **AL/3-26**.

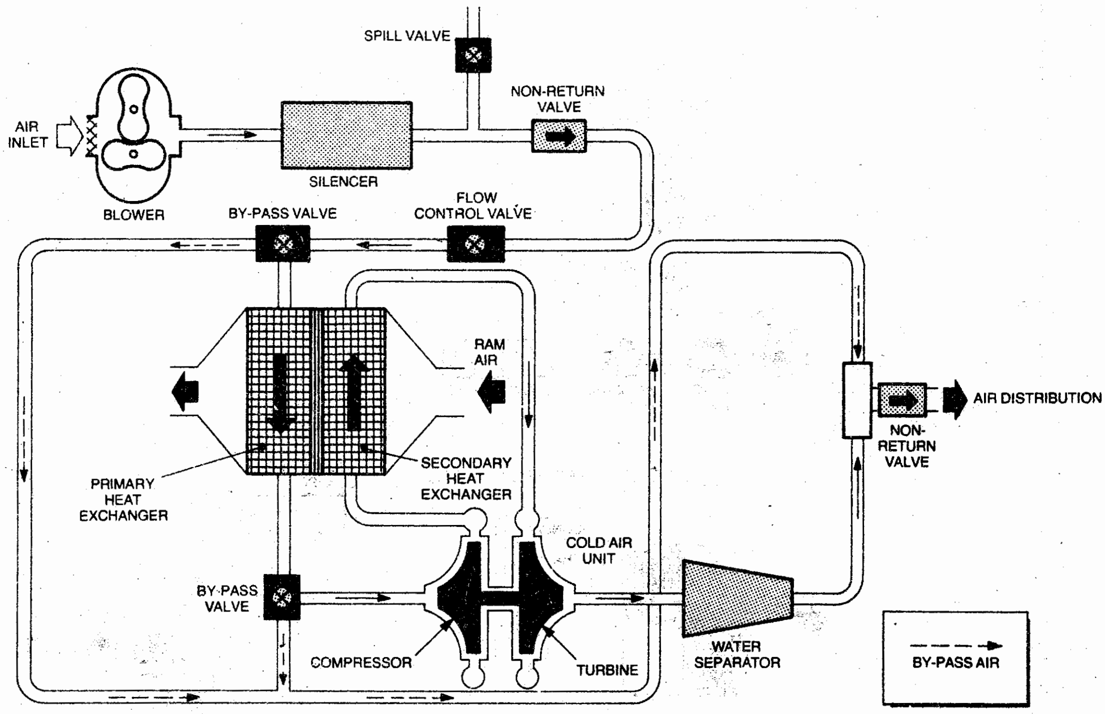


Figure 3 SYSTEM EMPLOYING A DISPLACEMENT TYPE BLOWER

2.5 **Compressors or Blowers.** This method is utilised in some types of turbo-jet, turbo-propeller and piston-engined aircraft, the compressors or blowers being driven by the engines via accessory drives, gear boxes or bleed air. Figure 3 diagrammatically illustrates a typical system employing an air displacement type of blower.

Air is drawn in through a ram air intake located in a wing leading edge or an engine nacelle fairing. A filter unit may be provided to protect the blower rotors from foreign matter and to ensure a clean air supply. In order to reduce the level of noise emanating from the blower, silencers are incorporated in the main supply ducting.

3 HEATING

3.1 **General.** The method of heating the air depends on the type of air supply system and one of the methods outlined in the following paragraphs may be adopted.

3.2 **Combustion Heating**

3.2.1 This method is normally associated with a direct type of ram air ventilating system, and depends for its operation on the combustion of a fuel and air mixture within a special cylindrical combustion chamber (see Figure 1).

3.2.2 Air for combustion is obtained from a blower and the fuel is metered from the aircraft fuel system by a solenoid-operated control valve. A filter and safety valve are also incorporated in the fuel supply line to the combustion chamber. The fuel-air mixture is ignited by a spark plug, the burning gases travelling the length of the combustion chamber and passing through transfer passages to an exhaust outlet. Ventilating air from the ram air intake passes through the heater and is heated by contact with the outer surfaces of the combustion chamber.

3.2.3 Blower operation and supply of fuel is normally controlled by a single switch. Regulation of the cabin temperature is carried out by the manual setting of a mechanically controlled switch installed in the ducting downstream of the heater.

3.3 **Engine Exhaust Heating.** This method is also associated with ram air ventilating systems, but heating of the air supply is effected in a simpler and more direct manner. Air enters through an intake connected to a heater muff which surrounds the exhaust pipe of a piston engine exhaust system. After heating, the air passes into the cabin via a chamber through which cold air also flows from an intake situated either in the fuselage or in the wing depending on the installation. Mechanically operated valves are provided to control the mixing of the air flows and so regulate the temperature.

3.4 **Compression Heating.** This system of heating relies on the principle whereby the air temperature is increased by compression and forms the basis of the heating method employed in air supply systems utilising engine driven compressors or engine bleed air (see paragraph 2.3 and Figure 3).

4 COOLING

4.1 **Ram Air.** In ram air supply systems the cooling method is of the simplest type whereby the cold air can be directly admitted to the cabin via adjustable louvres (see Figure 1). In the more complex systems cooling may be accomplished by either the air cycle or the vapour cycle method.

4.2 Air Cycle Cooling

4.2.1 The operation of an air cycle cooling system is based on the principle of dissipating heat by converting its energy into work. The principle components of a typical system are the primary and secondary air-to-air heat exchangers, a turbo-compressor cold air unit and a water separator. The interconnection of these components in a 'bootstrap' arrangement, is illustrated in Figures 2 and 3.

4.2.2 Heated air is directed through air passages of a matrix assembly within the primary heat exchanger and is pre-cooled by air entering a ram air intake and passing across the matrix. The pre-cooled air then enters the cold air unit via the axial inlet of the compressor and is compressed by the action of the compressor impeller and diffuser assembly.

The air leaves the compressor outlet and passes through a matrix assembly of the secondary heat exchanger which dissipates a large proportion of the heat produced by compression. From the secondary heat exchanger the air enters the turbine of the cold air unit. The air expands through the turbine and in causing the latter to drive the compressor, sufficient pressure drop across the turbine is achieved to cause further cooling of the air.

4.2.3 The water separator (coalescer) is installed downstream of the cold air unit to extract a percentage of free moisture from the air which subsequently ventilates and pressurises the cabin. Air from the cold air unit turbine enters the separator and passes through an assembly in which the moisture in the air coalesces into large water droplets. The droplets are then carried by the air to a separator assembly which extracts the water. The water is then drained away through a drain line to an overboard vent, or into the heat exchanger ram air supply to provide additional cooling. To ensure that the flow of air to the cabin is maintained in the event of the water separator assembly becoming obstructed by ice, a safety valve is normally provided.

NOTE: In some systems, the water separator is combined with an airflow silencer unit.

4.3 Vapour Cycle Cooling

4.3.1 The principle of vapour cycle cooling is based upon the ability of a refrigerant to absorb heat through a heat exchanger in the process of changing from a liquid into a vapour. The major components of a typical system and their interconnection with each other is diagrammatically illustrated in Figure 4. These components are generally mounted together to form a refrigeration pack, and comprise the following:—

(a) **A Liquid Receiver:** to provide a storage area for the liquid refrigerant.

(b) **A Thermostatic Expansion Valve:** to control and meter the liquid refrigerant into the evaporator.

(c) **An Evaporator:** which is a form of heat exchanger designed to extract heat from the main air supply prior to distribution into the aircraft.

(d) **A Compressor:** to provide the motive force for refrigerant re-circulation, and in conjunction with the thermostatic expansion valve, maintain a pressure differential between the condenser and evaporator. The effect of this differential improves both vaporisation and condensation of the refrigerant as follows. The compressor in drawing vapour from the evaporator assembly, decreases the effective pressure acting upon it, the consequence of which reduces the boiling point of the refrigerant. Conversely, on the discharge side of the compressor, vapour pressure is increased. This has the effect of increasing the boiling point and condensation point of the refrigerant, which returns to a liquid state when the latent heat is removed in the condenser.

NOTE: The coupled turbine of the compressor may be driven by an independent air supply (e.g. a tapping from a wing de-icing system), the main air supply, or electrically.

(e) **A Condenser:** which is a form of heat exchanger designed to extract heat from the vaporised refrigerant.

(f) **A Condenser Fan:** which provides (in the absence of ram air), cooling air for the condenser.

(g) **The Refrigerant:** which is a low boiling point volatile liquid such as; ammonia, sulphur dioxide, or dichlorodifluoromethane generally referred to by the trade name of 'Freon'.

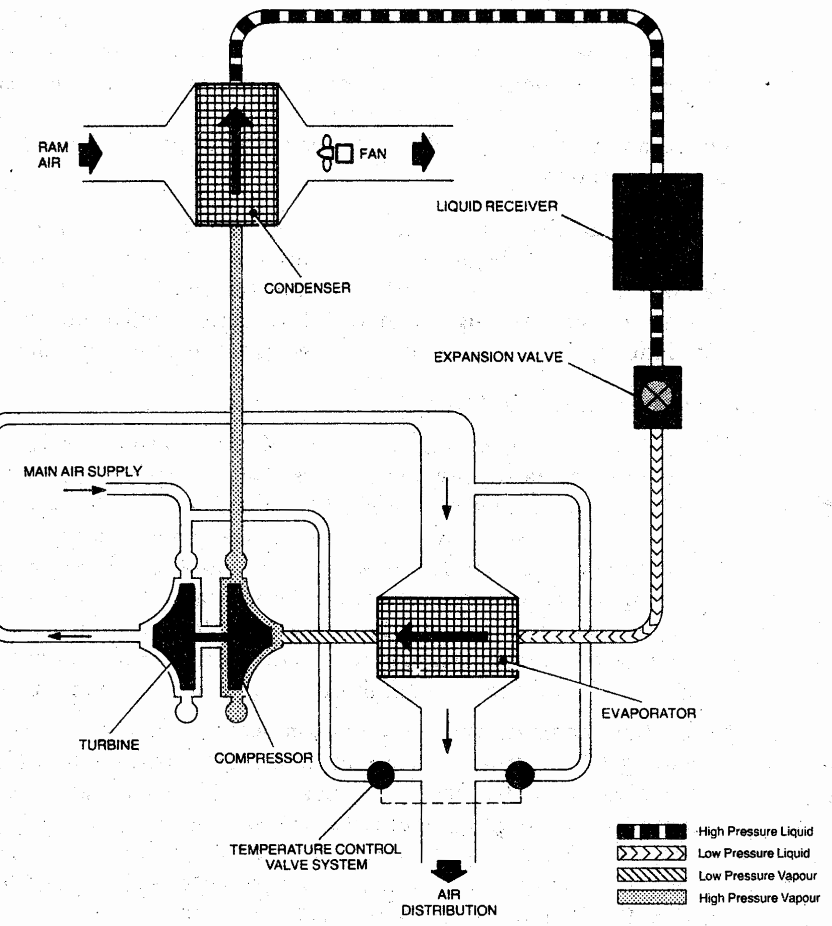


Figure 4 VAPOUR CYCLE COOLING SYSTEM

4.3.2 The Vapour Cycle is as follows (see Figure 4):—

(a) Liquid refrigerant passes from the liquid receiver to the thermostatic expansion valve for controlled release into the matrix of the evaporator.

(b) Heated air from the main air supply system (prior to entry into the cabin distribution system) passes through the evaporator matrix and by induction releases heat into the liquid refrigerant.

NOTE: The main air supply entering the distribution system is now at a reduced temperature.

(c) As a consequence, the liquid refrigerant boils to a vapour.

(d) The vaporised refrigerant is then drawn into the compressor, compressed to a high pressure and temperature (see paragraph 4.3.1 (d)), to enter the condenser.

(e) The condenser; cooled by ram air, reduces the temperature of the vaporised refrigerant, and as a consequence returns the vapour back to a liquid form which then flows back into the liquid receiver to repeat the cycle.

5 TEMPERATURE CONTROL

5.1 **General.** Control of air temperature conditions in passenger cabins, flight crew and other compartments, is accomplished by modulating the valves installed in the air ducting of heating and cooling sections of the air conditioning system. The methods of control vary and depend on the type of aircraft and the air conditioning system employed. In general, two principal methods are adopted, mechanical and electromechanical. The information given on these two methods in the following paragraphs is of a general nature, and reference should always be made to specific Aircraft Maintenance Manuals for full operating details.

5.2 **Mechanical Control.** One mechanical method, which, for example, is employed in aircraft utilising an engine exhaust heating system, and consists of valves which can be manually positioned to regulate the temperature by varying the proportions of hot and cold air passing through a mixing box before delivering it to the cabin. In some installations, hot and cold air enters the cabin through separate valves and ducting.

5.3 **Electromechanical Control**

5.3.1 The electromechanical method of temperature control used in some types of combustion heating system, is also used in all air conditioning systems which utilise the compression method of heating, and air cycle or vapour cycle methods of cooling. In a combustion heating system, the electrical power supply to the solenoid valve is automatically controlled by the duct thermostat. When the temperature of the air flowing from the heater exceeds the thermostat setting, the thermostat de-energises the solenoid valve to isolate the fuel supply to the heater. As the heater cools, the thermostat opens the valve to restore the fuel flow and combustion process. By cycling on and off, the heater maintains an even temperature in the cabin.

5.3.2 In systems utilising compression heating, air cycle, or vapour cycle methods of cooling, the electromechanical temperature control system is designed to automatically modulate actuator motors which control particular valves. A typical system comprises, a duct temperature sensing element, a temperature selector, cabin temperature sensing element and automatic control unit. These components are electrically interconnected to form a resistance bridge circuit which is only in balance when the cabin air temperature is at the selected value.

If the bridge circuit is placed out of balance by a resistance change in either of the sensing elements due to temperature variation, or by varying the selector switch setting, an error signal is produced which is fed to an amplifier stage of the control unit. The amplified signal is then fed to the appropriate actuator motors which position their respective valves to adjust the air flows and so correct the temperature change until the bridge circuit is restored to a balanced condition. Manual controls are provided to permit overriding of the automatic circuit. Low temperature and high temperature limit control devices are also provided and respectively they prevent icing in the water separator, and ensure that upper limits of supply air temperature are not exceeded.

NOTE: **In some aircraft employing compression heating, control is by manual means only and is effected by placing a temperature control valve switch to a 'COOL' or 'HEAT' position as appropriate.**

6 DISTRIBUTION

6.1 General

6.1.1 The air used for conditioning purposes is distributed by a ducting system the layout of which depends on the type of aircraft and its air conditioning system. In a basic system, such as that employing a ram air supply and combustion heating (see Figure 1) the ducting is generally in two distinct sections and provides for separate flows of cold and heated air. The outlets for cold air are normally of the adjustable louvre type and are installed so that air flows from such points as below hat racks, cockpit and cabin sidewalls.

Heated air is distributed through outlet grilles situated at floor level, the degree of heat being regulated by mechanical valves directly controlled at the outlets, or by control knobs in the flight compartment. The heated air duct also has a branch duct which directs heated air to the windshield panels for demisting purposes.

6.1.2 In larger aircraft the air conditioning equipment is normally grouped together in its own compartment or bay. The conditioned air is distributed to passenger cabins through underfloor and hat rack ducting, the latter containing outlet grilles and the requisite number of individual adjustable cold air louvres which are supplied from a cold air source. The distribution of air to flight crew compartments may, in some cases, be through separate ducting or it may be through ducting tapped into the passenger cabin ducting. Typical locations for the air outlets are at floor and roof levels and in sidewalls.

Tappings are taken from the cabin and flight crew compartment ducting systems for supplying warm air to cabin windows and windshields for demisting purposes. After circulation the air is exhausted to atmosphere through the discharge or outflow valves in the pressurisation system.

6.2 **Materials.** Materials used in the manufacture of typical ducting systems are light-alloy, plastic, fibreglass reinforced plastic and stainless steel, the latter being normally used for the hot air sections of engine bleed air supply systems. There are various methods of joining the duct sections together and to components. In those most commonly used the joints are made by flanges and ring clamps of V-section, by rubber sleeves fitted over the ends of duct sections and secured either by adjustable clamps or by a rubber adhesive, and by bolted flanges.

Fibreglass, formed into blanket sections by a covering of synthetic material e.g. nylon, is used for lagging of duct sections. To permit longitudinal movement of ducting as it expands and contracts, expansion bellows, sliding clamps and gimbal mountings are provided in some of the larger aircraft systems.

7 HUMIDITY CONTROL

7.1 **General.** In some aircraft operating for long periods at high altitudes, it is necessary to increase the moisture content of the air used for conditioning and pressurising the cabin in order to overcome physical discomfort arising from low relative humidity. Various humidity-control methods may be adopted but a typical system consists of a humidifier unit supplied with water (from an individual tank or galley water system) and also with air under pressure. The water and air supplies; which are controlled by electromagnetic valves, pass through a jet nozzle system within the humidifier in such a manner that the water is atomised and enters the distribution ducting in the form of a fine spray.

7.2 At the other extreme, operation of aircraft at low altitude and on the ground in regions of high relative humidity, necessitates a reduction of the moisture content of the air supply. In addition to the passenger comfort aspect, it is necessary to decrease the humidity in order to reduce condensation and its effects. Therefore, a water separating device similar to that described in paragraph 4.2.3 is installed for this purpose.

8 GROUND AIR CONDITIONING

8.1 **General.** In some aircraft provision is made for the conditioning of cabin air while an aircraft is on the ground. The methods adopted depend on the type of aircraft and the associated air conditioning system.

8.2 In aircraft employing combustion heating systems, cabin heating is normally obtained by switching on the heater and a ventilating fan located in the main air supply ducting. On the ground, limited cooling of the cabin air can be obtained by switching on the ventilating fan.

8.3 For heating the cabin air in aircraft equipped with an engine exhaust heating system it is necessary for the engine(s) to be running, and for the mechanical air flow control valves to be appropriately adjusted to provide the desired conditions. Limited cooling may be obtained in a manner similar to that referred to in paragraph 8.2.

8.4 Aircraft using more complex methods of air conditioning are often provided with special external connections to which ground service equipment can be coupled. These units supply either pre-conditioned air into the main cabin air distribution system, or pressurised air into the air conditioning packs. In some cases ground service equipment may be used when carrying out ground test procedures.

8.5 In addition to the ground connections, some aircraft are equipped with an auxiliary power unit (see Leaflet **AL/3-26**) for use in the absence of ground conditioning units. Electrically operated blowers may also be fitted for use either as simple cool air ventilators, or in conjunction with a 'bootstrap' air conditioning system, to provide a flow of cooling air to the heat exchangers.

9 INSTALLATION PROCEDURES

9.1 **General.** The information given in the following paragraphs is of a general nature, and is intended as a guide to the procedures associated with the installation of the principal components of air conditioning systems. Full details are contained in the Aircraft Maintenance Manuals for specific aircraft types. Therefore, reference must be made to these publications.

9.2 Compressors and Blowers

9.2.1 Before installation a check should be made to ensure that units are free from damage and that ducts, air inlets and outlets, and mating surfaces are free from oil, dust and other foreign matter. Rotors should also be checked for freedom of rotation observing any special precautions and procedures specified for the appropriate types of unit.

Pipes, metering units and filters of bearing lubricating oil systems should also be inspected for cleanliness and signs of cracks or other damage. Priming of the lubricating oil system should be carried out as specified in the Component and Aircraft Maintenance Manuals (see paragraph 10.2.2).

9.2.2 Units must be adequately supported during installation to ensure that their weight is not allowed to bear on parts of the main drive; for example, a quill shaft which drives a displacement blower. In some aircraft employing compressors a special hoist is provided for installation and removal of units and this should be used in the prescribed manner.

9.2.3 After a compressor or blower has been lowered on to the engine or gearbox mounting pad, its securing nuts or bolts, as appropriate, should be torque-tightened to the values specified in the Aircraft Maintenance Manual. In some compressor installations the units must also be secured by bolting them to the casing of their respective engines via link assemblies.

9.2.4 Inlet and outlet duct attachment flanges should be clean and free from damage. In displacement blower systems, manifolds normally provide for the attachment of duct sections to the blower casing. The bolts securing each manifold to the blower, are, in some cases, of different lengths. Therefore to avoid distortion of the inner face of the blower casing they must be refitted in their correct position before tightening. New sealing rings should be fitted between duct sections and corresponding attachment points on compressors and blowers. The sections should fit squarely and not be subjected to undue strain or load, or be in contact with other components which may abrade duct surfaces.

9.3 Combustion Heaters

9.3.1 Before installation, combustion heaters should be inspected, and when necessary, pressure tested in the manner prescribed in the Aircraft Maintenance Manual to ensure that no fuel or combustion products leak into the cabin air supply (see Airworthiness Notice No. 40).

9.3.2 Heaters should be installed in the manner specified in the Aircraft Maintenance Manual concerned, taking care that air and fuel leakages do not occur at duct joints or connections. There should be no connection between the combustion air and cabin air supplies and no leakage of air or exhaust gas into the aircraft.

9.3.3 Equipment associated with the heating system such as flow valves, air regulators, thermostatic devices and ducts should be correctly interconnected, and mechanical movements, flows and temperature settings checked and adjusted.

9.3.4 After the installation of a heater the system should be ground tested in the manner specified in the relevant Aircraft Maintenance Manual.

NOTE: Unburnt fuel or fuel vapour should not be allowed to accumulate within the combustion system or aircraft particularly during component functioning tests (see Leaflet **AL/3-8**).

9.4 Engine Exhaust Heaters

9.4.1 When installing heater muffs around piston engine exhaust systems it must be ensured that they are in such isolation that exhaust gases cannot enter the muff and subsequently be discharged into the heating and ventilating system (see Airworthiness Notice No. 40).

9.4.2 Cooling air intakes and hot air ducting should be installed so that no obstruction or leakage of the air supply can occur. All joints should be correctly aligned and clamps securely fixed.

9.5 **Heat Exchangers**

9.5.1 Before installation, heat exchangers should be inspected to ensure that no foreign matter has entered the various connections, that there are no evident cracks or other damage and that ram air passages are free from obstruction.

9.5.2 Heat exchangers are heavy units and they must therefore be adequately supported during installation to prevent them fouling ducting, other system components and parts of the aircraft structure.

9.5.3 The fore-and-aft and transverse clearances for mounting flanges and bolts should be checked to ensure that they are within the limits specified in the relevant Maintenance Manuals. Mounting bolts should be tightened to the required torque values.

9.5.4 New seals and O-rings should be fitted to the joints between system ducts, cooling air inlet and outlet flanges, and charge-air connections. Nuts, bolts and clamps should not be overtightened as connection flanges may distort and cause damage to adjacent brazed joints. After installation the joints should be leak tested in accordance with the procedure laid down in the relevant Aircraft Maintenance Manual.

9.5.5 If disturbed during installation of a heat exchanger, cooling air shutters or flaps should be tested and adjusted as necessary. Movable parts should operate freely, and the limit switches of electrical actuators should isolate the power supply when the shutter or flap has moved through its full travel.

9.6 **Cold Air Units**

9.6.1 When installing cold air units care is necessary to exclude dirt and oil from the air ducts and casings. Dirt and other foreign matter may damage the rotating parts and oil may introduce unpleasant or flammable vapours into the cabin air supply. Duct attachment flanges, unit mounting flanges, and casings, should be examined for signs of burns, cracks, distortion or other damage.

9.6.2 Units with integral wet sump lubrication should be primed with oil to the approved specification to ensure that all bearing surfaces have been lubricated. Reference should be made to the Maintenance Manuals of relevant units for details of the lubricants required. The unit should be supported on a bench in the normal operating attitude while the quantity of oil specified for the unit is poured in. To ensure that oil is distributed to the bearings, the rotating assembly of the unit should be spun over by hand at the same time checking that the rotation is free and without noise or vibration (see Note). The unit should then be drained and installed in the aircraft and after securing it to its appropriate mounting, refilled with oil to the level marked on the sump dipstick.

NOTE: In some cold air units, air bearings are used to support the main rotating assembly, which do not allow free rotation from the idle state. Therefore reference should be made to the specific Maintenance Manual for further details.

9.6.3 The lubricants recommended for Cold Air Units are various and possibly incompatible with each other. Therefore, when priming or servicing these units, care should be taken to ensure that the oil is of the correct type and specification and the containers used are clean and free from contamination of any kind.

9.6.4 New seals should be fitted between the air distribution ducts and attachment flanges on the cold air unit, and when securing the ducts it should be ensured that they fit squarely and are not subjected to undue strain or load. Leak checks on units should be carried out during functional testing of the air conditioning system.

9.7 **Refrigeration Systems.** The individual components of a refrigeration system can usually be removed and installed separately. However the Maintenance Manuals appropriate to the system and aircraft should always be referred to before attempting such work. Some of the general precautions applicable to closed circuit Vapour Cycle Systems are as follows:—

(a) Gloves and goggles should be worn when handling liquid refrigerants which can be harmful to the skin and eyes.

(b) Before charging a newly installed system, or recharging a system which has been partly disconnected, all air should be evacuated in the manner prescribed in the relevant Maintenance Manual.

(c) While refilling is in progress, care should be taken to ensure that refrigerant used is of the specified type, and quantity, and that all precautions recommended by the manufacturer are observed.

NOTE: The Refrigerant used in Vapour Cycle Cooling Systems, usually contains a specific amount of oil to lubricate the compressor bearings. Therefore, in order to maintain the correct ratio of constituent parts, reference should be made to the relevant Maintenance Manual for the correct volume of oil to be added.

9.8 **Temperature Control System Components**

9.8.1 The temperature control of complex air conditioning systems is usually accomplished either electrically or electronically. Consequently the following precautions are normally adopted when installing such equipment.

9.8.2 As temperature-sensing elements are positioned so that they will be directly affected by the changes in duct and cabin air temperatures. Therefore, care should be taken to ensure that elements sensing cabin air temperature are not shielded by loose upholstery, and are protected if paint spraying or similar operations are performed in their vicinity.

9.8.3 The damping effect of shock absorbers and anti-vibration mountings which may provide support for electronic amplifiers and similar sensitive equipment, should be checked by hand after installation.

9.8.4 Cables interconnecting components must be of the rating specified by the manufacturer and all connections must be clean and securely made.

9.8.5 When installing control units, care should be taken that such controls as pre-set potentiometers and fine adjustment resistors are not disturbed.

9.8.6 On completion of the installation of a component, sensitivity tests and final balance adjustments should be carried out in accordance with the procedure laid down for the specific aircraft system. Tests of the overall controlling function should also be made by selecting various temperature settings and noting that the actuators controlling such components as heat exchanger cooling air flaps, by-pass valves, etc., move in the appropriate directions.

9.9 **Valves**

9.9.1 Mechanically and electrically-operated valves are employed in the various types of heating, ventilating and air conditioning systems and therefore Maintenance Manuals should always be referred to for the appropriate installation procedures. The details given in the following paragraphs are of a general nature.

9.9.2 All valves should be inspected before installation for cleanliness, signs of damage and freedom of movement. Functional checks should be made on electrically-operated valves, e.g. spill valves, by-pass valves and choke valves to ensure that limit switches are correctly adjusted at the extremes of valve travel.

9.9.3 Valves are often marked with arrows to indicate the direction of flow and particular care is necessary to ensure that the valve is installed in correct relation to flow.

9.9.4 The attachment of valves to their respective mountings and duct sections must be secure and torque loadings strictly observed.

9.9.5 Electrical connections to actuators and to position indicators where fitted, should be checked against the relevant wiring diagrams, and plugs, sockets and terminal screws checked for security.

9.9.6 On completion of the installation of a valve, an in-situ functional test should be carried out in accordance with the procedure specified in the relevant Component and Aircraft Maintenance Manual.

9.10 **Distribution Systems**

9.10.1 **General.** The methods of installing ducting and other components of distribution systems depend on the type of air conditioning system and reference must, therefore, always be made to the relevant Aircraft Maintenance Manual and the procedures specified carried out.

9.10.2 The following summary serves as a guide to some important aspects common to installation procedures:—

(a) Ducting should be inspected externally and internally for cleanliness, signs of damage and security of end fittings.

(b) Lagging, where fitted, should be inspected to ensure freedom from tears, damage and evidence of deterioration.

(c) When fitting ring clamps, the sealing rings must be correctly positioned between duct and fittings and the fittings should abut each other squarely before the clamps are tightened.

(d) Ring clamps should be torque-tightened to the loads specified; the loadings should be rechecked after the engine run following installation.

(e) Ducts made from fibreglass, plastic and reinforced plastic should not be subjected to any weight or load during installation, and the straps or clamps attaching the ducts to support brackets should not be overtightened.

(f) After replacement of a duct, the disturbed joints should be checked for leakage.

(g) Where specified, ducts must carry identification labels.

(h) When assembled on ducts, rubber sleeves should be in a free condition, i.e. they should not be twisted, stepped or collapsed.

(i) Bedding tape or metal clips must be fitted between rubber sleeves and adjustable clamps to prevent damage to the sleeves when tightening the clamps. Expansion bellows, sliding clamps or gimbal mountings where installed, should be checked for full and free movement.

(j) Electrical bonding leads must be properly secured.

10 MAINTENANCE

10.1 **General.** The information given in the following paragraphs on maintenance, periodic inspection and testing, is of a general nature and should be read in conjunction with the Maintenance Manuals and Schedules for the components and aircraft concerned.

10.2 Compressors and Blowers

10.2.1 Units should be inspected for damage and for security of mounting attachment to engine drives and accessory gearboxes, and also duct attachments.

10.2.2 Oil transfer pipes should be examined for security of attachment, signs of chafing and other damage, and for leaks. At the periods specified in the Maintenance Manual, oil filters should be removed for examination and cleaning or renewed as appropriate. If it is suspected that dirt is present in the lubrication system, all pipes and oil passages should be cleaned in the manner prescribed in the Maintenance Manual for the relevant unit. In units having an integral lubricating system, the oil level in the sump should be checked and replenished as necessary taking care that the equipment for dispensing the oil is scrupulously clean.

10.2.3 Where magnetic chip detectors are fitted to the lubrication system they should be removed and inspected for metal particles. If no particles are found, the chip detector, together with a new sealing ring, should be refitted and wire locked. If metal particles are present the unit should be replaced with a serviceable item.

NOTE: When refitting bayonet type chip detectors extreme care should be taken to ensure positive engagement.

10.3 Combustion Heaters

10.3.1 Heaters should be examined for security of attachment and signs of malfunctioning, the fuel system should be carefully checked for signs of leakage and drain pipes should be checked to ensure freedom from obstruction. At the specified inspection periods, igniter plugs should be cleaned, and heaters should be subjected to a pressure test in accordance with the procedure laid down by the manufacturer.

10.3.2 Electrical wiring and associated components should be checked for security of attachment, loose connections, chafing of insulation, etc. The sheath of the igniter plug cable should be examined for any possible indications of arcing, which would be evidenced by burning or discolouration of the sheath.

10.3.3 Filters, air and fuel regulating devices, safety devices (e.g. overheat switches, fuel cut-off valves, etc.), and all controls should be inspected, adjusted and tested as required by the Approved Maintenance Schedule.

10.3.4 System operation should be checked in accordance with the procedure laid down in the relevant Aircraft Maintenance Manual.

NOTE: In order to reduce the risk of the cabin air supply becoming contaminated by high concentrations of carbon monoxide from the exhaust system, it is imperative that the procedures for inspection, servicing and overhaul of combustion heaters and their associated exhaust systems are maintained to a high level (see also Airworthiness Notice No. 41).

10.4 **Engine Exhaust Heating.** Careful examination of heater muffs is necessary to ensure that no leakage of exhaust gases into the air delivered to the cabin can occur (see Airworthiness Notices Nos. 40 and 41). Unless damage can be rectified within the scope of an approved repair scheme, exhaust pipes or muffs which show signs of cracking, corrosion or excessive high temperature scaling should be renewed. All muffs should be pressure-tested when specified in the Maintenance Schedule.

Hot and cold air ducts associated with the heating system should be free from obstruction and all controllable shutters, valves, etc., should be checked for correct functioning. The operation of the complete system should be checked during engine running.

10.5 **Heat Exchangers**

10.5.1 Heat exchangers should be inspected for security of attachment to the aircraft structure, security of air duct connections and freedom from damage.

10.5.2 The external surfaces of a heat exchanger matrix must be clean and the cooling air passages free from obstruction. If dirt or other forms of contamination are found the surface and air passages should be cleaned by means of a clean dry air blast.

NOTE: Instructions laid down in specific Aircraft Maintenance Manuals regarding the closing of cooling air flaps to ground blower units and ground test connections must be observed.

10.5.3 If a matrix has not been satisfactorily cleaned due to the contamination being excessive or hardened on to the surfaces, or if internal contamination or leakage from the charge air passages is suspected, the heat exchanger should be removed for cleaning and repair and replaced by a serviceable unit.

10.5.4 Cooling air shutters or flaps, linkages and actuators should be examined for freedom of movement and should be lubricated when necessary. Linkages and hinges of shutters or flaps should be checked for excessive play and lost motion.

10.5.5 During functional testing of a complete air conditioning system, a check should be made at all joints for air leakage.

10.6 **Cold Air Units**

10.6.1 Cold air units should be inspected for security of mountings and external locking devices, cleanliness, freedom from damage, oil leaks, and leakage of air from duct connections. In some units a magnetic chip detector is fitted to the oil sump drain plug; this should be removed and inspected for metal particles. If particles are present, the cold air unit should be replaced by a serviceable unit. If no particles are present, the chip detector together with a new sealing ring should be refitted and wire-locked.

10.6.2 The oil level must be checked and replenished if necessary taking care that the oil is to the specification approved for the unit (see paragraph 9.6.2), that the equipment for dispensing the oil is scrupulously clean, and that the system is not overfilled.

10.7 **Refrigeration Systems.** Refrigeration packs and associated components should be checked for security of mountings, security of pipe line connections between components, and level of refrigerant. If the level is low the system should be checked for leaks and, after rectification, recharged with the refrigerant specified for the system taking care that all precautions are observed (see also paragraph 9.7 and Note).

10.8 **Temperature Control Systems**

10.8.1 All components should be inspected for security of attachment and electrical connection, signs of damage, deterioration of electrical cables etc.

10.8.2 The operation of individual components should be checked during specified ground tests to ensure that they respond correctly whenever different heating and cooling conditions are selected, and also that, in combination, they maintain cabin temperature conditions within a comfortable range. It should be borne in mind that, apart from considerations of comfort, cabin temperature control limits the misting and icing of windscreens and windows and therefore affects the safe operation of aircraft. The operation of components, systems and circuits, designed specifically for emergency operating conditions, must also be checked during ground test procedures.

10.8.3 The test procedures vary and the extent to which a system can be tested may be limited, particularly in relation to ram air methods of cooling. On the other hand, full-range temperature control of a system in some aircraft may be checked on the ground. Reference must therefore always be made to the relevant Aircraft Maintenance Manual and Maintenance Schedule for the procedure to be adopted and precautions to be observed.

10.9 **Valves**

10.9.1 The maintenance of valves associated with air temperature control is usually confined to; inspection for cleanliness, security of attachment ducting attachments and, where applicable, security of electrical connections, functioning tests and light lubrication specified by the manufacturer of the component.

10.9.2 Sliding or rotating parts of valve assemblies should be free from scores, damage or excess static friction. The maximum effort required to move a valve should be checked when necessary and should not exceed the figure recommended by the manufacturer. However some electro-mechanically operated valves are not designed to operate without the application of an electrical supply. Therefore reference should be made to the specific Maintenance Manual for test instructions, before manual operation.

10.9.3 Lubricants should be of the type specified for the component and should be applied sparingly taking care to prevent oil entering air supply ducts.

10.9.4 Valve seats and valves faces should be kept free of dust or traces of lubricant.

10.9.5 Checks on the operation of valves should normally be carried out during ground testing of temperature control systems since their functions are integrated.

10.10 **Distribution Systems**

10.10.1 All ducting and associated air distribution components should be inspected for security and general condition, particular attention being given to joints between duct sections and components.

10.10.2 Lagging should always be properly secured and free from oil, hydraulic fluids etc. It should be remembered that duct sections in some parts of a system often become heated to a degree sufficient to make oil-soaked lagging flammable (see Leaflet **AL/3-8**).

10.10.3 When specified, ducts should be proof-tested at the pressure recommended by the manufacturer; normally a workshop function. Pressure tests are however, more often made with the object of detecting leaks, in which case the test pressure is not critical provided it does not exceed a value which might damage the duct.

10.10.4 It is usually more convenient to test a complete distribution system by dividing it into sections and applying a recommended pressure separately and in sequence. The sections should be selected so that all critical joints are subjected to the test pressure; advantage being taken of shut-off valves, non-return valves, etc., where these provide convenient boundaries between sections.

10.10.5 Leaks can be detected by sound or feel, although these are sometimes revealed by discolouration and holes blown in the lagging. If there is difficulty in locating leaks, the soap and water method can be used.

NOTE: Because of the high operating temperatures and pressures involved, it is recommended that care should be taken when carrying out a physical check for air leaks.

AL/3-25

Issue 1.

11*th June*, 1974.

AIRCRAFT

SYSTEMS AND EQUIPMENT

OXYGEN SYSTEMS

1 INTRODUCTION This Leaflet gives information of a general nature on the types of gaseous oxygen systems and equipment used in aircraft, installation and maintenance practices, and precautions to be observed. Because of the wide variation in the design of oxygen equipment installed in different types of aircraft it is important that this Leaflet is read in conjunction with the appropriate aircraft Maintenance Manual and the approved Maintenance Schedule. The following Leaflets contain information associated with the subject covered by this Leaflet and reference should be made to these as appropriate:—

AL/3-14 Installation of Rigid Pipes in Aircraft

AL/3-23 Pressurisation Systems

BL/6-15 Manufacture of Rigid Pipes

EEL/1-6 Bonding and Circuit Testing

1.1 The Air Navigation Order, 1972, prescribes the conditions under which oxygen equipment is required, and British Standards N1, 2N 100, and N2 specify general requirements for aircraft oxygen equipment and materials and processes to be used in its manufacture. The breathing oxygen used in aircraft systems should comply with British Standard N3 and International Standard ISO 2046.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet AL/6-6, Issue 1, dated 21st June 1968.

2 PURPOSE OF OXYGEN SYSTEMS With increase in altitude the pressure of the atmosphere and the partial pressure of its oxygen content decreases, resulting in a deficiency of oxygen in the blood and tissues of individuals subjected to such pressures. This condition, known as "anoxia", seriously impairs physical and mental abilities and prolonged exposure to it can prove fatal. The purpose, therefore, of oxygen systems in aircraft, is to offset the varying effects of anoxia by supplying oxygen through a breathing mask at a controlled rate of flow.

2.1 Information on the physiological effects of altitude may be obtained from BS 2N 100, but for the purpose of this Leaflet the following is quoted from that document: "Unless oxygen is administered at high cabin altitudes unconsciousness and finally death will occur, the time of onset of unconsciousness depending on the cabin altitude, for example, without added oxygen the time of useful consciousness at 25,000 feet is approximately three minutes and at 40,000 feet it is twenty seconds." Table 1 also contains some relevant information extracted from a more detailed Appendix to the British Standard 2N 100.

TABLE 1

Physiological Effects of Altitude	Feet
Maximum altitude without oxygen at which flying efficiency is not seriously impaired	8,000
Altitude at which the incidence of decompression sickness increases rapidly with exposures exceeding ten minutes	25,000
Maximum altitude at which sea level conditions can be maintained by breathing 100 per cent oxygen	33,000
Maximum allowable altitude without pressure breathing	40,000

3 OXYGEN SYSTEMS Civil transport aircraft cruise at altitudes where cabin pressurisation (see Leaflet **AL/3-23**) is necessary to maintain conditions inside the cabin approximately equal to a maximum altitude of 8,000 feet, regardless of the actual altitude of the aircraft above this figure. Under such conditions oxygen is not normally needed for the comfort of the passengers and crew. However, as a precaution, oxygen equipment is installed for use in the event of a cabin pressurisation system failure. In addition, portable oxygen sets are also provided for therapeutic purposes, and for cabin attendants' use while moving about the passenger cabin during low cabin pressure emergencies.

3.1 In some of the smaller and medium size aircraft designed without a cabin pressurisation system, oxygen equipment may be installed for use by passengers and crew when the aircraft is flown above 10,000 feet. In other cases where there is no oxygen system installation, passengers and crew depend on portable oxygen sets stowed in convenient positions.

3.2 The design of the various oxygen systems used in aircraft depends largely on the type of aircraft, its operational requirements and, where applicable, the pressurisation system. In some aircraft the continuous flow oxygen system (see paragraph 3.3) is installed for both passengers and crew but the diluter demand system (see paragraph 3.4) is widely used as a crew system, especially on the larger types of transport aircraft. Many aircraft have a combination of both systems which may be augmented by portable sets.

3.2.1 The oxygen is normally stored in gaseous form but, in some cases, systems may be used in which oxygen is produced when required, by special oxygen generators operating on a chemical reaction principle (see paragraph 3.5). Gaseous oxygen is stored at approximately 1,800 lb/in^2 and is reduced to the low pressure required for breathing purposes by pressure regulator valves or reducer valves. In oxygen generator systems the gas is produced directly at low pressure.

NOTE: The pressure in most systems is normally reduced in one stage from high to low, but in some aircraft a two-stage reduction is effected, i.e. from high pressure to medium, and then to low pressure.

3.3 **Continuous Flow Oxygen Systems.** A typical continuous flow oxygen system is illustrated in simplified form in Figure 1. When the line valve and cylinder valve are turned "on" oxygen will flow from the charged cylinder through the high pressure pipe to the pressure reducing valve which reduces the pressure to that required at the mask connection points. Reducing valves may be fitted directly to cylinders together with shut-off valves, or they may be separate units designed for "in-line" coupling. A calibrated orifice is normally provided in the sockets to control the flow of oxygen delivered to the mask.

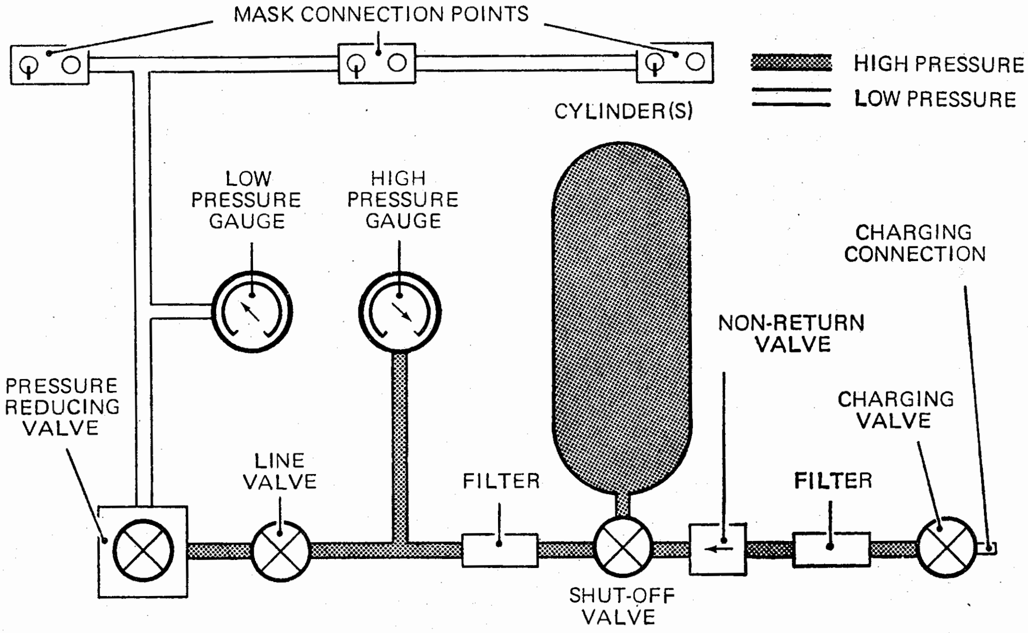


Figure 1 TYPICAL CONTINUOUS FLOW SYSTEM

3.3.1 The passenger system may consist of a series of supply sockets with mask plug-in connections at each passenger seat group, or it may be the "drop-out" mask arrangement where, in the event of pressurisation system failure, individual masks are presented automatically to each passenger from service units. When the masks are pulled to the useable position, valves are opened to permit oxygen to flow to the masks, the flow being indicated by a simple flow indicator within each mask hose. Any automatic control (e.g. barometric control valve) in the ring main supply can be overridden manually by a member of the crew. Service units are also provided with a plug-in receptacle for attaching a separate mask for therapeutic use.

3.3.2 Figure 2 illustrates a continuous flow system commonly used in some types of light aircraft carrying a pilot and five passengers. The cylinder contains gaseous oxygen at 1,800 lb/in^2 and has the pressure regulator and pressure gauge fitted directly to it. The shut-off valve is also on the regulator and is opened and closed by a mechanical linkage connected to a control knob in the cockpit. Mask connections are of the plug-in type and each mask hose contains a simple device which indicates that oxygen is flowing. A cylinder charge valve is incorporated in the system and is usually of the self-sealing, automatic opening and closing type.

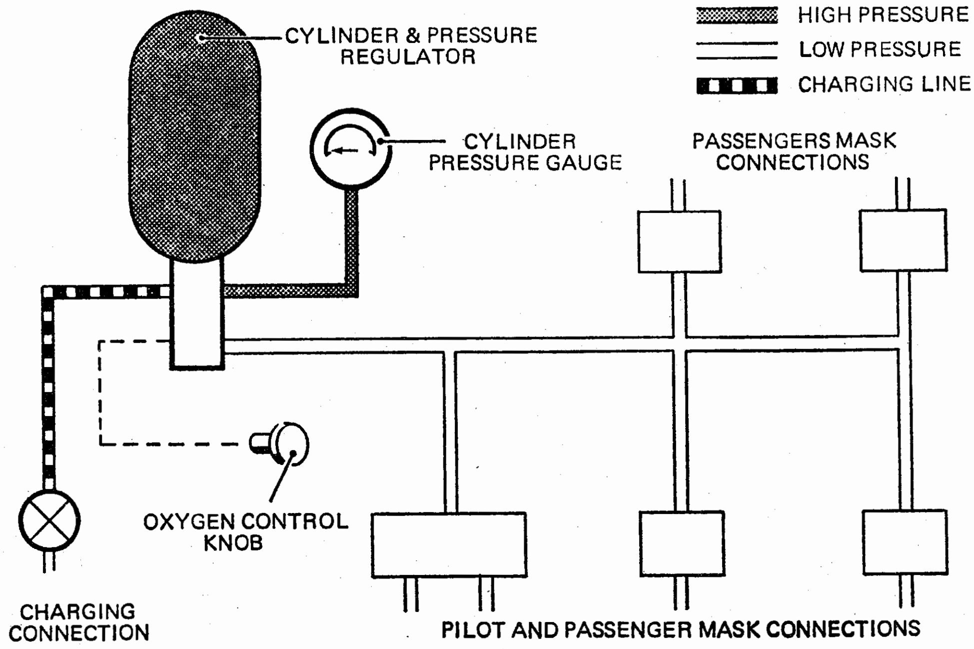


Figure 2 TYPICAL LIGHT AIRCRAFT SYSTEM

3.4 **Diluter Demand System.** A diluter demand system is one in which the oxygen is diluted with air and the mixture is supplied only when the user inhales, i.e. as demanded by an individual respiration cycle. The interconnection of a typical system is illustrated in simplified form in Figure 3. It will be noted that there is a regulator for each crew member who can control the regulator according to his requirements. The operation of a typical regulator is described in paragraph 4.7.

3.5 **Chemical Oxygen Generator Systems.** In these systems, oxygen is produced by chemical generator and dispenser units which are contained within service panels at each group of passenger seats and other essential locations.

3.5.1 In the basic form, a unit consists of a generator, a "drop-out" mask and hose. The generator (see Figure 4) is comprised of a corrosion resistant steel cylinder containing a thermal insulating liner, a compressed block of sodium chlorate and iron powder, a filter, and an electrically operated firing mechanism mechanically connected to the mask by a lanyard. The power supply required for electrical operation is 28 volts d.c. The mask is ejected automatically from the service panel by a release mechanism controlled by an aneroid switch, the contacts of which are set to make at the appropriate cabin altitude, e.g. 14,000 feet.

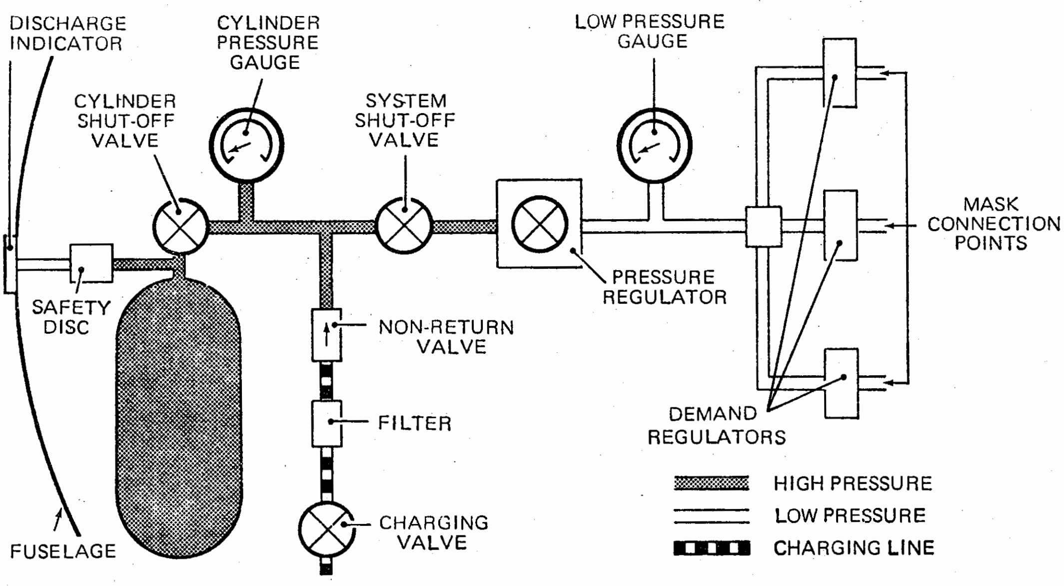


Figure 3 TYPICAL DILUTER DEMAND SYSTEM

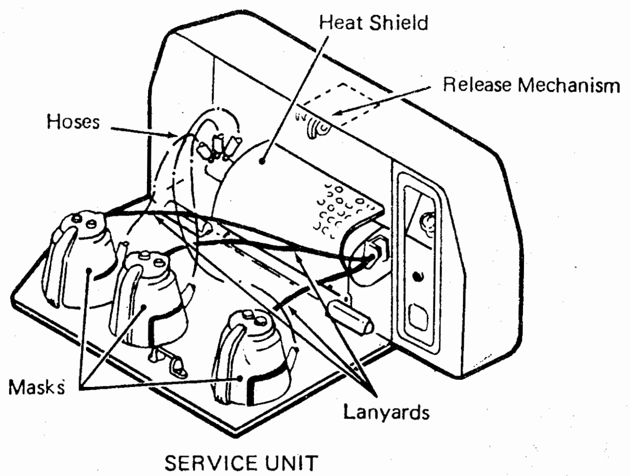
3.5.2 When the mask is pulled towards the user, the lanyard trips the generator firing mechanism which then ignites the sodium chlorate charge block. As the temperature of the block is raised a chemical reaction is created, thereby producing a supply of low pressure oxygen which flows through the filter to the mask. This process continues until the charge block is expended. Oxygen normally flows for a period of 15 minutes, and although extremely high temperatures are generated, the temperature of the oxygen delivered at the mask does not exceed 10°C above ambient.

NOTE: In some generator systems, the sodium chlorate charge block is ignited by current supplied through the aneroid switch.

3.5.3 Oxygen generators are made in three sizes depending on the number of passenger masks to be supplied. A valve to relieve any excess pressure is incorporated, and an indication of an expended generator is also provided by the change in colour of a band of thermal paint around the outside of the case.

3.6 **Portable Oxygen Sets.** A typical portable oxygen set consists of an alloy steel lightweight oxygen cylinder fitted with a combined flow control/reducing valve and a pressure gauge. A breathing mask, with connecting flexible tube and a fabric carrying bag with the necessary straps for attachment to the wearer completes the set. The charged cylinder pressure is usually 1,800 lb/in^2. The capacities of sets vary, a size most commonly used being 120 litres.

3.6.1 Depending on the type of set, it is normally possible to select at least two rates of flow, "Normal" and "High". With some sets three flow rate selections are possible, i.e. "Normal", "High" and "Emergency" which would correspond to 2, 4 and 10 litres per minute with an endurance under these flow rates of 60, 30 and 12 minutes respectively for a cylinder of 120 litre capacity.



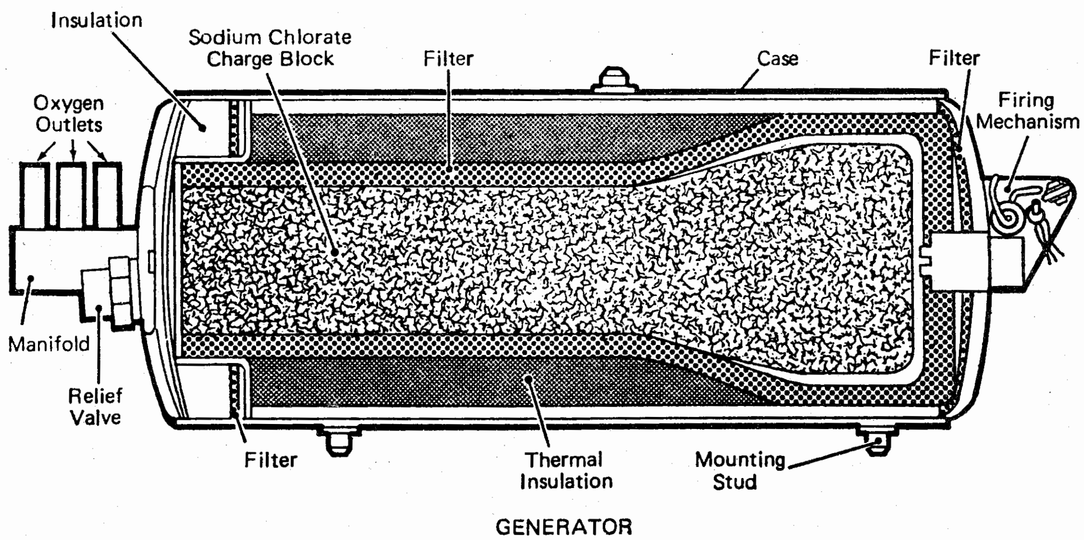


Figure 4 CHEMICAL OXYGEN GENERATOR SYSTEM

4 COMPONENTS

4.1 Brief details of some of the components commonly used in oxygen systems are given in the following paragraphs. Full descriptive details of the components installed in specific types of aircraft are contained in the relevant Maintenance Manuals and reference should be made to these documents.

4.2 **Oxygen Storage Cylinders.** Cylinders designed for the storage of gaseous oxygen are made from drawn high tensile alloy steel and normally have a manual stop valve and, in many instances, a pressure regulator and a pressure gauge threaded into the neck of the cylinder. The charged pressure is usually 1,800 lb/in^2 and capacities vary from 80 litres for portable sets to 2250 litres for large installations.

4.2.1 Cylinders are often provided with an excess pressure rupture disc, usually fitted in the valve body, which vents the cylinder contents to the outside of the aircraft in the event of a dangerous pressure rise. An indicator is provided in some aircraft to indicate discharge resulting from pressure relief (see paragraph 4.13).

NOTE: The disc is designed to rupture before excessive pressure could cause damage.

4.2.2 Cylinders for use in aircraft oxygen systems are colour coded for identification purposes, and there are two codes presently adopted: (i) black for the main body and white for the top hemispherical portion (the valve end) and (ii) green for cylinders of American origin. As a means of further identification of cylinder contents, it is also necessary for the name of the gas and its chemical formula to be marked at the valve ends of cylinders in accordance with British Standard 2N 100 and International Organisation for Standardisation recommendation ISOR448. In addition, the following information is painted or stencilled on the bodies of the cylinders:—

(i) In red letters on a white background: "Use No Oil".

(ii) In white letters on the black cylindrical portion:

Name of manufacturer
Drawing assembly No.
Capacity .... litres
Test pressure ....
Working pressure ......
Test date..................

NOTE: The test date refers to a pressure test and may also be stamped on the neck ring of a cylinder.

4.3 **Pipe Lines.** The characteristics of the pipe systems vary widely between different types of aircraft and the particular oxygen system installed and reference should be made to the relevant manuals for full details. High pressure pipes are usually made of either stainless steel or copper-based alloys, while pipes for low pressure areas of systems are made of aluminium-based alloys. Pipe also vary in size and some typical values are $\frac{3}{16}$ to $\frac{1}{4}$ inch outside diameter for high pressure pipes, and $\frac{5}{16}$ inch outside diameter for low pressure pipes.

4.3.1 The types of couplings normally used for pipe joints are of the standard AGS type and MS flareless tube type (see Leaflet **BL/6-15**). Because of the difficulty of ensuring the complete removal of flux and scale, silver soldered connections are, generally, not used.

4.3.2 Identification of pipes in the system by symbols and colour coding is widely used and should comply with BS 3M.23. Tie-on metal tags or metal identification rings should not be used as they may cause damage through vibration, or become detached and foul moving parts of control systems.

4.4 **Non-Return Valves.** These components are designed to prevent flow reversal and are installed in a pipe line or at a connector adaptor. Of the two basic types commonly used, one consists of a housing containing a spring-loaded valve which is forced against the spring when pressure is applied to the inlet side, thus breaking the seal and allowing oxygen to flow. When pressure is equalised the spring returns the valve onto its seating, so preventing any reversal of oxygen flow. The other type is a bell-mouthed hollow cylinder fitted with a captive ball in its bore. When pressure is applied at the bell-mouthed (i.e. inlet) end, the ball is forced onto the seating of a port at the opposite end and at the same time, its displacement uncovers holes in the wall of the valve to allow oxygen to flow into the pipe or connection. Any tendency for the flow to be reversed is prevented by the oxygen forcing the ball back onto its seating at the inlet end. The normal direction of flow for both types of valve is indicated by an arrow on the valve body.

4.5 **Filters.** Filters, generally of the gauze or sintered bronze type, are provided at points downstream of oxygen cylinders and in some cases, immediately after the ground charging connection. In most systems in current use a filter, usually of the sintered bronze type, is normally embodied in the supply connection of a particular component, e.g. a regulator or a reducing valve. In some instances the charging connection is counter-bored to house a slug-type sintered bronze filter which also acts as a restrictor to guard against too rapid charging of the system.

4.6 **Pressure Reducing Valves.** These valves reduce the high pressure oxygen from the storage cylinders to the pressure required in the low pressure part of the system. In a continuous flow system the reduced pressure is supplied to the mask connection points. In a pressure demand system the pressure from the reducing valve is comparatively higher than that for a continuous flow system and further pressure regulation is necessary at each regulator.

4.6.1 Design features vary considerably, but in general, reducing valves comprise a pressure reducing pre-set spring and valve control mechanism with a relief valve to safeguard against overloads. Pressures can be reduced to the pressure required for a particular system (e.g. from 1,800 lb/in^2 to 80–100 lb/in^2).

4.7 **Oxygen Diluter Demand Regulators.** These regulators are used in crew oxygen systems (see paragraph 3.4) and are designed to adjust the output ratio of oxygen and air in accordance with cabin pressure and to supply, on demand, the correct air/oxygen mixture. A typical diluter demand regulator operates as follows:—

(i) With the oxygen supply "on" and "normal oxygen" selected by the appropriate control lever on the regulator, diluted oxygen in accordance with cabin altitude will be supplied to the crew member's mask when the user inhales. The amount of air mixed with oxygen is controlled by the regulator and the air decreases with increase in cabin altitude until a cabin altitude of 32,000 feet is reached when approximately 100 per cent oxygen is supplied.

(ii) If the crew member selects "100% oxygen" the regulator air valve is closed and 100 per cent oxygen is supplied when the user inhales, irrespective of cabin altitude.

(iii) If "Emergency" is selected, e.g. to provide protection against smoke and other harmful gases, a flow of 100 per cent oxygen is supplied at a positive pressure to avoid any inward leakage into the mask. Depending on the type of regulator, the oxygen may either flow only when the user inhales, or continuously and irrespective of the user's respiration cycle.

(iv) When "Test mask" is selected oxygen is supplied at a higher pressure than that provided for the "Emergency" condition and is used for testing the masks and equipment for fit and leakage.

4.8 **Supply Sockets.** These components provide connections between the aircraft system and individual oxygen mask connecting tubes. Some embody two socket points for "Normal" or "High" flow and others may have only one socket point with a flow selector lever. Calibrated orifices in the socket points of continuous flow systems control the flow rate to the masks. Socket points are made with self closing shut-off valves, spring loaded in the closed position, and open when the mask tube connecting plug is inserted in the socket.

4.9 **Pressure and Contents Indicators.** Pressure indicators are provided to indicate cyclinder pressure and, where necessary, medium and low pressure in the supply lines. The indicators are normally of the direct-reading Bourdon tube type calibrated in lb/in^2, and may be located on cylinders, pressure regulators and at oxygen system servicing panels. In aircraft requiring monitoring of system high pressure at a flight engineer's station, electrical indicating systems are also employed. These consist of a transducer which senses high pressure and converts it to a variable electrical signal for controlling an indicator at the flight engineer's panel. The power supply required for operation is 28 volts d.c. and a regulating circuit is incorporated to ensure that pressure indicators are not affected by fluctuations in supply voltage.

4.9.1 Pressure switches are installed in the low pressure sections of some passenger oxygen systems to illuminate warning lights, thereby indicating that a system is in use. The lights are located on a cockpit overhead panel and on cabin attendants' panels.

4.9.2 Contents indicators, as opposed to pressure indicators, are fitted to some types of cylinders and they are normally marked with coloured sectors to indicate contents in terms of "FULL", "$\frac{3}{4}$ FULL", etc.

4.10 **Oxygen Masks.** There are numerous types of oxygen masks in use which vary widely in design and detailed information is outside the scope of this Leaflet. It is important that the masks used are suitable for the particular oxygen system concerned.

4.10.1 In general, crew masks can be fitted to the wearer's face with minimum leakage and may be of the self-contained re-breather type. Crew masks also contain a microphone cord and jackplug for connection into the aircraft communications system. In some instances there is a requirement for pressurised aircraft to carry oxygen masks designed for the protection of crew members in a smoke- or fume-laden atmosphere. These masks are of the full-face type consisting of a transparent visor, oxygen supply hose and adjustable head straps, or of the "sweep-on" type with pre-set head straps and/or elasticated sides. A demand regulator may also be fitted to some masks to control the flow. The hose connections are of the plug-in type designed for insertion into the supply sockets of a ring main system or, alternatively, a portable cylinder.

4.10.2 The masks provided in automatic drop-out systems for passengers are normally simple cup-shaped rubber mouldings sufficiently flexible to obviate individual fitting. They may be held in position by a simple elastic head strap, or may require holding to the face by the passenger. In non-automatic systems, the masks are usually plastic bags fitted with a simple elastic head strap.

4.11 **Flow Indicators.** Oxygen flow is often indicated by a direct type of flow indicator, e.g. a float inside the transparent hose of a mask, or by a pressure-operated blinker type of instrument.

4.12 **Thermal Compensators.** Thermal compensator assemblies are installed in the charging lines of some oxygen systems for the purpose of minimising temperature build-up when oxygen, at charging pressure, flows through. A compensator consists of a brush-like wire element approximately 5 inches long, inserted into a stainless steel tube provided with connectors at each end.

4.12.1 There are two types of thermal compensators in use, one for connection to oxygen cylinders and the other for connection to shut-off valves or regulators. Those fitted to oxygen cylinders have a coupling nut fitting that attaches direct to a cylinder and the downstream end has a flareless tube connection. The second type of compensator is attached to the component by means of a corrosion-resistant steel union through which the wire element extends. A flareless tube connection is fitted to the upstream end.

4.13 **Discharge Indicators.** In some aircraft, discharge indicators are mounted flush to the fuselage skin in an area adjacent to the oxygen system servicing panels. They are connected to the pressure relief lines from the oxygen cylinders and consist of a green plastic disc which is normally retained within its holder by a circlip. In the event of an excess pressure within a cylinder the safety valve opens and escaping oxygen will blow out the indicator disc, thereby providing a visual indication that discharge has occurred.

4.14 **Ground Charging Valves.** Oxygen systems are provided with valves to permit "in-situ" charging of the cylinders from special ground servicing units. The charging connections to the valves are normally sealed off by blanking cap nuts. A short length of chain between a cap nut and an adjacent part of the structure, ensures retention of the nut at the charging point location when removed for charging purposes.

4.14.1 In some systems, the charging valve incorporates manual temperature and pressure compensation adjustments which allow the system cylinder to be charged to optimum pressure at the ambient temperature in the vicinity of the cylinder. The charging rate is automatically controlled by the valve to a safe value thereby minimising the hazard of heat build-up. A pressure/temperature correction chart is normally displayed near the charging valve for reference purposes.

NOTE: An air temperature indicator is sometimes fitted at the location of aircraft cylinders to record ambient temperature conditions.

5 INSTALLATION AND MAINTENANCE PRACTICES To ensure that oxygen systems serve their purpose of supplying hygienically clean oxygen under emergency conditions in an efficient and safe manner, strict observance of servicing instructions, and the necessary safety precautions, is essential during the installation and maintenance of components. Failure to observe such precautions could result in fire and explosions and consequent serious injury to personnel and severe damage to an aircraft. The emphasis is, at all times, on cleanliness and on the standards of the work to be carried out at the appropriate stages of installation and maintenance.

5.1 The information given in the following paragraphs is intended to serve as a guide to practices and precautions applicable to systems in general. Details relevant to specific types of aircraft systems are contained in the approved Maintenance Manuals and the schedules drawn up by an aircraft operator, and reference must always be made to these documents.

5.2 **Servicing Personnel.** Servicing personnel must fully understand the operation of an aircraft system, the relevant ground charging equipment and its connection to charging points, and must have a full knowledge of any appropriate engineering and maintenance regulations in force. Personnel should also be alert to emergency situations which could arise during oxygen system servicing.

5.3 **Oxygen Fires or Explosions.** An oxygen fire or explosion depends on a combination of oxygen, a combustible material and heat. The danger of ignition is in direct ratio to the concentration of oxygen, the combustible nature of the material exposed to the oxygen, and the temperature of either the oxygen or the material, or both.

5.3.1 Oxygen itself does not burn but it supports and vigorously intensifies a fire with any combustible material. The term "combustible material" is used in its widest sense, denoting not only flammable materials but also such materials as steel, normally considered to be non-combustible, but which is in fact combustible at high temperatures in the presence of oxygen under pressure.

5.3.2 Any oxygen system leak can lead to a build-up of near-pure oxygen in unventilated zones, particularly in aircraft that remain idle. A concentration of oxygen in such a zone, e.g. behind upholstery, or thermal/acoustic lagging, or in control panels, could result in a fire or explosion by contact with grease, oil or electrical hot spots. Any indication of pressure loss or leaks must, therefore, be treated as hazardous and must be traced and eliminated before further flight (see also Airworthiness Notice No. 12, Appendix No. 3).

5.3.3 Heat can be generated in an oxygen system by sudden compression or by resonance of oxygen under relatively low pressure impinging into a dead-end cavity. It can also be caused by the vibration of a seal, "O" ring, or other non-metallic material which is exposed to oxygen under pressure. A small high pressure leak could cause ignition of the material through which it is leaking due to heat generated by friction.

5.3.4 Many materials such as oils, grease, fuel, paint, flammable solvents and metal swarf (e.g. from a damaged thread or a pipe coupling) are liable to ignite or explode spontaneously when exposed to oxygen under pressure. Similarly, extraneous matter such as dust, lint from a cleaning rag or natural oil from the hands getting into the system or into a component could cause ignition or explosion. It is essential therefore to keep these materials and other extraneous matter away from exposed parts of oxygen systems to prevent contamination. Clean areas should be used for dismantling and assembly of all oxygen system components.

5.4 **Safety Precautions.** Before carrying out any work on an oxygen system, the following precautions against fire should be taken:—

(i) Provide adequate and properly manned fire-fighting equipment.

(ii) Display "No Smoking" and other appropriate warning placards outside the aircraft.

(iii) If artificial lighting is required, use explosion-proof lamps and hand torches (e.g. equipment complying with BS 229 and BS 889).

(iv) Testing of aircraft radio or electrical systems should be avoided.

(v) Ensure that the aircraft is properly earthed.

(vi) Ensure that charging or servicing units, appropriate to oxygen systems are used and that they, and all other necessary tools, are serviceable and free of dirt, oil, grease or any other contaminants.

(vii) Where work on an oxygen system is to be performed in a confined space within the aircraft, adequate ventilation must be provided to prevent a high concentration of oxygen.

(viii) Pipe and component connections should be wiped clean and dry if contamination is present.

(ix) One of the most serious hazards with oxygen is the penetration of the gas into clothing which can take place when a person has been exposed to an oxygen-rich atmosphere. In this state an infinitesimal particle of hot ash from a pipe or cigarette, can ignite the clothing which will immediately burst into a fierce flamc. Clothing which has been saturated by oxygen should be kept away from naked lights or any other source of heat until a period of a quarter of an hour has elapsed, or until thorough ventilation with air has been effected.

(x) A clean area, with bench surfaces and tools free of dirt and grease, should be used whenever it is necessary to carry out work on oxygen system components.

5.4.1 The following general procedures and precautions should be followed when handling, testing and cleaning any part of an oxygen system:—

(i) Clean, white, lint-free cotton gloves should be worn by servicing personnel.

(ii) Before installing a component it must have been cleaned in accordance with the cleaning instructions laid down in relevant manuals (see also paragraph 5.10). In order to avoid contamination, protective/blanking caps should not be removed until immediately before the installation of the component. When the caps are subsequently removed, the fittings of the component should be checked to ensure they are clean and free of contaminants e.g. flaked particles from protective caps.

(iii) Shut-off valves should always be opened slowly to minimise the possibility of heat being generated by sudden compression of high pressure oxygen within the confined spaces of valves or regulators. Particular attention must also be paid to any torque values specified for valve operation.

(iv) Before uncoupling a connection the oxygen supply must be turned off. Connections should be unscrewed slowly to allow any residual pressure in the line or component to escape.

NOTE: If a cylinder valve is not completely closed, or is leaking, and there is a time lag after bleeding a line, sufficient oxygen pressure could build up in the line to become potentially dangerous.

(v) Certain components are stored in polythene bags which should not be opened until immediately prior to installation. If a bag containing a component has been torn or unsealed during storage, the component should be re-cleaned.

(vi) All open pipe ends or component apertures should be kept capped or plugged at all times, except during installation or removal of components. Only protection caps or plugs designed for the purpose should be used (see also paragraph 5.5.3. (viii)).

(vii) On replacement of a component requiring electrical bonding or power supply connections e.g. an electrical pressure transducer, the circuit should be tested (see also Leaflet **EEL/1-6**).

(viii) For leak testing, only those solutions specified in the relevant manuals must be used. Care must be taken to prevent a solution from entering any connection, valve or component. All tested parts must be wiped clean and dried immediately (see also paragraph 5.7).

(ix) For the testing of components, clean dry filtered air or nitrogen may be used instead of oxygen. On completion of the tests, components should be purged with breathing oxygen.

NOTE: Guidance on the requirements for gases to be used for testing is given in Appendix "C" to British Standard 2N 100.

5.5 **Components.** The following paragraphs detail some of the procedures and precautions generally applicable to the installation and maintenance of the principal components comprising oxygen systems. Reference should always be made to the approved Maintenance Manual relevant to a specific aircraft and system for full details.

5.5.1 **Cylinders.** The handling and transportation of cylinders requires that extreme care be exercised at all times. They must not be allowed to fall over, or be knocked or jarred against hard or sharp objects, or against each other. On no account must they be rolled from a truck or trolley directly onto the ground.

(i) Rapid opening of valves to allow a sudden release of oxygen under pressure from the outlet connections should be avoided. This applies particularly to cylinders which do not incorporate a pressure reducing valve. Apart from the fire risk, the reaction from the pressure discharge can cause an insecurely held cylinder to become a dangerous uncontrollable object.

(ii) Cylinders must be checked to ensure that the date of the last pressure test (see paragraph 5.8) has not expired and that the storage pressure is not below the minimum specified in the relevant manual. A pressure of 200 to 300 lb/in^2 is typical.

(iii) Where specified, it is necessary to carry out tests to ensure that there is no leakage of oxygen from the seats and spindle glands of cylinder valves.

(iv) Control valves and, where appropriate, pressure regulators and gauges, are fitted by the cylinder manufacturers and no attempt should be made to remove them during service.

(v) The exterior of cylinders should be checked for signs of corrosion and damage such as dents, cuts, gouging, or marking by metal stamps other than that prescribed by the manufacturer on defined areas of the body. If the acceptability of a cylinder is in question after making these checks it must be withdrawn for more detailed inspection and overhaul.

(vi) Checks on threads of connections should be carried out to ensure they are clean and free from damage. Thread lubricants should not be used (see also paragraph 5.6). Protective caps should remain on the connections until a cylinder is ready for installation and should be replaced immediately a cylinder is removed.

(vii) During installation of cylinders a check must be made that they are properly aligned with their respective pipelines before finally tightening cylinder clamps and pipe connecting unions.

(viii) After installation, cylinder valves should be slowly opened to pressurise the high pressure lines, and a leak test carried out at the cylinder connections and any other connections which may have been opened. On satisfactory completion of a leak test, cylinder pressures should be checked and recharging to normal system pressure carried out where necessary (see also paragraph 5.12) and valves should be wire locked in the open position.

(ix) If cylinders are inadvertently discharged below the minimum specified pressure, condensation will occur. Cylinders in this condition should be identified for special action when re-charging (see also paragraph 5.12.2 (vii)).

5.5.2 **Chemical Oxygen Generators.** Unexpended generators should be handled with extreme care to prevent inadvertent removal of the firing pin. A blanking cap is normally fitted over the pin and this should remain in position until the generator is finally installed and the lanyard is tied to the disconnect ring of the mask. If a generator should become activated it should be immediately placed on a non-combustible surface.

(i) A minimum clearance of $\frac{3}{8}$ inch must exist between a generator and its heat shield to allow proper cooling when the generator is activated.

(ii) Oil or grease must not be used to lubricate the hinges or latch mechanism of a service panel door.

(iii) When closing the door of a service panel it should be checked that the hoses between the generator and masks will fold without kinking or twisting.

5.5.3 **Pipes and Fittings.** Pipes and fittings should be inspected for damage, cleanliness and signs of corrosion. If a pipe is damaged or deformed it should be removed and a new pipe fitted. The security of pipe attachments such as "P" clips, support brackets, etc., and the conditions of electrical bonding connections should be checked.

(i) Only pipes and fittings designated for use with oxygen and cleaned by an approved method must be installed (see also paragraph 5.10).

(ii) Clearances between pipes and aircraft structure should be in agreement with those specified in the relevant aircraft manuals and installation drawings, otherwise damage may be caused by vibration. Particular care is necessary to ensure clearance between pipes and moving parts such as aircraft control rods, and levers.

(iii) Before making a connection it is important to verify that any loose parts which may form part of the connection such as nipples and filters, are properly positioned and that any identification (e.g. filter notice or direction of flow) relating to the connection is clearly shown.

(iv) Pipes and fittings should align with each other and with components such as cylinders, valves, etc., and be assembled without using undue force, and no gap should exist between the fittings.

(v) Pipes should, in the first instance, be positioned and only partially coupled (i.e. turning union nuts through one or two threads) to each other or components as the case may be. The alignment of the tubes should then be adjusted for optimum clearance, and the tubes partially secured to the structure by the appropriate attachment method. Commencing at either end of the pipe run, the union nuts should be backed off and a check made on the seating of the fittings. If satisfactory, union nuts should be re-fitted and tightened and the pipe attachments finally secured.

(vi) Torque values specified for a particular oxygen system should be strictly observed when tightening the fittings. A fitting should never be overtightened to effect a seal or to establish a proper electrical bond; loosen the fitting and retorque it several times, if necessary, until the seal or bond has been established.

(vii) When tightening or disconnecting a pipe coupling, a second spanner should be used as a back-up to prevent rotation of the fitting to which the pipe union is attached.

(viii) If a section of the pipeline system is left open or disconnected during installation or removal, clean blanking caps must be fitted to open lines, fittings or parts to prevent contamination of the system. In connection with the application of blanking caps, the following points should be particularly noted:—

(a) Plastic caps should only be used on plain sections of pipes, e.g. flareless pipes. Plastic caps should not be re-used.

(b) Where caps are to be fitted to threaded unions or fittings they should be of the metal type.

(c) Plugs which can be jammed into pipes should not be used.

(d) Metal caps may be re-used after cleaning in accordance with an approved method.

(e) Blanking caps should be sealed in polythene bags and should not be opened until ready for use. After opening, the bags should be re-sealed immediately to prevent contamination of unused caps.

(ix) During installation and removal of thermal compensators care must be taken not to separate the connector couplings and nuts. The elements should not be rotated within unions since damage to the wire bristles and jamming of the element may result.

(x) Flexible hoses should not be twisted, kinked or collapsed during installation. In some aircraft, flexible hose assemblies are used in both the high and low pressure systems and these can be connected to standard pipe connectors. Care must, therefore, be taken to ensure that the hoses are not interchanged.

(xi) On completing the installation of pipes a leak test must be carried out on all relevant connections and fittings (see also paragraph 5.7). If a connection leaks, a check should be made that the specified torque values were used in tightening. If the leak persists, using the specified torque value, the connection should be re-opened and inspected to find the cause. Defective pipes or fittings should be replaced by serviceable items.

5.5.4 **Masks.** The procedure for the installation of masks depends largely on whether they are of the plug-in type or automatic drop-out type, and full details should, therefore, be obtained from relevant manuals. In general, the following points should be observed during installation and maintenance:—

(i) Masks should be properly stored without kinking or twisting of the hoses.

(ii) Masks and hoses should be free from cracks, breaks and other damage or deterioration. Plug-in couplings should be checked for proper insertion and removal.

(iii) Stowage compartments should be inspected for cleanliness and general condition.

(iv) Reservoir bags, where used in service panels, must be correctly positioned and folded to ensure efficient drop-out.

(v) Masks should be cleaned and disinfected before installation, and also whenever the oxygen system has been used, and at the periods specified in approved Maintenance Schedules (see also paragraph 5.10.1 (vii)).

5.6 **Thread Lubrication.** With the exception of teflon sealing tape to specification MIL-T-27730, it is recommended that the application of any other lubricants or anti-seize compounds to the threads of pipe or component connections be avoided. The tape, which contains a lubricating compound, should be applied to all except the first two threads of male fittings, and not more than three wraps of tape should be used. The tape should be wrapped in a direction opposite to the running thread; any excess should be trimmed off.

NOTE: All traces of previous tape should be removed from threads and extreme care must be taken to prevent debris from entering the oxygen system.

5.7 **Leak Testing.** Whenever a system component e.g. cylinder, pipe or regulator, etc., has been removed, re-installed, or the system has in any way been disconnected, tests for leakage should be carried out. The system pressure should be at its normal maximum value.

5.7.1 Leaks should be located using a leak detecting solution free from any combustible substances unless, of course, particular leaks are large enough to be heard or felt. Solutions recommended for this purpose are those conforming to specifications MIL-L-25567 "B" and MIL-L-25567 "C" Type 1.

5.7.2 The solution should be applied with a soft brush and the suspected connections checked for signs of frothing or bubble formation. After testing, all traces of solution must be removed by a thorough rinsing with clean water and drying with a soft lint-free cloth.

5.7.3 Where it may be necessary to check a leak-rate (e.g. through a valve) a leak-rate tester should be used. A simple tester consists of a flexible tube into which has been inserted a length of ¼ inch bore glass tube. To check a leak-rate, the free end of the flexible tubing is fitted over the outlet to be tested whilst the glass tube is immersed one inch below the surface of water in a glass jar. The leak-rate can then be calculated from the number of bubbles passing through the water. Eight bubbles are considered equal to 1 c.c. therefore eight bubbles per minute would show a leak-rate of 60 c.c. per hour.

NOTE: Where very accurate leak-rate measurement is necessary, special leak-rate testing instruments are available and should be used as appropriate.

5.8 **Pressure Tests.** Pressure testing of oxygen cylinders is required at stated periods (e.g. every four years) normally indicated in the relevant manuals and schedules. The date of pressure test is usually stamped on the neck ring of a cylinder or painted on the top hemispherical portion.

NOTE: The dates of any previous pressure tests should not be over-stamped or obliterated.

5.9 **Flow Testing.** Where the testing of flow rates is required at various points in a system (e.g. at mask socket connections) special oxygen flowmeters should be used in accordance with the manufacturer's instructions. These flowmeters generally consist of a float inside a glass cylinder graduated for the appropriate flow ranges in litres per minute.

5.10 **Cleaning.** Cleanliness is of the utmost importance in the installation and maintenance of an oxygen system since contamination can provide noxious or toxic fumes to the user, prevent system components from operating properly, or cause fires and explosion. Contamination of the exterior surfaces of components may also cause fires in the presence of leaking oxygen and possible sources of ignition (e.g. electrical equipment). In addition to observing the handling precautions noted earlier in this Leaflet, it is necessary for cleaning operations to be performed at certain stages of installation and maintenance procedures.

5.10.1 Details of the methods to be adopted, the solvents to be used, and periods at which cleaning is to be carried out are given in relevant manuals, drawings and schedules and reference should always be made to these documents. The following paragraphs detail certain important aspects applicable to cleaning operations generally.

(i) For external cleaning of components and pipelines after testing and installation, and at specified inspection periods, a clean, lint-free cotton cloth should be used moistened, if necessary, with the approved solvent.

(ii) Pipes and fittings should be cleaned by a vapour degreasing process. After cleaning, pipes must be washed through with boiling water followed by a thorough flushing with demineralised water, and finally purged and dried (see paragraph 5.10.1 (iv)).

(iii) Thermal compensator assemblies where required, should be cleaned by either an ultrasonic or vapour degreasing process.

(iv) After cleaning, pipes, fittings or components should be purged and dried with clean dry nitrogen, clean, dry, water-pumped air, or breathing oxygen. Particular attention should be paid to the evaporation of degreasing fluid from reverse or "U" bends in pipes. When thoroughly dry, all openings should be blanked by the appropriate type of blanking caps (see also paragraph 5.5.3 (viii)).

(v) Air which has been compressed by an oil-lubricated compressor must not be used unless it has passed through an oil separator, dehydration unit or filter system specifically designed to ensure clean air for use with oxygen components. Compressed air can be checked for freedom from oil or water by allowing the air to impinge on to a clean mirror held at about 45 degrees to the air stream. The mirror should remain clean and dry. If a deposit does appear, warming the face mirror will evaporate the water and any oil will remain on the surface.

(vi) If components or fittings are not to be used immediately after cleaning they should be individually sealed in polythene bags. The bags should be identified as to their contents and also contain the date on which the parts were cleaned and sealed.

(vii) Oxygen masks should be cleaned by a mild solution of soap, or other detergent product, and warm water. The solution should be applied to facepieces with an absorbent cheesecloth or sponge applicator. After cleaning, all traces of solution should be removed with clean warm water and the masks dried with cloth or allowed to air-dry. An approved disinfectant should then be applied from an antiseptic spray or an aerosol can.

NOTE: When cleaning crew masks, microphones should be removed to prevent contact with cleaning solutions.

5.11 **Functional Testing.** The functional testing of systems "in-situ" should be carried out at the periods specified in approved Maintenance Schedules and whenever a component has been changed. The methods of conducting tests, and the equipment required, vary between types of systems and reference should always be made to the relevant manuals for full details. In general, the methods include tests for leakage (see also paragraph 5.7), flow checks at mask connections and, where appropriate, the simulation of the automatic drop-out action of masks.

5.12 **Charging of Oxygen Systems.** For the charging of oxygen system cylinders, breathing oxygen to British Standard N3 must be used. Oxygen produced for other applications, e.g. welding, may contain excess water which could freeze in and obstruct pipelines, regulators and valves of the oxygen system.

5.12.1 To facilitate the charging procedure, the oxygen is supplied in large transport cylinders at a pressure of 3,600 lb/in², several of which are interconnected and mounted in a special oxygen servicing trolley. The pressure is reduced to between 1,800 and 1,900 lb/in² for charging purposes by a regulator consisting basically of a manually adjustable reducing valve and a shut-off valve. The regulator is mounted in the servicing trolley together with pressure gauges which indicate the transport cylinder pressure and the charging pressure. A special oxygen high pressure hose for connecting the trolley to the aircraft's charging point completes the basic equipment.

NOTE: An oxygen servicing trolley must never be used for the charging or testing of systems and components designed for operation by compressed air or other gases.

5.12.2 Before charging a system, reference should be made to the relevant aircraft Maintenance Manual to determine any special procedures to be adopted for the particular system, and also to the operating instructions appropriate to the type of servicing trolley. In addition to the safety precautions referred to in paragraph 5.4 of this Leaflet, the following points which apply generally to charging should be observed:—

(i) The servicing trolley and aircraft should be properly bonded.

(ii) The operation of ground power units should not be permitted in the vicinity during charging operations.

(iii) The aircraft and servicing trolley hose charging adaptors and servicing panels, where appropriate, should be scrupulously clean both internally and externally.

(iv) Before coupling to the aircraft, the charging hose should be purged by slowly opening the trolley shut-off valve to produce a low pressure flow of oxygen in the hose.

(v) Care should be taken when coupling the hose and aircraft coupling adaptors since, in many instances, the adaptors have a left-hand thread.

(vi) Charging valves and cylinder valves must be opened slowly and pressures allowed to stabilise. Servicing trolley and aircraft system pressure gauges should be continuously monitored to ensure that excessive pressures are not applied and to prevent high cylinder temperatures.

(a) Charging graphs are located at the servicing points of many types of aircraft and the maximum permissible charging pressure should be determined from the graphs, after having checked the ambient temperature in the vicinity of the aircraft cylinders.

(b) In charging a system that incorporates manual temperature and pressure compensation adjustments, the dials should be set to the most restrictive setting, i.e. that corresponding to the lower pressure of the system and to the lower value of ambient temperatures in the vicinity of the aircraft cylinders. This will ensure that a conservative rate of charging is applied and that the maximum pressure is not exceeded.

(vii) If a cylinder has been emptied, contamination resulting from moisture can develop (see paragraph 6). In such cases, the cylinder should be blanked off either by closing its shut-off valve or by using blanking caps. It should be removed and suitably identified as requiring purging before recharging.

NOTE: Depending on the degree of exposure to moisture, it may be advisable to examine a cylinder for internal corrosion.

(viii) On completion of charging, the trolley shut-off valve and aircraft charging valve should be closed and the pressure in the aircraft system allowed to stabilise. A check should then be made on the cylinder pressure gauges and other system gauges if fitted, to ensure that the cylinders are fully charged.

(a) Trolley hose adaptors should always be removed slowly from the aircraft charging adaptor to dissipate any trapped pressure.

(b) Aircraft charging adaptor blanking caps must be checked to ensure that they are scrupulously clean before re-fitting.

6 OXYGEN CONTAMINATION

6.1 At specified periods, or if for any reason the system is thought to be contaminated, the oxygen should be tested and if necessary the system purged. Purging should always be carried out if it is known that a system is empty.

6.2 The main cause of contamination is moisture in the system and this may be due to damp charging equipment, charging of cylinders when their pressure is below a certain minimum value, and the small amount of moisture contained in breathing oxygen may, due to repeated charging especially in very cold weather, also cause contamination.

NOTE: In some cases it has been known for the system to freeze due to the presence of moisture, thus restricting the flow of oxygen.

6.3 Although the introduction of moisture into the aircraft oxygen system can be considerably reduced by using the correct charging procedure, cumulative condensation in the system cannot be entirely avoided. There have been instances where oxygen systems, unused for long periods, have developed an unpleasant odour which necessitated purging to clear the system of moisture.

6.4 **Oxygen Moisture Tests.** To test the moisture content of oxygen in the aircraft system a hygrometer, based on the dew-point principle, is normally used.

6.4.1 By determining the dew-point (i.e. the temperature at which the gas becomes saturated) of the oxygen and referring this to a conversion chart the moisture content of the oxygen can be established.

6.4.2 The type of apparatus normally used depends on a flow of oxygen (at a constant rate and pressure) impinging on the surface of a mirror, the temperature of which is gradually lowered (e.g. by means of carbon dioxide) until a film of moisture is formed on the mirror thus determining the dew-point.

NOTE: Breathing oxygen dew-point is −40°C at 300 lb/in^2 with a flow rate of 15 litres per minute. This corresponds to a moisture content of 0·0056 grammes per cubic metre at Standard Temperature and Pressure.

7 SOLDERING If soft soldering or silver soldering is required on any part of an oxygen system it is important that only specified materials are used, particularly in the case of fluxes. After soldering, or silver soldering operations have been completed, it is of the utmost importance to ensure that all traces of flux or scale are completely removed by thorough cleaning. A trace of flux or a minute piece of scale inside a pipe or component could cause an explosion when in contact with high pressure oxygen. Resin-based soldering fluxes should never be used for soldering nipples, connections, etc. on oxygen system pipes.

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AIRCRAFT

SYSTEMS AND EQUIPMENT

AUXILIARY POWER-UNITS

1 INTRODUCTION Auxiliary power-units (APUs) are employed in many types of transport aircraft, their purpose being to provide a source of electrical power and pressurized air (e.g. for air conditioning and main-engine starting) thereby rendering aircraft less dependent on ground support equipment. Operation of an APU is based on a small turbine engine which, not infrequently, is left running unattended for prolonged periods between flights. In addition, the installation design of some systems may require in-flight operation of an APU. The integrity and satisfactory operation of APUs must, therefore, be ensured by regular monitoring, and by observing maintenance practices which, in many respects, are similar to those applied to the main power-units of an aircraft.

1.1 This Leaflet outlines typical constructional features of APUs and also provides guidance on their operation, installation and maintenance. As relevant details can vary between types of unit and aircraft, the information is of a general nature only. The Leaflet should, therefore, be read in conjunction with the Maintenance Manuals and other approved documents for the APU concerned, and for the type of aircraft in which it is installed. Reference should also be made to the following Leaflets which contain certain relevant information:—

AL/3-8 Fire—General Precautions
AL/3-9 Fire Detection Equipment
AL/3-10 Fire Extinguishing Equipment
AL/3-23 Pressurization Systems
AL/3-24 Air Conditioning
EL/3-10 Turbine Engines
EL/3-12 Turbine Engines—Starter and Ignition Systems

2 GENERAL DESCRIPTION An APU is a self-contained unit which, generally, consists of a small gas turbine engine coupled to a gearbox which provides the means for driving a generator of a similar type and power rating to the generator driven by each of the main engines of the aircraft. The gearbox also drives the APU accessories such as the fuel pump, oil pump, tachometer generator and a centrifugal switch. The purpose of the centrifugal switch is to control the starting and ignition circuits, the governed speed indication circuit and the overspeed protection circuit of the APU (see also paragraph 3.3).

2.1 **Location.** An APU is located in an unpressurized compartment of the fuselage of an aircraft, usually in the tail section. The compartment is separated from the remainder of the fuselage by a firewall and the unit is secured to the fuselage structure by rubber-bonded anti-vibration mountings. Access to the compartment is normally via hinged cowling panels positioned either one at each side of the compartment, or a single panel at the bottom of the compartment.

2.2 **Air Supply.** Air for the APU compressor is drawn in through either single or twin intakes, connected, via ducting, to the APU intake section. Doors are provided in the intake sections of most APU installations, and are normally opened and closed by electric actuators; the actuator circuits are interconnected with the APU master control switch to ensure the correct operating sequence during starting and shut-down. In one type of aircraft the doors are operated by a pneumatic ram, the air supply being controlled via an electromagnetic valve energized from the APU control system. Door positions are indicated by indicator lights which, depending on the installation, are connected to either micro-switches, or proximity switches at the door locations.

2.2.1 The APU compressor discharges air into a plenum chamber which is connected, via ducting, to the air conditioning system and the main-engine air-starting system of the aircraft. The bleed air thus supplied, is automatically regulated to provide the correct amount without overloading the APU. The bleed-air system of some types of APU is also designed to by-pass air not required by the aircraft, into the engine exhaust duct. In addition to supplying bleed air, the plenum chamber also serves to distribute air to the engine combustion system, in which a mixture of air and fuel is burned to drive the turbine.

2.3 **Fuel Supply.** Fuel is supplied to the APU from one of the tanks in the main fuel system of the aircraft via a solenoid-operated valve, and is regulated by a fuel control unit which controls the acceleration of the APU and maintains the speed by proportioning fuel flow to load conditions.

2.4 **Lubrication.** Lubrication of all gears and bearings within an APU is provided by a self-contained system consisting of an oil tank, pump, filter, cooler, oil jets and associated supply lines. Monitoring of system operation is effected by indicator lights and instruments associated with such functions as oil pressure, quantity and, in some cases, oil temperature.

2.5 **Starting and Ignition.** Rotation of the engine for starting is accomplished by an electric starter motor connected to a drive shaft in the accessories gearbox. The motor is normally powered by the aircraft batteries and, in some instances, power may also be obtained from an independent APU starter battery. The ignition system is of the high-energy type (see Leaflet **EL/3-12**) and is controlled from the master control switch, and via the centrifugal switch (see paragraph 3.3).

2.6 **Cooling.** Cooling and ventilation of the APU compartment is normally provided by a fan driven by the APU accessories gearbox. Air is also ducted from the fan for cooling the a.c. generator and APU lubricating oil.

2.7 **Anti-icing.** In some types of APU the air intake area is protected against ice formation by bleeding a supply of air from the compressor and using it to heat vulnerable surfaces.

2.8 **Fire Detection and Extinguishing.** The detection and extinguishing of a fire in an APU compartment is normally accomplished by a continuous-wire detection system and a single-shot fire extinguisher (see Leaflets **AL/3-9** and **AL/3-10**). In some aircraft having a centre rear-mounted main engine, the fire extinguisher installation for that engine is also designed to discharge into the APU compartment in lieu of an independent extinguisher system. Detection circuits are so arranged that, in addition to actuating warning lights and/or warning horn systems, they automatically shut down the APU. The extinguishant is discharged by manually-operated switches on the appropriate APU system control panel. In one particular installation, discharge also takes place automatically whenever the detection system is activated.

2.9 **Controls and Indicators.** All switches, warning lights and indicating instruments necessary for the starting, stopping and normal operation of an APU are located on control panels in the flight compartment and in fuselage compartments accessible from outside the aircraft. An APU can normally only be started from the flight-compartment control panel, although in some installations, provision for starting is also made at a fuselage compartment panel. Shut-down of an APU is accomplished from either of the panels (see also paragraph 3.4).

2.9.1 Operation of an APU is monitored by an exhaust gas temperature indicating system, and, in the majority of installations, an hourmeter or an elapsed time indicator, the latter instruments recording the number of hours an APU has been in continuous operation. Depending on the installation, provisions for monitoring APU starting current, engine rev/min, generator output voltage and frequency, generator bearing temperature, and connection of an APU test set may also be included.

3 APU OPERATION The operating characteristics of an APU are such that the possibility of injury to personnel and damage to aircraft and associated equipment exists. It is, therefore, necessary in the interests of safety to observe certain precautions, and to carry out checks prescribed for the particular APU installation.

3.1 **Precautions.** The following precautions are those which, in general, must be observed. Additional precautions appropriate to specific operating or maintenance tasks are outlined in the relevant paragraphs of this Leaflet.

(a) As with any type of turbine engine operating under ground-running conditions, danger zones are created around the air intake and exhaust unit of an APU. These zones should, therefore, be kept clear of personnel, loose debris and equipment. The area of danger zones varies with the type of engine and the location of the APU, and reference should be made to the appropriate manuals for details of zone clearances.

(b) During operation, an APU has a high noise level; maintenance personnel should, therefore, wear appropriate types of ear-protection devices, when working in close proximity to a unit.

(c) In some installations, prolonged ground operation of an APU in high ambient temperature conditions may cause an extreme build-up of temperature in the APU compartment, and in any adjacent compartment. Reference should, therefore, be made to the relevant aircraft Maintenance Manual for details of any operating limitations or procedures which may make it necessary for compartment cowlings or access doors to be left open.

(d) Fire extinguishers should be positioned adjacent to the aircraft during all ground-running operations of an APU.

(e) When an APU is used for pressurization tests, it must be ensured that smoke masks are available for use by personnel within the aircraft, in the event of fire.

(f) A communication link should be established between ground crew members outside the aircraft and at the APU control panel in the flight compartment, to ensure safe operation of the APU. In most types of aircraft, this is facilitated by the provision of headset jackplug points connected to the intercommunication system of the aircraft.

NOTE: An APU may be cleared to run unattended, subject to the provision of various automatic shut-down facilities (see paragraph 3.4.1) or that the possibility of hazardous failure occurring is extremely remote.

(g) The height of an APU location from the ground varies between types of aircraft, but normally it is such that a fall from a workstand, or platform, could result in a person sustaining serious injuries. Stands or platforms must, therefore, permit adequate freedom of movement by personnel, and must be equipped with protective rails.

(h) Before attempting any work on an APU 'in situ', the power supply to the unit must be isolated by opening the circuit breaker and placing the master control switch in the OFF or STOP position. The circuit breaker and switch should each be placarded to the effect that work on the APU is being performed.

(j) In some aircraft, bleed air from the APU is supplied to the leading-edge flap control system. Before starting the APU or before operating the bleed valve, a check should, therefore, be made to ensure that the flap control system will not be inadvertently operated.

(k) When working on an APU located in a compartment below the rudder of an aircraft, personnel should keep clear of the rudder. A notice should be displayed in the flight compartment warning personnel not to operate the rudder controls while work is being undertaken on the APU.

(l) The electrical energy stored in the ignition system of an APU is potentially lethal and certain precautions are necessary before carrying out any work on system components. The power supply to the system should be switched off, the circuit breaker tripped, and at least 3 minutes allowed to elapse before touching the high-energy ignition unit, high tension lead or igniter plug. After disconnecting an HT lead the complete discharge of the capacitors in the high-energy ignition unit should be ensured by immediately grounding the ignition lead.

(m) Air intake doors must remain closed when APU operation is not required and on occasions prior to the use of de-icing fluids around the tail area of an aircraft.

(n) An APU should be allowed to operate at 'no-load' governing speed for approximately two minutes prior to shut-down.

(o) After shut-down, sufficient time should be allowed for an APU to cool down before carrying out any work on the unit.

3.2 **Pre-starting Checks.** In addition to observing the precautions outlined in paragraph 3.1, it is necessary to carry out certain checks on an APU and its installation, before starting. The following checks are those which are generally applicable:—

(a) Ensure that there is sufficient fuel available in the relevant tanks of the aircraft to supply the APU for the period of ground running required.

(b) Check the quantity of oil in the lubricating system against the dip stick and, where appropriate, against the oil quantity indicator. Replenish the tank as necessary. The tank should not be overfilled, otherwise oil may be forced into the engine exhaust casing to cause exhaust smoke, carbon deposits and lowering of system performance.

NOTE: Oil must be to approved specifications detailed in the relevant Maintenance Manuals. Any substitution, use of non-approved lubricants, or mixing of brands may be harmful.

(c) Ensure that there are no fuel or oil leaks.

(d) Check all overboard drains to ensure that they are open.

(e) Remove all covers and blanks.

(f) Ensure that the appropriate source of d.c. power is available, and check that the fuses and circuit breakers of all systems associated with APU operation are intact and closed.

(g) Note the battery voltage and ensure that it is not below the minimum specified for starting (a typical value is 23 V).

(h) With d.c. power on, check that indicator lights are illuminated as appropriate to the APU installation. A check should also be made on indicating devices associated with automatic shut-down circuits, to ensure that they are clear of relevant warnings.

(j) Note and record the outside air temperature, and the hours run as indicated by the hourmeter.

(k) Check the fire detection system for serviceability, and also check the fire extinguishing system to ensure that the extinguisher is in a charged condition.

3.3 **Starting Procedure.** The sequence of starting an APU is fundamentally the same for all types of unit, and is initiated by either a toggle- or push-type master control switch on the APU control panel in the flight compartment of the aircraft. When the control switch is operated, the air inlet doors are opened, and the APU engine is 'motored up' to a speed at which the fuel and ignition system controls are activated. After ignition, or 'light up', has taken place, the engine with the assistance of the starter motor, begins to accelerate to its governed speed. At a certain percentage of the governed speed (typical values are from 35 to 50%) the circuit to the starter motor is automatically interrupted by the centrifugal switch, and the motor is disengaged from the driving gear. The engine continues to accelerate under turbine power until at 95% of governed speed, the centrifugal switch interrupts the ignition circuit and combustion becomes self-sustaining. Acceleration then continues until the no-load governed speed is reached. Governing of speed and bleed-air load is carried out by a sensing system which automatically meters the fuel supply to the engine in response to variations in speed and exhaust temperature. The APU should be allowed to run at its no-load governed speed for one minute before selecting bleed-air and electrical loads. If the speed regulation system fails, an overspeed sensing circuit is activated (normally at 110% of governed speed) by the centrifugal switch, and automatically shuts down the APU.

3.3.1 Careful monitoring of APU behaviour throughout the complete starting and operating procedure is vital for the purpose of detecting failure to 'light up', and in particular, the detection of high exhaust gas temperature when a load is applied in the governed speed condition.

(a) If 'light up' does not occur, or the APU does not reach governed speed within the time specified for the relevant unit, the master control switch should be selected to the OFF or STOP position. Before attempting to re-start, sufficient time should be allowed for excess fuel to drain overboard. The number of successive attempts to start should not exceed that specified in the relevant aircraft Maintenance Manual. In addition, the specified duty cycle of the battery should be strictly observed to ensure that batteries and APU starter motors are not overheated. If an APU fails to start after the specified number of attempts, the fault should be investigated and rectified.

NOTE: After setting the master control switch to its OFF or STOP position, it should not be returned to the starting position until the APU engine has ceased running. Damage to the starter motor and drive is possible if they are engaged with a rotating engine.

(b) When an APU is operated at governed speed, the exhaust gas temperature indications should be carefully monitored to ensure that specified limitations are not exceeded regardless of load applied. In the event of limitations being exceeded, the electrical and/or bleed-air load should be shed as soon as possible and the APU shut down. The fault should then be investigated and rectified as appropriate.

3.4 **Shut-down.** An APU is normally shut down by allowing it to operate at no-load governed speed for approximately two minutes, and then selecting the OFF or STOP position of the master control switch located at either of the two control panels.

3.4.1 Depending on the type of APU and its installation requirements, shut-down of an APU can also take place automatically as a result of any one of the following conditions:—

(a) Overspeed.

(b) High exhaust gas temperature.

(c) Loss of exhaust gas temperature signal to the electronic control system.

(d) Low oil pressure.

(e) High oil temperature.

(f) APU fire detection system operation.

(g) Opening or closing of cooling air shut-off valve before 95% of governed speed has been attained.

(h) Overheating of the APU bleed-air delivery duct just forward of the APU compartment.

(j) When specified airspeed or altitude limitations are exceeded.

(k) Operation of landing gear shock-strut micro-switches on take-off.

3.4.2 In some installations, the APU can also be shut down in an emergency by using a FIRE switch on the control panels, or by pulling a FIRE handle on the flight compartment panel. When using a FIRE switch, the fire extinguisher discharge circuit is armed, and care must be taken to prevent inadvertent discharge of extinguishant.

3.4.3 After an automatic shut-down has occurred, the master control switch should be selected to the OFF or STOP position. The reason for the shut-down should then be determined and appropriate remedial action taken.

NOTE: In order to indicate which circuit or system has caused a shut-down, most APU installations incorporate appropriate indicating devices, e.g. magnetic 'doll's eye' type indicators.

4 INSTALLATION The procedure to be adopted for the installation of an APU varies between types of aircraft, and reference should always be made to the relevant Maintenance Manuals for precise details. Certain aspects are, however, of a common nature and these are given in the following paragraphs.

4.1 **Pre-installation Checks**

(a) Circuit breakers relevant to the APU and its systems should be open, and the master control switch selected to the OFF or STOP position before installation. The switch should be placarded to the effect that work on the APU installation is being undertaken.

(b) Dirt and foreign matter which may have accumulated within the APU compartment should be removed. Sound proofing, heat-shields and any fireproofing seals should be checked for security and possible oil soakage.

(c) Mountings, attachment fittings and structural attachment points should be checked for damage and general security.

(d) Air intake and other ducting should be checked for security, signs of damage, and freedom from obstruction.

(e) The APU cooling fan should be checked for freedom of movement and signs of damage to blades.

(f) All blanking caps and plugs should be removed from APU connections within the APU compartment.

(g) Pipelines and drains should be checked to ensure that they are undamaged and free from obstruction.

(h) Cable harness assemblies and components associated with the APU electrical circuits, e.g. starting, ignition and generator, should be checked for security of attachment and for signs of damage to insulation and connectors.

(j) On satisfactory completion of all requisite checks within the APU compartment, the APU itself should be checked to ensure that it is undamaged and is complete. Inhibiting fluid should be drained out.

4.2 **Installation**

(a) The installation of an APU is carried out by means of a hoist and cable assembly which, for many types of aircraft, is supplied as an item of ground equipment. If an alternative type of hoist assembly is to be used, it must be ensured that the hoist is capable of adequately supporting the weight of the APU.

(b) Hoists should be connected to the attachment points normally provided in the APU compartment, and, with the APU and its mounting stand, or 'dolly', positioned below the compartment, the hoist cables should be connected to the 'slinging' points on the APU.

(c) After taking up slack in the hoist cables, the APU should be released from its attachment points on the stand, or 'dolly', and then hoisted into its compartment. During hoisting it must be ensured that the APU clears all obstructions to prevent damage to compartments and aircraft structure.

(d) The APU should then be carefully manoeuvred into alignment with its mountings and appropriate ducts, and the mounting bolts inserted and torque-tightened to within their specified limits.

(e) The hoist assembly and cables should be disconnected and removed, and all requisite mechanical and electrical connections should be made in accordance with the procedures specified in the relevant Maintenance Manual.

(f) In installations employing electrically-actuated air inlet doors and an exhaust door, the air inlet doors should be driven to the closed position before connecting the flexible shaft to the exhaust door, otherwise the actuator jack shafts will hit their internal stops, resulting in damage to, or failure of, the flexible shaft. Care must be taken to keep hands away from door areas when doors are in operation.

(i) Door-actuating gearbox shafts must be properly indexed with door torque shafts to ensure that the correct opening and closing relationship is obtained.

(g) The APU fuel system should be bled (see also paragraph 5.2.6), and the oil tank contents should be checked and replenished as necessary.

4.3 **Inspection and Tests**

4.3.1 On completion of the procedures in paragraphs 4.1 and 4.2, a post-installation inspection should be carried out to ensure that:—

(a) Pipelines, ducts and cables have adequate clearance to prevent fouling or chafing.

(b) Pipelines are not kinked or twisted.

(c) All mountings, connections, fittings and clamps are secure, and also that they have been made 'safe' in accordance with the appropriate installation requirements.

(d) The sensing element of the fire detection system is correctly routed and connected to its associated warning circuit.

(e) All tools, equipment, spilled fluids, loose hardware and debris have been removed from the APU compartment.

4.3.2 On completion of the installation procedures, the APU should be started, and appropriate functional tests and adjustments carried out.

5 INSPECTION AND MAINTENANCE The frequency at which inspection and maintenance of an APU is to be carried out is given in the aircraft Maintenance Schedule, and details concerning the procedures to be adopted, type of test equipment required, and any precautions to be observed, are contained in the appropriate Maintenance Manuals. It is essential, therefore, to refer to these documents at all times. The information given in the following paragraphs, although based on some typical installations, is intended to serve only as a general guide.

NOTE: Details of all tests, adjustments, and abortive starting cycles, should be recorded in the APU log book or record card.

5.1 **Inspection.** The inspection of an APU may be considered under two main headings: (a) external inspection and (b) 'hot end' inspection.

5.1.1 **External Inspection.** This inspection comprises visual checks for security and signs of damage to the APU and all its components, pipelines, electrical cables, etc., which are externally mounted.

5.1.2 **'Hot end' Inspection.** This inspection is one requiring checks on the combustion system, turbine assembly and exhaust unit of the engine of an APU for signs of excessive carbon deposits, cracking, erosion, blade rubbing and heat distortion. The checks, which are most indicative of a critical engine condition having occurred, may normally be carried out 'in situ', by removing such items as the combustion chamber and the turbine torus assembly, and also by means of borescopes inserted through inspection ports. Permissible limits associated with the checks are given in the relevant Maintenance Manual together with illustrations to show the probable location and extent of cracks and other damage.

5.2 **Maintenance**

5.2.1 **Proof Test.** This test is carried out after the installation of an APU and, where specified, after changing certain components.

(a) Before starting, all necessary precautions relevant to the ground running of an APU must be observed, and the appropriate pre-starting checks carried out (see paragraphs 3.1 and 3.2).

(b) During the starting procedure (see also paragraph 3.3) the following should be noted and recorded:—

(i) Reduction in battery voltage (a typical minimum value is 18 V).

(ii) Time taken for the engine to 'light up'.

(iii) Maximum exhaust gas temperature and its duration, e.g. 760°C for 15 seconds.

(iv) Engine speed at which the starter motor is disengaged from the engine. This check is normally applicable only to those installations which incorporate an indicator light in the starter motor circuit.

(v) Engine speed at which the oil pressure warning light, where appropriate, goes out.

(vi) No-load governing speed and exhaust gas temperature.

(c) With the APU running at its no-load governing speed, check that there are no fuel, oil or air leaks.

(d) If the APU is a new one, it should be shut-down after five minutes running at no-load governing speed and the oil and fuel filters changed.

(e) With the APU supplying bleed air to the air conditioning system, the latter should be checked for proper functioning, and the APU checked for stable operation under load. Exhaust gas temperature indications should be monitored to ensure that the specified maximum is not exceeded.

(f) The bleed air supply for main-engine starting should be checked by selecting a main engine and allowing the APU to 'blow' the engine for 30 seconds. The stability of APU operation under these conditions should also be checked.

(g) The APU generator output voltage and frequency should be checked to ensure that they are within the specified limits; typical values are respectively 200 ± 4 V and 400 ± 4 Hz. This check should be carried out with the APU also supplying bleed air to the air conditioning system.

(h) On completion of the foregoing checks, the APU should be shut down, and the 'run down' time recorded from the moment of setting the master control switch to OFF or STOP. Checks should be made that there are no abnormal noises coming from the APU and that drainage from fuel drains is not excessive.

(j) With the engine stationary, a check should be made that there are no oil or fuel leaks.

5.2.2 **Adjustments.** Various adjustments are required after an APU has been installed, and whenever a control system component has been changed. The nature of the adjustments, which are carried out with the aid of appropriate test sets, depends on the type of APU and as already indicated in paragraph 5, the procedures detailed in the relevant manuals must be followed. Some of the adjustments commonly required, and typical methods of carrying them out are outlined in the following paragraphs.

(a) **Exhaust Gas Temperature.** The purpose of this adjustment is to ensure that the APU engine is operated within its proper maximum gas temperature limits. The adjustment is normally required after installing an APU and after installing such components as a fuel control unit, thermocouple and harness assembly, load control valve, and electronic temperature control unit. The APU is started, and, after allowing it to run at no-load governed speed for one minute, the bleed-air and electrical loads are selected. A check is then made on the exhaust gas temperature, and, if it is necessary to bring it within the specified operating range, adjustments are made by turning a screw-controlled potentiometer on the temperature control unit in the appropriate direction. The directions are normally in the sense, clockwise to decrease and anti-clockwise to increase. Potentiometer sensitivity is typically 22°C for each quarter of a turn of the adjusting screw control.

(b) **Load Control.** This adjustment should be carried out after installation of a load control valve, the purpose of which is to maintain the electrical and bleed-air loads on the APU within the specified limits. The APU is started in the normal manner, and, after allowing it to stabilize at its no-load governing speed, the generator load is switched on and the exhaust gas temperature allowed to stabilize. The full bleed-air load is then selected, and from the moment of selection it should be noted that the time taken for the exhaust gas temperature to rise to its stabilized value on full load is within the specified limits (a typical time is from 18 to 22 seconds). If it is necessary to increase the valve operating rate, the APU should be shut down and the metering valve of the load control valve adjusted accordingly. The foregoing operations should be repeated until the correct valve operating rate is achieved. On satisfactory completion of the adjustment procedure, the adjusting device should be made 'safe' in the appropriate manner.

NOTE: Care must be taken not to over-adjust the valve. In the event that the operating rate is greater than the specified time, the valve should be removed for rectification and re-calibration.

(c) **Surge Control Valve.** This valve operates in conjunction with the load control valve to modulate the bleed-air load and thereby prevent pressure surges, and also prevent stalling of the APU engine compressor. The valve should normally be adjusted after installation of an APU whenever the valve is changed, and whenever there is a reduction of maximum bleed-air load performance or a tendency for the APU to surge. The APU is run at its no-load governed speed, and a check is then made on the difference between the total pressure and static pressure which are sensed by a flow sensor unit in the ducting between the APU plenum chamber and load control valve. Both pressures are supplied to the surge control valve, and measurement is facilitated by connecting a differential pressure gauge (or a test rig manometer) and specially calibrated restrictor assemblies to two test points provided on the valve. Depending on the type of APU, differential pressure limits can vary between 3 and 8 in. Hg. The pressure is adjusted within the specified limits by turning an adjusting screw on the surge control valve in the appropriate direction, i.e. anti-clockwise to increase the pressure differential and clockwise to decrease it. On completion of adjustments, the APU should be shut down, the measuring equipment disconnected, and the blanking caps or plugs refitted to the test points. The APU should then be re-started and checked for correct operation.

(d) **Fuel Control Unit.** Adjustment of a fuel control unit is necessary whenever the unit has been changed, the purpose of the adjustment being to bring the speed of the APU within its prescribed limits. Adjustment is effected by a governor adjusting screw while the engine is running at the no-load governed speed. The direction of screw rotation is normally clockwise to increase speed and anti-clockwise to decrease speed.

(e) **Air Inlet Doors.** These require adjustment each time a door, or part of its actuating mechanism, is changed. Such adjustment is necessary to ensure that doors fair with the fuselage skin and that excessive gaps are reduced or eliminated between doors and frames. On completion of adjustments, doors should be cycled from their fully-closed to their fully-open positions, and back to closed. During cycling, a check should be made to ensure that the doors do not interfere with other components or parts of the airframe structure. The time taken for doors to fully open, and close, should also be checked.

(f) **Proximity Switches.** In some APU installations, a proximity switch is provided at each air-inlet door location. Each switch consists of two components which are so designed that when in very close proximity they complete a circuit to a 'door open' indicator light. During checks on door operation, the clearance between the components and switches should also be checked as their respective doors near the fully-open position. If a clearance is not within the specified limits, the position of the switch component mounted on the appropriate inlet door, should be adjusted.

5.2.3 **'Motoring'.** 'Motoring' refers to the procedure of rotating the APU engine compressor and turbine by means of the starter motor only; it can be either 'wet' or 'dry' depending on whether relevant maintenance checks are to be carried out with or without a flow of fuel to the engine. In both cases, the times specified for starter motor operation must not be exceeded. During 'wet motoring' a fire hazard is created as a result of fuel passing through drains and into the engine exhaust unit. All appropriate safety precautions must, therefore, be strictly observed.

5.2.4 **Starter Motor.** At the periods specified in the approved Maintenance Schedule, the brushes of the starter motor should be checked for wear, by measuring the distance from the tops of the brush holder caps to the tops of the brushes. Brush assembly leads should also be checked for discoloration and security. If wear exceeds the limit specified in the relevant Maintenance Manual, or if the leads are discoloured, the starter motor should be removed for the fitting of new brushes and subsequent 'bedding-in' procedures. Before refitting the clamping strap around the brush and commutator end of the starter body, any accumulation of brush residue should be removed by means of clean, dry, low-pressure compressed air.

5.2.5 **Lubrication System.** The following paragraphs outline some of the checks normally required during routine maintenance of the lubrication system.

(a) **Oil Changing.** When it is necessary to change the oil, draining of the system should be carried out while the oil is at, or near, its normal operating temperature. The drained oil should be examined for the presence of metal particles. A similar examination should also be made on the oil filter and the magnetic chip detector of the oil tank drain plug. If any particles are found, the engine should be inspected before replenishing with fresh oil, to determine the extent of any damage and the remedial action to be taken.

(i) A new filter element and housing gasket should be fitted (see (b)) and, after refitting the oil tank drain plug, the tank should be replenished with fresh oil to the same specification as that of the oil drained from the system (see also paragraph 3.2 (b)). The lubrication system should then be primed, and, after 'dry motoring' for 30 seconds, the APU should be started and run at 'no-load' governed speed for 3–5 minutes in order that the oil pressure indications may be monitored and the oil system may be checked for leaks.

(ii) If the tank is replenished with another type of approved oil, then, after running the engine for approximately 5 minutes, the tank should again be drained and the oil checked for metal particles or other contaminants. If the oil is uncontaminated, the tank should be replenished and the engine started and run for approximately 15 minutes; during this period the oil pressure and temperature should be carefully monitored. If either the oil pressure or temperature fluctuates, the entire draining and replenishing procedure should be repeated until fluctuations cease.

(b) **Filters.** Filter elements should be inspected and renewed whenever the oil is changed and also at the periods specified in the relevant aircraft Maintenance Schedule. Filter housings should be cleaned with the specified solvent and dried with clean, dry compressed air, but housing seals should be discarded and replaced by new seals, which should be coated with a specified lubricant. Before fitting a new filter element, it should be dipped in oil to the same specification as that used in the system. After installation, the oil level should be checked and the tank replenished as necessary. The APU should then be run in order to check for oil leaks. After the APU has been shut down, a further check on the oil level should be carried out.

(c) **Oil Pumps.** Oil pumps are normally designed for mounting on a pad of the APU accessory gearbox, but in some types of APU the pump may be submerged in the oil tank. In the latter case, pump removal and replacement cannot be accomplished as a single unit operation.

(i) Whenever a pad-mounted pump is installed, a new seal should be fitted between the pump and gearbox drive. After installation, the oil system should be primed, and, after 'dry motoring' for 30 seconds, the APU should be started and run at 'no-load' governed speed for 3–5 minutes in order that the oil pressure indications may be monitored, and the system may be checked for oil leaks. After the APU has been shut down, the oil level should be checked and the tank replenished as necessary.

(d) **Chip Detector Plugs.** Plugs should be removed and examined for traces of metallic particles. If particles are found, the cause should be investigated and remedial action taken in accordance with the procedures set out in the relevant Maintenance Manual.

(i) Plugs should be washed in clean kerosene and dried with clean, dry compressed air, before refitting. Where appropriate, a new seal, lightly coated with lubricant, should be fitted to a detector plug before it is installed.

(ii) The magnetic strength of a plug should also be checked against the weight of ferrous material it will lift; a typical weight is half an ounce.

5.2.6 **Fuel System.** Some of the checks normally required during routine maintenance of the fuel system of an APU are outlined in the following paragraphs.

(a) **Bleeding.** Bleeding of the system should be carried out on the following occasions: (i) after installation of an APU, (ii) whenever it is suspected that air leaks in the system are causing difficulties in starting, and (iii) after removal and replacement of such fuel system components as filters, pumps, fuel control units and fuel supply lines. Bleeding is carried out by connecting an overboard drain line, or special bleed tool, to the appropriate discharge port, and 'motoring' the APU until 'solid' streams of fuel are observed flowing from the drain line. The APU ignition system must be isolated during bleeding, and the times specified for starter motor operation must not be exceeded. Whenever the fuel tank supplying the APU has been drained, or the low pressure system between the tank and APU has been opened, the relevant section of the aircraft fuel system should be bled in the manner appropriate to that system.

(b) **Fuel Atomizer.** Whenever a fuel atomizer assembly is suspected of causing erratic combustion, and also prior to the installation of an assembly, its functioning should be checked. Briefly, this check is carried out by setting up the assembly in a test rig, and then observing the conical spray pattern of the fuel as it is pumped through the atomizer at varying pressures. The fuel is allowed to spray into a spray basin, while the angular limits of the pattern are referenced against a protractor. The pattern should always be steady and even. If any abnormalities appear in the spray pattern, such as sudden changes in spray angle, fluttering, bubbling, discontinuity or solid jets of fuel, the atomizer assembly should be rejected and sent for rectification.

5.2.7 **Ignition System.** High-energy ignition units should be inspected to ensure that they are undamaged and show no signs of corrosion. This also applies to igniter plugs but, in particular, these must be inspected to ensure that the ceramic insulation is not chipped or cracked, and that burning, or erosion of the central electrode and outer shell is within the limits specified in the Maintenance Manual. Whenever a high-energy ignition unit or an igniter plug has been changed, the functioning of the complete ignition system should be checked by energizing the power supply circuit to the system. When the necessary switches are selected, operation of the system will be heard as regular clicking noises from the igniter plug as electrical discharges occur.

NOTE: Before energizing the power supply circuit, it must be ensured that the APU engine fuel system is isolated, and that there is no possibility of fuel or fuel vapour being ignited. If, after the functioning check, it is necessary to change an ignition system component, sufficient time must be allowed for all electrical energy to decay before handling any component (see also paragraph 3.1(l)).

AL/7-1

Issue 3

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AIRCRAFT

STRUCTURES

INSPECTION OF METAL AIRCRAFT AFTER ABNORMAL OCCURRENCES

1 INTRODUCTION

1.1 Aircraft are designed to withstand flight and landing loads within specified limits; these limits are calculated to allow for all normai manoeuvres and exercises which may be undertaken by that aircraft, and include safety factors to allow for unforeseen circumstances. If design limits are exceeded due to abnormal occurrences, the integrity of the structure may be jeopardised and safety impaired. Any report or evidence on the aircraft which suggests that the design limits have been exceeded or equipment damaged should, therefore, be followed by a careful inspection appropriate to the nature of the occurrence and in accordance with the Approved Maintenance Manual.

1.2 The types of occurrence which may lead to structural damage are considered in the following paragraphs, but these should be considered as a general guide and not as a complete list; additional inspections may be required on some aircraft, and these will be described in the appropriate manuals. Inspections peculiar to helicopters are described in paragraph 7 of this Leaflet, and some guidance on the inspection of wooden aircraft structures is given in Leaflet **AL/7-9**.

1.3 **General.** The appropriate aircraft Maintenance Manual and other relevant literature, such as Service Bulletins, should be consulted to ascertain the particular inspections which are necessary, and the areas where damage has been known to occur in similar circumstances on aircraft of the same type. The aircraft should then be viewed for obvious damage such as distortion or twisting of the main structure, before carrying out the detailed inspections applicable to the particular incident.

1.4 The repairs necessary, if damage is found during inspection, are outside the scope of this Leaflet, and reference should be made to Leaflet **AL/7-14**, and to the manufacturer's Overhaul and Repair Manuals.

1.5 The subject headings are as follows:—

1.6 Related CAIP Leaflets:—

AL/3-23 Pressurisation Systems
AL/7-9 Inspection of Wooden Structures
AL/7-12 Rigging Checks on Aircraft
AL/7-14 Repair of Metal Airframes

2 HEAVY OR OVERWEIGHT LANDINGS

2.1 An aircraft landing gear is designed to withstand landing at a particular aircraft weight and vertical descent velocity. If either of these parameters is exceeded during a landing, then it is probable that some damage may be caused to the landing gear or its supporting structure. Overstressing may also be caused by landing with drift or landing in an abnormal attitude, e.g. nose or tail wheel striking the runway before the main wheels.

2.2 Some aircraft are fitted with heavy landing indicators, which give a visual indication that specified 'g' forces have been exceeded, but in all cases of suspected heavy landings, the flight crew should be consulted for details of aircraft weight, fuel distribution, landing conditions, and whether any noises indicative of structural failure were heard.

2.3 The damage which may be expected following a heavy landing would normally be concentrated around the landing gear, its supporting structure in the wings or fuselage, the wing and tailplane attachments and the engine mountings. Secondary damage may be found on the fuselage upper and lower skin and structure, and wing skin and structure, depending on the configuration and loading of the aircraft. On some aircraft it is specified that, if no damage is found in the primary areas, the secondary areas need not be inspected; but if damage is found in the primary areas, then the inspection must be continued.

2.4 Because of the number of factors involved, it is not possible to lay down precise details of the inspections which must be made after any incident, on any type of aircraft, but a preliminary inspection should normally include the items detailed in paragraphs 2.5 to 2.10.

2.5 **Landing Gear**

(a) Examine tyres for excessive creep, flats, bulges, cuts, pressure loss, excessive growth, and security of balance weights/patches.

(b) Examine wheels and brakes for cracks, other damage, and fluid leaks.

(c) Examine axles, struts and stays for distortion and other damage.

(d) Check shock struts for fluid leaks, scoring and abnormal extension.

(e) Examine landing gear attachments for signs of cracks, damage or movement. In some instances this may require removal of certain bolts in critical locations, for a detailed magnetic crack detection test.

(f) Examine structure in the vicinity of the landing gear attachments for signs of cracks, distortion, movement of rivets or bolts, and fluid leakage.

(g) Examine doors and fairings for damage and distortion.

(h) Jack the aircraft and carry out retraction and nose-wheel steering tests in accordance with the approved Maintenance Manual; check for correct operation of locks and warning lights, clearances in wheel bays, fit of doors, and signs of fluid leaks.

2.6 **Mainplanes**

(a) Examine the upper and lower skin surfaces for signs of wrinkling, pulled rivets, cracks, and movement at skin joints. Inertia loading on the wing will normally result in wrinkles in the lower surface and cracks or rivet damage on the upper surface, but stress induced by wing-mounted engines may result in wrinkles on either surface.

(b) Check for signs of fuel leaks, and seepage from integral tanks.

(c) Examine root end fillets for cracks and signs of movement.

(d) Check flying controls for freedom of movement; power-controlled systems should be checked with the power off.

(e) Check balance weights, powered flying control unit mountings and control surface hinges for cracks, and the control surfaces for cracks or buckling.

(f) Where possible, check the wing spars for distortion and cracks.

2.7 **Fuselage**

(a) Examine fuselage skin for wrinkling or other damage, particularly at skin joints and adjacent to landing gear attachments and centre section.

(b) Examine pressure bulkheads for distortion and cracks.

(c) Examine, for distortion and cracks, the supporting structure for heavy components such as galley modules, batteries, water tanks, fire extinguishers, auxiliary power units, etc.

(d) Check that the inertia switches for the fire extinguishers, emergency lights, etc., have not tripped.

(e) Check instruments and instrument panels for damage and security.

(f) Check ducts and system pipes for damage, security, and fluid leaks.

(g) Check fit of access doors, emergency exits, etc., and surrounding areas for distortion and cracks.

(h) Check loading and unloading operation of cargo containers, and condition of cargo restraint system.

(i) Check gyroscopic instruments for erection time, precession and unusual noises.

2.8 **Engines**

(a) Check engine controls for full and free movement.

(b) Examine engine mountings and pylons for damage and distortion. Tubular members should be checked for bow greater than prescribed limits, and cracks at welds. Mounting bolts and attachments should be checked for damage and evidence of movement.

(c) On turbine engines check freedom of rotating assemblies, and on piston engines check freedom of rotation with sparking plugs removed.

(d) Examine engine cowlings for wrinkling and distortion, and integrity of fasteners.

(e) Check for oil, fuel and hydraulic fluid leaks.

(f) Where applicable, check the propeller shaft for shock loading in accordance with the procedure in the Maintenance Manual.

(g) Check propeller attachments and counterweight installations.

(h) Check oil system filters/chip detectors.

2.9 **Tail Unit**

(a) Check flying controls for freedom of movement.

(b) Examine rudder and elevator hinges for cracks, and control surfaces for cracks and distortion, particularly near balance weight fittings.

(c) Examine tailplane attachments and fairings, screw jacks and mountings, for distortion and signs of movement.

2.10 **Engine Runs.** Provided that no major structural distortion has been found, engine runs should be carried out in accordance with the appropriate Maintenance Manual, in order to establish the satisfactory operation of all systems and controls. A general check for system leaks should be carried out while the engines are running, and on turbine engines the run-down time should be checked.

2.11 **Inspection of Damaged Areas.** If any superficial damage is found during the preliminary inspection, the supporting structure should be examined for distortion, loose rivets, cracks or other damage, and rigging and symmetry checks should be carried out; see Leaflet **AL/7-12** to ascertain whether the damage has twisted or warped the main airframe structure. Where flying controls pass through supporting structure, cable tensions should be checked. On pressurised aircraft a cabin leak rate check should be carried out; see Leaflet **AL/3-23** to ascertain whether the sealing of the fuselage is satisfactory and unaffected by the damage.

3 BURST TYRE INCIDENTS

3.1 Tyre failures on large transport aircraft particularly wide-body types, have resulted in serious incidents and accidents. The principal problem is that if one tyre fails, its axle companion becomes overloaded, and sometimes fails. If a tyre bursts during taxying, take-off or landing, fragments of the tyre may fly off the rotating wheel and cause damage to parts of the aircraft in line with the wheel disc. Where single wheels are employed, more serious damage may occur through the wheel rolling on the paved runway and transmitting shocks to the landing gear leg and supporting structure. Multiple wheel landing gears will generally be less seriously affected by a single burst tyre, but the axles, bogies, torque links or steering mechanism may become bowed or strained as a result of the effects of uneven loading. In some cases extensive damage, including fire, has resulted from tyre and wheel degradation and there has been an attendant reduction in braking performance.

3.2 In most cases the wheel on which the burst occurred will generally be damaged and must be returned for overhaul. In addition, the following inspections should be carried out:—

(a) Examine for damage, the wheels and tyres which have not burst.

NOTE: Where one of the tyres on a multi-wheel undercarriage has burst, it may be specified that all tyres on that leg or axle should be discarded, or removed for detailed examination.

(b) Examine the brake units on the affected leg for damage. On those wheels which are not fitted with fusible plugs, the tyre burst may have resulted from overheating caused by a binding brake, and when the replacement wheel is fitted attention should be given to the operation of the associated brake including, in particular, freedom of rotation of the wheel with brakes released.

(c) Examine the landing gear bay for damage and hydraulic fluid leaks.

(d) Examine the affected leg, including pipelines, operating jacks, etc., for damage and hydraulic fluid leaks.

(e) Inspect the supporting structure and attachments of the affected leg, for cracks, warped panels and loose rivets. In some instances it may be specified that certain highly-stressed bolts in the supporting structure or retraction mechanism should be removed for non-destructive crack detection tests.

(f) Examine the adjacent fuselage or wing skinning, and landing gear doors, for damage.

(g) Check rear-mounted engines for possible ingestion of debris.

4 FLIGHT THROUGH SEVERE TURBULENCE

4.1 If an aircraft has been flown through conditions of severe turbulence, the severity of the turbulence may be difficult to assess and report upon, but an indication may be obtained from the accelerometers or fatigue meters fitted to some aircraft. However, these instruments are designed to record steady loads, and force peaks recorded during flight through turbulence may be exaggerated due to instrument inertia, and should not be taken as actual loads. Generally, if readings exceeding −0·5 g and +2·5 g are recorded on transport aircraft, then some damage may be found. With other types of aircraft (e.g. aerobatic or semi-aerobatic), accelerometers and fatigue meters are seldom fitted, and reported flight through turbulence should always be investigated.

4.2 Severe turbulence may cause excessive vertical or lateral forces on the aircraft structure, and the effects may be increased by the inertia of heavy components such as engines, fuel tanks, water tanks, and cargo. Damage may be expected at main assembly points such as the wing-to-fuselage joints, tail-to-fuselage joints, and engine mountings. Damage may also occur in those areas of the wings, fuselage, tailplane and control surfaces where the greatest bending moment takes place, i.e. part way along their length, and may be indicated by skin wrinkles, pulled rivets or similar faults.

4.3 An inspection for damage, after a report of flight through severe turbulence, should include the inspections detailed in paragraph 2, except, in most cases, those covering the landing gear.

NOTE: Further dismantling and, in some cases, removal of some portions of the skin, may be necessary in order to inspect supporting structure where skin damage has been found.

5 LIGHTNING STRIKES

5.1 Lightning is a discharge of electricity between highly charged cloud formations, or between a charged cloud and the ground. If an aircraft is flying, or on the ground in the vicinity of such a cloud formation, the discharge may strike the aircraft and result in very high voltages and currents passing through the structure. All separate parts of an aircraft are electrically bonded together to conduct a lightning strike away from areas where damage may hazard the aircraft, e.g. fuel tanks or flying controls, and during manufacture special precautions are often taken with non-metallic components such as wing tips, external fuel tanks and nose cones.

5.2 Lightning strikes may have two effects on an aircraft; strike damage where the discharge enters the aircraft, and static discharge damage subsequent to the strike. Strike damage is generally found at the wing tips, leading edges of wings and tail unit, and at the fuselage nose, but on some aircraft types other areas may be particularly susceptible, and this information should be obtained from the appropriate Maintenance Manual. Static discharge damage will usually be found at wing tips, trailing edges and antennae.

5.3 Strike damage is usually in the form of small circular holes in the exterior skin, either in clusters or spread out over a wide area, and often accompanied by burning or discolouration, blisters on radomes and cracks in glass fibre. Static discharge damage is usually in the form of local pitting and burning at trailing edges.

5.4 **Inspection.** Since both lightning and turbulence occur in thunderstorms, an inspection for lightning damage will often coincide with an inspection following reported flight through severe turbulence. The areas mentioned in paragraph 5.2 should be examined for signs of strike or static discharge damage, and bonding strips and static discharge wicks should be examined for burning and disintegration. All control surfaces, including flaps, spoilers and tabs, should be inspected for damage at their hinge bearings; unsatisfactory bonding may have allowed static discharge and tracking across the bearings, causing burning, break-up or seizure. A check for roughness and resistance to movement at each bearing, will usually indicate damage at such points. In addition, the following inspections should be carried out:—

(a) Examine engine cowlings and engines for signs of burning or pitting. If a lightning strike is evident, tracking through the bearings may have occurred, and some manufacturers recommend that the oil filters and chip detectors should be examined for signs of contamination; this check should be repeated periodically for a specified number of running hours after the occurrence.

(b) Examine the fuselage skin and rivets generally, for burning or pitting.

(c) If the landing gear was extended when the lightning strike occurred, examine the lower parts of the gear for static discharge damage. Check for residual magnetism and demagnetize where necessary.

5.5 The inspections outlined in paragraph 5.4 should be followed by functional checks of the radio and radar equipment, instruments, compasses, electrical circuit, and flying controls, in accordance with the relevant chapters of the approved Maintenance Manual. On some aircraft a bonding resistance check on radomes may also be specified.

6 DAMAGE FROM JET BLAST

6.1 Considerable damage may be caused to an aircraft through the action of another aircraft turning or taxying in the vicinity. The damage may be caused by blast or impact from debris, and may be particularly severe in the case of light aircraft.

6.2 Flying control surfaces should be inspected for distortion, particularly where they were unlocked and may have been driven hard against their stops.

6.3 An inspection for impact damage in the form of skin dents and cracked or chipped windscreens or windows, should be made, and the air intakes for engines, heat exchangers, etc., should be examined for debris which may have blown into them.

6.4 With light aircraft, further inspections may be necessary to ensure that no structural damage has been sustained, particularly when the jet blast has been sufficiently strong to move the whole aircraft.

7 HELICOPTERS

7.1 The inspections necessary on helicopters following unusual occurrences, are broadly similar to those detailed in the preceding paragraphs, but additional checks are normally specified for the main rotor blades, head and shaft, tail rotor and transmission, following heavy landings or flight through severe turbulence. Inspections are also required following overspeeding of the rotors. The inspections outlined below are typical.

7.2 **Heavy Landings or Flight Through Severe Turbulence**

7.2.1 **Rear Fuselage or Tail Boom.** Examine for evidence of strike damage from the main rotor blades, and if damage is found check for cracks, security and symmetry.

7.2.2 **Main Rotor Blades.** Remove the rotor blades and examine them for twisting and distortion. Check the surface for cracks, wrinkles, or other damage, and check the security of the skin attachment rivets or structural bonding. If the main rotor blades are badly damaged through impact with the tail boom or ground, certain components in the transmission may be shock-loaded, and it is sometimes specified that, for example, the main rotor shaft, pitch change rods, and main gear box mounting bolts, should also be removed for inspection.

7.2.3 **Main Rotor Head.** Disconnect pitch change rods and dampers, and check that the flapping hinges, drag hinges and blade sleeves move freely, without signs of binding or roughness. Examine the rotor head and blade stops for cracks or other damage, and the dampers for signs of fluid leaks. Damage in this area may be an indication of further damage inside the main gearbox.

7.2.4 **Tail Rotor.** Examine the blades for damage and security, and the coning stops for evidence of damage. Damage to the tail rotor blades which is beyond limits, will normally entail either inspection or replacement of the hub, pitch change links, tail rotor gear box and drive shaft.

7.2.5 **Skid Type Landing Gear.** With the helicopter jacked clear of the ground, check cross tubes for excessive bowing, fasteners for integrity and security, and abrasion plates for wear. Where Float Gear is fitted, check for leaks, fabric scuffing, and integrity of attachment straps.

7.3 **Rotor Overspeeding.** The extent of the inspection will normally depend on the degree of overspeeding. Overspeeding below a specified limit will usually entail checking the rotor blades for distortion and damage, and the rotor head for cracks and smooth operation, but, if this limit is exceeded it is usually specified that both the main rotor head and tail rotor head should be removed for overhaul. If damage has occurred to the main rotor blades, the rotor head, shaft, pitch control rods, tail rotor and transmission should also be removed for overhaul, and the gearbox attachments should be inspected for damage.

8 OTHER OCCURRENCES Occurrences not covered in the preceding paragraphs, or peculiar to a particular aircraft type, may necessitate a special inspection, and this is often specified in the appropriate Maintenance Manual. Where no specific instructions exist, experience on the type of aircraft, combined with a knowledge of the structure and stress paths, will normally enable a satisfactory inspection to be carried out. As an example, if the flap limiting speed has been exceeded, the flaps should be examined for twisting and buckling, the hinge brackets on the wings and flaps should be examined for damage such as cracks and strained attachment rivets and bolts, and the operating mechanism should be examined for general distortion, bowing, cracks and security. Provided these checks are satisfactory, and operation of the system reveals no evidence of malfunction, or excessive friction, then the aircraft may be considered airworthy.

AL/7-2

Issue 1

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AIRCRAFT

STRUCTURES

AIRFRAME DESIGN AND CONSTRUCTION

1 INTRODUCTION The structure, or airframe, of an aeroplane or helicopter is designed to carry the loads imposed by the forces of lift, thrust, drag and weight and to do so in such a way that is efficient aerodynamically and yet still permit a commercially viable payload. The object of this Leaflet is to provide a simple introduction to the basic mechanics of an airframe structure and to consider different examples of structural components, the methods of their fabrication and the materials employed. A grasp of such fundamentals is important to an engineer who is responsible for the maintenance and inspection of airframe structures because an understanding of how loads and stress are distributed will provide essential guidance on where to look for problems.

2 BASIC MECHANICS Any structure can be divided into individual elements that will behave in a certain way when loaded in any direction. Generally speaking a simple structure is made up of three types of members, that is, beams, struts and ties. A member subject to bending is known as a beam, one subject to compression as a strut and one subject to tension as a tie. Each will be considered in turn in the following paragraphs.

2.1 The load applied to a member is the force in pounds, kilograms or Newtons, but the most important factor from the point of view of the strength of a member is not the load it has to carry but the relationship between the load and the cross-sectional area of the member. This is called the stress in the member and is measured in pounds per square inch, Newtons per square metre or some other suitable units.

2.2 When a load is applied to a member in a framework it will, to some extent, move under the load. For example, a tie will stretch under load. The vertical movement of the wing tips of a large aeroplane is evidence of the extension and compression of the upper and lower surfaces. This movement under load is called strain. Two statements will summarise this paragraph:

$$\text{Stress} = \frac{\text{Force}}{\text{Area}} \qquad \text{Strain} = \frac{\text{Change of length}}{\text{Original length}}$$

2.3 A beam was defined as a member subject to bending. A beam may be simply supported at the ends, the supports may be in a little way from the ends or it may be supported at one end only, in which case it is termed a cantilever. With any beam, as it takes up its deflected position due to loading, the surface that is on the outside of the bend will be in tension while the surface on the inside of the bend will be in compression. With a solid member there will be a plane in the middle that is neither in compression nor in tension and this is known as the neutral plane, or neutral axis.

2.4 In a simple beam there are two main stresses that are present to cause failure should they rise above the strength of the beam; stress due to bending, caused by the bending moment, and stress due to shear. If a beam supported at the ends is considered and a load is applied in the centre, the bending moment will be greatest in the centre where the load is applied and this is where the beam is most likely to break if the load is increased sufficiently. The bending moment distribution is simply represented on a graph or bending moment diagram (Figure 1(A)). In the case of a cantilever beam loaded at the free end, the bending moment is greatest at the support end, hence if the load is increased the failure would occur at this point (Figure 1(B)). In practice a beam can be tapered to provide a uniform distribution of stress along its length. But a beam is subject to shear as well as bending. This is the force that is trying to slice the beam through. Shear force is greatest near to the points of support and least in the centre of the span in a simply supported beam. In a cantilever beam, shear force does not vary along the length of the beam (assuming that the weight of the beam is neglected).

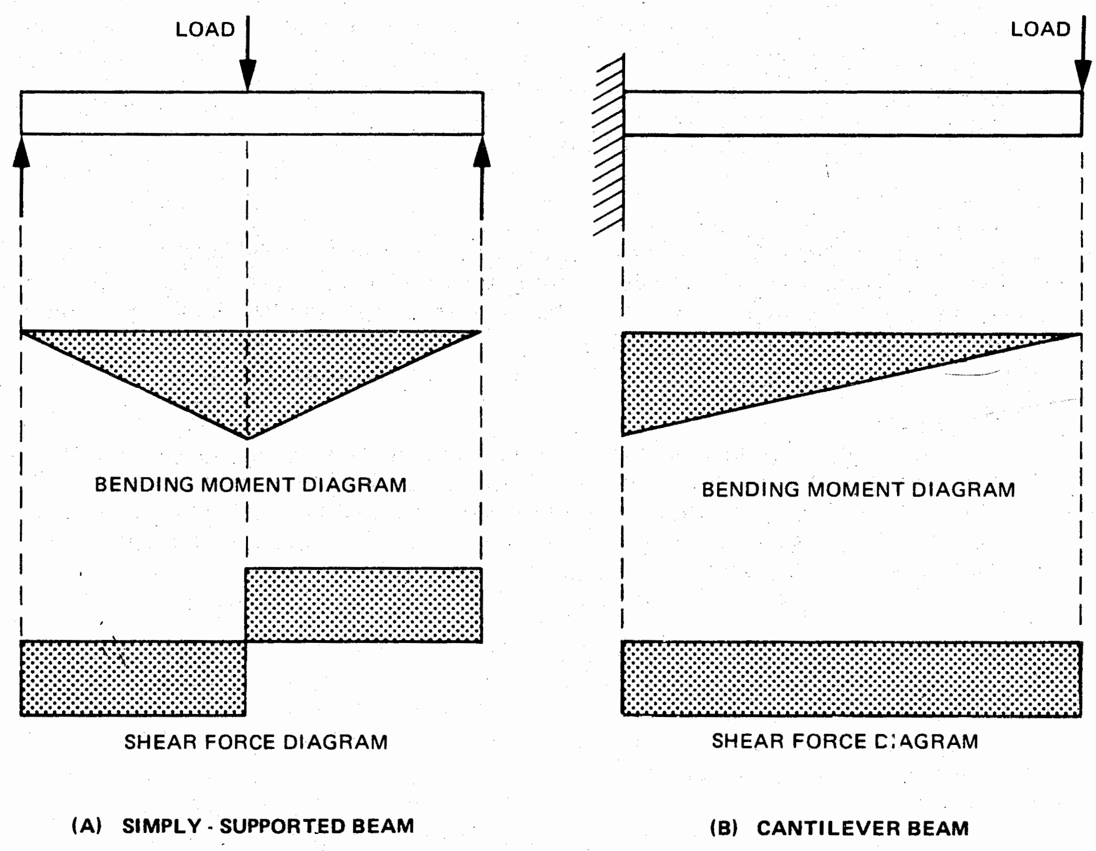


Figure 1 BENDING MOMENT AND SHEAR FORCE DIAGRAMS

2.5 A strut is a member in compression and a tie is a member in tension and it will have been noticed from everyday experience that a strut is usually hollow whereas a tie is often made from a solid rod or even a wire. In practice there are few members that are purely one thing or the other and their design takes into account the different loadings. A wire would make a poor strut because of its liability to bend when an end load is applied. When there is any tendency to bend it has been seen that the greatest stresses will always occur at the outside and at the inside of the bend, with hardly any stress along the neutral plane, or axis. A hollow tube is simply a rod from which the material at the centre has been removed and distributed round the edge. The cross-sectional area of the material is the same and so is its ability to resist tension or compression but its resistance to bending is considerably increased.

2.6 The structure of an aircraft is composed of a mixture of struts, ties and beams and this assembly is known as a framework. The roof truss of a hangar is an example of a framework containing the three structural elements. Figure 2 shows a simple cantilever framework and indicates which members are in tension and compression with the loading shown. In an aircraft structure the vertical members remain in the form of frames but the diagonal members are often replaced by the sheet metal skins. Since a large area of relatively thin sheet metal will not make a good strut it is often necessary for the sheet to be stiffened and reinforced with lighter members, known as stringers, in order to prevent buckling caused by compressive stresses.

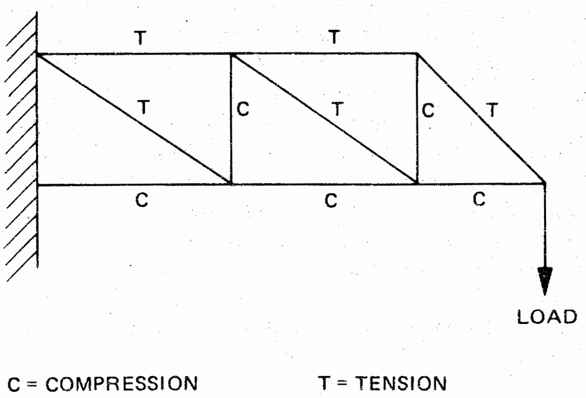


Figure 2 CANTILEVER FRAMEWORK

2.7 In a pressurised aircraft the structure is subjected to stress that derives from the fact that there is a difference in pressure between the inside and outside of the pressurised area of up to 65·5 kN/m^2 (9·5 lbf/in^2). This is known as hoop or circumferential stress (Figure 3). If the pressurised area is considered as a thin-walled cylinder then it can be understood that the internal pressure will tend to expand the cross-sectional area, this expansion creating a tensile load in the circumference of the cylinder. This load and its resulting stress is in addition to the loads deriving from normal ground and flight operations. The internal pressure also acts against the bulkheads at the ends of the pressurised area and creates stress along the length of the cylinder. However, the longitudinal stress is always less than the hoop stress, resulting in a difference in design strength between joints in different directions.

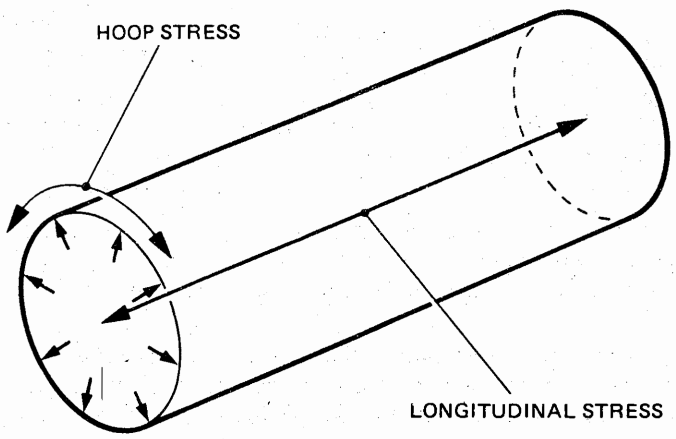


Figure 3 STRESS IN A THIN-WALLED CYLINDER

2.8 When the strength of a structure is being calculated, the main consideration is that of safety. There is no difficulty in making the design strong enough but there is a difficulty in designing a structure that has the necessary strength with a weight that makes the aircraft a viable commercial carrier. For an aircraft it is necessary to have a structure that is as light as possible and yet has sufficient strength to carry all the loads placed upon it. When the strength of a member is being considered it must be remembered that the elastic limit of the material is reached at a lower load than the breaking point, or ultimate strength — the elastic limit being the maximum load a material can carry and still return to its original shape and size when the load is released. So for practical purposes the member must be stronger than the normal working load in the member. In addition, an aircraft structure is subject to vibration, extra loads due to wind gusts and heavy landings and a certain level of general deterioration with age. The relationship between the strength of a member necessary to carry the working load and its ultimate strength is known as the factor of safety. The minimum factor of safety specified in British Civil Airworthiness Requirements is 1·5 with special provisions being made for castings and forgings. On this basis if a part has a working load of 100 pounds it must be designed to carry $(100 \times 1{\cdot}5) = 150$ pounds.

2.9 Large, modern aircraft are designed with a fail-safe structure. This can be described as a structure in which failure of a particular part is compensated for by another part that is able to carry the loads, for a limited period at least. Typically this is a structure which, after any single failure or crack in any one structural member, can safely carry the normal operating loads until at least the next periodic inspection. Examples of this type of construction in practice are the use of multiple spars in wings and tailplanes, instead of the more usual two spar layout, and the use of multiple hinges on control surfaces. It must be remembered that once an initial failure has taken place the redundancy in the structure is no longer present and an inspection programme capable of finding the failure before it progresses too far is essential. This programme is as much part of a fail-safe design as the actual hardware. The inspection cycle is determined on the basis that if a crack of detectable length has been missed at the first inspection, the structure will allow this crack to develop until a second inspection before it becomes critical. The minimum detectable length of a crack is agreed at the time of certification.

2.10 **Flight and Ground Loads.** Most of the parts of an aircraft cannot be simply classified as a strut, a tie or a beam because the loads applied to them can change direction dependent on whether the aircraft is in flight or on the ground. A typical example is the lift strut of a high-wing light aeroplane. It is in fact a strut only when the aircraft is on the ground and it is supporting the weight of the wing. In a heavy landing the compressive loads on the strut are increased considerably. In flight it is no longer a strut but acts as a tie since the lift developed by the wing has reversed the loads. The spar of a helicopter rotor blade will be in tension at the upper surface and in compression at the lower surface with the aircraft on the ground and the rotor stationary. In flight the situation is reversed with the upper surface experiencing the compressive stress. Each part of the aircraft can be treated in the same way for the different conditions of operation and an appreciation gained as to the direction of the loads applied. Such knowledge is useful when inspecting for possible damage. In addition to the loads imposed by lift and weight there are also loads imposed by thrust and drag and, on the ground, manoeuvres such as braking and turning.

2.11 There is another factor to be taken into account when considering the strength of a structure. If the load on a material is repeatedly applied and released, or if it alternates between tension and compression, a phenomenon called fatigue sets in and the material becomes weaker and weaker. Whilst the actual mechanism of fatigue is complex it can be simply demonstrated by repeatedly flexing a piece of metal in alternating directions. Eventually it will fail along the bend line.

3 FUSELAGE STRUCTURES Having outlined the basic mechanics of a structure, consideration will now be given to the way in which a practical airframe embodying these principles is constructed. An ideal airframe would be designed to provide perfect load paths in an efficient aerodynamic shape. However, it is unlikely that the requirements for both of these could be realised at the same time particularly if the aircraft is to carry a commercial load. Since the aircraft is designed as a load carrier the designer starts with the payload (and other operational requirements) and designs an airframe that is a compromise between the ideal and the practical.

3.1 **Fuselage Construction.** The fuselage, whether it be of an aeroplane or helicopter, provides space for the crew and the payload and transmits the weight of these to the lifting surfaces. It also provides the unit through which the reactions of control forces from tail and rotors are felt. In many cases the landing gear is attached to the fuselage and it also absorbs the inertia loading from wings, tail and rotors in the landing phase. Thus, whilst the shape is to some extent dictated by the nature of the payload, there will be well defined load paths through the structure to cater for the loads mentioned.

3.2 The cabin structure illustrated in Figure 4 is typical for a light, pressurised, twin-engined aircraft but it embodies the same principles as are applied to the much larger airliner. The wing panel attaches to the two carry-through spars by means of forgings and special close-tolerance bolts. The front spar is built up from two extruded aluminium alloy channel booms joined together with sheet metal shear webs. The webs are stiffened and reinforced with extruded or rolled angles to prevent buckling under compressive loads. It can be seen that the spar behaves in the same way as the theoretical beam already considered.

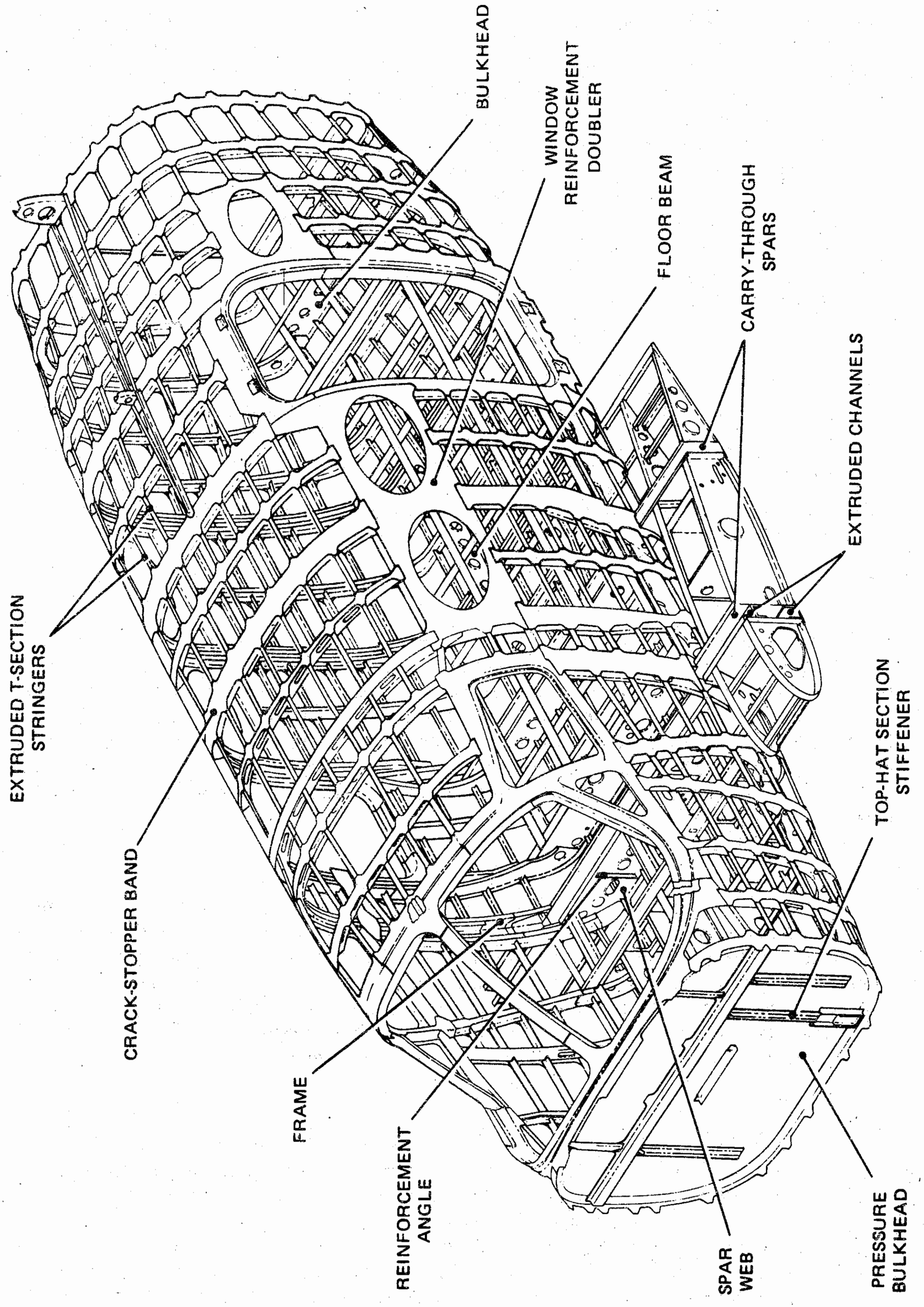


Figure 4 PRESSURISED FUSELAGE STRUCTURE

3.3 Attached to each spar is a heavy gauge frame which not only gives shape to the fuselage but integrates the spar into the rest of the fuselage structure. The frames are the primary members which, with the skin, absorb the stresses produced when the cabin is pressurised (see hoop stress in paragraph 2.7). The lower section of each main frame is joined to a bulkhead which consists of a sheet metal web flanged at the edges. These bulkheads provide the necessary support for the floor panels and hence the payload of the aircraft. The holes through the webs of the bulkheads are flanged or dished in order to stiffen the web. The holes also provide a means of lightening the structure without impairing the strength since it has already been seen that there is relatively little bending stress along the neutral axis of a beam. At each end of the pressurised area there is a pressure bulkhead consisting of a flat sheet filling in the centre area of the end frame. To stiffen the sheet and prevent buckling under the pressurisation loads, top-hat section stiffeners are riveted in place. The frames are joined together longitudinally by stringers which stiffen the skin against buckling. Different stringer cross-sections are used dependent upon the loads involved and the location of the stringer in the structure; typical stringer sections are illustrated in Figure 5. Open-section stringers are normally used in the lowest section of the fuselage, the bilge, in order to facilitate inspection and the drainage of moisture. Both extruded and rolled sections are employed, the former where higher stresses are involved. The frames are also joined together by heavy longitudinal members similar to bulkheads in construction. These are the floor beams and provide the attachments for the seat tracks and the floor panels.

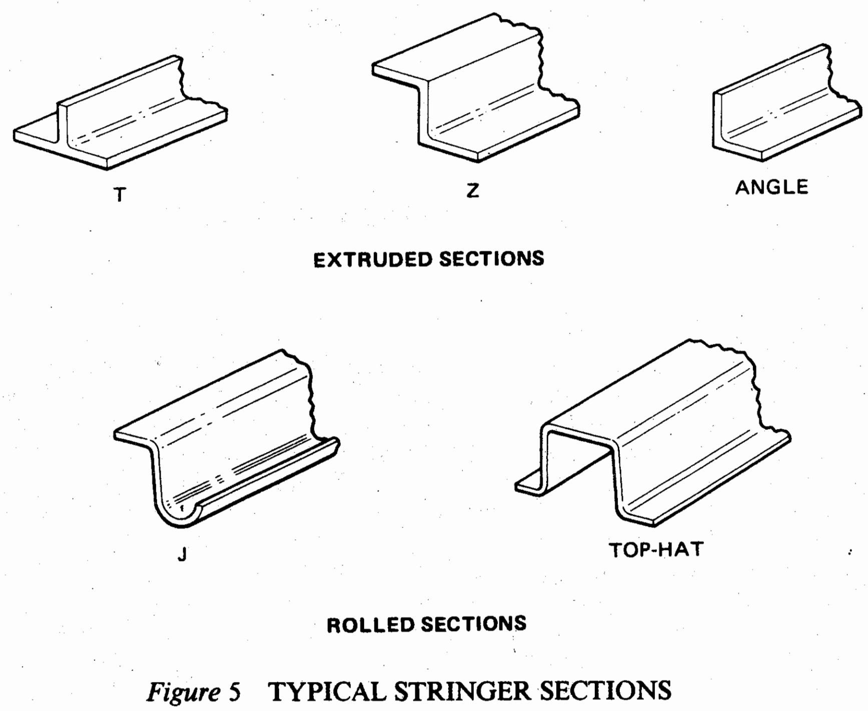


Figure 5 TYPICAL STRINGER SECTIONS

3.4 The structure illustrated in Figure 4 is of a fail-safe design, the integrity of which has been demonstrated during cabin pressure tests by cutting various elements of the structure without total failure of the structure. One fail-safe feature in this airframe example is the provision of crack stopper bands at each frame location between the frame and the skin. A further feature is the provision of reinforcement doublers round each opening in the pressure cabin, such as the cabin door, escape hatch and windows. Another fail-safe design found in some larger aircraft is that the frames and stringers are continuous and are joined to each other by cleats (Figure 6).

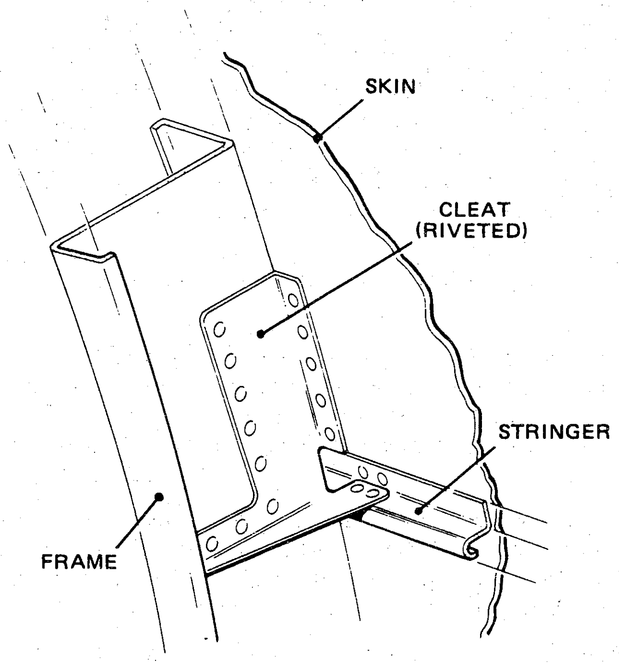


Figure 6 CLEATED CONSTRUCTION

3.5 The helicopter fuselage is built on the same principles as the fuselage for an aeroplane but the loads carried are of a different nature and in different directions. The main structural members in the fuselage illustrated in Figure 7 are the two large I-section floor beams. These beams, tapering at the front and rear, are made up from sheet metal webs with back-to-back extruded angles forming the flanges. The lift forces from the rotor are transmitted through the main gearbox casing and a single lift link into the lift beam. This beam forms the forward face of a vertical box structure which is tied into the floor beams. The side panels of this box structure are removable but are in fact stressed panels forming an essential part of the structure. The tailboom is attached to the rear frame by means of high-strength bolts. The roof structure carries relatively little stress and is made of lighter gauge materials. A helicopter tailboom is illustrated in Figure 8 and is constructed from the same basic components that have been previously described.

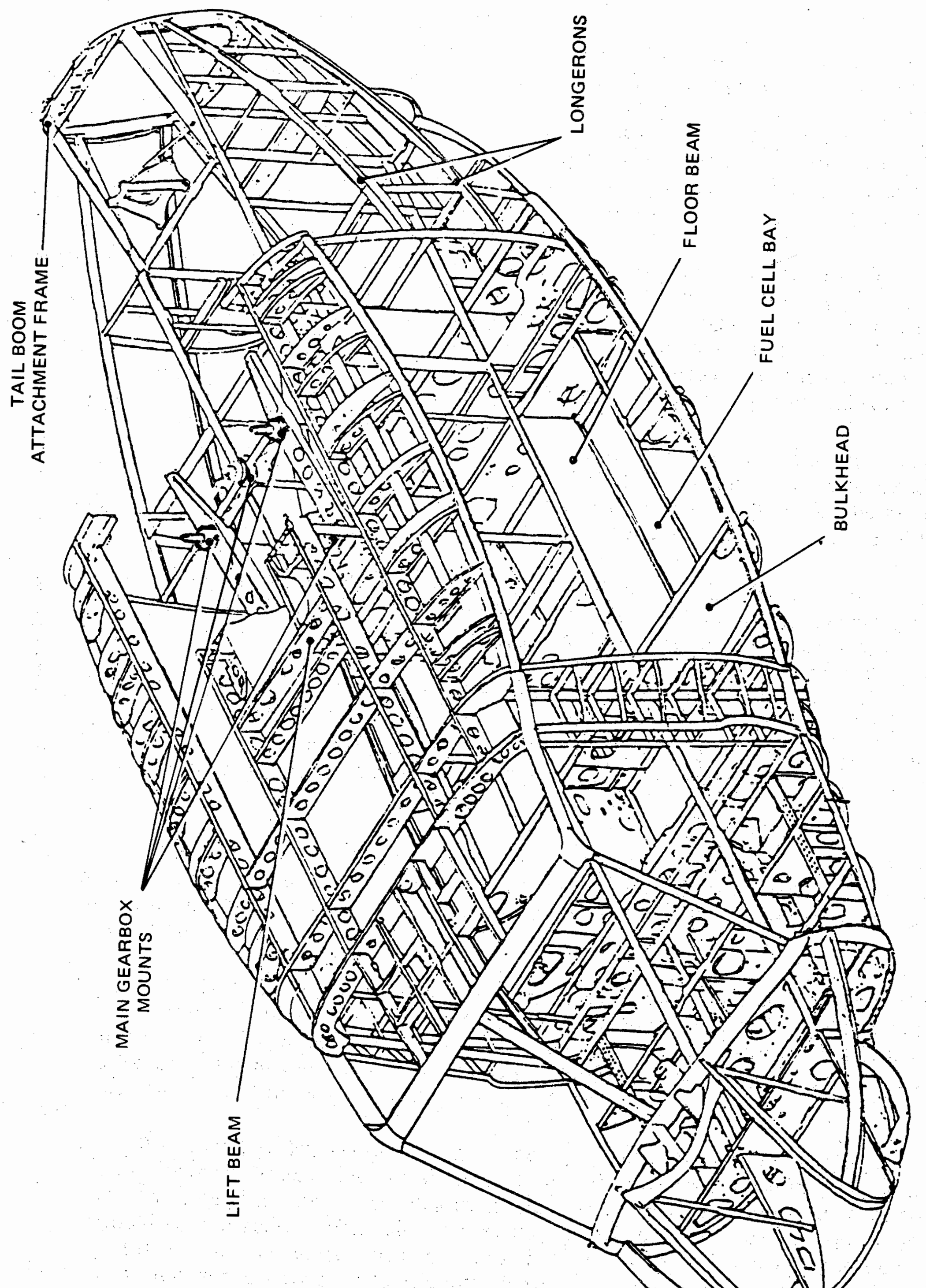


Figure 7 HELICOPTER FUSELAGE STRUCTURE

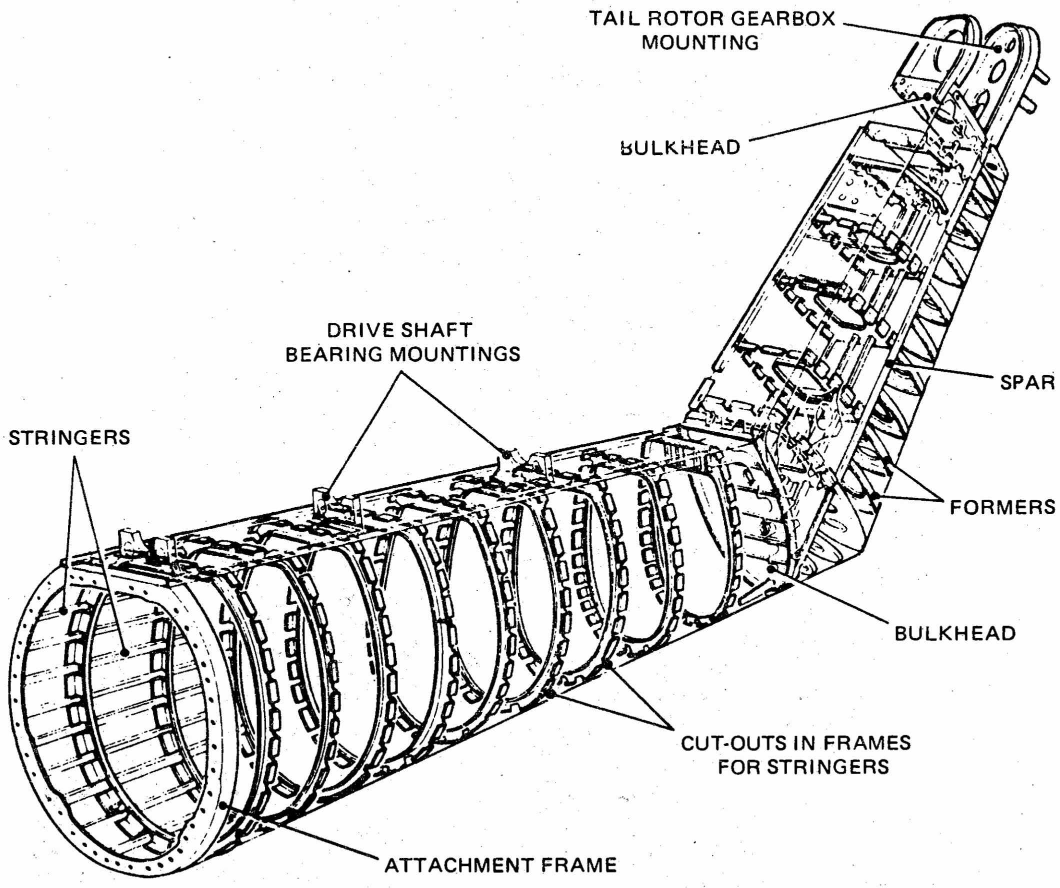


Figure 8 HELICOPTER TAILBOOM STRUCTURE

3.6 Any component of a structure is liable to collect moisture due to spillages, condensation and ingress of atmospheric moisture. This is particularly true of a pressurised cabin, partly due to the pressurisation of the air and partly due to the lower outside air temperatures experienced at the operating altitudes of pressurised aircraft. This being the case it is important that provision is made for adequate drainage. Design for drainage ensures that the open side of horizontal stringers faces downwards and that drain holes are provided at the lowest point of each bay to permit accumulations of moisture to drain to some other compartment and then overboard. Unpressurised aircraft simply use open holes at the lowest points of the structure when in the ground attitude to provide overboard drainage but this is not possible in pressurised areas of the structure. In such areas drain valves are provided that are open when the compartment is unpressurised and closed when pressurised. In their simplest form a rubber diaphram provides both the seal and the means of operation (Figure 9).

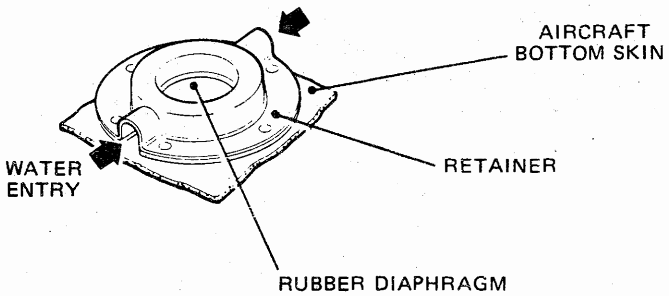


Figure 9 DRAIN VALVE

3.7 **Pressurised Cabin Sealing.** Where an aircraft design embodies a pressurised cabin it is necessary for it to be completely sealed to prevent unintentional escape of the pressurising air. All permanent riveted and bolted joints are sealed on assembly with appropriate sealants on the faying surfaces, and many other parts are sealed with a fillet or bead of sealant along their edges. Fasteners penetrating the pressurised cabin are assembled wet (i.e. dipped in sealant before assembly) and then over-coated on the inside after fastening is complete. Electrical cables passing through a pressure bulkhead are either sealed by specially designed cable connectors or they pass through a nylon collar which is filled with sealant under pressure.

3.8 Cabin doors and emergency exits are normally sealed by inflatable rubber seals, the simplest deriving the inflation air from the cabin through holes in the hollow seal (Figure 10). In a more sophisticated arrangement the seal is pressurised by an independent air supply from the engine air bleeds via a pressure regulator.

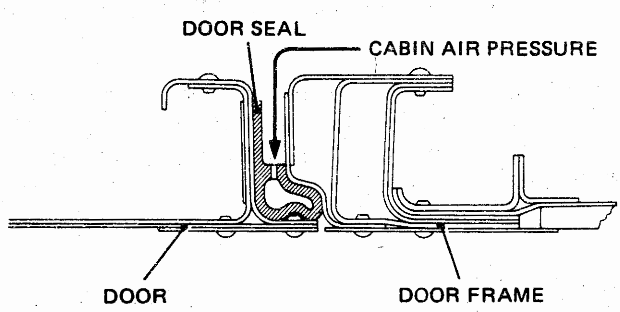


Figure 10 CABIN DOOR SEAL INSTALLATION

3.9 Flying control cables exit the pressurised area through rubber labyrinth seals that are installed in the manner shown in Figure 11. To reduce cable and seal wear, the assembly is packed with grease and it is very important that only the correct grease is used. Some greases contain synthetic products that are not compatible with all seal materials. Where rods are used for operating controls or landing gear, the seals take the form of a convoluted boot attached to the bulkhead and sealed to the rod with a hose clip.

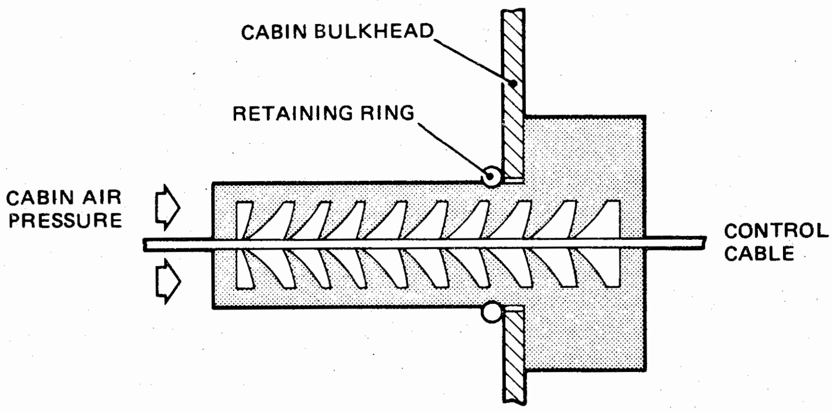


Figure 11 LABYRINTH CABLE SEAL

3.10 It is important to provide adequate access into the various parts of a structure both for inspection purposes and for the maintenance of systems and components contained inside the structure. Panels which are designed for frequent removal are usually fitted with quick-release fasteners and are simple unstressed panels. They are provided with a soft rubber seal to prevent the ingress of moisture. However, many panels used in the aircraft are removed at infrequent intervals and are designed to carry part of the structural load. Such panels will be retained by bolts or high-strength machine screws. Since such panels are structural parts they should not be removed without first ascertaining if the surrounding structure must be supported or if there are limitations on moving the aircraft with them removed. Some may require special sealing techniques on refitting.

3.11 Cabin and freight bay floors may take a variety of forms ranging from a simple reinforced light alloy sheet to fully composite panels. The majority of composite flooring panels are made from a polyimide honeycomb core dipped in phenolic resin and bonded to two glassfibre skins and are able to resist all forms of impact loading and corrosive fluids.

3.12 In wide-bodied aircraft it has been found necessary to provide a floor venting system to equalise pressures rapidly above and below the floor in the event of the loss of a cabin or a cargo compartment door. Without such a venting system major structural distortion can occur leading to disruption of controls and essential services.

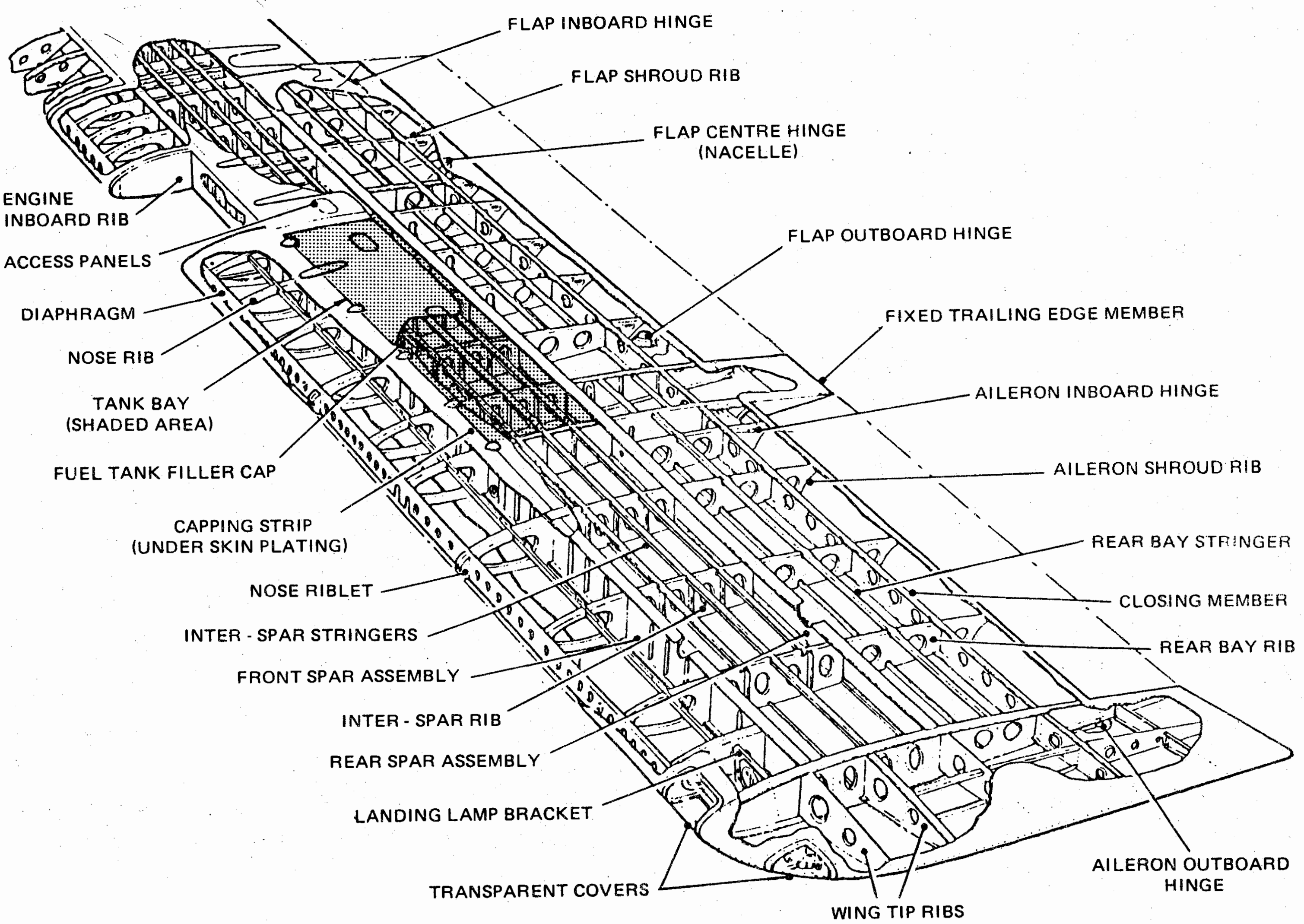
4 AEROFOIL STRUCTURES In both fixed and rotary wing aircraft the purpose of the aerofoils is to provide the lift that makes flight possible. This is also true for auxiliary aerofoils such as tailplanes and synchronised elevators although the lift developed is used for control and stability purposes rather than supporting the weight of the aircraft. It is thus clear that the aerodynamic shape is of paramount importance. But the typical aerofoil is also a cantilever beam and therefore must be designed to support the loads imposed on it taking due consideration of the distribution illustrated in Figure 1(B). In addition to the basic loading produced by the lift developed, there is the dynamic loading produced by gusts, manoeuvres and ground loads such as landing and taxying. The aeroplane wing also provides a convenient place to attach engines and landing gear and an area in which to store fuel. Each of these items has its own effect on the loading of the beam and must be taken into account in the design, the result being a compromise between aerodynamic requirement and structural possibility.

4.1 **Aeroplane Wing Construction.** The cantilever wing of a typical light aircraft illustrated in Figure 12 reveals many of the points mentioned previously. The shear stress being approximately constant along the span, the spars are of constant depth but because the bending moment varies along the span the structure is heavier and stronger at the inboard end. It will be noticed that the ribs are closer together inboard of the engine mounting and become progressively wider apart towards the wing tip. The shaded integral fuel tank area is completely sealed to provide the storage capacity. The use of the wing as a fuel tank has advantages in that it will provide relief of the bending moments to some degree and this is the reason for some aircraft having their main tankage in the wing tips.

4.2 The spars are built up from sheet metal webs and a T-section cap strip. The web is stiffened with vertical angle sections to provide additional resistance to buckling in the space between the ribs. At the inboard end the web is increased in thickness with tapered doublers where the stresses are highest. The basic shape of the wing is controlled by the ribs and in the example shown these are made up of a number of parts riveted to the spars and other members. As in a fuselage, stringers are provided along the span of the structure and are riveted or bonded to the skin in order to stiffen it. The ribs are cut out as necessary in order to provide clearance for the stringers. The skin is riveted to the spars, ribs and stringers and, in addition to closing the structure, it braces the structure to absorb the drag loads imposed on the assembly. The thickness of the wing skin is increased towards the root end to cater for the increased loads. At the rear of the wing additional members provide the attachment points for the flap and aileron hinges. Other strong points provide attachments for the engine and landing gear and for attachment to the fuselage.

4.3 **Auxiliary Aerofoils.** The construction of tailplanes and fins is similar to that of the wing but is of lighter construction since the loads involved are smaller.

4.4 **Helicopter Rotor Blades.** The helicopter main rotor blade, as a lifting aerofoil, has much in common with the aeroplane wing and is subject to a similar pattern of bending and shear forces. However, because the whole assembly is rotating, the structure is also subject to centrifugal force in an outward direction, the value of the force depending upon the radius of rotation at which it is considered (assuming a constant speed of rotation). In a large helicopter this force will be many tons and is constantly superimposed upon the bending and shear forces and the fluctuations in them produced by manoeuvres and wind variations.


FLAP INBOARD HINGE
FLAP SHROUD RIB
FLAP CENTRE HINGE
(NACELLE)
ENGINE
INBOARD RIB
ACCESS PANELS
FLAP OUTBOARD HINGE
DIAPHRAGM
NOSE RIB
FIXED TRAILING EDGE MEMBER
TANK BAY
(SHADED AREA)
AILERON INBOARD HINGE
FUEL TANK FILLER CAP
AILERON SHROUD RIB
CAPPING STRIP
(UNDER SKIN PLATING)
REAR BAY STRINGER
NOSE RIBLET
CLOSING MEMBER
INTER - SPAR STRINGERS
REAR BAY RIB
FRONT SPAR ASSEMBLY
INTER - SPAR RIB
REAR SPAR ASSEMBLY
LANDING LAMP BRACKET
TRANSPARENT COVERS
WING TIP RIBS
AILERON OUTBOARD
HINGE

4.5 **Rotor Blade Construction.** Rotor blades are constructed on the base of a spar which may be of either composite or metal construction. Typically a composite spar is made up of glassfibre rovings running continuously from the tip to the root of the blade, round the root end attachment bush, or bushes, and out to the tip again (Figure 13). These straps provide the main strength of the spar to accept the centrifugal loading. Crossplied laminations provide a core for the spar, and the straps and the core are covered by a further crossplied lamination taking the torsion loads in the blade. The whole assembly is laid up with a suitable resin and cured under heat and pressure in the desired shape. Bonded to the aft side of the spar is a fairing to complete the aerodynamic shape of the blade. This fairing consists of a honeycomb core covered with a skin of crossplied glassfibre laminate and reinforced at the trailing edge with uni-directional glassfibre or carbon fibre filaments or strips. The leading edge is protected by a titanium nose cap bonded to the spar and the outer portion of this is protected by a nickel erosion strip.

4.6 A typical metal rotor blade is constructed upon a tubular metal spar formed to the approximate section of the blade. The metal skins are supported by an aluminium honeycomb and the whole assembly is bonded together. Some metal blades use individual 'pockets' made from sheet metal and attached to the rear side of the spar. Some 20 or more of these form the aerodynamic section of the blade aft of the spar. Tail rotor blades follow the constructional techniques of the larger main rotor blades but, since the forces involved are smaller, a lighter structure can be used.

5 CONTROL SURFACE STRUCTURES The term control surface is taken to include the primary flying controls of ailerons, elevators and rudder; the secondary flying controls of trim tabs, servotabs and balance tabs; and lift control devices such as flaps, slats and spoilers. The structural requirements of each of these surfaces are different due to the fact that they are operated under different conditions in different parts of the flight envelope.

5.1 **Primary Flight Controls.** Whilst the aerofoil section of each control differs, the structure is essentially similar, being relatively light when compared with the main surface to which they are attached.

5.2 The example of an aileron shown in Figure 14 is typical of the design used on smaller twin-engined aircraft. The main structural element of the aileron is a torsion box consisting of the main and rear spars and the upper and lower skins. Inter spar ribs brace the structure. A second torsion box is formed by the leading edge skin and the main spar and this is reinforced with nose ribs, particularly at the cut-outs for the hinge points. The trailing edge skin is fluted in order to stiffen it and prevent buckling, thus obviating the need for stringers. The same principles of construction apply to the ailerons of larger aircraft except that the structural details are commensurate with the larger size and operating loads involved. Elevators and rudders are constructed along similar lines.

5.3 **Control Surface Balance.** It will be noticed that an external mass balance weight is fitted to the aileron illustrated in Figure 14. The purpose of the weight is to statically balance the control surface in order to prevent flutter. Flutter is a rapid oscillation of the control surface about its hinge that is excited by changes in the airflow under certain flight conditions. Primary control surfaces are always balanced but trim tabs are rarely balanced, depending upon their low mass to avoid the problem. It is also very important that backlash in the tab operating system should be kept to a minimum in order to reduce the likelihood of flutter. In the absence of any data from the manufacturer, the free play at the trailing edge of the trim tab should not exceed 2·5% of the maximum chord of the tab. Should it be necessary to repair or re-finish a control surface at any time, it is essential that the balance is checked against the manufacturer's limits and adjusted if necessary.

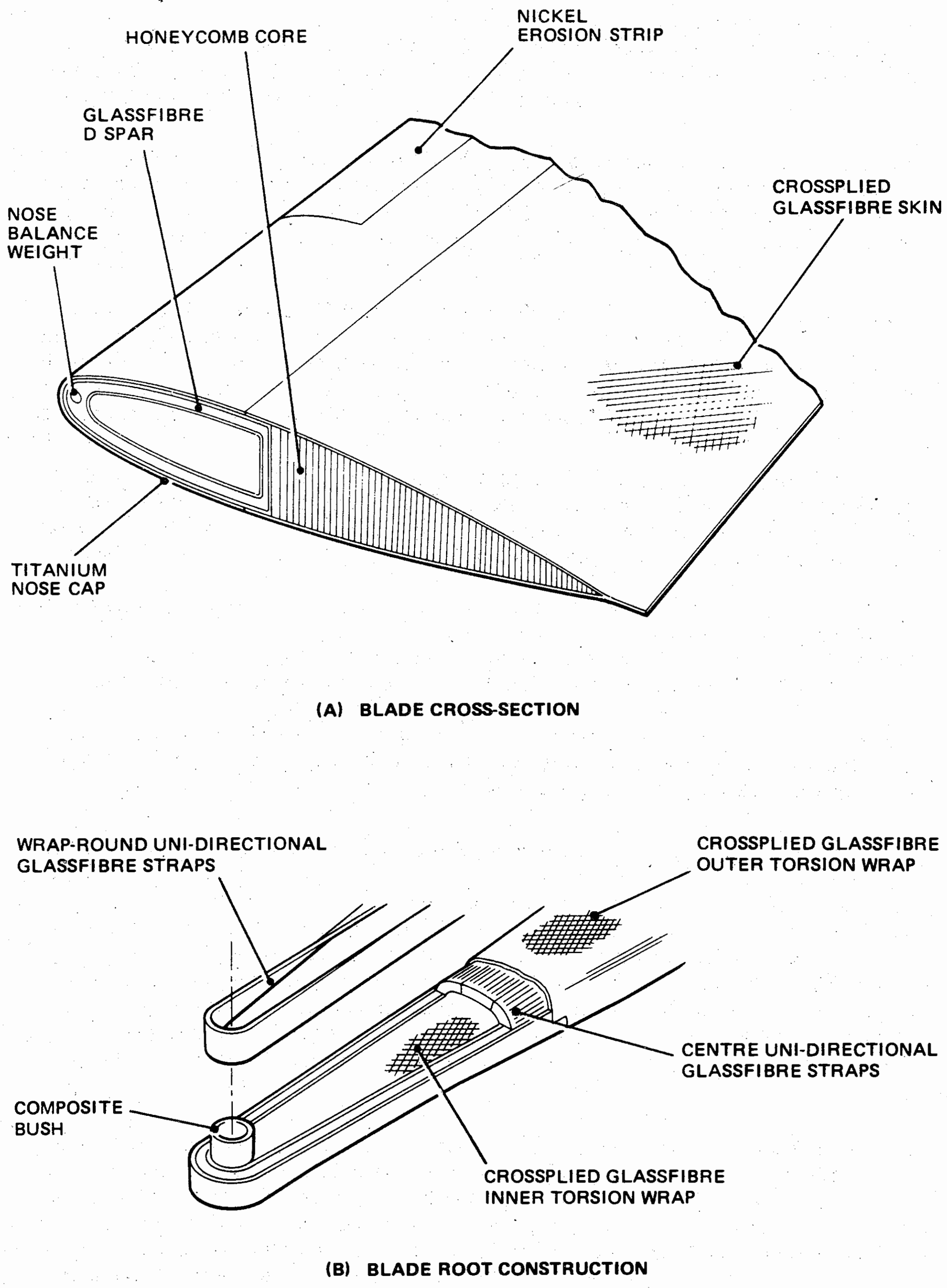


Figure 13 COMPOSITE ROTOR BLADE CONSTRUCTION

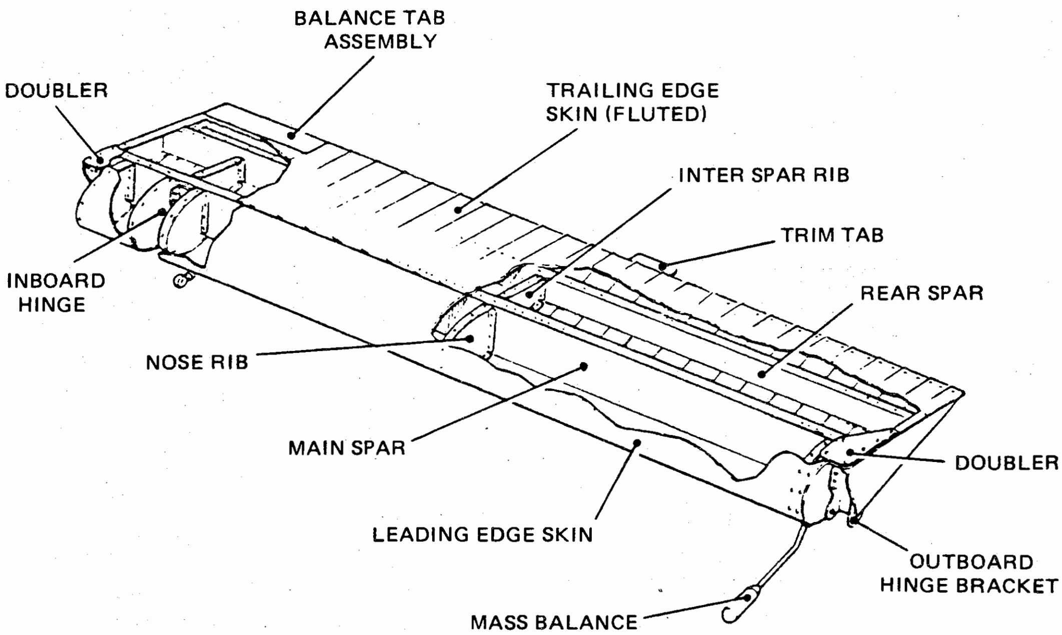


Figure 14 AILERON CONSTRUCTION

6 AIRFRAME LOCATIONS Leaflet **AL/7-12** gives guidance as to the placing of an airframe in the rigging position, that is longitudinally and laterally level. This is the basic position used when making dimensional checks on an airframe. Whilst this enables basic angular and linear measurements to be made it does not necessarily enable a specific point on the airframe to be defined. A system of planes is used that enables a point to be defined in relation to the three axes of the aircraft. A fixed wing aircraft is taken as the example in Figure 15.

6.1 Points along the longitudinal axis are termed Fuselage Stations and these are measured from a datum plane transverse to the longitudinal axis. The datum is fuselage station zero, more usually expressed as FS.0. The figures shown on the diagram indicate the number of inches of a point from the datum but any other unit may be used. Conventionally, stations forward of the datum are negative and stations aft of the datum are positive. In many aircraft the datum is a plane in space forward of the nose of the aircraft in order to make all the fuselage stations positive thus simplifying weight and balance calculations.

6.2 Horizontal planes through the aircraft transverse to the normal (vertical) axis are termed water lines. Lines above the datum are positive and lines below the datum are negative. Vertical planes transverse to the lateral axis are termed buttock (butt) lines or wing stations, the datum being the centre line of the fuselage, that is the longitudinal axis. To indicate whether the station is to the left or right of the datum the suffix letters L or R are added to the number as appropriate.

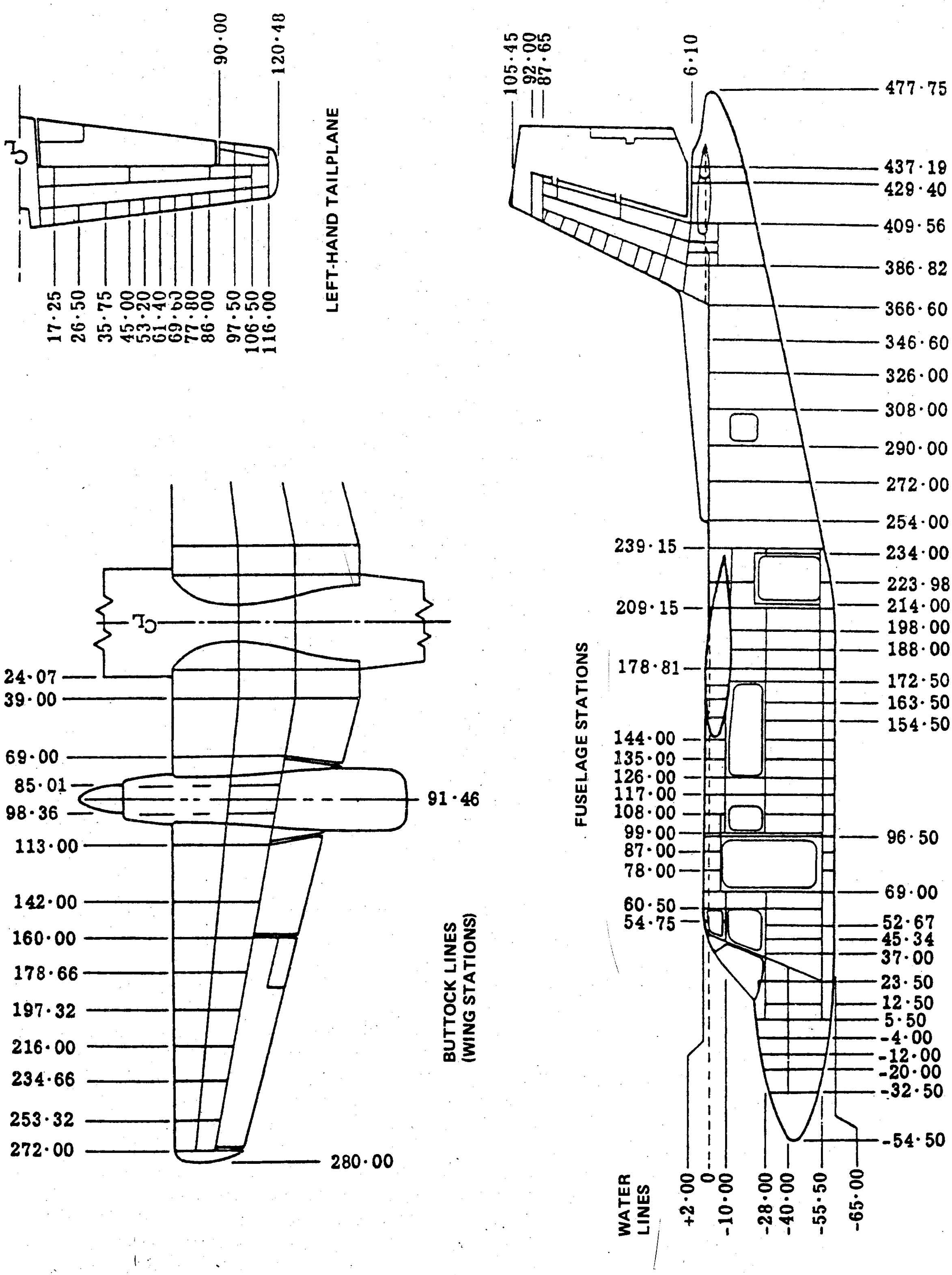


Figure 15 STATION DIAGRAM

7 MACHINED COMPONENTS The structural details described previously have comprised components manufactured from sheet metal and standard extrusions. The individual items have been commonly assembled by riveting. In recent years there has been a growing trend with large aircraft to employ structural components that are machined from a solid billet, examples being ribs, spars and skins with integral stringers. The adoption of this type of construction reduces the number of parts and hence the number of joints in the structure. Since each joint is a discontinuity in the load path and a possible stress raiser the abolition of as many joints as possible should result in a more reliable structure. It also makes the task of inspection easier although repair becomes more difficult. Figure 16 illustrates typical structure using machined detail parts.

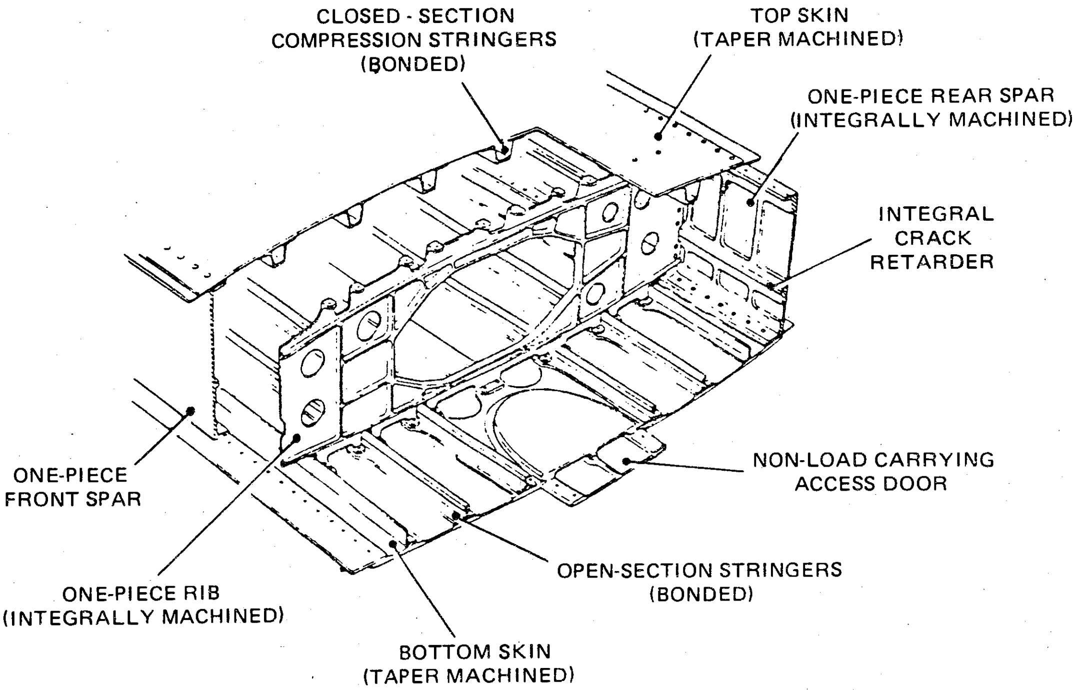


Figure 16
MACHINED STRUCTURAL COMPONENTS OF MAIN WING BOX STRUCTURE

AL/7–4

Issue 3

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AIRCRAFT

STRUCTURES

TRANSPARENT ACRYLIC PANELS

1 INTRODUCTION This Leaflet gives guidance on the fitting and maintenance of transparent acrylic panels, but does not include detailed information on specialised workshop processes, such as the moulding of panels from the plasticised state.

1.1 The types of panels used vary considerably with different aircraft, therefore this Leaflet should be read in conjunction with the relevant aircraft Maintenance Manual and the Approved Repair Manual for the aircraft concerned.

1.2 Information on windscreen assemblies is given in Leaflet **AL/7-10**, and on the fabrication of acrylic panels and shapings in Specification DTD 925.

2 MATERIAL The material used for the manufacture of transparent acrylic panels is unplasticised polymethyl methacrylate sheet, which, like all acrylic materials, is little affected by prolonged exposure to atmospheric conditions. At normal temperatures acrylic sheet is rigid but rigidity decreases with increase of temperature. This change starts between temperatures of 80°C and 120°C, and at temperatures of 120°C and above the material is soft and rubber-like. In this state the material can be shaped under low pressure and, if cooled with the shaping pressure maintained, a rigid shape which is stable over a wide range of temperatures can be obtained. However, the shape starts to 'de-mould' at raised temperatures, and at 150°C returns rapidly to its original cast shape. The material is normally supplied either in the 'stretched' condition for applications where prolonged and/or high frequency of cyclic loading will be applied, or 'as cast' for low fatigue applications.

2.1 Acrylic sheet can be machined, heat-shaped and cemented easily, has clarity and light stability, has a high strength-to-weight ratio and has good dimensional stability, although the coefficient of linear expansion is about eight times that of steel, i.e. approximately 80 to 100 x 10^{-6} per °C.

2.2 The material is not highly flammable, its burning characteristics being comparable to medium density wood. Although tough, it is soft, its resistance to scratching being comparable to aluminium; in many instances damage caused by scratches can be removed by polishing (see paragraph 7).

2.3 In general, acrylic sheet is resistant to inorganic chemicals and to some organic compounds, such as aliphatic (paraffin or fatty) hydrocarbons, hydrogenated aromatic compounds, fats and oils, but is attacked and weakened by aromatic hydrocarbons (e.g. benzene), esters (generally in the form of solvents, and some de-icing fluids), ketones (e.g. acetone), chlorinated hydrocarbons, etc. Some hydraulic fluids are also very detrimental to acrylic material, which also has low water absorption qualities. (See Airworthiness Notice No. 12 Appendix No. 22.)

2.4 **Acrylic Sheet for Aircraft Glazing.** Acrylic sheet complying with Specification DTD 5592 is available in two grades, one of which provides special freedom from defects for use where the highest optical qualities are required, and the other which can be used for all other forms of aircraft glazing. On some 'sandwich' type windscreens an acrylic sheet is used in conjunction with a toughened glass outer panel, usually with a rubber interspacer ring (see Leaflet **AL/7-10**).

3 MACHINING AND TRIMMING Tools similar to those used for light metal working or, in some instances, woodworking, can be used for machining acrylic sheet. All tools should be kept clean and well sharpened. Tools should be prevented from overheating, since the swarf produced under such conditions may bond itself to the panel. A convenient method of cooling is by the use of compressed air.

NOTE: Care must be taken to avoid excessive overheating of the material, since this may introduce local stresses which, in turn, may cause cracks, especially near the edge of the panel, and may cause crazing in service.

3.1 **Cutting.** Sawing with high-speed band saws or circular saws is the generally accepted method for cutting acrylic material, which should be slowly fed into the machine. Hand sawing with fret saws or hack saws is possible for small pieces, but the process is slow and the saw tends to stick due to overheating, resulting in frequent breakages. Another method of cutting small or awkwardly shaped pieces is to use a small tapered reamer as a cutting tool in an air or electric drill and using gentle side pressure on the reamer. This method is reasonably quick and minimises the tendency to cracking due to local overheating as in hand sawing.

3.1.1 Band saw blades having a tooth pitch of 2·5 mm to 5 mm (10 to 20 teeth per in) and running at a speed of 1500 m (5000 ft) or more per minute are suitable. Circular saws should be hollow-ground or should have a slight 'set' to prevent binding and overheating; the most suitable tooth pitch varies according to the thickness of the material to be cut, but the peripheral speed of the saw should be about 3000 m (10,000 ft) per minute.

3.1.2 Thin sheet of 2·5 mm (0·1 in) or less can be scribed and snapped along the scribed line. Even pressure, continuous support on the under-side and adequate clamping are essential for this process.

3.2 **Drilling.** It is recommended that special multi-stepped drills having small incremental increases in diameter are used. These drills are capable of cutting good smooth holes with no stress cracks around the edges. Standard twist drills can be used for drilling holes provided the cutting angle is reduced by grinding the point sufficiently flat to avoid splitting the sheet when the drill breaks through. Drills with a slow spiral and a wide polished flute are also suitable. A slow cutting-speed should be used and a hand feed is recommended, so that the swarf can be cleared frequently to prevent binding and overheating. Adequate support on the underside of the sheet is essential. Coolant, such as soluble oil or water, will help to produce accurate, strain-free holes; when used, it must be ensured that it reaches the tip of the drill.

3.3 **Routing and Spindling.** Standard high-speed wood-working machines can be used for these operations. High speed is necessary for good results and, as with other machining operations on acrylic materials, sharp tools are essential. Routing and spindling operations are usually done without lubricants. In the case of routing, it is an advantage to remove the swarf and cool the cutter with a compressed air jet.

3.4 **Hand Shaping.** A number of hand woodworking tools may be used, including planes, providing very light cuts are taken. Spokeshaves and chisels for forming curves and wood scrapers for edge cleaning may also be used, as may coarse files, providing very light cuts are taken.

3.5 **General.** It should be ensured that the protective paper is left in position during machining operations, with local removal to provide a margin on either side of the machining lines to prevent swarf collecting under the paper. The material may become electrostatically charged during machining operations and swarf may adhere to the edges; although difficult to remove at once, it can be shaken off after a short while.

3.5.1 After machining, all sharp edges and burrs should be removed by means of a planing machine, sanding machine or by the use of an abrasive cloth or scraper. The edges of the material and the periphery of the holes should be polished and slightly chamfered. It is general practice to stress relieve the material after any form of working by annealing in accordance with DTD 925.

3.5.2 After all mechanical work has been completed, the protective covering should be removed, the material washed and then re-protected (see paragraph 10) if it is not required for use and is to be stored.

4 FITTING PANELS The coefficients of linear expansion of transparent acrylic panels (see paragraph 2.1) and metal mounting frames differ considerably; therefore, in all mountings, provision must be made for the relative movement of the panel to the frame. In this respect, all dimensions of panels and fixing details must be in accordance with approved Maintenance Manuals, drawings and/or any associated installation instructions.

4.1 Acrylic sheet is notch-sensitive and if small cracks or inequalities occur at the end of the panel or at holes then, under quite light stresses, cracks may be propagated through the material. This is particularly important when bolting directly through the panel and in all such cases the holes should be polished and radiused. The holes must be oversize to allow for contraction and expansion and a flexible rubber grommet, manufactured of a material compatible with acrylic sheet, must be inserted between the bolt and the panel. Bolting directly in this manner is used only where very light loads are taken by the panel.

4.2 On pressurised aircraft, or where the loads are at all considerable, the panels are held in a suitably shaped mounting frame, the expansion differences being taken up by rubber mouldings or strips, any bolts, e.g. for securing glazing strips, being positioned in the frame outside the perimeter of the panel. For such an assembly the edge of the panel must be smooth and polished.

4.3 When a panel or moulding is fitted to its mounting frame, the material must not be strained in any way in order to make it fit; if straining appears necessary, the panel should be removed and checked to ensure that it is dimensionally correct. Because of relative movement the specified clearances must be observed.

4.4 After installation the panel should be carefully checked for any damage which might have occurred during installation. A check should also be made to ensure that the edges of the panel extend the correct amount under the glazing strips; inspection holes for this purpose are usually provided. It is also important to ensure that the rubber moulding or beading has not been displaced during assembly, and that the panel is not in direct contact with the metal frame. A gap is usually specified between the edge of any raised portion of the panel and the glazing strip, as shown in Figure 1, sufficient to allow for any differential expansion which may occur (see paragraph 2.1).

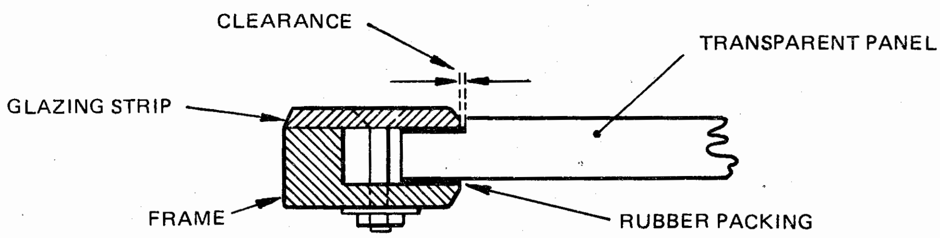

Figure 1 PANEL MOUNTING

4.5 It is important to ensure that any glazing or sealing compound used is that specified in the Maintenance Manual and that it is only used where specified.

5 PROTECTIVE COVERINGS Acrylic sheets are usually supplied with protective paper coverings or a suitable lacquer (see paragraph 10.2) to prevent damage during handling and storage; these protectives should be left in position for as long as possible. Paper coverings on flat sheets can often be used for marking out, but when the material is to be shaped all protectives must be removed and the sheet cleaned prior to heating, otherwise staining of the panel may occur.

5.1 Where paper protective is concerned, a gelatine adhesive is normally used, and the paper can generally be peeled off by easing one corner off the sheet and pulling. Any trace of gelatine adhesive remaining on the surface must be removed in accordance with the instructions contained in the relevant Maintenance Manual. In the absence of any specific instructions the panel should be thoroughly washed with warm water and soap and then gently wiped with a soft cloth or pad of cotton wool. After rinsing in clean water, the panel should be wiped with a soft cloth or chamois leather. Harsh fabrics should never be used and care should be taken to avoid picking up grit on the cleaning cloths.

5.2 If panels are not properly protected by covering they will be detrimentally affected by certain chemicals or, in some cases, their vapours (see paragraph 2.3). These chemicals (or their vapours) will cause a 'crazing' or 'frosting' effect on the panel surfaces which, apart from affecting visibility, will considerably weaken the panel. It should be noted that when an aircraft is being sprayed the vapours may affect other aircraft nearby.

5.3 To mask panels during spraying, etc., soft soap, covered by paper may be used. When adhesive masking tape is used, care should be taken in selecting the tape, as some adhesive tapes contain solvents which would cause crazing.

6 CLEANING Transparent acrylic panels should be maintained in a clean condition and any slight scratch or slight crazing should be removed by cleaning and polishing (see paragraph 7). Panels should never be left in a dirty state, since this will affect their optical qualities.

6.1 Warm water (40°C maximum temperature) and soap is recommended for cleaning, using a soft clean cloth or cotton wool pad; after washing, the panels should be rinsed and dried with a clean chamois leather. Some aircraft manufacturers recommend a proprietary detergent which is also suitable for the surrounding aircraft structures and therefore to some extent simplifies cleaning operations; it is important to ensure that only the detergent specified is used and that the proportion of detergent to water is observed.

6.2 Grit or dirt should, at regular intervals, be removed from recesses, such as where, for example, the panel joins the frame, to prevent its being picked up by the polishing cloth. The accumulation of cleaning and polishing materials in recesses must be avoided.

7 POLISHING Various proprietary polishing kits are available which usually consist of a jar of cleaning compound, a jar of polishing compound, polishing cloths and application cloths. Material to Specifications DTD 770 (polish) and DTD 763 (polishing cloths) should be used unless otherwise specified by the manufacturers.

7.1 Polishing cloths and application cloths must be kept separate. Polishing cloths may be used until soiled but application cloths should be discarded after use.

7.2 When using cloths that are not specifically obtained for cleaning or polishing transparent material, it is essential to ensure that the cloth is of soft texture and clean.

7.3 Scratches can usually be removed by polishing, the depth of the scratch being the controlling factor. The repair manual of the aircraft concerned should be consulted to ascertain the extent, depth and location of any scratches or damage that may be removed, since apart from the amount of material that may be removed, the optical qualities of the panel may be affected.

NOTE: A dry cloth should never be used to remove dust or dirt.

7.4 **Static Charges.** Because of the high surface and volume resistivities of acrylic sheet, a static charge is built up when it is rubbed with a dry cloth. Treating the surface with an anti-static polish approved for use on acrylic will help to prevent this static charge and reduce the resultant accumulation of dust.

7.4.1 A small quantity of the specified type polish (which may be thinned down with water if desired) should be applied to the sheet and spread evenly, using a soft cloth. Finally, the panel should be rubbed with a clean soft cloth until a bright polish is obtained.

7.4.2 This treatment helps to eliminate the static charge and so reduce dust collection for approximately two months under normal dry indoor conditions. Frequent polishing with a dry cloth does not impair the efficiency of the treatment, but washing destroys the anti-static effects and polish must be re-applied.

NOTE: It is important to ensure that all surfaces are treated.

8 INSPECTION When inspecting transparent acrylic panels, the following points should be borne in mind.

8.1 The optical standard and the standard of cleanliness of cockpit panels can have a direct effect on the flying of the aircraft especially in conditions of poor visibility. A hazy panel blurs the details, reduces black to grey and dims outlines. Dirt or slight scratching scatters the light and makes it impossible for the pilot to see against the sun.

8.2 The soft nature of acrylic panels (compared with glass) makes them very susceptible to scratching. Some of the common causes of scratches are as follows:

(a) Protective paper covering, which has slipped.

(b) Cloths of a rough texture used for cleaning or polishing.

(c) Dirty cloths used for cleaning or polishing.

(d) Dirty hands.

(e) Contact with any hard object.

8.3 During maintenance, the following precautions should be taken:

(a) Panels should be cleaned as detailed in the aircraft Maintenance Manual, and only approved polishes and soft, clean polishing cloths should be used.

(b) Panels should not be covered with rough canvas covers. In frosty or changeable weather, covers especially designed for the purpose should be used. In damp weather, prolonged rain or fog, the panels should be left uncovered.

(c) Personnel should not touch panels with bare hands.

(d) Fuel should never come in contact with panels.

(e) Any damage to the panel should be carefully checked in accordance with the requirements of the aircraft Maintenance Manual.

(f) Because of the adverse reaction of acrylic material to various chemical vapours, the cockpit and cabin should be well ventilated during maintenance.

8.4 **Crazing.** Stress crazing is caused if the surface tensile stress of a panel exceeds a critical value. Crazing consists of multiple hairline surface cracks which, being very narrow, relatively deep and sharp at the bottom, act as notches and may cause a serious drop in strength. The depth of the crack may increase with time if the formation of the surface cracks does not relieve the stress, and so could ultimately penetrate through the sheet. Stress crazing is a time-dependent phenomenon and, therefore, it may occur at lower stresses after longer periods of loading.

8.4.1 Stress crazing is not usually dangerous because the loss of strength in the presence of such crazing is small and in any case the window would be changed because of appearance long before it became too weak. However, crazing caused by solvents can be much more serious in that the window can suffer appreciable loss of strength. It is impossible to distinguish between the causes of crazing, hence the necessity of keeping harmful solvents away from panels, both in storage and in service.

8.4.2 Crazing usually occurs in the vicinity of a joint and, when the panel is held up to the light, the faulty area appears sparkling and iridescent. It should noted that hot sun will further aggravate craze-prone areas.

9 **REPAIRS** Only the repairs detailed in the aircraft repair manual or on approved repair drawings may be made. On load carrying panels, the repairs permitted are usually confined to the removal of scratches by polishing, and the amount of material removed, as well as the location of the repair, will be carefully defined.

9.1 On some aircraft, where the panels are not considered load carrying, some repairs are permissible, but irrespective of the aircraft, all repaired transparent acrylic panels should, whenever possible, be renewed, since it is impossible to restore the full strength of the panel by repair methods.

9.2 **Patches.** Repairs by patching may be grouped in two categories, i.e. inlay patches secured at the edges by adhesive cement, and lap joints secured by adhesive cement (a typical method of holding patches in position while the cement is drying is illustrated in Figure 2). Where the clarity of vision is essential and the use of a patch will impair the transparency, the panel must be renewed.

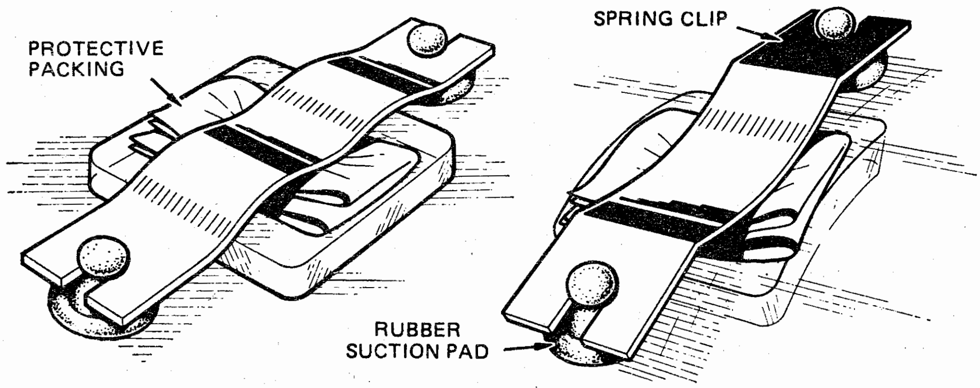

Figure 2 METHOD OF SECURING PATCHES

9.2.1 Inlay patches call for a high degree of skill when fitting; good results can only be obtained if the edges to be joined mate perfectly, otherwise air bubbles will cause weaknesses in the joint and transparency will be impaired.

9.2.2 The surfaces of lap joints should be perfectly clean and the use of clamps should be avoided. Undue pressure during the application of the adhesive may lead to crazing; the adhesive itself also tends to produce a minute crazing effect.

9.2.3 For the purpose of making patches only, acrylic sheet may be remoulded by the application of heat and light pressure. The temperature must be closely controlled (see Specification DTD 925).

NOTE: Over 130°C (i.e. above softening point), materials will permanently shrink 2%, but any subsequent application of temperature will cause the material to expand and then contract back to its reduced length.

9.3 **Cracks.** Cracks should be prevented from spreading by drilling, but, owing to the brittle nature of the material, it should only be drilled when the hole is to be filled with a cemented patch.

9.3.1 Cracks which start at the edge of a panel should be arrested (drilled) and then opened up by inserting a sharp instrument (a razor blade is often suitable) as near to the edge of the panel as possible. The surface of the panel immediately adjoining the crack should then be painted with adhesive cement, using a fine clean brush (preferably sable or camel hair), and the adhesive should be allowed to run into the crack. When the adhesive becomes tacky, the instrument should be withdrawn to allow the faces of the crack to come together; surplus adhesive should then be wiped off and the repair allowed to dry.

9.3.2 The adhesive cements (i.e. DTD 900, AN 4142 and 4143) used for repair work are highly flammable and the fumes are poisonous. Therefore, naked lights must be avoided and good ventilation is essential.

10 STORAGE Acrylic sheets are best stored on edge, with the protective paper left in position; this will help to prevent particles of grit, etc., becoming embedded in the surfaces of the sheets. When this is not possible, the sheets should be stored on solid shelves, and soft packing, such as cotton wool, should be placed between each sheet. The pile of sheets should be kept to a minimum and should never exceed 12 sheets.

10.1 Curved panels should be stored singly with their edges supported by stops to prevent 'spreading'.

10.2 There are several proprietary lacquers available for the protection of acrylic panels and shapings during handling and storage, including those complying with Specifications DTD 900/4051, DTD 900/4294 and DTD 900/4356. Protective paper may also be used, but to prevent deterioration of the adhesive between the protective paper and the sheet, store rooms should be well ventilated, cool and dry. The material should not be placed near steam pipes or radiators, as hot conditions will cause the adhesive to harden and make the subsequent removal of the paper difficult.

10.3 Acrylic sheets or panels in storage should not be exposed to strong sunlight, particularly when light shines through a glass window which might cause a 'lens' formation, as this may result in local overheating and be detrimental. (See also Leaflet **BL/1-7**.)

AL/7-6

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AIRCRAFT

STRUCTURES

REPAIR OF LAMINATED AND HONEYCOMB STRUCTURES

1 INTRODUCTION This Leaflet gives guidance on the repair of laminated and honeycomb structures made from or containing metallic or reinforced plastics material, with particular reference to aluminium alloy and glass-fibre. Repairs to similar structures made from other materials may require special procedures, and reference should be made to the relevant manufacturer's manuals.

2 GENERAL Many components in modern aircraft are manufactured from reinforced plastics or honeycomb sandwich structures, including external parts such as fillets, leading edges, wing tips, control surfaces, engine cowlings and radomes, and internal parts such as tanks, heater ducts, cable ducts, floors and furnishings. The materials used in the construction of a particular component depend on many factors, such as aerodynamic shape, strength, stiffness, heat resistance, chemical resistance and dielectric properties required, and the materials used in a repair must be identical to the original materials, or be alternatives having the same properties and approved for such use by the aircraft manufacturer. The repair of reinforced plastics may be more difficult than the original manufacture, and the type and extent of repairs carried out must, therefore, be strictly in accordance with the relevant aircraft manual or be specifically approved by the design authority. Personnel carrying out these repairs must have the skill and knowledge necessary for working with these materials, and should preferably have undertaken suitable training.

2.1 The following topics are discussed in this Leaflet:

Para.	**Topic**	**Para.**	**Topic**
3	Materials	7	Repairs to glass-fibre laminates
4	Preparation and curing of resins	8	Repairs to glass-fibre honeycomb
5	Assessment of damage to glass-fibre components	9	Repairs to aluminium honeycomb
6	General repair considerations	10	Radomes and dielectric panels

3 MATERIALS Laminated or reinforced plastics material is generally made from resin-bonded glass-fibre cloth or uni-directional glass fibres, but nylon cloth or carbon fibres may be used in some components. Sandwich material may have a solid core of end-grain balsa wood or a honeycomb core of glass-fibre, nylon paper or aluminium foil, and is usually faced with aluminium or laminated glass-fibre, which is bonded to the core with a resin adhesive. The core material on some radomes, however, may be of expanded polyvinyl chloride or similar low-density product.

3.1 **Glass-fibre Cloth.** This is the reinforcing material in the laminate, and it is manufactured in various thicknesses and types of weave, usually in accordance with British Standard (BS) 3396 or U.S. Military Standard MIL-C-9084. Twisted glass-fibre strands may also be used for local stiffening, and chopped glass-fibres may be used for moulding or repair work. Glass-fibre cloth is also supplied pre-impregnated with resin, to facilitate manufacture and repair.

3.2 **Resin.** Polyester or epoxy resin is used both for bonding laminated glass-fibre parts and as an adhesive for glass-fibre-to-metal and metal-to-metal joints. These resins are formulated to provide specific properties such as heat-resistance and flame-proofing, although in some cases an additive is used to impart these properties, and pigments may also be used. The type of resin to use is, therefore, most important, since a particular type will have been chosen at the design stage to provide the necessary properties in a particular component and may not be suitable for carrying out repairs in different locations. Resin is usually in liquid form, but for metal-to-metal joints is also supplied in the form of a dry film adhesive with a strippable protective sheet on each side.

3.3 **Additives.** Resins will not harden on their own, and must usually be mixed with one or more additives, which provide a chemical cure. Polyester resins generally require the addition of a catalyst and an accelerator, while epoxy resins generally only require the addition of a hardener or activator. Either type of resin may be cold cured at room temperature (not below 20°C) or heat cured (by the use of infra-red lamps or electric heaters), but the temperature of the resin should not be allowed to exceed the maximum specified for the material. Cold curing of a resin may be accelerated by adding heat after it has gelled, or by varying the quantities of the additives within specified limits.

3.3.1 In addition to the chemicals added for curing purposes, mica powder or other proprietary material may be used to add flame retarding properties, while fillers such as plastics micro-balloons or chopped glass-fibre may be added for filling gaps or voids in the structure.

3.4 **Core Materials.** Many core materials are made in a honeycomb pattern from glass-fibre cloth, nylon paper or aluminium foil of various thicknesses, and this is bonded to the inner and outer skins. The strength of the honeycomb structure is chosen during design, and when permanent repairs are carried out an identical core material or an approved alternative must be used. The direction of the honeycomb strips may also be important, and new core materials should be assembled in the same direction as the original core. Radomes and dielectric panels may have glass-fibre honeycomb, expanded nitrile ebonite or expanded PVC cores, to provide structural strength and rigidity, and suitable dielectric properties. Replacement of the correct core and skin material, and maintenance of the original cross-section and contour is, therefore, especially important when carrying out repairs to these components.

4 PREPARATION AND CURING OF RESINS Extreme care is necessary when preparing a resin mixture for use, firstly because the chemicals could damage the eyes or cause dermatitis, and also because an explosion could result from mixing an accelerator with a free catalyst. Safety goggles and rubber gloves should be worn when handling these materials, adequate ventilation should be provided, and the manufacturer's instructions regarding the mixing of the various ingredients should be carefully followed. If the chemicals do come into contact with the skin, they should be washed off immediately with soap and warm water. If the eyes are affected they should be irrigated with water, and medical attention should be sought.

4.1 **Mixing.** The ingredients of the resin mixture are usually stored in a cool place (less than 10°C for maximum storage life), and should be allowed to assume room temperature before use. Powder and solid additives must be free from dirt or grease and thoroughly dry, and all utensils used for measuring and mixing the materials must be scrupulously clean. The resin and additives should be carefully measured into glass or non-absorbent cardboard containers, in the proportions required for the particular application; these proportions are usually specified as percentages, by weight, of the quantity of resin required for the task in hand. The catalyst should be thoroughly mixed with the resin before adding the accelerator, then any additional material, such as filler, chopped glass-fibre or micro-balloons should be added, and stirred until thoroughly mixed.

4.2 **Pot Life.** Once mixed, the resin begins to cure and has a limited life (pot life) before it has gelled to such an extent as to become unworkable. The pot life varies from a minimum of five minutes to several hours, depending on the formulation of the ingredients and the ambient temperature. All operations should be performed within the pot life of the mixed resin for the results to be satisfactory, and, to prevent waste, only the quantity of resin known by experience to be necessary, should be prepared for use.

4.3 **Curing.** Most resins used on aircraft structures will cure at room temperature (normally 20°C or above), but although they may solidify in a few hours, complete curing may take several days. It is often necessary therefore, to accelerate the cure by heating the resin to a specified temperature after it has gelled. Those resins which will not fully cure at room temperature must be heated throughout the curing period. The times and temperatures required to effect a cure on a particular component are specified in the relevant Maintenance or Repair Manual, and these recommendations should always be followed.

4.4 **Film Adhesives.** Film adhesives are generally easier to use than liquids, since the ingredients are already mixed in the correct proportions, and the amount required is simply cut from the sheet so as to overlap the repair area by approximately 3 mm (0·125 in). Care is necessary during handling, however, and the film should not be stretched, creased or folded in use. Once the protective sheets have been removed, the adhesive film should not be touched with the bare hands, since this will impair the adhesive qualities, and the repair should be assembled and cured as soon as possible.

4.5 **Heating.** Heat is usually applied by means of an infra-red lamp, an electric heater, or, in the case of components which have been removed for repair, in an oven of suitable size. An oven is the most satisfactory heating method since the temperature can be accurately controlled, but the other methods are more generally used, and temperature is checked by use of temperature indicating lacquer or pencils (such as 'Tempilaq' and 'Tempilstick'). Marks made by these methods, adjacent to a repair, will melt at a predetermined temperature. Manufacturers may specify a maximum curing temperature, and if this is exceeded damage to the resin or buckling of the repair may result.

5 ASSESSMENT OF DAMAGE TO GLASS-FIBRE COMPONENTS Damage to glass-fibre components can result from a number of causes, such as rain or hail erosion, lightning strikes or static discharges, and bird strikes or other impacts. Radomes are protected from erosion by either fitting neoprene overshoes over the nose area and cementing them in position, or by applying a coating of neoprene or polyurethane. Other glass-fibre parts are given a 'gel' coat of resin, and are painted in accordance with the aircraft paint scheme.

5.1 Physical damage may be hard to detect, since the surface will often spring back to its original shape after impact, and may only be visible as cracks, crazing, stains, or scuffs on the paintwork or overshoe. Any such marks must be investigated, to ascertain whether damage to the glass-fibre has actually occurred, and the structure should be examined for secondary damage such as may occur at attachments and fittings, and where the shock may have been transmitted to adjacent parts. Damage may also result from chafing against internal or mating structure, pipes, cables, etc., and if this occurs, consideration should be given to trimming, clamping or re-routeing these parts to prevent a recurrence of the damage.

5.2 Any damage to the surface of a glass-fibre laminate or honeycomb will allow moisture to enter the structure and cause damage to the bond between the glass-fibre and the resin, and, once moisture has entered, the repeated cycle of freezing and thawing may eventually destroy the bond between the glass-fibre laminations and between the honeycomb core and skins, thus extending the damage over a wide area. When it is suspected that moisture has entered the structure through a rupture in the surface, an investigation should be carried out to check the extent of the moisture absorption, and on radomes it is often recommended that a 'moisture meter' should be used. Prior to scanning, the surface of the radome must be dry, and scanning should be carried out on the inner surface, care being taken when probing the surface to avoid scratching or denting the resin. Where the use of a moisture meter is impractical, X-ray methods may be helpful in assessing moisture quantity.

5.2.1 Moisture must be removed before carrying out a repair, and this is usually done by the application of heat, either by placing the component in an oven or by the use of a warm air jet. With honeycomb components it may be recommended that an outlet path should be provided for the moisture by drilling holes into the affected cells before heat is applied.

5.3 Delamination may be caused by moisture absorption or by impact damage, and when either is known to exist the area surrounding the visible damage should be checked to ensure the structural integrity of the laminations. This can be determined by tapping the skin with a small metallic object such as a coin, which should produce a live resonant tone if the bonding is sound, but if delamination has occurred a flat, dead response will be obtained.

5.4 Since glass-fibre structures are often located at the aircraft nose or wing tips, where lightning strikes and static discharges are most likely to occur, lightning diverter strips are often fitted to a radome and bonding strips or cages are often fitted to other glass-fibre components, and these are electrically bonded to the adjacent metallic structure. The electrical bonding of these components should be checked after removal and replacement, and at other times specified in the relevant Maintenance Schedule (see Leaflet **EEL/1-6**). It is also important to check that the strips are securely attached to the glass-fibre component.

5.5 Electrical discharge damage on the outer surface of a radome may be difficult to locate, and an air pressure test may help to pinpoint the position of the damage. The radome should be removed from the aircraft, and the position of the internal damage should be noted. The overshoe should be removed from the nose of the radome (when necessary), and the paint should be removed from a small area of the outer surface opposite to the internal damage. A film of uncured resin should then be applied over this area, and an air pressure of 20·7 kN/m^2 (3 lbf/in^2) applied to the inside surface by means of a flexible funnel located over the internal damage. Bubbles in the uncured resin will indicate the position of the external damage.

5.6 The extremities of any damage found in a glass-fibre structure should be marked, and the maximum area and depth of damage should be assessed in order to determine whether a repair is required, and if so, the type of repair which should be carried out. The limits of the various standard repairs which can be carried out are defined in the relevant Maintenance Manual or Repair Manual for the aircraft concerned, and may vary considerably, depending on the type of structure and its location. It must be emphasized that repairs may only be made in accordance with the manufacturer's instructions, and that repairs may be prohibited in certain areas. In some instances repairs may not be permitted within a specified distance from the edge of a panel, while in other instances temporary repairs may be permitted, but these must usually be replaced by a permanent repair within a specified time period. It should also be noted that, although extensive repairs to radomes and dielectric panels are permitted on most aircraft, some manufacturers do not recommend repair of these components, because of the possible effect on radar performance.

6 GENERAL REPAIR CONSIDERATIONS When a large repair is being carried out it may be necessary to support the adjacent structure, so as to prevent bow, twist and distortion. The supports should be secured before commencing the repair and left in position until the repair has cured. A repair must be of the correct profile, and, if it is likely to be thicker than the original material, a check may have to be carried out to ensure that there will be no interference between the repair and adjacent moving parts; clearance from, or satisfactory contact with, adjacent or mating parts, as appropriate, should also be checked. Repaired components which move during operation should be checked for correct functioning and freedom from chafing/or binding through their complete range of movement, and the balance of control surfaces should be checked and adjusted as necessary.

6.1 **Materials.** Glass-fibre materials and resins should be mixed and applied in a warm, dry atmosphere, and it is obviously preferable that a component should be removed from an aircraft and repaired in a specially-prepared workshop. When this is not possible, the repair area and local surroundings should be kept at a temperature of at least 20°C while effecting the repair and curing the resin.

6.1.1 Materials should normally be stored in a cool, dry place, the catalyst and accelerator being stored separately to prevent inadvertent contact. Resins have a shelf life of up to 12 months, depending on their type, after which time they should be discarded. Before use, careful note should be taken of the life expiry date marked on the container. When required for use, the resin should be removed from storage and kept at room temperature for at least 24 hours before being mixed. Resin which has absorbed moisture and become cloudy should normally be discarded, but, when permitted, it may sometimes be recovered by heating to 120°C; if the resin becomes clear on cooling down it may be used, but if it remains cloudy then it must be rejected. Glass-fibre materials should be stored in their original wrappings, and must be kept dry and free from dust, oil or other contaminants.

6.2 **Cleaning.** It is most important that an area being repaired should be thoroughly clean, and once cleaned it should not be touched with the bare hands. All paint in the vicinity of the damage should be removed by sanding (paint remover could have an adverse effect on a bonding adhesive and should not be used unless specifically recommended), care being taken not to damage any glass-fibre material not included in the repair. The area should then be washed with acetone or methyl ethyl ketone (MEK) to remove any dust or residue, and allowed to dry before commencing the repair.

6.3 **Use of Pressure.** Manufacturers often recommend that pressure should be applied to a repair while it is being cured, since this helps to effect a satisfactory bond and to maintain the correct profile. Pressure may be applied by means of a vacuum bag, or by clamps or weights. A sheet of cellophane or polyvinyl chloride (PVC) should be placed over the repair area before applying pressure, as this will prevent the resin from sticking to the bag, clamp or weight.

6.4 **Moulds.** A repair to damage which includes all plies of a laminated skin will usually require supporting in its desired shape while carrying out the repair and during the curing period, particularly if pressure is being applied to the surface. The support for components which are flat or have a single curvature may often be provided by a wooden block or aluminium alloy plate, or, for a small area, by means of a cellophane sheet taped to the surface, but parts with a complicated curvature may require the use of a specially-made mould.

6.4.1 A mould is generally made from laminated glass-fibre cloth, plaster of Paris, wood or metal. It can be made on the damaged surface, on the surface of an identical component, or, as is often the case with a symmetrical component such as a radome, in an identically shaped area on the same component.

6.4.2 When making a glass-fibre/resin mould, the area from which the shape is being taken must be covered with a release agent such as cellophane or wax, to prevent it sticking to the mould. Before using a plaster of Paris mould, it must be thoroughly dried and the pores must be filled with wax.

6.4.3 Whichever type of mould is to be used, a release agent must be applied to the surface abutting the repair area.

6.5 **Health Hazards.** Mention has already been made (paragraph 4) of the health hazards which may result from mixing and using resin, and it should also be noted that the fine dust produced by sanding glass-fibre can cause skin and respiratory irritation. Suitable protective clothing should be worn when carrying out these operations, and adequate ventilation should be provided.

6.6 **Care of Tools.** Brushes and tools used for mixing and applying resin must be cleaned in acetone before the resin has set. Once resin has hardened it is almost impossible to remove.

7 REPAIRS TO GLASS-FIBRE LAMINATES The repairs outlined in this paragraph may, when authorized in the relevant Repair Manual or approved by the design authority, be applied to single-skin laminated structures such as are used for some fillets, ducts, wing tips and panels, and may also be applied to the glass-fibre skins of sandwich structures. Any dimensions quoted are typical values, but may not be applicable in all cases.

7.1 **Temporary Repairs.** In some instances, where the proper repair materials are not available, a temporary repair to a glass-fibre laminate may be permitted. This may be effected by means of doped-on fabric patches, or by a bolted aluminium alloy plate. The patches or plate should overlap the damage by at least 50 mm (2 in), and in the case of the aluminium plate, large plain washers should be used under the nuts to prevent them pulling through the glass-fibre. Temporary repairs should be replaced by permanent repairs at the earliest opportunity.

7.2 **Scratches, Pits and Dents.** Scratches, pits and dents which do not penetrate the glass cloth are considered to be minor damage, and should be repaired as follows:

(a) Clean the area surrounding the damage (paragraph 6.2).

(b) Mix a small quantity of resin and hardener and fill all scratches, pits and dents to restore the original profile.

(c) Allow the resin to cure, then sand any irregularity in the surface of the repair.

(d) Wash-off any residue and repaint the repair to the original standard.

7.3 **Small Blisters and Delamination.** The extent of any blisters or delamination of edges should be checked in order to determine whether the damage is within the limits for this type of repair (normally less than 25 mm (1 in) diameter or length). Repairs should be carried out as follows:

(a) Blisters should have at least two small holes 0·7937 mm (0·03125 in) diameter drilled through the separated layer close to the edge, and mixed resin should be injected, by means of a hypodermic syringe, into one of the holes, until it completely fills the void. Pressure should then be applied to flatten the blister and remove excess resin, and this pressure should be maintained until the resin has cured. Surplus resin should then be sanded off, and the paint renewed as necessary.

(b) Edge delamination should be thoroughly cleaned (paragraph 6.2) and mixed resin should be forced between the separated plies so as to fill the voids. Pressure should then be applied to the damaged area, care being taken to maintain the original edge profile. When the resin has cured, the excess resin should be sanded off and the paintwork renewed.

7.4 **Small Holes.** Holes which pass completely through the skin and are less than 9·5 mm (0·375 in) diameter may be repaired as indicated in Figure 1.

(a) One glass-fibre ply should be removed from each side of the laminate, in a circular area extending at least 12 mm (0·5 in) from the edge of the damage. This operation must be performed very carefully, so as not to cut into the fibres of the inner plies. A sharp knife or disc cutter should be used to cut round the outside of the cut-out, and a radial cut should be made into the damaged area. A knife can then be used to pry up and peel off the damaged layer, commencing at the inner part of the radial cut.

(b) The area should then be cleaned (paragraph 6.2) and any loose fibres should be removed.

(c) Two pieces of glass-fibre cloth, of identical thickness and weave to the original cloth, should be cut to fit exactly into the places from which the damaged plies were cut.

(d) The resin should be mixed and separated into two parts, one part being mixed with chopped glass-fibres (in the proportions specified in the relevant Repair Manual) to plug the hole, and the other part being used to impregnate the glass-fibre cloth.

(e) The hole through the inner plies should be plugged with the resin/glass-fibre mixture, and the repair plies should be placed on each side of the damaged area, with their weave running in the same direction as the original plies.

(f) The second part of the resin mixture (without the chopped glass fibres) should be brushed into the repair plies, to thoroughly impregnate them and to leave a layer of resin on the surface. It may often be necessary to support the area while carrying out the repair and while the resin is curing (paragraph 6.4).

(g) The resin should be left to cure, and when hard should be sanded to the contour of the surrounding laminate. If any glass fibres become exposed during the sanding, a thin coating of catalysed resin should be brushed over the repair and, when it has cured, the paint should be re-applied as appropriate.

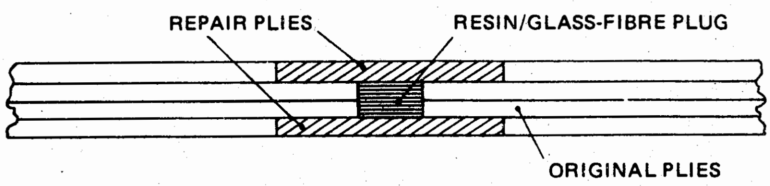

Figure 1 SMALL-HOLE REPAIR

7.5 **Multiple Lamination Repairs.** The type of repair permitted when a number of plies have been damaged, or when a hole larger than that covered by a 'small hole' repair, has been made in a laminate, will depend on the structural importance of the component and requirements such as aerodynamic cleanliness. Figure 2 illustrates several repairs of this type, but the method used for a particular repair must be in accordance with the relevant Repair Manual, in order to ensure that the properties designed into the original structure are maintained.

7.5.1 The overlay repair illustrated in Figure 2(A) would be applied, for example, to an air duct, for which the main concern would be the prevention of leaks. This type of repair would be carried out in the following way:

(a) Remove any loose material from the damaged area and press the surrounding material back into shape. Where possible insert a support, covered with a release agent, into the duct, to support the area while carrying out the repair.

(b) Sand the duct outer surface in an area extending 12 mm (0·5 in) x number of plies from the edge of the damage, taking care not to damage the sound glass-fibre material. Wipe off the dust produced by sanding with a cloth moistened with MEK.

(c) Cut new pieces of glass-fibre cloth of the same type as the original, to cover the repair as shown in Figure 2(A). The same number of plies as in the original laminate should be used.

(d) Mix a quantity of the specified resin and brush this over the sanded area. Place the largest repair ply in position over the damaged area, and brush in resin to completely impregnate the fibres. Cover the area with a sheet of cellophane, and sweep out excess resin and air bubbles with a squeegee made from rubber or plastics. Remove the cellophane and wipe excess resin from the outside of the repair

(e) Place the next repair ply in position, impregnate the fibres, then remove excess resin and bubbles as outlined in paragraph (d).

(f) Repeat paragraph (e) for each of the remaining repair plies.

(g) Cover the repair with a sheet of cellophane, apply pressure if required, and allow the resin to cure. Remove the cellophane and the support.

(h) Further finishing is not normally necessary with this type of repair.

7.5.2 **Scarfed Repair.** This type of repair (Figure 2(B)), and the stepped repair described in paragraph 7.5.3 (Figure 2(C)), are used for the repair of components which must have a smooth outer surface, such as fairings, leading edges and nose cones. The scarfed repair is carried out as follows:

(a) Remove damaged fibres, and carefully cut back the lowest damaged ply to sound material, in a circular or oval shape.

(b) Scarf the area surrounding the damage by sanding, and also sand the outer surface for at least 25 mm (1 in) outside the repair area; care must be taken not to damage sound fibres when sanding. The slope of the scarf should not exceed 1 in 10, but may be as low as 1 in 100 if the laminations are thin. After sanding, wipe the area with a cloth moistened with MEK.

(c) Cut repair plies from glass-fibre cloth which is identical to the original cloth, in such a way that the weave of each ply corresponds to the weave of the ply it replaces. The largest repair ply should be 12 mm (0·5 in) larger all round than the repair area, and subsequent plies should be 12 mm (0·5 in) smaller all round than the underlying ply.

(d) Mix the appropriate resin, and brush a coat over the whole of the sanded area.

(e) Apply the largest repair ply and thoroughly impregnate with resin. Place a sheet

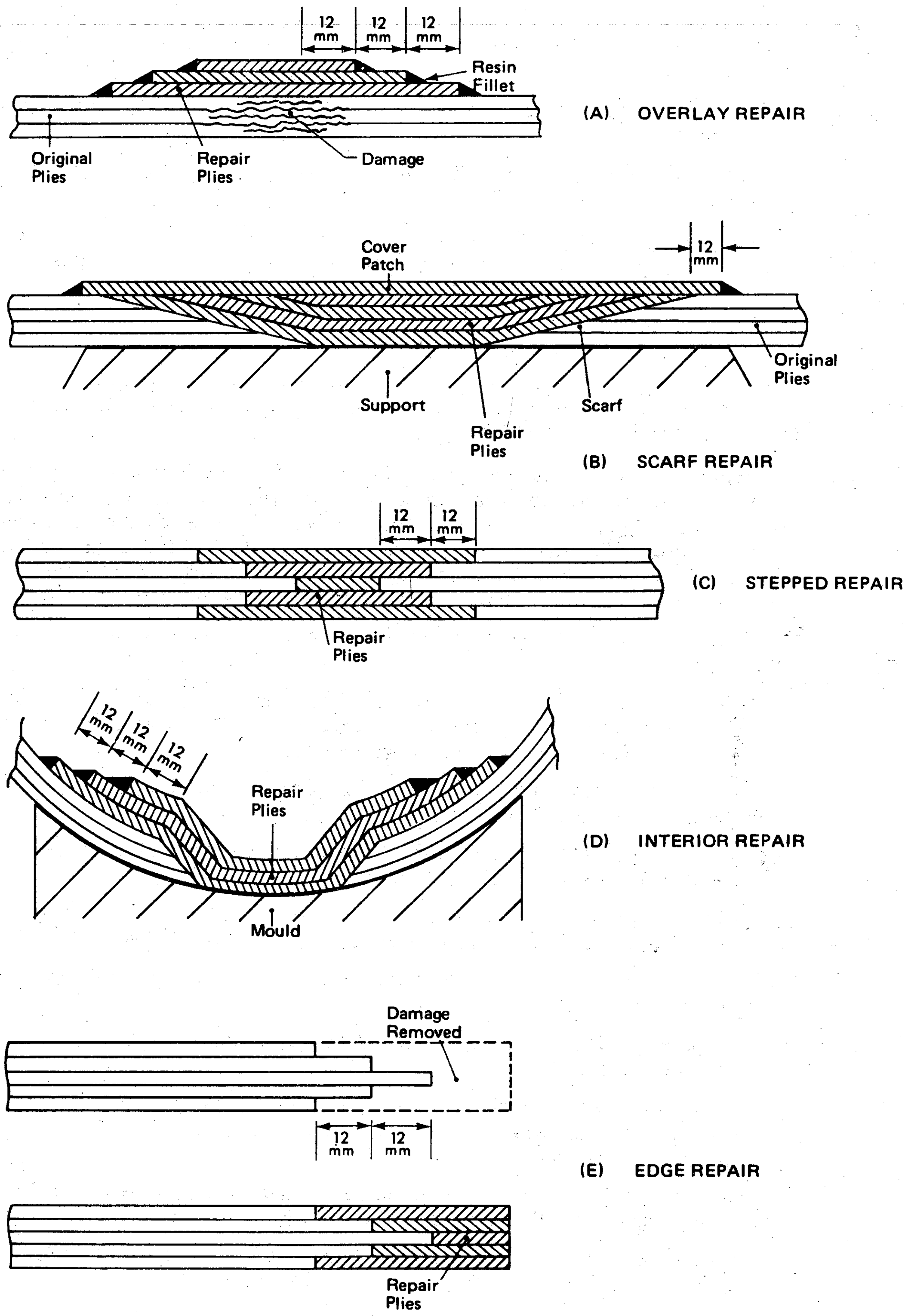

Figure 2 LAMINATE REPAIRS

of cellophane over the ply and sweep out all bubbles and excess resin using a roller or squeegee. Remove the cellophane and wipe off excess resin from the outside of the ply.

(f) Repeat paragraph (e) for each repair ply, until the repair has been built up to the original contour.

(g) Cover the repair with cellophane, and allow to cure, using supports and pressure as required.

(h) When the resin has cured, sand the outer surface to the original contour. If a cover patch is specified for the repair (Figure 2(B)), cut a piece of glass-fibre cloth as shown, and apply as indicated in paragraph (e). Sand this patch smooth when cured, leaving a resin fillet as shown in the illustration.

(j) Paint the repair to the prescribed scheme.

NOTE: Figure 2(D) illustrates a repair which is carried out from the inside. A mould is used to obtain the required shape of the outer surface, and when the repair has cured, this surface is sanded smooth and painted. The inside of the repair is left as shown.

7.5.3 **Stepped Repair.** A stepped repair (Figure 2(C)) is specified for many components, and serves the same purpose as a scarfed repair; in practice, however, separation of the plies may prove to be very difficult. Damage extending through several plies of the laminate can be repaired from the damaged side, but damage affecting all plies should normally be repaired from both sides if practicable, as shown in the illustration. This type of repair is carried out as follows:

(a) Remove damaged fibres and carefully cut back the damaged area to sound material.

(b) Scribe a line on both surfaces, 12 mm (0·5 in) x number of plies to be replaced on that side, from the edge of the damaged area, in a circular or oval shape. Scribe a radial line from the circumference to the centre.

(c) Using a sharp knife, cut through the outer ply along the lines scribed on one surface, taking care not to cut into the lower plies.

(d) Commencing at the inner end of the radial line, pry up and peel off the outer ply within the area enclosed by the cut line.

(e) Scribe a second line, 12 mm (0·5 in) inside the previous line, and remove the second ply. Repeat for subsequent plies until the centre layer is reached.

(f) Turn the laminate over, and repeat operations in paragraphs (c), (d) and (e) on the other side of the laminate.

(g) Sand all exposed surfaces, and sand off all paint within 25 mm (1 in) of the repair, on both sides.

(h) Cut pieces of glass-fibre cloth to the same specification as the original, to fit exactly into the stepped areas, with the weave in the same direction as the corresponding original plies.

(j) Place a support (covered with a release agent) under the original centre ply, to prevent sagging while the first part of the repair is carried out.

(k) Place the smallest repair ply in position, impregnate it with catalysed resin, and remove surplus resin and bubbles as indicated in paragraph 7.5.2 (e).

(l) Position the remaining repair plies on that side, impregnating the cloth and sweeping off excess resin and bubbles before applying the next ply, until the laminate is built up to the original contour.

(m) Turn the component over, support the lower surface, and complete the repair in the same manner as indicated in paragraph (l).

(n) Cover the repair with a sheet of cellophane, apply pressure as required, and allow to cure.

(p) When cured, sand smooth on both sides, apply a thin coat of catalysed resin over any exposed fibres, and when this has cured, finish in accordance with the relevant paint scheme.

7.5.4 **Edge Repairs.** Damage to the edges of glass-fibre laminates frequently occurs through careless handling. Such damage should be rectified by means of a stepped repair such as that illustrated in Figure 2(E), and if the damage is closer than 25 mm (1 in) to a fastener, then the repair should be extended to include the fastener. New material is usually left protruding slightly past the required edge line, and is cut to shape when the repair has cured. It is also often specified that an extra ply of glass-fibre cloth should be overlayed on the outside of the repair, to ensure that the original strength is maintained. Similarly an extra ply may be specified at positions where fasteners are fitted. The repair should be carried out in the same way as the stepped repair explained in paragraph 7.5.3, and particular attention should be paid to sealing the edge of the panel with catalysed resin after it has been trimmed to shape.

7.5.5 **Blind Repairs.** Repairs may sometimes have to be carried out when only one side of the laminate is accessible. In these cases the damage should be removed in an oval shape, so that a backing plate can be inserted through the hole and fixed to the inaccessible side of the laminate. The backing plate should be fabricated from one or two layers of glass-fibre cloth, of sufficient size to overlap the damage by 25 mm (1 in) all round. The repair should be carried out as follows:

(a) Prepare the damaged area for a scarfed or stepped repair.

(b) Cut out two layers of glass-fibre cloth to form a backing plate.

(c) Lay a sheet of cellophane over a mould, or a component having the same contour as the inaccessible side of the damaged area, and impregnate the two layers of glass-fibre cloth onto this surface. Sweep off excess resin and bubbles and allow to cure.

(d) Sand the upper surface of the cured backing plate, and drill two small holes in its centre. Pass a wire through these holes so that the plate can be secured in position.

(e) Apply catalysed resin to the upper surface of the backing plate, insert it through the cut-out and secure it to a support frame as shown in Figure 3. When this resin has cured, remove the wire and support frame, and continue with the repair.

8 REPAIRS TO GLASS-FIBRE HONEYCOMB Damage to, or separation of, the laminated facings of a glass-fibre honeycomb sandwich structure should normally be repaired in the manner described in paragraph 7. Where damage extends into the core material or through the complete structure, however, the core material must also be replaced. Typical repairs are described in this paragraph.

8.1 **Temporary Repairs.** Temporary repairs may be permitted to some components made from glass-fibre honeycomb sandwich material, but permanent repairs should be effected as soon as possible.

8.1.1 **Repairs Using Glass-Fibre.** Loose material should be cut away from the damaged area, and paint should be removed from the surface (within 50 mm (2 in)

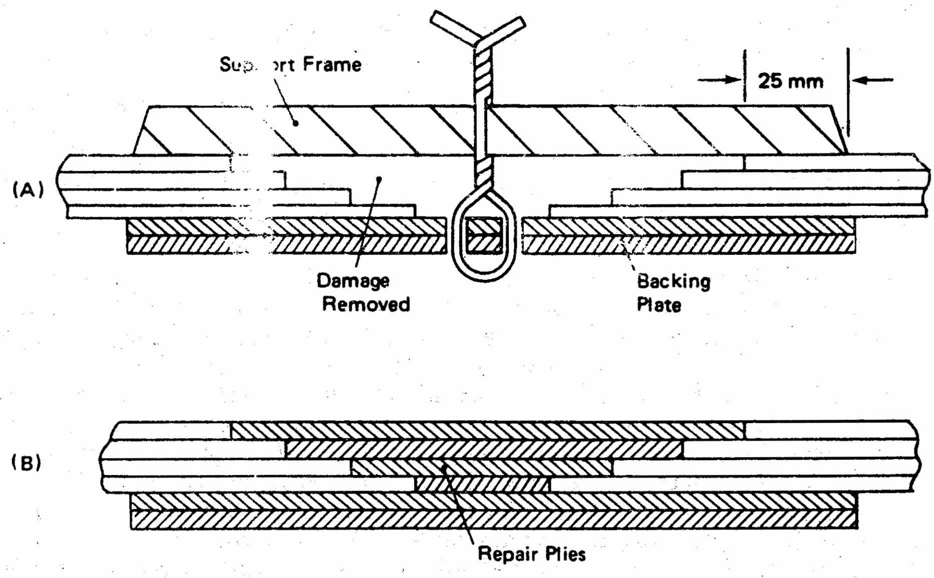

Figure 3 BLIND REPAIR

of the damage) by sanding. The voids in the exposed core material should be filled with catalysed resin (or resin and chopped glass-fibres), and two layers of glass-fibre cloth should be impregnated onto the sanded surface; the lower layer of cloth should overlap the damaged area by 25 mm (1 in) all round, and the upper layer of cloth should overlap the lower one by the same amount. When cured the repair should be sanded smooth.

8.1.2 **Repairs Using Sheet Metal.** Two pieces of thin aluminium alloy sheet (approximately 24 s.w.g.) should be cut and shaped to overlap the damage by at least 25 mm (1 in) all round. After cutting out all loose material, these repair plates should be bolted on each side of the sandwich structure, using distance pieces at the bolt positions to prevent crushing the sound material.

8.2 **Repairs to Core and One Facing.** When the core and one facing have been damaged by physical impact, delamination or water contamination, the core and facing must be cut back to sound material and a repair carried out as illustrated in Figure 4. The procedure is as follows:

(a) Cut out the damage to the facing and core, in the smallest circular or oval shape which will include all the damage. A suitable tool for cutting out the core is a hand-held drill with a circular cutter fitted into the chuck. The lower facing should be supported during this operation and the minimum of pressure should be used, so as to prevent separation of the bonding in the surrounding structure.

(b) Scarf or step the surface laminations to form a shallow depression with a taper of 12 mm (0·5 in) for each ply.

(c) Sand the exposed core and surface of the lower facing to allow the replacement core to seat properly. Sand the scarfed or stepped area, and the surface within 25 mm (1 in) of the perimeter of the repair.

(d) Clean the whole repair area with acetone or MEK.

(e) Cut a section of replacement core material to fit exactly into the cut-out, with the direction of the strips corresponding to the original material. Lightly sand the bottom and sides of the new core, and wash in acetone or MEK.

NOTE: Although the core material will usually be identical to the original honeycomb, in some cases a wood block filling may be permitted and in other cases the damaged core may be replaced by a mixture of resin and micro-balloons.

(f) Coat all mating surfaces of core and cut-out with catalysed resin, and press the core into position.

(g) Fit the repair plies as described in paragraphs 7.5.2 or 7.5.3 as appropriate, and finish in accordance with the relevant paint scheme.

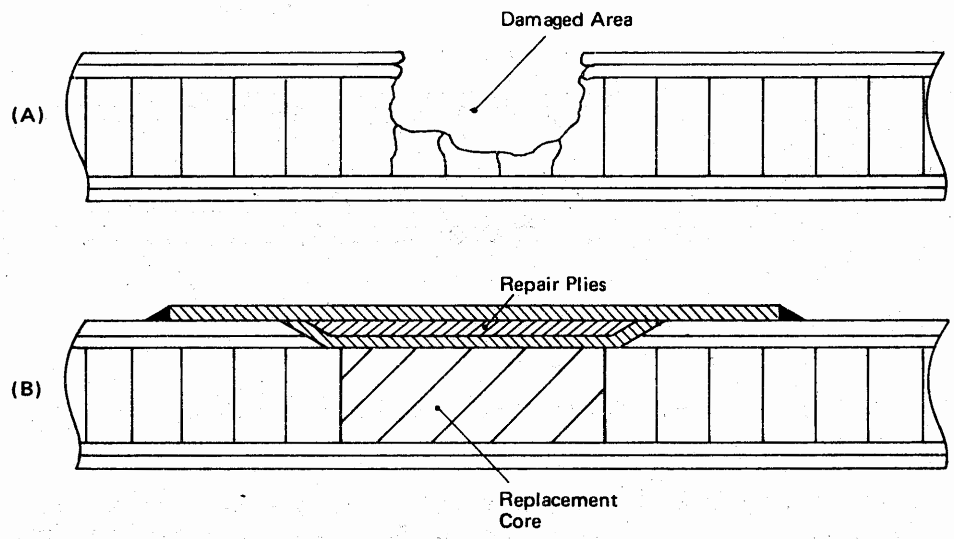

Figure 4 REPAIR TO CORE AND ONE FACING

8.3 **Repairs to Core and Both Facings.** When the damage extends through the whole structure, the repair procedure is similar to that described in paragraph 8.2, but is completed in two steps as follows:

(a) Cut out damaged areas of facings and core, in the smallest circular or oval shape that will remove all damage.

(b) Scarf or step the outer facing laminations to form a shallow depression with a taper of 12 mm (0·5 in) for each ply.

(c) Lightly sand the surfaces of the core cut-out, laminations, and the surface area within 25 mm (1 in) of the periphery of the repair.

(d) Prepare a mould to fit the contour of the inner facing, and cut a distance piece the thickness of the inner facing, which will fit exactly into the cut-out. Apply a release agent to the mould and distance piece, and assemble them to the structure as shown in Figure 5.

(e) Complete the repair to the core and outer facing as described in paragraph 8.2, and allow to cure.

(f) Remove the mould and distance piece, scarf or step the inner facing, and fit the repair plies as described in paragraphs 7.5.2 or 7.5.3 as appropriate.

(g) Allow repair to cure, sand smooth, and finish in accordance with the relevant paint scheme.

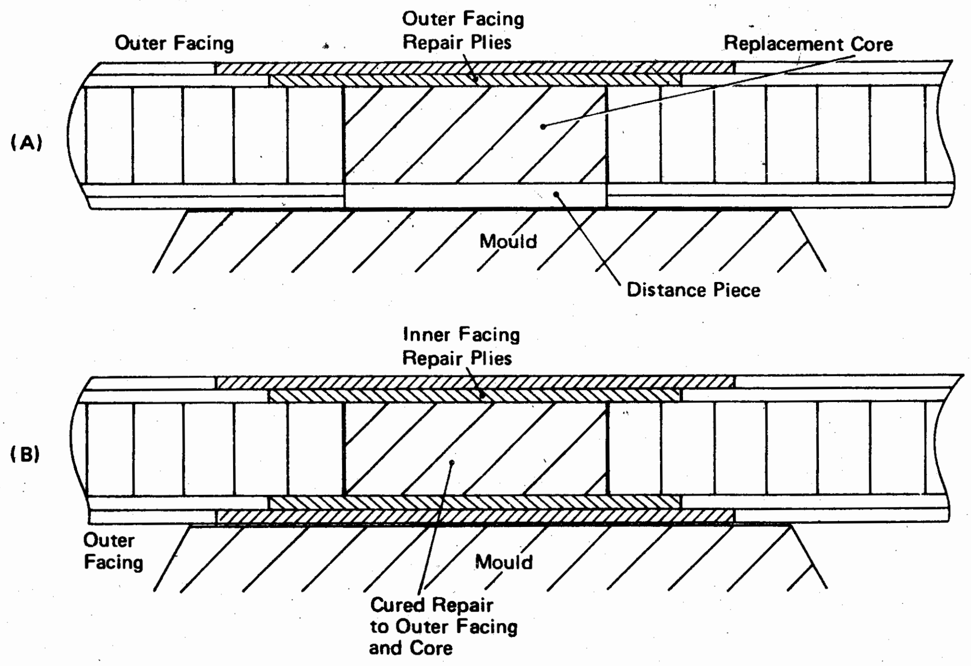

Figure 5 REPAIR TO CORE AND BOTH FACINGS

9 REPAIRS TO ALUMINIUM HONEYCOMB Many aircraft components, such as control surface panels, flap trailing edges, and floor panels, are made from aluminium alloy honeycomb sandwich; both glass-fibre and aluminium material may be used when effecting repairs. Repairs will usually be necessary for dents or other damage exceeding 100 mm (4 in) in any direction, and smaller areas of damage which contain cracks or cannot be sealed to prevent water contamination. Any damage assessed as allowable and not requiring repair should be inspected at frequent intervals to ensure that it is still within acceptable limits.

9.1 **Temporary Repairs.** Temporary repairs may often be permitted on minor damage to certain components, but a permanent repair must be carried out as soon as possible. Examples of temporary repairs are described in paragraphs 9.1.1 and 9.1.2, and illustrated in Figure 6.

9.1.1 Damage sustained, for example, by a wing trailing edge, which extends less than 75 mm (3 in) in any direction, may sometimes be repaired as follows:

(a) Cut out all damaged material, and trim all rough edges, as shown in Figure 6(A).

(b) Thoroughly clean all exposed surfaces with a solvent.

(c) Apply catalysed potting compound (a viscous resin) to all exposed surfaces, to seal the component against water penetration. Allow to cure.

9.1.2 Minor damage which cannot be repaired by the method described in paragraph 9.1.1, may sometimes be repaired by covering it with a riveted metal plate. This type of repair might be considered satisfactory for 100 hours of operation before a permanent repair need be made. The method of carrying out this repair is as follows:

(a) Trim the damaged skin to a regular outline.

(b) Cut and shape a repair patch as shown in Figure 6(B), from aluminium alloy sheet or clad sheet (approximately 22 s.w.g.). Drill pilot holes for rivets at the positions shown.

(c) Temporarily fit the repair patch over the damage and open out the pilot holes to the specified size (clearance holes for 3 mm (0·125 in) rivets are generally required).

(d) Remove repair patch and de-burr all holes.

(e) Clean mating surfaces with trichloroethylene or MEK.

(f) Catalyse potting compound and coat the surface of the component.

(g) Assemble the repair patch, secure with blind rivets, and allow to cure.

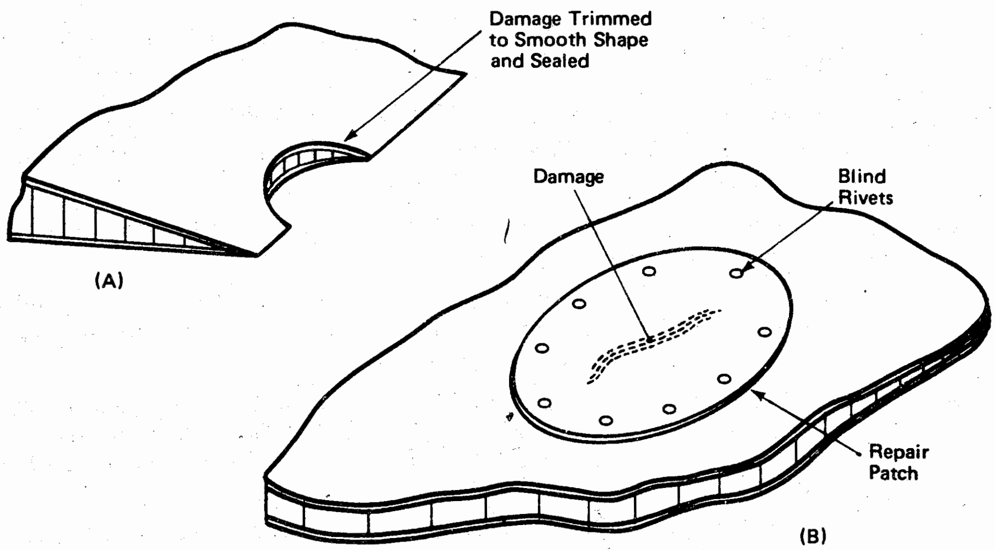

Figure 6 TEMPORARY REPAIRS

9.2 **Edge Delamination.** The delamination should be cleaned as far as possible with MEK. Catalysed cold-setting resin should then be forced into the delaminated area, and allowed to cure under pressure. Pressure may be applied to wedge-shaped edges by means of a clamp and tapered blocks; parts with flat edges may usually be secured by means of solid rivets, which should be closed with a squeeze riveter rather than by hammer blows.

9.3 **Repairs Using Glass-fibre.** Glass-fibre materials are used in many repairs to aluminium honeycomb structures, mainly because they are easier to shape and require no special tools. The resulting repairs may not completely restore the strength of the part, however, and some components may have to be repaired as described in paragraph 9.4. The following glass-fibre repairs are typical of those recommended for many aircraft.

9.3.1 **Skin Cracks.** Providing there is no delamination, cracks in a facing skin may be repaired as follows:

(a) Stop-drill the ends of the crack, using a 6 mm (0·250 in) drill.

(b) Remove all paint and other surface finish within 50 mm (2 in) of the crack by scrubbing with MEK or other approved solvent, then lightly sand to remove surface oxides, taking care not to penetrate the cladding. Paint stripper must not be used unless permitted by the manufacturer, since it could affect the bonding adhesive.

(c) Wipe off all residues with a cloth moistened with MEK or trichloroethylene, wiping off the solvent with a separate cloth before it dries.

NOTE: Trichloroethylene should not be used in enclosed areas.

(d) Apply adhesive primer to the cleaned surface in a thin continuous film and allow to dry.

(e) Cut two pieces of glass-fibre cloth to overlap the crack by 38 mm (1·5 in) all round.

(f) Impregnate the glass-fibre patches on a flat surface as follows:

(i) Cut two pieces of parting film (or cellophane) which will overlap the glass-fibre patches by 75 mm (3 in) all round.

(ii) Place one piece of parting film on a flat surface and brush on a layer of mixed adhesive.

(iii) Place one glass-fibre patch centrally on the adhesive, cover with the second piece of parting film, and work the adhesive into the glass-fibre patch, using a roller or squeegee.

(iv) Remove the upper parting film, spread a film of mixed adhesive over the impregnated patch, place the second glass-fibre patch in position and cover this with the parting film. Again sweep with a roller or squeegee, to impregnate the second patch and remove air bubbles.

(v) Remove patches and parting film together from the flat surface, and trim to the required shape.

(g) Apply a coat of prepared adhesive over the repair area, remove the lower parting film from the patches and place them centrally over the repair.

(h) Remove the upper parting film and replace it with a piece which overlaps the glass-fibre patches by 12 mm (0·5 in).

(j) Sweep out excess adhesive with a roller or squeegee, so that it forms a faired edge around the patches.

(k) Remove the parting film and wipe off excess adhesive; allow repair to cure.

(l) Repaint to the appropriate paint scheme.

9.3.2 **Repairs to Core and Skin.** These repairs are carried out in a similar way to the repairs described in paragraphs 8.2 and 8.3 for glass-fibre honeycomb structures.

(a) Remove damage in a circular or oval shape, using a hole saw or a router and template (paragraph 9.4.3(a) to (d)). If only the outer skin is damaged, the core should be removed down to the surface of the inner skin, but leaving the original adhesive intact.

(b) After removing the debris, sand the core edges with abrasive cloth and prepare the surface as described in paragraphs 9.3.1(b) to (d).

(c) Prepare the replacement core material to fit exactly into the cut-out, but be flush with the outer surface of the skin (Figure 7). A variety of replacement core materials may be used, depending on the purpose for which the structure is required, but glass-fibre honeycomb or mixed resin and micro-balloons are usually specified.

(d) Install replacement core as detailed in paragraphs 8.2(f) and (g).

(e) Fit surface patches of glass-fibre cloth as detailed in paragraphs 9.3.1(e) to (l).

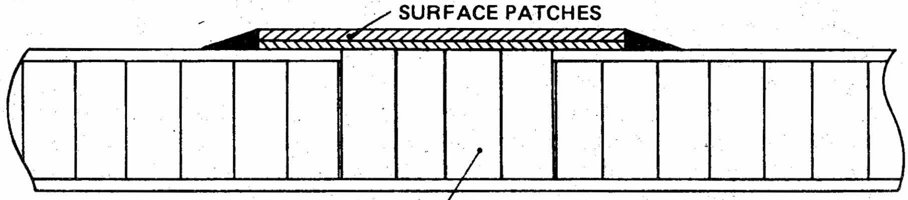

Figure 7 GLASS-FIBRE REPAIR OF METAL STRUCTURE

9.4 **Repairs with Aluminium Material.** When the maintenance of structural strength or the provision of a smooth aerodynamic surface is required, a repair using aluminium materials may be specified. These repairs are carried out in a similar way to repairs using glass-fibre materials, but particular methods of cleaning mating surfaces and the use of a primer to improve adhesion may be recommended; cover patches are often attached by a film adhesive, which is cured using both heat and pressure. A typical flush insert repair is described in paragraph 9.4.3 and illustrated in Figure 8, but the methods used are also applicable to other types of repair and should be used as appropriate.

9.4.1 **Cleaning.** The thorough cleaning of mating aluminium surfaces is particularly important. Some manufacturers require these surfaces to be chemically etched, but abrasive methods such as the use of aluminium oxide cloth, 'Scotch Brite', or a paste made from aluminium oxide powder and water, may also be suitable. Because of the nature of the chemicals used for etching, the manufacturer's instructions appertaining to the etching process must be strictly observed, and any warnings of hazards to health which may be presented, should be noted. Foam or liquid chemicals should be prevented from becoming trapped in inaccessible areas, and all traces should be washed off before continuing with the repair. Once the surfaces have been cleaned, washed and dried, they must be kept completely free from contamination, and the primer or adhesive should be applied as soon as possible.

NOTE: In some cases a 'water break test' may be specified to check the cleanliness of the metal surfaces before continuing with the repair.

9.4.2 **Machining of Aluminium Honeycomb Core.** When it is necessary to shape a piece of aluminium honeycomb for use in a repair, difficulty may be experienced in holding it while machining is carried out. This may be overcome by fixing the honeycomb to a flat metal plate in the following manner:

(a) Place a layer of powdered polyethylene glycol on a flat metal plate, and heat until it melts.

(b) Place core on the metal plate, remove heat, and apply light pressure on the core until the polyethylene glycol has solidified.

(c) If extensive sawing, sanding and machining are required, the honeycomb should be filled with melted polyethylene glycol after the core has been attached to the plate.

NOTE: Machining operations should be carried out without the use of oil or coolant, and care must be taken not to heat the core excessively.

(d) After the machining has been carried out, heat the plate to melt the polyethylene glycol, and hold the core in boiling water to clean it.

9.4.3 **Typical Insert Repair.** The repair described in this paragraph is a flush insert repair such as would be used for damage extending through the core and both skins. It uses material cut from a repair panel (a complete sandwich structure) in the form of a plug, and a fairing patch to provide a smooth exterior contour. Should the damage be confined to the core and one skin, the repair is identical to the flush repair, but, since the damage will usually be on the outside skin, the repair will be raised above the surrounding surface. When a separate core and skin are used the repair methods are similar, but a cover plate will have to be fitted to cover the core and surrounding surface. The repair should be carried out as follows:

(a) Mark the extent of the damage and select a hole saw or router template which will enclose this damage. Remove the damage in a circular or oval shape.

(b) Select and position a hole saw or router template to cut a path through the inner skin 12 mm (0·5 in) outside the cut-out, as shown in Figure 8(A).

(c) Peel off the inner skin between the cut-out and the routed path.

(d) Using a drill fitted with a grinding disc, remove the honeycomb core down to the bonded surface of the outer skin. Remove the remaining adhesive by lightly sanding with fine aluminium oxide paper, taking care not to damage the metal surface (Figure 8(B)).

(e) Prepare a repair insert from a repair panel of the same thickness and strength as the original, so that the ribbon direction matches the existing honeycomb; ideally the new honeycomb should be 1·5 mm (0·0625 in) smaller than the cut-out. Shape a fairing from material of the same type and thickness as the outer skin and, if a separate honeycomb core was used, also shape an inner patch and a cover plate (Figure 8(C)).

(f) Deburr all sharp edges, remove all paint in the area of the repair, and clean all mating surfaces. When the manufacturer does not specify chemical cleaning methods, the procedure outlined in paragraph 9.3.1 may be used.

(g) Mix the adhesive, and apply it to the exposed edges of the core and all mating surfaces of the repair parts and the original skins.

(h) Assemble the repair parts and cure with heat pressure as specified in the Repair Manual.

(j) When the method of applying pressure to the repair is as shown in Figure 8(D), the repair should first be assembled without the fairing. The bolt and pressure plate may then be removed, the bolt hole filled with adhesive, and the repair completed by fixing the fairing in position (Figure 8(E)).

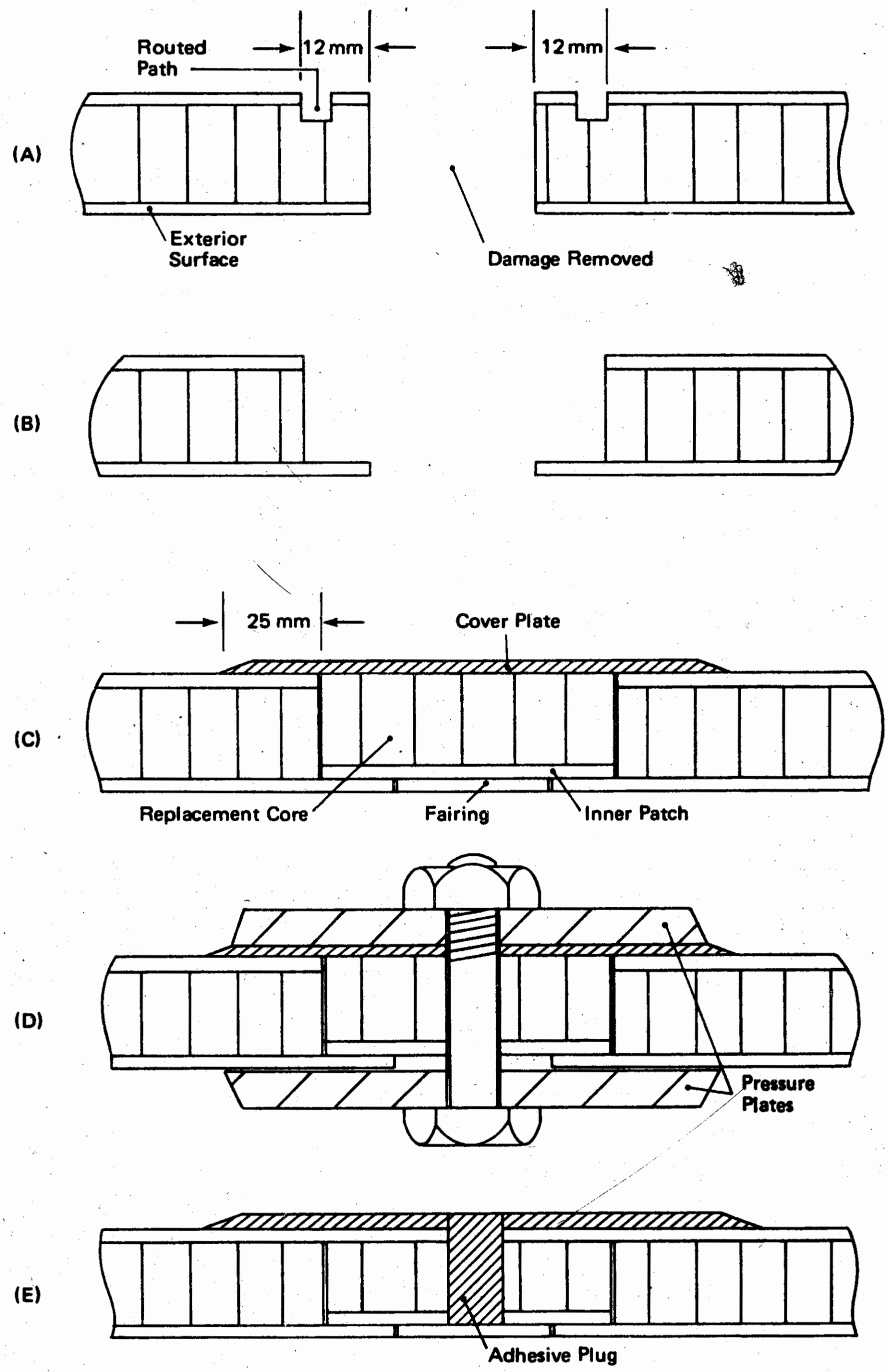

Figure 8 METAL REPAIR OF METAL STRUCTURE

10 RADOMES AND DIELECTRIC PANELS The construction and thickness of a radome or dielectric panel are determined by the structural strength required and the frequency of the signals transmitted by the equipment it houses. Any repairs carried out must, therefore, result in a structure with the same strength, contour, thickness and density as the original. Although in some cases repairs to a radome are not considered a satisfactory proposition, and are not recommended, in other cases quite extensive repairs are permitted, the main factor limiting the size of the repair being the ability to maintain an accurate profile and thickness. It follows, therefore, that particular care must be taken when carrying out repairs to these components, that accurate moulds must be prepared, and that satisfactory means of measuring the thickness of the repair must be available.

10.1 **Repair Limits.** Electrical discharge damage less than 25 mm (1 in) in diameter, and other damage less than 100 mm (4 in) in diameter, may usually be repaired without special electrical tests to check the satisfactory transmission of signals through the radome; a number of these repairs, covering up to 10% of the surface area of the radome may be permitted provided that a specified minimum distance between repairs is maintained. Repairs to larger areas of damage require tests to be made to verify the satisfactory operation of the radome, and if the necessary test equipment is not available the radome should normally be returned to the manufacturer or to an approved repair organization. The tests which must be carried out after a repair has been completed are described in Leaflet **RL/2-5**.

10.2 **Temporary Repairs.** Damage up to approximately 25 mm (1 in) in diameter may often be repaired on a one-flight basis, to enable the aircraft to be flown to a base where permanent repairs can be carried out. It must be appreciated, however, that operation of the radar may be impaired.

10.2.1 Loose debris should be removed, and the damage should be cleaned out to a smooth finish. The hole may be filled with sealant or by a plug made from wood or other suitable material, and a neoprene patch, overlapping the damage by at least 12 mm (0·5 in) all round, should be fixed over the damaged area with a suitable adhesive.

10.3 **Permanent Repairs.** Repairs to a damaged radome or dielectric panel are the same as repairs carried out to other parts of similar construction, but special care must be taken to ensure that the final thickness over the repair area is as near as possible to the original thickness. In some cases the dimensional limits for different areas on the radome are specified in the relevant Repair Manual, and, if the final thickness of the repair is outside these limits, electrical tests must be carried out. If the repair does not have a flat inner and outer surface (Figure 9), measurement of the thickness is essential, and eddy current instruments are often used; repairs with surfaces conforming to the original contour (Figure 10) may often be performed using a mould for the inner surface and templates for the outer surface.

10.3.1 **Scarfed Repair.** This repair should be carried out as described in paragraphs 8.2 or 8.3 as appropriate, but the core material must be to the same specification as the original core, no alternative generally being permitted. In addition, the repair of the inner-facing laminations is made larger than that on the outer-facing laminations, so as to minimize the increase in thickness which could result from facing repairs of the same size. The repair is illustrated in Figure 9.

10.3.2 **Stepped Repair.** A stepped repair is also carried out in a similar way to that described in paragraphs 8.2 or 8.3 as appropriate, but the edges of the inner-facing repair plies should be staggered between those of the outer-facing plies (Figure 10). In addition, the edges of the original plies should be chamfered and the edges of the repair plies should be frayed, so as not to produce an abrupt change of section in the repair.

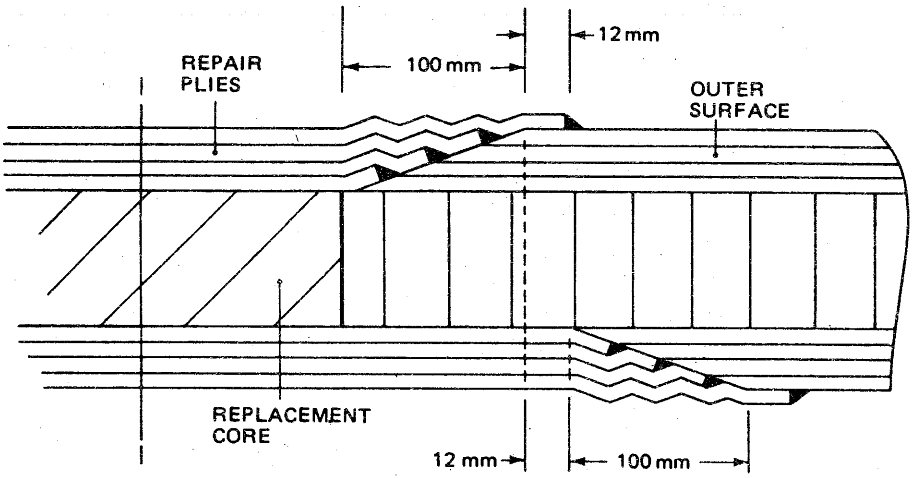

Figure 9 SCARFED RADOME REPAIR

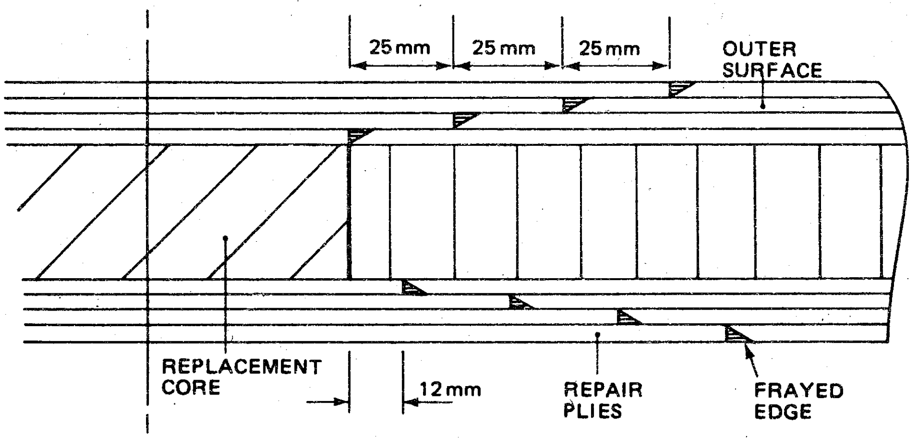

Figure 10 STEPPED RADOME REPAIR

10.3.3 Although it is generally recommended that a repair should be circular or oval in shape, some manufacturers suggest that a better fit may be obtained by shaping a square or rectangular replacement core, and permit this type of repair. The facing plies should also be removed in a square or rectangular outline, with the sides parallel to the weft and warp of the original glass-fibre cloth, but with rounded corners of at least 25 mm (1 in) radius.

AL/7-8

Issue 4

September, 1988

AIRCRAFT

STRUCTURES

ASSEMBLY AND MAINTENANCE OF CRITICAL BOLTED JOINTS

1 INTRODUCTION

1.1 In the context of this Leaflet the term 'critical bolted joint' is used to describe any bolted joint or attachment where stress levels are high and where inadequate assembly techniques could result in fatigue failure. Examples of critical bolted joints are spar joints, tailplane attachments, wing attachments, and engine mounting structure.

1.2 This Leaflet gives guidance on the recommended assembly procedure for critical bolted joints and on the extent to which inspection can verify that design requirements have been met. Guidance is also given on the inspections necessary during maintenance and overhaul to ensure the continued effectiveness of the joint.

1.3 Where specialised procedures or techniques are specified for the preparation or assembly of a critical bolted joint, the manufacturer's published procedures should be referred to and their recommendations observed.

1.4 Related CAIP Leaflets:—

BL/4-1	Corrosion — Its Nature and Control
BL/4-2	Corrosion — Removal and Rectification
BL/4-3	Corrosion — Methods of Protection
BL/6-30	Torque Loadings
BL/8-5	Magnetic Flow Detection

1.5 The subject headings are as follows:—

2 ASSEMBLY PROCEDURE

2.1 During the initial assembly of a joint, checks should be made to ensure that the component parts are protected against corrosion, that the edges of holes are de-burred, chamfered or radiused as appropriate and that mating surfaces are free from swarf or other foreign matter.

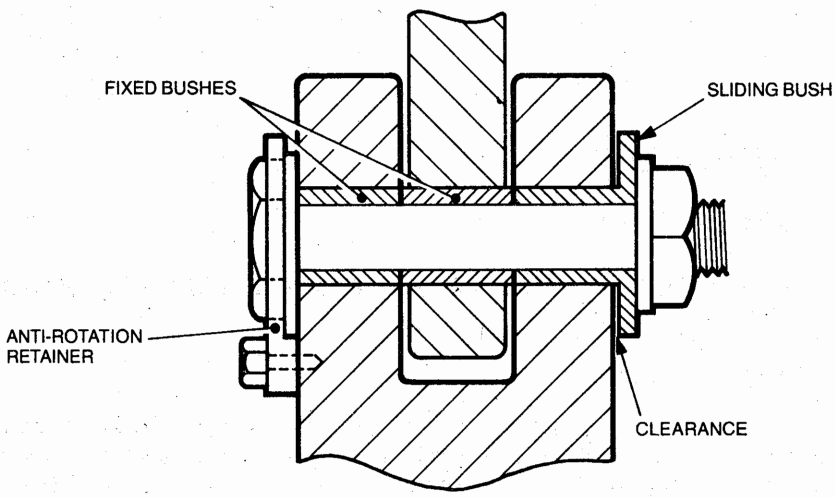

Figure 1 FORK FITTING WITH SLIDING BUSH AND ANTI-ROTATION RETAINER WHEN APPLICABLE

2.2 Before bolts are inserted it must be ensured that parts are correctly assembled and that no mis-alignment is present. Where one component is a fork-type fitting, a sliding bush may be fitted in one arm of the fork; provided that a clearance is maintained between the head of the bush and the fork during tightening of the assembly bolt (Figure 1), stressing of the fork fitting will be avoided. In other cases a good fit is obtained by selective assembly or by fitting shims or washers; if play is present in this type of joint the tightening of attachment bolts will induce a stress and weaken the fork fitting.

2.3 In some instances assembly instructions may require good bearing contact between the mating surfaces of the various components and also on the pressure faces of bolt heads and nuts. Tapered bolt holes should be checked by applying engineers blue to the hole and lightly rotating the bolt, while flat surfaces should be checked on a surface table, or by the use of engineers blue or feeler gauges during a trial assembly. Poor bearing surfaces should then be corrected by light lapping. Each hole should be checked using its own assembly bolt.

2.4 In some instances the surfaces of bolt holes in critical locations are stressed to prevent crack propagation and fatigue failure. Plastic deformation of the material surrounding the holes is produced by some form of broaching, such as the use of an interference fit mandrel, before the assembly bolt is fitted. In the case of tapered bolts in aluminium alloy components the hole is reamed until the bolt stands proud of the surface by a specified amount then, during final tightening, the tapered bolt expands the hole and induces compressive stress in the hole surface.

2.5 When performing operations such as drilling, reaming, lapping, etc., prior to final assembly of a joint, it is essential that the assembly is trued and held securely in position by clamps, slave bolts etc. This will prevent the ingress of swarf between faying surfaces and ensure that the joint is retained in this position when the joint bolts are finally inserted. Greater joint accuracy will be ensured if the joint bolts are inserted in sequence on each side of the joint immediately after each bolt fitting operation.

2.6 Parallel holes which have been opened to full size during assembly may be checked for size by means of plug gauges, but in certain instances, particularly when interference fits are required, the use of more specialised measuring equipment such as a pneumatic bore gauge may be necessary.

2.7 Careless fitting or assembly can considerably reduce the fatigue life of a joint. A burr on a bolt, or a piece of swarf left in a hole can scratch the surface of the hole and result in the concentration of stresses. To prevent the scoring of bolts and holes thorough cleanliness must be maintained and if shouldered bolts are used a 'bullet' should be fitted to protect the thread and provide a lead-in for the bolt shank. Lubrication of the bolts is usually recommended and the lubricant (or sealant) should be kept in a sealed container to prevent contamination when not in use. (See paragraph 3.)

2.8 It will be appreciated that many highly stressed joints will require no hand fitting. The components may be jig built to very fine tolerances which obviate most of the fitting precautions outlined in the preceding paragraphs. However, a high standard of cleanliness and care in handling the components is still necessary if design strength is to be maintained.

2.9 Where joints or fittings have more than one bolt, progressive tightening should be carried out in order to prevent stresses being induced. In some cases the final tightening sequence will be stipulated on the appropriate drawing. Nuts should be fitted finger-tight then progressively tightened to the appropriate pre-load value, but new parts may require bedding-in by first tightening to half the pre-load, slackening, then finally tightening in accordance with the manufacturer's recommendations.

3 JOINTING COMPOUND

3.1 There are a number of different compounds in use which are selected according to the type of joint, the probable frequency of disassembly, the material involved, the method of assembly, the protective treatments applied and the conditions of operation.

3.2 Pigmented varnish jointing compound to DTD 369, or other compounds covered by specification DTD 900, are frequently used to prevent scuffing and corrosion in joints, and cold-setting polysulphide synthetic rubber materials are often used for joint sealing. Other materials may be specified for use in particular locations, and reference should be made to the appropriate aircraft manual for instructions regarding their use.

3.3 In joints where hard-setting compounds are specified, precautions should be taken to ensure that the joint is tightened whilst the compounds are still wet, otherwise dimensional tolerances may be seriously affected if the compounds become dry before the joint is tightened.

3.4 Care should be taken to ensure that only the specified jointing compound is used, since, for example, that complying with DTD 369 is not suitable where temperatures in the vicinity of the joint may exceed 200° C, whilst hard-setting compounds are unsuitable in areas where vibration may occur.

3.5 Jointing compounds will give unsatisfactory results if kept in open containers which allow them to become semi-dry before application, and to ensure consistent results from occasional use are often supplied in squeeze-tubes.

3.6 Sealants are usually supplied in twin-pack form, and mixing instructions should be followed carefully. Once mixed the sealant starts to harden, and final assembly of a joint should be completed within a specified application time. Sealant which is not used within its application time must be discarded.

4 TIGHTENING OF BOLTS

4.1 The tension (pre-load) applied to a bolt during tightening should be greater than the highest stress likely to be encountered in service. The most efficient joint would be obtained by tightening each bolt to its yield point but, due to manufacturing tolerances and other variables, the practice would be dangerous to apply; in addition, each bolt could only be used once. A number of other ways of pre-loading bolts have been devised, and although these may result in a less-than-optimum tension, have proved satisfactory in service.

4.2 Under-tightening of bolts in highly stressed joints may, when load is applied, result in lack of contact or rigidity between the separate parts of the assembly. Where alternating or fluctuating loads are applied to such joints early fatigue failure may occur. Conversely, over-tightening is likely to cause immediate failure of the bolts or distortion of one or more parts of the assembly.

4.3 The general problem of applying a specified pre-load to a bolt is also affected by the need to line up split-pin holes. Unless the bolt pre-drilling suits the joint and nut dimensions, or the bolt is drilled after tightening, the applied pre-load will be inaccurate to the extent of the nut adjustment. In some applications this inaccuracy may be acceptable, but in others the selection of alternative nuts or washers may be recommended.

NOTE: For some installations the bolt head is indexed and must be maintained in the required position by an anti-rotation retainer (see Figure 1).

4.4 **Torque Loading.** The most common method of pre-loading is by applying a specified torque to the nut during tightening. Laboratory tests are carried out to ascertain an appropriate torque loading for any particular application, taking into account the type of thread, bolt and nut materials, manufacturing tolerances, type of anti-corrosive treatment and type of lubricant. This loading is applied by means of a torque wrench and results in a reasonably consistent pre-load being applied to the bolt. The use of torque wrenches is discussed in Leaflet **BL/6-30**.

4.5 **Pre-load Indicating Washers.** The value of the pre-load applied to a fastener by means of a torque wrench may vary considerably and, because of this, specified torque loadings are usually low compared with the actual strength of the fastener. In certain critical bolted joints the manufacturer may consider that more accurate clamping is required and specify the use of pre-load indicating (PLI) washers.

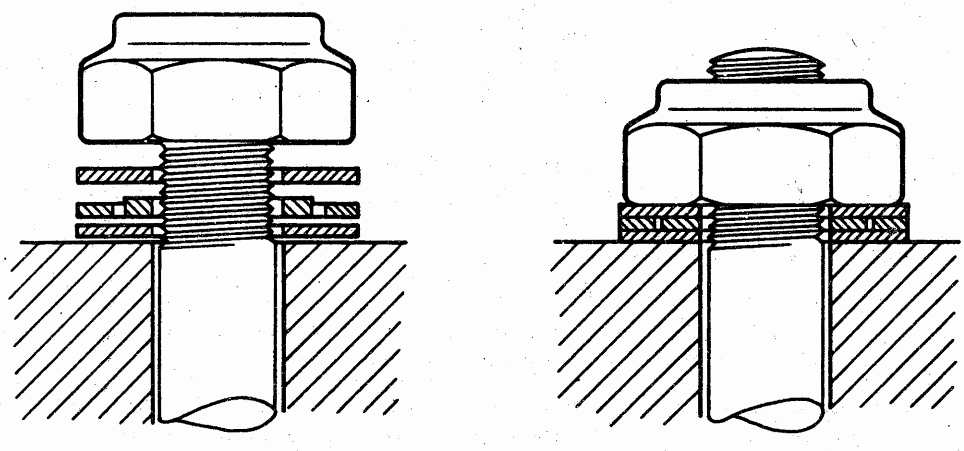

Figure 2 PRE-LOAD INDICATING WASHERS

4.5.1 PLI washers consist of concentric inner and outer rings, and two high-strength steel washers as shown in Figure 2. The outer ring is thinner than the inner ring and has a series of radial holes drilled through it.

4.5.2 A stiff wire tool is inserted in holes in the outer ring and used to check whether the ring is free to rotate (Figure 3). As the nut is tightened the inner ring is compressed until, at a predetermined pre-load, the outer ring is nipped between the washers; at this point the outer ring can no longer be rotated and tightening is complete.

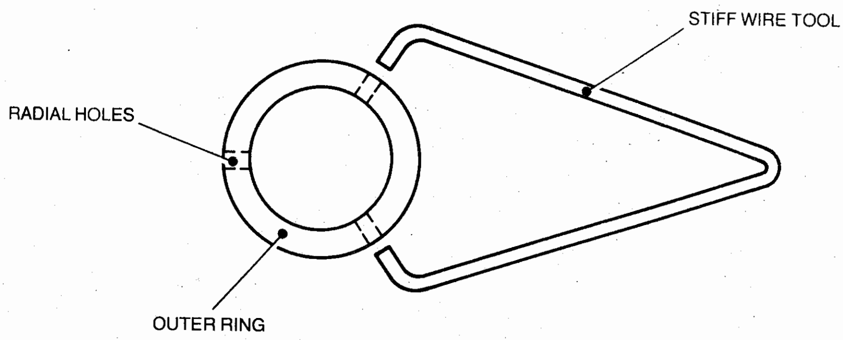

Figure 3 CHECKING PLI WASHER FOR ROTATION

4.5.3 PLI washers are unaffected by thread or nut friction, or by lubrication, and provide a means of pre-loading a bolt which is more consistent than torque loading. The pre-load applied to any particular size of bolt can be varied to suit its application by changes in the material or dimensions of the inner ring. However, since the inner ring is compressed during tightening it can only be used once, and if slackened must be replaced.

4.5.4 Due to the method of tightening, PLI washers can only be used with self-locking nuts.

4.6 **Shear Type Fasteners.** A number of proprietary fasteners are available which permit a reasonably accurate pre-load to be applied to a bolt without the use of torque wrenches. The nut normally used has an upper hexagonal wrenching portion, separated from the main nut by a deep groove. The hexagon portion shears off during tightening when a predetermined clamping force is reached.

4.7 **Bolt Extension.** An accurate method of pre-loading which, unfortunately, can not often be used in airframe applications for reasons of inaccessibility, is the measurement of bolt extension. The bolts are tightened until a specified extension has taken place, as measured by means of a micrometer or similar instrument.

4.8 **Dished Washers.** These washers are sometimes used on dynamically loaded structures. The washers consist of circular discs of constant thickness and have an initial 'dish' raising the centre, so that when nipped they act as a spring of very high rating and will accommodate a certain amount of stretch in the bolt shank, or bedding-in of the head. By variation of the thickness, outer diameter and height, a wide variety of load deflection characteristics can be obtained, but unlike pre-load indicating washers, there is no reliable way of ensuring when optimum tightness has been reached.

4.9 **Standard Spanners.** The use of standard spanners is seldom recommended as the only method of tightening a critical bolted joint. British Standard 192 gives the lengths of spanners to be used with the different sizes of nuts, and this leverage is usually adequate for general engineering work. It would, however, be impossible for even a skilled operator to apply a consistent amount of pre-load to a variety of bolt sizes. A reasonably accurate torque loading could be applied, in emergency, by using, for example, a double ended ring spanner and a spring balance, with the direction of pull at 90° to the spanner. The balance reading multiplied by the spanner length would give the torque loading applied.

NOTE: In certain installations the material of the component dictates use of special tools or protection from contact with standard tools.

5 INSPECTION OF BOLTED JOINTS

5.1 Unless bolts are extracted, visual examination is unlikely to reveal the faults which are usually associated with the beginning of cracks, fretting, corrosion etc. However, visual inspection is important as a means of checking that there are no indications of movement in the joint and that the external protective treatment is in good condition.

5.2 At the periods specified in the approved Maintenance Schedule, bolts should be extracted to enable a detailed examination to be made. Although this can be done most conveniently if the joint is broken down during major overhaul, on some aircraft one or more bolts may be required to be removed from critical joints at more frequent intervals. Whenever bolts are to be removed from these joints it will be necessary to support the surrounding structure in such a way as to remove the loads normally taken by the joint. The supports should be adjusted so that no residual loads are present in the joint when the bolts are removed, and this may often be checked by fine adjustments to the supports until the bolts rotate easily. Bolts may often be removed by means of a suitable extractor but, if the bolts are tight or stuck because of the presence of corrosion products or jointing compound, it may be preferable to punch them out with a drift. Extreme care is necessary to avoid damaging the bolt threads as this could result in damage to the hole and induce stress failure; it is also advisable to support the structure round the head of a bolt using a hollow dolly.

5.3 **Examination of Bolts.** When bolts are removed they should be examined for signs of steps, cracks, fretting or corrosion. An appropriate type of non-destructive testing must be used when checking for cracks, the electromagnetic process being suitable for most steel bolts. See Leaflet **BL/8-5**.

5.3.1 Where applicable, the protective coating should be examined for condition and, if the plating is scored or partially rubbed away, the bolt should either be replated or discarded.

5.3.2 The threads should be thoroughly cleaned and examined to ensure freedom from damage. Failure to do this may result in excessive friction between the bolt and nut, and lead to incorrect pre-loading if a torque wrench is used.

5.3.3 If, after examination, a doubt exists regarding the serviceability of the bolts, they should be rejected.

5.4 **Examination of Bolt Holes.** The bolt holes should be examined for signs of scoring, fretting, corrosion and cracks. A preliminary examination should be made before the hole is cleaned, since this is the most suitable time for detecting corrosion deposits, but it may be found that jointing compound obscures much of the hole surface.

5.4.1 The hole should be cleaned out with a suitable solvent, such as trichloroethylene, and then re-inspected.

5.4.2 The inspection of bolt holes can sometimes be difficult, but an optical aid such as a borescope is often used and eddy current methods are also frequently recommended.

5.5 **Fretting.** Examples of aircraft components which have failed through fatigue originating in areas of fretting, have shown that fractures do not necessarily pass through adjacent bolt holes.

5.5.1 Fretting at major joints is often revealed, by black or grey dust or paste in aluminium structures and brown rust stains in steel parts, at the periphery of faying surfaces. Cracks may develop from the outer edge of a fretted area and extend across the component. An examination of a component showing signs of fretting should, therefore, include the flat surfaces as well as the bolt holes.

5.5.2 An inspection of this nature would entail disassembly, and examination by means of penetrant dye, eddy current or ultrasonic (surface wave) methods.

5.6 **Reassembly of the Joint.** When reassembling the joint the assembly recommendations given in the preceding paragraphs should be taken into consideration.

6 LOCKING Locking devices must be sufficiently effective to prevent loosening or turning of the threaded parts and they should be fitted as specified in the relevant drawing or manual. Most locking devices may only be used once, but those which can be re-used should be checked for effectiveness before being refitted.

AL/7-9

Issue 3.

1*st October*, 1972

AIRCRAFT

STRUCTURES

INSPECTION OF WOODEN STRUCTURES

1 INTRODUCTION This Leaflet gives guidance on the inspection of wooden aircraft structures for evidence of deterioration of the timber and glued joints. It should be read in conjuction with the relevant aircraft manuals, approved Maintenance Schedules and manufacturers' instructions, from which details of particular structures may be obtained.

1.1 Information on the conversion of timber into aircraft parts is given in Leaflet **BL/6-6** and on the use of synthetic resin adhesives in **BL/6-7.**

2 CAA POLICY Airworthiness Notice No. 50 describes the extent of the deterioration which has been found in wooden structures and the dismantling which may be necessary to enable thorough inspections to be carried out. Airworthiness Notice No. 67 reflects the CAA policy towards re-certification and flying of certain types of aircraft manufactured principally from wood. It also contains a list of aircraft with glued ply and timber torsion box spars, which will only be granted a new Certificate of Airworthiness following detailed investigation of each aircraft.

2.1 While these notices express concern at the extent of deterioration found in some aircraft, it is also pointed out that there is no reason why aircraft constructed in these materials should not have a satisfactory life provided they are protected from the adverse effects of extreme temperature and humidity and are kept in suitable hangars when not in use.

3 GLUED STRUCTURES Provided that protective varnish was applied to all exposed wood surfaces after gluing and satisfactorily maintained during the life of an aircraft, rapid deterioration of timber and glued joints would be unlikely. However, access to internal structure is often difficult or even impossible, and deterioration takes place for a variety of reasons.

3.1 Some of the main factors which may cause deterioration are:—

(i) Chemical reactions of the glue itself due to ageing or moisture, to extremes of temperature or to a combination of these factors.

(ii) Mechanical forces due mainly to timber shrinkage.

(iii) Development of mycological growths (i.e. fungus).

(iv) Oil percolating from the engine installation.

(v) Fuel contamination due to system leaks or spillage in the tank bays.

(vi) Blockage of water drainage holes.

3.2 Aircraft which are exposed to large cyclic changes of temperature and humidity are especially prone to timber shrinkage which in turn may lead to glue deterioration. The amount of movement of timber members due to these changes varies with the volume of each member, the rate of growth of the tree from which the timber was cut and the way in which the timber was converted. Thus, two major members in an aircraft structure, secured to each other by glue, are unlikely to have identical characteristics and differential loads will, therefore, be transmitted across the glue film with changes of humidity. This will impose stresses in the glued joint which, in temperate zones, can normally be accommodated when the aircraft is new and for some years afterwards. However, with age the glue tends to deteriorate, even when the aircraft is maintained under ideal conditions, and stresses at the glued joint, due to changes in atmospheric conditions, may cause failure of the joint.

3.2.1 In most wooden aircraft of monoplane construction the main spars are of box formation consisting of long top and bottom transverse members (i.e. spar booms) joined by plywood webs. The spar booms may be built up from laminations glued together, and at intervals vertical wooden blocks are positioned between the two booms to add support to the plywood sides.

3.2.2 The main spars carry most of the loads in flight and are, at times, subject to flexing. The glued joints should, therefore, be free from deterioration but, unless the spar is dismantled or holes cut in the webs, internal inspection may be virtually impossible.

3.2.3 Long exposure to inclement weather or strong sunlight will tend to destroy the weatherproofing qualities of fabric coverings and of surface finishes generally. If fabric-covered ply structures are neglected under these conditions the surface finish will crack, allowing moisture to penetrate to the wooden structure and resulting in considerable deterioration through water soakage.

4 SURVEY OF STRUCTURE Before commencing a detailed examination of an aircraft structure, the aircraft should be inspected externally for signs of gross deformation, such as warped wing structures, tail surfaces out of alignment or evidence of obvious structural failure. In some cases of advanced deterioration this assessment may be sufficient to pronounce the aircraft beyond economical repair, and thus avoid further work.

4.1 Whenever possible the aircraft should be housed in a dry, well ventilated hangar, and all inspection panels, covers and hatches removed before continuing with the survey. The aircraft should be thoroughly dried out before examining glued joints or carrying out repairs.

4.1.1 Immediately after opening the inspection panels, etc., each component should be checked for smell. A musty smell indicates fungoid growth or dampness and, if present, necessitates further examination to establish which areas are affected.

4.1.2 Where the wings, fuselage or tail unit are designed as integral stressed structures, such as inner and outer ply skins glued and screwed to structural members (Figure 1) no appreciable departure from the original contour or shape is acceptable.

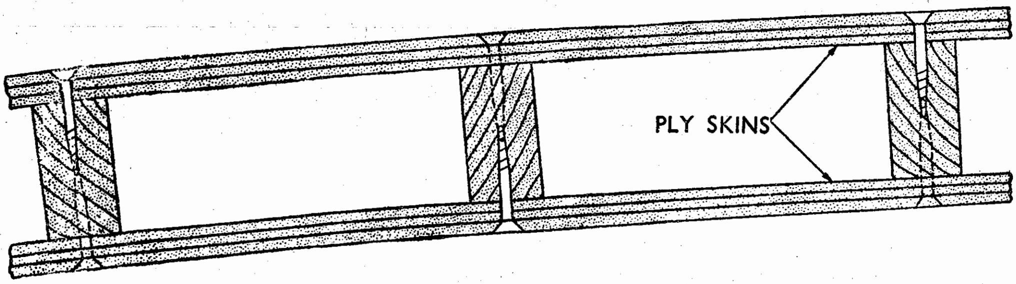

Figure 1 DOUBLE SKIN STRUCTURE

4.1.3 Where single skin plywood structures are concerned, some slight sectional undulation or panting between panels may be permissible provided the timber and glue is sound. However, where such conditions exist, a careful check must be made of the attachment of the ply to its supporting structure, and moderate pressure with the hand, to push the ply from the structure, should be used. A typical example of a distorted single skin structure is illustrated in Figure 2.

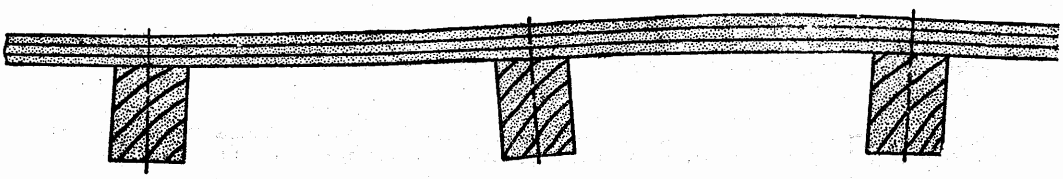

Figure 2 SINGLE SKIN STRUCTURE

4.1.4 The contours and alignment of leading and trailing edges are of particular importance and a careful check should be made for deformities. Any distortion of these light ply and spruce structures indicates deterioration, and a careful internal inspection should be made for security of these parts to the main wing structure. If a general deterioration is found in these components the main wing structure may also be affected.

4.1.5 Where there are access panels or inspection covers on the top surfaces of wings or tailplane, care is necessary to ensure that water has not entered at these points where it can remain trapped to attack the surrounding structure.

4.2 Splits in the proofed fabric covering on plywood surfaces should be investigated by removing the defective fabric in order to ascertain whether the ply skin beneath is serviceable. It is common for a split in the ply skin to be the cause of a similar defect in the protective fabric covering.

4.3 Fabric having age cracks, and thick with repeated dopings, may indicate that the structure underneath has not been critically examined for a considerable time. Insertion patches in the fabric could also indicate that structural repairs have been made at that point.

4.4 Whilst a preliminary survey of the external structure may be useful in roughly assessing the general condition of the aircraft, it should be noted that timber and glue deterioration often takes place inside a structure without any external indications. Where moisture can enter a structure, it will tend to find the lowest point, where it will stagnate and promote rapid deterioration. Other causes of glue deterioration are listed in paragraph 3.1.

5 INSPECTION OF TIMBER AND GLUED JOINTS Assessment of the integrity of glued joints in aircraft structures presents considerable difficulties since there is no positive non-destructive method of examination which will give a clear indication of the condition of the glue and timber inside a joint. The position is made more difficult by the lack of accessibility for visual inspection.

5.1 The inspection of a complete aircraft for glue or wood deterioration will necessitate checks on remote parts of the structure which may be known, or suspected trouble spots and, in many instances, are boxed in or otherwise inaccessible. In such instances, considerable dismantling is required and it may be necessary to cut access holes in ply structures to facilitate the inspection; such work must be done only in accordance with approved drawings or the repair manual for the aircraft concerned and, after the inspection has been completed, the structure must be made good and protected in an approved manner.

5.2 All known or suspected trouble spots must be closely inspected regardless of log book records indicating that the aircraft has been well maintained and properly housed throughout its life.

NOTE: Where access is required and no approved scheme exists, a scheme should be obtained from the aircraft manufacturer or an Organisation appropriately approved by the CAA for such work.

5.3 **Access Holes.** In general, access holes are circular in shape and should be cut with a sharp trepanning tool to avoid jagged edges. It is essential to avoid applying undue pressure to the tool, especially towards the end of the cut, otherwise damage may be caused to the inner face of the panel by stripping off the edge fibres or the ply laminations.

5.3.1 Where rectangular access holes are prescribed care is necessary to ensure that they are correctly located and that corner radii are in accordance with drawing requirements.

5.3.2 The edges of all access holes must be smoothed with fine glasspaper, preferably before inspection is commenced, since contact with the rough edges may cause wood fibres to be pulled away.

5.4 It is important that the whole of the aircraft structure, including its components, e.g. tailplane, elevators, etc., is inspected in detail before any decision is reached regarding general condition. It is possible for the main airframe to be in good condition but for a marked deterioration to have occurred in, for example, a control surface.

5.5 **Glue Line.** When checking a glue line (i.e. the edge of the glued joint) for condition, all protective coatings of paint should be removed by careful scraping; it is important to ensure that the wood is not damaged during the scraping operation, and scraping should cease immediately the wood is revealed in its natural state and the glue line is clearly discernible.

5.5.1 The inspection of the glue line is often facilitated by the use of a magnifying glass. Where the glue line tends to part or where the presence of glue cannot be detected or is suspect, then, providing the wood is dry, the glue line should be probed with a thin feeler gauge and, if any penetration is possible, the joint should be regarded as defective.

NOTE: It is important to ensure that the surrounding wood is dry, otherwise a false impression of the glue line would be obtained due to closing of the joint by swelling. In instances where pressure is exerted on a joint, either by the surrounding structure or by metal attachment devices such as bolts or screws, a false impression of the glue condition could be obtained unless the joint is relieved of this pressure before the glue line inspection is carried out.

5.5.2 The choice of feeler gauge thickness will vary with the type of structure, but a rough guide is that the thinnest possible gauge should be used. Figure 3 indicates the points where checks with a feeler gauge should be made.

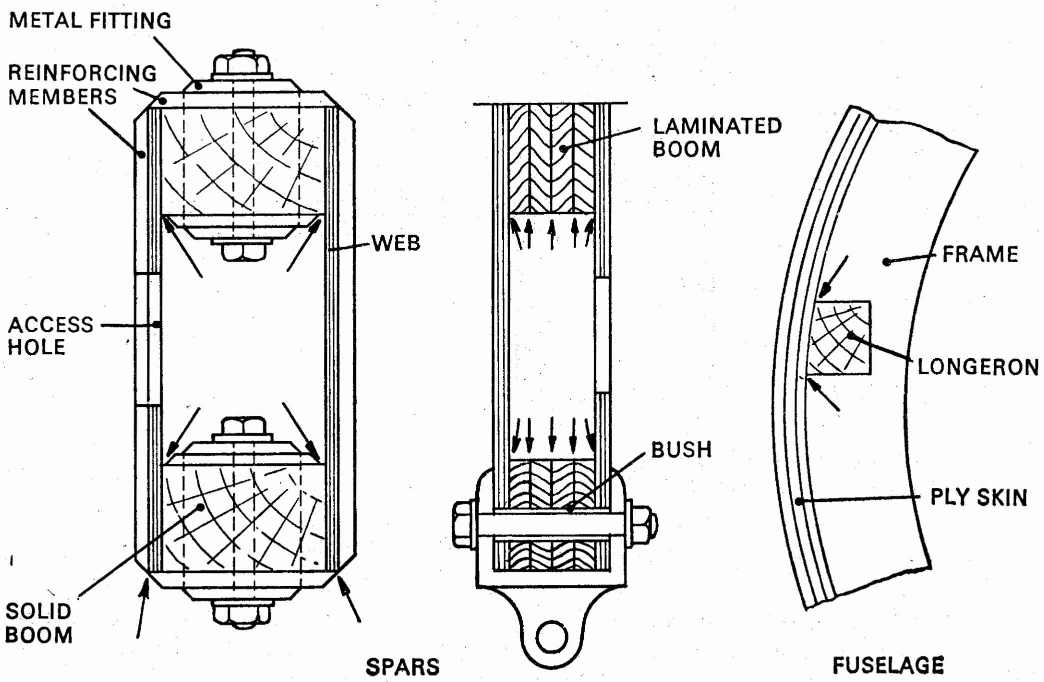

Figure 3 GLUE LINE CHECKS

5.6 **Timber Condition.** Dry rot and wood decay are not usually difficult to detect. Dry rot is indicated by small patches of crumbling wood, whilst a dark discolouration of the wood surface or grey streaks of stain running along the grain are indicative of water penetration. Where such discolouration cannot be removed by light scraping the part should be rejected, but local staining of the wood by the dye from a synthetic adhesive hardener can, of course, be disregarded.

5.6.1 **Water Penetration of Structure.** In some instances where water penetration is suspected, the removal of a few screws from the area in question will reveal, by their degree of corrosion, the condition of the surrounding joint (see Figure 4).

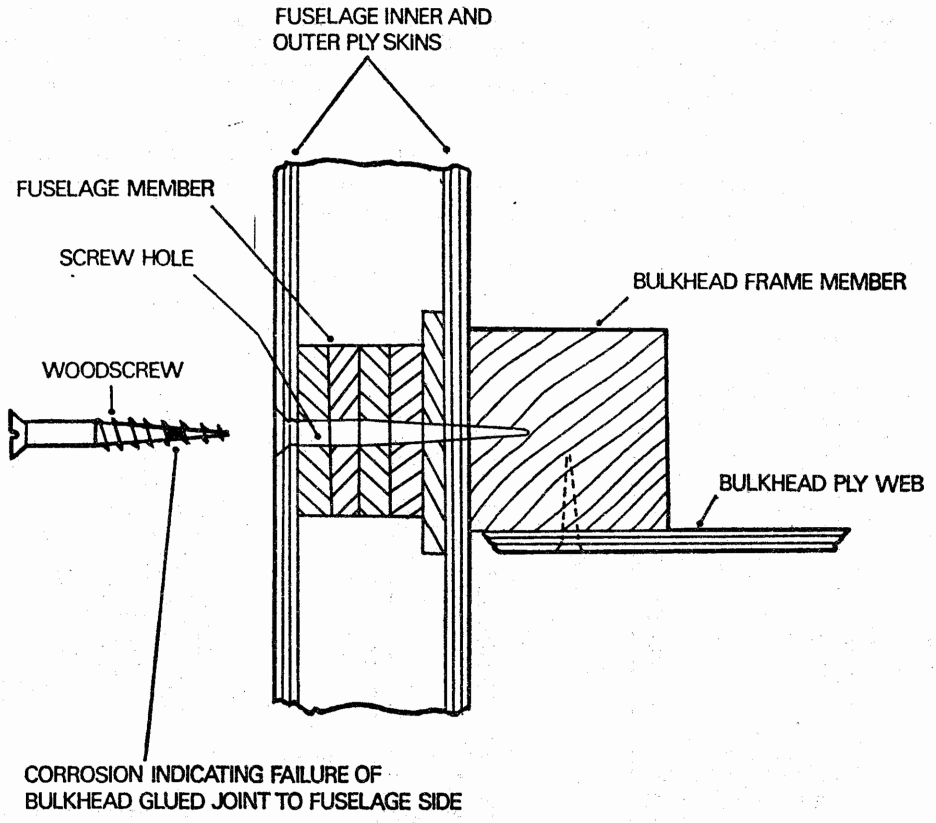

Figure 4 CHECK FOR WATER PENETRATION

(i) Slight corrosion of the screw due to the adhesive will occur following the original construction, therefore, the condition of the screw should be compared with that of a similar screw, removed from another part of the structure known to be free from water soakage.

NOTE: Plain brass screws are normally used for reinforcing glued wooden members, although zinc coated brass is sometimes used. Where hard woods such as mahogany or ash are concerned, steel screws are sometimes used. Unless otherwise specified by the aircraft constructor, it is usual to replace screws with new screws of identical length but one size larger.

(ii) Another means of ascertaining if water penetration has taken place is to remove the bolts holding fittings at spar root-end joints, aileron hinge brackets, etc. (see Figure 3). Primary joints may have bushed holes, and the bushes should also be withdrawn. Corrosion on the surface of these bolts and bushes, and timber discolouration, will provide a useful indication of any water penetration which has taken place. Bolts and bushes should be smeared with an approved protective treatment before being refitted through wooden members.

NOTE: When refitting bolts it is important to ensure that the same number of shrinkage washers are fitted as were fitted originally.

(iii) Experience of a particular aircraft will indicate those portions of the structure most prone to water penetration and moisture entrapment (e.g. at window rails or the bottom lower structure of entry doors), but it must be borne in mind that this is not necessarily indicative of the condition of the complete aircraft.

(iv) Where drain holes have become blocked, water soakage will invariably be found. Drain holes should be cleared during routine maintenance.

5.6.2 **Water Penetration of Top Surfaces.** As indicated in paragraph 3.2.3, the condition of the proofed-fabric covering on ply surfaces is of great importance. If any doubt exists regarding its proofing qualities or if there are any signs of poor adhesion, cracks, or other damage, it should be peeled back to reveal the ply skin.

(i) The condition of the exposed ply surface should be examined and if water penetration has occurred, this will be shown by dark grey streaks along the grain and a dark discolouration at ply joints or screw countersunk holes, together with patches of discolouration. If these marks cannot be removed by light scraping or, in the case of advanced deterioration, where there are small surface cracks or separation of the ply laminations, then the ply should be rejected. Where evidence of water penetration is found, sufficient of the surfaces should be stripped to determine its extent.

(ii) Providing good care is taken of the protective covering from the beginning, much deterioration can be avoided.

5.6.3 **Miscellaneous Defects.** During the inspection of the aircraft, the structure should be examined for other defects of a more mechanical nature. Guidance on such defects is given in the following paragraphs.

(i) **Shrinkage.** Shrinkage of timber, as well as inducing stresses in glued joints, can cause looseness of metal fittings or bolts and, if fluctuating loads are present, can result in damage to the wood fibres at the edges of the fittings or around the bolt holes. Shrinkage can be detected by removing any paint or varnish as described in paragraph 5.5, and attempting to insert a thin feeler gauge between the timber and the fitting or bolt head.

(ii) **Elongated Bolt Holes.** Where bolts secure fittings which take load-carrying members, or where the bolts are subject to landing or shear loads, the bolt holes should be examined for elongation or surface crushing of the wood fibres. The bolts should be removed to facilitate the examination and, in some cases, the bolt itself may be found to be strained. Rectification of elongated bolt holes must be carried out in accordance with the approved Repair Manual, the usual method being to open out the holes and fit steel bushes.

(iii) **Bruising and Crushing.** A check should be made for evidence of damage such as bruises or crushing of structural members, which can be caused, for example, by overtightening bolts. Repair schemes for such damage are governed by the extent and depth of the defect.

(iv) **Compression Failures.** Compression failures, sometimes referred to as compression 'shakes', are due to rupture across the wood fibres. This is a serious defect which at times is difficult to detect, and special care is necessary when inspecting any wooden member which has been subjected to the abnormal bending or compression loads which may occur during a heavy landing. In the case of a member having been subjected to an excessive bending load, the failure will appear on the surface which has been compressed, usually at a position of concentrated stress such as at the end of a hardwood packing block; the surface subjected to tension will normally show no defects. In the case of a member taking an excessive direct compression load, the failure will usually be apparent on all surfaces. Where a compression failure is suspected, a hand torch shone along the member, with the beam of light running parallel to the grain, will assist in revealing this type of failure.

(v) **Previous Repairs.** When examining a structure for signs of the defects mentioned above, particular attention should be paid to the integrity of repairs which may have been carried out previously.

6 JOINT FAILURE A glued joint may fail in service as a result of an accident or due to excessive mechanical loads having been imposed upon it, either in tension or in shear. It is often difficult to decide the nature of the load which caused the failure, but it should be borne in mind that glued joints are generally designed to take shear loads.

6.1 If a joint is designed to take tension loads, it will be secured by a number of bolts or screws (or both) fairly closely pitched in the area of tension loading. If a failure occurs in this area, it is usually very difficult to form an opinion of the actual reasons for it, due to the considerable break-up of the timber occurring in close proximity with the bolts.

6.2 In all cases of glued joint failure, whatever the direction of loading, there should be a fine layer of wood fibres adhering to the glue, whether or not the glue has come away completely from one section of the wood member. If there is no evidence of fibre adhesion, this may indicate glue deterioration, but if the imprint of wood grain is visible in the glue this is generally due to 'case hardening' of the glue during construction of the joint, and the joint has always been below strength. If the glue exhibits a certain amount of crazing or star shaped patterns, this indicates too rapid setting, or the pot life of the glue having been exceeded. In these cases, the other glued joints in the aircraft should be considered suspect.

NOTE: The use of a magnifying glass will facilitate the above inspections.

6.3 Damage caused by a heavy landing may be found some distance away from the landing gear attachment points. Secondary damage can be introduced by transmission of shock from one end of a strut or bracing to its opposite end, causing damage well away from the point of impact. A thorough inspection of the existing paint or varnish at suspected primary or secondary impact points may reveal, by cracks or flaking, whether damage has actually occurred.

Issue 2.

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AIRCRAFT

STRUCTURES

GLASS WINDSCREEN ASSEMBLIES

1 INTRODUCTION This Leaflet gives guidance on the installation and maintenance of aircraft glass windscreen assemblies of both the simple and complex electrically heated type. As the assemblies fitted to different aircraft vary considerably, the information given in this Leaflet should be read in conjunction with the Maintenance Manuals and the approved Maintenance Schedule for the type of aircraft concerned. Reference should also be made to Leaflet **AL/11-4,** Windscreen De-icing and Anti-icing Systems for details concerning the installation and maintenance of the components associated with electrically-heated windscreens and also for the overall testing of a system. The CAA Requirements regarding tests on pressure panels are given in Chapter D3-7 of British Civil Airworthiness Requirements.

2 GLASS Glass is a hard, brittle material having the outstanding quality of transparency. To overcome brittleness but to leave transparency unimpaired is the main object of the manufacture of safety glass as used for aircraft windscreens. Examples of specifications which meet the requirements are DTD 218 Laminated Safety Glass, DTD 869 Laminated Safety Glass, High Light Transmission, DTD 761 Safety Glass Windscreen, Gyro Sight Quality and DTD 5576A Electrically Heated Laminated Safety Glass.

2.1 **Characteristics of Glass.** Glass, unlike metals, is non-crystalline. When heated or cooled it shows no sharp change in physical properties and has no definite melting point, but at about 600°C plate and sheet glass begin to flow under their own weight.

2.1.1 Glass may be broken by loading in various ways, e.g. impact, tension, twist, compression or shear and fracture will occur under any type of loading when deformation has produced the necessary tensile stress.

2.1.2 The breaking strength of glass is greatly influenced by five factors:—

(i) Heat treatment (paragraph 2.2).

(ii) Length of time of loading (paragraph 2.3).

(iii) The rate of application of a load (paragraph 2.4).

(iv) The condition of the surfaces and edges (paragraph 5).

(v) Method of installation (paragraph 3.2).

2.2 **Heat Treatment**

2.2.1 **Annealing.** After manufacture glass is cooled very slowly so that stress set up during the forming of the sheet may dissipate. If this were not the case, built-in tensile stress would weaken the glass to such an extent that it could break spontaneously. When glass of greater strength than annealed glass is required, a tempered glass is used.

2.2.2 **Tempered Glass.** The glass is heated to some point within the range in which it becomes soft and then the surfaces are quickly cooled by blasts of compressed air. This chills and hardens the outer surfaces whilst the inside is still hot and contracting, thus putting the outer 'skins' of the glass in a state of compression, resulting in a considerable increase in strength.

(i) The main drawback of tempering is that the glass will break up into tiny particles when fractured (the greater the degree of tempering the smaller will be the particle size) thus seriously obstructing vision.

(ii) In the United Kingdom, glass which has been tempered to give maximum strength is termed 'toughened glass' (e.g. Type 1 of DTD 5576A). The term 'strengthened glass' (e.g. Type 2 of DTD 5576A) is used to indicate glass which has been tempered to a lesser degree than toughened glass. Although less strong than toughened glass it has the advantage of larger particle size should fracture occur.

(iii) Because of the physical nature of tempered glass it cannot be filed, drilled or trimmed in any way, therefore any adjustments required during fitting must, of necessity, be done on the mounting frame. Great care is necessary when fitting the glass to prevent damage, for example chipping. Scratches, chips, flaws and other surface defects weaken glass very considerably and on this score alone every effort must be made to avoid such defects, particularly at the edges of the glass (see paragraph 5).

2.3 **Fatigue.** Cyclic fatigue of toughened glass at commonly used stress level, is effectively non-existent.

2.4 **Safety Factors.** The safety factors required on glass components are very much higher than for other materials used in aircraft construction, because of the loss of strength with duration of load, scatter in strength inherent in glass, thickness tolerances and high notch sensitivity.

3 WINDSCREEN DESIGN The design of windscreens varies considerably according to the type of aircraft to which they are fitted, the extent of de-misting and impact strength required and also on whether an electrical method of anti-icing is to be used. The details given in the following paragraphs are of a general nature, outlining some design features of typical windscreen assemblies.

3.1 Windscreens are of laminated construction and in general can be considered as belonging to one of two categories, (i) the simple windscreen, usually fitted to non-pressurised aircraft having limited performance, and (ii) the electrically-heated panel windscreen fitted to pressurised aircraft with all-weather capability.

3.1.1 **Simple Windscreens.** A panel is usually made up of two pre-formed and pre-tempered glass layers or plies, each of which is bonded to a sandwiched sheet or ply of reinforcing material termed the 'interlayer'. The suitability of a material for use as an interlayer depends on a number of factors, the most important of which are its ability to withstand impact, to prevent breakage into dangerous fragments and to prevent detachment of such fragments from the inner surface of a panel. The material normally used for the interlayer is polyvinyl butyral (plasticised with dibutyl sebacate or triethylene glycol de-hexoate), generally referred to as vinyl.

(i) The vinyl and glass layers are bonded by the application of pressure and heat, the temperature being considerably less than that required for tempering the glass and below the temperature at which vinyl would flow. The bond is achieved without the use of a cement as vinyl, after laminating, has a natural affinity for glass.

3.1.2 **Electrically Heated Windscreens.** These windscreens are used on pressurised aircraft to prevent the formation of ice and mist on the panels and to improve the impact resistance of the windscreen panel at low temperatures (see Appendix 2 of Chapter D4-2 of British Civil Airworthiness Requirements). The physical properties of vinyl vary considerably with changes in temperature. Considering a range of ambient temperatures normally encountered under flight operating conditions, the vinyl would be brittle in the lower part of the range and plastic in the upper part. Since the desired impact resistance characteristics of a windscreen depend to a large degree on the plasticity of the vinyl interlayer, it follows that impact resistance is dependent on interlayer temperature.

(i) The panels are of special laminated construction containing a resistance type heating element in the form of a film deposited on the inner surface of the outer glass layer. The heating element is supplied with power from the aircraft electrical system via terminals on the panel frame and by busbars 'fired' on to a glass layer at the top and bottom edges of the element. The temperature of the panel is controlled by a temperature-sensing element laminated into the panel and connected to an automatic control unit (see Leaflet **AL/11-4**).

(ii) The windscreens in certain of the larger types of aircraft consist of up to seven transparent layers made up of glass, vinyl, acrylic plastic and polyester material. In a typical assembly, three thin vinyl interlayers are employed and they sandwich two layers of thick stretched acrylic plastic. Together the acrylic layers provide most of the windshield structural integrity. The outer layer of the windscreen is a thin, chemically toughened and abrasive-resistant glass layer, and its inner face is covered with the heating element which is supplied with power from busbars at the top and bottom of the windscreen. Two sensing elements for automatic temperature control and an overheat sensing element are laminated into the panel. Only one of the control elements is used; the other serves as a spare. The inner layer of the windscreen assembly is made of an abrasion-resistant polyster material.

(iii) There are two types of heating elements in general use; namely, tin oxide and gold film, the latter complying with specification DTD 5576A. These panels are briefly described in the following paragraphs.

(a) **Tin Oxide Film Panels.** In this type of panel, the heating element is produced by spraying with a flame gun a coating (0·000002 inch thick) of tin oxide at 1000°C on the inner surface of the outer glass layer which is then bonded to the vinyl interlayer.

(b) **Gold Film Panels.** In these panels a combined film of gold and metal oxide is used as the heating element. The film is electrically-deposited on the surface of the glass in a vacuum chamber.

3.2 **Windscreen Attachment Methods.** There are several methods of attaching windscreen assemblies dependent on the type employed. The method frequently adopted for simple type windscreens is the one generally referred to as 'Friction Mounting'; it is illustrated in Figure 1. The periphery of the panel is clamped between metal glazing strips and the fuselage frame by a series of bolts. To avoid damaging the glass and to ensure that the joint will be watertight, a suitable lining, usually in the form of a special rubber strip or moulding, is fitted or bonded to the structure.

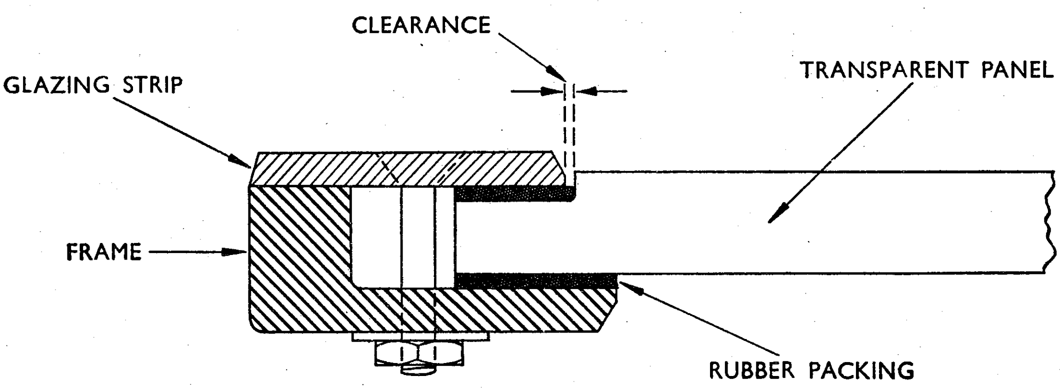

Figure 1. FRICTION MOUNTING

3.2.1 The impact strength of a laminated panel is based on the ability of the interlayer to stretch and deform and thus absorb the shock load, assuming that the impact is great enough to shatter the glass layers. Under such conditions it is essential that the vinyl interlayer be held securely around the edges of the panel. It is for this reason therefore, that panels designed to resist high impact loads and in particular electrically heated panels, are secured to the windshield frames by bolts passing through the edges of the panels rather than relying on the clamping action shown in Figure 1.

(i) The vinyl interlayer of this type of windscreen is generally thicker than that used in ordinary laminated windscreens and it is extended beyond the periphery of the glass layers. In windscreens employing layers of acrylic plastic this applies to these layers also. A further refinement in the design is an aluminium alloy reinforcing strip, which is in the form of a frame and is embedded in the vinyl. This strip, together with aluminium alloy inserts in each of the bolt holes, assists in preventing the vinyl from deforming at the edges under pressurisation loads and also when tightening bolts during installation. A typical assembly is shown in Figure 2.

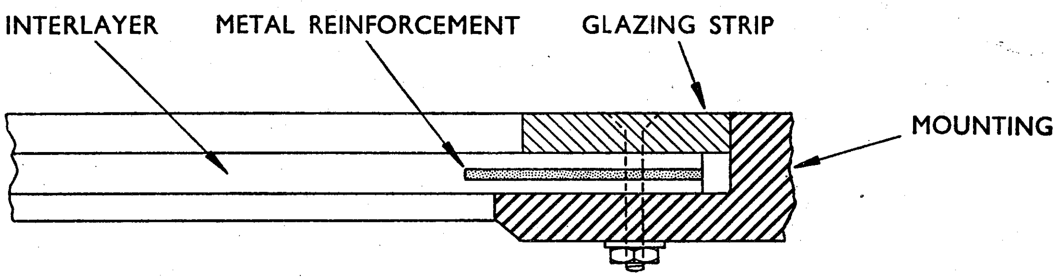

Figure 2. EXTENDED INTERLAYER METHOD

4 INSTALLATION The installation of windscreen panels must be in accordance with the procedure specified in the relevant aircraft Maintenance Manual. The information given in the following paragraphs is of a general nature and is intended as a guide.

4.1 Before installation, panels should be carefully checked for any sign of damage such as scratches and chips (see paragraph 5.1.2 and 5.1.3). The frames must be clean and seals, where fitted, must be undamaged. Frame mounting faces should be inspected for flatness and freedom from distortion.

NOTE: Cleaning agents must be of the type specified in the relevant aircraft Maintenance Manual and should not be applied indiscriminately to windscreens and surrounding structure. Incorrect cleaning agents may attack the interlayer and cause delamination.

4.2 Where specified, clearances between panels and fuselage structure must be checked to ensure that they are within limits. In some instances, particularly for simple type windscreens, the edges of panels are rebated (see Figure 1) to accommodate the glazing strips and specified clearances between strips and raised portions of panels must be maintained.

4.3 The condition of pressure and weather seals should be examined before installation of a panel and, where necessary, replaced or repaired in the manner specified for the particular type of aircraft.

4.4 In installations requiring a fluid plastic compound for sealing purposes, the compound must be applied in a uniform layer and of the correct thickness to form a gasket between windscreen and fuselage frames, the required thickness being obtained by bolting a windscreen to its respective frame. In some cases a bedding-down template is provided for this purpose.

NOTE: The compound must be left to cure for the relevant time period before finally tightening the attachment bolts.

4.5 A silicone grease (sometimes referred to as a release agent) of the type specified in the appropriate aircraft Maintenance Manual, should be applied to the mating surfaces of windscreen frames to form a silicone film which is non-adhesive to pressure and weather seals and facilitates subsequent removal of panels.

NOTE: In some types of aircraft, a preformed strip or gasket may also be fitted to serve this purpose.

4.6 On electrically heated windscreen panels fitted to certain types of aircraft, a code number is etched in the corner of the glass near the busbar terminals to indicate the heating element resistance. As it is possible for the number to be covered when the panel is installed, details should be noted before installation to ensure correct heating circuit connections.

4.7 In aircraft in which a standby magnetic compass is located on a structural support between two windscreen panels, care must be taken to ensure that the panel attachment bolts in the vicinity of the compass position are of non-magnetic material. After installation, a check compass swing must be carried out to prove the accuracy of the standby compass, with current to the windscreens switched both 'on' and 'off'.

4.8 Attachment bolts and nuts should be coated with a compound to provide a seal at each of the bolt holes. Where compounds are specified, details of types and methods of use are contained in the relevant aircraft Maintenance Manual.

4.9 During the initial stages of fitting attachment bolts, the panel should always be adequately supported to prevent it resting on the bolts thus preventing the countersunk heads from seating correctly. Locating keys are provided for this purpose in some types of aircraft and they should be used in the manner specified. When installing windscreens of the extended interlayer type, it is important to ensure that the specified clearance exists between fixing holes and bolts.

4.10 Attachment bolts should be tightened evenly and in a staggered sequence ensuring that the panel is not distorted and that bolt torque loadings are as specified.

4.11 Cable terminals on electrically heated windscreen panels should be suitably protected against damage. After installation the anti-icing system cables should be connected to their respective terminals, identified in accordance with the relevant wiring diagram and the heating system checked for correct functioning.

4.12 After installation of a windscreen panel in a pressurised cabin type aircraft, and elapse of the requisite curing time for sealing compounds, a cabin pressurisation and leak rate test should be carried out if prescribed in the relevant aircraft Maintenance Manual.

5 INSPECTION AND MAINTENANCE The information given in the following paragraphs is of a general nature and should be read in conjunction with the Maintenance Manuals and approved Maintenance Schedules for the aircraft concerned. Information on the inspection and maintenance of circuits and components associated with electrically heated windscreen panels is contained in Leaflet **AL/11-4;** reference should therefore be made to this Leaflet.

5.1 **Damage.** Panels should be inspected for defects and any signs of damage such as delamination, chipping and cracking of glass layers. The following brief descriptive details are intended as a guide to this type of damage and other defects which may occur.

5.1.1 **Delamination.** This is a defect which can occur in laminated windscreens characterised by the separation of a glass layer from the vinyl interlayer. Delamination should not be confused with deliberate stress-relieving edge separation of panels which is sometimes employed. In such cases a parting medium is used, introducing a separation penetrating the edges of the panel assembly to a distance of 0·25 inch to 1 inch and giving a yellowish or brownish appearance at the edges.

(i) Defective delamination has characteristics that tend to divide it into the following main types, and resulting from different types of stress at the glass/vinyl interface.

(a) **Clear (or cloudy).** Of the two types, delamination is apt to be clear. However cloudy delamination will result if moisture penetrates the delaminated area. In doubtful cases delamination can be confirmed by carrying out a reflection test by means of a flaw detector using a light beam. The beam is directed on to the surface of the windscreen and produces two sharply defined lines on a ground-glass screen representing the top and bottom surfaces of the windscreen. Any delamination present will produce an additional line and its proximity to either of the other lines is helpful in deciding which of the layers has separated.

(b) **Rough-edge.** This is characterised by its irregular, sharp or jagged boundary. It may develop long finger-like projections if, during the course of delamination the parting between vinyl and glass is not uniform.

(c) **Smooth-edge.** Smooth-edge delamination advances with a smooth boundary. It does not have rough or jagged areas within it, nor indications of internal cracks or chips.

(ii) A small amount of delamination is permitted on most aircraft but details of the permissible extent and any limits concerned with aircraft flight operations, e.g. flights under pressurised conditions, should be obtained from the relevant aircraft Maintenance Manual and Flight Manual.

5.1.2 **Scratches.** Scratches are defects in the surface of a panel and every effort must be made to avoid them. They are normally more prevalent on the outer surface where windshield wipers are indirectly the primary cause. Any dust or grit trapped by a wiper blade can immediately become an extremely effective cutting device as soon as the wiper is set in motion. Wiper blades must therefore be maintained in a clean condition and should only be operated when the windscreens are wet.

(i) On the basis of severity, scratches may be classified as hairline, light and heavy.

(a) **Hairline Scratches.** A hairline scratch can be seen but is difficult to feel with a fingernail. It can be caused by wiping the glass with a dry cloth. To avoid hairline scratches, the glass should be cleaned with a mild detergent and water, using a soft brush or clean, soft cotton cloth, followed by drying with a clean, soft cotton cloth.

(b) **Light Scratches.** A light scratch is less than ·010 inch deep and can be felt with a fingernail. This type of scratch ordinarily has few edge chips.

(c) **Heavy Scratches.** A heavy scratch is ·010 inch or more in depth and can be readily felt with a fingernail. This type of scratch is apt to show extensive edge chipping.

(ii) If the integrity of a panel is not suspected and provided visibility is not seriously affected, scratches are permissible within limits detailed in the relevant aircraft Maintenance Manual.

(iii) Scratches can be removed by polishing, but due to an uneconomic time factor, possible optical distortion and problems of assessing optical standards acceptable in the ultimate operational situations, it is recommended that a panel assembly be returned to the manufacturer and replaced by a serviceable assembly.

5.1.3 **Chipping.** Chips are flakes or layers of glass broken from the surface which can occur if the exterior surfaces of a panel are struck by a sharp object. The inner surfaces of a lamination of the panel may also chip in unheated areas, as a result of high internal stresses. There are two types of chips: conchoidal and V-shaped. Conchoidal chips are usually circular or curved in shape with many fine striations that follow the outline of the outer edge. V-shaped chips are sharp and narrow, the 'V' appearing to propagate toward the interior of the glass. Visibility through chipped areas of a windscreen panel is usually poor.

(i) Chips occurring at the inner surfaces of glass panes are critical because the existing condition may result in cracking or shattering of a pane, or in the case of an electrically heated windscreen, destruction of the resistance heating film. These chips are usually associated with rough-edge delamination (see paragraph 5.1.1).

5.1.4 **Cracks.** These are serious defects which, depending on the type of glass and the formation and propagation of the cracks, may result in considerable strength reduction of the windscreen and effects on visibility varying from slightly impaired to complete obscurity. In annealed glass the damage may take the form of single cracks, or cracks forming an irregular criss-cross pattern. The more usual result of damage to strengthened glass is the formation of cracks spreading radially from the point of damage and in these cases, vision is impaired but not completely obscured. Cracks in a toughened glass form a pattern defined as shattering, a defect resulting in considerable reduction in strength and loss of vision. A windscreen having such a defect should be removed and replaced by a serviceable assembly.

(i) The extent to which cracks are permitted, limitations on aircraft operation and the action to be taken in order to rectify the defects, may vary between aircraft types. Details are given in the relevant aircraft Maintenance Manual and Flight Manual and reference must therefore always be made to these documents.

5.1.5 **Vinyl Rupture.** Vinyl rupture consists of a failure across the section of vinyl at the inner edge of the metal insert (Figure 2) and necessitates changing the panel.

5.1.6 **Vinyl 'Bubbling'.** Small bubbles occurring within the vinyl interlayer of electrically heated windscreens are not a delamination nor are they structurally dangerous. They are usually due to overheating conditions, being formed by a gas liberated by the vinyl. They need not be a cause for windscreen replacement unless vision is seriously impaired. Their presence, however, may indicate a defective window heat control system which should be rendered inoperative pending rectification. (See also Leaflet **AL/11-4**).

5.1.7 **Discolouration.** Electrically heated windscreens are transparent to direct light but they normally have a distinctive colour when viewed by reflected light. This apparent discolouration is due to the resistance heating film and it may vary slightly between windscreens. Only black or brown discolouration, when viewed normal to the surface, should be regarded as a possible defect necessitating removal of the windscreen and replacement by a serviceable one. The cause of such discolouration may be a burnout of the heating film or a carbon deposit between a busbar and the heating film due to overheating.

5.2 **Sealants.** Weather sealants provided around the periphery of windscreens must be inspected for evidence of erosion, lack of adhesion, separation or holes. The obvious purpose of maintaining an effective weather sealant is to protect the windscreens against moisture entry and the delamination or electrical problems associated with moisture penetration. When new sealant is required, the damaged material should be removed, the area cleaned, and new material applied in the manner prescribed in the relevant aircraft Maintenance Manual.

NOTE: Damaged material should always be removed with a plastic tool that will fit, without binding, in the gap between windscreen and frame. The use of a metal tool is inadvisable, as this could damage the glass or vinyl interlayer.

5.3 **Cleaning of Windscreens.** Windscreens should be washed regularly with warm water and mild detergent, using a clean, soft cloth or cotton wool pad; after washing the panels should be rinsed and dried with a clean, soft cotton cloth. Scratching of the glass must be avoided.

5.3.1 Some aircraft manufacturers recommend the use of a proprietary detergent which is also suitable for the surrounding aircraft structure and therefore to some extent simplifies cleaning operations; it is important that only the detergent specified is used and that the prescribed proportion of detergent to water is observed.

5.3.2 Grit, dirt, etc., should be removed at regular intervals from recesses, for example, where the panel joins the frame, to prevent it being picked up by the cleaning cloths and causing scratching. The accumulation of cleaning and polishing materials in recesses must be avoided.

6 STORAGE Extreme care is necessary during transportation, storage and handling of windscreens to prevent damage. It is recommended that panels should be packed with both faces covered with adhesive polythene; they should then be wrapped in acid-free paper and cellulose wadding and put into reinforced cartons, these being covered with waxed paper and secured with adhesive tape.

6.1 The panels should be stored in their cartons on suitable racks, away from sunlight or strong artificial light, at a controlled temperature of between 50°F to 70°F in well ventilated conditions.

6.2 It is important to ensure that during handling or storage the thicker glass ply of a laminated panel is kept uppermost to prevent delamination (paragraph 5.1) and that the polythene film is not removed until the panel is fitted to the aircraft.

Issue 2.

December, 1979.

AIRCRAFT

STRUCTURES

THE EFFECT OF DISTURBED AIRFLOW ON AEROPLANE BEHAVIOUR

1 INTRODUCTION This Leaflet gives general guidance on the cause and effect of disturbed airflow on aeroplane behaviour, with particular reference to high-performance aeroplanes. It emphasises the need for special care in the preservation of correct airframe contours because of the serious effect on aeroplane behaviour, particularly at high speeds, of seemingly trivial discontinuities in contour, profile, etc.

1.1 It is important that the point of transition from laminar to turbulent airflow on aerofoil surfaces occurs at the position intended in the design. At high subsonic speeds the transition point may be designed to be effective at a position some 30 to 50% along the wing chord from the leading edge, and can be very sensitive to even small protuberances or discontinuities on the wing surface.

1.2 Faulty contours can have dangerous effects on an aeroplane flying at or near the stalling speed, whilst rough surfaces, badly fitting joints, gaps, etc., will adversely affect, to some extent, performance in all regimes of flight. However, defects which may be considered of minor importance to low-speed aeroplanes may have a considerable influence on aeroplanes flying at higher speeds. For example, the behaviour of the airflow over an aileron can be seriously affected by those departures from design which influence the position of the transition point, thus affecting the response, or the rate of response, of the aeroplane, the trim and the drag.

1.3 No attempt is made in this Leaflet to describe any aerodynamic principle or theory; any description or illustration given is solely to help clarify the 'cause and effect' of the defect and is not considered to be a formal aerodynamic representation.

1.4 Since the methods used to determine the causes of flying faults (and the methods of rectification) vary considerably with different types of aeroplanes, it is essential that the manufacturer's instructions, as specified in the relevant manuals, should be carefully followed.

1.5 Guidance on the rigging and adjustment of flying controls is given in Leaflet **AL/3-7**, on the general rigging of aeroplanes in Leaflet **AL/7-12**, and on the inspection of aeroplanes after heavy landings or abnormal flight loads in Leaflet **AL/7-1**.

2 GENERAL In high performance aeroplanes the surfaces subjected to airflow are constructed to within relatively close contour and gap limits, and these limits have to be maintained if increased drag and other penalties are to be avoided. In this connection, the most critical areas of the aeroplane, where high accuracy in manufacture and the greatest care in maintenance are involved, include the leading edges of wings, tail plane and flying control surfaces, shrouds and trailing edges, engine intakes and static-vent areas. However, it should be noted that production tolerances are normally permitted, and thus it should never be necessary to adjust any dimension to give an accuracy greater than that required by design solely for the purpose of maintaining performance standards.

2.1 Modern high performance aeroplanes are so constructed that the original smoothness of contour is maintained more effectively than in previous generations of aeroplanes (e.g. by the use of machined skin panels). Nevertheless, small departures from the prescribed alignment and contours can occur during service and may be very difficult to recognise. Although such irregularities may have a negligible effect at lower speeds, changes of trim may occur as the aeroplane reaches its limiting Mach number.

NOTE: Although an aeroplane may be flying at subsonic speed, it is not unusual for the airflow over certain sections to be at transonic or supersonic speed.

2.2 Apart from changes of attitude and trim which may or may not occur due to departures from the original aerodynamic contours (e.g. malalignment of control surfaces, incorrect fitting of inspection panels, fairings and cowlings, dents or wrinkles in wing skins, protruding bolt heads, etc.), such defects will also cause an increase in drag, resulting in a deterioration in aeroplane performance and range. For long-distance flights the results could be a marked increase in fuel consumption and seriously reduced fuel reserves.

2.3 In addition to defects which may be 'built in' as described in paragraph 2.2, it should be borne in mind that fairings and other fittings which are insecurely attached, might distort in flight, with similar results.

2.4 In summing up, it can be said that anything which disturbs the normal smooth airflow over an aerodynamic surface will have an adverse effect on the handling and performance of the aeroplane. However, if such adverse effects are reported, the full range of ground-set trim adjustments should be utilised before a search is made for the less obvious profile defects.

3 DEFECTS For the purpose of this Leaflet, it is assumed that the more common control faults, such as mechanical stiffness, jerkiness of controls, excessive play, etc., have been dealt with, and that servo motors, cable tensions, spring struts, rigging limits, etc., are satisfactory.

3.1 **Engine Cowlings and Fairings.** The correctness of the fit of engine cowlings and fairings is important and must be within drawing tolerances, since, for example, if excessive airflow enters inside the cowlings, considerable pressure build-up may occur and drag may result (see also paragraph 3.4.2). The gaps between the edges of cowlings and fairings should be within design limits (see Figure 1) and no overlap should be permitted unless this is the design intention. It is essential that any rubbing strips or seals on to which the cowlings or fairings bed should be in good condition.

3.1.1 The contours of cowlings and fairings should be maintained in the design condition, since dents, bent corners or protruding attachment bolts or other securing devices will affect the flow of air over the component. It should also be ensured that the cowlings and fairings are so adjusted and locked that they cannot move or vibrate in flight as a result of aerodynamic loads.

3.1.2 The contours of turbine engine air-intake ducts are of particular importance, since dents or damage to the lips of the ducts or the skin inside will interfere with the smooth airflow to the engine, with a resultant loss in performance and an increase in fuel consumption. In some cases such defects have resulted in rough running of the engine because of uneven distribution of air to the compressor and, in other cases, in inefficient operation of the engine cooling system.

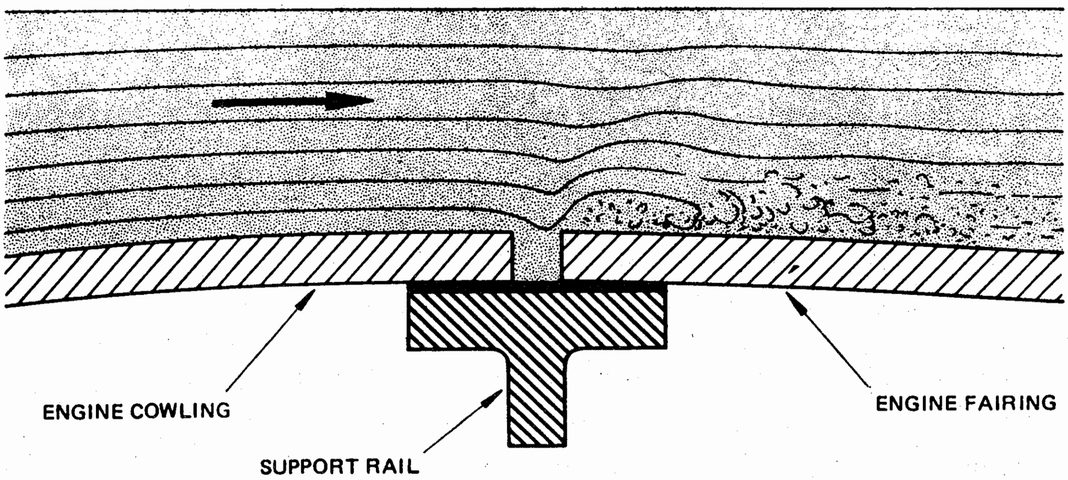

Figure 1 DRAG DUE TO GAP IN COWLINGS

3.1.3 Cowlings and fairings should be stored and handled with care (see also paragraph 4.4). Attachment devices, locating dowels and fittings should be checked for looseness resulting from strain, wear, etc. Toggle fasteners should be correctly adjusted to give the required 'over-centre' loading and the associated fairings should be a good flush fit.

3.2 **Fuselage.** Cabin pressure leaks can cause a severe disturbance to the smooth flow of air along the fuselage and will create a considerable increase in drag. It should be ensured that cabin pressurisation seals at entrance doors, emergency hatches, clear-vision panels, etc., provide a complete and effective seal. The effect of such a defect is illustrated in Figure 2.

3.2.1 Entrance doors, hatches, etc., should be carefully checked for alignment with the fuselage skin, with the fuselage pressurised where appropriate, since if any wear has occurred to the latches, locks, rails or hinges, it may permit the door, hatch, etc., to protrude beyond the normal fuselage contour, creating a disturbance to the airflow.

3.2.2 It should be noted that the effect of pressurisation leaks, malalignment of aerodynamic contours, etc., is particularly detrimental towards the forward end of the fuselage, and special care should therefore be given to the fit of windscreens, glazing strips, crew entrance doors, nose fairings and radomes.

3.3 **Wings.** The smoothness and contour of the wing surfaces, especially the top surfaces, is of the utmost importance if increased drag is to be avoided and the lateral trim of the aeroplane is to remain unaffected throughout the speed range.

3.3.1 It is necessary, for example, on aeroplanes fitted with fuel filler caps designed to be flush with the top surface of the wing, to ensure that the cap is fitted properly and not protruding above the wing contour; this is particularly important, for example, after fitting new sealing washers.

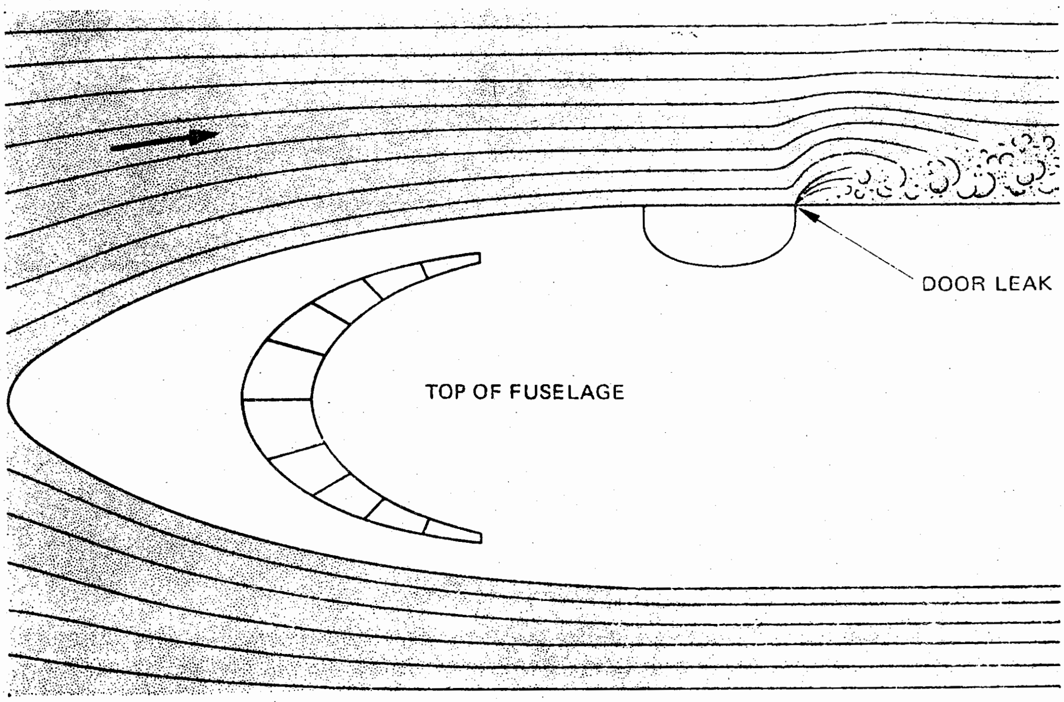

Figure 2 PRESSURE LEAK FROM FUSELAGE

3.3.2 Even small irregularities such as those caused by protruding rivet or bolt heads, badly replaced screws in panels, stepped or gapped panel joints, convexity and concavity or ripples in the wing skin which may not be obvious during normal inspection, must not be ignored, since all can result in a break in the smoothness of the airflow over the wing.

3.3.3 An important factor from the point of view of high Mach number performance, is waviness, and this is most important near the leading edges of lifting surfaces. Waviness can cause early shock-wave effects, which result in increased drag and a lower buffet boundary.

3.3.4 On aeroplanes which carry dinghies or life-rafts in wing stowages, the fit of the stowage cover is of paramount importance in maintaining the design airflow over the wing. The fit of the cover with the surrounding skin contour must be maintained within permitted tolerances. Correct fit may be obtained by adjustment of the cover retaining attachments, but can also be affected by the weather-seal around the interior of the cover.

3.3.5 The wing tip is also an important part of a wing, and should be examined for surface condition. Detachable wing tips should also be examined to ensure that the chord line and rigging are satisfactory.

3.3.6 To ensure freedom from defects such as those described in 3.3.1 to 3.3.5, some manufacturers of high speed aeroplanes provide contour jigs or templates with which to check the wing surfaces, including the leading edges, shrouds, and trailing edges. Such jigs should be used with considerable care and in accordance with the manufacturer's instructions; any departures from contour in excess of permitted limits should be rectified.

3.3.7 When jigs are not available, a rough check for contour defects may, in some cases, be made by running the fingers around the suspected surfaces, since this may reveal irregularities in surface finish which may not otherwise be perceptible. It is also sometimes helpful in the detection of more obvious defects, such as skin dents, malalignment of shrouds and ailerons, etc., when jigs are not available, to stretch a thin cord across the wing, from the leading edge to the trailing edge and parallel to the line of flight, and to check as indicated in Figure 3.

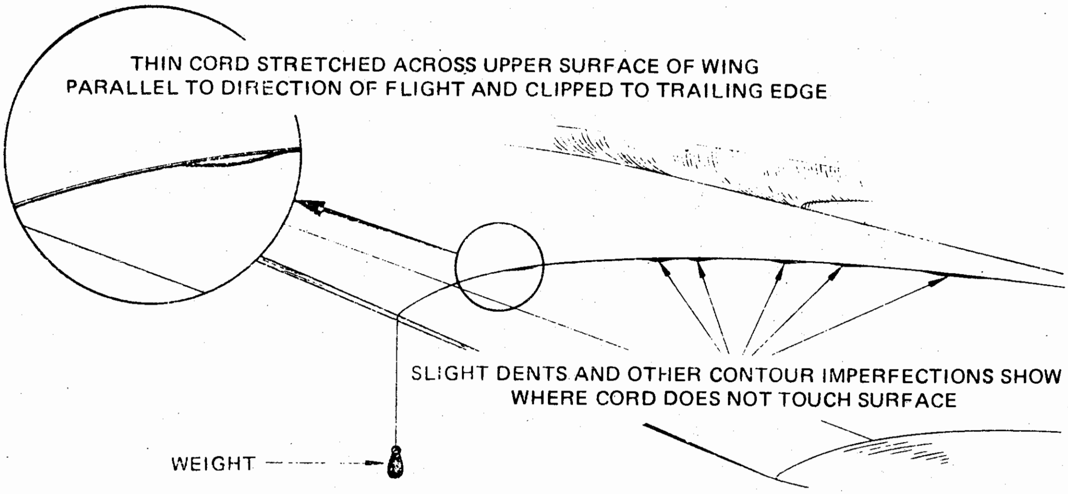

Figure 3 CHECKING CONTOURS

3.3.8 It is sometimes possible to make a rough check on the more obvious types of defects by locking all the flying controls in the neutral position and then standing aft of the aircraft as shown in Figure 4. This may reveal distortion or damage to the trailing edges of the wings, flying controls and shrouds, which may sometimes be caused by accidental contact with ground equipment.

(a) By slightly altering his position (up or down) the observer can make a rough check on the control surfaces and the rear of the wing surfaces. This is mainly done to check access points, tank doors, rear edges of cowlings, etc., to ensure that they blend into the natural contours of the aerofoil surfaces.

3.3.9 A check similar to that outlined in paragraph 3.3.8 can be made from a position forward of the wing, in order to check the contour of the wings and tailplane, with special emphasis on the leading edges, since defects in these areas are particularly critical.

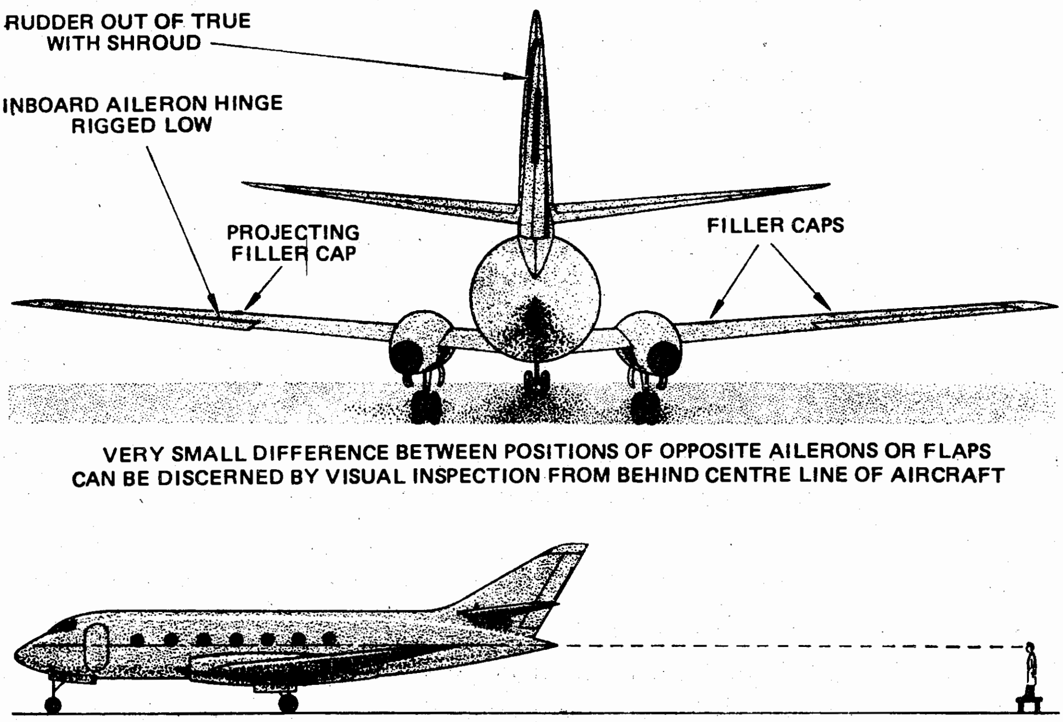

Figure 4 CHECKING BY OBSERVATION

3.4 **Landing Gear Doors and Fairings.** Landing gear doors and fairings are often the cause of considerable drag and should, therefore, be carefully inspected in the retracted position for fit, contour and sealing. In addition, such components may be subjected to high aerodynamic loads, and the possibility exists that badly fitting or ineffectively secured panels could become detached from the aeroplane, with serious results. Where such components are subjected to high aerodynamic loads the rigging procedures normally incorporate a degree of pre-loading to counter the effect of air loading.

3.4.1 In some cases it may be found necessary to simulate aerodynamic loads by loading the doors with weights or by use of a spring balance. This practice would indicate any excessive play or backlash in the mechanical linkage. In mechanically-actuated door operating systems, this check would be sufficient to ensure against sag in flight, but when the door operating system is completely or partially hydraulically operated, subsequent sag in flight may depend on the efficiency of the hydraulic system. In the latter case every effort should be made to ensure that the relevant part of the hydraulic system is free from both internal and external leaks.

3.4.2 A landing gear door, fairing or seal which is in any way badly fitting when the door is closed may allow air to enter the landing gear bay and eventually escape at the aft end of the door or fairing, creating considerable drag. In this case drag is caused by the fact that the air leaking into the cavity loses speed and then has to be speeded up again as it leaks out at the other side. Figure 5 illustrates the more serious case of flow breakaway as a result of leakage, but even if this does not occur, the drag penalty may still be quite high.

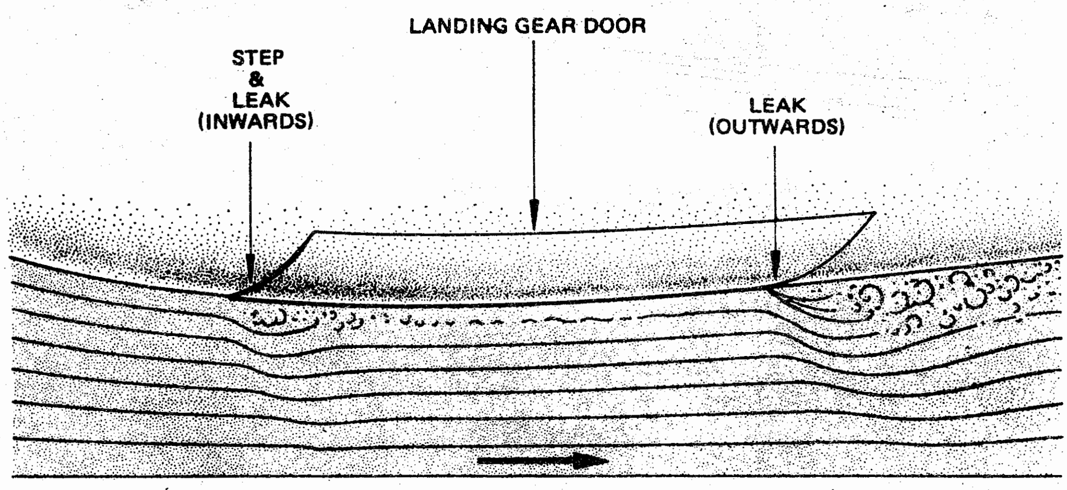

Figure 5 LEAKS AT LANDING GEAR DOOR

3.5 **Flaps.** The undersurface of the flaps should be examined for damage caused by debris thrown up during take-off and landing, and flap shrouds should be checked for security, damage and distortion. The flaps should also be checked for sagging when in the "up" position. In the case of flaps which employ slots for improved efficiency it should be ensured that the correct gaps are maintained.

3.6 **Aileron Shrouds.** The clearances between ailerons and aileron shrouds are very critical and must be checked carefully. The shrouds should be rigid and free of any form of damage on both bottom and top surfaces, and care must be taken to ensure that no distortion of the shroud, or the wing skin immediately in front of the shroud has occurred, since this could upset the airflow over the aileron in a manner similar to that illustrated in Figure 6.

3.7 **Movable Leading Edge Devices.** Movable leading edge devices should be checked in the retracted position to ensure that they conform to the contour of the main wing, particularly on the upper surface. The condition of any seals in the leading edge should also be checked, to ensure that there is no air leakage from the lower to the upper surface. The leading edge devices should also be checked in the extended position to ensure that the correct gap is maintained between the devices and the wing.

3.8 **Airbrakes/Spoilers.** Airbrakes and spoilers should be checked to ensure that they are a flush fit when retracted. Where spoilers are used for lateral control, they should be checked to ensure that the 'dwell' before spoiler extension with control displacement is correct.

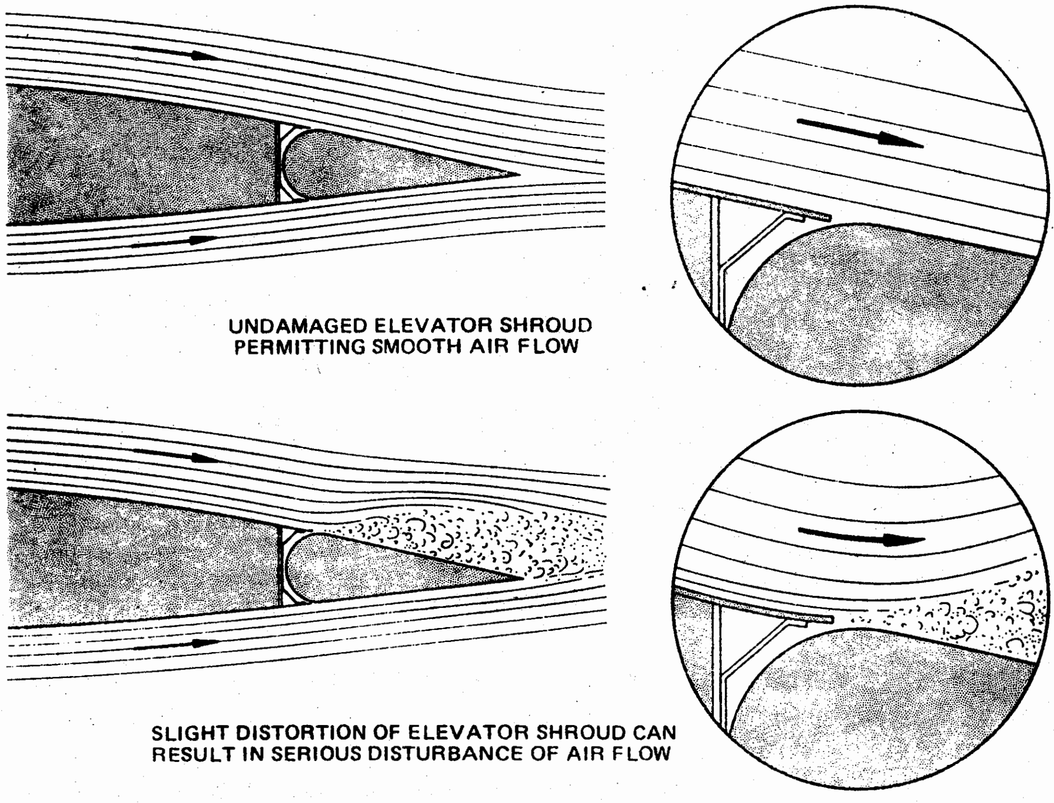

Figure 6 AIRFLOW OVER ELEVATOR

3.9 **Vortex Generators.** A check should be made to ensure that vortex generators are not bent or distorted, and that none is missing.

3.10 **Wing Fences.** Wing fences should be checked for alignment and, in addition, the condition of any seals between the fence and the wing should be carefully checked.

3.11 **Tail Unit.** Care should be taken to ensure that any fillets between the tailplane and fin, and the fin and fuselage, are in good condition and free from dents and other damage.

(a) The leading edges and surfaces of the tailplane and elevators should be checked for damage caused by debris thrown up during engine run, take-off and landing.

(b) Particular care should be paid to the alignment and clearance of rudder and elevator shrouds, since these can become very critical at speeds approaching Mach 1. Slight distortion of tailplane shrouds or excessive clearances can create a breakaway of the airflow over the elevator surfaces at high speeds which can result in little or no response to elevator control inputs. As these conditions would generally occur only at speeds approaching the limiting Mach number for the aeroplane concerned, it should be assumed that the lack of elevator response might occur in a dive when a dangerous condition could result. The airflow which occurs over the elevators is illustrated in Figure 6.

4 PRECAUTIONS DURING MAINTENANCE To ensure as far as possible against damage to aeroplane surfaces during maintenance, the precautions outlined in the following paragraphs are recommended as the minimum necessary.

4.1 When working on the top surfaces of aeroplanes, precautions should be taken to avoid damage to the surface by scratching, etc., and suitable mats or protective coverings, as detailed in the appropriate manual, should always be placed in position before work is commenced.

4.2 Ladders or trestles should never be rested against any part of the aeroplane, and fuelling hoses should not be dragged over flying control surfaces, wing leading or trailing edges, etc.

4.3 When removing inspection covers, panels, cowlings, fairings, etc., they should never be levered off, since this may damage and distort them. Leverage should not be applied when securing or unlocking fasteners, since this may strain the fasteners to such an extent that the associated panel could become loose.

4.4 Cowlings, fairings, etc., should never be placed directly on to concrete floors. It is recommended that suitable racks should be provided on to which the cowlings can be placed immediately after removal from the aeroplane.

4.5 When a panel, fairing, etc., is removed, it should be checked to ensure that the condition of any rubber moulding or sealing strip is satisfactory.

4.6 In certain wet take-off conditions followed by freezing, the landing gear door seals may sustain damage as a result of icing, and these should be checked for any such damage.

4.7 On aeroplanes having painted surfaces, it is essential that the thickness of the paint coating, particularly at leading edges, should be carefully controlled, since the amount of paint on the top side of a leading edge can easily influence the trim of an aircraft. This is particularly important where fillers are used to restore leading edge contours and the finished work should always be checked with a contour jig.

4.8 All surfaces should be kept clean, since dirt, oil or mud will always adversely affect the performance of the aeroplane.

4.9 When changing control surfaces or other aerofoil components, care should be taken to ensure that the new components fitted are in correct aerodynamic alignment with the surrounding structure, since the slight differences which can occur in nominally similar components, as a result of manufacturing tolerances, could affect the trim or performance of the aeroplane.

AL/7-12

Issue 1.

15*th April*, 1964.

AIRFRAME

STRUCTURES

RIGGING CHECKS ON AIRCRAFT

1 INTRODUCTION This leaflet gives guidance on methods of checking the relative alignment and adjustment of aircraft main components and should be read in conjunction with the appropriate manual for the aircraft concerned. Information on flying control components and the rigging of flying controls is given in Section AL/3 of the Procedures. Guidance on checking the rigging of aircraft after abnormal flight loads or heavy landings is given in Leaflet AL/7-1.

2 LEVELLING THE AIRCRAFT The position or angle of main components is related to a longitudinal datum line parallel to the aircraft centreline and a lateral datum line parallel to a line joining the wing tips. Before these positions or angles are checked,

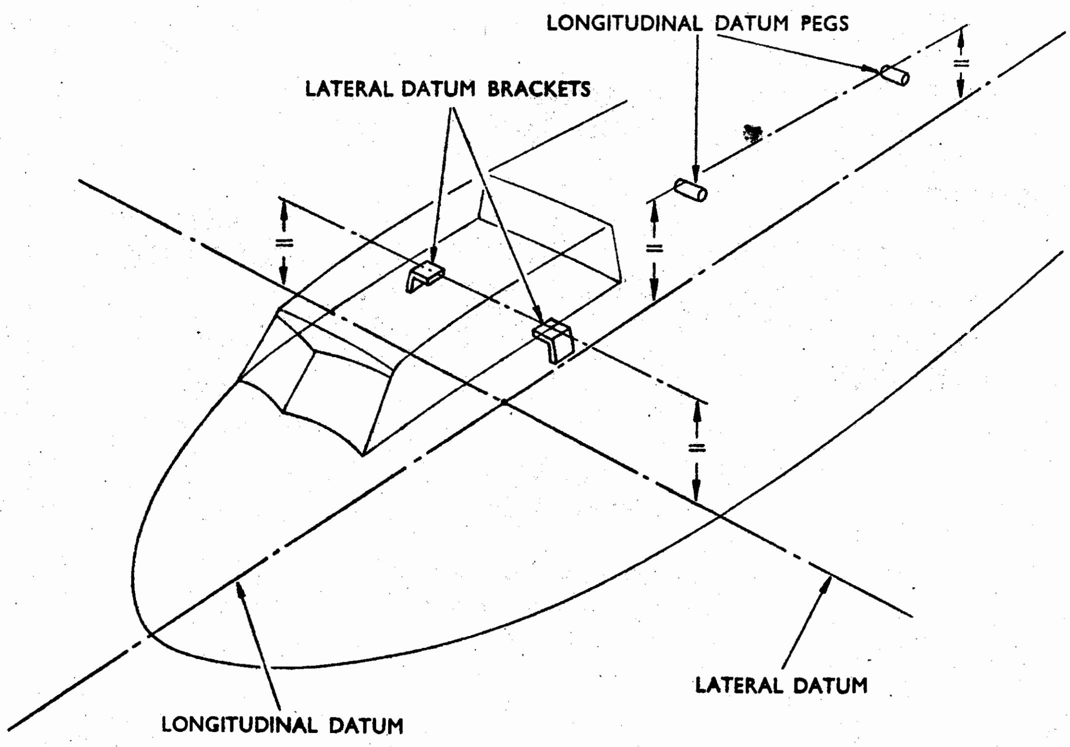

Figure 1 DATUM LINES AND LEVELLING POINTS the aircraft should (generally) be brought to the rigging position (i.e. with the lateral and longitudinal datum lines horizontal) by means of jacks or trestles, depending on the particular aircraft type, with the wheel just clear of the ground.

2.1 For the purpose of checking the level of smaller types of aircraft, fixed or portable datum pegs or blocks, on which can be rested a straight-edge and spirit level and which are generally attached to the fuselage parallel to or co-incident with the datum lines, are used, although in some instances parts of the structure which run parallel with the datum lines (e.g. top longerons or canopy rails of some aircraft) may be utilised. A typical levelling arrangement is shown in Figure 1.

2.2 The methods of checking the levelling given in paragraph 2.1 are also applicable to many of the larger types of aircraft, but other methods are sometimes used, e.g. the "grid" method illustrated in Figure 2. The grid plate is a permanent fixture on the floor of the aircraft and, when the aircraft is to be levelled, a plumb bob is suspended from a predetermined position in the roof of the aircraft over the grid plate. The adjustments necessary to the lifting gear to bring the aircraft to the level position are indicated by the grid scale, true level being obtained when the plumb bob is immediately over the centre point of the grid.

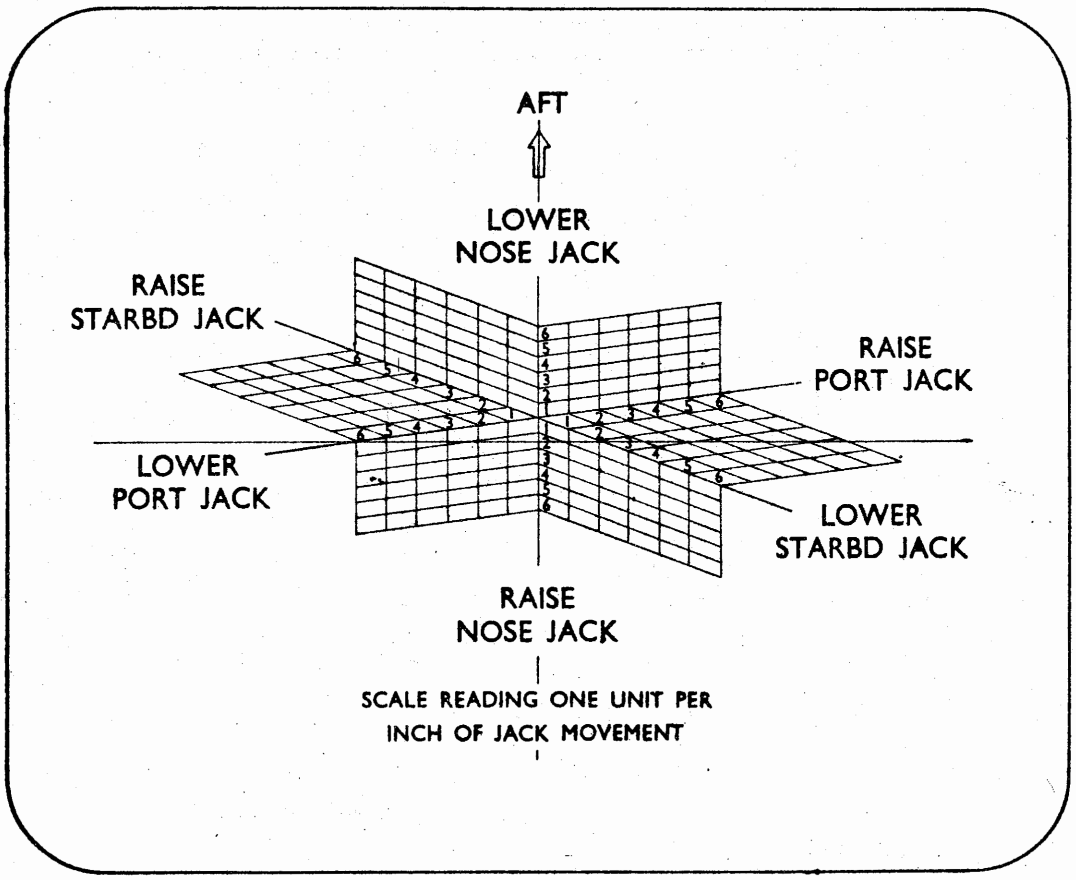

Figure 2 TYPICAL GRID PLATE

2.3 The method of bringing the aircraft to the rigging position depends largely on the size and type of aircraft and whether a nose wheel or tail wheel configuration applies, the general procedures applicable to each case being given in paragraphs 2.9 and 2.10 respectively. However, there are certain precautions that must be observed in all instances and guidance on these is given in paragraphs 2.4 to 2.8. Guidance on precautions to be taken when lowering the aircraft is given in paragraph 4.

2.4 A level site capable of bearing the load to be applied should be selected for the operation otherwise, where trestles are used, it may not be possible to level the aircraft, and where jacks are used, the danger of the jacks toppling and dropping the aircraft would exist.

2.5 Rigging checks should not normally be undertaken in the open, but if this is unavoidable the aircraft should be positioned nose into wind. In any case the aircraft should not be lifted in strong winds or gusts.

2.6 The weight and loading of the aircraft for the rigging check should be exactly as described in the manual or as quoted on the original rigging chart supplied by the manufacturer. Variations from this condition, especially in the case of larger aircraft, will prohibit a comparison with the original figures. In any case the aircraft should not be lifted until it is ensured that the maximum jacking weight (if any) specified by the manufacturer will not be exceeded.

2.7 All equipment which may cause damage to the aircraft during the lifting operation should be moved away before lifting is commenced and no personnel other than those directly connected with the rigging check should be permitted on or around the aircraft for the duration of the complete operation.

2.8 For most aircraft the brakes should be OFF and the wheels chocked prior to lifting but for aircraft fitted with levered suspension undercarriage units the wheels should be left unchocked.

2.9 **Tail Wheel Aircraft**

2.9.1 The tail should be raised to an approximately level position by means of the appropriate jacks or adjustable trestle accurately positioned under the rear lifting position. Where single-engine aircraft in particular are concerned, it may be necessary to weight down the tail to prevent the aircraft nosing over due to the weight of the engine. This weight must not be allowed to swing but must touch the ground and be secured by a taut rope to that part of the aircraft specified by the manufacturer.

2.9.2 The appropriate jacks or adjustable trestles should be accurately positioned under the main lifting points and the aircraft raised evenly by operating both jacks or trestle gears together until the wheels are just clear of the ground and the aircraft is in the (approximate) rigging position.

2.9.3 The lateral and longitudinal levels should be checked and adjusted as necessary by means of the lifting gear. Where hydraulic jacks are used, the locking devices provided must be applied immediately the aircraft has been correctly positioned and, to ensure the safety of personnel, at any time when the jack is not actually being operated during the lifting of the aircraft.

2.9.4 If steady trestles are placed under the wings after the aircraft has been supported in the rigging position, it must be ensured that they are not in contact with the wings when incidence or dihedral checks are being made, that no adjustments are made to the lifting gear with the steady trestles in position and that the trestles are removed before any attempt is made to lower the aircraft (paragraph 4).

2.10 **Nose Wheel Aircraft.** The appropriate trestles or jacks should be accurately positioned under the main, nose and (if applicable) tail positions. The main and nose lifting gear should be operated simultaneously and evenly until the aircraft is just clear of the ground and the operation completed as described in paragraphs 2.9.3 and 2.9.4.

3 RIGGING CHECKS Although the dihedral (paragraph 5.2) and incidence (paragraph 5.5) angles of conventional modern aircraft cannot be adjusted (with the possible exception of adjustable tailplanes) they should be checked at specified periods and after heavy landings or abnormal flight loads (see also Leaflet **AL/7-1**) to ensure that the components are not distorted and that the angles are within permitted limits. The relevant figures together with permitted tolerances are specified in the appropriate manual for the aircraft concerned, but the actual figures relevant to an individual aircraft are recorded in the aircraft log book.

3.1 The usual method of checking rigging angles is by the use of special boards (or the equivalent) in which are incorporated or on which can be placed an instrument for determining the angle, i.e. a spirit level or clinometer as appropriate. On a number of modern aircraft the rigging can be checked by means of sighting rods and a theodolite. Guidance on rigging checks with rigging boards is given in paragraphs 3.3 and 3.4 and on the use of sighting rods in paragraph 3.5.

3.2 **Sequence of Rigging Checks.** A suitable sequence for checking the rigging is as follows; it is essential that the checks should be made at all the positions specified in the relevant manual.

(i) Wing dihedral angle(s)

(ii) Wing incidence angle(s)

(iii) Engine alignment

(iv) Tailplane lateral level or dihedral

(v) Tailplane incidence angle

(vi) Verticality of fin

(vii) Symmetry check

NOTE: Where rigging checks on control surfaces are being combined with these checks, guidance on suitable methods is given in Leaflets AL/3-1 and AL/3-5.

3.3 Checking Aircraft with Rigging Boards

3.3.1 **Dihedral.** The dihedral angle should be checked in the specified positions with the special boards provided by the aircraft manufacturer or, if no such boards are provided, with a straight-edge and clinometer. The methods of checking with both types of board are shown in Figure 3.

NOTE: Certain portions of the wings or tailplanes may sometimes be horizontal or on rare occasions, anhedral angles may be present.

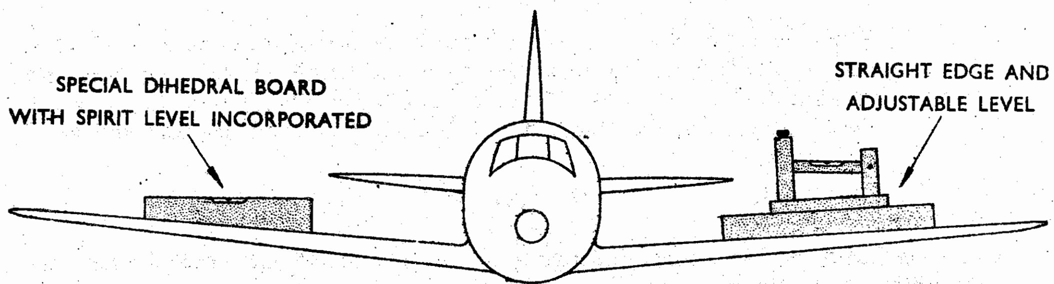

Figure 3 CHECKING DIHEDRAL

3.3.2 **Incidence.** The incidence is usually checked in at least two specified positions, inboard and outboard, on the component to ensure that it is free from twist.

(i) There are a variety of types of incidence boards, some having stops at the forward edge which must be placed in contact with the leading edge of the wing, whilst others are provided with location pegs which fit into some specified part of the structure, but the main purpose in each case is to ensure the board is fitted in exactly the position intended and, if the rigging is correct, that a clinometer on the top of the board will register zero or within a permitted tolerance about zero. In most instances the boards are kept clear of the wing contour (so that the incidence check is not influenced by any irregularities which may occur in the contour) by means of short feet attached to the board. A typical wooden incidence board is shown in Figure 4 although, of course, some are manufactured of metal.

(ii) It must be borne in mind that modifications in areas where incidence boards are located may affect results. For example, if leading-edge deicing shoes were fitted this might seriously affect the position taken up by a board having a leading edge stop as shown in Figure 4.

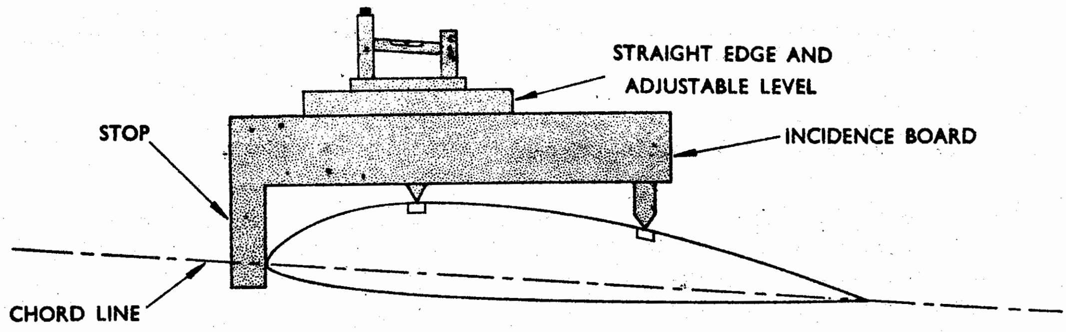

Figure 4 TYPICAL INCIDENCE BOARD

(iii) Where possible, the vertically of the incidence board should be checked with a plumb bob. Where the checks are being taken in the open (see paragraph 2.5) and it is difficult to steady the plumb bob due to wind, the suspension of the plumb bob in a container of oil or water will be of assistance.

3.3.3 **Verticality of Fin.** After the rigging of the tail planes has been checked, the verticality of the fin relative to a lateral datum can be checked from a given point on either side of the top of the fin to a given point on the port and starboard tail planes respectively; the measurements should be similar within prescribed limits. When the verticality of the fin stern post has to be checked, it may be necessary to remove the rudder and drop a plumb bob through the rudder hinge attachment holes, when the cord should pass centrally through all the holes. It should be noted that some aircraft have the fin offset to the longitudinal centreline to counteract engine torque.

NOTE: Guidance on the checks necessary after the refitting of a flying control surface is given in the AL/3 group of leaflets.

3.3.4 **Engine Mountings.** Engines attached to the wings are usually mounted with the thrust line parallel to the horizontal longitudinal plane of symmetry but not always parallel to the vertical longitudinal plane, since, due to their disposition along the wing, the outboard engines are often offset a degree or so to enable the slipstream from the propellers to converge on the tailplane. The check to ensure that the position of the engine, including the degree of offset, is correct depends largely on the type of mounting, but usually entails a measurement from the centre line of the mounting to the longitudinal centre line of the fuselage at a point specified in the relevant manual. (See also Figure 5).

3.3.5 **Symmetry Check.** Figure 5 illustrates the principle of a typical symmetry check, the relevant figures and tolerances for which will be found in the appropriate manual, although the actual measurements relating to the aircraft concerned are given in the aircraft log book.

(i) For the smaller types of aircraft the measurements between points are usually taken by means of a steel tape. It is recommended that a spring balance should be used on the longer distances to obtain an equal tension, 5 lb. usually being sufficient.

(ii) Where the larger types of aircraft are concerned, it is more usual to chalk the floor locally under the positions where the dimensions are to be taken, to drop plumb bobs from the checking points, marking the floor with an "X" immediately under the point of each plumb bob, and then to measure the distance between the centre of the markings. This method has the advantages of ensuring more accurate measurement and reducing the amount of walking necessary on main planes and tail planes.

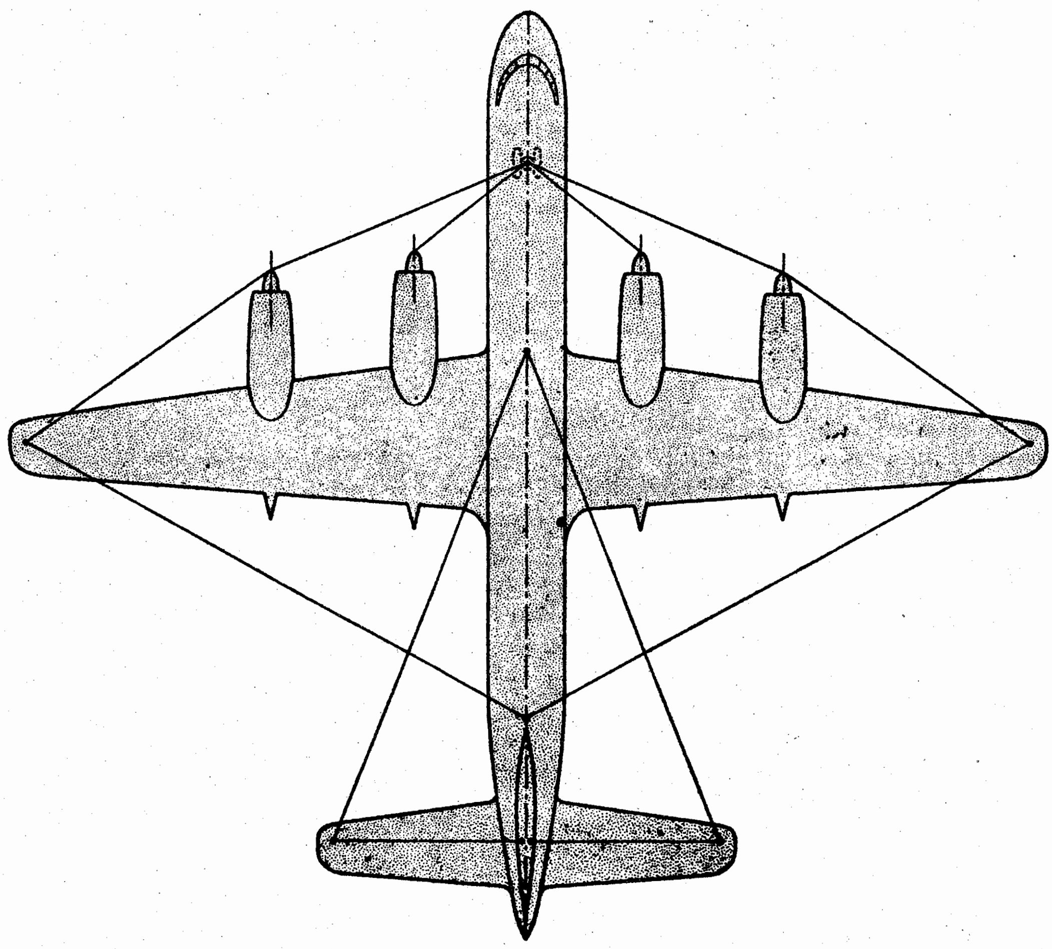

Figure 5 SYMMETRY CHECK

3.4 **Rigging Checks on Biplanes.** In general the rigging checks applicable to single-engined biplanes during reassembly after overhaul are as follows, but specific requirements relating to a particular type of aircraft should be ascertained from the relevant approved manual. The use of rigging boards, etc., is described in paragraph 3.3, as are other checks (such as the symmetry check) which are not peculiar to biplanes.

3.4.1 The fuselage should be levelled laterally and longitudinally as described in paragraph 2. The centre-section should be placed on suitable trestles and the centre-section struts and wires (complete with fork-ends) attached.

NOTE: It is important that the fork-ends should be screwed the same number of turns on each end of the wire to provide for subsequent adjustment.

3.4.2 The centre-section should be erected onto the fuselage and the stagger (paragraph 5.7) and lateral symmetry checked. The stagger should be checked by dropping plumb bobs from the leading edge of the upper portion of the centre-section (or other defined position) and measuring the distance from the plumb bobs to the leading edge of the lower portion of the centre-section (or other defined position). If necessary, the stagger can be adjusted by means of the front centre-section struts on most aircraft of this type. The symmetry about the centre line should be checked by measuring from plumb bobs to the sides of the fuselage and can be adjusted, if necessary, by means of the bracing wires.

NOTE: It is essential that the centre-section rigging checks should be accurately carried out, since small errors in the centre-section bracing can result in large errors in the general rigging.

3.4.3 The port (or starboard) top main plane should be attached to the centre-section, care being taken to ensure that the main plane is adequately supported during the assembly. The landing wires (paragraph 5.4) should then be attached to the centre-section, the port (or starboard) lower main plane attached to the centre-section, the interplane struts, flying wires (paragraph 5.3) and incidence wires (paragraph 5.6) fitted and the whole assembly lightly tensioned up. The completed side of the aircraft should be steadied with a trestle whilst the opposite side is assembled in the same order.

NOTE: Although usually of similar appearance, front and rear interplane struts are usually of slightly different lengths to compensate for wing contour, thus it is important to ensure that the correct strut has been fitted in the correct position.

3.4.4 After assembly the fuselage level should be rechecked and adjusted as necessary, after which the main planes should be trued-up by adjustments to the appropriate wires, the aim being to achieve the correct dihedral first and then to work the incidence and stagger together. Care must be taken during rigging to ensure that the main flying and landing wires are not over-tensioned to the extent of bowing the main plane spars or interplane struts.

NOTE: The specified lengths and permitted tolerances applicable to all wires are given in the rigging diagrams appropriate to the aircraft type, but the actual figures to which the aircraft had previously been rigged is recorded in the aircraft log book. If using the same components it is advisable to re-rig to the log book figures, since these may have been determined specifically to counteract a flying fault.

3.4.5 After the rigging of the main planes has been completed, it should be ensured that all forkends, etc., are in safety, are not "butting" against the ends of the fitting and have been correctly locked (Leaflets **AL/3-1** and **BL/5-1**), that the wires are in streamline and that anti-chafing discs and spreader bars are correctly fitted to prevent vibration of the wires.

3.4.6 **Empennage.** The empennage should be attached in accordance with the instructions contained in the relevant manual and adjusted (where this is possible) to within the limits specified in the relevant rigging diagram. It should be noted that the tail plane struts are usually handed and, unless these are correctly positioned, the fairings will not be in line of flight.

NOTE: Tail planes provided with an adjustment mechanism must be set to the neutral position before checking is commenced.

3.4.7 **Twin-Engine Biplanes.** The general procedure for rigging twin-engined biplanes is basically similar to that described above for single-engined biplanes but it must be ensured that the weight of the engines is taken up on the appropriate struts before completing the general rigging.

3.5 **Checking Rigging with Sighting Rods.** This method of checking rigging is used mainly on the larger types of aircraft and consists basically of sighting with a theodolite positions of datum marks on a series of rods of graduated lengths, each of which is inserted into a specified jigged position on the underside of the aircraft.

3.5.1 For the initial check, the aircraft should be brought to the rigging position (paragraph 2) and the sighting rods inserted at the appropriate stations.

NOTE: Since any rod can be fitted into any socket, it is important to ensure that the rods are inserted in their correct positions.

3.5.2 A theodolite, erected at an appropriate distance and position from the aircraft should be levelled up with the datum mark on the master sighting rod (usually the shortest rod fitted under the fuselage) and then readings should be taken from this sighting line at each rod station and recorded. A typical method of taking the readings is illustrated in Figure 6.

NOTE: (i) A method which provides accurate vertical adjustment and rigidity for a theodolite is to mount it on a hydraulic jack.

(ii) It may not be possible in every instance to obtain a reading on every sighting rod from one theodolite position, in which case the theodolite should be appropriately repositioned realigned on the master rod, and the check continued in the same manner as before.

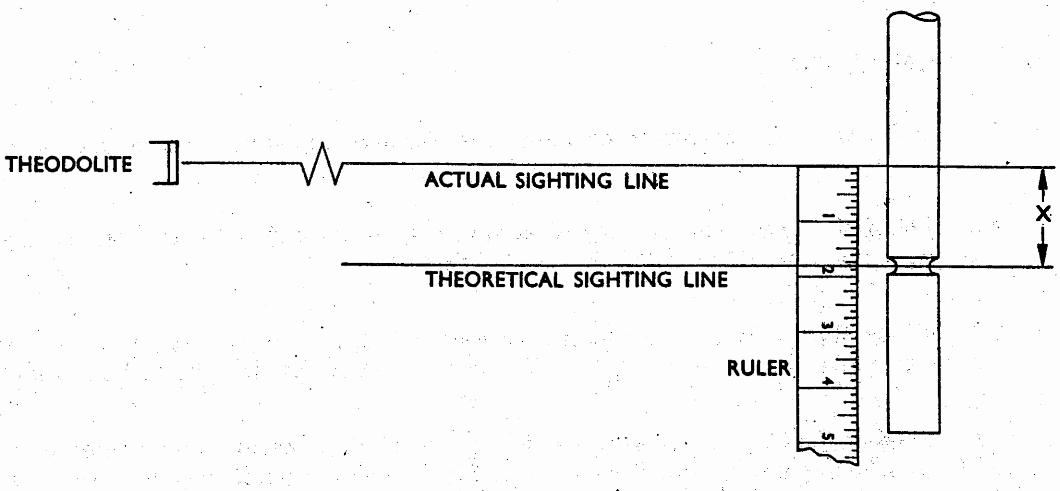

Figure 6 TYPICAL METHOD OF TAKING READINGS

3.5.3 The readings thus obtained must be within the tolerances permitted by the manufacturer (details of which are usually included in the rigging drawing), and entered in the aircraft log book for permanent record.

3.5.4 There are two basic methods applicable to the use of sighting rods and these are described below.

(i) On some types of aircraft the sockets into which the sighting rods are inserted are adjustable in the vertical direction so that once variations from nominal figures have been recorded, the rods can be "zeroed" and permanently locked. Thus the sighting line on all subsequent checks should in fact coincide with the datum marks on all the rods if the rigging is correct. Rods used for this method have the single datum as illustrated in Figure 6.

(ii) The second method is to use sighting rods on which are marked the datum line, on either side of which is also marked graduations indicating the permissible tolerance on the nominal figure in increments of ¼ degrees. With this method the sockets into which the rods are inserted are not adjustable and subsequent readings should be given the actual figures recorded on the initial check.

NOTE: When rods of the "screw-in" type are used it should be ensured that they are fully screwed home before the check is commenced.

3.5.5 When a component (e.g. wing or tail plane) is changed, it will be necessary to again carry out the initial check to ascertain actual figures.

4 LOWERING THE AIRCRAFT Before any attempt is made to lower the aircraft to the ground it must be ensured that wing supports and any other equipment which might foul and damage the aircraft are moved clear. The aircraft should be lowered evenly and, when the aircraft weight is accepted on the undercarriage, the jacks should be further lowered to ensure that they can be removed without fouling the aircraft structure.

5 DEFINITIONS

5.1 **Anhedral.** An inclination outwards and downwards relative to the lateral datum.

5.2 **Dihedral.** The angle (or angles) at which the wings and tail planes are inclined outward and upward relative to the lateral datum.

5.3 **Flying Wires.** Wires the principal function of which is to transfer the lift of the main planes to the main structure. These wires are sometimes termed "lift wires".

5.4 **Landing Wires.** Wires which brace the main plane against forces opposite in direction to the direction of lift, as occur, for example, in landing. These wires are sometimes termed "anti-lift wires".

5.5 **Incidence.** The angle between the chord line of the wing or tail plane and the longitudinal datum.

5.6 **Incidence Wires.** Wires bracing the main plane structure in the plane of a pair of front and rear struts.

5.7 **Stagger.** The distance between the leading edge of the lower plane and the projection of the leading edge of the upper plane on the chord of the lower plane.

AL/7-13

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AIRCRAFT

STRUCTURES

INSPECTION OF METAL AIRCRAFT STRUCTURES

1 INTRODUCTION This Leaflet gives general guidance on the inspection of those parts of a metal aircraft structure which, because of their remoteness, complexity or boxed-in design, are not readily accessible for routine maintenance or require special attention in the light of operational experience.

2 GENERAL Deterioration may arise from various causes and can affect various parts of the structure according to the design of the aircraft and the uses to which it is put. Therefore, this Leaflet should be read in conjunction with the appropriate manufacturer's publications and the Maintenance Schedule for the aircraft concerned.

2.1 Although considerable guidance may be given in the appropriate publications as to suitable opportunities for inspecting normally inaccessible structures (e.g. when a wing tip is removed permitting access to the adjacent wing structure) experience should indicate to the operator further opportunities for such inspections which can be included in the Maintenance Schedule. Apart from the airworthiness aspects, these combined inspections could often be to the operator's advantage, since they would obviate the need for future dismantling.

2.2 Where access has been gained to a part of the structure which is normally inaccessible, advantage should be taken of this dismantling to inspect all parts of systems thus exposed. Guidance on the inspection of pipes, controls, etc., is given in the appropriate CAIP Leaflets.

3 CORROSION The presence of corrosion in aircraft structures is liable to result in conditions which may lead to catastrophic failures. It is therefore essential that any corrosive attack is detected and rectified in the earliest stages of its development.

3.1 In general, no corrosive attack on an aircraft structure will occur without the presence of water in some form. However, a fact less well appreciated is that, in a wide variety of ambient conditions, condensation will form on various parts of the structure and this is one of the main causes of corrosion.

3.1.1 By the nature of their operation, aircraft are exposed to frequent changes of atmospheric temperature and pressure and to varying conditions of relative humidity; therefore, all parts of the structure are subject to some form of condensation. The resultant water takes into solution a number of corrosive agents from the atmosphere or from spillages (which convert the water into a weak acid) and will corrode most metal surfaces where the protective treatment has been damaged or is inadequate. Cases of serious corrosion have been found in both closed and exposed parts of structures of aircraft operated under a wide variety of conditions.

3.1.2 Corrosion can be intergranular; therefore, the removal of the surface products of corrosion followed by reprotection is not necessarily effective. Once the surface is penetrated the reduction in strength due to corrosion is disproportionate to the reduction in thickness of the metal.

3.2 **Treatment and Rectification of Corrosion.** Reference should be made to Leaflet **BL/4-1** on the nature and control of corrosion, to Leaflet **BL/4-2** on the removal and rectification of corrosion, and to Leaflet **BL/4-3** on methods of protection from corrosion. Information on some of the protective treatment processes commonly used to protect structural parts can be found in the following Leaflets:—

BL/7-1	Anodic Oxidation
BL/7-2	Cadmium Plating
BL/7-3	Chromate Treatment of Magnesium Alloys
BL/7-4	Phosphating of Steels
BL/6-20	Painting

3.3 **Air-conditioned Compartments.** In air-conditioned compartments, condensation will occur where the warm inside air impinges on the colder areas of the structure such as the inner surfaces of a pressure cabin skin. Considerable quantities of water will tend to collect and run down the inside of the cabin walls.

3.3.1 To avoid corrosion it is important to ensure that the water is unimpeded in its flow down to the bilge area. The structure and all drain holes through stringers, etc., should be kept clean and free from obstructions, and drainage ducts should be checked for clearance and damage. A check should be made to ensure that water or moisture is not being trapped by the thermal acoustic lining or any other form of upholstery.

3.3.2 Water collecting in the lower parts of the structure and in the bilge area can be highly contaminated. It will not only contain the corrosive agents mentioned in paragraph 3.1.1, but also other impurities due to fumes, spillages, etc., emanating from the galley, toilets and smoking compartments, thus intensifying the corrosive nature of the water. At specified periods these parts of the structure should be thoroughly cleaned and carefully inspected for signs of corrosion and for deterioration of the protective treatment.

3.3.3 Thermal acoustic linings usually have a waterproof covering on the side adjacent to the structure, or the thermal acoustic material may be completely enveloped in a waterproof covering. Any damage to the waterproof covering may lead to considerable absorption of water into the lining, setting up corrosion between the damaged lining and the surrounding structure.

NOTE: Water soakage of upholstery and especially of thermal acoustic linings can also result in an appreciable increase in aircraft weight. Instances have also occurred where saturated compartment linings have caused electrical failures.

3.4 **Structural Parts Susceptible to Corrosion.** The constructor's publications give general guidance on the inspection of those parts of the structure which are most likely to be attacked by corrosion. Nevertheless, it should be noted that, in the light of operational experience, other parts of the structure may require special attention. Engineers should be on the alert for any signs of corrosion in parts of the structure not specifically mentioned in the constructor's publications or instructions.

3.4.1 In 'blind' or boxed-in structures where accessibility is difficult and where cleaning and maintenance are awkward, dirt and dust tend to collect and lodge in various parts. This dirt and dust acts as a 'wick' for moisture which, in the course of time, will work through any inadequate protective treatment and penetrate to the metal to act as an electrolyte. Even on new aircraft the problem is still present in some boxed-in or intricate structures.

NOTE: Protective treatments with a rough surface finish, such as primer paints, tend to hold dust and dirt, and cleaning is rendered more difficult because of this tendency of dust and dirt to adhere to such surfaces. Hard gloss finishes, such as epoxy resin paints, will provide a more effective and lasting protection.

3.4.2 Completely boxed-in structures should be adequately vented to prevent stagnation of the internal air. It is important to ensure that vents and drain holes are clear, are of the correct size and are unobstructed by ice in freezing conditions on the ground.

3.4.3 Honeycomb structures, especially those in components of small cross-sectional area (e.g. wing flaps), are often prone to the collection of water if careful attention has not been given to the sealing around attachment screw holes and at skin joints to prevent ingress of moisture. Cases are known where the trapped water in the structure has frozen and caused distortion of the outer skin of the component due to internal expansion.

3.4.4 Fuselage keel areas, structures concealed by upholstery (see e.g. paragraph 3.3) and the double skin of freight bay floors, are typical areas liable to corrosion. Special attention should be given to all faying surfaces in these areas and particularly the faying surfaces of stringers to skin panels and skin lap joints. In general, visual inspection supplemented by radiological methods of examination is a satisfactory way of detecting corrosion, provided it is expertly carried out and proper correlation between the findings of each method is maintained. In some instances, however, normal methods of visual inspection supplemented by radiological examination have not proved satisfactory and dismantling of parts of the structure may be required to verify the condition of the faying surfaces.

3.4.5 Structures constructed from light gauge materials which are spot-welded together, such as the faying surfaces of stringers mentioned in the previous paragraph, are liable to serious and rapid corrosion as this method of attachment precludes the normal anti-corrosive treatments (e.g. jointing compound) at the faying surfaces. Cases of serious corrosion have also been found in similar structures riveted together where the jointing compound has been found to be inadequate.

3.4.6 In some instances, where stringers are of top-hat section and are bonded to the panel by a thermosetting adhesive, corrosion has been known to affect the stringers, the panel and the bonding medium; such stringers are often sealed at their ends to prevent the ingress of moisture, etc. Where adhesive is used to attach a doubler to a skin, corrosion can occur between the surfaces and will eventually be indicated by a quilted appearance.

3.5 **Exhaust Gases.** Structural parts which are exposed to exhaust gases are prone to corrosion due to the sulphur content of exhaust gases and jet efflux. Although this problem can be reduced by regular and thorough cleaning, particular attention should be given to the condition of the protective treatment of these structures.

3.6 **Stress Corrosion**

3.6.1 Stress corrosion in aluminium tends to occur mainly in the high-strength alloys and is due to locked-in stresses resulting from some aspects of heat treatment or inappropriate assembly practices. Stress corrosion takes the form of cracking which, in conjunction with other corrosion, can lead to the sudden and complete failure of structural parts.

3.6.2 Stress corrosion cracking in titanium depends on the composition of the alloy, its processing and its notch sensitivity. Some titanium alloys may develop rapid crack growth if contaminated with a saline solution after a crack has been initiated.

3.7 **Fretting.** Fatigue failures often result from fretting at structural bolted joints. Fretting is revealed by black or greyish brown powder or paste around the periphery of the faying surfaces and may result in the formation of cracks at the outer edge of the fretted area; these cracks may develop across the component and will not necessarily pass through the bolt hole. Dismantling of suspect parts is usually necessary and an inspection by penetrant dye, magnifying lens, eddy current or ultrasonic (surface wave) methods should be carried out.

4 SPILLAGE Spillage or system leaks of extraneous fluids which may penetrate the structure during maintenance, repair or operation of the aircraft, should be carefully traced and thoroughly cleaned out. Where required, any protective treatment should be restored. Fluids such as ester-based engine oils, glycol defrosting fluids, etc., will damage most protective treatments not intended to be in contact with them. Accidental spillage of refreshments such as mineral waters, coffee, etc., have a particularly deleterious effect on floor structures.

4.1 With an aircraft in operation there are areas where spillages invariably occur, such as in galleys and toilet compartments. Here, careful cleaning and the maintenance of any special floor protection is important. The floor structures around and below these compartments should receive special attention to ensure protection against seepage and corrosion. Where animals are carried, special precautions are essential because corrosion due to animal fluid can cause rapid deterioration of metals. The floor and sides of compartments in which animals are housed should be protected by suitable means against seepage, and the structure below the floor should be carefully inspected for any signs of seepage or corrosion.

NOTE: Where animals are not housed in containers specially designed for air transport, unbroken impervious sheeting such as waterproof canvas or heavy polythene sheet, should be laid on the floor and fixed at the required height on the fuselage sides and bulkheads to prevent any seepage into the aircraft structure. A form of matting, preferably made of absorbent material, should be laid on the sheeting to prevent damage due to animal movements.

4.2 Battery compartments should be examined for any signs of acid corrosion. Compartment vents should be clean and undamaged and the anti-sulphuric protective treatment should be carefully maintained. Special attention should be given to the structure in the immediate vicinity of the battery for any signs of corrosion caused by acid spillage or a damaged battery. It should be noted that heavy concentrations of battery fumes, resulting from faulty compartment venting or a runaway battery, may also lead to corrosion in the surrounding structure.

NOTE: If there is any indication of corrosion, the parts affected should be cleaned with a solution of water and washing soda, then rinsed with fresh water and dried out. After 24 hours a re-check should be made for further signs of corrosion and, if satisfactory, the protective treatment should be restored.

4.3 The spillage of mercury in an aircraft can have devastating effects on any aluminium alloy skin or structure with which it comes into contact. The effects of mercury spillage and the various methods of decontamination, where this is possible, are discussed in Leaflet **BL/4-10**.

5 CORROSIVE EFFECTS OF AGRICULTURAL CHEMICALS On aircraft used for crop spraying or dusting, considerable attention and special care should be given to the inspection of the structure owing to the highly corrosive nature of certain of the chemicals used for these purposes. The corrosive effect of some of the chemicals used for agricultural purposes may not always be fully known. Some chemicals which were considered to be harmless to aircraft materials, have proved, in the course of time, to be corrosive.

5.1 Thorough cleaning of the whole aircraft structure after agricultural spraying operations is very important. Unless otherwise specified by the manufacturer of the chemical, the aircraft should be thoroughly washed, both internally and externally, with copious supplies of clean water. Engine intakes and exhausts, and other openings, should be blanked during the washing to prevent the ingress of water. After washing, it is essential to check that no pockets of chemicals or water remain trapped in the structure, that all drains are clear and that all covers or devices used to prevent the ingress of chemicals are properly refitted.

5.2 A check should be made to ensure that the spray equipment tanks, pipes, pumps, etc., are leak-proof and that spray booms or spray nozzles are in their correct positions.

5.3 When filling up with chemical spray fluids care is necessary to avoid spillage. Where there is no provision to prevent spilled fluid finding its way into the structure, it is essential to avoid over-filling, and the chance of accidental spillage can be reduced by using the proper filling equipment. If spillage does occur, it should be cleaned out immediately before it has penetrated into parts of the structure where cleaning would be more difficult.

6 METAL FATIGUE Metal fatigue can be briefly described as a weakening of a metal part under repeated applications of a cycle of stress. The weakening effect can be seriously accelerated by corrosion of the metal.

6.1 In the early stages, fatigue damage is difficult to detect by visual inspection and one of the methods of non-destructive examination outlined in the **BL/8** series of Leaflets (see also paragraph 9) is usually specified; the method used depending on the type of structure and material concerned. In the majority of cases the presence of fatigue damage is revealed by the formation of a small hairline crack or cracks.

6.2 Those parts of a structure where fatigue damage may occur are determined by design calculations and tests based on the expected operational use of the aircraft, and substantiated by operational experience. At the periods specified in the appropriate publications, examination or renewal of the parts will be required. These periods are usually in terms of flying time or the number of landings, or from readings logged by load recording instruments. With certain materials and structures, renewal or sampling checks may be required on a calendar basis.

6.3 It is important to note that some parts of a structure may be liable to fatigue damage resulting from unforeseen causes, e.g. parts damaged or strained on assembly, invisible damage to the structure during assembly or maintenance work, or fretting (see Leaflet **AL/7–8**). When carrying out inspections it is important to check carefully for any signs of cracks emanating from points of stress concentration such as bolt-holes, rivets, sharp changes in section, notches, dents, sharp corners, etc. Fatigue damage can also be caused by pits and notches created by corrosion, although the corrosion may no longer be active. During the application of repeated stress cycles, crevices can be opened up and may eventually result in a fatigue failure.

NOTE: Poor fitting or malassembly can reduce fatigue life considerably. A spar has been known to fail under tests at a fraction of its normal life as a result of the stress concentration caused by a tool mark in a bolt-hole. Defects such as a burr on a bolt can cause a scratch inside the bolt-hole, which can seriously accelerate fatigue damage in a stressed member.

7 CLEANLINESS It is important that aircraft should be thoroughly cleaned periodically and reference should be made to Leaflet **BL/6–19.**

7.1 Care should be taken not to damage protective treatments when using scrubbing brushes or scrapers, and any cleaning fluids used should have been approved by the aircraft constructor. For final cleaning of a boxed-in type of structure an efficient vacuum cleaner, provided with rubber-protected adaptors to prevent damage, should be used. The use of air jets should be avoided as this may lead to dirt, the products of corrosion, or loose articles, being blown from one part of the structure to another.

8 INSPECTION The structure should be maintained in a clean condition and a careful check should be made for any signs of dust, dirt or any extraneous matter, especially in the more remote or 'blind' parts of the structure. Loose articles such as rivets, metal particles, etc., trapped during construction or repair, may be found after the aircraft has been in operation for some considerable time. It is important to examine these loose articles to ensure that they did not result from damaged structure. It is generally easy to determine if a loose article has formed part of the structure by its condition, e.g. an unformed rivet could be considered as a loose article, but a rivet which had been formed would be indicative of a failure.

8.1 **General**

8.1.1 The structure should be examined for any signs of distortion or movement between its different parts at their attachment points, for loose or sheared fasteners (which may sometimes remain in position) and for signs of rubbing or wear in the vicinity of moving parts, flexible pipes, etc.

NOTES: (1) A wing structure has been known to have had a rib sheared at its spar attachments due to the accidental application of an excessive load, without any external evidence of damage, because the skin returned to its original contour after removal of the load.

(2) For the inspection of bolted joints see Leaflet **AL/7-8.**

8.1.2 The protective treatment should be examined for condition. On light alloys a check should be made for any traces of corrosion, marked discoloration or a scaly, blistered or cracked appearance. If any of these conditions is apparent the protective treatment in the area concerned should be carefully removed and the bare metal examined for any traces of corrosion or cracks. If the metal is found satisfactory, the protective treatment should be restored.

NOTE: To assist in the protection of structures against corrosion some constructors may attach calcium chromate and/or strontium chromate sachets to the vulnerable parts of the structure. The presence of chromate in the sachets can be checked by feel during inspection. After handling these materials, the special precautions, e.g. hand washing, given in the constructor's manual, should be followed.

8.1.3 In most cases where corrosion is detected in its early stages, corrective treatment will permit the continued use of the part concerned. However, where the strength of the part may have been reduced beyond the design value, repair or replacement may be necessary. Where doubt exists regarding the permissible extent of corrosion, the constructor should be consulted.

8.1.4 The edges of faying surfaces should receive special attention (see also paragraph 3.4.4); careful probing of the joint edge with a pointed instrument may reveal the products of corrosion which are concealed by paint. In some instances slight undulations or bumps between the rivets or spot welds, or quilting in areas of double skins due to pressure from the products of corrosion, will indicate an advanced state of deterioration. In some cases this condition can be seen by an examination of the external surface, but as previously mentioned in this Leaflet, dismantling of parts of the structure to verify the condition of the joints may be required.

NOTES: (1) To avoid damage to the structure, the probing of a joint with a pointed instrument should be carried out with discretion by an experienced person. Any damage done to the protective paint coating, however small, should be made good.

(2) Where dismantling of parts of the structure is required, reference should be made to Leaflet **AL/9-1.**

8.2 **Visual Examination.** Nearly all the inspection operations on aircraft structures are carried out visually and, because of the complexity of many structures, special visual aids are necessary to enable such inspections to be made. Visual aids vary from the familiar torch and mirrors to complex instruments based on optical principles and, provided the correct instrument is used, it is possible to examine almost any part of the structure.

NOTE: Airworthiness Requirements normally prescribe that adequate means shall be provided to permit the examination and maintenance of such parts of the aeroplane as require periodic inspection.

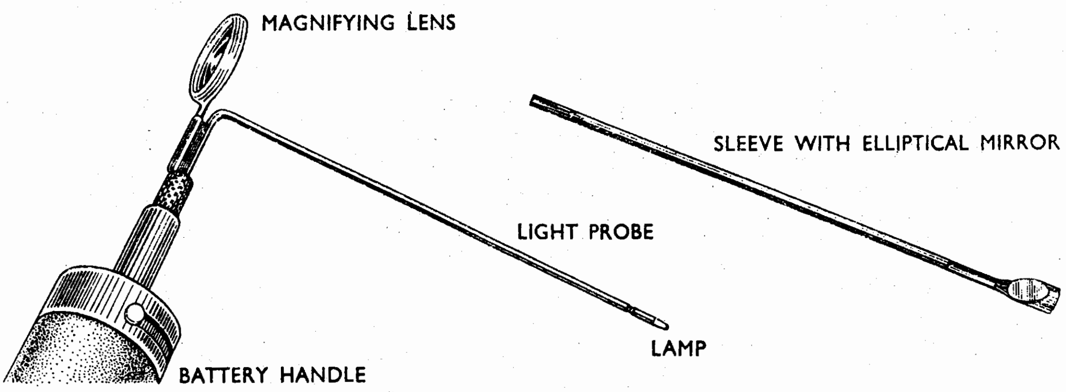

Figure 1 TYPICAL LIGHT PROBE

8.2.1 **Light Probes.** It is obvious that good lighting is essential for all visual examinations, and special light probes are often used.

(a) For small boxed-in structures or the interior of hollow parts such as the bores of tubes, special light probes, fitted with miniature lamps, as shown in Figure 1, are needed. Current is supplied to the lamp through the stem of the probe from a battery housed in the handle of the probe. These small probes are made in a large variety of dimensions, from 5 mm ($\frac{3}{16}$ in) diameter with stem lengths from 50 mm (2 in) upwards.

(b) Probes are often fitted with a magnifying lens and attachments for fitting an angled mirror. Such accessories as a recovery hook and a recovery magnet may also form part of the equipment.

(c) For the larger type of structure, but where the design does not permit the use of mains-powered inspection lamps, it is usually necessary to use a more powerful light probe. This type of light probe consists of a lamp (typically an 18 watt, 24 volt type) which is protected by a stiff wire cage and mounted at one end of a semi-flexible tube or stem. On the other end is a handle with a light switch and electrical connections for coupling to a battery supply or mains transformer. As the diameter of the light probe is quite small it can be introduced through suitable apertures to the part of the structure to be inspected.

NOTE: Where spillage or leakage of flammable fluids may have occurred or when inspecting fuel tanks, etc., it is important to ensure that the lighting equipment used is flameproof, e.g. to BS 229.

8.2.2 **Inspection Mirrors.** Probably the most familiar aid to the inspection of aircraft structures is a small mirror mounted at one end of a rod or stem, the other end forming a handle. Such a mirror should be mounted by means of a universal joint so that it can be positioned at various angles thus enabling a full view to be obtained behind flanges, brackets, etc.

(a) A useful refinement of this type of mirror is where the angle can be adjusted by remote means, e.g. control of the mirror angle by a rack and pinion mechanism inside the stem, with the operating knob by the side of the handle, thus permitting a range of angles to be obtained after insertion of the instrument into the structure.

(b) Mirrors are also made with their own source of light mounted in a shroud on the stem and are designed so as to avoid dazzle. These instruments are often of the magnifying type, the magnification most commonly used being 2X.

8.2.3 **Magnifying Glasses.** The magnifying glass is a most useful instrument for removing uncertainty regarding a suspected defect revealed by eye, for example, where there is doubt regarding the presence of a crack or corrosion. Instruments vary in design from the small simple pocket type to the stereoscopic type with a magnification of 20X. For viewing inside structures, a hand instrument with 8X magnification and its own light source is often used.

(a) Magnification of more than 8X should not be used unless specified. A too powerful magnification will result in concentrated viewing of a particular spot and will not reveal the surrounding area. Magnification of more than 8X may be used, however, to re-examine a suspected defect which has been revealed by a lower magnification.

(b) When using any form of magnifier it is most important to ensure that the surface to be examined is sufficiently illuminated.

8.2.4 **Endoscopes.** An endoscope (also known as an introscope, boroscope or fibre-scope, depending on the type and the manufacturer) is an optical instrument used for the inspection of the interior of structure or components. Turbine engines, in particular, are often designed with plugs at suitable locations in the casings, which can be removed to permit insertion of an endoscope and examination of the interior parts of the engine. In addition, some endoscopes are so designed that photographs can be taken of the area under inspection, by attaching a camera to the eyepiece; this is useful for comparison and record purposes.

(a) One type of endoscope comprises an optical system in the form of lenses and prisms, fitted in a rigid metal tube. At one end of the tube is an eyepiece, usually with a focal adjustment, and at the other end is the objective head containing a lamp and a prism. Depending on the design and purpose of the instrument a variety of objective heads can be used to permit viewing in different directions. The electrical supply for the lamp is connected near the eyepiece and is normally supplied from a battery or mains transformer.

(i) These instruments are available in a variety of diameters from approximately 6 mm (¼ in) and are often made in sections which can be joined to make any length required. Right-angled instruments based on the periscope principle are also available for use where the observer cannot be in direct line with the part to be examined.

(b) A second type of endoscope uses 'cold light', that is, light provided by a remote light source box and transmitted through a flexible fibre light guide cable to the eyepiece and thence through a fibre bundle surrounding the optical system to the objective head. This type provides bright illumination to the inspection area, without the danger of heat or electrical sparking, and is particularly useful in sensitive or hazardous areas.

(c) A third type of endoscope uses a flexible fibre optical system, thus enabling inspection of areas which are not in line with the access point.

9 NON-DESTRUCTIVE EXAMINATION In cases where examination by visual means is not practicable or has left some uncertainty regarding a suspect part, the use of one of the methods of non-destructive examination will normally determine the condition of the part.

9.1 A brief outline of the methods of non-destructive examination most commonly used on aircraft structures is given in the following paragraphs. For further information on these and other methods reference should be made to the **BL/8** series of **Leaflets**. The selection of the method to be used will depend largely on the design of the structure, its accessibility and the nature of the suspected defect.

9.2 **Penetrant Dye Processes (BL/8-2).** These processes are used mainly for checking areas for those defects which break the surface of the material, which may be too small for visual detection by 2X magnification and where checking at higher magnifications would be impractical. Basically, the process consists of applying a red penetrant dye to the bare surface under test, removing after a predetermined time any excess dye and then applying a developer fluid containing a white absorbent. Any dye which has penetrated into a defect (e.g. crack) is drawn to the surface by the developer and the resultant stain will indicate the presence and position of the defect.

NOTE: Penetrant dye processes of inspection for the detection of surface defects require no elaborate equipment or specialised personnel. It is emphasised that the cleanliness of the surface to be tested is of prime importance if this process is to reveal microscopic cracks.

9.2.1 The manufacturer's detailed instructions regarding the applications of the process should be carefully followed. The most suitable processes for testing parts of aircraft structures 'in situ' are those which employ water-washable dye penetrants, with the penetrant and developer contained in aerosol packs.

9.2.2 The characteristics of the red marks, such as the rapidity with which they develop and their final size and shape, provide an indication as to the nature of the defect revealed.

9.2.3 After test, the developers should be removed by the method prescribed by the process manufacturer and the protective treatment should be restored.

NOTE: A similar process to the Penetrant Dye Process is the Fluorescent Penetrant Process. However, this process is less adaptable for testing aircraft parts 'in situ' because portable 'black light' lamps are used to view the parts, and dark room conditions are generally required.

9.3 **Radiographic Examination (BL/8-4).** The use of radiography will often facilitate the examination of aircraft structures, and it is used for the detection of defects in areas which cannot be examined by other means because of inaccessibility or the type of defect.

9.3.1 Radiography can be a valuable aid to visual inspection, and the examination of certain parts of an aircraft structure by an X-ray process will often result in a more comprehensive inspection than would otherwise be possible. However, radiographic methods can be both unsatisfactory and uneconomical unless great care is taken in the selection of suitable subjects. In this respect the opinion of the aircraft constructor should be sought.

9.3.2 During routine inspections, the use of radiography based on reliable techniques of examination can result in more efficient and rapid detection of defects. In some instances, defects such as cracking, loosening of rivets, distortion of parts and serious corrosion of the pitting type can be detected by this method. It should be borne in mind, however, that a negative result given by a general NDT method such as radiography is no guarantee that the part is free from all defects.

9.3.3 Where radiography is used for the detection of surface corrosion it is recommended that selected areas should be radiographed at suitable intervals, each time simulating the original radiographic conditions, so that the presence of corrosion will become apparent by a local change in the density of succeeding radiographs.

9.3.4 The accurate interpretation of the radiographs is a matter which requires considerable skill and experience if the maximum benefits are to be obtained. It is essential that the persons responsible for preparing the technique and viewing the results have an intimate knowledge of the structure.

NOTE: Close contact should be maintained with the aircraft constructor who will be aware of problem areas on an aircraft and be able to advise on particular inspection techniques.

9.4 **Ultrasonic Examination (BL/8-3).** In some instances ultrasonic examination is the only satisfactory method of testing for certain forms of defects. Ultrasonic flaw detectors can be used to check certain aircraft parts 'in situ' and it is sometimes an advantage to use this method to avoid extensive dismantling which would be necessary in order to use some other method. The chief value of ultrasonic examination in such circumstances is that cracks on surfaces which are not accessible to visual examination should be revealed. Thus solid extrusions, forgings and castings which are backed by skin panels, but which have one suitably exposed smooth surface, can be tested for flaws on their interface surface without breaking down the interface joint. On some aircraft, spar booms and similar extruded members require periodic examination for fatigue cracks, but the areas of suspected weakness may be inaccessible for examination by the penetrant dye method. In such cases radiography may be recommended, but where ultrasonic testing can be used it will give quicker results on those parts which lend themselves to this form of testing, and may also be useful to confirm radiographic evidence.

9.5 **Eddy Current Examination (BL/8-8).** Eddy current methods can detect a large number of physical and chemical changes in a conducting material, and equipment is designed specifically to perform particular types of test, e.g. flaw detection, conductivity measurement and thickness measurement.

9.5.1 The main advantages of this method of inspection are that it does not require extensive preparation of the surface or dismantling of the part to be tested and does not interfere with other work being carried out on an aircraft. In addition, small, portable, battery-operated test sets can be used in comparatively inaccessible parts of the structure.

9.5.2 Eddy current testing is usually of the comparative type, indications from a reference piece or standard being compared with indications from the part under test. A technique for detecting a particular fault is established after trials have indicated a method which gives consistent results.

9.6 **Magnetic Flaw Detection (BL/8-5).** Magnetic flaw detection methods are seldom used on aircraft structures and are generally restricted to the manufacturing, fabrication and inspection of parts. The method has, however, sometimes been used where other non-destructive testing methods have proved to be unsatisfactory. Before using the method, the effects of magnetisation on adjacent structure, compasses and electronic equipment should be considered, and it should be ensured that the magnetic ink or powder can be satisfactorily removed. If this method is used, demagnetisation and a test for remnant magnetism must be carried out to ensure that there will be no interference with the aircraft avionic systems and magnetic compasses.

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AIRCRAFT

STRUCTURES

REPAIR OF METAL AIRFRAMES

1 INTRODUCTION This Leaflet gives general guidance on repairs to the structure of metal aircraft and should be read in conjunction with the relevant approved publications.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet **AL/9-1**, Issue 2, dated 15th April 1965.

1.1 Repairs must be carried out in accordance with the appropriate Repair Manual or approved repair drawings relative thereto, in conjunction with any other related information contained in other documents recognised or approved by the CAA.

NOTE: For American manufactured general aviation aircraft, where specific repair manuals or repair documentation is not available, the FAA publication "Advisory Circular AC 43.13-1A Acceptable Methods and Techniques—Aircraft Inspection and Repair" may be used for guidance*.

1.2 Chapter **A4-2** of British Civil Airworthiness Requirements prescribes that in the case of structural repairs to aircraft where the repairs are of a major nature or not covered in the particular approved manual, the approved organisation or the appropriately licensed aircraft maintenance engineer concerned should advise the nearest CAA area office of the nature of the repair or repairs before work commences (see Airworthiness Notice No. 2 for addresses). Repair schemes not previously approved by the CAA will normally be investigated as modifications in accordance with the procedures in BCAR Chapter **A4-1.**

2 PREPARATION FOR REPAIR

2.1 **General.** Details of the inspections necessary before repair and the methods of assessing the extent of damage, supporting the structure, checking alignment and geometry, and assessing allowance for dressing of damage and limits of wear are generally given in the Repair Manual.

2.1.1 In the case of damage not covered by the Repair Manual but which, nevertheless, is thought to be repairable, a suitable repair scheme can often be obtained by application to the aircraft constructor (or to a Drawing Office holding the appropriate Design Approval). When supplying information of the damage to the constructor, photographs showing details of the damage are often helpful and may save both time and expense.

2.2 **Preliminary Survey of Damage.** A preliminary survey enables the damage to be classified (e.g. negligible, repairable or necessitating replacement) and a decision to be made as to the preparations necessary before commencing the repair. How the aircraft was damaged or overloaded should be determined as accurately as possible, and perusal of the pilot's or ground staff's accident report will give guidance to the necessary checks.

*Obtainable from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, U.S.A.

2.2.1 Structure distortion which can be evident at the site of the incident, may not be apparent when the aircraft is lifted and the locally imposed loads have been removed. Therefore, the aircraft should normally be inspected on the site where the damage occurred and the damage and distortion plotted on a station chart and ideally photographed before the aircraft is moved, providing a valuable indicator as to areas that require a more detailed inspection.

2.2.2 Depending on the results of the preliminary survey, the expected duration of the repair work and the precautions necessary as a result of local conditions, it may be necessary (among other things) to remove the batteries, drain the fuel system and/or inhibit the engines.

2.3 **Supporting the Aircraft.** If the aircraft requires lifting to facilitate the repair operations or supporting to avoid distortion of structural parts during dismantling, the aircraft should preferably be placed in the rigging position (see Leaflet **AL/7-12).** To ensure that the aircraft has not moved during the progress of the repair a daily check should be carried out by a responsible person, such checks being based on inspections to ensure that seals placed on jacks have not broken and, at the other end of the range, theodolite checks carried out against established references.

2.3.1 Trestling and jacking equipment is usually designed for this operation by the aircraft manufacturer and will facilitate any alignment, rigging or functioning checks necessary during or after repair. With large aircraft it is essential to follow the jacking instructions laid down by the aircraft manufacturer and to use the recommended equipment. The jacks used for these aircraft are usually fitted with a pressure gauge, so that each jack load can be calculated during the lifting operation. In some cases extension and retraction of all jacks used in a lifting operation are controlled from a central source.

NOTE: If the fuel system is not drained, the maximum permissible jacking weight should be verified before lifting.

2.3.2 **Additional Support.** In some instances it may be necessary to provide additional support or temporary bracing in order to prevent distortion or movement of the airframe during removal of primary structure such as stressed skin and other load bearing panels; this is usually provided by means of adjustable trestles and/or jury bracing devices.

2.3.3 **Adjustable Trestles.** Adjustable trestles are often made up from specially designed sets of steel members which can be bolted together to form trestles of various sizes. The sets usually contain top cross-beams, adjustable at each end by means of screw jacks, which can be fitted with wooden formers shaped to the contour of the structure they are required to support. To avoid damage to the structure, the formers should be lined with a layer of felt or similar cushioning material, which must be dry and free from extraneous matter (particularly swarf), and covered with polythene sheeting. Rubber should not be used for lining.

(a) Prior to use, the trestles should be checked for correct assembly and it is important to ensure that the maximum permissible load will not be exceeded.

(b) Trestling positions or 'strong points' where trestles may be positioned are given in the Maintenance and Repair Manuals and may also be stencilled on the aircraft. The positioning of the trestles in relation to these points should be carefully supervised, since supporting an aircraft at other than recognised load-bearing positions may result in considerable damage.

2.3.4 When adjustable trestles or jacks are being used to support a structure during repair, the adjusting mechanism, controls, etc., of such should be locked to prevent inadvertent movement whilst repairs are in progress.

2.3.5 **Jury Structures.** Special bracing devices, often referred to as 'Jury' structures, are sometimes needed to take the loads carried by structural parts before they are removed or cut for repair purposes. A jury structure may consist of no more than a length of timber cramped or bolted to the structure, or it may be a specially made strut or jig designed to prevent movement and distortion by holding various key points of the structure in their correct positions. When such devices are made up locally, it must be ensured that they conform in every way with the requirements of the Repair Manual, especially with regard to strength and accuracy of dimensions.

2.4 **Alignment and Geometry Checks.** In instances where the airframe has sustained unusually high loading, structural distortion may have occurred. Although in most instances there will be visual evidence (e.g. skin wrinkling, cracking of paint at the joints of structural members, loose rivets, etc.), this is not always the case and alignment and geometry checks should be made. Similarly, if the aircraft has been damaged by impact, malalignment and distortion of the structure may have occurred in areas remote from the initial impact point in addition to the damage which may be clearly visible at the impact point.

2.4.1 The control and structural integrity of an aircraft are, to a large extent, dependent on the correct alignment of its separate components, not only in themselves but in their relationship one to another, and malalignment may result in the imposition of stresses of such magnitude that a premature structural failure could occur. It is therefore essential that alignment is checked before, during and after repair work and guidance on this is given in Leaflet **AL/7-12.**

2.5 **Cleaning.** When the structure requires cleaning, this should be carefully supervised, otherwise useful evidence may be lost (e.g. the products of corrosion will help in locating corroded parts and the presence of a dark dusty substance at a structural joint will indicate fretting). Where mud, oil or other extraneous matter has to be removed, the cleaning solutions should be those given in the Repair or Maintenance Manual. Where a fire has occurred, it is important to remove all traces of fire extinguishant and smoke deposits as soon as possible, as some of these products promote rapid corrosion.

2.5.1 It is important that the cleaning fluids specified in the manual are used in the strengths recommended and in applications where their use has been specified. Cases have arisen where cleaning fluid in combination with kerosene has had a deleterious effect on aircraft structure, the penetrating quality of kerosene promoting seepage into skin joints. Such cases are particularly troublesome and it becomes difficult to diagnose the cause of corrosion. Unspecified cleaning fluids may contaminate or destroy pressure cabin and fuel tank sealing media and should not be used.

3 INSPECTION BEFORE REPAIR Structural damage can result from a variety of causes, such as impact, corrosion, fatigue, fire and overloads due to heavy landings or turbulence. In every case careful inspections must be made to ascertain the full extent of the damage and to ensure that other damage not necessarily associated with the particular incident is also rectified. The applicability of all repair schemes involved should be established as soon as possible by reference to the Repair Data, so that if none is given to cover the case in point, delay is avoided in making application to the aircraft constructor for a suitable scheme. Guidance on the nature of the inspections to be made and subsequent repairs is given in the following paragraphs.

3.1 **Cracks.** Care should be taken that cracks, however minor they appear to be, are not overlooked. Where visual inspection is not completely satisfactory, especially at points of concentrated stress, one of the methods of non-destructive examination described in the BL/8 series of Leaflets should be used.

3.2 **Corrosion.** Particular attention should be given to evidence of corrosion. Guidance on the methods of assessing the damage and of carrying out any rectification necessary is given in Leaflets **BL/4-1, BL/4-2** and **BL/4-3.** In cases of doubt, the use of one of the non-destructive testing methods detailed in the BL/8 series of Leaflets may be beneficial.

3.3 **Scores and Abrasions.** Where a score or abrasion in a stressed part is within the limits specified in the Repair Data for blending out into a smooth surfaced shallow depression, it is often necessary to submit the part to one of the non-destructive testing processes described in the BL/8 series of Leaflets. This will ensure that minute cracks are detected and included in the assessment of damage.

3.4 **Bolted Joints.** Checks should be made on all bolted joints in the locality of the damaged area, or where overstressing is suspected, for evidence of bolt and associated hole damage. Where no obvious sign of movement is detected, sample inspection by removal of bolt(s) is often advised. (For bolted joint inspection see also Leaflet **AL/7-8.)**

3.5 **Skin Panels**

3.5.1 Where buckling of a skin panel is apparent, a careful check of the area and related structure should be made for loose bolts, loose or sheared rivets, cracks and distortion. This should include any remote positions where the loads induced by the particular incident may have spread. In some instances where buckling is within limits specified in the Repair Manual, schemes are provided for fitting a strengthening member, otherwise a new panel should be fitted after any associated structure has been repaired.

NOTE: Loose rivets are often indicated by grey or brown stains around the head.

3.5.2 Where denting in skin panelling is in the form of a smooth and fairly circular depression and no other damage is present, it may in some cases, be considered negligible provided the ratio between the depth and area of the depression is within the limits given in the Repair Data. For example, if a depression of 1·2 mm (0·05 in) is within the limits of the depth permitted, then provided the smallest linear dimension across the depression is not less than fifteen times the depth of the depression the damage may be considered negligible. In the example given above the smallest linear dimension permitted would be 1·2 mm x 15 = 18 mm (0·05 in x 15 = 0·75 in).

3.6 **Internal Inspection.** The internal inspection of a structure is particularly important since damage or defects can often be present without any outward indication. In instances where the damage is extensive, the whole structure should be inspected. Guidance on the internal inspection of structures, together with the various aids which may be used to facilitate the inspection, is given in Leaflet **AL/7-13,** which should be read in conjunction with this Leaflet.

NOTE: In areas where sealants are used (i.e. integral tanks and pressure cabins), structure inspection is made more difficult and it may be necessary to remove the sealant at sample areas to ensure that the structure is free from damage. The sealant should be removed using only the solvent specified, and eventually restored strictly in accordance with the instructions given in the relevant manual or repair scheme.

3.7 **Removal of Damage.** In some instances it will be necessary to cut away the damaged material and dress back the surrounding structure. Although it should be ensured that no more material than is necessary is removed, it is necessary to make sure that the adjacent structure to which the repair is to be applied is in a sound condition.

3.7.1 When removing riveted structure, care must be taken not to damage those rivet holes which are to be used again (e.g. by burring, enlargement or undercutting) since circular, smooth-edged holes are essential if the risk of failure by fatigue is to be kept to a minimum.

NOTE: A method widely used for removing rivets is to centre-punch the middle of the preformed rivet head and then, using a drill equal in diameter to that of the rivet, drill only to the depth of the rivet head. The area surrounding the rivet should then be supported on the reverse side and the rivet punched out with a parallel pin-punch slightly smaller in diameter than the rivet.

3.7.2 Bolt holes should be treated with equal care, it being particularly important that the holes in stressed parts should be free from scores or burrs. Where necessary, bolts should be eased with penetrating oil before extraction but it is also necessary to ensure that the oil does not damage adjacent sealing media. Bolts on which the nuts were locked by a peening over process must have the burrs removed to remove the nuts and these bolts must not be used again.

NOTE: A check should be made to note whether the structure 'springs' as bolts are withdrawn. If this occurs interchangeability fixtures should be used when rebuilding the structure to ensure correct alignment and prevent the introduction of locked-in stresses.

3.7.3 When damaged panels are to be removed by cutting (i.e. not by dismantling at a production joint) all edges must be free from burrs and notches and trimmed to a smooth finish. It is important that the corner radii of stressed panels are correct and that the dimensions and locations of cuts are within the limits specified in the repair drawing.

3.7.4 Special care is necessary when damaged parts are removed by cutting, to ensure that the remaining structure or material is not damaged by drills, rotary cutting tools, hack-saw blades, etc.

3.7.5 Repairs in pressure cabin and integral fuel tank areas may involve separation of members riveted and sealed together. Some sealants have considerable adhesion and may cause difficulty in separating the members after the rivets have been removed. Where such separation is necessary, the solvents specified and methods of separation detailed in the Repair or Maintenance Manual must be strictly followed.

NOTE: After repairs in a pressurised area or a fuel tank, either a leak test or a pressure test may be specified in the appropriate manual.

3.8 **Wear.** Where holes are found to be elongated by stress the part must be renewed. However, if elongation is due to wear and is beyond the limits permitted by the Repair Manual, rectification schemes are usually given.

3.8.1 The corresponding pin or bolt assemblies should be inspected for wear, distortion, 'picking-up' and shear, and where necessary renewed. Lubricating ducts should be checked for obstruction.

3.8.2 Where bushed holes are fitted it is usual to renew the worn bush, but where the hole in the fitting has become enlarged so that the new bush is loose, a repair scheme is usually available for reaming out the hole and fitting an oversize bush.

3.8.3 When excessive wear has taken place in unbushed holes the fitting should be renewed unless there is an approved scheme available whereby the hole can be reamed oversize and a bush fitted; in some cases an oversize bolt or pin may be specified.

3.8.4 Wear in ball and roller bearings should be checked as described in Leaflet **BL/6-14.**

3.9 **Fire Damage.** It is extremely difficult to assess the damage caused to a structure which has been exposed to an abnormally high temperature, since apart from the more obvious damage, such as buckling, the mechanical properties of some of the light alloys may be adversely affected, without any apparent indication. In some instances non-blistering of the paint is a good guide that temperatures have not been unduly high but this cannot be taken as a general rule.

3.9.1 In some cases an eddy current test can determine the extent of fire or heat damage by measuring the change in conductivity in the material (see Leaflet **BL/8-8**), but where doubt exists, sample portions of panels, ribs or frames should be cut out for mechanical testing by an approved test house. Where it is not possible to remove such samples the advice of the aircraft constructor should be sought.

3.9.2 It is generally necessary to renew any parts made from magnesium, plastics or rubber which were in the vicinity of a fire. This applies, for example, to the bag type of fuel tank in contact with a tank bay wall, the other side of which was affected by the fire.

3.10 **Damage by Lightning.** In a properly bonded aircraft, lightning damage is not usually of a major character and can generally be rectified by the application of one of the standard repairs. However, it is important to note that because of the unpredictable nature of the damage it is important to make a thorough inspection of the whole aircraft, its engines, systems and equipment. The most common form of damage is numerous small burns or punctures in the skin of the aircraft, or the disintegration or burning of non-metallic materials on the exterior, e.g. radomes, radio aerial covers and navigation light covers.

3.10.1 Where a control surface has been struck, the bearings and hinges should be checked for pitting and/or stiffness due to the passage of the lightning discharge, and all control surfaces should be checked for full and free movement.

3.10.2 The bonding of the aircraft should be checked as described in Leaflet **EEL/1-6.**

3.10.3 The compasses may have been affected by the magnetising of steel parts near to them and should be check swung as described in Leaflets **AL/10-5** or **AL/10-6** as appropriate. If the compasses are found to be affected, a landing compass should be used to locate the disturbing magnetic fields, and steel parts found to be magnetised should be de-magnetised, as described in Leaflet **BL/8-5.**

3.10.4 When a structure is de-magnetised, the compasses and any instruments having permanent magnets in their mechanisms should be temporarily removed from areas in which degaussing is being carried out.

3.11 **Repair Report.** A report detailing all the repair work and the procedures involved should be compiled. The details of the rectification work necessary should be based on approved repair schemes, the reference numbers and any other relevant details of which should be quoted.

3.11.1 In addition, the report should record any maintenance work, such as mentioned in paragraph 3.8, which could usefully be carried out during the repair work, since this may obviate the need for further dismantling after a relatively short period.

3.11.2 According to the nature of the repair, stage inspections will be necessary during the progress of the repair work (e.g. inspection of rivet or bolt holes, inspection of structures before covering for workmanship, protection, security, locking of screw-threaded parts and duplicate inspection of controls. These inspections should be listed on an Inspection Record Sheet in a sequence related to the repair report, and should give details of the inspection required.

NOTE: Before any disturbed parts of the aircraft or engine control systems are concealed, they must be inspected in duplicate as prescribed in Chapter **A5-3** of BCAR and further guidance for this is given in Leaflet **AL/3-7**.

4 REPAIRS A repair to a stressed structure usually involves the removal of damaged panels, the complete or partial removal of structural members such as frames, ribs and stringers and the rebuilding of the structure in accordance with the repair scheme. The particular procedure involved will obviously vary with the design of the aircraft but paragraphs 4.1 to 4.3 cover the general aspects of a repair.

NOTE: If the repair is at all extensive it is often advantageous to have the approved repair drawings duplicated and displayed at the site of the repair.

4.1 Materials used for the repair should be checked for correct specification and gauge thickness and, where applicable, heat treated in accordance with specification requirements.

NOTE: General guidance on the heat treatment of wrought aluminium alloys is given in Leaflet **BL/9-1**.

4.2 On completion of bending or forming operations the material must be free from defects such as scratches, scribe marks, hair line fractures on the outside of bends, cracks at edges adjacent to bends, tool marks, twisting and warping.

NOTE: Complete detail parts must be manufactured by suitably Approved Organisations in accordance with the appropriate drawings. The holder of an Aircraft Maintenance Engineer's Licence in Category B is not authorised to certify the manufacture of aircraft parts.

4.3 Where panels are concerned, care is necessary to prevent buckling and distortion, particularly in the case of large panels, which should be allowed to attain the ambient temperature of the repair site before being fitted. Where the application of heat (e.g. by means of an electric blanket) during the fitting of a panel is specified, it is important that the heat application and control should be strictly in accordance with the requirements of the applicable Repair Data.

4.3.1 In some instances the aircraft constructor may provide preformed and partially built-up parts for incorporation into the repair (e.g. sections of leading edge fitted with nose ribs, panels fitted with stringers, saddle pieces, bridging joints in stringers, etc.), and it should be ensured that such parts are correctly identified and bear evidence of prior inspection.

4.3.2 Particular attention should be given to the drilling of holes, which should be circular and free from scores and sharp edges in order to satisfy design requirements. In some cases it may be specified or recommended that holes in stressed parts should be drilled with a drill reamer, or drilled and then reamed to size. It is also important that drills are sharpened correctly so as to produce the intended hole diameter; a drill running off-centre will produce an oversize hole.

4.3.3 Where existing rivet holes are to be used again, repair schemes may often call for special repair rivets to be used. These rivets have a slightly larger shank diameter but the same size head. However, when necessary (e.g. due to hole damage), the use of rivets the next size larger than the original may be permitted, in which case it should be ensured that the landing limits between the new rivets and the sheet edge or other rivets are maintained. In instances where blind rivets are used it is usually necessary to replace the original rivet by the next size larger, and the same precautions regarding landing limits apply.

4.3.4 With some repair schemes the method of riveting may be very similar for a wide range of applications, but may vary in detail according to the location of the repair (e.g. the type of rivet or the pitch may vary). Similar variations may also apply to the type of jointing compound used (e.g. in pressurised areas), and to the protective treatment required. The repair drawing should therefore be studied very carefully for any special instructions.

4.3.5 Care is necessary, particularly with large repairs, in keeping swarf out of places where it may present a hazard. This applies to joints, wiring looms, exposed moving surfaces (e.g. jack rams and pulley assemblies), and unsealed bearings, all of which should be protected before work is commenced. When drilling through laminations or lap joints which cannot subsequently be separated for cleaning, it is essential to ensure that the parts comprising the joint are held firmly together during the drilling operation.

4.3.6 Before assembling a joint it should be ensured that the contacting surfaces are clean and free from swarf, and that all holes and edges are deburred. If specified, jointing compound should be applied evenly before final assembly and riveting and should form a fillet at the edges of the joint when assembly is complete. The manufacturer's instructions regarding the mixing, working and curing time of the jointing compound should be carefully followed.

4.3.7 Guidance on riveting aircraft structures, particularly from a repair aspect, is given in Leaflet **BL/6-29**, on the assembly of bolted joints in Leaflet **AL/7-8** and on the main types of rivets in Leaflets **BL/6-27** and **BL/6-28.**

4.3.8 When repairs have been made to control surfaces, the balance may have been upset by the additional weight of metal or paint. Such surfaces should be checked for balance by the method given in the appropriate manual and the balance corrected as necessary. For reasons of balance the repairs permitted on control surfaces are often limited in area and position.

5 METAL-TO-METAL ADHESIVE

5.1 Since a metal adhesive often requires special heating and pressing equipment, its use may be impracticable for repair work. The damaged part should therefore be cut out as shown in the approved Repair Scheme and a new part riveted in position.

5.2 It is possible, however, in certain large repairs to obtain from the aircraft manufacturer a built-up section or pre-formed skin panel with parts secured in position by adhesive. The repair then consists of removing the damaged section complete and riveting the replacement section into position.

5.3 When it is necessary to remove parts which are secured with adhesive, e.g. a stringer, this can be done as shown in Figure 1. Care should be taken to avoid damaging any parts or material other than those to be removed.

NOTE: When paint is removed in the area of a metal-to-metal adhesive joint, only the paint stripper stipulated should be used. Some strippers may have a deleterious effect on metal-to-metal adhesives.

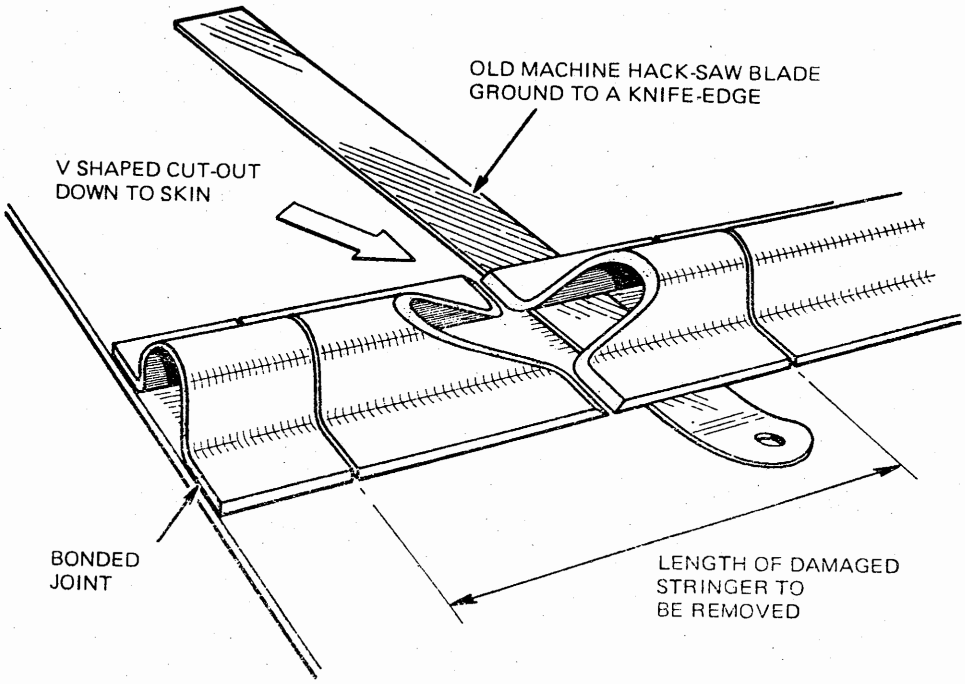

Figure 1 REMOVAL OF BONDED COMPONENT

6 REPAIRS BY WELDING Repairs by means of welding are often specified for welded structures such as landing gear structures, engine mountings, etc. The welding procedure to be used will depend on the design and construction of the structure and will be fully detailed in the Repair Data. It will often be necessary to use jigs or jury structures to ensure that the main structure is held in the correct position during welding.

6.1 **Welding Procedures.** Some of the welding procedures most commonly used for aircraft repairs are the following: Oxy-Acetylene Welding (Leaflet **BL/6-4**), Arc Welding (Leaflet **BL/6-5**) and Spot Welding (Leaflet **BL/6-12**).

6.1.1 Where highly stressed components have been repaired by welding they should be submitted to one of the non-destructive examination tests outlined in the BL/8 series of Leaflets.

6.1.2 Before welding is commenced any protective treatment in the area of the repair must be completely removed and the parts prepared in accordance with the repair scheme applicable.

6.1.3 As prescribed in Chapter **A8-10** of BCAR welders must be approved by the CAA.

6.2 **Typical Oxy-Acetylene Welding Repairs.** The oxy-acetylene welding technique is more widely used than any of the other methods, and in the following paragraphs a brief outline of some oxy-acetylene welding repairs is given.

6.2.1 **Welded-Patch Repair.** This type of repair illustrated in Figures 2 and 3 is often used for rectifying such damage as cracks, dents, or holes in tubes, provided certain limitations are not exceeded.

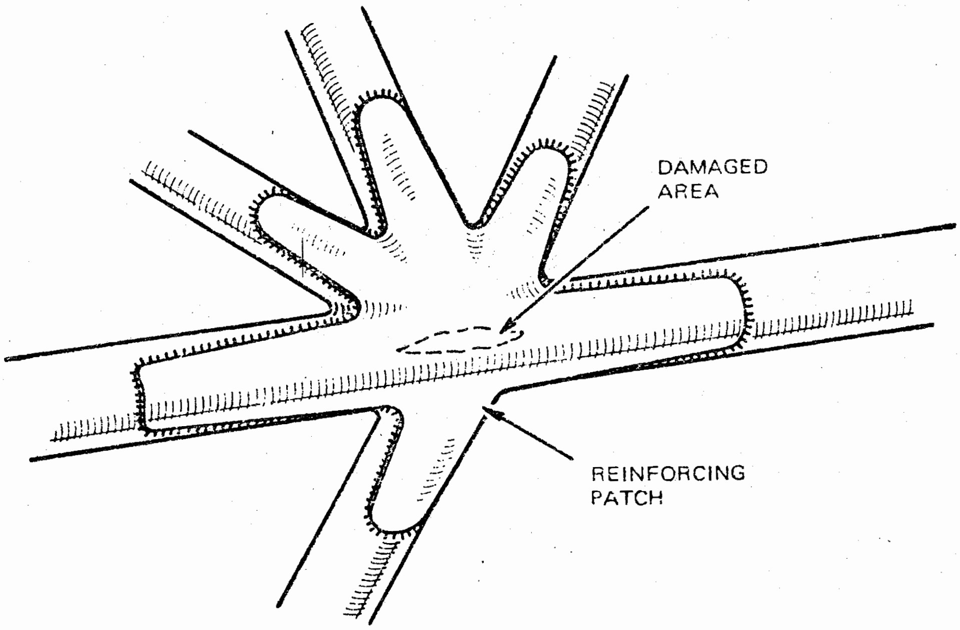

Figure 2 PATCH AT TUBE JOINT

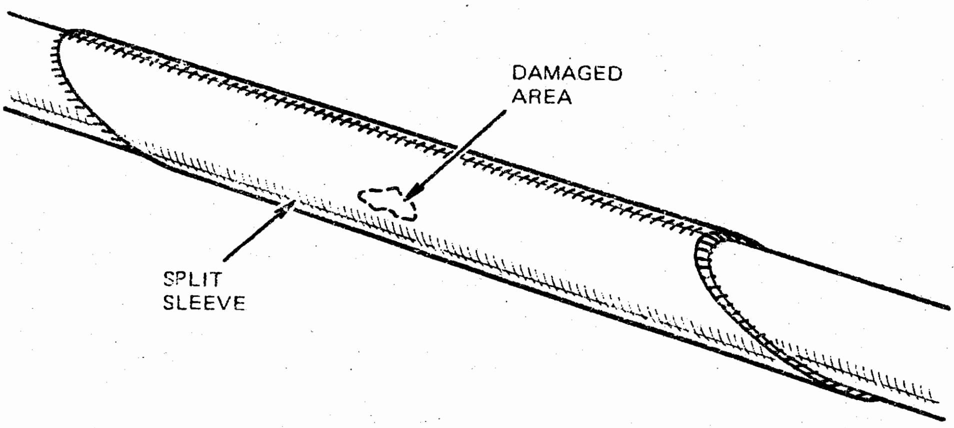

Figure 3 EXTERNAL SLEEVE REPAIR

6.2.2 **Partial Replacement—Inner Sleeves.** Fairly extensive damage to a tube is often repaired by the use of an inner sleeve splice as shown in Figure 4.

(a) The condition and location of the associated structure should be checked and secured to prevent movement when the damaged portion is removed.

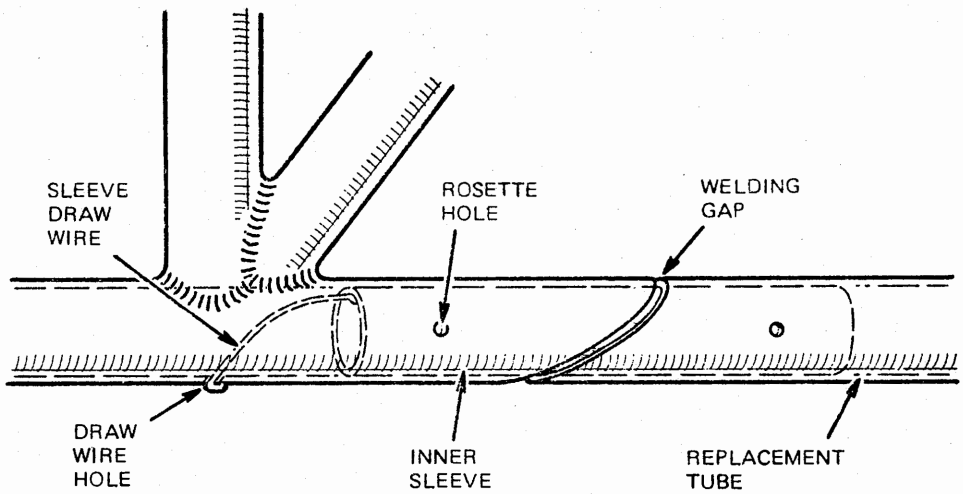

Figure 4 INTERNAL SLEEVE REPAIR

(b) The damaged portion of the tube should be cut out using 30° or 45° diagonal cuts, and the burrs inside the tube should be removed.

(c) A replacement piece of tube should be cut to fit where the damaged portion was removed and a gap of approximately 2·4 mm ($\frac{3}{32}$ in) should be left for welding.

(d) The inner sleeves should be cut to length and a check made to ensure that they slide smoothly in both tubes. If rosette holes are required they should next be cut and the burrs removed; when a draw wire is required it should be welded into position.

(e) The inner sleeves should be marked at the half-way position, fitted into the replacement tube and positioned with the midpoint at the diagonal cut.

(f) The repair should be completed by welding at the diagonal cuts and at the rosette holes or the draw wire hole as applicable.

6.3 **Partial Replacement—Outer Sleeves.** This method should only be used where it is impracticable to use inner sleeves. The procedure is basically the same as for inner sleeves except that the replacement tube should be cut square at both ends and the outer sleeves scarfed at 30° or 45°.

6.4 **Protective Treatment.** After welding, the parts concerned should be thoroughly descaled, cleaned, and the protective treatment restored.

7 GAUGING DAMAGE

7.1 Where a score, dent, or corrosion damage in a stressed part has been removed by blending out into a smooth surfaced hollow depression, the maximum depth of the depression will have to be measured to ensure that it is within the limits given in the Repair Data. This should be done before applying any protective treatment.

7.1.1 A method of gauging the depth of such a depression is by mounting a dial test indicator on a special adaptor block as illustrated in Figure 5. The bottom edge of the block should be straight and radiused to about 1·2 mm (0·05 in), and the dial test indicator (DTI) stem should be at right angles to this edge. The point of the conical anvil should be lightly stoned to avoid scratching the surface of the depression.

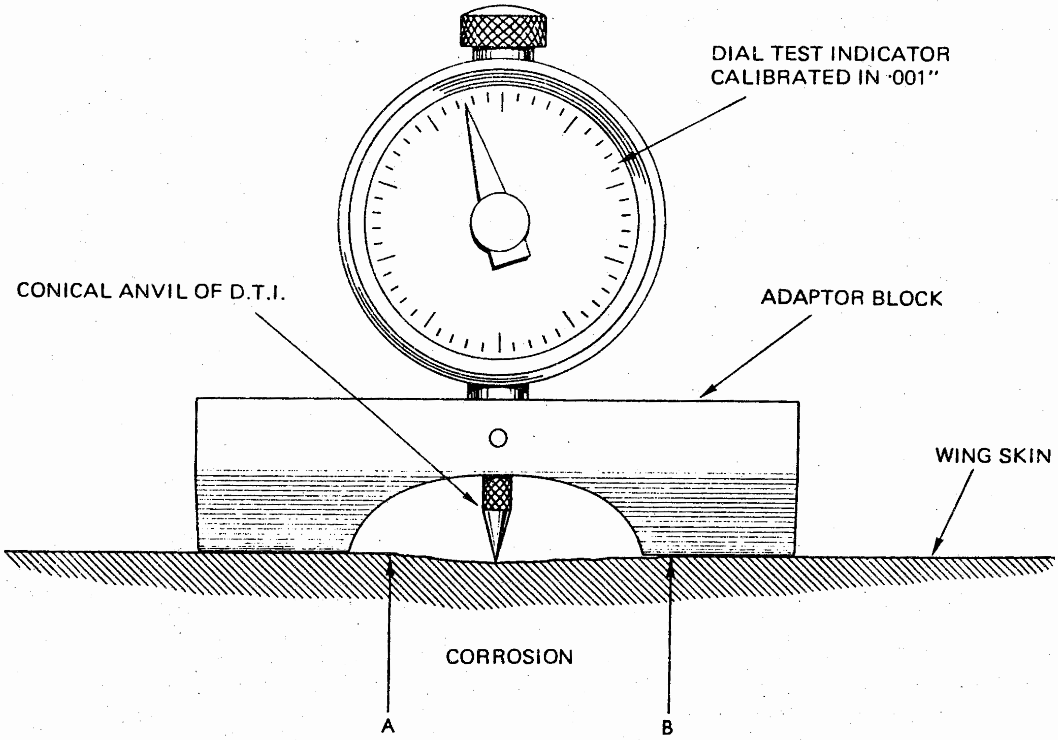

Figure 5 MEASUREMENT OF SURFACE DAMAGE

7.1.2 When gauging the depth of a depression, a reading should first be taken at two points, adjacent to but unaffected by the depression (such as A and B in Figure 5), then the maximum depth reading (D) should be taken. By subtracting the average of the two point readings $\frac{A + B}{2}$ from the depth reading (D) the actual depth of the depression will be obtained thus: depth of depression $= D - \frac{A + B}{2}$

7.2 **Bowing Limits.** To measure the amount of bow in a structural member (e.g. a strut), a straight edge and a set of feeler gauges can be used, providing the part to be measured is free from protruding fittings and the straight edge can be applied directly along the surface of the member. The straight edge should be placed along the entire length of the member and parallel to its axis, then by inserting feeler gauges at the point of maximum clearance the amount of bow can be calculated by the formula:—

$$\text{Bow} = \frac{\text{Clearance measured by feeler gauges}}{\text{Length of member}}$$

7.2.1 For example, if the length of the member is 2 ft and the clearance measured by the feeler gauge is 0·040 in, the amount of bow is:

$$\text{Bow} = \frac{0{\cdot}040}{24{\cdot}0} = \frac{4}{2400} = \frac{1}{600} \text{ or 1 in 600}$$

NOTE: In general a maximum bow of 1 in 600 is normally acceptable unless otherwise stated in the Repair Manual. However, in some instances the manual may permit tolerances for bow greater than this figure.

7.2.2 To measure a member which has protruding fittings, a trammel fitted with three pointers can be used to bridge the fittings. The three points should be checked for truth against a straight edge or surface table and adjusted if necessary. The outer points should be placed at the ends of the member and any clearance between the member and the centre point checked with a feeler gauge, the amount of bow being calculated as in paragraph 7.2.1.

7.2.3 For more accurate measurement the central trammel point can be replaced by a depth gauge in which case the neutral reading on the depth gauge in relation to the outer points should be carefully noted by checking on a surface table.

7.3 **Curved Sections.** When checking the maximum depth of a depression in a curved surface (e.g. a leading edge), the adaptor block or the trammel must be placed over a line at right-angles to the curvature of the part, i.e. parallel to the longitudinal axis of the curve.

8 CERTIFICATION The CAA's requirements regarding certification after repair are given in Chapter **A4-3** of BCAR and are also outlined in Leaflet **BL/1-8.**

8.1 Full particulars of the work done should be entered in the appropriate log book and a Certificate of Compliance should be signed.

8.2 According to the nature of the repair made, the aircraft should be weighed, the Weight and Centre of Gravity Schedule should be amended or replaced by a revised Schedule, a certificate of fitness for flight should be issued and the aircraft should be tested in flight. Particulars and results of such testing must be provided.

AL/10-1

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AIRCRAFT

INSTRUMENTS

FLIGHT INSTRUMENTS—PITOT-STATIC SYSTEMS

1 INTRODUCTION This Leaflet gives guidance on the installation and maintenance of pitot-static systems, their associated instruments and components. It should be read in conjunction with manufacturer's drawings, Maintenance Manuals, and operator's Maintenance Schedules; such documents providing details of construction, major servicing, repairs and calibration procedures relevant to specific items and aircraft systems.

1.1 For those not familiar with the basic principles of flight instruments dependent upon pitot and static pressures for their operation, brief details of operating principles are given in the paragraphs dealing with individual instruments.

2 SOURCES OF PITOT AND STATIC PRESSURES Pitot pressure, which varies with air speed and air density, is the ram air pressure built up by the movement of an aircraft through the air and is sensed by a pressure head externally located at some accurately selected position (see paragraph 5). Static pressure is the ambient pressure prevailing at the altitude at which the aircraft is flying and may also be sensed by a pitot-static head or, as in some aircraft, by a separate static vent system. Both pressures are communicated to the flight instruments through pipelines; the air-speed indicator and other air-speed measuring instruments utilise pitot pressure and static pressure, while instruments such as the altimeter and the vertical speed (rate-of-climb) indicator utilise static pressure only.

3 PRESSURE HEADS Pressure heads are of two main types, i.e. the pitot-static type which senses and transmits both pitot and static pressures and the pitot-only type which is used in conjunction with a separate static vent system.

3.1 Pressure head pipe connections are arranged to suit the method of installation, i.e. frontal installation, fuselage side, or under-wing installation. In the frontal installation the connections emerge in line with the head while in the other two they emerge at 90° to the axis of the head. The connections may be of the low pressure type for use with rubber grommets, or of the high pressure type for use with flared pipes and collets.

3.2 As prevention against ice formation, pressure heads are equipped with an internal system of appropriately positioned heating elements. Pressure heads designed for fuselage side or underwing mounting have additional elements located inside the support mast. In many cases separate static vents also incorporate heating elements. The heaters are supplied with power from the aircraft electrical system and controlled from the cockpit. Display panels for open circuit detection of elements may also be fitted.

3.3 **Installation.** Pressure heads should be examined for physical damage and freedom from obstruction, including drain holes, before installation, and it should be confirmed that the type of head is correct for the particular aircraft. Before connecting heater element cables it must be ensured that the pitot heating circuit of the aircraft is isolated from electrical power sources.

3.3.1 Drain holes of a calibrated size are provided in the bodies of some types of electrically-heated pressure heads and these must be at the bottom when such heads are installed. Certain types of pressure head designed for mounting on the sides of a fuselage are 'handed', and the drain holes and support mast drain screw are located in such a way that they are at the lowest point compatible with the angular position of the head when installed. It is therefore important to ensure that the correctly handed pressure head is fitted.

3.3.2 In order to prevent distortion of mounting flanges, fixing screws or bolts, pressure heads must be adequately supported during installation and not allowed to hang on their fixing screws when these are being tightened.

3.3.3 Pressure heads should not be painted as this may impair their thermal efficiency. Furthermore, paint may cause inadvertent obstruction of the necessary orifices and result in inaccurate sensing of pitot and static pressures.

3.3.4 After installation, the pressure connections should be checked for security and locking, and a leak test of the complete pitot-static system carried out in accordance with the requirements of the aircraft Maintenance Manual (see also paragraph 15.5). The heating elements of electrically-heated pressure heads should be checked for functioning by connecting an ammeter in the circuit and noting that the current consumed is correct for the voltage and power ratings of the pressure head installed. As pitot heads are in positions which make them vulnerable to lightning strikes, bonding should be checked for effectiveness (see **EEL/1-6**).

NOTE: Heater elements can reach very high temperatures when switched on in still air. In order not to impair their life the heating circuit should not be switched on for longer than the period recommended by the manufacturer to carry out the functioning checks.

4 STATIC VENTS In order to minimise the effects of position error (see paragraph 5) and to provide greater freedom from ice formation, the sensing of static pressure is by means of separate vents in the form of flat metal plates secured to the fuselage skin at pre-determined positions. There are two principal types of static vent in use, their application being governed by the size and the number of pitot-static systems required for a specific aircraft type.

4.1 In the basic system, the static vent consists of a flat brass plate, rounded at the ends and having through its centre a 6 mm (0·25 in) diameter hole communicating with a short section of plain pipe which provides for the connection of the vent with the pipeline system. The pipe section may, in some versions, be positioned at 90° to the plate or directed upward at 30° to provide drainage for moisture. A drain tap is usually fitted in the section of pipeline immediately adjacent to vents of the former type.

4.2 In aircraft employing several independent pitot-static systems, the static vent consists of a flat stainless steel plate through which are drilled a number of 5 mm (0·188 in) diameter holes. Each hole is connected to the pipeline of a specific system or component requiring static pressure, by means of a threaded coupling adapter welded concentric with the hole. Holes in the fuselage skin accommodate the coupling adapters of the plate which is bolted to the skin.

4.3 **Installation.** The vents are normally fitted in a position free of turbulence from aerials or other external fitments and located where the skin in the area of the vent is flush riveted and free of butt straps, etc., since such features would cause a varying behaviour of the boundary layer.

4.3.1 In order to reduce errors due to pressure unbalance at the vents whenever yawing of the aircraft takes place, static vents are fitted on each side of the fuselage and are interconnected into the same static pressure line.

4.3.2 Brass static vent plates should be provided with a stiffener plate on the inside of the fuselage skin to prevent distortion of the vent plate. On metal aircraft, a metal stiffener, similar in shape to the vent plate, should be riveted to the skin, while with aircraft having a plywood skin, a plywood stiffener should be glued to the skin. The vent plates should make complete contact at their outer edges and be secured to the fuselage skin by means of the spigots provided on the rear face, and by knurled nuts which should be tightened by hand and wirelocked; overtightening may cause the vent plate to distort. A suitable sealing compound should be used between the contacting surfaces of the vent and skin. Exuded sealant should be trimmed off by using a plastic scraper.

4.3.3 Stainless steel vent plates should be bolted directly to the fuselage skin and, depending on the modification state of the aircraft system, are sealed either by sealing rings around the flanges of the coupling adapters, or by filling the inner surface recess with sealing compound.

4.3.4 Smoothness of the outer surface of all static vent plates is vital to the accurate sensing of static pressure. They must therefore be kept free of scratches and other indentations, and must never be painted.

5 PRESSURE ERROR Pressure error may be defined as that part of the difference between the calibrated air speed and the indicated air speed due to the recorded static pressure not being equal to the ambient pressure. The error, which is strongly influenced by the position of pressure heads and static vents, is determined for each type of aircraft by conducting a series of prototype test flights over various ranges of speed, altitude, configuration, weight, etc. Details of the error so determined, and the corrections to be applied to the readings of airspeed indicators and altimeters, are presented in either tabular or graphical form and contained in an appropriate section of the aircraft's Flight Manual.

5.1 Any subsequent alteration in the position of either pressure heads or static vents, the provisioning of additional systems, or alterations occasioned by modifications or repair to the aircraft in the vicinity of pressure heads or static vents, may affect the pressure error, necessitating further test flights and alterations to the Flight Manual.

5.2 If a system is added or repositioned after issue of a Certificate of Airworthiness, major modification action in accordance with Section A, Chapter **A4-1** of British Civil Airworthiness Requirements will be necessary.

6 PIPELINES Pitot and static pressures are transmitted throughout systems by means of light alloy pipes (tungum pipes may also be used in some aircraft) and flexible hoses such as nylon 11, nylon 66, or rilsan, the latter being used for the connection of resilient-mounted instruments and components. In order to prevent moisture blockage and to minimise pressure lag, the inside diameter of pipelines must not be less than 6 mm (0·25 in).

6.1 The procedure for the installation and removal of pipelines depends upon the size and complexity of individual systems; reference should always be made to the aircraft Maintenance Manual. The following points, common to applied practices, are given as a general guide:

(a) Before installation, pipelines should be blown out with a clean, dry, low-pressure air supply to ensure cleanliness and freedom from obstruction.

(b) When tightening the end connections of flexible hoses it must be ensured that the hoses do not become twisted; a yellow or white tell-tale line running along the length of the hose will indicate any twisting.

(c) Bending of pipes through too small a radius, and kinking, must be avoided since the resulting depressions and reduction in bore diameter will create unwanted moisture traps and erratic transmission of pressure.

(d) Metal pipes must be securely attached to the airframe structure at regular intervals throughout their run and should slope towards points at which drain traps or drain valves are located.

(e) Pipelines leading from static vents should be installed so that they rise continuously towards the instruments but, if this cannot be achieved, they should rise for the first 150 mm (6 in) at least. Where two static vents are inter-connected, the pipelines from each should be symmetrically disposed.

(f) Clearance must exist between a newly installed pipe and other pipes or structural parts to avoid chafing during flight.

(g) When pipelines are removed from an aircraft, blanks should be fitted to their end connections and all other connections in the system which become exposed by the removal. Support clamps should be returned to their original positions as soon as a pipeline has been removed to ensure their correct location.

(h) The mating surfaces of pipe ends and connections must be clean.

(j) When connecting pipelines employing low-pressure unions and rubber grommets, the union nuts should be tightened by hand and should then be secured by a half-turn with a spanner, since overtightening may damage the grommet and result in a leaking joint.

(k) After installation of a pipeline, the system with which it is associated must be checked for leaks in the manner prescribed in the aircraft Maintenance Manual. On satisfactory completion of such individual checks, a leak test of the complete pitot-static system must be carried out (see paragraph 15.5).

7 DRAINS In addition to the moisture drainage of pressure heads, facilities must also be provided for the removal of moisture which might accumulate in the pipelines connecting the sources of pressure to instruments and associated equipment. Such draining facilities may take the form of either drain traps or drain valves (in some aircraft they are used in combination) located at the lowest points in pitot and static pipe runs. The design, construction and application of drains varies between manufacturers and type of pitot-static system. Reference should therefore be made to the Manuals concerning the component and aircraft type.

8 ALTIMETERS As the name implies, altimeters measure the altitude of the aircraft either above sea-level or above a point of known altitude such as an aerodrome. They are basically sensitive pressure gauges which operate on the aneroid barometer principle and indicate the changes in atmospheric pressure which occur with changes in altitude. The calibration of altimeters is in accordance with the ICAO law for the standard atmosphere, which is based on certain assumed values of pressure and temperature to provide a conventional relationship between pressure and altitude.

8.1 An altimeter mechanism consists of a stack of two or, in some versions, three aneroid capsules which are exhausted of air and sealed, and connected to a pointer mechanism via a lever and rocking shaft linkage system. The strength and resiliency characteristics of the material used in the construction of the capsules is such that they expand or contract under the influence of varying external atmospheric pressure. The complete mechanism is housed within a case which, with the exception of a static pressure connector at the rear, is completely sealed. A barometric pressure-setting device (see paragraph 8.2) also forms part of the mechanism. Static pressure is exerted on the outside of the capsules and as changes in this pressure take place the capsules expand or contract; for example, as altitude increases, static pressure decreases and the capsules expand. The small deflections thus obtained are magnified through the lever and rocking shaft linkage and gear train system to produce an indication of the pressure changes in terms of aircraft altitude.

8.2 Since altimeters are calibrated to standard atmospheric conditions, any departure from the assumed values will change the pressure/altitude relationship causing errors in indication. For example, if the prevailing atmospheric pressure at a sea-level aerodrome falls below the standard value, an altimeter situated at the aerodrome will respond correctly to the pressure change and indicate that the aerodrome now stands at a certain altitude above sea-level; in other words, the altimeter over-reads. Conversely, the instrument would under-read should the atmospheric pressure increase. In order to compensate for these barometric errors, a pressure-setting device consisting primarily of an adjusting knob, a scale or digital counter and a gear mechanism, is interposed between the capsule stack and the pointers. The scale or counter may be calibrated in either millibars or inches of mercury, the readings being visible through an aperture in the main dial. When the adjusting knob is rotated, the scale or counter and the complete altimeter mechanism are also rotated, the gearing being so arranged that, for any atmospheric pressure setting, the altimeter pointer or pointers rotate to indicate the altitude equivalent of that pressure. Thus, to correct the reading of the altimeter in the example considered and so make the pointers indicate zero feet, the scale or counter must be set to the atmospheric pressure prevailing at the aerodrome.

8.3 The setting and correction of altimeters to known atmospheric pressures forms part of aircraft operating procedures and is of great importance for take-off, landing and for maintaining adequate height separation of aircraft and terrain clearance. Three settings are normally used and are signified under the ICAO Q Code for the transmission of meteorological and other operational information. They are:

(a) Setting aerodrome atmospheric pressure so that an altimeter reads zero on landing and take-off (QFE).

(b) Setting mean sea-level atmospheric pressure so that an altimeter reads the aerodrome altitude above mean sea-level (QNH).

(c) Setting mean sea-level atmospheric pressure in accordance with the ICAO standard atmosphere, i.e. 1013·25 millibars or 29·92 inHg (QNE).

8.4 Variations in atmospheric temperature affect the rate at which pressure changes with altitude relative to standard conditions; therefore, errors in the indications of altimeters can also occur due to such temperature variations. Correction of these errors is applied in flight by means of a height calculator based on the slide-rule principle. The effects of temperature on pressure-sensing capsules and linkage mechanisms are compensated by devices operating on the bi-metallic principle.

8.5 The presentation of altitude by altimeters in current use varies from the multi-pointer type to the drum and single pointer, the digital counter and single pointer, and the digital counter, drum and single pointer types. Presentations typical of those in current use are illustrated in Figure 1. In the multi-pointer type, the pointers are of different lengths and indicate 'hundreds', 'thousands', and 'tens of thousands' of feet against a common scale. In the drum/pointer type of presentation the pointer indicates 'hundreds' of feet against a fixed scale, while 'thousands' of feet are indicated by a drum which is proportionally rotated by the pointer mechanism. The drum scale is visible through an aperture in the instrument dial and is referenced against a datum marker across the aperture. In the digital counter/pointer method of presentation 'thousands' and 'tens of thousands' of feet are indicated by the incremental changes of separate counters located across the centre of the dial. The counter/drum/pointer type of altimeter presentation provides a 5-digit numerical display of altitude with the last three digits forming the drum and showing 'hundreds'of feet. The pointer displays 1000 ft for each complete revolution with 20 ft scale markings.

8.5.1 In order to avoid the mechanical loads which would otherwise be imposed on the pressure-sensing capsules by actuating several counters, a servo drive system may be used in altimeters employing these latter types of presentation. The movement of the capsules actuates the armature of an electromagnetic pick-off assembly producing a signal proportional to the prevailing pressure. This output signal is amplified by an external amplifier unit and supplied to a servomotor located within the indicator, to drive the pointer and counters through special gear assemblies. The amplified signal may, in some cases, also be used to drive synchros which in turn drive indicators and transponders for altitude reporting (see paragraph 8.7). In the event of electrical power failure to the instrument, a power failure warning flag is incorporated to indicate that the altimeter is inoperative.

8.5.2 Because of the inherent pressure error (see paragraph 5) servo altimeters generally have a built-in correction system, 'tailored' for the particular aircraft design, that minimises this error for the full range of flight speeds and altitudes. Correction for datum pressure changes in the servo altimeter is achieved by mechanically displacing the datum of the electromagnetic pick-off assembly. The pick-off senses this change and the system runs to null the datum change, thereby driving the pointer to zero.

8.6 The use of altimeters employing any of the three principal presentation methods, is governed primarily by the ease with which readings may be interpreted over the altitude ranges in which a specific type of aircraft must operate. Multi-pointer presentations, particularly the three-pointer type, are very susceptible to misreadings, e.g. 1000 ft for 10,000 ft, and various modifications have been incorporated to overcome this difficulty; for example, the type illustrated in Figure 1 employs distinctively shaped pointers and low altitude warning sectors. However, the use of multi-pointer altimeters as a standard for all types of aircraft is severely limited by performance characteristics and operational altitude ranges. For high-performance turbo-jet aircraft, in which misreading of altimeters may prove hazardous, the counter/pointer presentation is preferred. Information concerning altimeter presentation and the terms of their acceptance by the CAA is contained in Airworthiness Notice No.77.

Figure 1 TYPICAL ALTIMETER PRESENTATIONS

8.7 **Encoding Altimeters.** To enable the altitudes of an aircraft to be known for air traffic control purposes, an airborne radar beacon transponder can be interrogated by a ground radar. These transponders have 4,096 codes available, so the encoding altimeters not only provide the flight crews with a visible read-out of the aircraft flight level but code the transponder so that it can reply to the ground station with a signal providing a visible indication on a radar screen of the aircraft's altitude in 100 ft increments. Encoding altimeters of the non-servo type must have an extra low torque pick-off and the majority now in use employ optical encoders. In this system, the capsule drives a glass disc, etched with transparent and opaque sectors. A light source shines through the disc onto photoelectric cells which convert the disc's movement into coded signals for the transponder. This type of pick-off provides a high degree of accuracy with very low torque requirements.

9 AIR-SPEED INDICATORS These instruments are, in effect, sensitive pressure gauges which measure the difference between the pitot and static pressures, and present such differences in terms of indicated air speed. Indicators are made by various manufacturers and, although fulfilling identical roles, they may vary in their mechanical construction; however, the basic construction and operating principle is the same for all types.

9.1 The mechanism, which is contained within an airtight case, is comprised of a pressure-sensitive capsule coupled to a pointer mechanism via a lever and rocking shaft linkage system. Two adapters, identified by the letters P and S, are located at the rear of the case and provide for the connection of the indicator to the pitot and static pressure pipelines respectively.

9.2 Pitot pressure is transmitted to the interior of the capsule via a short length of capillary tube connected between the capsule and pitot adapter, while the static pressure is transmitted directly to the interior of the indicator case and acts on the outside of the capsule. Changes in either of the two pressures establishes a differential across the capsule causing it to expand or contract. The small deflections of the capsule are transmitted through the lever and rocking shaft linkage system via a gear quadrant and pinion to the pointer mechanism, which produces a magnified angular deflection of the pointer or pointers over a scale calibrated in knots or in miles per hour.

9.3 **Maximum Allowable Air Speed Indicators.** Another type of air-speed indicator in use is the maximum allowable air speed indicator which includes a maximum allowable needle to indicate a decrease in maximum allowable air speed with an increase of altitude. It operates from an extra capsule in the air-speed indicator which senses changes in altitude and measures this change on the dial of the instrument. Its purpose is to indicate maximum allowable indicated air speed at any altitude.

9.4 **True Air Speed Indicator.** The case of this instrument holds both an air-speed indicator which moves the pointer and an altimeter mechanism which moves the dial. The movement of the altimeter mechanism is opposed or aided by the action of a bi-metallic spring exposed to outside air flow, and, as the aircraft increases in altitude, the dial rotates in such a direction that the pointer will indicate a higher value. If the air is warmer than standard for the altitude at which the aircraft is flying, the temperature sensor will assist the altimeter to cause the true air speed reading to be higher than under standard temperature conditions.

10 VERTICAL SPEED INDICATORS These indicators are sensitive differential pressure gauges which are connected to the static system and sense the rate of change of static pressure and present it in terms of vertical speed (rate of climb and descent) in feet per minute. The mechanism is housed in a cylindrical case which is rendered airtight except for the static pressure connector at the rear of the case. Basically the mechanism consists of a sensitive capsule, a 'calibrated leak' assembly or metering unit, a lever and rocking shaft linkage system, and a gear type pointer mechanism. The connection of the capsule and metering unit to the pressure connector is arranged so that static pressure is fed directly to the interior of the capsule and also allowed to 'leak' at a calibrated rate to the interior of the instrument case. Thus, when the static pressure varies due to changing altitude, the metering unit has a restrictive effect causing the pressure change in the case to lag behind the pressure change in the capsule. The resulting differential pressure across the metering unit and the capsule causes the latter to expand or contract and drive the pointer via the linkage and gear mechanisms. The scale is calibrated to indicate climb and descent, in the clockwise and anti-clockwise directions respectively, from a zero graduation situated at the 9 o'clock position.

A set screw, or in some instruments an adjusting knob, is provided in the lower left-hand corner of the bezel to permit the capsule datum position to be adjusted and thus reposition the pointer to zero via the linkage and gear mechanisms within the limits set by the manufacturer.

10.1 In level flight, the pressures inside the capsule and the instrument case remain the same; therefore the mechanism is at rest and the pointer indicates zero. When the aircraft climbs, the static pressure decreases inside the capsule but, due to the metering unit, the case pressure will remain the greater and so cause the capsule to contract and drive the pointer to indicate a rate of climb. The pressure difference thus established is maintained until any further alteration to rate of change of altitude takes place. During a descent the changes in static pressure are in the opposite sense causing the capsule to expand and to drive the pointer to indicate the appropriate rate of descent until level flight is resumed and no further altitude change takes place.

10.2 **Instantaneous Vertical Speed Indicator.** The ordinary vertical speed indicator whose indication lags the pressure change would be of greater value if it had no lag, and for this reason the instantaneous vertical speed indicator has been developed. An instantaneous vertical speed indicator uses a vertical speed indicator mechanism in the case with an accelerometer-operated pump or dashpot across the capsule. When the aircraft noses over to begin a descent, the inertia of the accelerometer piston causes it to move upwards, instantaneously increasing the pressure inside the capsule and lowering the pressure at the metering unit. This gives an immediate indication of a descent. By the time the lag of the ordinary vertical speed indicator has been overcome so it will indicate, there is no more inertia from the nose-down rotation and the piston is again centred making the instruments ready to indicate instantly the levelling off from the descent.

11 MACHMETERS. In the operation of high performance aircraft capable of speeds approaching or exceeding that of sound, it is necessary to measure air speeds which are directly related to altitude and also to the variations in speed of sound which occur with atmospheric density variations. Therefore, in addition to conventional air-speed indicators, instruments integrating both speed and altitude measuring functions and referred to as Machmeters, are installed in aircraft of this type. Machmeters indicate the air speed in terms of a Mach number which is defined as the ratio of the air speed of an aircraft to the speed of sound under the prevailing atmospheric conditions in which the aircraft is flying. The ratio may be expressed as a numerical percentage but for convenience is designated decimally and with the suffix M; thus, 0·8M means a speed that is 80% of the speed of sound under the ambient conditions in which the aircraft is flying.

11.1 The mechanism of a Machmeter consists basically of an air-speed measuring unit and an altitude measuring unit both of which are connected through calibration arms and sliding shafts to a common gear mechanism actuating a single pointer. The complete assembly is housed in a case provided with pitot and static pressure connectors at the rear. A lubber mark mounted over the instrument dial provides for the setting of the limiting Mach number specified for the aircraft in which the instrument is to be installed, and may be adjusted either by a screw or knob at the front of the instrument.

11.2 The capsule of the air-speed measuring unit expands and contracts in response to the difference between pitot and static pressure and deflects the pointer to positions related to corresponding air speeds. The altitude unit capsule expands and contracts in response to changes in static pressure only, and since it is interconnected with the air-speed measuring unit it determines the point of contact between the calibration arms thereby modifying the magnification ratio of the air-speed unit. Thus, the final deflected position of the pointer relates to a constant air speed at a particular altitude and, as atmospheric temperature variations are taken into account by the basic calibration formula, the Mach number as conventionally defined is therefore measured in terms of a pressure ratio.

12 PRESSURE SWITCHES AND PRESSURE TRANSDUCERS These units are connected in the pitot-static systems of certain types of aircraft for the purpose of actuating devices which give aural, visual or physical warning to a pilot of an approaching dangerous condition, or for controlling the operation of systems whose functions are related to speed or altitude, e.g. flight recorders and altitude recorders. In some installations switch units may be used in both the warning and controlling mode.

12.1 The mechanisms of pressure switch units are similar in basic construction and operation to those employed in air-speed indicators, Machmeters and altimeters. In place of linkage and pointer mechanisms, however, the capsules actuate special electrical contact assemblies which are supplied with power from the aircraft electrical system, and connected into the relevant warning or controlling circuit.

12.2 Pressure transducers are units designed to provide air-speed and altitude information in the form of electrical signals to flight recorder and encoding systems. The units employ pressure sensing elements connected to either d.c. potentiometer or synchro type electrical elements. The output signals which are proportional to air speed and altitude are fed to a computer unit for encoding and transmission to the recording unit.

12.3 The arrangement and setting of pressure switch contacts, operating ranges of pressure transducers and adjustment methods, depends upon the aircraft operating requirements and the design of units and recording systems adopted. Reference should therefore be made to the appropriate aircraft Maintenance Manual and manuals supplied by the equipment manufacturers.

13 AIR DATA COMPUTERS Air data computers are units connected to the pitot-static systems of some types of high performance aircraft for the supply of pitot-static pressure information to instruments indicating height, etc., which in this application are of the electro mechanical type. This information is also transmitted to other systems utilising these pressures as datum references, i.e. autopilots, automatic throttle control systems, etc. The units house capsules and electrical transducer elements which convert pitot and static pressures, total air temperature and possibly angle of attack, into electrical signals representing altitude and air-speed quantities and other derived quantities such as Mach number, true air speed and static air temperature, rate of climb and descent, and transmit the signals through a synchronous system. There are a number of variations in the design and method of computation within air data systems and reference should be made to the manufacturer's relevant publications for details of operation, installation and maintenance.

14 INSTALLATION OF PITOT-STATIC INSTRUMENTS Before installation, instruments should be inspected for damage or deterioration which might have occurred in storage or transit. New or overhauled instruments are normally kept in their special packaging containers until required and the packaging should be carefully examined for signs of damage before removing the instrument. It must be verified that the shelf life (which is usually indicated on the container) has not been exceeded.

NOTE: The functioning of instruments must never be checked by applying the mouth and blowing into the pressure connectors. This will not only cause moisture penetration of mechanisms but also the derangement of pressure-sensing capsules due to inadequate control of pressures applied in this manner.

14.1 The dials of air-speed indicators should be checked to ensure that, where applicable, they bear coloured arcs and radial lines at various parts of the scale corresponding to the normal operating and limiting speeds laid down for specific aircraft types. It may be necessary in some instances to apply the arcs and radial lines to the cover glasses. When this is done, the precaution must be taken of painting a short white line from the glass to the bezel in a position which does not conflict with the essential operational marks. Thus, the correct position of the glass may be readily checked.

NOTE: Further information on operational markings is given in Joint Airworthiness Requirements (JAR) 25.1545 or Section D, Chapter **D7-3** of British Civil Airworthiness Requirements.

14.2 In some instances instruments are fitted with cover glasses whose surfaces are 'bloomed' to reduce surface reflection. These glasses may be identified under normal daylight conditions by their bluish tint and their anti-reflection properties. Care must be taken not to scratch bloomed glasses, or to touch them unless absolutely necessary. Any finger marks or other stains should be immediately removed from the glass using a dry, clean, 'lint-free' cloth and approved isopropyl alcohol cleaning solvent. All traces of solvent should be removed with the cloth and should not be allowed to dry off naturally. Water must not be used for cleaning purposes.

14.3 The method of mounting instruments on their respective panels depends on whether the cases of the instruments specified for use in a particular aircraft type are of the flanged or flangeless design. In the former design the bezel is flanged in such a manner that the instrument is flush-mounted in its cut-out from the rear of the panel. Integral self-locking nuts are provided at the rear faces of the flange corners to receive fixing screws from the front of the panel. The mounting of instruments having flangeless cases is a simpler process in that separate fixing screws and nuts are unnecessary, and mounting of the instruments may be done from the front of the panel. A special expanding type of clamp, shaped and dimensioned to suit the instrument case, is secured to the rear face of the panel at the appropriate cut-out location by two retaining screws. Two actuating screws are connected to the clamp and are arranged to be accessible from the front of the instrument panel. The screws must be released sufficiently to allow the instrument to slide freely into the clamp. After positioning the instrument, the actuating screws are then rotated so as to draw the clamp tightly around the case of the instrument. To avoid strain or distortion care must be taken to ensure that instruments seat squarely in their cut-outs while being secured to the instrument panels. This is of particular importance when installing instruments having flanged cases.

14.4 Before connecting instruments to the pitot and static pressure pipeline system, the lines should be blown through with a clean, dry, low-pressure air supply to remove any dust or moisture that may have accumulated, and the system should be drained at the draining points provided. When installing instruments requiring electrical power, for example a servo altimeter or a pressure switch unit, the appropriate electrical circuit must be isolated from the power supply until post-installation checks and tests can be carried out.

14.5 When tightening the union nuts or adapters of pipelines onto the connectors of instruments, the connector must be held securely with a spanner to avoid undue stress upon the cases of the instruments.

14.6 After the pipelines have been connected to the instruments, a leak test of the complete pitot-static system must be carried out (see paragraph 15.5). The electrical functioning of pressure switch units must also be checked by carrying out the tests prescribed in the relevant aircraft Maintenance Manual.

15 MAINTENANCE OF PITOT-STATIC SYSTEMS The following paragraphs detail the general maintenance necessary on pitot-static systems and their major components, and should be read in conjunction with the Maintenance Manuals for the type of aircraft and equipment concerned.

15.1 **Pressure Heads.** Pressure heads and their supporting tubes or masts should be inspected for security of mounting and signs of distortion. Where specifically required, checks on the lateral and longitudinal alignment with respect to the aircraft datum must be carried out to ensure that they are within the limits given in the aircraft Maintenance Manual. Checks should also be made that electrical connections at all appropriate points are secure and the insulation of cables does not show signs of cracking or chafing. The pitot pressure entry hole, drain hole and if applicable the static holes should be inspected to ensure that they are unobstructed.

NOTE: The size of static holes and drain holes is aerodynamically critical and they must never be cleared of obstruction with tools likely to cause enlargement or burring. In the absence of special clearing tools, which may be locally manufactured from drawings given in manufacturer's manuals, the use of a stiff non-metallic brush is recommended, taking care not to displace debris into the system and cause obstruction.

15.1.1 **Electrical Checks.** Heating elements should be checked for functioning by ensuring that pressure head casings and, where applicable, support masts and static vent plates, commence to warm up when switched on or, if an ammeter is fitted in the heating circuit, by a current consumption check. An insulation check on the resistance between the electrical leads and the appropriate component should be made by connecting a voltage supply appropriate to the rating of the heating elements, switching on the supply and allowing the component to warm up until it is just too hot to hold with the bare hand. The current should then be switched off and, while the component is hot, the insulation resistance measured, using the specified tester. The component should then be allowed to cool and the insulation resistance measured in this condition. The resistance values thus obtained should not be less than those quoted in Maintenance Manuals; a typical value is 3 megohms.

NOTE: Measured values less than those specified may be due to moisture penetration of the heating elements.

15.1.2 **Leakage Tests.** The method of checking pressure heads for leaks differs with the various types, and in each instance the procedures given in the relevant Manual should be followed.

NOTE: All pressure heads are sealed on manufacture and no attempt should be made to dismantle or tamper with them in any way. If a pressure head fails a leakage test it should be renewed.

15.1.3 **Protection Covers.** If the aircraft is to be left standing for prolonged periods, e.g. during overnight parking or hangar maintenance checks, pressure heads must be covered with a moulded protective sheath or cover to prevent the entry of foreign matter and contamination by water or other liquids. Any protective sheath or cover should be able to 'breathe', and extreme care should be taken also to ensure that pressure head heaters are not operated. The sheath or cover should be of a prominent colour and have a streamer attached to it, to attract attention should a take-off be attempted before removal of the sheath or cover.

15.2 **Static Vents.** Static vent plates should be inspected to ensure that exposed surfaces are free from scratches, indentations, etc., and that the holes are unobstructed and their edges free of burrs and other damage. Mud and dirt should be removed from exposed surfaces with a clean 'lint-free' cloth to ensure that particles of material are not rubbed off into the vent holes. Protection of static vents during prolonged standing periods of the aircraft is effected by blanking the vent holes with special vent plugs. If plugs made from rubber are used they should be able to 'breathe' otherwise pressure differential can build-up, causing air data systems to operate when electrical power is applied. They should also be periodically inspected for signs of cracking and fracture. This is important since, if part of a fractured plug remains in the vent when the plug assembly is thought to be removed, incorrect instrument readings will result. The plugs should be of a prominent colour and have a streamer attached, to attract attention should a take-off be attempted before removal of the plugs.

15.3 **Pipelines.** Pipelines should be checked to ensure freedom from corrosion, kinking and other damage, and that the pipes are securely clamped and their connections tight and locked. Flexible hoses should be carefully inspected for security and evidence of kinking, twisting, deterioration (particularly at the joints between hose and connectors), and other defects. At the periods specified in the aircraft Maintenance Schedule, the pitot-static system should be drained at each of the draining points provided, and pipes disconnected from the instruments and blown through with a clean, dry, low-pressure air supply. To avoid contamination of adjacent parts of the structure or adjacently mounted equipment, a suitable container should be positioned at the draining points for the collection of water.

15.4 **Instruments.** The checks to be carried out on individual instruments, pressure switch units, etc., are primarily concerned with security, visual defects and calibration tests. Precise details of these checks and their frequency are given in relevant Maintenance Manuals and Schedules and reference should always be made to such documents, but the following summary serves as a guide to the general nature of the checks required:

(a) Security of attachment to instrument panels and appropriate parts of the airframe structure.

(b) Security of pressure and electrical connections.

(c) Evidence of cracking of cases, bezel mounting flanges and cover glasses. The latter should always be carefully inspected as cracks caused by glancing blows struck by safety harness fittings, head sets, etc., are often difficult to detect.

(d) Checking of dial markings, counters and pointers for legibility, discoloration and flaking.

(e) Checking of coloured operational markings (see also paragraph 14.1).

(f) Presence of moisture or water inside the cover glass or on the dial.

(g) Functioning and smoothness of pointer operation during leak testing of pitot-static systems (see paragraph 15.5).

(h) Checking of pointer direction and that pitot and static lines are connected to their respective instrument connections.

15.4.1 The zero setting of pointers must also be checked and in particular this applies to altimeters and vertical speed indicators. At the time an inspection is carried out, the aerodrome barometric pressure should be ascertained (QFE) and set on the barometric pressure scale or counter of an altimeter by rotating the adjusting knob. With this pressure set, the instrument should read zero within the tolerances specified for the type installed. No adjustment of any kind must be made, and if a reading is not within limits the instrument must be renewed. Because of the sensitivity of altimeters, due consideration should be given to any difference in height between the level at which the prevailing barometric pressure is obtained, and the level at which the inspection takes place.

NOTE: When checking servo altimeters and altimeters connected to air data computer units, the system power supplies must be ON.

15.4.2 Under the atmospheric conditions prevailing at the time of an inspection, vertical speed indicators should indicate zero. If however, the pointers are displaced either side of the zero mark and such displacement is within the specified tolerances, the pointers may be set at zero by means of the adjustment screw provided. Indicators requiring settings outside the adjustment range specified must be renewed.

15.4.3 Calibration tests of all instruments should be carried out prior to installation, when their operation and indications are suspect, and at the periods specified in the aircraft Maintenance Schedule.

15.5 **Leak Testing of Pitot-Static Systems.** Aircraft pitot-static systems must be tested for leaks after the installation of any component parts, at any time system malfunctioning is suspected, and at the periods specified in the aircraft Maintenance Schedule. The method of testing consists basically of applying pressure and suction to pressure heads and static vents, respectively, by means of a special leak tester and coupling adapters, and noting that there is no leakage, or the rate of leakage is within the permissible tolerances prescribed for the system. Leak tests also provide a means of checking that the instruments connected to a system are functioning correctly, but they do not serve as a calibration test (see paragraph 15.4.3).

15.5.1 Specific applications of the basic method of leak testing and the type of equipment recommended depend on the type of aircraft and its pitot-static system, and as these are detailed in relevant manufacturer's and aircraft Maintenance Manuals, reference must always be made to these documents. There are, however, certain aspects of the procedures and precautions to be observed which are of a standard nature, and these are summarised for guidance as follows:

(a) Pressure and suction must always be applied and released slowly to avoid damage to instrument capsules. In multi pitot-static systems involving the use of selector valves, pressure or suction must be restored to ambient pressure before operating the valves as specified in the tests.

(b) If two static vents are interconnected, one vent should be blanked off before the tests are commenced.

(c) When fitting leak tester adapters to pressure heads, care must be taken not to apply loads which tend to disturb their alignment.

(d) In carrying out a leak test of a static pressure system an apparent leak will be indicated by the dropping back of the altimeter pointer. This is a normal indication which stabilises when the static pressure across the vertical speed indicator capsule has equalised.

(e) When conducting leak tests and functioning checks of air data computer systems, the electrical power supply must not be interrupted as there is the possibility of the system becoming de-synchronised.

(f) When testing a system to which autopilot altitude and air-speed locks are connected, the autopilot must be powered but not engaged with the aircraft's flight control system.

(g) On completion of tests which have necessitated the blanking-off of various sections of a system, a check must be made that all blanking plugs and adapters have been removed.

AL/10-2

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AIRCRAFT

INSTRUMENTS

FLIGHT INSTRUMENTS—GYROSCOPIC SYSTEMS

1 INTRODUCTION This Leaflet gives guidance on the installation and maintenance of flight instruments utilising gyroscopic principles and which provide primary indications of an aircraft's attitude and direction. It does not include information on instruments associated with proprietary integrated flight systems or other electronic equipment. The Leaflet should be read in conjunction with manufacturer's drawings, Maintenance Manuals, and operator's Maintenance Schedules which provide details of construction, major servicing, repairs and calibration procedures relevant to specific instruments and aircraft installations.

2 GENERAL Information on the attitude and direction of an aircraft is provided by the gyro horizon or artificial horizon, turn and slip indicator and direction indicator. These instruments depend for their operation on the fundamental properties of a gyroscope designed to establish stabilised references which, in conjunction with the indications of pitot-static instruments (see Leaflet **AL/10-1**), are required for various conditions of flight operations.

2.1 For those not familiar with the basic principles of these flight instruments, brief operating details are given in the paragraphs dealing with the individual instruments.

3 GYROSCOPES A gyroscope (normally abbreviated to gyro) is a rotating mass having freedom in one or more planes at right angles to the plane of rotation. It possesses two fundamental characteristics: gyroscopic inertia or rigidity, and precession. Gyroscopic inertia is the property a rotating mass has of reluctance to change its plane of rotation in space unless acted upon by an external force. (Newton's first law of motion; every body continues in its state of rest or of uniform motion in a straight line unless it is compelled by forces to change that state.) Precession is the angular change of direction of the plane of rotation, under the action of an external force.

3.1 **Definitions**

(a) **Free Gyro:** A gyro having complete freedom in three planes at right angles to each other. This is also sometimes known as a 'space' gyro.

(b) **Tied Gyro:** A gyro having freedom in three planes at right angles to each other but controlled by some external source.

(c) **Earth Gyro:** A tied gyro controlled by gravity to maintain its position relative to the earth.

(d) **Rate Gyro:** A gyro having one plane of freedom at right angles to the plane of rotation, so constructed as to measure rate of movement about the plane at right angles to both the plane of rotation and the plane of freedom.

3.2 **Practical Applications.** Mechanically, a wheel can only be mounted so that it has complete freedom in three planes by mounting it in a system of rings or gimbals. The spinning rotor in aircraft instruments constitutes the gyro. All practical applications of the gyro are based on the two characteristics — gyroscopic inertia, and precession.

3.2.1 **Gyroscopic Inertia.** When the rotor of a free gyro is spinning it will maintain its plane of rotation fixed in space and will not be affected by movement of its outer gimbal system.

3.2.2 **Precession.** When a torque is applied to disturb the plane of rotation of a gyro, the gyro will resist angular movement in the plane of that torque, but will move in a plane at right angles to the disturbing torque; this resulting movement is called precession. The direction of the precessional movement is dependent on the direction of the disturbing force and the direction of rotation of the gyro, and can be determined by considering the applied torque as due to a force acting on a point on the rim of the gyro rotor at right angles to the plane of rotation. If that imaginary point is carried around the rotor 90° in the direction of rotation, that will be the point at which the force is apparently taking effect, moving that part of the rotor rim in the same direction as the disturbing force (see Figure 1).

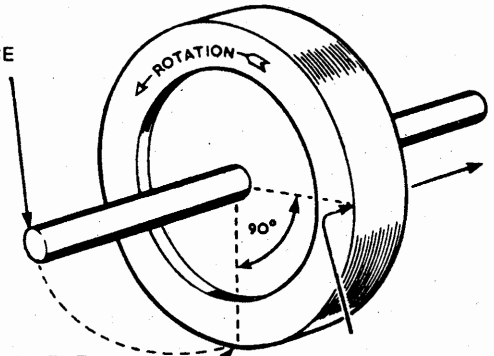

Figure 1 PRECESSION

3.3 When the gyro rotor is spinning, it maintains its plane of rotation fixed in space, but there is no definite attitude in space which the gyro will naturally assume. Therefore, if the gyro is to be used as a reference it must be controlled, so that the gyro assumes a definite attitude either in space or relative to the earth, after which it will be stabilised by its own inertia. A gyro fitted with such a device is called a 'tied' gyro. If tied by gravity control, it is called an 'earth' gyro. An example of a tied gyro is the directional gyro, which has its axis of rotation maintained in a plane at right angles to the outer gimbal ring. An example of an earth gyro, is the gyro horizon, which has its axis of rotation maintained in a vertical position relative to the earth's surface, by a pendulum control.

3.4 **Rate Gyros.** If a gyro is mounted so that it has freedom about two axes only, it can be adapted to be used as a 'rate' gyro, i.e. to measure rate of angular movement. If there is an angular movement in the plane in which the gyro has no freedom, the rotor will be precessed until its plane of rotation coincides with the plane of angular freedom and its direction of rotation coincides with the direction of the angular movement (see Figure 2).

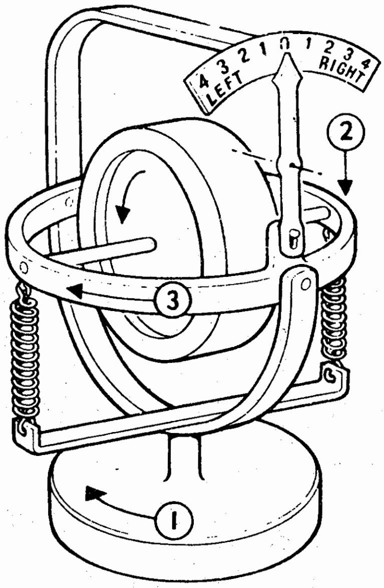

Figure 2 A BASIC RATE GYRO

3.4.1 In order to obtain an indication of rate, it is necessary to restrict precession of the rotor so as to apply a torque to it which will cause precession in the same plane as the angular movement. This is usually done by springs (see Figure 2). On turning the base, the rotor will precess until the spring applies a force to the rotor sufficient to cause it to precess about the turning axis at exactly the same rate as the base is being turned. This amount of precession against the spring will be dependent on the rate of angular movement.

3.4.2 Turning the base of the gyro illustrated in Figure 2, in the direction of arrow 1 will cause the rotor to precess so that the needle will move over to the right-hand side of the scale. The right-hand spring will now exert a force down (as shown by arrow 2). This force will precess the rotor to turn in the same plane and at the same rate as the base. Since the base and rotor axis are fixed in relation to each other, any change in the rate of angular movement of the base must cause a change in the precessional rate of the rotor. This rate of angular movement of the base must always be balanced by precession of the rotor in the same plane. This balance is achieved by precession against the spring to produce the requisite force, and any given rate of turn will be shown as a definite amount of movement of the needle over the scale provided the rotor speed is constant.

4 POWER SUPPLIES REQUIRED FOR INSTRUMENT OPERATION The rotors of the gyros may be driven either pneumatically from a vacuum source, or from an electrical power supply system; the application of instruments utilising either method being governed by the installation requirements for the type of aircraft. The electrical method of operation is most widely used in current types of aircraft gyro horizons and turn and slip indicators. Electrically-operated direction indicators usually form part of a remote-indicating compass system or of an integrated flight system, details of which are given in the appropriate manuals.

4.1 **Vacuum Supplies.** In installations using pneumatic instruments the supply of vacuum is obtained from either a venturi or an engine-driven vacuum pump.

4.1.1 The venturi is usually mounted at the side of the fuselage and is exposed to the propeller slipstream which, passing through the venturi, creates a correspondingly low pressure. The low pressure is transmitted to the instruments by a pipeline from the venturi.

4.1.2 In vacuum pump installations the pump is directly connected to a splined coupling adapter of the engine auxiliary gear drive system. The low pressure side of the pump is connected to a manifold which distributes the vacuum to the instruments via flexible hoses. An oil separator is connected to the discharge outlet of the pump and is designed to vent the pump to atmosphere and also to return the oil used for pump lubrication to the engine. In duplicate pump systems, non-return valves are installed to prevent vacuum loss in the event of failure of either pump.

4.1.3 The vacuum required for instrument operation is usually between 89 to 114 mmHg (3·5 to 4·5 inHg) when measured at the instrument case and can be pre-adjusted by a vacuum relief valve connected in the supply line. Turn and slip indicators used in some installations require a lower operating vacuum and this is obtained by means of an additional regulating valve in the individual supply lines, or, in some instances, by a section of restricted-diameter pipeline. Indication of the supply of vacuum is provided by a direct-reading vacuum gauge mounted on the instrument panel.

4.1.4 The case of a vacuum-operated instrument contains two air connections; one is connected to the vacuum source and the other is a filtered inlet open to the surrounding atmosphere and connected internally to an air jet system. In some installations a central air filter mounted adjacent to both the gyro horizon and direction indicator serves as a common inlet for these instruments. When vacuum is applied to an instrument a depression is created within its case and surrounding air enters the filtered inlet and passes through the air jet system. The air issuing from this system impinges on buckets cut in the periphery of the gyro rotor. After spinning the rotor, the air circulates through the instrument case and is then drawn off at the vacuum connection.

4.2 **Electrical Supplies.** The electrically-driven gyro horizon is designed to operate from an alternating current supply at a controlled frequency of 400 Hz. Turn and slip indicators may be designed to operate from a 400 Hz supply and/or a 28-volt direct current supply system. In duplicate instrument installations the power supply distribution system is split in such a way that the failure of a supply source does not affect both instruments simultaneously. Alternate sources of power are provided for gyroscopic instruments to ensure operation in the event of failure of the main power source.

4.2.1 The alternating current is supplied from an inverter system or from engine-driven alternators, special units being incorporated for the regulation of the voltage and the frequency within the required output values. The operating voltage is usually 115-volts three-phase, although certain types of gyro horizon operate from a 55-volts supply provided by a special inverter unit or a transformer within the instrument.

4.2.2 The gyro rotors are specially constructed motors designed on conventional alternating current and direct current motor principles, i.e. they are of the synchronous induction and permanent magnet types. Electrical power is supplied to the rotors via slip rings about their respective axes.

4.2.3 Indication of power supply failure to the instruments is provided by small warning flags which are actuated by integral electromagnetic devices. If the main supply cannot be restored, changeover facilities are incorporated in the installation to connect the instruments to an emergency supply.

5 GYRO HORIZONS Gyro horizons utilise vertical spin axis gyros and provide visual indications of any change of pitch and roll attitude of an aircraft by the attitude of fixed references relative to gyro-stabilised references. Pitch attitude is indicated by the position of a symbol, representing the aircraft, relative to a stabilised bar symbolising the natural horizon. The bar is pivoted on the outer gimbal ring of the gyro in such a way that relative positions are magnified. Simultaneously the bank attitude of the aircraft is indicated by the position of a fixed bank angle scale relative to a bank pointer which is also gyro-stabilised. The gyro assembly is pivoted about the longitudinal axis of the instrument case to provide freedom of movement about all three axes of the aircraft.

5.1 With the instrument in operation, gyroscopic rigidity maintains the spin axis in its normal operating position and the horizon bar with respect to the aircraft symbol. When the bank attitude of the aircraft changes, the instrument case and aircraft symbol move together with the aircraft about the longitudinal axis, and will lie at an angle to the horizon bar. At the same time the bank angle scale moves with the aircraft, indicating against the bank pointer the number of degrees of bank.

5.2 If the aircraft changes its attitude in pitch, the case and aircraft symbol move together with the aircraft about the lateral axis of the gyro so that the aircraft symbol will be above or below the horizon bar to respectively indicate a climb or descent.

5.3 The gyro assemblies of all gyro horizons incorporate a levelling device which maintains the gyro in its normal operating position. In some electrically-operated versions additional fast erection systems are incorporated which are controlled by a knob located at the front of the instrument. The operation of a fast erection system varies but, in general, it may be based on mechanical locking or caging of the gimbal system, or on the principles of increasing the current applied to the normal levelling device.

6 TURN AND SLIP INDICATORS These instruments indicate the rate of turn of an aircraft and also any slip or skid during a turn. Two separate indicating mechanisms are utilised; a turn indicating mechanism consisting of a gyro-controlled pointer referenced against a turn scale, and a gravity-controlled slip indicating mechanism which may be of the ball-in-tube inclinometer type, or of the gravity weight and pointer type. The gyro is of the two-axis type, known as a rate gyro, and consists of a single gimbal ring supporting the rotor about a horizontal axis. The gimbal ring is pivoted about the longitudinal axis of the instrument case. A calibrated rate spring is connected between the gimbal ring and the case. The pointer may be coupled directly to the gimbal ring, or coupled to it by means of a gear mechanism, depending on the manufacturer's design. Transient movements of both turn and slip indicating mechanisms are minimised by special damping devices.

6.1 When the aircraft turns, a force is exerted on the gyro which precesses the gyro about its longitudinal axis against the tension of the rate spring until equilibrium is established. The displacement of the gyro is therefore related to the rates of performance and aircraft turn, the latter being indicated on the scale by the deflection of the pointer on the appropriate side of the scale's zero position.

6.2 The slip indicating mechanisms depend upon the effects of gravitational and centrifugal forces for their operation. During straight flight in the normal lateral attitude gravity acts vertically through the mechanism, and the ball or pointer remains at the central datum. In turning flight, centrifugal forces are added vectorially to those of gravity and the indicating mechanism will therefore indicate the resultant, or direction of, apparent gravity. When turns are correctly banked the forces are such that the apparent gravity will maintain the ball or pointer at the central datum. If a slip or skid occurs the apparent gravity will be deviated causing a displacement of the ball or pointer in the direction of slip or skid by a related amount.

7 DIRECTION INDICATORS Direction indicators provide a stabilised directional reference for maintaining a desired course and for turning on to a new heading. They are also used as complementary instruments to direct-reading magnetic compasses. The instrument is non-magnetic and consists of a gyro pivoted about the vertical axis of the case so that the rotor spins about a horizontal axis. A rectangular opening in the front of the case carries a fixed lubber line which is referenced against a circular card graduated in degrees and secured to the outer gimbal ring of the gyro.

7.1 With the instrument in operation, gyroscopic rigidity stabilises the gyro and circular card and a certain heading is registered against the fixed lubber line. If the aircraft heading changes, the instrument case and lubber line turn with the aircraft about the stationary gyro and card, thus giving an indication of the number of degrees through which the aircraft turns. Headings corresponding to those indicated by the magnetic compass are set in direction indicators by means of a setting knob at the front of the instrument. When the knob is pushed in, it engages a locking mechanism with the gyro assembly which can then be rotated to the desired heading by turning the setting knob. The knob has a secondary function of caging the gyro assembly to prevent damage during transit, installation and removal.

8 INSTALLATION OF INSTRUMENTS AND COMPONENTS Before installation, instruments and associated system components should be inspected for damage or deterioration and tested (see also paragraph 9.3.3). New and overhauled instruments are normally kept in special containers until required. The packaging should be carefully examined for signs of damage before removing the instruments. The date of manufacture which is sometimes indicated on the container of the instrument must be checked to give an indication of shelf life. Type numbers and relevant operating supply data must be verified to ensure that instruments and components comply with the requirements of the particular aircraft installation.

8.1 **Handling Gyroscopic Instruments.** The mechanisms of gyroscopic flight instruments are delicate and the importance of careful handling during installation, removal and maintenance cannot be overstressed. In addition to the items mentioned in paragraph 8, the following points should be observed when handling these instruments:

(a) All gyroscopic instruments should remain in their original packaging containers or other well-padded shock-absorbent containers until installed in the aircraft to avoid shocks and vibration. If this is impractical, instruments should be hand carried with special care.

(b) Electrical gyroscopic instruments should not be lifted from containers, or carried, by their power supply cables.

(c) Instruments provided with caging facilities should be stored and transported in the caged condition. The caging device of some types of vacuum-operated gyro horizons is actuated by a screw inserted through the bottom of the case. Prior to installation this screw must be replaced by a shorter length blanking screw. When removed the appropriate screw should be retained for subsequent use. A gyroscopic instrument should never be removed or installed when the rotor is spinning as shocks on bearings could be caused by reactionary gyroscopic forces set up when removing the instrument. For example, a gyro horizon tilted more than 90° in the running condition, could develop a gimbal lock to start the complete gimbal system spinning fast enough to damage the gimbal bearings. The rotors operate at high rev/min and it is recommended that before moving an instrument in any way, at least 15 minutes be allowed to elapse after disconnecting the supply to allow the rotor to stop.

8.2 **Mounting Gyroscopic Instruments.** The method of mounting instruments on main panels is dependent on whether the case of the instrument is flanged or flangeless. In the former design the bezel is flanged so that the instrument is flush-mounted in its cut-out when fitted from the rear of the panel. Integral self-locking nuts are provided at the rear of the flange corners to receive fixing screws from the front of the panel. In gyro horizons incorporating a fast erection control device (see paragraph 5.3) the control knob is situated at one corner of the mounting flange and fixing of these instruments is by means of three screws and nuts. The mounting of instruments having flangeless cases (e.g. certain types of electrically-operated turn and slip indicators) is from the front of the panel and fixing screws and nuts are unnecessary. A special expanding type of clamp, shaped and dimensioned to suit the instrument case, is secured to the rear face of the panel at the appropriate cut-out location by two retaining screws. Two actuating screws are connected to the clamp which are accessible from the front of the instrument panel. The screws must be released sufficiently to allow the instrument to slide freely into the clamp. After positioning the instrument, the actuating screws are rotated to draw the clamp tightly around the case of the instrument.

8.2.1 A check on the vertical position of instrument panels should be made to ensure that after installing instruments (particularly direction indicators and gyro horizons), the gyroscopic axes will be correctly aligned in their operating positions. Instruments must be seated squarely in their cut-out, thereby also ensuring alignment of axes, and cases must not be subjected to strain or distortion.

NOTE: **The instrument panels of some types of aircraft are inclined towards the nose of the aircraft, and gyro horizons having wedge-shaped bezels are specified for such panel installations.**

8.3 **Vacuum System Instruments and Components.** The procedure for the removal and installation of vacuum-operated instruments and components depends upon the size and complexity of the particular system and detailed reference should be made to the Maintenance Manual appropriate to the aircraft type. The information given in the following paragraphs is a guide to the general practices:

8.3.1 **Pipelines**

(a) Before installation, pipelines should be blown through with clean, dry, low-pressure air to ensure cleanliness and freedom from obstruction.

(b) Flexible hoses must not be twisted during tightening of the end connections.

(c) Bending of pipes through too small a radius, and kinking of the pipes, must be avoided.

(d) Metal pipes must be properly secured to the airframe structure at the specified attachment points and there must be adequate clearance between all pipelines and structural parts to avoid chafing during flight.

(e) When pipelines are removed from an aircraft, blanks should be fitted to the end connections and all other exposed connections in the system. Support clamps should be returned to their original positions as soon as a pipeline has been removed to ensure their correct re-location.

(f) The mating surfaces of pipe ends and connections must be clean.

8.3.2 **Venturis.** Before installation, a venturi should be checked for damage to the threaded connector and distortion of its tubular sections and attachment bracket. The port located at the venturi throat communicating with the threaded connector should also be checked to ensure freedom from damage and obstruction. When installing a venturi it must be ensured that it is properly aligned and facing in the correct direction at the location specified for the particular aircraft type. The direction is sometimes indicated by an arrow on the venturi mounting.

8.3.3 **Vacuum Pumps.** Vacuum pumps should be checked before installation for signs of damage to the body, threaded inlet and outlet connections, and drive shaft splines. The pipe-connecting unions should be fitted to the pump before its installation and where a thread lubricant is recommended it must be applied sparingly and to male threads only. The oil passages in the pump and at the engine drive adapter should be probed to ensure that they are open and, when positioned over the mounting studs, the pump gasket should not obscure the passages. The drive shaft splines should be lightly coated with a high-temperature grease and, after alignment with the splines on the engine drive adapter, the pump should be slid into position and secured to the pad mounting studs.

8.3.4 **Valves.** In duplicate vacuum systems, non-return valves must be installed in the supply lines at the points specified and in conformity with the direction of normal air flow which is indicated on the body of the valve. Relief valves are installed in the supply line of all vacuum systems to control the amount of vacuum required for instrument operation. The type of valve may vary and reference should always be made to the relevant aircraft Maintenance Manual. The valve most commonly used has an exposed filter screen and when being installed it should be positioned with the filter screen downwards to prevent the accumulation of dust and other foreign matter. After installation, the relief valves must be adjusted to give the required vacuum (see paragraph 9.1.6).

8.4 **Electrical Systems.** The installation procedure for systems utilising electrically-operated gyroscopic instruments is simpler than that required for vacuum systems because there are fewer component parts. During installation the most common points to be observed are as follows:

(a) Electrical power must be isolated.

(b) Instrument circuit fuses should be checked for serviceability.

(c) Cables should be secure and the connectors positively mated to the instruments and power supply distribution points.

8.5 After installation, instruments should be checked for proper functioning (see paragraph 9.3.2).

9 MAINTENANCE The following paragraphs detail the general maintenance necessary on gyroscopic flight instrument systems and should be read in conjunction with the Maintenance Manuals for the type of aircraft and equipment concerned.

9.1 **Vacuum System Components**

9.1.1 **Venturis and Pumps.** Venturis should be checked for cleanliness, freedom from obstruction particularly at the throat, security of attachment and correct alignment. Vacuum pumps should be checked for security of attachment to the mounting pads on the engine and for signs of oil leakage around the gasket.

9.1.2 **Pipelines.** These should be checked to ensure freedom from corrosion, dents, nicks and abrasions, security of supporting clamps and connections. Flexible hoses should be carefully inspected for evidence of kinking, twisting and deterioration, especially at the joints between pipelines and components located in engine nacelles (e.g. pumps and oil separators).

9.1.3 **Relief Valves.** Relief valves should be inspected for damage, and cleanliness of their filter screens. The adjusting screw should be securely locked after any adjustment of the valve during system operational checks (see also paragraph 9.1.6).

9.1.4 **Filters.** The element of a central air filter (see paragraph 4.1.4) should be inspected for signs of dirt accumulation and damage. This type of filter is usually positioned so that inspection and replacement of the element can be made without having to remove the complete assembly from the pipelines. Cleaning of the element should be carried out in the manner stated in paragraph 9.1.5.

9.1.5 **Vacuum System Cleaning.** In general, low-pressure, dry, compressed air should be used for cleaning vacuum system components. Components such as oil separators and suction relief valves which accumulate engine oil and nacelle dirt should be washed with an approved solvent (e.g. Inhibisol) then dried with a low-pressure air blast. If an obstructed pipeline is to be cleared, it should be disconnected at both ends and blown through in the direction leading to the normal source of vacuum.

9.1.6 **Vacuum System Testing**

(a) Vacuum systems are usually checked after changing a component and at times specified in the aircraft Maintenance Schedule. Basically, the checking procedure consists of running an engine at a specified speed, testing the system for leaks and then adjusting the relief valve until the aircraft vacuum gauge indicates the value required for the installation. In duplicate systems, each relief valve must be adjusted separately. The engine speed and also the vacuum vary between aircraft types, and these details must be obtained from the relevant Maintenance Manuals which will also give the procedures to be followed.

(b) In instances where vacuum gauge readings are too high or too low, an investigation into the condition of instrument and system filters, pipelines (obstructions and leaks), venturis and pumps should be made before adjusting a relief valve.

9.2 **Electrical System Components.** The maintenance checks required on components of electrically-operated gyroscopic instrument systems are mainly the security and condition of power supply cables, connectors, switches, and circuit fuses. Supply voltages and frequencies should be within the limits specified for the particular electrical system but as they vary in different aircraft installations, reference must always be made to the appropriate Maintenance Manuals and Schedules.

NOTE: To eliminate the risks of electric shocks, arcing, burning of connector pins, etc., extreme care must be exercised when carrying out checks on components which require that sections of a circuit be 'live'.

9.3 **Instruments.** The maintenance checks to be carried out on gyroscopic instruments are mainly concerned with security, visual defects, functioning and performance tests. Precise details of these checks are given in relevant Maintenance Manuals and Schedules. The information in the following paragraphs is a guide to the general practices.

9.3.1 **Security and Visual Defects.** Checks should be made for the following:

(a) Security of attachment to instrument panels.

(b) Security of vacuum and electrical connections.

(c) Evidence of cracking of cases and bezel mounting flanges. Cover glasses should always be carefully inspected for cracks which could be caused by glancing blows from safety harness fittings, head sets, etc., and are often difficult to detect.

(d) Dial markings and pointers for legibility, discoloration and flaking.

9.3.2 **Functional Tests during Maintenance**

(a) **Gyro Horizons.** After the vacuum or electrical power has been applied, the rotor should be allowed to run up to normal operating speed and a check made that the horizon bar settles to indicate the attitude of the parked aircraft. In electrically-operated instruments incorporating power failure warning flags, it should be checked that the flags retract from view when electrical power is applied. Fast erection systems should be checked for functioning by pushing in the control knob and checking that the gyro erects quickly to the vertical. In some gyro horizons employing a mechanical fast erection system, the power failure warning flag should retract from view when the knob is pushed in. To prevent violent hunting of the gyro assembly, the control knob of an electrical fast erection system must not be pushed in until 15 seconds have elapsed after switching on the supply. The time of holding the knob in must be kept to a minimum and must not exceed 1 minute; this will prevent damage to the levelling system while checking the fast erection.

NOTE: In certain types of instrument embodying electrical fast erection, the normal erection system is cut out if the gyro assembly is out of the vertical by more than 10° in pitch or roll. The gyro can then only be re-erected by pushing in the fast erection control knob.

(b) **Turn and Slip Indicators.** With the aircraft laterally level, indicators should be checked to ensure that slip pointers or inclinometer balls are at the zero position. It is a characteristic of the rate gyros of these indicators that in their static condition the turn pointer provides no indication of the gyro having run up to normal operating speed. In order to check this, and also that the pointer mechanism is not sticking, the shock-absorbed instrument panel should be displaced at one or other corner within the limits of its mounting. This will simulate a slight turn and cause displacement of the turn pointer in the appropriate direction.

(c) **Direction Indicators.** The caging knob should be checked for freedom of rotational and axial movement. With the gyro running and caged a slight resistance to rotation of the knob should be felt. The indicator should be set to the heading corresponding to that indicated by the magnetic compass, and after uncaging, the drift from this heading should be noted. A maximum drift of 3° in 15 minutes is usually acceptable.

9.3.3 **Performance Tests.** Performance tests of instruments should be carried out before installation, at times when their operation and indications are suspect, and at the periods specified in the aircraft Maintenance Schedule. The procedures for testing each type of instrument are given in the relevant manufacturer's and aircraft Maintenance Manuals, and reference must always be made to these documents.

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AIRCRAFT

INSTRUMENTS

ENGINE INSTRUMENTS

1 INTRODUCTION This Leaflet gives guidance on the installation and maintenance of instruments employed for monitoring the operation of aircraft engines and associated systems. It should be read in conjunction with Maintenance Manuals and operators' approved Maintenance Schedules; such documents providing details of construction, major servicing, repairs and calibration procedures relevant to specific items and engine systems. Reference should also be made to the following Leaflets which contain information closely associated with the instruments covered by this Leaflet.

AL/3-13 Hose and Hose Assemblies.
AL/3-14 Installation and Maintenance of Rigid Pipes.
AL/3-15 Tanks.
AL/3-17 Fuel Systems.
AL/10-1 Flight Instruments—Pitot Static Systems.
EL/3-10 Turbine Engines.
EL/3-11 Turbine Engine Fuel Systems.
EEL/1-6 Bonding and Circuit Testing.
EEL/3-1 Cables—Installation and Maintenance.

2 GENERAL The information given in this Leaflet is set out as follows:

For those not familiar with basic operating principles of individual instruments, brief details are given in the appropriate paragraphs.

2.1 Many of the instruments utilise electrical elements based on the principle of measuring the required variables at source and transmitting the data through the medium of a synchronous signal link system. Various types of synchronous data transmission systems may be used and as some are applied to certain of the instruments to be described, an outline of their general construction and operation is given at this stage to avoid repetition.

3 SYNCHRONOUS DATA TRANSMISSION SYSTEMS All the systems consist of two principal components: a transmitting element and a receiving element, electrically interconnected through signal lines and supplied with power from the aircraft electrical system. Depending on the synchronous link adopted the power supply required may either be direct current or alternating current. The most common form of d.c. synchronous system is the "Desynn" of which there are three circuit variations; the application of each circuit being governed by the variables to be measured.

3.1 **Basic Desynn Circuit.** This circuit is applied to engine systems in which the position of a mechanical component is required to be known, e.g. a fuel trim actuator or a float mechanism of a fuel quantity indicator.

3.1.1 The transmitter unit consists of a circular wire-wound resistance or toroid tapped at three points 120° apart, and a brush assembly made up of two diametrically opposed contact arms suitably insulated from each other. The brush assembly rotates in contact with the toroid and serves to lead the d.c. supply to the system. Rotation of the brush assembly is effected by a slotted arm which engages with a crank pin connected through a mechanical linkage to the appropriate mechanical component. The type of linkage varies, but in a typical application to component position indication (e.g. fuel trim actuator position) it consists of a lever arm and spring-controlled gearing. The lever arm normally operates through 60° against a control spring, and the gear ratio between the arm and the crank pin may either be 3:1 or 6:1 so that the brush assembly can move through 180° or 360°. Stops limit lever arm movement to 70°.

3.1.2 The receiving or indicating instrument is made up of a two-pole permanent magnet rotor pivoted inside a soft-iron stator carrying a three-phase star-connected winding supplied from the three tappings of the transmitter toroid. A pointer is attached directly to the rotor spindle and rotates over a scale calibrated in the units appropriate to the required measurements.

3.1.3 When the brush assembly rotates over the toroid, the current flow to the indicator stator windings varies in magnitude and direction. The current is distributed through the windings and produces a magnetic field which rotates in synchronism with the brush assembly. The magnet aligns itself with this field thus carrying the pointer to positions indicating the amount of brush movement. When the power supply to the system is interrupted, the pointer is returned to an off-scale position by a weak pull-off magnet which attracts the main magnet rotor.

3.2 **Micro-Desynn Circuit.** The Micro-Desynn circuit is applied to systems in which less power and very small displacements of a primary actuating system is available, e.g. in the measurement of fuel or oil pressure. The circuit is a development of the basic one and the principle remains the same. In place of the toroidal resistance, however, two resistance coils are used and the brushes are arranged to move together over the whole length of their respective coils and through an angle of about 60°. This movement, combined with the method of electrically tapping the coils, corresponds to one revolution of the contacts of a toroidal transmitter and results in 330° movement of the indicator pointer. The brushes are rotated by means of a push-rod and rocking shaft assembly coupled to a bellows type of pressure-sensing element. In applications of the circuit to liquid quantity measurement, the brushes are rotated by a mechanically coupled float mechanism. With the exception of the dial calibration markings, the receiving or indicating element is similar to that employed in the basic Desynn circuit.

3.3 **Slab-Desynn Circuit.** In both the basic and micro circuits, the voltage at each of the transmitter tappings, although varying proportionally with the brush movements, produces a magnetic field in the indicator stator which causes a slight cyclic error. This deviation, plus frictional losses and contact wear, are characteristics of both circuits which can be taken into account during initial calibration. For some applications it is necessary for the effects of these characteristics to be minimised within the circuit itself and for this reason the Slab-Desynn circuit was developed.

3.3.1 The resistance of the transmitter element is wound on a flat former, hence the term 'slab', and the power supply is connected at either end. This arrangement produces a uniform potential gradient. The pick-off assembly consists of three brushes spaced at 120° and is equivalent to the three tappings on the other types. As the assembly rotates, voltages are distributed to the indicator stator which vary according to a sine law. Another feature of this arrangement is that as each contact carries less current wear is reduced.

3.4 **A.C. Synchronous Systems.** These systems which are generally known as 'synchros' are manufactured under a variety of trade names such as "Selsyn", "Autosyn", and "Asynn" the names being contractions of the functional terms adopted, e.g. "Selsyn" is a contraction of 'self synchronous'. The operating principle of these systems is basically the same, each consisting of electrical transmitter and receiving elements. However, unlike d.c. systems, both elements are similar in construction and employ a two-pole single-phase rotor free to rotate inside a three-phase wound stator. The stator windings of each element are interconnected and in most instrument applications the rotors are supplied with alternating current (26-volts or 115-volts) via slip rings.

3.4.1 When alternating current is supplied to the rotors a definite combination of voltages is induced in both stator windings. If both rotors are in the same position in relation to their respective stators both sets of stator voltages will be equally opposed and no current will flow in the coils. Thus, there is no magnetic field torque and the rotors remain in alignment. When the transmitter rotor is moved the induced voltages are unbalanced and currents flow in the windings of both stators producing magnetic fields which turn the receiver synchro rotor to the same position as that of the transmitter, restoring a balanced condition. There is a tendency for the transmitter synchro rotor to be turned within its stator, but as it is mechanically coupled to the appropriate measuring element, it is prevented from doing so and the receiver synchro is made to follow the transmitter.

PRESSURE INDICATORS The indicators used for the measurement of pressure in the systems of various types of engine are of two main types: direct-reading and remote indicating. A brief outline of the operating principles of typical indicators and systems is given in the following paragraphs.

4.1 **Direct-reading Indicators.** Direct-reading indicators are mechanically operated, and as the name implies, are connected directly to the source of pressure. The most common form of indicator operates on the Bourdon tube principle. A Bourdon tube is a C-shaped tube of oval cross-section having one end closed and the other secured and open to the pressure source. When pressure is admitted to the tube it tends to straighten out causing movement of the closed end and this movement is transmitted to the pointer of the indicator via a link and gear mechanism. When applied to low pressure measurements such as manifold pressure and engine power loss, the pressure sensing elements are in the form of flexible bellows or capsules.

4.1.1 **Manifold Pressure Gauges.** Manifold pressure gauges are in most cases of the direct-reading type, designed to measure the absolute pressure at the induction manifold of supercharged engines. The principle of operation and construction of a typical indicator is as follows:

(a) The pressure sensing element consists of two metallic bellows mounted in tandem. The rear bellows is connected by a pipeline to the engine induction manifold and the front bellows is evacuated and sealed and is spring-loaded by an internal spring. The outer ends of each bellows are secured to the instrument frame and the inner ends are connected to a common distance piece. The distance piece is connected to a gear type pointer mechanism via an arm, rocker shaft and lever mechanism. Gauges are fitted with a lubber mark which may be pre-adjusted to indicate the maximum manifold pressure permitted for engines with which they are associated.

(b) When the engine is stopped and the pressure is at standard conditions, the evacuated bellows assumes a position where its tendency to collapse is balanced by the internal spring. The bellows therefore provides an atmospheric pressure datum against which induction manifold pressure is referenced. The instruments are calibrated in either pounds per square inch, or millimetres or inches of mercury. The zero position on gauges calibrated in the former units corresponds to standard pressure of 14·7 lbf/in^2 while on gauges calibrated in millimètres or inches of mercury, the equivalent value of 760 mm or 29·92 inHg is read directly. Under engine operating conditions variations in manifold and atmospheric pressures cause relative displacements of the bellows which are transmitted to the pointer via the distance piece, rocker shaft and lever mechanism.

4.1.2 **Power Loss, Engine Pressure Ratio and Percentage Thrust Indicators.** These indicators are sensitive differential pressure gauges designed to indicate the thrust output of turbojet engines in terms of the absolute pressure within the exhaust unit. The application of each type of indicator depends on the type of engine and installation. A typical indicator consists of two capsules connected by a lever and gear train assembly to a pointer which rotates over a scale calibrated in either in. Hg absolute (Power Loss and Engine Pressure Ratio indicators) or percentage of thrust. One of the capsules is connected by a sensing line to the exhaust unit and responds to the difference between exhaust unit pressure and static pressure supplied to the indicator case. The other capsule is of the aneroid type and is sensitive to static pressure only which, in the case of power loss indicators and percentage thrust indicators, is supplied from a static vent of the pitot-static system (see Leaflet **AL/10-1** Flight Instruments—Pitot-Static Systems). In the case of engine pressure ratio indicators static pressure is supplied from a vent at the engine air intake. The deflection of the lever system in response to displacements of both capsules is equal to exhaust unit pressure, and is transmitted to the pointer via the gear train.

4.2 **Remote-indicating Instruments.** These instruments measure pressure at source and transmit the measured values to panel-mounted instruments through the medium of either a liquid or electrical signal transmission system. Depending on the type of aircraft the liquid transmission system may either be of the closed capillary type, or pressure transmitter type. Remote indicating instruments employing the electrical signal transmission principle consist of separate transmitting and indicating units which may form part of a d.c. or a.c. synchronous data transmission system, or a ratiometer system. The pressure sensing element of a transmitter may either be a flexible metal bellows or a Bourdon tube, depending on the application of the indicating system.

4.2.1 **Capillary Type.** The capillary system consists of a transmitter unit containing a capsule which is connected by a length of capillary tubing to a Bourdon tube indicator mechanism. The capsule, capillary tubing and Bourdon tube are completely filled with a special fluid such as Heptane (a paraffin hydrocarbon having a low freezing point and very little viscosity change) the whole assembly forming a single sealed system. The transmitter unit is directly connected by means of a hollow bolt to the particular engine system (e.g. oil system) and when pressure is admitted a force is exerted on the capsule to cause displacement of the transmitting fluid. This displacement in turn tends to straighten out the Bourdon tube in the manner of a direct-reading pressure gauge.

4.2.2 **Pressure Transmitter System.** A pressure transmitter system functions in a similar manner to the capillary system, but has the advantage that the transmitting and indicating units are separate thus facilitating removal and installation, and also permitting filling of the system in situ (see paragraph 10.4.2). The transmitter unit consists of two flanged circular housings bolted together and divided into an inlet chamber and an outlet chamber by a neoprene diaphragm. The inlet chamber is connected to the pressure source, while the outlet chamber is connected via small bore tubing to a direct-reading Bourdon tube pressure gauge. A spring-loaded ball valve is teed into the gauge connection and serves as a bleed during filling operations. The outlet chamber, tubing and Bourdon tube are filled with a mineral base oil. A second spring-loaded ball valve is incorporated in a connection in the lower part of the outlet chamber, the connection being used for filling purposes. A metal centralising disc in the outlet chamber prevents distension of the diaphragm when the system is being filled, and may be re-positioned by a centralising knob.

(a) In operation, pressure is exerted on the diaphragm causing it to distend and to transmit the pressure to the fluid in the outlet chamber. The fluid tends to force itself out of the chamber, but as the system is a closed one the Bourdon tube is displaced and the indicator reads the pressure applied at the transmitter.

4.2.3 **Ratiometer Pressure Indicators.** These instruments are used principally for the measurement of pressures in engine fuel and oil systems, and depending on the type specified, operate from either a direct current or alternating current source. In both cases the ratio of currents flowing through two coils of the indicator is measured in terms of pressure. The transmitter units normally consist of a pressure sensing bellows assembly mechanically coupled to an electrical element which in the case of a direct current system takes the form of a modified Micro-Desynn element connected to a moving coil ratiometer. The electrical element of an alternating current operated transmitter consists of inductor coils the iron cores of which are positioned by the bellows assembly. The indicator consists of two coils connected to the transmitter coils and two cam-shaped discs free to rotate in the air gaps of the cores. The discs are mounted on a common shaft connected to the pointer. When pressure at the transmitter changes it causes an increase in current in one coil circuit and a decrease in the other, the discs rotating in a direction determined by the coil carrying the increased current. Rotation of the discs and pointer ceases when a balance is reached by the torques produced at the discs.

4.2.4 **Pressure Switches.** Pressure switches are used in conjunction with warning lights to indicate that the pressure in a particular fluid system (e.g. fuel, oil and water methanol systems) has reached a pre-determined value. Depending on the application this value may be the upper or lower limit of the safe working pressure. Some switches are also employed to initiate a sequence of controlling operations when a certain pressure is reached in a fluid system.

(a) A typical unit consists of a metal diaphragm sandwiched between the flanges of a contact box which forms the main body and a base through which the system fluid is admitted, and a fixed and moving contact switch assembly. Connection of the base to the pressure source varies but, in general, it is either of the banjo fitting type or direct flange-mounted type. The movable contact is actuated by a push-rod bearing against the upper surface of the diaphragm. The stationary contact is adjustable to provide various pressure settings. Access to the adjusting screw is gained by removal of an access plate in the cover of the contact box, or as in some units by removal of the cover itself.

(b) The pressure of the fluid entering the base of the switch unit acts against the diaphragm causing the push-rod to operate the movable contact. The contact position is thus changed to either make or break the warning or controlling circuit.

5 ENGINE SPEED INDICATORS These indicators measure the rotational speeds of piston engine crankshafts and compressor shafts of turbine engines. Two principal types are in use; mechanical as used in some types of single-engined aircraft, and electrical which are used in aircraft having multi-arrangements of piston engines, and in all turbine-powered aircraft.

5.1 **Mechanical Indicators.** Mechanical indicators consist of a flyweight assembly connected to the engine by a flexible drive shaft and coupled to a gear type pointer mechanism. The gear ratios at the engine and indicator are such that the flexible drive shaft rotates at a lower speed to minimise wear. As the shaft rotates centrifugal forces act on the flyweight and cause it to take up a certain angular position. The displacement is transmitted to the pointer which rotates over the scale to indicate the speed of the engine crankshaft.

5.2 **Flexible Drive Shafts**

5.2.1 A flexible drive consists of a flexible inner shaft which is free to rotate within a stationary outer casing. The inner shaft embodies a central core of hardened steel wire over which five layers, each of four strands of finer gauge wire are wound, alternate layers being wound in opposite directions. After the inner shaft has been cut to the appropriate length a connector is secured to each end by swaging. Both connectors incorporate squared shanks which engage the hollow squared ends of the engine drive shaft and indicator shaft respectively. The shank at the engine end of the drive is longer than that at the indicator end.

NOTE: In some types of flexible drive, the connector shank at the engine end is designed to engage with a keyway in the engine drive shaft, while the shank at the indicator end is hollow.

5.2.2 The outer casing is a continuous winding of two specially-formed steel wires and is flexible, oil tight and waterproof. Flanged collars are swaged to each end of the outer casing to provide a means of attachment to the engine and indicator. Axial movement of the inner shaft is restricted by a shoulder on the connector at the indicator end which abuts on the end of the flanged collar and also by an interposed slip washer. This arrangement permits considerable end float of the shaft in the outer casing.

5.3 **Electrical Indicating Systems.** Electrical indicating systems comprise an alternating current generator which supplies a synchronous motor-driven indicator. The generator consists of a permanent magnet rotor and a three-phase stator winding. The rotor may be driven by a short length flexible drive shaft, or as in the case of turbine engines which have high rotational speeds prohibiting the use of flexible drives, by direct coupling to a splined shaft driven by the compressor shaft via reduction gearing.

5.3.1 The synchronous motor of an indicator is coupled to an eddy current drag type of mechanism consisting of a permanent magnet, a cup-shaped or disc type of drag element, and a controlling spring. The drag element is mounted on a spindle connected to a gear mechanism which drives a large and a small pointer to indicate hundreds and thousands of revolutions per minute respectively.

5.3.2 Rotation of the generator rotor induces a three-phase voltage in the stator windings which is transmitted to the windings of the indicator synchronous motor causing the rotor to revolve at a speed proportional to the generator frequency and therefore engine speed. The permanent magnet of the drag mechanism is also rotated and induces eddy currents in the drag element tending to rotate it at the same speed as the magnet. As the controlling spring is coupled to the drag element spindle it restrains rotation of the element to a position at which spring force and drag torque are in balance. The pointers are therefore positioned to indicate the engine speed.

5.3.3 **Percentage Speed Indicators.** These indicators are designed to indicate the speed of a turbine engine as a percentage of the nominal maximum speed. The scales are graduated from 0 to 100%, the 100% indication corresponding to the nominal maximum engine speed and a specific generator drive speed which is usually 4,200 rev/min. Indicators allow for slight increases in nominal maximum engine speed by reading up to 110%. In principle they operate in a similar manner to the conventional alternating current type of indicating system.

5.4 **Synchroscopes.** Synchroscopes are designed for use in multi-engined aircraft to indicate the degree of synchronism existing between a selected 'master' engine and the remaining engines designated as 'slaves'. They form part of an engine speed indicating system, each engine being associated with a complete synchroscope unit housed within the instrument.

5.4.1 A typical unit consists of a synchronous motor having a three-phase star-wound stator and rotor. A small double-ended pointer is attached to the rotor shaft and is referenced against a dial marked SLOW to the left and FAST to the right. In some types of synchroscope the left and the right positions of the dial are marked INCREASE and DECREASE respectively.

5.4.2 The generator of the selected 'master' engine is electrically connected to the synchroscope rotor while the 'slave' engine generator is connected to the stator. The output from the master engine generator induces a rotating magnetic field in the synchroscope rotor at a frequency proportional to the generator speed. Similarly, the generator of the slave engine induces a rotating magnetic field in the synchroscope stator. Both fields rotate in the same direction, and under synchronised speed conditions they interact to maintain the rotor and pointer at some stationary position. When there is a difference between generator speeds field interaction causes the rotor to rotate at a speed equal to the difference, and in a clockwise or anti-clockwise direction according to whether the speed of the slave engine is greater or less than the master engine speed.

5.5 **Rotation Indicators.** In turbine engines of the by-pass type severe damage may arise if the low-pressure shaft is not free to rotate during the starting cycle; the damage being caused by the re-circulation of hot gases around the high-pressure system. In order to indicate that the low-pressure shaft has begun to rotate and that it is safe to continue the starting cycle, rotation indicators are provided.

5.5.1 The basis of an indicator is an amplifier connected to one phase of the engine speed indicator system to accept signals from it as a speed reference input. The output stage is connected to an indicator lamp located on the main instrument panel, or on a panel at a flight engineer's station. Depending on the design, an amplifier may require a power supply of 115-volts at 400 Hz, or may be completely independent of aircraft power supplies.

5.5.2 When the input reaches a critical level, the amplifier produces sufficient output current to light the indicator lamp. A typical critical input level is 6 mV, corresponding to a rotation speed of a fraction of 1 rev/min. This speed is reached in the first few degrees of rotation and the lamp starts flashing immediately the shaft begins to rotate. Input signals in excess of the critical cause the amplifier to saturate and the lamp to remain alight but without being overloaded.

5.5.3 An indicator is only required during the starting cycle and for this reason the power supply to the amplifier is fed via an engine starting circuit. For multi-engine installations, a single amplifier and indicator lamp serves to indicate rotation of each engine which is automatically selected during each starting cycle.

6 TEMPERATURE INDICATORS All temperature indicators are of the transmitting type and fall into three main categories:

(a) Capillary.

(b) Electrical Resistance.

(c) Thermo-Electric.

6.1 **Capillary Thermometers.** Capillary thermometers are used to measure the temperature of liquids in aircraft systems such as oil and coolant and although superseded by electrical resistance thermometers are still fitted to certain types of small aircraft. In general the construction is similar to a liquid transmission type of pressure indicator which consists of a transmitter unit joined to a Bourdon tube indicator by a length of capillary tubing. In this case the transmitter unit is in the form of a 'bulb' which is immersed in the fluid whose temperature is to be measured, the transmitting fluid contained within the system being either mercury or ethyl ether. When the bulb temperature changes the mercury expands or contracts, or in the case of ethyl ether the vapour pressure increases or decreases, causing displacement of the Bourdon tube and corresponding movement of the pointer.

6.2 **Electrical Resistance Thermometers.** Thermometers of this type are comprised of a separate bulb and moving coil indicator electrically interconnected and supplied with direct current from the aircraft electrical system. The bulb contains a coil of nickel or platinum wire which forms a variable resistance arm of a bridge circuit contained within the indicator. When the bulb temperature changes, the coil resistance increases or decreases causing current to flow through the moving coil system corresponding to the temperature resistance characteristics of the bulb material used. The circuit arrangements may be either of the Wheatstone Bridge or ratiometer type.

6.2.1 **Wheatstone Bridge Circuit.** In this arrangement a measure of the temperature at various points throughout the range, and for a given supply voltage, is obtained in terms of an out-of-balance current. By suitable arrangement of the bulb material the bridge may be balanced at a pre-determined temperature, and no current will flow through the indicator. This is known as the 'null point' and in general is used to indicate the critical temperature of the instrument since, when these conditions prevail, the indication is independent of supply voltage. At all other points on the scale the out-of-balance current depends not only on the bulb resistance but also on supply voltage; therefore, there will be an error in indicated reading if this voltage differs from that for which the instrument was calibrated. This error will be proportional to the percentage difference change in the supply voltage from that used in calibration, and to the amount by which the pointer is deflected from the 'null point'. A device for adjusting the moving coil and pointer to the 'null point' is always provided and may be set by a screw at the front of the indicator bezel.

6.2.2 **Ratiometer Circuit.** In the ratiometer circuit arrangement the moving coil system is made up of two coils rotating in a magnetic field which, unlike conventional moving coil instruments, is non-uniform. One of the coils carries a reference current while the other is connected to the resistance bulb and therefore carries a current proportional to the resistance and temperature of the bulb. The ratio of these two currents determines the position of the complete coil assembly and the pointer, the indication being virtually independent of variations in the supply voltage.

6.3 **Thermo-electric Systems.** Thermo-electric systems are utilised principally for the measurement of air-cooled piston engine cylinder head temperatures and exhaust gas temperatures of turbine engines. The system comprises a single or multiple thermocouple arrangement located at the appropriate source of temperature, a moving coil millivoltmeter calibrated to relevant temperature/e.m.f. characteristics in degrees C, and connecting cables (see paragraph 6.3.6) of known length and resistance.

6.3.1 **Principle.** A thermocouple assembly is made up of two dissimilar metal conductors joined together to form a hot junction. The open ends of the conductors are connected by cables to the indicator which forms a cold junction. When the hot junction is subjected to temperature an e.m.f. is generated which causes a current to flow in the closed circuit. The magnitude of the e.m.f. depends on the materials used for the thermocouple and the difference between the hot- and cold-junction temperatures.

6.3.2 **Cold-junction Temperature Compensation.** To avoid errors in indicator readings due to the effects of temperature changes at the cold junction, automatic compensation devices are fitted to thermo-electric system indicators. Three methods are normally employed, (i) mechanical, (ii) electrical and (iii) magnetic; methods (ii) and (iii) compensating for changes in moving coil resistance to ensure proper instrument current.

(a) The mechanical method directly compensates for cold-junction temperature changes and consists of a bi-metallic spiral, the outer end of which is connected to the outer end of the controlling hairspring. When the cold-junction temperature changes the magnitude of the circuit e.m.f. changes and causes an error in the required hot-junction temperature indications. For example, if it increases, the difference between hot- and cold-junction temperatures, and circuit e.m.f., is reduced and the moving coil and pointer tends to indicate a lower hot-junction temperature. The bi-metallic spiral is also affected by the cold-junction temperature change, but as it is wound in a direction opposite to that of the controlling hairspring it opposes the moving coil and a constant hot-junction temperature indication is maintained.

(b) In the electrical method a neutraliser coil is connected in series with the moving coil, the characteristics of the material being such that under the same temperature conditions its resistance change equally opposes that of the moving coil material. In some instruments a thermistor shunted by a Eureka coil serves as the compensator.

(c) The magnetic method of compensation is accomplished by means of temperature sensitive magnetic strips (magnetic shunt) clamped across the permanent magnet of the indicator. These have the effect of shunting the magnet poles so that the flux strength in the air gap is varied at a rate proportional to the rate at which moving coil resistance changes.

6.3.3 **Engine Cylinder Head Temperature Indicating Systems.** The metal combinations used for cylinder head temperature thermocouples are either copper/constantan or iron/constantan. Depending on the type of engine the hot-junction may be formed either for bolting under a sparking plug or in direct contact with a cylinder head. A thermocouple is attached to the cylinder which tests have shown to be the hottest on an engine in any particular installation. The indicators are of the semi-circular scale type usually calibrated over the range 0-350°C, and are provided with terminal type connections at the rear of their cases. The terminal identified by a positive sign is connected to a copper or iron lead depending on the thermocouple combination used. Adjustment of the pointers to prevailing cold-junction temperatures (see paragraph 11.11.2 (a)) is effected by a device located at the front of the instrument and which is adjusted by a screwdriver.

6.3.4 **Turbine Exhaust Gas Temperature Indicators.** Gas temperature is a critical variable of turbine engine operation and it is essential to provide an indication of this temperature. The two control positions in an engine at which measurements are normally taken are: (i) At the exhaust unit. (ii) Within the turbine at one of the stator positions.

(a) Several factors have to be considered before any position is adopted; for example, temperatures related to the performance of the engine can be measured more accurately nearer to the upstream end of the turbine. The principal disadvantages of this method are that the number of thermocouples required for averaging becomes greater and the environmental temperatures in which they must operate are increased. However, as the temperature drop across the turbine varies in a known manner, it is usual to measure the temperature at the turbine outlet by locating a small number of thermocouple probes (see paragraph 6.3.5) in the area of the exhaust unit, in other words by adopting position (i). In certain types of turbopropeller engine control position (ii) is adopted by locating thermocouple probes at the leading edges of intermediate nozzle guide vanes.

(b) Gas temperature indicators, referred to variously as exhaust gas temperature (EGT), turbine gas temperature (TGT) or jet pipe temperature (JPT) indicators, may be of the semi-circular or circular scale type calibrated over the ranges 0-800°C and 0-1000°C respectively. Terminal type connections are provided at the rear of the cases, the terminal identified by a positive sign being connected to the chromel lead of the cable system. Adjustment of pointers to the required datum temperature values (see paragraph 11.11.2 (b)) is effected by a device which depending on the type of aircraft may be positioned either by a screwdriver or special adjusting tool.

6.3.5 **Thermocouple Probes.** A gas temperature thermocouple is mounted in a ceramic insulator and encased in a metal protection sheath the whole assembly forming a probe which can be projected into the gas stream. The thermocouple is made from Chromel (a nickel-chromium alloy) and Alumel (a nickel-aluminium alloy). The hot junction protrudes into a space inside the end of the sheath which has transfer holes in it to allow the exhaust gas to flow across the hot junction. The relative positions of the transfer holes depend on whether the thermocouple is of the 'stagnation' type or the 'rapid response' type. In the 'stagnation' type which is applied to turbojet engines, the exhaust gas enters the probe through a forward facing inlet, and after circulating round the hot junction it passes through a smaller exit hole higher up and on the opposite side to the inlet hole. This arrangement allows the gas passing through to become relatively stagnant thus minimising the effects of the high velocities. The 'rapid response' type of thermocouple is designed for use in low exhaust gas velocities as in turbopropeller engines, and has equal size transfer holes arranged directly opposite each other so that gas can pass over the hot junction with minimum stagnation.

(a) Probes may be of single, double or triple thermocouple element construction. A single element provides for temperature measurement only and a double element provides an additional identical circuit for transmitting a temperature signal to an engine temperature control system. The triple element type of probe provides for a further circuit for use in a warning system to detect a combustion fault. In some versions, the probe sheath is contained within a heat-resistant metal pitot tube which senses the exhaust unit pressure required when power loss indicators form part of engine instrumentation. A sleeve inside the lower end of the tube separates it from the probe sheath thus forming an annulus between the two. Three forward facing holes in the tube connect the annulus to exhaust unit pressure which is transmitted to the indicating system via a sensing line coupled to a union in the probe mounting flange, and a pressure manifold.

(b) In order to obtain a good average indication of gas temperature conditions and also to ensure functioning of the indicating system in the event an element becomes defective, a number of probes are radially disposed in the gas stream and the electrical outputs are connected to form a parallel circuit. The cables from the thermocouple probes are formed as a harness around the engine and terminate at a junction box which also provides the connecting point for the cables leading to the indicator.

(c) In some engine installations thermocouple probes may also be positioned in the air intake to transmit signals to a temperature indicating and control system, thus giving a reading of gas temperature compensated for intake temperature variations.

6.3.6 **External Circuits.** In addition to temperature/e.m.f. characteristics, the calibration of thermo-electric system indicators takes into account certain constant external circuit resistance values. The external circuit is the section from the thermocouple probe(s) to the indicator terminals and some typical resistance values are: 2 and 8 ohms for engine cylinder head temperature indicators, and 8 and 25 ohms for gas temperature indicators. In some cases the appropriate resistance values may be found on the indicators.

(a) The cables connecting probes and indicators may be one of the following types:

(i) **Extension** or those made of the same material as the thermocouple.

(ii) **Compensating** or those which are made of a different material to the thermocouple, but having a resistance equal to that of the equivalent extension cables.

(b) Whichever type of lead is used a stranding is selected to make up the correct overall circuit resistance required. In some turbine gas temperature indicator installations, a trimming resistor is connected in one of the leads to adjust the external circuit resistance to the required value. The resistor is made of either Eureka (a copper-nickel alloy) or Manganin (a copper-manganese alloy) wire wound on a spool. A Eureka resistor is connected in the negative lead, while a Manganin resistor is connected in the positive lead.

(c) In addition to the trimming resistor, the external circuit of an indicating system used with certain types of turbine engine includes a ballast resistor. The resistor is fitted because an engine may have an acceptable turbine inlet temperature but have a high exhaust temperature due to temperature scatter in the exhaust unit. The resistor reduces this scatter and brings the indicated temperature down. The value of the resistor is determined from test bed results, and because of this it must not be replaced by a resistor of a different value during the overhaul life of the engine. The specified resistance value is usually marked on the thermocouple system junction box or engine data plate and is also included in the engine log book.

7 ENGINE VIBRATION INDICATING SYSTEMS These systems provide continuous indication of vibration conditions normally existing when turbine engines are running, and from any sudden variations in amplitude can also provide an early warning of defects in the internal rotating parts and bearings, permitting corrective action to be taken before extensive damage occurs.

7.1 A system consists of an engine mounted pick-up unit which, in a typical application contains a spring-supported magnet and inductor coil assembly, an amplifier and an indicator mounted on the appropriate instrument panel. The scale of the indicator is graduated in units of fixed relative amplitude. A test push switch and an amber warning lamp also form part of a system. The power supply required for system operation is 115-volts single-phase, 400 Hz.

7.2 When an engine is running and electrical power is applied to the system, vibration causes relative motion between the magnet and coil and signal voltages are induced in the coil which are proportional to the velocity of vibration. These signals are applied to the amplifier where they are processed and fed to the indicator moving coil causing displacement of the pointer to positions indicating corresponding values of relative vibration amplitudes. If the vibration level exceeds a predetermined value a circuit is completed to illuminate the warning lamp. The purpose of the test switch is to check the continuity of the complete circuit. Operation of the switch connects a standard test signal, generated in the indicator-amplifier, to the pick-up unit and if the circuit is fault-free the test signal produces a standard value of vibration amplitude on the indicator.

8 FUEL QUANTITY INDICATORS The design and choice of a system for measuring and indicating fuel quantity is governed largely by the configuration of an aircraft fuel tank system. Most of the indicating systems in current use are based on electrical signal transmission principles, although in some types of light aircraft direct-reading indicators may be fitted. A general description of the construction and operation of typical indicators is given in the following paragraphs.

8.1 **Float Type Systems.** The transmitter or tank unit, consists of a cork or metal float attached to an arm pivoted at one end of a support assembly. The arm is mechanically coupled via a sealing unit to the electrical element which may either be of the basic or Micro-Desynn type (see paragraphs 3.1 and 3.2) or a simple wiper arm moving over a variable resistance connected to a moving coil indicator. The length and shape of individual float arms are designed to suit the tanks for which they are intended and the length of the support assembly may also vary accordingly. Stops are provided to keep the float clear of the top and bottom of the tank. The unit is assembled into a tank through an appropriately dimensioned aperture and is flange-mounted so that the electrical element is positioned externally. Leakage of fuel from the tank is prevented by a sealing washer interposed between the flange and mounting surface of the tank.

8.1.1 As the fuel level changes, the float arm moves through an angle and positions the contacts of the electrical element to produce a corresponding change of current flow through the indicator.

8.2 **Capacitance Type Systems.** These systems operate on the variable capacitance principle and consist of a number of electrical capacitance type tank units, an amplifier and an indicator. All components are interconnected by cables of the co-axial and standard type, and dependent on the particular design a system requires a power supply of either 115-volts a.c., 28-volts d.c., or both.

8.2.1 The capacitance of a capacitor is dependent on three main factors: (i) the area of its plates, (ii) the distance between them, and (iii) the dielectric constant or permittivity of the dielectric medium between the plates. In applying the capacitor principle to fuel quantity measurements the first two factors are made constant by constructing the capacitors in the form of either two concentric tubes or, two flat plates, the dimensions of which are fixed to suit the tank. The capacitance can therefore be varied only by changing the permittivity of the dielectric.

8.2.2 When such a capacitor is placed in a full fuel tank its dielectric is fuel, but as the tank empties the dielectric becomes fuel and a mixture of air and fuel vapour. Since the permittivity ratio between fuel and air varies in a known manner, then any change in fuel quantity between the tank-full and tank-empty conditions produces a corresponding capacitance change.

8.2.3 The method of connecting a tank unit capacitor in a gauge system varies, but in a typical version, the unit is connected in a rebalancing bridge circuit and its capacitance is compared with that of a reference capacitor. The signal proportional to the difference between them is applied to the amplifier, the output of which drives a two-phase induction motor coupled, via a gear train, to a potentiometer wiper and to the indicator pointer. The amount of motor rotation required to rebalance the bridge circuit through the potentiometer is therefore a measure of the change in tank unit capacitance and quantity of fuel in the tank. In some systems the amplifier output is converted to a d.c. signal which is measured by a moving coil ratiometer type of indicator.

8.2.4 Several tank units connected in parallel are used in fuel tanks to automatically compensate for aircraft attitude changes or surging of fuel. If the units are correctly sited in a tank, a gain in capacitance by some of the units resulting from a change of aircraft attitude will automatically be compensated by a loss of capacitance in others so that the total capacitance and indicator readings are unchanged. To ensure that capacitance changes are proportional to actual changes in quantity and not affected by the shape of a tank, certain of the tank units are characterised. This is effected by matching conducting surface areas to the different fuel levels resulting from the tank contour.

8.2.5 The permittivity of a fuel varies between different grades so that indication errors can arise when using different fuels. These errors are compensated by incorporating a reference or compensator unit in the tank. The unit is similar to a standard tank unit, but it has an additional capacitor at its lower end, and is so disposed in the tank as to be completely immersed down to very low fuel levels. It is connected into the balancing bridge circuit so that its capacitance change, due only to fuel permittivity opposes that of the standard tank units and error voltages and currents are cancelled.

8.2.6 Adjustment of a complete indicating system at the tank-full and tank-empty conditions is provided by two variable resistors in the sensing circuit from the tank units. Depending on the type of system installed, the resistors may be located at the rear of an indicator, within an amplifier unit or within separate adjuster boxes. In some systems a switch is provided for functional testing purposes. The switch is so connected that when depressed it unbalances the bridge circuit, and if the system is operating satisfactorily the indicator pointer rotates towards the 'tank-empty' position. On releasing the switch, bridge balance is restored and the pointer returns to its original position.

8.3 **Direct-reading Indicators.** Direct-reading indicators usually consist of a float contained within a metal support tube. The float engages with a spiral slot cut in the tube so that as the fuel level changes, the float moves up and down the tube and rotates at the same time. Rotary movement of the float is conveyed to an indicating element located at the top of the tube and magnetically coupled to a spindle which passes through the float.

9 FUEL FLOWMETERS Fuel flowmeters measure and provide visual indication of the instantaneous rate at which fuel flows to an engine, and in the majority of engine fuel system installations, provide a secondary indication of the quantity of fuel consumed. A system consists of a transmitter connected in the main fuel supply line and a motor-driven indicator calibrated in either gallons, kilogrammes or pounds per hour. The transmitter contains a specially calibrated metering unit and an electrical signal pick-off unit. As fuel passes through the metering unit it drives a rotating element which is coupled to the pick-off unit. Signals proportional to the fuel flow rate are induced in this unit and are transmitted to the indicator motor which positions the pointer at the scale graduation corresponding to the flow rate.

NOTE: There are a number of variations in the design and construction of fuel flowmeter systems. For detailed information on the operating principles adopted reference should therefore be made to the relevant Manufacturer's publications.

10 INSTALLATION

10.1 **General.** Before installation, instruments should be inspected for damage or deterioration which might have occurred in storage or transit. New or overhauled instruments are normally kept in their special packaging containers until required and the packaging should be carefully examined for signs of damage before removing the instrument. It must be verified that the shelf life (which is usually indicated on the container) has not been exceeded.

10.1.1 The dials of indicators should be checked to ensure that, where applicable, they bear coloured arcs and radial lines at various parts of the scales corresponding to the operational limitations laid down for specific types of engine. It may be necessary in some instances to apply the arcs and radial lines to the cover glasses. In such cases, the precaution must be taken of painting a short white connecting line between the glass and the bezel, and in a position which does not conflict with the essential operational marks. Thus, the correct alignment of the glass and operational marks may be readily checked.

NOTE: Further information on operational markings is given in Chapter D7-3 of British Civil Airworthiness Requirements.

10.1.2 The method of mounting instruments on their respective panels depends on whether the cases of the instruments specified for use in a particular aircraft type are of the flanged or flangeless design. In the former design the bezel is flanged in such a manner that the instrument is flush-mounted in its cut-out from the rear of the panel. Integral self-locking nuts are provided at the rear faces of the flange corners to receive fixing screws from the front of the panel. The mounting of instruments having flangeless cases is a simpler process in that separate fixing screws and nuts are unnecessary and mounting of instruments may be done from the front of the panel. A special expanding type of clamp, shaped and dimensioned to suit the instrument case is secured in the rear face of the panel at the appropriate cut-out location by two countersunk retaining screws. Two round head actuating screws are connected to the clamp and are arranged to be accessible from the front of the instrument panel. The screws must be released sufficiently to allow the instrument to slide freely into the clamp. After positioning the instrument, the actuating screws are then rotated so as to draw the clamp tightly around the case of the instrument. To avoid strain or distortion care must be taken to ensure that instruments seat squarely in their cut-outs while being secured to the instrument panels. This is of particular importance when installing instruments having flanged cases.

10.1.3 Code numbers of instruments and associated components, etc., should be checked to ensure that they comply with installation requirements, and where electrical instruments are concerned all wiring and connections must be in accordance with relevant Manufacturer's drawings.

10.2 **Direct-reading Pressure Gauges.** Before installing a gauge the bore of the connecting union should be inspected to ensure that it is clean, free from damage and obstruction; bleeding of the system must also be carried out. With the gauge in position the rigid pipe line, or flexible hose as appropriate, should be connected to the union. The union should be held by a spanner at the hexagonal portion to prevent straining of the gauge mechanism fixing screws while tightening the pipe line or hose union nuts.

10.2.1 **Manifold Pressure Gauges.** Before installation, the lubber mark should be checked to ensure that it is set at the correct maximum permissible pressure for the engine with which the gauge is to be used. The method of adjusting the lubber mark varies; reference should therefore be made to the relevant manual for details of the procedure to be adopted. The gauze filter should be removed from the pressure connector and examined for damage and cleanliness. When replacing a filter it must be ensured that it is inserted the correct way round, e.g. certain types of filters are open at one end and must be inserted this end first. Pipelines and fuel traps where necessary, must be installed in accordance with the requirements specified in the relevant aircraft installation drawing.

10.3 **Capillary Pressure Gauges.** The installation of these instruments should be commenced at the instrument panel end by passing the banjo fitting and capillary tubing through the cut-out. The capillary tubing is normally wound on a cardboard drum and it should be reeled off from this without pulling away at sharp angles. The tubing should be disposed along its route until the gauge can be bolted to the instrument panel. Cleating of the tubing to adjacent parts of the structure is normally required at intervals of not more than 225 mm (9 in). Sharp bends should be avoided; the radius of any essential bend should not be less than 15 mm ($\frac{5}{8}$ in).

10.3.1 Any spare length of tubing at the engine end should be formed into a coil of not less than 100 mm (4 in) diameter, the coil being cleated in at least three places to an adjacent part of the structure. A new annealed copper washer should be placed on either side of the hollow bolt attachment of the banjo fitting before connecting it to the engine.

10.4 **Pressure Transmitter Systems.** A pressure transmitter should be mounted vertically with the outlet connection to the gauge uppermost, as usually indicated by an arrow embossed on the body of the outlet housing. Four spacers screwed to the flanges of both housings provide for the mounting of the transmitter on the engine side of a fireproof bulkhead, or by means of tube clamps, on the engine bearers. The spacers must not be disturbed as this would affect the tightness of the flanges and cause distortion of the body and subsequent leakage. When attaching the fixing screws to the spacers the latter should be held with a spanner to prevent any tendency to rotate during tightening.

10.4.1 Two pressure connections are provided in the inlet housing and the flexible hose conveying the source should be connected to the most convenient inlet. The other connection should be sealed by the blanking plug provided with the transmitter. The filler valve should be secured to the transmitter inlet housing and blanked off until filling and bleeding of the system is carried out.

10.4.2 **Filling and Bleeding.** A special filling apparatus is normally supplied for filling and bleeding, capable of applying pressure up to a maximum of 175 kN/m^2 (25 lbf/in^2). The filling apparatus must be thoroughly clean before being filled with fluid, and all air should be expelled by operating its filling pump until bubble-free fluid flows from the end of the filling line.

(a) Before commencing filling operations the pipeline between the transmitter and indicator should be disconnected and cleared of any dirt particles by blowing through clean, dry air at a pressure of approximately 175 kN/m^2 (25 lbf/in^2). When it is evident that the line is completely clear it should be re-connected.

(b) The blanking plug should be removed from the transmitter filling valve and the filling apparatus connected to the valve. The locknut and the centralising knob shaft should then be slackened off and the centralising knob pushed inward and turned by hand in a clockwise direction for about one-half turn until the shaft locks in place. This action locates the centralising disc against the diaphragm and maintains it in a central position to prevent excessive distension of the diaphragm during the filling process. If the centralising knob shaft is a little difficult to push in, it may be lightly tapped; pliers or a wrench must not be used to rotate it.

(c) The blanking plug should be removed from the bleed valve at the gauge connection and a suitable length of flexible tubing connected to act as a bleed line. A suitable receptacle containing a small quantity of filling fluid should be positioned below the bleed valve and the free end of the bleed line immersed in the fluid. As an aid in detecting air bubbles the bleed line should incorporate an end section of transparent flexible tubing.

(d) The filling device should then be operated to force fluid into the system, ensuring that the pressure does not exceed 175 kN/m^2 (25 lbf/in^2), which is the pressure necessary to open the bleed valve. Pinching off the bleed line several times during filling will help in removing air. When air bubbles cease to appear at the free end of the bleed line it may be assumed that the system is filled.

(e) On satisfactory completion of the filling operation the filler and bleed lines should be disconnected and the blanking plugs replaced on the valves. The transmitter centralising disc is returned to its normal position by turning the knob anti-clockwise and withdrawing it to its maximum extent, and then secured in this position by tightening the locknut.

10.5 **Power Loss, Engine Pressure Ratio and Percentage Thrust Indicators.** The indicators should be secured at their panel cut-out locations by the appropriate mounting method (see paragraph 10.1.2) and their respective connections coupled to the static and pitot pressure pipelines. After installation indicators must be tested for proper functioning under static and running conditions of their associated engines (see also paragraph 11.3.1).

10.6 **Electrical Pressure Gauges.** The code numbers of transmitters and indicators should be checked to ensure that the units are correct for use in combination. Transmitters other than flange-mounted types must be supported on an anti-vibration mounting which should be attached to the airframe or engine structure, as specified for the aircraft. When connecting pipelines to Micro-Desynn pressure transmitters care must be taken not to disturb the setting of the pressure unit. Two spanners must be used one to hold the body of the pressure connecting union while tightening the pipeline union nut. Flange-mounted transmitters must be attached to the appropriate location on the engine with the specified type of gasket fitted between the mounting faces. After the necessary electrical connections have been made and the power supply has been switched on, a check should be made that indicator pointers move from an off-scale position to zero. During engine running it must be checked that pointers move smoothly without signs of flickering. On completion of engine running, transmitters and pressure connections must be checked for signs of leakage.

10.7 **Engine Speed Indicators**

10.7.1 **Indicators and Synchroscopes.** These should be properly secured at their panel cut-out locations by the appropriate mounting method (see paragraph 10.1.2). When installing mechanical type indicators it must be ensured that the flexible drive has adequate clearance behind the panel and that any necessary bends are not sharp or would cause strain on the instrument when it is secured to the panel. Cable connections to electrical indicators and synchroscopes must be made in accordance with the relevant Maintenance Manuals and Wiring Diagrams.

10.7.2 **Generators.** Before installation, the insulation and phase resistance of generators should be checked in accordance with the procedure laid down in the Maintenance Manual for the specific type. Generators coupled to an engine by a flexible drive are normally mounted on a platform type of bracket secured to the engine. When fitting a flexible drive with square shank connectors it must be ensured that it is located the correct way round, i.e. short connector at the generator and long connector engaged with the engine drive. The union nuts should be securely tightened and wire-locked. Before installation of a spline-drive generator the face of its mounting flange and corresponding face of the engine mounting pad should be clean and undamaged and the splines should engage with the engine drive shaft without difficulty. A "Langite" or other approved gasket must be fitted between both mounting faces. After locating the generator on the mounting studs, the securing nuts must be tightened evenly and in sequence.

10.7.3 **Rotation Indicators.** For details of pre-installation checks and installation procedures, reference should be made to the relevant aircraft Maintenance Manual.

10.8 **Temperature Indicators**

10.8.1 **Capillary Thermometers.** The procedure for installing thermometers of this type is similar to that adopted for capillary pressure gauges (see paragraph 10.3).

10.8.2 **Electrical Resistance Thermometers.** Resistance bulbs should be screwed into the required position and after tightening, the union nuts should be wire-locked. Electrical connection of a bulb and indicator system must be made in accordance with the relevant Maintenance Manuals and Wiring Diagrams. After switching on the power supply a check should be made that an indicator pointer moves from a 'null' position (Wheatstone Bridge type) or an off-scale position (ratiometer type) to a position indicating the prevailing temperature of the liquid in which a bulb is immersed.

10.8.3 **Thermo-electric Systems.** The visual checks to be carried out on thermocouples, harnesses and leads and the methods of installing them, depend on the aircraft and engines with which they are associated; the instructions provided in the appropriate Maintenance Manuals must therefore be followed. Certain aspects are common to installation practices and may be summarised as follows:

(a) Freedom from cracks at brazed joints between thermocouple element and cables in protecting sheaths and cable conduits.

(b) Alignment of gas inlet and outlet holes in relation to the key provided for locating the probe.

(c) Position and condition of elements as seen through gas holes.

(d) Universal joint movement, where applicable.

(e) Identification of positive and negative conductors and correct pairing of elements at terminals.

(f) Condition of cable sheathing and conductors. If stranded leads are used, check for fraying and if this is evident the leads should be rejected.

(g) When making connections ensure that continuity of polarity and conductor identity is preserved.

(h) Before fitting thermocouples or harness systems, lightly smear the threads of captive nuts or bolts with a graphited grease; this will facilitate removal, particularly in hot zones of an engine.

(j) Exhaust gas thermocouples should be correctly aligned in engine adaptors or mounting bosses and their securing nuts or bolts tightened to the specified torque load.

(k) The overall circuit resistance is critical, therefore all terminals must be clean and the nuts securing the cables must be tightened to the specified torque load. When torque loading, care must be taken to ensure a direct load on the torque spanner avoiding side loads.

(l) No alteration must be made to the length of leads, otherwise the circuit resistance will be incorrect resulting in inaccurate indications of temperature.

(m) In order to damp the moving coil element of indicators and thus help obviate damage during transit and other handling, the terminals must be short-circuited by a piece of copper wire. It should be removed during testing, but afterwards should be replaced until an indicator is installed in the aircraft.

NOTES: (1) Thermocouple conductor leads are identified by a colour code as follows: Red-Positive-Iron, Copper and Chromel; Blue-Negative-Constantan and Alumel.

(2) In addition to the foregoing pre-installation checks, the electrical continuity, resistance and millivolt output of thermocouples, harnesses and leads should also be tested, and in the manner specified in the relevant Maintenance Manual.

10.9 **Engine Vibration Indicating Systems.** Before installing a vibration pick-up unit it should be ensured that the internal magnet has freedom of movement. This may be done by holding the unit and checking that an audible 'click' is produced when a slight flick is imparted to the unit. The resistance of the inductor coil should also be checked to ensure that it is within the limits specified. After securing the unit to the engine, connect the cable assembly and secure it with the coupling nut provided. The unit fixing screws and coupling nut should be wire-locked. Indicator-amplifier units should be secured to the instrument panel and connected to their appropriate cables. A function test of the complete system under engine static conditions, should be carried out by switching on the power supply and noting that when the test switches are pressed the indicators read a specified standard value of vibration amplitude, and noting also that the warning lamps come on.

10.10 **Fuel Quantity Indicators**

10.10.1 **Float Type.** Before installing tank units and indicators the following tests and checks should be made:—

(a) Insulation resistance and continuity tests of tank units, indicators and the indicating system cables in the aircraft.

(b) Check that code numbers are correct for the particular aircraft fuel tank installation.

(c) Check that float arms have not been accidentally bent, and that other parts of the actuating mechanism are clean and show no signs of corrosion.

(d) Check that floats have freedom of movement where applicable, no signs of dents or flaking of fuel-resistant lacquers with which cork floats are coated.

(e) Test the float arm freedom of movement between the 'full' and 'empty' limit stops.

(f) Test the functioning of tank units and indicators against the appropriate Test Sets and/or Master Indicators in the manner prescribed in the Maintenance Manuals.

(g) Ensure that the mating surfaces of a tank unit and tank are clean and fit a new sealing gasket coated on both sides with a fuel resistant sealing compound.

NOTE: When a tank is fitted with a separate inspection cover adjacent to the tank unit, it should be removed to enable the float arm position to be checked.

(i) A tank unit should be positioned correctly in relation to the tank so that the float arm may be inserted without fouling the tank sides or baffles. After lowering it onto the tank mounting face it should be located by inserting two or three of its fixing screws, and if possible the float arm checked for clearance and freedom of movement by hand, through an adjacent inspection hole. The remaining fixing screws should be inserted and all screws tightened evenly working diametrically across the flange. The electrical leads should be connected in accordance with the relevant aircraft wiring diagram taking care to ensure correct terminal polarities, and that there are no loose strands of wire which could short-circuit the terminals.

(ii) After installation the power supply should be switched on and the operation of the system checked. If an inspection hole is available this may be done by moving the float arm by hand from the empty to the full position and noting that the indicator pointer moves smoothly in the corresponding direction. In all instances a functional test must be made by adding fuel in measured quantities over the total range of tank capacity. Particular attention should be paid to the accuracy of the indicator at the lower end of the scale (refer also to paragraph 11.14.1 (e)).

10.10.2 **Capacitance Type.** The method of installing components of capacitance type fuel quantity indicating systems varies particularly in connection with tank units and aircraft fuel tank systems. The instructions given in the relevant Maintenance Manuals must therefore be observed. The following gives details of certain important aspects associated with systems generally:

(a) The code numbers of tank units must be checked to ensure that they are of the type corresponding to the location and fitting specified, e.g. centre of a tank, compensated unit, internal or external mounting. Units must be inspected for signs of damage to the electrodes and co-axial connector assemblies and if they are of the external mounting type, cleanliness of the mounting flange surface. When installing units care must be taken to pass them through the holes provided so that electrodes are not damaged or distorted, and the co-axial connectors face in the correct direction for mating with the cables. Externally mounted units are secured to the tank by means of fixing screws and sealed by a gasket and jointing compound. Internally mounted units are installed and located in their mounting brackets, through hand holes. When fitting the cables to the co-axial connectors the cable coincidence and terminal identifications must be checked to ensure that they are in accordance with the system wiring diagram.

(b) Before installing co-axial cables they must be examined for signs of damage, erosion or other defects and tested for insulation resistance and continuity. Extreme care is essential when installing cables to ensure that the bends are not excessive (minimum permissible bend radius is 25 mm (1in) and that the cables are so placed to avoid being cut by sharp edges, etc. Precautions must also be observed in connection with the insulation of cables and ambient temperatures to which they may be subjected. For example, cables of the polythene insulated type are not suitable for location in areas subject to temperatures in excess of 60°C. Failure to observe this precaution will result in melting of the insulation and subsequent failure of the gauge system. Where temperatures in the vicinity of a cable are likely to be above 60°C, cables having PTFE (polytetrafluoroethylene) insulation must be used. Cable connector nuts must be tightened to the torque value specified in the Manufacturer's Maintenance Manual. Connector body assemblies must not be rotated during tightening of the nuts.

(c) After the installation of a component in a tank system and any necessary adjustments, a test must be carried out in accordance with the procedures specified in the relevant Maintenance Manuals.

10.11 **Fuel Flowmeters.** The pre-installation checks of fuel flowmeter system components and the methods of installation vary between systems; reference should therefore be made to the relevant Maintenance Manuals.

11 INSPECTION AND MAINTENANCE The checks to be carried out on individual instruments and associated components are primarily concerned with security, visual defects, circuit testing and calibration tests. Precise details of these checks are given in relevant instrument and aircraft Maintenance Manuals and reference should always be made to such documents. The following summary and the information given in subsequent paragraphs serves as a guide to checks of a general nature and to specific inspections and tests related to the instruments covered by this Leaflet. The summary of checks:

(a) Security of attachment to instrument panels and appropriate parts of the airframe or engine structure.

(b) Security and cleanliness of pressure and electrical connections.

(c) Evidence of cracking of cases, bezel mounting flanges and cover glasses. The latter should always be carefully inspected as cracks caused by glancing blows struck by safety harness fittings, head sets, etc., are often difficult to detect.

(d) Checking of dial markings, counters and pointers for legibility, discoloration and flaking.

(e) Checking of coloured operational markings.

(f) Presence of moisture or water inside the cover glasses or on the dials of instruments connected to a static pressure source, e.g. power loss indicators.

(g) Smoothness of pointer movements during functional testing and under engine operating conditions.

(h) At the specified maintenance check periods or at any time instruments or associated components are suspected of malfunctioning, they should be removed from an aircraft and the relevant bench checks and tests carried out.

11.1 **Manifold Pressure Gauges.** Under static conditions of an engine the readings should be checked against the prevailing atmospheric pressure reading of a barometer. For instruments calibrated in inches of mercury the reading should be the same as that of the barometer. For instruments calibrated in pounds per square inch, the barometer reading should be converted to these units and the gauge reading checked to ensure that it indicates the difference between prevailing and standard atmospheric pressures within the permissible tolerances.

11.2 **Capillary Type Pressure Gauges.** Capillary tubes should be inspected for security at their attachment points, signs of kinking or other damage. The hollow bolt attachment should also be inspected for signs of leakage of fluid from the appropriate engine system. When carrying out functional tests in situ, care must be taken to ensure that the capillary tubing is not pulled through too sharp a bend when connecting the banjo fitting to the test apparatus. The test apparatus should be supported at the same level as the point at which the banjo fitting is normally located in order to minimise 'head effects'.

11.3 **Power Loss, Engine Pressure Ratio and Percentage Thrust Indicators.** Indicators should be checked to ensure that under static conditions and also when engines are run at their governed speeds, they indicate the appropriate values within the limits given in the aircraft Maintenance Manual.

11.3.1 At the specified check periods, or whenever indications are suspect, functioning tests should be carried out by applying air pressure from a suitable rig and noting that indicator readings correspond to the specified master gauge reading. Care must be taken never to exceed the upper limit of applied pressure or damage to the pressure sensing capsules may result. In addition to the functioning test, water drain traps should be checked, the exhaust pressure and static pressure sensing lines should be disconnected from the engine and the indicator, and pressure tested in the manner prescribed in the relevant aircraft Maintenance Manual.

11.3.2 Filters are provided in the connections of some indicators and these should be inspected for cleanliness. If dirt is evident, the appropriate filter should be extracted from the bore of the connector and washed in a cleaning solvent such as Inhibisol. After thoroughly drying out, the filter and pipe connection should be re-connected.

11.4 **Electrical Pressure Gauges.** During engine running the correct functioning of a system should be checked by observing that the indicator pointer moves smoothly across the scale without flickering. In systems employing moving contact type transmitters pointer flicker will most often develop at the scale point where the pointer settles under normal operating conditions. This is usually owing to wear on the resistances caused by a continuous rubbing of the contacts under conditions of vibration. In such circumstances the complete transmitter should be replaced by a serviceable unit. Pressure connections should be checked for signs of fluid leakage and transmitters for security of attachment. Anti-vibration mountings should be inspected for signs of damage and also to ensure that they provide the required floating action of their transmitters.

11.5 **Flexible Drive Shafts.** The locking wire should be removed from the union nuts, the nuts unscrewed and the complete drive assembly removed from the aircraft. The flexible shaft should then be removed from the outer casing by firstly pulling out the indicator or generator end as far as possible and bending and removing the slip washer. The flexible shaft is then withdrawn by pulling out from the engine drive end. All components should be thoroughly cleaned and inspected.

(a) It is particularly important to verify that there are no kinks, worn spots, loose or fractured strands in the flexible shaft and that the end connectors are secure. A kink may be detected by holding the complete assembly vertically at one end and slowly rotating the flexible shaft between the fingers to feel for binding and jerky motion. In instances where the flexible shaft is rejected because of loose strands, it is advisable to renew the complete drive as it is possible that the bore of the casing may have been damaged and this would result in excessive wear of the new flexible shaft.

(b) The outer casing should be inspected for kinks, sharp bends and security. Two holes are provided in the collar at the engine end which permit surplus oil from the drive to drain away. The holes should be kept clear.

(c) Prior to re-assembly the flexible shaft should be coated with an approved grease. With the shaft in position in the outer casing, the slip washer at the indicator or generator end should be re-assembled and using a pair of flat-nosed pliers, flattened so that it will remain on the shaft.

11.6 **Electrical Engine-speed Indicating Systems.** When an engine is running at idling speeds it may be found that the indicator pointers tend to fluctuate and read low; this is an indication that the indicator motor is not synchronising with the generator output. As the engine speed is increased the pointers should jump forward as the motor synchronises, and register the speeds correctly without any appreciable lag. The speeds at which synchronising takes place is governed by the upper limit of the indicator's speed range, and generator ouput, and these should be ascertained from the Manufacturer's Maintenance Manual for the specific type of system.

11.6.1 If instrument pointers oscillate at speeds above the synchronising value it should be verified that the total oscillation does not exceed the permissible ranging tolerances. Where excessive oscillation is observed it is necessary to determine whether the instrument or one of the other components in the system is at fault. If a flexible drive to the generator is employed, oscillation may be due to insecure attachment of the outer casing thus permitting the drive to 'whip' slightly. It may also be due to 'binding' of the drive as a result of lack of lubrication. If, after rectifying these faults, oscillations still persist and all electrical connections are secure, a new drive should be fitted.

11.6.2 With flexible drive generators and also direct-drive generators, if the drive and electrical connections have been eliminated as the source of the defect, pointer oscillation is most likely to be associated with the indicator, e.g., the drag element may be touching the rotating magnet at a certain position within the air gap. The indicator should be removed for testing and if oscillation persists, a new indicator should be installed.

11.7 **Synchroscopes.** Synchroscopes should be checked to ensure that during engine running pointer rotation is in the correct direction at differing speeds of master and slave engines, and that no rotation takes place when speeds are synchronised. The checks are done firstly by maintaining the slave engine or engines at idling speed and then increasing the speed of the master engine. Under these conditions it should be noted that the synchroscope pointer or pointers rotate anti-clockwise to the SLOW or INCREASE marking. The speed of the slave engine or engines should then be increased to a value higher than the master and pointer rotation noted to be clockwise to the FAST or DECREASE marking. Finally, it should be noted that as speeds are brought into synchronism, the pointer or pointers remain stationary at some position over the dial.

11.8 **Rotation Indicators.** The method of carrying out maintenance checks, tests and adjustments depends on the type of engine and on the systems adopted. Reference must therefore be made to the relevant Maintenance Manuals.

11.9 **Capillary Thermometers.** Capillary tubes and bulb fittings should be inspected for security at their attachment points, signs of kinking or other damage, and leaks. Under engine static conditions the indicator readings should correspond to the prevailing temperature conditions of the fluid in which the bulb is immersed. When carrying out functional tests of a thermometer in situ, care must be taken to ensure that the capillary tubing is not pulled through too sharp a bend when connecting the bulb to the test apparatus. The test apparatus should be supported at the same level as the point at which the bulb is normally located in order to minimise 'head effects'.

11.10 **Electrical Resistance Thermometers.** When electrical power is switched on instruments should be observed and a check made that pointers move from a 'null' position or an off-scale position to one indicating prevailing temperature conditions. In the event that the pointers of an indicator move to a position beyond maximum scale reading, the power supply should be switched off immediately and a continuity check of the bulb and cables carried out, as this fault is an indication of an open circuit in the temperature sensing signal line.

11.11 **Thermo-electric Systems.** Thermocouples are not normally repairable items and if defective must be rejected for scrap or returned to the manufacturer for investigation. The mechanical condition of thermocouple units, harnesses and leads should be checked for defects paying particular attention to the following:

(a) Fracture or erosion of thermocouple hot junctions.

(b) Deterioration, cuts or fractures in insulation of leads.

(c) Cracks, or damage to the leading edge of machined probes, e.g. those installed at intermediate nozzle guide vanes of turbine engines.

(d) Blockage or enlargement of gas holes and damage to their edges.

(e) Cracks in or distortion of sheaths and conduits.

(f) Stiffness or seizure of universal joints in thermocouple units employing this method of attachment.

11.11.1 **Circuit Resistance Checks.** The resistance of thermocouples and external circuits of engine cylinder head temperature and exhaust gas temperature indicating systems, must always be checked to ensure that it is within the limits specified. The checks are done under ambient temperature conditions by disconnecting the thermocouple harness and external circuit leads from their junction box and connecting them in turn to a Wheatstone Bridge, or similar test instrument by means of special test leads. The test leads are of a known resistance, the value of which must always be subtracted from that obtained during the test.

NOTE: The test leads must be connected to the leads under test by clamp type connections, e.g. nuts and bolts. Crocodile clips or clamps are not satisfactory.

(a) Depending on the modification state of certain types of turbine engines the nominal value of external circuit resistance is related to one particular ambient temperature. For conditions of ambient temperature above or below the value specified, reference must always be made to tables in the relevant engine Maintenance Manual to obtain the correct circuit resistance.

(b) If after testing an external circuit containing a trimming resistor, it is found that the resistance is too high, the trimming resistor wire should be released from its terminal and its length reduced by unwinding the wire from its bobbin. Insulation should be removed from the wire locally and after re-connecting the wire to its terminal the total circuit resistance should be measured. This process should be repeated until the specified nominal resistance value is obtained.

NOTE: The wire should always be unwound in small increments thus working down to the required resistance and also preventing uninsulated wire being wound back on the bobbin.

(c) If a test indicates that the resistance is too low, a new trimming resistor should be fitted.

11.11.2 **Functional Tests.** These tests are mainly concerned with checking readings against a datum temperature value and setting the pointer by means of the adjusting device provided. The procedure to be adopted and type of test equipment required, depends on the temperature measurements with which the indicating system is associated, i.e. cylinder head temperature or exhaust gas temperature. The following points serve only as a guide to the general nature of testing; reference must always be made to the relevant engine and aircraft Maintenance Manuals.

(a) The datum temperature for the setting of a cylinder head temperature indicator is the temperature prevailing at the indicator itself when disconnected from the rest of the circuit, and is obtained by suspending a mercury-in-glass thermometer as close to it as possible. After allowing the temperature to stabilise, the thermometer and indicator readings should be compared. If the indicator is not reading accurately, correction should be made by rotating the adjusting device in the appropriate direction.

(b) Exhaust gas temperature indicators are set to a datum temperature corresponding to a specific cruise temperature and require the use of a pyrometer test set. The test set is connected to the indicator, or in some installations to a special test receptacle, and its controls adjusted to inject an e.m.f. into the circuit until the datum temperature is obtained. The indicator reading is then compared with the test set and if necessary, corrected by the adjusting device.

(c) When tests have been completed satisfactorily, indicating system leads must be re-connected at the appropriate points ensuring correct polarity and security of connections.

NOTE: After making any adjustments to indicated readings, adjustment devices should be rotated a fraction of a turn in a direction opposite to that which gave the required reading. This will relieve any stresses set up in the hairsprings and bi-metal cold-junction compensator.

11.12 **Engine Vibration Indicating Systems.** At the periods specified in the Maintenance Schedule and in addition to visual checks for security of components and signs of damage, a functional test of systems should be carried out (see also paragraph 10.9).

11.13 **Fuel Quantity Indicators — Float Type.** An indicating system should be checked when the associated fuel tank is being filled, by noting that the amount of fuel being added is correctly shown by the indicator when the aircraft is in the prescribed attitude. If the indications appear correct no additional routine maintenance is necessary. At the specified check periods, and whenever a system malfunction occurs, tank units and indicators must be removed for inspection and testing in the manner laid down in relevant Maintenance Manuals.

11.14 **Fuel Quantity Indicators — Capacitance Type.** As in the case of float type indicating systems, gauge readings should be checked during a refuelling operation. Where test switches are provided these should be depressed and released and a check made that indicator pointers move down-scale and then return to original readings. Some aircraft are provided with a special fuel load control panel containing an additional set of quantity indicators, and located at a point accessible from outside the aircraft. A switch is sometimes provided for changing over tank unit signals from the cockpit indicators to those on the panel enabling readings to be taken from the latter. On completion of an operation the tank units are switched back again to the cockpit indicators and a check made that they indicate their respective tank quantities.

11.14.1 At the specified check periods, and whenever a system malfunction occurs, system components must be removed for inspection and testing. The number of checks to be made are greater than those related to other forms of indicating systems, and having regard to the operating principles adopted and improved accuracy obtainable, the test procedures are of necessity more complex. The instructions given in Maintenance Manuals must therefore be strictly observed. The following summary serves as a guide to certain important aspects common to the inspection and maintenance of all capacitance type systems:

(a) Tank units must be inspected for mechanical damage to the tubes and for faults in electrical connections. Dents or flattening of the outer tube may give an incorrect capacitance figure or cause a short circuit; faulty connections can cause intermittent readings or complete open circuit.

(b) Externally mounted tank units should be checked for signs of fuel leakage around the flange.

(c) If it is necessary to renew a co-axial cable connector, care must be taken in removing the defective connector to avoid damage to the cable end and the insulation. A connector must be unsoldered from a cable and not cut off since it is essential to maintain original cable length.

NOTE: The preparation of cables having an outer covering of PTFE and soldering of connectors to these cables, should only be done in a well ventilated atmosphere. As a further protection against dust particles and gases which can be produced when the cables are subjected to high temperatures, smoking should be prohibited.

(d) In addition to continuity and insulation resistance tests, co-axial cables must be tested for capacitance.

(e) The calibration of systems must be checked using the appropriate test sets and may be carried out either with the aircraft tanks full, or at the unusable fuel level (gauge 'zero') condition. Unusable fuel level refers to the quantity remaining when, under the most adverse conditions, the first evidence of engine malfunctioning occurs.

(f) Adjustments at the 'empty' and 'full' positions must be made in the correct sequence and to within the permissible tolerances specified for a system.

(g) Electrical power supplies must be isolated before coupling or decoupling cable and component connectors.

11.15 **Fuel Flowmeters.** Transmitter units should be inspected for signs of fuel leakage at metering chamber housings and at pipeline connecting unions. During engine running, indicators must be checked for correct indication of relevant fuel flow rates and fuel consumption. If a system is operative, but a fault affecting calibration is suspected, calibration checks on individual components should be carried out in the manner prescribed for the relevant flowmeter system. After installation of transmitter units, bleeding of the fuel system must be carried out.

NOTE: Reference should also be made to Leaflets AL/3-15 and AL/3-17; such Leaflets providing information relevant to fuel quantity indicators and fuel flowmeters, and on precautions to be observed when working on aircraft fuel systems.

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AIRCRAFT

INSTRUMENTS

COMPASS BASE SURVEYING

1 INTRODUCTION In carrying out a swinging procedure for direct-reading and remote-reading compasses, the primary object is to determine the deviations caused by the magnetic field components of an aircraft. It is, therefore, necessary for swinging to be undertaken at a location where only these aircraft field components, and the earth's magnetic field, can affect the readings of compasses. The location must be carefully chosen and surveyed to prove that it is free from any interfering local magnetic fields, and also to establish it as the base on which all aspects of swinging procedures are to be carried out. The effect of interfering fields is to cause distortion of the direction and intensity of the earth's field. The effects on direction are the most critical, and, therefore, it is necessary for these to be determined during a survey. Any significant effects on the horizontal intensity will be detected as a change in direction, if suitable procedures are employed. The purpose of this Leaflet is to outline the basic requirements of a compass base, to define the accepted base classifications, and also to outline the procedures which may be adopted for surveying selected locations.

1.1 The CAA does not carry out surveys or approve compass bases, but its interest in surveying procedures lies in the fact that the accuracy of a base is a significant factor in meeting British Civil Airworthiness Requirements relevant to the overall accuracy of compasses installed in aircraft. Surveys may be carried out by an operator or by an airport authority, and in this connection, the standards set by the Admiralty Compass Observatory (ACO) are recognised by the CAA. The ACO is a Ministry of Defence department, and although it has the responsibility for surveying compass bases for military aircraft, its services in an advisory capacity, or for carrying out an entire survey, can be obtained. It should, however, be noted that the latter service is confined to airline operators and airport authorities.

1.2 This Leaflet should be read in conjunction with Leaflets **AL/10-5** and **AL/10-6** which deal with the swinging procedures for Direct-Reading Magnetic Compasses and Remote-Reading Compasses respectively.

2 BASE REQUIREMENTS A compass base must meet the following minimum requirements:—

(a) It must be accessible, reasonably level in all directions, and its use should not interfere with normal aircraft movements on the airport.

(b) It must be free from magnetic fields, other than that of the earth, which might cause aircraft compass errors. Most surface causes of errors are obvious, i.e. buildings and installations containing ferromagnetic components such as wire fences, drain and duct covers, picket points and lighting installations. The most likely underground causes of magnetic interference are:—

(i) Buried scrap metal and old brickwork.

(ii) Reinforced concrete.

(iii) Pipelines including drainage systems.

(iv) Magnetic soil and rocks.

(v) Electrical cables, conduits and airfield lighting transformers.

(vi) Ferromagnetic pipes.

If such items are found at the selected location they should be removed if possible. Even though the area may be within permitted maximum limits of deviation (see paragraph 3) it is recommended that any ferromagnetic material present should still be removed as its magnetic effect may change with time and thereby down-grade the accuracy of the base. Where electrical cables cannot be avoided, their effects, with and without current flowing, must be checked at intervals along their length, especially around known joints. If a new base is being constructed great care must be taken to ensure that the area is not magnetically contaminated after survey and during construction. Steel reinforcing must obviously be avoided and any aggregate or hardcore used in the foundations must not be magnetic or contain magnetic items such as steel wire or drums, bricks, boiler clinker, blast furnace slag or magnetic rock. All steel shuttering and associated pins used when laying concrete must be removed. On completion of all work a full survey must be repeated.

(c) A base should be sited so that its datum circle (see paragraph 2 (f) (iii)) is at least 50 yards away from hangars and other steel-framed buildings, and at least 100 yards away from buildings containing electrical power generation and distribution equipment, and also from overhead or underground power cables.

NOTE: Proposed building programmes should be examined to ensure that the site is not scheduled for other work.

(d) A base must be large enough and of such load-bearing strength as to take all types of aircraft for which it is likely to be used. In this connection, some important factors to be considered are:—

(i) Whether an aircraft will be towed or taxied during the swing.

(ii) The radii of the turning circles of the aircraft.

(iii) The position of sighting rods and target fixtures on the aircraft and their likely path during the swing.

(iv) The likely positions of flux detector units of remote-reading compass systems.

(e) The surface of the base should not preclude its use in wet weather.

(f) The base should be clearly and permanently marked to show:—

(i) The base centre.

(ii) The central area in which a direct-reading compass, or flux detector unit of a remote-reading compass system, should remain during the swing.

(iii) The datum compass circle, i.e. the circle around the central area showing where the datum compass should be placed.

(iv) Areas of magnetic anomalies which cannot be removed.

(v) Nose wheel turning circles.

(vi) If the base is to be used for carrying out "electrical" swings a North-South line should be painted on the base, together with markings to indicate the locations of the compass calibrator monitor and turntable, and the bearing of the reference target used when sighting the monitor (see also paragraph 5.6).

NOTE: Paint is the best medium for marking concrete. The datum compass circle, which may be on grass, must be marked permanently with a narrow continuous path of non-magnetic material such as tarmac or gravel.

3 BASE CLASSIFICATIONS Compass bases may be established as either Class 1 or Class 2, the difference between them being only in the limits of permitted maximum deviation to be found anywhere within the base area as follows:—

(a) **Class 1.** The maximum permissible deviation is $\pm 0{\cdot}1°$. Bases of this accuracy are required for carrying out refined swings, e.g. swinging of aircraft in which remote-reading compasses are used as magnetic heading reference systems, in conjunction with such equipment as Doppler Systems.

(b) **Class 2.** The maximum permissible deviation is $\pm 0{\cdot}25°$. Bases of this accuracy are suitable for carrying out standard swings, e.g. swinging of aircraft in which the primary heading reference is provided by a remote-reading compass system, with a direct-reading compass serving as a standby.

NOTE: A location, the permissible deviation of which is greater than $\pm$ 0·25°, may be used where a direct reading compass is used as the primary heading reference (see paragraph 5.5).

4 TYPES OF SURVEY The following types of survey are normally carried out to assess the suitability of a location at which a compass base is to be finally established:—

(a) **Initial Survey.** This is the first assessment survey of a location to determine gross errors, and should be carried out by the aircraft operator or airport authority. If the deviations obtained appear to be within the permissible limits laid down for Class 1 and Class 2 bases there is justification for carrying out an establishment survey.

(b) **Establishment Survey.** This survey is of a more detailed nature in that measurements are taken at a greater number of more closely spaced points. The survey may also be carried out by the aircraft operator or airport authority, but, where appropriate, it is recommended that the services of the ACO be obtained (see paragraph 1.1).

(c) **Periodic Re-survey.** After a base has been established a detailed re-survey must be carried out at the following intervals:—
   (i) Class 1, every five years.
   (ii) Class 2, every two years. In addition, bases of this accuracy should where possible, be surveyed by the ACO every six years.

(d) **Annual Check.** All bases should be checked annually to ensure that markings and boundaries are clearly defined, and that no work has been done which might affect their magnetic properties, and also to take into account changes in magnetic variation. If any doubt exists, the suspect area should be given a detailed magnetic survey.

(e) **Area Survey.** An area survey (see paragraph 5.6) is normally confined to the selection of a location which is to be used for carrying out a more specialised form of compass calibration procedure known as an "electrical" swing.

5 SURVEY METHODS There are two principal methods which may be adopted for the surveying of a compass base: (a) the reciprocal bearing method (see paragraph 5.3) and (b) the distant bearing method (see paragraph 5.4). In both methods, the use of accurate magnetic bearing compasses of either the medium landing type or the high-precision datum type will be required to determine the effects of interference from local magnetic fields. There is also a third surveying method (see paragraph 5.5), but being of a lower order of accuracy its adoption should be strictly limited. For the area survey referred to in paragraph 4(e) units of a specially designed compass calibrator set are used (see paragraph 5.6 and also Leaflet **AL/10-6**).

5.1 **Checking and Correction of Survey Instruments.** Before carrying out a survey the appropriate survey instrument(s) should be given the full serviceability checks prescribed in the relevant operating manual, paying particular attention to checks which affect the repeatability of readings, e.g. pivot friction. Reference should also be made to any associated instrument test certificates to ascertain any instrument errors requiring correction. When the reciprocal bearing method (see paragraph 5.3) is used, bearings should be taken on a distant object with both compasses to establish a correction which can be applied to every reading taken from one of the compasses.

5.2 **Positioning of Survey Instruments.** In order that the deviation limits of a chosen location may be accurately assessed for base classification purposes from an establishment survey, the survey instrument(s) should be set up at close regular intervals, e.g. every 20 feet, to cover the area quadrant by quadrant. The instrument(s) should be at the maximum height of its tripod which is approximately 5 feet. In most types of aircraft, direct-reading compasses and flux detector units of remote-reading compasses are above this height. If a base is also to be used for an aircraft the compasses and detector units of which are below 5 feet, assessment should then be made closer to the ground.

NOTE: At certain stages of an area survey procedure, assessments are made with the tripod set at both minimum and maximum heights (see paragraph 5.6).

5.3 **Reciprocal Bearing Method.** This method is the most accurate and may be adopted for an initial assessment survey, a detailed establishment survey, and a periodic re-survey. It requires the use of two precision datum compasses, one being designated the master compass, and the other the mobile compass. The procedure is as follows:—

(a) Following the checks for serviceability, both compasses should be aligned to a common magnetic datum. This is done by setting them up, in turn, on a tripod positioned as near to the anticipated centre of the base as is practical, and sighting the compass on a distant object and noting, for each compass, the average of several determinations of the magnetic bearing. This produces the correction referred to in paragraph 5.1 which is subsequently applied to the readings of the mobile compass. Frequent checks on the accuracy of this correction should be made throughout the subsequent stages of the survey procedure.

(b) The master compass and tripod should be kept in its original position, and the mobile compass and its tripod should be positioned at various points around the area to give good coverage (see paragraph 5.2). At each point, the two compasses are aligned on each other's sighting telescope object lenses.

(c) When the compasses are aligned, bearings should be taken from the bearing plates of the compasses, and the magnetic deviation between the two compass positions should be obtained by taking the difference between bearing plate readings and subtracting 180°. The sign convention used for the deviation is that, if the reading of the mobile compass is greater than that of the master compass, the deviation is negative. Conversely, the deviation is positive if the master compass reading is greater than that of the mobile compass.

(d) The deviations should be recorded on an observation log, which should take the form of a scaled diagram of the area. The positions of any objects in the area such as drains, cable duct covers, lights, picketing points, etc., should also be indicated on the log. Areas in which deviations are in excess of the limits permitted by the appropriate base classification, should be investigated and, where possible, the source of magnetic interference should be eliminated. Where magnetic interference cannot be eliminated the area should also be indicated on the observation log as a prohibited area, i.e. an area which must be avoided when positioning an aircraft and datum compass for the purpose of swinging.

(e) Care should be taken to ensure that there are no obvious magnetic objects near the chosen centre of the base. If the deviations are such that their mean is more than half the deviation limits for the class of base being surveyed, it should be assumed that there is a buried object near the base centre.

5.4 **Distant Bearing Method.** This method should be used only for initial surveys, and for gross error checks of Class 2 bases carried out because of doubts raised during annual checks. The procedure to be adopted is as follows:—

(a) Select a distant object at least 2 nautical miles away, and accurately locate its position and the position of the compass base on a large scale map and measure the distance between them. Mark the line of sight from the centre of the compass base to the distant object.

(b) Calculate the angular correction to be applied to bearings taken away from the base centre using the formula:—

$$\text{Correction Angle} = \frac{\text{Lateral distance from line of sight} \times 180}{\text{Distance to the object} \times \pi} \text{ degrees}$$

(c) After ensuring that there are no objects in the area of the base centre likely to have a magnetic influence, the bearing compass, which may be of the medium landing type or precision datum type, should be set up and a datum bearing obtained by measuring the bearing of the distant object.

(d) Take bearings of the distant object from selected points around the base area, and after applying the calculated corrections, compare the bearings with the datum bearing. Any difference obtained will be due to deviations present, assuming that the base centre is free from deviation. The deviations should be recorded on an observation log (see paragraph 5.3(d)).

5.5 **Surveying Pole Method.** This method is simpler than those already described and requires the use of two poles similar to those used by a land surveyor, and, in addition, a medium landing compass. Its survey accuracy is, however, of a lower order, principally because it does not utilize magnetic bearings of distant objects as a datum. The use of this method should, therefore, be restricted to the surveying of locations at which deviation limits outside those permitted under Class 1 or Class 2 (see paragraph 3) are acceptable; for example, a location for swinging aircraft using direct-reading compasses as the primary heading reference. It may also be used in such cases as the initial assessment of gross errors prior to a detailed establishment survey of a base, and where, in the absence of an established Class 1 or Class 2 base or more accurate surveying equipment, a swing is necessary to enable an aircraft to undertake a positioning flight. The procedure for carrying out this method is as follows:—

(a) One surveying pole should be placed in the centre of the area chosen and the medium landing compass should be positioned and levelled 30 feet to the south of the pole. A plumb bob should be suspended from the centre of the compass to the ground, and the sighting device should be set to read due North. The second pole should be positioned 30 feet to the North of the centre pole, so that, when viewed with the compass sights as set, the two poles are in alignment.

(b) The plumb bob position should be marked with a peg or a painted mark, and the position of the second pole and the compass should be interchanged. The compass reading with the poles as now positioned should be checked and should be within $\pm 1°$ of the reciprocal of the initial reading.

(c) A further check should be made by moving and sighting the compass along a line between the North and South points already obtained, taking at least four readings at approximately equidistant intervals. The compass should not deviate by more than 1° from the original reading at any position.

(d) The same procedure outlined in paragraphs (a), (b) and (c) should be followed for determining the East and West positions.

(e) The geometric location of the cardinal points should be proved by checking the chord distances between the points, as indicated by pegs or painted marks. If they are equal then the North-South and East-West lines are at right angles. In any case, the measurements should agree within ± 3 inches.

(f) The whole of the foregoing procedure should be followed for determining deviations in the inter-cardinal areas and in the area around which the compass is to be positioned during the swinging procedure.

5.6 **Area Survey.** This survey is carried out using the monitor and console control units of a compass calibrator set which is also designed for the "electrical" swinging of remote-reading compass systems (see Leaflet **AL/10-6**). In this type of survey the principal objectives are (a) to determine the direction and strength of the earth's magnetic field at the locations of aircraft flux detector units (detector unit location check); (b) to select the point at which the compass calibrator monitor unit should be located in order to carry out an "electrical" swing (monitor location check), and (c) to mark out the monitor and turntable location points, and also a North-South line over which an aircraft must be positioned during a swing. The full setting-up procedures and operating instructions are detailed in the calibrator operating manual and reference to this document should, therefore, always be made. The information given in the following paragraphs is for general guidance only.

5.6.1 **Detector Unit Location Check.** The purpose of this check is to determine the uniformity not only of direction, but also the strength of the earth's field at points of the compass base which will correspond to the locations of detector units, e.g. in the vertical stabilizer, or wing tips of an aircraft. The strength of field is determined in order to obtain certain voltage values which must be set up in the calibrator control console unit, during an "electrical" swing procedure, to simulate the earth's field. The monitor and console control units are electrically interconnected by the appropriate cables, and are set up within 10 to 15 feet of each other. Magnetic direction and strength is measured in both the vertical and horizontal planes.

(a) Measurements in the vertical plane are taken with the monitor mounted on its tripod, adjusted firstly to the minimum height position, and then to the maximum height position. Direction is determined in each position of the tripod by setting the monitor on each of the four cardinal headings, and noting the difference between these headings and the headings recorded on the control console unit. The average of the errors (the algebraic sum divided by four) is recorded as the monitor index error. The difference between the index errors at the minimum and maximum height positions is then calculated. If the difference exceeds the specified value (six minutes is a typical value) the area surveyed is unsuitable. Field strength is determined at the minimum and maximum height positions of the monitor tripod, by setting the monitor to a heading of zero degrees and obtaining voltage values from settings made on the control unit.

(b) Measurements in the horizontal plane are carried out to determine the uniformity of the earth's field direction and strength over a circle of five feet radius, the centre of which is at the location of the flux detector unit on the aircraft. The readings are taken at the centre of the circle with the monitor tripod at its normal operating height, and with the monitor set, in turn, on each of the four cardinal headings. The differences between monitor and control console unit headings are then noted, and a monitor index error obtained in the same manner as that described in (a). Readings are then taken on the cardinal headings with the monitor and tripod positioned, in turn, at four equidistant points on the perimeter of the circle, and corresponding monitor index errors are obtained. The algebraic difference between these errors and the index error at the centre of the circle is then calculated, and should be within the limits $\pm$ 6 minutes. Field strength is determined by setting the monitor to a heading of zero degrees and obtaining voltage values with the monitor at the centre of the circle and at the four equidistant points on its perimeter.

5.6.2 **Monitor Location Check.** The purpose of this check is to select the location for the monitor in order to measure the earth's field during the "electrical" swinging procedure. The location selected should be such that with an aircraft positioned on the base, the monitor readings will not be influenced by magnetic effects of the aircraft itself. A distance of 75 to 100 feet is normally sufficient. The direction and strength of the earth's field is determined at the selected location and corresponding monitor index error and voltage values, calculated. The bearing of a reference target at least one-half mile distant from the location is also obtained. As this target is to be used during a compass swing it should be ensured that it will be visible from the monitor location when an aircraft is positioned on the base. The suitability of the selected monitor location is then determined by re-positioning the monitor at the flux detector unit location and measuring the direction and strength of the earth's field, and then calculating the algebraic difference between values at each location. The readings at each location should be taken within a time of 30 minutes of each other to lessen the possibility of a change in the earth's field.

5.6.3 **Marking of Base.** On completion of the foregoing checks, markings must be permanently set out on the base to indicate the following:—

(a) **Location of Flux Detector Units.** For aircraft the flux detector units of which are installed in the vertical stabilizer, the marking is made on the North-South line (see (c)), and for aircraft the flux detector units of which are installed in each wing tip, the markings are made each side of the North-South line at distances corresponding to those from the aircraft centre line.

(b) **Location of Monitor.** In addition to this marking, the bearing of the reference target used during the survey should also be marked at the monitor location.

(c) **North-South Line.** This line should be marked out from a point which is used as a reference in determining the flux detector unit location. The monitor is set up over this point, and by lowering the monitor telescope so that its graticules are observed against the base, several other points are marked out; firstly, with the monitor on a corrected zero degree heading and then on a heading of 180 degrees. The points are then joined by a painted line.

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AIRCRAFT

INSTRUMENTS

DIRECT-READING MAGNETIC COMPASSES

1 INTRODUCTION This Leaflet gives general guidance on the installation of direct-reading magnetic compasses which are used as either primary or standby heading indicators, and also on the methods of compensating for deviation errors. It should be read in conjunction with Leaflet **AL/10-4** Compass Base Surveying, relevant compass and aircraft Maintenance Manuals, and approved Maintenance Schedules. Reference should also be made to certain relevant information contained in Chapters **D6-8** and **K6-1** of British Civil Airworthiness Requirements and British Standard BS 3G.100 Part 2.

1.1 Deviation is the angular difference between magnetic and compass headings, and is caused by magnetic influences in or near the aircraft. It is called Easterly (positive deviation) or Westerly (negative deviation) dependent on whether the North-seeking end of the magnet system is deflected to the East or the West of the magnetic meridian.

1.2 The technique of deviation compensation is known as "swinging" and consists of (a) observing the compass readings on different headings of the aircraft, (b) calculating the deviation errors and determining coefficients, (c) neutralizing the magnetic fields of the aircraft by adjustment of permanent-magnet compensator devices and (d) recording any residual deviations on a deviation or "steer by" card.

NOTE: This Leaflet describes one of the methods used for swinging, calculating deviations and applying corrections. There are other procedures in use which adopt different calculation sequences.

2 COMPASS ERRORS AND METHODS OF COMPENSATION In connection with the compensation of direct-reading compasses, the following principal errors have to be taken into account:—

(a) **Index Error.** This error, which is also known as Coefficient "A" error, results from malalignment of a compass in its mounting and has the same magnitude on all headings. The error is calculated by averaging the algebraic sum of the deviations on each of the cardinal and quadrantal headings. Compensation is effected by rotating the compass in its mounting through the number of degrees calculated, and relative to the longitudinal axis of the aircraft.

(b) **One-cycle Errors.** These refer to the deviations produced in compass readings as a result of the effects of components of permanent or hard-iron magnetism of the aircraft's structure. The deviations vary as sine or cosine functions of the aircraft's heading, the maximum deviations being termed Coefficients "B" and "C" respectively. Other sources of these errors are components of soft-iron magnetism induced by the earth's field, the hard iron itself, and the effects of electric currents from cables or equipment which may be mounted in the vicinity of the compass. The Coefficient "B" error is calculated by averaging the algebraic difference of the deviations on the East and West headings, while the Coefficient "C" error is calculated by averaging the algebraic difference of deviations on the North and South headings. Compensation is effected by a permanent magnet type compensator unit, which, depending on the type of compass, is either secured direct to the compass bowl or is mounted separately on the compass support bracket. The unit contains two pairs of magnets, the axes of which are so disposed that their fields neutralize the effects of the magnetic components producing "B" and "C" deviations. Each pair of magnets can be rotated by a shaft provided with either a screwdriver slot or a shaped end requiring the use of a key.

3 TYPES OF COMPASS Two types of direct-reading magnetic compass are in use, the card type and the grid-steering type. The major differences between the two are in the magnet system arrangement, the method of heading presentation, and the arrangement of the deviation compensator devices.

3.1 Card type compasses, which are designed for mounting on an instrument panel or on a coaming panel, indicate magnetic headings by means of a graduated card affixed to the magnet system and registering against a lubber line in the front of the bowl. The deviation compensator device is usually secured directly to the compass bowl.

3.2 Grid steering type compasses employ a needle and filament type magnet system which is referenced against a grid-ring located over the compass bowl. The grid-ring, which may be rotated and clamped in any position, has a graduated scale and two pairs of parallel grid wires in the form of an open T. Magnetic headings are indicated by the number of degrees read against a lubber line in the compass bowl, when the needle and filaments lie parallel to the grid wires, and the North-seeking filament points to the North mark on the grid ring. These compasses may be designed for mounting on a bracket below an instrument panel or for inverted mounting in a cockpit roof. In the latter case, heading indications are observed by means of a mirror attachment. Deviation compensator devices are normally separate and are mounted on the compass supporting bracket.

4 LOCATION The location of a compass in an aircraft is important and factors such as angle of observation, illumination, vibration, and in particular, the effect of magnetic disturbances, require careful consideration. The location is determined during the aircraft's design stage and should not be altered unless authorised by the Airworthiness Authority.

4.1 Compensation may be made for a reasonable amount of permanent magnetism, but variable sources of deviation must be kept distant in order to minimize their effects.

4.1.1 Where practicable, magnetic steel parts, especially movable parts, should not be positioned near the compass.

4.1.2 Electrical cables carrying uni-directional current produce a magnetic effect on the compass magnet system which is governed by the current and distance from the compass. All such cables should be positioned, if possible, at least 2 feet away from the compass. If double pole cables are used (i.e. supply and return cables run closely together) the magnetic effects of the cables are usually insignificant.

4.1.3 To minimize the effect on the compass of items of equipment with magnetic fields, such items should not be located closer to the compass than the relevant compass safe distance specified for each item by the manufacturer.

NOTE: Compass safe distance is defined as the minimum distance from a compass at which an item of equipment may be located to produce a maximum deviation of 1° under all operating conditions. This distance is measured from the pivot of the compass magnet system to the nearest point on the surface of the equipment.

4.1.4 The possibility of magnetic fields generated by electric currents passing through windscreen pillars and frames, or through instrument mountings, should not be overlooked.

4.1.5 The effect of modifications to instrument installations, radio installations, electrical control panels or wiring in the vicinity of the compass must be considered, and tests should be made to determine whether any deviation will be caused under operating conditions.

NOTE: The most adverse combinations of electrical loads must not cause deviation in excess of 2° (5° for light aircraft).

4.1.6 In some instances, particularly in light aircraft, certain components and parts of the structure, e.g. control columns, control arches, tubular frames, may exhibit residual magnetism in varying amounts which cannot be corrected by compass deviation compensating devices. The origin and cause of such magnetism must be investigated and the appropriate remedial action must be taken. A simple practical detection method is to position a small pocket compass near suspect components or parts and to note any deflections of the needle.

5 INSPECTION AND TESTS BEFORE INSTALLATION Compasses are particularly susceptible to damage in transit and to deterioration during storage. They should be stored in the transit boxes supplied by the manufacturer, and should be handled carefully to avoid shocks which might impair the pivot action or cause other damage. Compasses should not be stored on steel racks or shelves, or in steel cupboards. Each compass should be inspected for serviceability before installation as follows:—

(a) The compass glass, anti-vibration devices and all movable or working parts, where appropriate, should be inspected for condition.

(b) In grid steering compasses, the grid-ring locking device should function correctly and the grid-ring should rotate freely when unlocked. The grid wires should be undamaged and the graduations should be legible.

(c) The compass bowl must be free from dents, and the card and liquid must not be discoloured.

(d) The liquid must be free from sediment and bubbles. There should be no sign of leakage from the bowl as indicated, for example, by staining of the bowl exterior.

(e) In compasses in which the deviation compensator devices are built in, the magnet adjusting screws or spindles should be slowly rotated through their full range of movement to check for roughness, "hard spots" and backlash in the gearing. There should be sufficient inherent friction to prevent disturbance of compensator settings by shock or vibration. On completion of these checks, the compensators should be returned to their magnetic neutral positions as indicated by the alignment of indicator lines or dots engraved on the spindles with their fixed datum marks.

(f) Compasses with integral lighting should be tested to ensure that no deflection of the magnet system is caused when the lighting is switched on.

5.1 **Pivot Friction*.** This should be checked with the compass in a level position. The magnet system should be deflected through approximately 10° and held for 30 seconds by placing magnetic material near the compass. The magnetic material should then be removed and the settling position of the magnet system noted. The system should then be deflected approximately 10° in the opposite direction, held there for 30 seconds, then released and the settling point noted. The angular difference between the two settling positions should not exceed the limits specified in the relevant manuals. During this test no tapping of the compass bowl is permissible.

5.2 **Damping Test*.** The magnet system should be deflected with an external magnet through 90° and held for 1 minute. The deflecting force should be removed. The time taken for the magnet system to return through 85° should not exceed the limits specified in the relevant manuals.

5.3 **Defect Rectification.** The rectification of defects, such as might be revealed by the inspections and tests referred to in this paragraph 5 may only be undertaken by an organisation approved by the CAA for such work.

6 INSTALLATION The compass should be so mounted that a line passing through the lubber line and the vertical pivot support is either on, or parallel to, the longitudinal axis of the aircraft. The lubber line in grid steering type compasses should always point forward. With card type compasses the lubber line faces aft. Compasses provided with adjustment slots and scale for index error (coefficient "A") correction, should be positioned so that the centre zero mark on the scale is aligned with the datum mark on the compass mounting.

6.1 When not integral, the compass deviation compensator device should be mounted as close as possible to the compass, and should be centrally disposed about the magnet system pivot support with the AFT engraving positioned aft.

6.2 Brackets, or other forms of compass supporting structure, should be made of non-magnetic materials; this also applies to all nuts, screws, washers and the tools used for mounting.

NOTE: In aircraft employing a direct-reading compass as a standby heading indicator, the instrument is usually installed adjacent to the central support frame of the windscreen panels. In such cases the retaining nuts and bolts used in this frame should also be of non-magnetic material.

6.3 The compass deviation or "steer by" card should be positioned so that it may be easily read during flight.

6.4 If the compass has an integral lighting system the wiring should be properly connected to the appropriate terminals. The lighting circuit should then be switched on and a check made to ensure that this does not cause a deflection of the magnetic system.

7 COMPASS SWINGING AREA Since the compass swinging procedure determines deviations caused by magnetic fields of an aircraft, it is necessary for the swinging to be undertaken at a location where only these fields and the earth's magnetic field can affect the compass readings. The location must, therefore, be carefully chosen and surveyed to prove that it is free from any interfering local magnetic fields (see Leaflet **AL/10-4** Compass Base Surveying).

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*These paragraphs deal only with pre-installational checks on compasses which have passed their schedule of tests. The tolerances given are general and vary in accordance with the type of compass, the compass specification, the latitude at which the test is made, temperature variation and the strength of the earth's magnetic field.

8 PREPARATION BEFORE SWINGING A check should be made to see that all airborne equipment is installed in the aircraft. Loose items or tools made from magnetic materials should not be left in the aircraft or carried by the personnel engaged in the swinging procedure. Any detachable cockpit mechanical control locks which might be magnetic should be removed and placed in their flight stowages. Where towing arms and towing vehicles are to be used for manoeuvring the aircraft, their possible magnetic effect should be investigated, and if significant they should be disconnected and moved clear before taking any compass readings.

8.1 Ensure that all equipment required for the swing is available, e.g. appropriate datum compass, sighting equipment and non-magnetic tools needed for deviation compensations.

8.2 Where appropriate, landing gear ground locks should be in position and landing gear shock struts should be checked to ensure that they are properly inflated. In some types of aircraft, a landing gear lever latch is employed which is solenoid-operated. The solenoid is normally energized in flight, and since its magnetic field may have an effect on the accuracy of the standby direct-reading compass, it should also be energized during the swinging procedure.

8.3 The flying controls should be in the normal straight and level flight positions when taking the readings, and should then be operated to ascertain that the movements have no adverse effect on the compass readings. Flaps, throttles, etc., should also be set to their "in flight" positions.

8.4 Electrical equipment, e.g. radio, instruments and pitot tube heaters, should be switched on to ascertain that there are no adverse effects on the compass. In this connection, reference should always be made to the relevant aircraft manuals for details of the electrical loads to be selected appropriate to the aircraft operating conditions, e.g. normal day or night operation, or operation with emergency power.

8.5 Deviation compensator devices should be set to their magnetic neutral positions after installation, or after replacement of a compass or deviation compensator device where this is a separate unit.

9 COMPASS SWINGING PROCEDURE Where compasses are to be compensated on a base with marked headings, the longitudinal axis of the aircraft must be aligned either on, or parallel to, the markings, usually with the aid of plumb lines dropped from points fore and aft along the axis. A datum compass such as the medium landing compass may also be used, whether or not a concrete or tarmac base is available. The datum compass should be aligned with the aircraft's longitudinal axis and positioned on the datum circle, or if this is not marked, at a specified distance from the aircraft (typical distances are 50 to 150 feet). In order that the longitudinal axis of the aircraft may be accurately determined, datum points on the aircraft and directions from which they are to be sighted, must be carefully selected (see also Leaflet **AL/10-6**). Some aircraft have provision for the fitment of sighting rods to aid determination of the longitudinal axis. The most straightforward direction for sighting is from the rear; the heading then corresponds to the datum compass reading. If the view from this aspect is unsatisfactory the view from ahead of the aircraft should be considered, bearing in mind that reciprocal headings will be indicated. It is not advisable to take sights from positions at angles to the longitudinal axis.

NOTE: When using a datum compass to position an aircraft, it is not necessary for the aircraft to be set exactly on the cardinal and quadrantal points; settings within 5° are acceptable.

9.1 Compasses installed in aircraft with fuselage-mounted engines should be compensated with engines running. If this is not practical then they should at least be re-checked on four equally spaced headings with the engines running, on completion of the swinging procedure.

9.2 **Compensating and Recording.** When taking compass readings a brief pause should be allowed after placing the aircraft on each heading and the compass should then be tapped gently while the magnet system is allowed to settle. A check should always be made on each heading to ensure that interference from each individual item of electrical equipment and its associated wiring, or the interference from the most adverse combination of the possible electrical load, has not been increased. For card type compasses, the readings are taken against the vertical lubber line. If the compass is of the grid steering type, the grid wires should be aligned parallel to the magnet system, North on North, and the reading against the lubber line should be observed. In both cases, observations should be such that parallax errors are avoided.

NOTE: When more than one direct-reading compass is fitted in an aircraft, or when a direct-reading compass serves as a standby to a remote-reading compass, all readings and subsequent adjustments should be made simultaneously on each heading.

9.2.1 All observed readings and associated deviation calculations obtained during swinging should be recorded on properly prepared record forms. The layout of forms varies for different compensation methods but, in general, their composition follows that associated with the method described in this Leaflet and as set out in Table 1.

9.2.2 The aircraft should first be headed N and the compass reading should be noted in column 2 of the Table, e.g. 006°. The deviation is the difference between the compass reading (column 2) and the magnetic heading indicated by the datum compass or compass base (column 1); the sign is plus or minus according to whether it is necessary to add the deviation to, or subtract it from, the compass reading in order to obtain the magnetic heading. In this example it is —6° and this should be recorded in column 3.

TABLE 1

Points	(1) Datum Compass or Base* Reading	(2) Aircraft Compass Cardinal Readings	(3) Deviation	(4) Deviations Corrected for C or B, as applicable	(5) Aircraft Compass Quadrantal Readings	(6) Deviation	(7) All Deviations Corrected for A	(8) Finally Corrected Readings for Card
N	000	006	−6	−4	—	—	−2	002
E	090	088	+2	+1	—	—	+3	087
S	180	182	−2	−4	—	—	−2	182
W	270	270	0	+1	—	—	+3	267
NW	315	—	—	—	317	−2	0	315
NE	045	—	—	—	048	−3	−1	046
SE	135	—	—	—	138	−3	−1	136
SW	225	—	—	—	227	−2	0	225

*A compass base was used in this example.

$$C = \frac{\text{Deviation on N-Deviation on S}}{2} = \frac{(-6)-(-2)}{2} = \frac{-6+2}{2} = \frac{-4}{2} = -2°$$

$$B = \frac{\text{Deviation on E-Deviation on W}}{2} = \frac{(+2)-(-0)}{2} = \frac{+2}{2} = +1°$$

$$A = \frac{\text{The sum of the Deviations on N E S W NW NE SE SW}}{8} = \frac{-4+1\ -4+1\ -2\ -3\ -3\ -2}{8} = \frac{-18+2}{8} = \frac{-16}{8} = -2°$$

9.2.3 The compass reading on E should next be checked, and the deviation obtained and recorded, e.g. 088° and +2°.

9.2.4 The aircraft should now be headed S and the compass reading and deviation also recorded, e.g. 182° and −2°. Coefficient "C" should be calculated algebraically from the formula shown in the Table; thus, from the example readings, "C" is −2°. This should be applied, with its sign unchanged, to the deviation noted on S and the result recorded in column 4, i.e. −4°. The sign of the coefficient should then be changed and applied to the deviation on N, the result being −4°, which should also be recorded in column 4. The appropriate adjusting spindle of the compensator device should be rotated until the compass indicates the corrected reading, i.e. 184°. The compass should be tapped gently whilst making the adjustment.

9.2.5 The compass reading on W should be checked next, and the deviation recorded, e.g. 270° and 0°. Coefficient "B" should be calculated algebraically from the formula shown in the table; thus, from the example readings, "B" is +1°. This should be applied, with its sign unchanged, to the deviation noted on W and the result recorded in column 4, i.e. +1°. The sign of the coefficient should then be changed and applied to the deviation on E, the result being +1°, which should also be recorded in column 4. The appropriate adjusting spindle of the deviation compensator device should be rotated until the compass indicates the corrected reading, in this case 269°. The compass should be tapped gently whilst making this adjustment. This completes the compensation of deviation on the cardinal headings.

9.2.6 The aircraft should again be headed on each cardinal heading and any residual deviations noted. A check should then be made on the compass reading, and deviation, at each quadrantal heading and these should be recorded in column 5 and column 6 respectively.

9.2.7 Coefficient "A" should be calculated from the formula shown in the table (after correction for coefficients "C" and "B"). It will be noted from the example readings that coefficient "A" is −2°. Corrections should be made by adding this coefficient (sign unchanged) to the compass reading on any aircraft heading, and by adjusting the mounting position of the compass (e.g. rotating it about bolts in slotted mounting lugs) through the appropriate number of degrees until the lubber line is aligned with the corrected heading.

9.2.8 After correction for coefficient "A", residual deviations should be calculated in order to obtain corrected readings for entry on the deviation card (column 8). The deviations, which should not exceed 3° (5° for light aircraft) on any heading, are calculated by subtracting coefficient "A" from the deviations noted in columns 4 and 6, recording the values as in column 7, and then finally subtracting these values from the datum compass or base readings (column 1).

9.3 **Deviation Card.** A deviation or "steer by" card (see Figure 1) should be compiled to show deviations related to standard headings at intervals of 45° (30° for light aircraft) and should be secured in a position adjacent to the respective compass. The card readings are those which the compass must indicate in order that the aircraft may be flown on correct magnetic headings, e.g. in order to fly on a magnetic heading 000 (North) the compass must indicate 002°. In cases where radio equipment is installed in instrument panels, it should also be stated whether the compass was swung with the equipment switched on or off. Details should be given on the back of the card to indicate aircraft type and registration, compass type and serial number, place and date of swing, signature and authority of the compiler. A record of the swing should be entered and certified in the aircraft log book.

For Magnetic Heading		Steer by Compass
N	000°	002°
NE	045°	046°
E	090°	087°
SE	135°	136°
S	180°	182°
SW	225°	225°
W	270°	267°
NW	315°	315°

Figure 1 TYPICAL DEVIATION CARD

10 COMPASS SWINGING IN SERVICE Swinging and compensation as detailed in paragraph 9 must be carried out whenever a direct-reading compass or separate deviation compensator device, if appropriate, is installed. On other occasions a check-swing is sufficient. A check-swing consists of placing the aircraft on four headings 90° apart, and comparing the deviations with those on the existing deviation card. If there is any difference between these deviations it will be necessary to carry out a complete swing. Compasses should be check-swung on the following occasions:—

(a) After a check inspection if required by the approved Maintenance Schedule.

(b) Whenever inaccuracies in heading indications are reported.

(c) After any modification, repair or major replacement involving magnetic material, particularly in aircraft the engines of which are mounted in the fuselage or wing nacelles.

(d) Whenever a compass has been subjected to shock, e.g. after a heavy landing.

(e) After the aircraft has passed through a severe electrical storm, or has been struck by lightning.

(f) Whenever the aircraft has been subjected to a magnetic crack detection examination.

(g) Whenever the sphere of operation of the aircraft is changed to one of different magnetic latitude.

(h) Whenever a significant change is made to the electrical or radio installation, particularly to circuits in the vicinity of the compass.

(j) Whenever a freight load is likely to cause magnetic influence and thereby affect compass readings.

(k) After the aircraft has been in long term storage.

11 ROUTINE INSPECTION The security of the mounting of each compass and deviation compensator device should be checked, and any adjustment or tightening should only be done by an organization approved by the CAA for such work or by an engineer licensed in the appropriate category. The compass should be inspected for bubbles in the liquid, discoloration, sediment, clarity of scale, liquid leakage, cracked glass and the effectiveness of the anti-vibration mounting where fitted. In compasses of the grid steering type, the functioning of the grid ring locking device should also be checked, and when in the unlocked position it should permit complete rotational freedom of the grid ring. The deviation card must be legible and secure in its holder.

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AIRCRAFT

INSTRUMENTS

REMOTE-READING COMPASSES

1 INTRODUCTION This Leaflet gives general guidance on the methods of compensating for deviation errors which can occur in remote-reading compasses. Brief details of the operating principle of compasses are also included, but as there are so many variations in application to systems in current use, such details are only of a fundamental nature. The Leaflet should be read in conjunction with Leaflet **AL/10-4**—Compass Base Surveying, relevant compass and aircraft Maintenance Manuals, and approved Maintenance Schedules. Certain relevant information is contained in Chapters **D6-8** and **K6-1** of British Civil Airworthiness Requirements and British Standard BS 3G.100 Part 2; reference should, therefore, be made to these publications.

1.1 Deviation is the angular difference between magnetic and compass headings and is caused by magnetic influences in or near the aircraft. It is called Easterly (positive deviation) or Westerly (negative deviation) dependent on whether the signals induced in the compass flux detector unit on any one heading are influenced to produce a change in heading indication to the East, or to the West of the magnetic meridian.

1.2 The technique of deviation compensation is known as "swinging" and consists of, (a) observing the relevant compass system indicator readings on different headings of the aircraft, (b) calculating the deviation errors and determining coefficients, (c) neutralizing the aircraft's magnetic fields by adjustment of compensator devices and (d) recording any residual deviations.

2 PRINCIPLE OF REMOTE-READING COMPASS SYSTEMS The principal component of any system is a flux detector unit, sometimes called a flux valve or fluxgate. It is located in an area relatively free from any disturbing magnetic fields of the aircraft itself (e.g. a wing tip or vertical stabilizer) so that the horizontal component of the earth's magnetic field can be more accurately detected by the sensing element within the unit. The sensing element forms part of a synchro type of transmission system which, in most compasses, is coupled to a horizontal-axis directional gyro contained within either a heading display indicator mounted on the main instrument panel, or a master gyro unit from which heading data is transmitted to a separate indicator. In some aircraft using an inertial navigation system, the flux detector sensing element is connected to a compass coupler unit instead of a directional gyro, the purpose of the unit being to develop a stabilized magnetic heading reference from both sensing element and inertial navigation system signals. The sensing element is pendulously suspended in such a way that it has a limited amount of freedom in the pitching and rolling planes, but has no freedom in the yawing plane. In one currently used system the element is stabilized by a vertical gyro.

2.1 The sensing element is made up of material having high magnetic permeability wound with an exciter or primary coil and three pick-off or secondary coils. The exciter coil is supplied with a low-voltage single-phase a.c. at a constant frequency (typical values are 26 V, 400 Hz) and this produces an alternating flux in the sensing element material. In addition to this flux, the horizontal component of the earth's magnetic field is also introduced; its effect being to change the total flux cutting the pick-off coils in such a manner that an e.m.f. is induced in them which, in terms of amplitude and phase, represents the magnetic heading.

2.1.1 The induced e.m.f. causes current to flow to the stator windings of a receiver synchro within either the display indicator, master gyro unit or compass coupler, as appropriate, and a field is set up across the stator in a direction determined by the current flow in the windings. If the detector sensing element and receiver synchro are in synchronism, the synchro rotor is in its 'null' position and no signal voltage is induced in its winding by the stator field cutting it. When a change in aircraft heading takes place, however, the position of the detector sensing element with respect to the earth's field also changes with the result that the current flow in the receiver synchro stator changes, causing the stator field to rotate. This, in effect, is the same as a rotor displacement from the 'null' position, and although the rotor itself always tends to rotate with the stator field it is restrained momentarily by the mechanical coupling between it and the gyro. Thus, an error voltage is induced in the rotor winding; the phase and amplitude of which being dependent on the direction and magnitude of displacement of the rotor from the 'null' position. The voltage is fed to an amplifier and finally to a slaving system which produces a torque to precess the gyro and its indicating element to indicate the heading change. At the same time, the synchro rotor rotates in synchronism with the stator field.

3 COMPASS ERRORS AND METHODS OF COMPENSATION In connection with the swinging and compensation of remote-reading compasses, the following principal errors have to be taken into account:—

(a) **Index Error.** This error, which is also known as Coefficient "A" error, results from malalignment of the flux detector unit and has the same magnitude on all headings. The error is calculated by averaging the algebraic sum of the deviations on each of the cardinal and quadrantal headings.

(b) **One-cycle Errors.** These refer to the deviations produced in compass readings as a result of the effects of components of permanent or hard-iron magnetism of the aircraft's structure. The deviations vary as sine or cosine functions of the aircraft's heading, the maximum deviations being termed Coefficients "B" and "C" respectively. Other sources of these errors are, components of soft-iron magnetism induced by the earth's field, the hard iron itself, and electric currents from cables or equipment which may be mounted in the vicinity of the flux detector unit. The error due to Coefficient "B" is calculated by averaging the algebraic difference of the deviations on the East and West headings, while the Coefficient "C" error is calculated by averaging the algebraic difference of deviations on the North and South headings.

(c) **Two-cycle Errors.** These errors result from imperfections in the transmission of heading data and are usually referred to as transmission errors. They can be caused by impedance or voltage unbalance in the flux detector sensing element or in the synchros of the compass system. Another source of two-cycle error is soft-iron magnetism.

(d) **Crosstalk Errors.** These errors occur particularly during an "electrical" swinging procedure (see paragraph 4.5) when the d.c. signals simulating the earth's field are applied. They are caused by different sensitivities of the flux detector unit coils and by unequal air gaps separating the flux collector horns; the overall effect being to produce quadrature components which offset the field from that originally intended.

3.1 **Methods of Compensation.** Typical methods of compensating errors are described in the following paragraphs.

3.1.1 **Index Error Compensation.** The error to be compensated is calculated from the Coefficient "A" formula (see 3(a)). In the most commonly used method, compensation is effected by rotating the flux detector unit in its mounting through the number of degrees so calculated, relative to a datum parallel to the longitudinal axis of the aircraft. The flux detector unit is rotated clockwise (when viewed from above) for a +A error and anti-clockwise for a −A error. In some compass systems the flux detector is first aligned with the centreline of the aircraft, and the "A" error is removed by providing an electrical differential by means of a differential synchro between the flux detector unit and its synchro.

3.1.2 **One-cycle Error Compensation.** The errors to be compensated are calculated from the Coefficient "B" and Coefficient "C" formulae (see 3(b)). Depending on the type of compass system installed, compensation may be effected by one of the methods described in (a) and (b).

(a) **Mechanical Methods.** In several types of compass systems, a permanent magnet type compensator unit is secured to the top of the flux detector unit. The compensator contains two pairs of magnets, the axes of which are so disposed that their fields neutralize the effects of the magnetic components producing "B" and "C" deviations. Each pair of magnets can be rotated by a shaft containing a screwdriver slot, and associated gearing. In one particular type of compass system, mechanical compensation is effected by screws, a metal cam and cam follower; the complete device being incorporated within the compass indicator. For details of this method of compensation reference should be made to the relevant Maintenance Manuals.

(b) **Electrical Methods.** Electrical compensation is normally effected by a compensator unit connected to, and located remote from, the flux detector unit. A compensator unit contains two adjustable potentiometers, one for each coefficient. Depending on the compass system installed, the potentiometers can be adjusted to vary either the electromagnetic fields produced in two coils mounted on top of the detector unit, or they can be adjusted to produce the correcting electromagnetic field within the flux detector pick-off coils, by supplying direct current to the coils themselves. In this latter case, the coils have the dual and simultaneous function of picking-off voltages resulting from heading changes and of deviation compensation. In certain types of compensator unit, test points are provided to permit measurement of the d.c. voltages across the two potentiometers.

3.1.3 **Crosstalk Error Compensation.** Compensation is effected during an "electrical" swing procedure, by applying d.c. signals to the flux detector unit coils and generating fields which oppose the quadrature components in the North-South and East-West directions.

4 COMPASS SWINGING PROCEDURES The procedure to be adopted depends primarily on the type of compass and the method by which magnetic heading reference datum is obtained, i.e. from a base having headings marked out on it, from a datum compass, or from a base established for carrying out "electrical" swinging as outlined in paragraph 4.5. Details of the procedure appropriate to a specific system and aircraft type are given in the Maintenance Manuals, and reference must, therefore, always be made to such documents. The information given in the following paragraphs is intended to serve only as a general guide to procedures and to certain associated important aspects.

4.1 **Compass Swinging Area.** Since the swinging procedure determines deviations caused by the magnetic fields of an aircraft, it is necessary for it to be undertaken at a location where only these fields and the earth's magnetic field can affect the compass readings. The location must, therefore, be carefully chosen and surveyed to prove that it is free from any interfering local magnetic fields (see Leaflet **AL/10-4**—Compass Base Surveying).

4.2 **Aircraft Sighting Points.** In all swinging procedures it is necessary to determine the position of the longitudinal axis of the aircraft with respect to a magnetic heading reference datum, and for this reason, two datum points on the aircraft (e.g. the aircraft nose and tip of the vertical stabilizer) and directions from which they are to be sighted, must be carefully selected. If the datum points are at different heights above the ground, and if the aircraft is rolled out of a level plane as a result of the compass base not being level, then an error can occur in the measured datum heading. Roll angles are normally small and the error approximates to:—

$$\text{Heading Error} \ldots \frac{\text{degree}}{\text{degree of roll}} \ldots \text{is} \ \frac{\text{Vertical distance between two points}}{\text{Horizontal distance between two points}}$$

In several types of large transport aircraft, sighting is facilitated by the provision of sighting devices which are attached to the aircraft prior to carrying out the appropriate swinging procedure. Some examples are described in the following paragraphs.

4.2.1 **Sighting Rods.** In this example, front and rear sighting rods are attached to corresponding points provided along the centre line at the underside of the fuselage. An extension rod is also provided for attachment to either the rear sighting rod, if datum compass sightings are to be taken from the front of the aircraft, or the front sighting rod, if sightings are to be taken from the rear.

4.2.2 **Telescopic Target Fixture**

(a) A typical fixture is shown in Figure 1. It is attached to the bulkhead of a main landing gear wheel well so that the scale and crosshair are on the inside of the turning circle of the aircraft. The setting of the fixture with respect to the longitudinal axis of the aircraft, is determined by sighting the telescope on a target mark located at the underside of the front fuselage, in this case at the forward jack pad position. The scale is of the centre-zero type, angles to the right being positive and angles to the left being negative, when sighted from the datum compass. Magnetic heading of the aircraft is determined during the swinging procedure by sighting the datum compass on the crosshair and scale of the target fixture, and calculating the difference between the scale reading and the datum compass reading, the latter being the bearing of a pre-selected reference target located at some distance from the base.

(b) Another example of a target fixture is shown in Figure 2. In this case the fixture is attached to the underside of the front fuselage, and its telescope is sighted on a target ball mounted on a cable, the ends of which are secured to the up-lock rollers of each main landing gear strut. When the cable is in position, the ball is situated to the left of the aircraft centreline. Magnetic heading of the aircraft is determined in a similar manner to that described in (a).

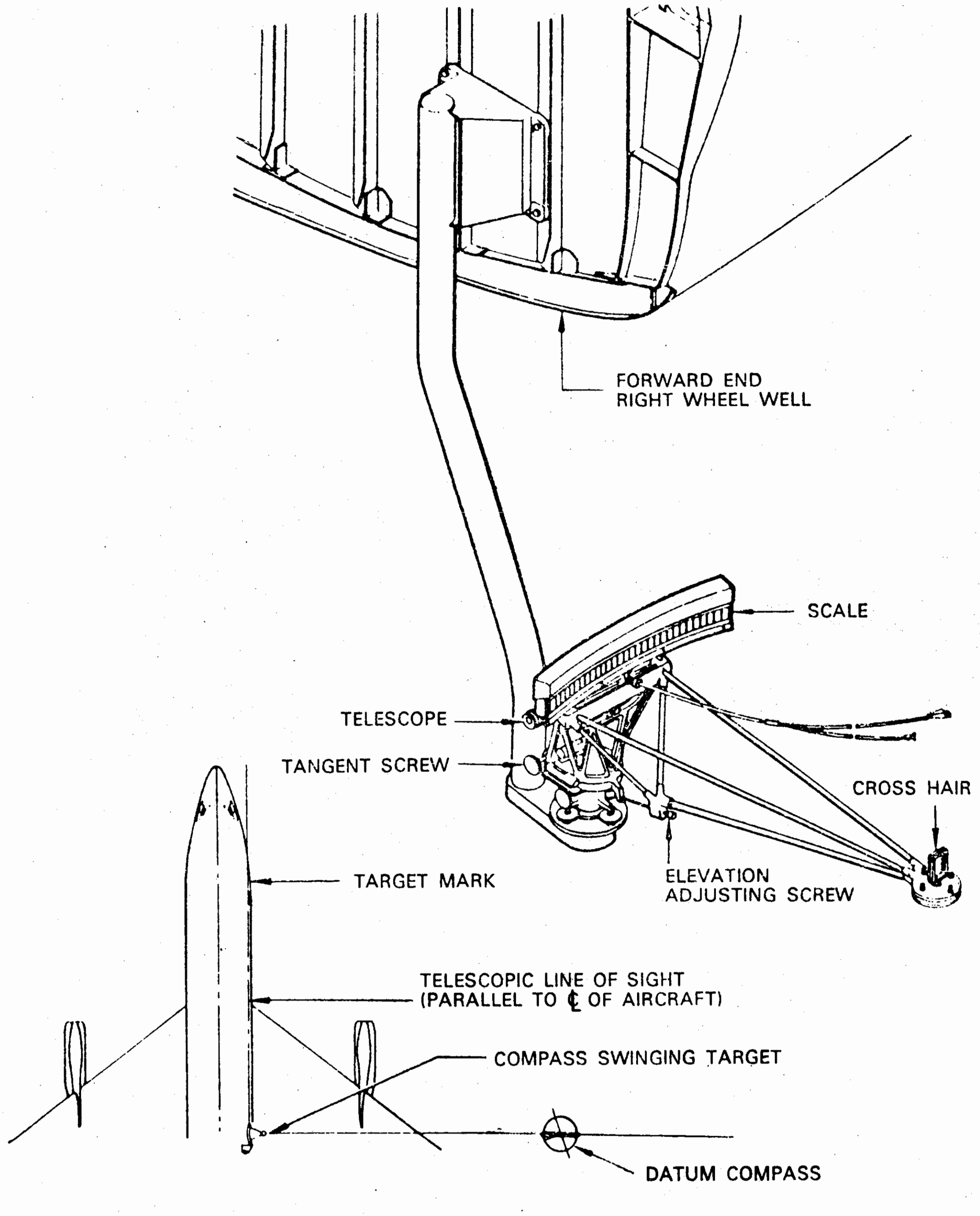

Figure 1 TELESCOPIC TARGET FIXTURE

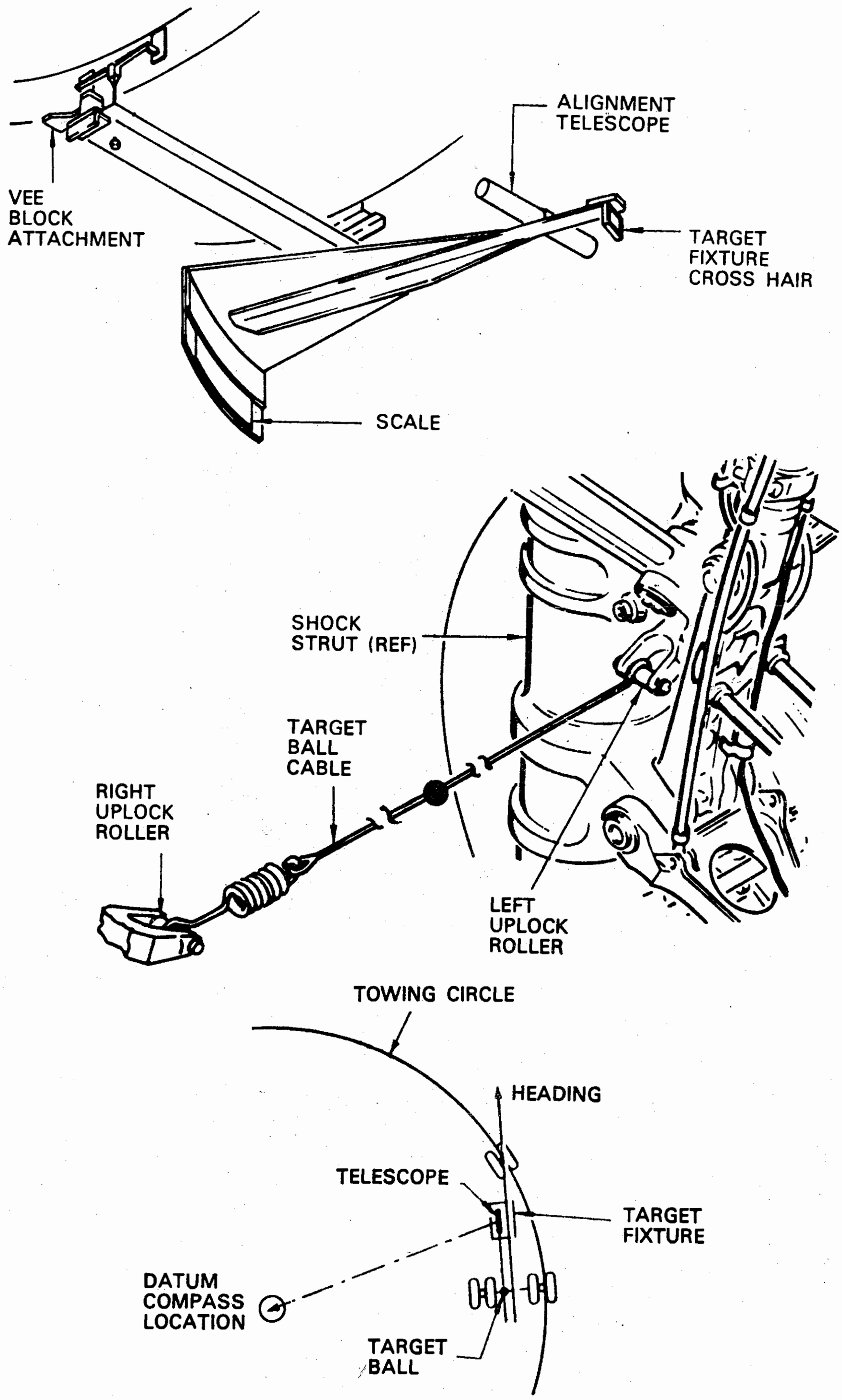

Figure 2 TARGET FIXTURE AND BALL

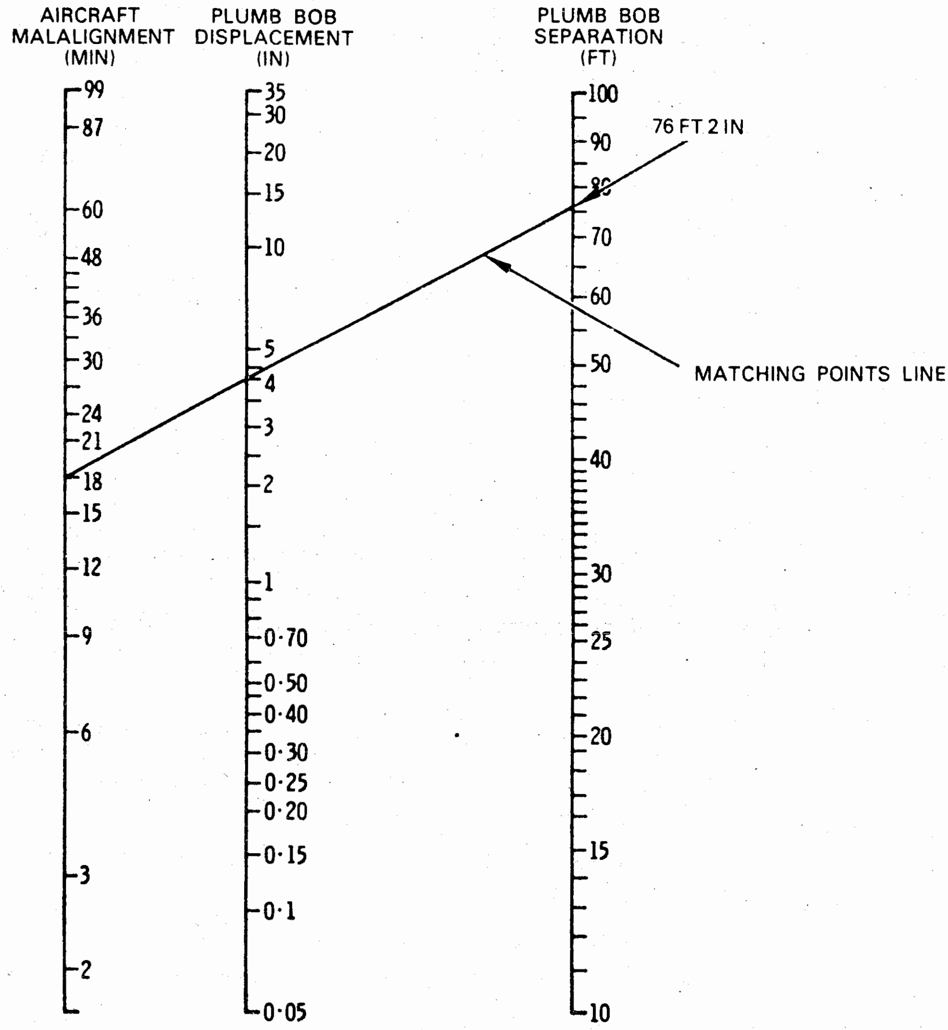

Figure 3 AIRCRAFT MALALIGNMENT NOMOGRAPH

4.2.3 **Plumb Line Sighting.** In this method, the longitudinal axis of an aircraft is indicated by the alignment of two plumb bobs suspended individually from fore and aft points at the underside of the fuselage. The use of the plumb bobs as a means of sighting depends on the compass swinging procedure adopted. If a swing is carried out on a base on which cardinal and quadrantal heading lines are marked out, the aircraft heading is determined by the position of the plumb bobs with respect to the marked lines.

(a) In the case of an "electrical" swinging procedure, the plumb bobs are used only for ensuring that the aircraft is aligned with the North-South line marked out on the base. Malalignment should not exceed a specified amount, usually 1 degree, and this is calculated from a nomograph comprising three scales corresponding to the separation between plumb bobs, to plumb bob displacement from the North-South line, and to aircraft malalignment. An example based on an aircraft in which the plumb bob suspension points are 76 ft. 2 in. apart is shown in Figure 3.

(i) When the aircraft is positioned over the North-South line, with its nose pointing North, the points where the plumb bobs come to rest are marked on the ground and the lateral displacement of each from the edge of the line is measured. If the displacement is West of the line it is negative, and if it is East it is positive. The algebraic difference between the two values is then obtained as a reference point on the plumb bob displacement scale, and aircraft malalignment is read off the appropriate scale at the point intersected by a line projected through the known points on the plumb bob separation and projection scales. Thus, in the example shown, the known points are 76 ft. 2 in. and 4 in., and a projected line intersects the malalignment scale at a value of 18 minutes. In the event that malalignment is greater than the maximum specified for the aircraft, the aircraft should be repositioned.

4.3 **Preparations Before Swinging.** The following aspects of preparation are generally applicable to all compass systems:—

(a) Carry out a serviceability test of the system in accordance with the procedure prescribed in the relevant Maintenance Manual.

NOTE: Throughout the serviceability test and other preliminary checks, and also subsequent swinging procedures, it is most important that power supplies to systems be continually monitored to ensure that voltage and frequency values remain constant within their prescribed limits.

(b) Ensure that all equipment required for the swing is available, e.g. appropriate datum compass, sighting equipment, test voltmeters and milliammeters, non-magnetic tools for adjustment of deviation compensators, and external power supply equipment.

(c) Check that all normal equipment is installed in the aircraft. In this connection, reference should also be made to the relevant aircraft manuals for details of electrical equipment which could influence compass system readings and, for this reason, must be in operation during a swinging procedure.

(d) Ensure that landing gear ground locks are in position and that relevant towing equipment is readily available.

(e) Check that main landing gear shock struts are properly inflated.

(f) Check that brake system pressure is normal for the appropriate type of aircraft.

(g) Ensure that personnel responsible for carrying out the swinging procedure remove from their person all metallic objects which are likely to cause deviation.

(h) Obtain appropriate clearance to tow the aircraft to the compass base.

4.4 **Conventional Swinging Procedure.** The term "conventional" is used here to signify a procedure in which the magnetic heading reference datum is obtained, either from a compass base with heading alignment marks painted on it, or from a datum compass. In the former case, and with the aid of plumb line sighting, an aircraft can be aligned precisely on the cardinal and quadrantal headings. When using a datum compass, such precise alignment is not essential since the compass is always positioned to sight on the aircraft. It is usual, therefore, for positioning of both aircraft and datum compass to be within certain permissible limits. Limits commonly specified are within the range $\pm$ 3 degrees to $\pm$ 5 degrees. A typical swinging sequence is outlined in the following paragraphs.

4.4.1 When the aircraft has been towed onto the base, the appropriate sighting equipment should be fitted (see paragraph 4.2) and the aircraft positioned so that it is heading North.

4.4.2 External power supply should be connected to the aircraft, and after the compass systems have been energized and their gyros allowed to run up to normal operating speed, carry out the preliminary checks specified in the appropriate Maintenance Manuals. The following checks are typical of those normally required for systems in current use:—

(a) Synchronizing of heading indicators against annunciator devices to ensure that magnetic monitoring by flux detector units, has ceased before taking readings. In certain types of compass system this check is effected by plugging a centre-zero milliammeter into "monitoring current" sockets provided in a unit (e.g. an amplifier) of the system. If the gyro has no drift, monitoring has ceased when the meter oscillations are evenly balanced about the indicator "null" position within the tolerances specified for the particular system. In some cases, a monitoring meter forms part of a compass indicator, thereby obviating the need for a centre-zero milliammeter.

(b) Slaving of compass system indicators and associated system indicators, e.g. radio magnetic indicators.

(c) Check heading signals to auto-pilot and other associated navigational systems after selection of appropriate system switch positions.

(d) Operational check of power failure warning and other indicating flags on all heading indicators.

(e) Drift rate check of gyros.

(f) Setting of deviation compensators to their neutral positions. This is normally only done during an initial swing procedure, and whenever a new flux detector unit or a deviation compensator is installed (see also paragraph 5). If a compensator is of the permanent magnet type, the slots of the adjustment screws should be aligned with datum marks on the compensator body. In the case of a potentiometric type compensator, the potentiometers should be adjusted until a "null" position, as indicated by a test meter plugged into the compensator, is obtained. If a new flux detector unit has been installed its index error scale should also be aligned at the zero datum.

NOTE: It is recommended that if no new components have been installed, compensators should remain at their previous settings so that with each subsequent adjustment procedure, some indication of how coefficients change with time can be obtained.

4.4.3 With the aircraft still heading North and compass indicators synchronized, the deviation, i.e. the difference between the indicated reading and the magnetic datum, should be calculated. The sign is plus or minus according to whether it is necessary to add deviations to, or subtract them from, the compass readings in order to obtain the magnetic heading.

NOTE: The procedures for swinging the compass systems of some types of aircraft, also require at this stage, the calculation and compensation of an initial four-point Coefficient "A" error. After noting the deviations on North, therefore, the aircraft is then positioned on the other cardinal headings and the average of the algebraic sum of the four deviations is determined.

4.4.4 Position the aircraft so that it is heading East and after allowing the compass indicators to synchronize, the deviation should be calculated and its sign determined as noted in paragraph 4.4.3.

4.4.5 Position the aircraft so that it is heading South and after calculating the deviation, determine the Coefficient "C" error by calculating the average of the algebraic difference between the deviations on the North and South headings. The sign of the coefficient should then be changed and added algebraically to the indicated readings to establish the corrected heading indications. The Coefficient "C" section of the appropriate deviation compensation devices (see also paragraph 3.1.2) should then be adjusted until, with the indicators synchronized, the corrected heading is indicated.

4.4.6 Position the aircraft so that it is heading West and, after calculating the deviation, determine the Coefficient "B" error by calculating the average of the algebraic difference between the deviations on the East and West headings. The corrected heading indications are established and applied in a similar manner to that described in paragraph 4.4.5, except that adjustments are made at the Coefficient "B" section of the appropriate compensation devices.

4.4.7 On completion of the Coefficient "B" correction, the aircraft should be positioned successively on the cardinal and quadrantal headings (starting at West) in order to calculate the Coefficient "A" error. The error is calculated by taking the average of the algebraic sum of the deviations on eight headings, and is corrected in the manner appropriate to the compass system installed (see also paragraph 3.1.1). After applying the Coefficient "A" correction, the compass indicator readings on the cardinal and quadrantal headings should again be noted and the residual deviations should be recorded.

NOTE: Where appropriate, the eight-point Coefficient "A" compensation is additional to that referred to in the Note to paragraph 4.4.3.

4.4.8 All observed readings and associated deviation calculations obtained during swinging should be recorded on properly prepared record forms, and a record of the swing should be entered and certified in the aircraft log book. A record should also be made of compensator settings. A deviation or "steer by" card should also be compiled from recorded residual deviations, to show the readings which a compass must indicate in order that the aircraft may be flown on correct magnetic headings. The deviations should be related to standard headings at intervals of 45 degrees; in some cases an interval of 30 degrees may be specified. Details should be given on the back of the card to indicate aircraft type and registration, compass type, place and date of swing, signature and authority of the compiler. On completion, the card should be displayed in the appropriate holder in the aircraft cockpit.

4.5 **"Electrical" Swinging Procedure.** An "electrical" swinging procedure is one in which the earth's magnetic field is simulated by electrical signals in such a way that it is unnecessary to rotate the aircraft onto the various headings as in the conventional forms of swinging. The aircraft is positioned heading North with its fore-and-aft axis coincident with a North-South line marked on the selected compass base, and with its flux detector units positioned over marked location datum points (see also paragraph 4.2.3 and Leaflet **AL/10-4**). The electrical signals are in the form of varying d.c. voltages, the values of which are determined during the appropriate compass base survey procedure (see Leaflet **AL/10-4**) and also during the swinging procedure. The signals are designated as E_1 and E_2 voltages, and are applied respectively to the A-leg pick-off coil, and the B-leg and C-leg pick-off coils of the flux detector sensing elements, by adjusting the controls of a console unit forming part of a special calibrator set which can be connected into the flux detector circuit. The electromagnetic fields produced by the E_1 and E_2 voltages, alter the effective magnitude and direction of the earth's field passing through the legs of the detector sensing element, resulting in a magnetic vector which rotates to various headings, thereby simulating rotation of the aircraft and detector unit relative to the earth's field. These simulated headings are compared with the actual headings indicated by the aircraft compass system to determine the deviation errors to be compensated.

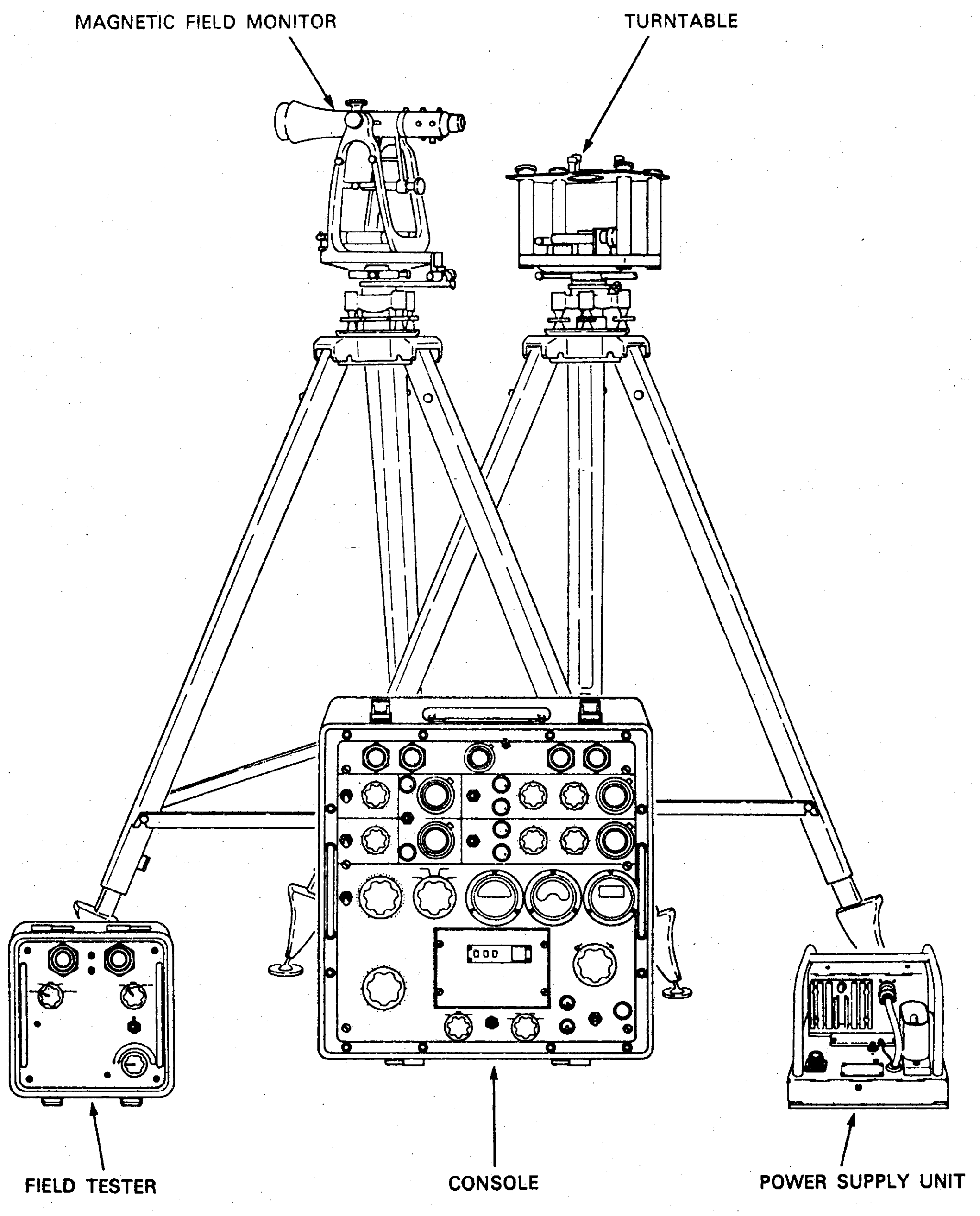

Figure 4 COMPASS CALIBRATOR SET

4.5.1 **Compass Calibrator Set.** It is beyond the scope of this Leaflet to go into the complete details of the compass calibrator set and its use in the "electrical" swinging procedure, reference should, therefore, always be made to the relevant manufacturer's operation manual. The information given in the following paragraphs serves only as a general outline.

(a) A compass calibrator set consists of the major components shown in Figures 4 and 5. The magnetic field monitor is a theodolite with a 22x telescope and a magnetic sensing element, and in conjunction with the console unit, it measures the strength, and determines the direction, of the horizontal component of the earth's field. It is used for the magnetic survey of areas required for swinging (see Leaflet **AL/10-4**) and also to monitor changes in magnetic conditions during a compass swing. The magnetic sensing element is similar to that employed in a remote indicating compass flux detector unit, except that it is non-pendulous.

(b) The turntable is also a theodolite but without a telescope and magnetic sensing element. It is used for calibrating and aligning certain types of flux detector unit (see paragraph 4.5.2 (b)) with magnetic North, and for determining the index or Coefficient "A" error before installing a unit in the aircraft.

(c) The console unit is the central control unit of the calibrator and contains all the switches, controls and indicators for programming the E_1 and E_2 voltage signals and for determining the errors in aircraft compass system indications to be compensated. The console also provides interconnection of the magnetic field monitor, turntable and power supply unit. The power supply unit is a solid-state inverter which converts a 28V d.c. input into a 115V 400 Hz a.c. output required to operate the calibrator.

(d) The optical alignment unit (see Figure 5) consists of a fixed-focus 8x telescope and appropriate adjustment devices, and is used for aligning certain types of flux detector unit in an aircraft during its transfer from the turntable, thereby ensuring that the index error compensation is maintained (see paragraph 4.5.2 (e)).

4.5.2 **Swinging Procedure.** The procedure for carrying out an "electrical" swing depends primarily on whether a flux detector unit is of the pre-indexed type, or of the master type (pre-calibrated and pre-indexed). Basically, however, the procedure consists of the following sequence of operations:—

(a) **Check on the Direction of Magnetic North.** This is done to determine whether there has been any shift from that obtained when the base survey was carried out. The check is carried out by sighting the calibrator monitor, from its location point on the base, on the pre-determined reference target, and then determining errors on the cardinal headings, and thus obtain an area compensation value for setting on the console control unit.

(b) **Magnetic Alignment of Detector Unit.** The purpose of this operation is to check the Index or Coefficient "A" Error, and thereby the amount by which the detector unit is to be offset in its mounting with respect to magnetic North. If the detector units are of the pre-indexed type, the check is done with the unit mounted on the calibrator turntable at its location on the base, and before the aircraft is towed onto the compass base. In the case of master type detector units, the aircraft can be towed onto the base at the outset of the swing procedure, since the units, being pre-calibrated on the four cardinal headings for a specific compass system and aircraft installation, are already installed and the use of the turntable is thereby eliminated.

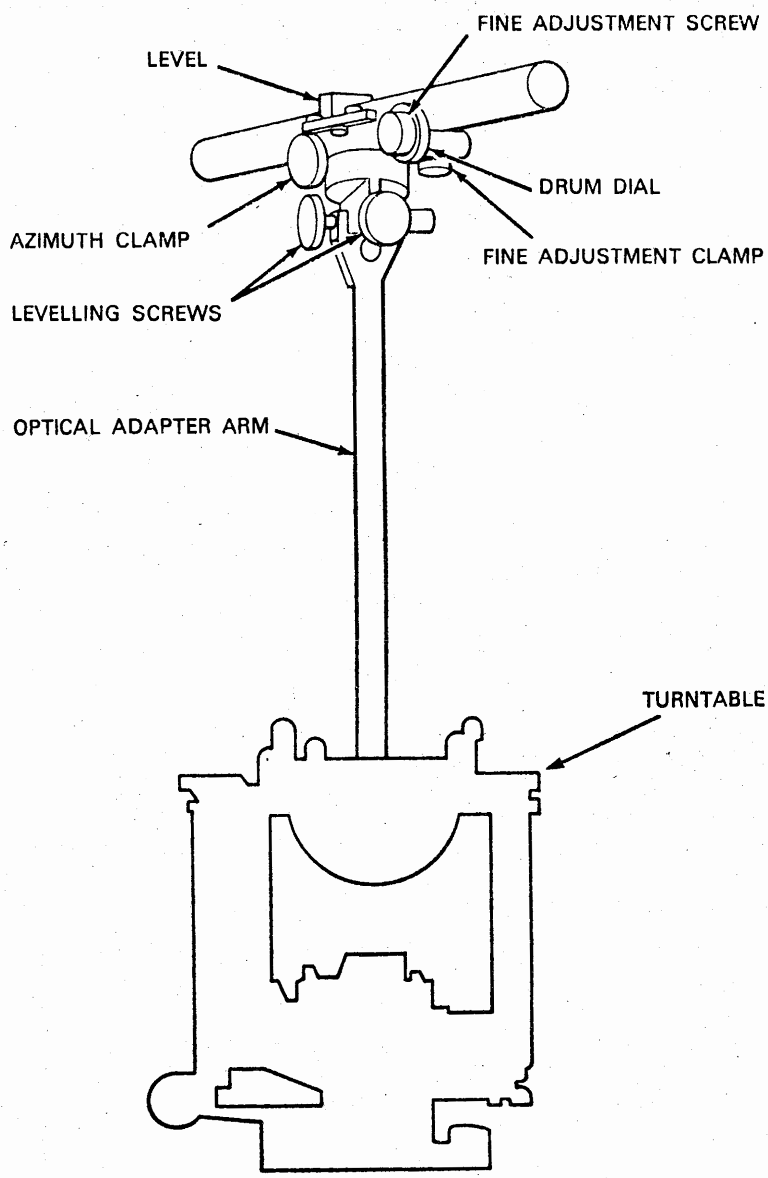

Figure 5 OPTICAL ALIGNMENT UNIT

(c) **E_1 and E_2 Voltages Check.** The purpose of this check is to determine the voltages required to simulate the earth's field effects which would be obtained if the aircraft and its detector units were rotated onto various headings. The check also determines the adjustments which are necessary to compensate for one-cycle errors, i.e. Coefficients "B" and "C", during the compass swing operation. The check applies to both pre-indexed and master type flux detector units, except that in the former case, voltage values are obtained by selecting headings on the calibrator turntable, while for master units selections are made on the calibrator monitor.

(d) **Determination of Crosstalk Errors.** These errors (see paragraph 3 (d)) are measured at headings of 90, 180 and 270 degrees. Crosstalk error does not occur at 0 degrees since no voltages are applied to the flux detector unit to simulate this heading.

(e) **Optical Transfer of Flux Detector Unit.** This operation is applicable only to flux detector units which have not been pre-indexed or pre-calibrated. It is carried out by means of the calibrator optical alignment unit, and is necessary in order to ensure that a detector unit will be installed in the same position with respect to magnetic North, as that determined by the calibrator turntable magnetic alignment check. The aircraft is towed onto the base and positioned so that not only is the longitudinal axis coincident with the North-South line with the nose pointing North, but also the flux detector unit access location is directly over that of the calibrator turntable. The optical alignment unit is then attached to the detector unit and a reference bearing is obtained by sighting the telescope on a target which is at least half-mile distant from the base. The values of aircraft malalignment, and flux detector unit index error, are then set into the optical alignment unit, and the detector unit, with equipment attached, is transferred to its mounting bracket in the aircraft and is rotated until the telescope is again aligned with the distant reference target. At this setting the detector unit is secured to its mounting bracket and electrically connected to its compass systems. The optical alignment unit is then removed.

NOTE: Optical transfer is a critical operation in "electrical" swinging procedure, and extreme care should be taken to prevent the telescope from being jarred or knocked out of adjustment before a flux detector unit is fully secured in its mounting bracket.

(f) **Compass Swinging.** This operation, which applies to all compass systems irrespective of the type of flux detector unit employed, is the one in which compensations are made for one-cycle (Coefficients "B" and "C") and two-cycle (transmission) errors. Before compensating, a final check on E_1 and E_2 voltage values should be made, and adjustments should, where necessary, be carried out to allow for any possible changes in the earth's field strength. On completion of all adjustments, a final swing through increments of 15 degrees should be carried out.

NOTE: Variations between compass system compensation can occur depending principally on the type of compensator used. Reference should, therefore, always be made to the relevant system and aircraft Maintenance Manuals.

4.6 **Swinging by Inertial Navigation Systems.** With the introduction of Inertial Navigation Systems (INS) into certain types of public transport aircraft, the use of system display unit heading information, as the datum for compass swinging, became a possibility. The swinging procedure, although basically similar to that employing an external magnetic datum, does however, require that the effects of diurnal changes in local magnetic variation be taken into account in order to minimize compass deviation errors.

4.6.1 Variation is the horizontal angle between the true and magnetic meridians, and in the United Kingdom it normally increases Westerly during the morning and decreases during the late afternoon. These diurnal changes, as they are called, are in the order of 0·1 degrees in the winter, and 0·3 degrees in the summer. During periods of high sunspot activity however, the changes become random and may increase in amplitude to 0·5 degrees, and have been known to be as large as one degree. In the case of a compass swing using an external magnetic reference datum, the diurnal changes do not affect the swing since both the datum compass and the aircraft compass are affected by the same changes and the correct deviations are calculated. Furthermore, as long as the compass base has a constant value of variation over it, an accurate compass swing can be carried out irrespective of the value of local variation. In using INS heading information as a datum, diurnal changes will, however, affect only the aircraft compass, thereby giving rise to false deviation errors which require the application of variation corrections. An outline of a method of applying the corrections, based on that prescribed for a particular type of aircraft using three inertial navigation systems, is given in the following paragraphs.

(a) The aircraft is positioned within two degrees of North using the readings of the INS display units, and the average of the three readings is noted. The aircraft's magnetic heading is then determined by applying the value for the local magnetic variation to the average of the display unit readings. For Westerly variation the value is added and for Easterly variation it is subtracted.

(b) The heading indications of the compass systems are then noted, after allowing each system to synchronize, and the deviations of each system on the North heading are calculated.

(c) The foregoing procedure is repeated on the other three cardinal headings, and the deviation coefficients are calculated and compensated in the manner prescribed for the particular compass systems.

4.6.2 Although the method described in paragraph 4.6.1 takes into account local variation on all cardinal headings, it should be noted that it is still possible for false deviations to occur as a result of diurnal changes taking place, for example, during the time required for compass systems to synchronize. Unless continuous calculations are made, or the aircraft headings are checked with the aid of an external datum compass, it is unlikely for local variation to be known accurately for the duration of the swing. Serious consideration should, therefore, be given to the maximum compass error which might occur during an INS datum swing compared with one using an external magnetic datum, and whether such error can be accepted for the aircraft compass systems concerned.

5 OCCASIONS FOR COMPASS SWINGING The swinging procedures described in paragraph 4 should normally be carried out after installation of a complete compass system, and whenever standard type, or pre-indexed type, flux detector units are changed. Changing of a master type detector unit does not usually downgrade the performance of its associated system unless alignment of the unit in its mounting bracket, or alignment of the bracket itself, has been altered. Normally, a complete swinging procedure should also be carried out after a deviation compensator device has been changed, although in some systems this may not be necessary provided that compensating voltage settings are properly transferred to the replacement unit. On all other occasions it is sufficient only to carry out a check swing by placing the aircraft on four headings 90 degrees apart, and comparing any deviations with those recorded on the previous calibration swing. If there is any difference between these deviations, a complete swinging procedure should be carried out. Occasions for a check swing are as follows:—

(a) After a check inspection if required by the approved Maintenance Schedule, or at any time that the accuracy of a system is in doubt.

(b) After any modification, repair or major replacement involving magnetic material.

(c) After any modification or repair to wing tips, or vertical stabilizers, in the vicinity of flux detector units.

(d) Whenever a compass has been subjected to shock, e.g. after a heavy landing.

(e) After the aircraft has passed through a severe electrical storm, or has been struck by lightning.

(f) Whenever the aircraft has been subjected to a magnetic crack detection examination.

(g) Whenever the sphere of operation of the aircraft is changed to one of different magnetic latitude.

(h) Whenever a significant change is made to the electrical or radio installation, particularly to circuits in the vicinity of flux detector units.

(j) Whenever a freight load is likely to cause magnetic influence and thereby affect compass system readings.

(k) After the aircraft has been in long term storage.

AL/11-1

Issue 4

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AIRCRAFT

ICE PROTECTION

PNEUMATIC DE-ICING SYSTEMS

1 INTRODUCTION

1.1 The purpose of this Leaflet is to provide general guidance and advice on the installation and maintenance of pneumatic aerofoil de-icing systems. The Leaflet should be read in association with Aircraft and Aircraft Component Maintenance Manuals, and Maintenance Schedules relevant to the specific items and aircraft installations.

1.2 Subject headings are as follows:—

2 STANDARD OF PROTECTION

2.1 The Air Navigation Order 1985, requires that aircraft in the Public Transport Category (Passenger or Cargo) registered in the United Kingdom, shall be provided with 'adequate equipment' to prevent impairment of the lifting surfaces through ice formation, where, meteorological forecasts indicate at the time of departure, the possibility of encountering weather conditions conducive to icing.

2.2 Aircraft ice protection certification acceptance standards are detailed in British Civil Airworthiness Requirements (BCAR) Section D Chapter **D4-7,** and Joint Airworthiness Requirements (JAR) Paragraphs 25.1416 and 1419. These requirements cover such considerations as, aircraft stability, flying control balance characteristics, jamming of flying controls and continuous engine(s) operation in icing conditions. However, certain basic standards have also to be complied with by all aircraft, which are intended to provide a reasonable protection if the aircraft is flown unintentionally for short periods in icing conditions.

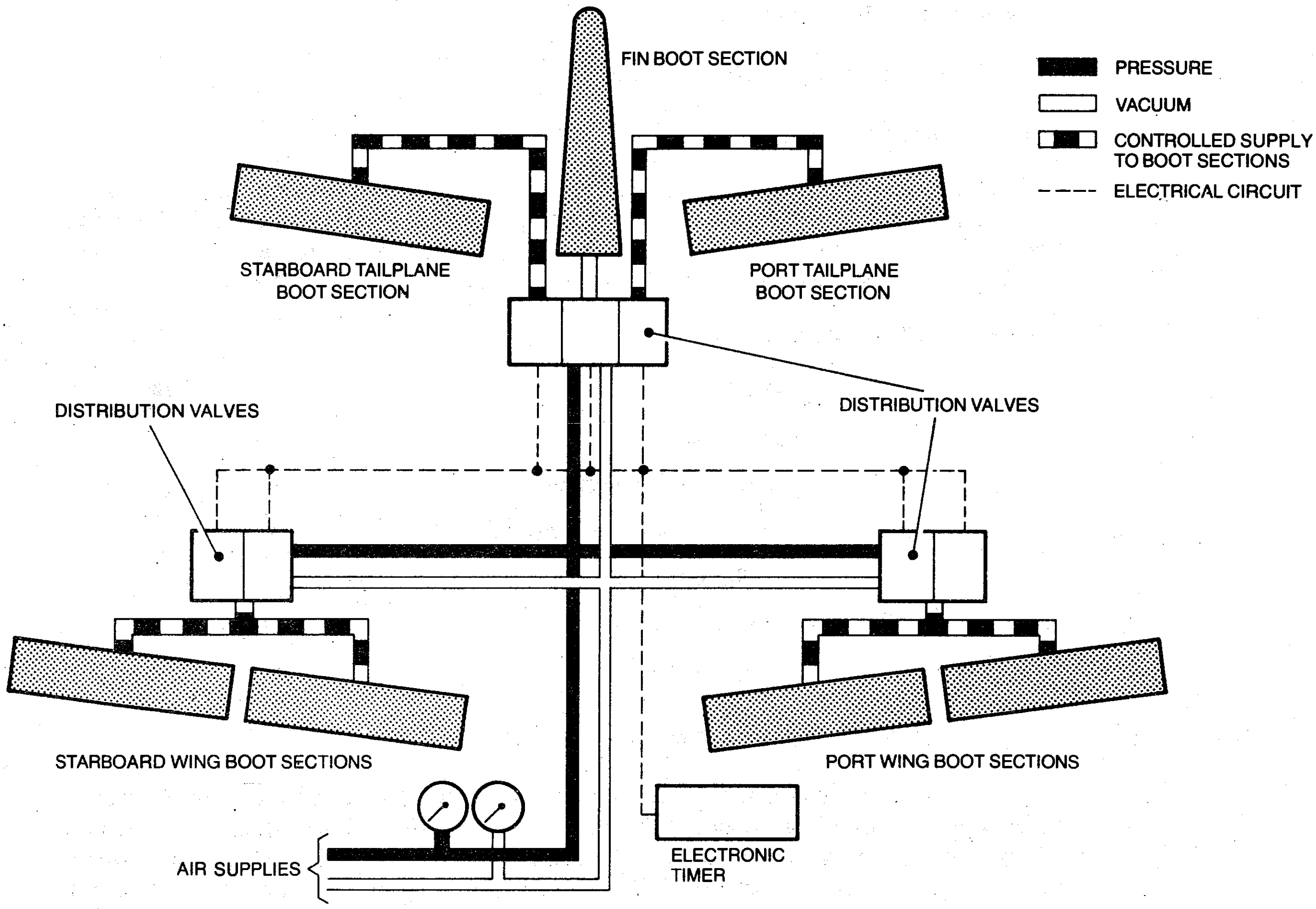

Figure 1 SCHEMATIC DIAGRAM OF A PNEUMATIC DE-ICING SYSTEM

3 THE PNEUMATIC DE-ICING SYSTEM

3.1 **General.** Pneumatic de-icing systems are employed in certain types of piston-engined and twin turbo-propeller aircraft. The number of components comprising a system varies with the operating principle. The typical de-icing system schematically illustrated in Figure 1 comprises the following:—

(a) The air supply system.

(b) The air distribution system.

(c) The pneumatic de-icer boots.

(d) The controls and indicators.

3.2 **Operation**

3.2.1 When the system is switched on, pressure is admitted to the pneumatic de-icer boot sections to inflate the tubes. This weakens the bond between the ice and de-icer boot surfaces, causing the ice to break away. At the end of the inflation stage of the operating sequence, the air in the inflation tubes is dumped to atmosphere through automatic opening valves, the tubes are then fully deflated by the vacuum supply. This inflation and deflation cycle is repeated whenever the system is in operation. When the system is switched off, vacuum is continually supplied to all inflation tubes within the de-icer boot sections to hold them flat against the wing and tail unit leading edges, thereby minimising aerodynamic drag.

3.2.2 The method of sequencing usually varies with the method of air distribution as referred to in paragraph 3.3. In most installations, sequencing control is effected by means of an electronic device, however reference should always be made to the relevant Aircraft Maintenance Manual for details of the method of control and operating time cycles.

3.3 **Air Supplies and Distribution**

3.3.1 The tubes in a pneumatic de-icer boot section are normally inflated by one of the following methods:—

(a) Air pressure from the pressure side of an engine-driven vacuum pump.

(b) Air pressure from a high pressure air reservoir, or

(c) as fitted to some types of turbo-propeller aircraft, air pressure from a tapping at an engine compressor stage.

3.3.2 Whenever the system is switched 'OFF' or at the end of the inflation stage of the operating sequence, the de-icer boots are deflated by vacuum derived from either a vacuum pump, or, in systems utilising an engine compressor tapping, from the venturi section of an ejector nozzle.

3.3.3 The method of distributing air supplies to the de-icer boots, depends on the type of de-icing system adopted for a particular type of aeroplane, but in general, there are three methods in use. One method employs shuttle valves which are controlled by a separate solenoid valve. The second method distributes air to each de-icer boot by individually solenoid-controlled valves; in the third method, distribution is effected by a motor-driven valve.

3.4 **Pneumatic De-icer Boots**

3.4.1 Pneumatic de-icer boots, or overshoes, consist of layers of natural rubber and rubberised fabric between which are disposed flat inflatable tubes that are closed at the ends. The inflatable tubes are made of rubberised fabric which are vulcanised inside the natural rubber layers. When the de-icer boots are in position on a wing, or tailplane leading edge, the tubes either run parallel to the span, or as in other arrangements, parallel to the chord. The inflatable tubes are connected to the air supply pipelines from the distribution valves by short lengths of flexible hose. These in turn are secured to connectors on the de-icer boots and air supply pipelines, by hose clips. The external surfaces of the de-icer boots are coated with a film of conductive material to discharge any accumulations of static electricity.

3.4.2 A de-icer boot may be attached to the leading edge of an aerofoil either by, screw fasteners (Rivnuts), or adhesive cement. To cover the edges of a screw-fastened de-icer boot, metal fairing strips are used on the upper and lower surfaces. To secure and prevent inward creep of the de-icer boot, end strips are also fitted. The strips are secured by the same screws and Rivnuts as those used to secure the edges of the de-icer boots to the leading edge.

3.5 **Controls and Indicators.** The controls and indicators required for the operation of a de-icing system depend upon the type of aircraft, and the particular arrangement of its de-icing system. In the basic arrangement, a main ON-OFF switch, pressure and vacuum gauges, or indicating lights, form part of the controlling section.

4 INSTALLATION

4.1 **General.** For full details of the checks to be carried out on pneumatic de-icing system components prior to installation, and the installation methods to be adopted, reference should always be made to the relevant Aircraft and Aircraft Component Maintenance Manuals. The information provided in the following paragraphs is therefore of a general nature, and intended only as a guide to installation practices.

4.2 **Pneumatic De-icer Boots**

4.2.1 **Screw-fastened De-icer Boots.** The following points should be observed when installing de-icer boots of this type:—

(a) The mating surfaces of the leading edges should be clean and free from projections or rough edges which may chafe the undersurfaces of the boot. Projections such as rivets may be covered with adhesive tape.

(b) Leading edges should be painted with a mixture of French Chalk and lead-free petrol or Methylated Spirit and allowed to dry thoroughly. This will leave a smooth even film of French Chalk on the leading edge skin to lubricate movement of the rubber de-icer boot.

(c) The undersurface of the de-icer boot should also be thoroughly dusted with French Chalk.

NOTE: The liquid mixture as applied to leading edges should not be used.

(d) To prevent chafing of the aerofoil surfaces, a narrow strip of adhesive tape should also be placed on the underside of the trailing edges of the fairing strips, taking care to ensure that the tape does not extend beyond the edge of the fairing strips.

(e) The de-icer boot should then be positioned adjacent to leading edges, and the hoses from the air supply system fitted to the correct de-icer boot connections.

(f) When fitting a screw-fastened de-icer boot, it is immaterial whether the upper or lower edge is attached first. The edge chosen should be the one most convenient to reach and perform the stretching operation described in paragraphs (g) and (h). The de-icer boot and a fairing strip should be loosely secured, along one edge, to the aerofoil. The screws should not be tightened until the other edge has been secured.

(g) To assist the ice shedding action and deflation, de-icer boots are secured under tension. This is effected by stretching the second edge into position. A special tool for gripping the edge of the de-icer boot is normally used to facilitate stretching, together with a number of pegs to locate the de-icer boot mounting holes over the rivnuts.

(h) When the de-icer boot is stretched back over the rivnuts, a peg should be forced through the de-icer boot mounting hole and into the appropriate rivnut. At least two additional pegs should be inserted in adjacent rivnuts, before releasing the tension. This operation should be repeated until the entire edge of the de-icer boot is attached. As the tension and pegging operation progresses, there may be a tendency for wrinkling to develop, this may be worked out by slapping the de-icer boot surface with the gloved hand which will also help to keep lengthwise shrinkage of the de-icer boot to a minimum.

(i) When all the pegs have been inserted, the fairing strip should be installed over the pegs, and working from one end, the pegs replaced with the appropriate attachment screws. These, together with those screws securing the other edge of the de-icing boot, should then be tightened and the end fairing strips fitted.

4.2.2 **Cemented De-icer Boots.** The following points should be observed when installing de-icer boots of this type:

(a) All paint should be removed from the complete leading edge skin surface of an aerofoil, which together with the undersurfaces of the de-icer boot, should be cleaned by swabbing the skin surface with a clean, lint-free cloth soaked in Toluol and then wiped dry with a clean dry cloth before the solvent has had time to evaporate. Cloths should be changed frequently to avoid re-contamination of the cleaned areas, and to ensure a completely clean surface, cleaning operations should be carried out at least twice.

(b) Immediately after the final drying operation, an even coat of the cement specified for use should be applied to the leading edge skin surface and undersurface of the de-icer boot. The surfaces should then be allowed to dry before a second coat of cement is applied and left to dry until completely tack-free. Drying times depend on temperature and humidity conditions. At 15°C or above with a relative humidity of up to 75%, a minimum of one hour drying time should be allowed. When the relative humidity is between 75% to 90%, a drying time of two hours between coats should be allowed.

(c) Before cementing a de-icer boot to the leading edge, it should be rolled up (undersurface outwards) and a check made to ensure that its air supply connecting tubes do not foul the edges of the holes provided in the leading edge. A check should also be made that when unrolled from this position, the de-icer boot will be correctly aligned with the entire leading edge. This second check is facilitated by marking a centre line down the length of the de-icer boot on the cemented surface, and a corresponding centre line along the front of the leading edge.

(d) The de-icer boot should be folded back at the air connection end, over a distance of 229 mm (9 in) to 305 mm (12 in), and tacky surfaces reproduced in this area on the de-icer boot and leading edge, by swabbing with a clean lint-free cloth moistened with Toluol. Excessive swabbing should be avoided to prevent removal of cement from the surfaces. The two tacky surfaces should be positioned together and the de-icer boot rolled down firmly with a 51 mm (2 in) wide rubber covered hand roller.

NOTE: Two sizes of hand roller are normally specified for use, a 51 mm (2 in) wide roller for main rolling and a 19 mm (¾ in) wide roller for rolling between the inflatable tubes. All rolling must be carried out parallel to the inflatable tubes.

(e) The de-icer boot should then be rolled back from the free end, and tacky surfaces reproduced over the de-icer boot and leading edge. The surfaces should then be joined and rolled together, working progressively in strips 305 mm (12 in) wide, until the de-icer boot is attached to the leading edge. If the de-icer boot becomes attached to the leading edge in an incorrect positon, the de-icer boot should be pulled up smartly and repositioned immediately avoiding any twisting or bending.

NOTE: If a blister appears during rolling operations a piece of wire should be gently inserted between the open end of the de-icer boot and the leading edge until it enters the blister. The wire should then be removed and the air rolled out along the "tunnel" formed by the wire. In areas clear of the inflation tubes, a blister may be dispersed by inserting a hypodermic needle into it.

(f) In some installations, fairing strips are fitted along one edge of a de-icer boot surface to permit flush fitting of the strip. Care must be taken when cutting to ensure that it is not done too deeply; a cut should be made one layer at a time.

(g) When the de-icer boots are finally cemented in position, the air supply connections should be made secure, and the ends of de-icer boots trimmed so that they lie flush with the end of the fairing strips and all excess cement cleaned away from the de-icer boot and metal surrounds. Additionally the de-icer boots should be sealed along their edges and ends by applying a special sealing cement. Reference should be made to the Aircraft Maintenance Manual for preparation details of the cement and the number of coats to be applied. When the final coat of sealing cement is dry, it should be 'capped' by the application of cement to the same specification as that to restore the conductivity of the surface (see paragraph 5.3).

(h) Finally, a test for the satisfactory adhesion of the de-icer boots to leading edge sections should be carried out in the manner specified in the relevant Aircraft Maintenance Manual, which also includes a check to ensure that the forces required to separate the specially prepared test pieces are within permissible limits.

4.2.3 **Other Components.** The methods of installing pressure and vacuum regulating valves, distributor valves, electronic timers, indicators and such other components appropriate to the de-icing system of a specific aircraft type, are detailed in the relevant Maintenance Manuals, and reference should therefore be made to these documents.

5 INSPECTION AND MAINTENANCE

5.1 **General.** The majority of inspection and maintenance procedures associated with pneumatic de-icing systems are related to the de-icer boots, since their location on an aircraft makes them vulnerable to damage which may be caused under actual operating conditions or during ground handling and servicing operations. Therefore, the information on inspection and maintenance procedures detailed in the following paragraphs is primarily concerned with de-icer boots and is intended to serve only as a general guide. Reference should therefore always be made to the relevant Aircraft and Component Maintenance Manuals and Approved Maintenance Schedules appropriate to the specific aircraft type.

5.2 At each inspection careful consideration should be given to the overall condition of de-icer boots. This applies particularly to the soft pliable rubber which may easily be damaged during servicing operations. The following are general precautions which should be observed:—

(a) Refuelling hose and other equipment must not be draggged over the surfaces of the de-icer boots.

(b) Ladders or service platforms which are placed near the de-icer boots during servicing operations must have sponge-rubber pads fitted to prevent damage.

(c) Oil or grease found on the surface of de-icer boots must be removed as soon as possible with soap and water or with a clean rag moistened with a lead-free petrol. Petrol should not be allowed to dry on the surfaces; it should be wiped off immediately with a clean cloth.

NOTE: Surfaces should not be rubbed hard during cleaning as damage to the conductive film may result.

(d) Personnel must not tread on de-icer boots during servicing operations.

(e) In tropical areas de-icer boots should not be exposed to sunlight for long periods.

5.3 **Conductive Surface Deterioration**

5.3.1 The conductive surface of cemented de-icer boots (paragraph 3.4.1) deteriorates slowly in service through general abrasion and this will be evident by the abraided condition and rough appearance of the surface. The method of restoring the conductivity of the surface is as follows:—

(a) Carefully clean the outer surface of the de-icer boot using soap and water or a clean lint-free cloth moistened with lead-free petrol. Liquids should be used sparingly and surfaces dried off immediately.

NOTE: The de-icer boot surfaces should not be rubbed hard during cleaning or damage to the conductive surfaces will result.

(b) Apply one coat of the conductive cement specified for the de-icer boots, ensuring that the identification and serial reference number details printed on a small part of the de-icer boot surface, are not obliterated. The cement should be applied evenly and sparingly over the surface, care being taken to prevent excess quantities running down and forming rippled ridges across it. While the cement is drying, the aircraft should remain in a warm, dry area. In dusty conditions, the de-icer boots should be covered loosely with paper which is sealed with tape at the edges.

NOTE: Conductive cement normally requires about 24 hours to dry. Therefore, whenever possible, de-icer boots should be resurfaced soon after the start of any periodic maintenance check on the aircraft.

5.4 **De-icer Boot Deterioration.** Continued operational use and exposure to intense sunlight causes the surface of de-icer boots to deteriorate by general crazing. If the surface is extremely crazed, with the cracks extending to the fabric reinforcing, the de-icer boot should be replaced. If the damage due to crazing does not extend into the natural rubber plies of the de-icer boot, then a coating of conductive cement will normally suffice in restoring the de-icer boot to a serviceable condition.

5.5 **Repairs**

5.5.1 **General.** Damage to de-icer boots found during inspections will vary from minor cuts, holes and scratches; which may be easily repaired, to extensive splitting of the tube areas which are beyond repair. Minor tears and holes can usually be detected by visual means or the sound of escaping air, or by system pressure not building up to the required operational value as indicated by the system pressure gauge. If there is difficulty in locating a leak, the de-icer boot should be inflated, and a soap solution applied to the suspected area.

5.5.2 **Repair Methods.** Repair schemes are devised, and detailed in Maintenance Manuals and in some cases, Structural Repair Manuals, for the relevant aircraft type. The repair methods to be adopted and the nature of the work involved, depends largely on the extent of the damage to the de-icer boot. Kits are provided for carrying out cold patch repairs in-situ which are normally confined to two size ranges of damage; cuts, holes or cracks up to 19 mm (¾ in) long, and from 19 mm (¾ in) to 51 mm (2 in) long. The kits normally contain moulded rubber patches of various sizes, cements, rubber and rubberised fabric sheets, and the appropriate tools. Where larger cuts, holes, or cracks have occurred, or where a portion of a de-icer boot has been torn away, a temporary emergency repair may be made with the aid of a cold patch repair kit.

5.5.3 Numerous cold patches greatly affect the efficiency of a de-icer boot, therefore these repairs must only be regarded as a temporary measure. When a de-icer boot has been extensively patched it must be removed from a leading edge in order that permanent repair by a vulcanising process may be carried out. Some important aspects of de-icer boot repair methods are summarised as follows:—

(a) Patches should be approximately 16 mm (⅝ in) larger all round than the cut. In the case of cuts which range in size from 19 mm (¾ in) to 51 mm (2 in), and for the emergency repair of more extensively damaged areas, the rubber or rubberised fabric sheet material should be cut 38 mm (1½ in) larger all round.

(b) Care should be taken to remove only the conductive coating from an area of the de-icer boot surface slightly larger than the patch required. To assist in this operation, a special buffing shield (supplied with the repair kit) with various sized apertures is held over the damage area in the selected position.

(c) After the removal of the conductive coating, the cleaned surface should be roughened with a wire brush and then smoothed as evenly as possible with an emery buffing stick. The surface should be finally cleaned with lead-free petrol and allowed to dry.

(d) The patch and damage area should be coated with cement, and after the specified air-drying time has elapsed, the patch should be applied to the de-icer boot. To ensure that the patch adheres centrally over the damage, one corner should be lightly applied and the remainder pressed down at the same time exerting a slight pulling action. The tension thus created will help to close up the puncture in the de-icer boot surface when the patch is finally in position.

(e) Patches should be pressed down carefully to prevent entrapment of air and rolled thoroughly with the steel roller supplied with the repair kit, ensuring that the edges of the patch have adhered closely to the de-icer boot surface.

(f) After allowing the appropriate time for setting, the patch and surrounding area should be wiped with a clean lint-free cloth moistened with lead-free petrol to remove all surplus cement. When the surfaces are thoroughly dry and clean, a coat of conductive cement should be applied to restore the conductive surface.

(g) If the damage to a de-icer boot is such that an inflatable tube is cut completely through, the inside surface should be patched first and then the outside. The patches must be cut from rubberised fabric sheet which is manufactured such that it stretches in one direction only. When in position, the patches should stretch normal to the inflation tubes, i.e. for de-icer boots using spanwise inflation tubes, the fabric stretch should be chordwise and vice versa.

NOTE: A pressure test must be carried out on the de-icer boot in accordance with the procedures specified in the Aircraft Maintenance Manual after repair to the inflatable tubes.

5.6 **Functioning Tests.** Functioning tests must be carried out at the check periods specified in the Approved Maintenance Schedules, or when a system malfunction occurs, or a major component (e.g. a distributor valve, regulator valve or de-icer boot) has been replaced, and also after repairs to a de-icer boot. The method of testing a system depends mainly on the type of aircraft and precise details must therefore be obtained from the relevant Maintenance Manual. The checks which in general form part of functioning test methods, are outlined as follows:—

(a) Tests may be carried out using either the aircraft engines or by deriving the requisite air supplies from a ground test trolley. If a system which uses engine compressor bleed air is to be tested by using a test trolley, the air supply must be clean, moisture-free and at a delivery pressure approximating that normally obtained at the engine compressor tapping.

(b) Pressure and vacuum indicators should be checked to ensure that supplies are maintained at the specified values. Adjustments should be made, where necessary, to relevant regulating and relief valves.

(c) With a system selected 'ON', de-icer boots should be checked to ensure that they inflate and deflate in the correct sequence and for the correct periods of time determined by the appropriate timing device. During this check it should also be noted that the pressure gauge pointer fluctuates simultaneously with de-icer boot inflation and deflation.

(d) If the de-icer boot section inflates and deflates sluggishly; even though the correct pressure is indicated, it may be the result of an obstruction in certain of the pipelines (e.g. those leading to the de-icer boot sections or to the distributor valves). If the distributor valves are of the electrically controlled type, sluggish inflation and deflation may also be due to sticking solenoids.

(e) Joints and sections of pipelines should be checked for leaks under operating conditions.

(f) When the system is selected to the 'OFF' position, the de-icer boot sections should deflate completely and lie flat against the leading edge of the appropriate aerofoil.

6 STORAGE OF DE-ICER BOOTS Before storing, the surface conditions of the de-icer boot should be inspected carefully, to establish that there are no operating defects. They should be cleaned and repaired, and where necessary (see paragraph 5.5) lightly dusted with French Chalk. Connectors should be blanked off and the de-icer boots rolled up commencing at approximately 153 mm (6 in) diameter. Rolling should be commenced at the end remote from valve connectors so that they are on the outside of the finished roll. Where connectors are located near the centre of the de-icer boot, a pad of corrugated paper should be placed over the connectors to protect the contacting surface. The rolled de-icer boot should then be thoroughly wrapped up in a heavy paper to exclude all light, and stored in a cool, dry, dark

place, where it will not be crushed or wrinkled. In cases where de-icer boots are precemented to detachable leading edge sections, the latter should be wrapped up and stored in such a manner that they are supported on their trailing edges.

AL/11-2

Issue 3

June 1986

AIRCRAFT

ICE PROTECTION

THERMAL (HOT GAS) DE-ICING SYSTEMS

1 INTRODUCTION This Leaflet gives guidance on the installation and maintenance of the thermal systems used for the de-icing of wings and tail units. It should be read in conjunction with Maintenance Manuals and approved Maintenance Schedules; such documents providing details of construction, major servicing, repairs and test procedures relevant to specific aircraft installations and components.

2 GENERAL In systems of this type, the leading edge sections of wings and tail units are usually provided with a second inner skin positioned to form a small gap between it and the inside of the leading edge section. Heated air is ducted to the wings and tail units and passes into the gap, providing sufficient heat in the outer skin of the leading edge to melt ice already formed and prevent further ice formation. The air is exhausted to atmosphere through outlets in the skin surfaces and also, in some cases, in the tips of wings and tail units. The temperature of the air within the ducting and leading edge sections is controlled by a shutter or butterfly type valve system the operation of which depends on the type of heating system employed.

3 AIR SUPPLIES There are several methods by which the heated air can be supplied and these include bleeding of air from a turbine engine compressor, heating of ram air by passing it through a heat exchanger located in an engine exhaust gas system and combustion heating of ram air.

3.1 In a compressor bleed system the hot air is tapped directly from a compressor stage and after mixing with a supply of cool air in a mixing chamber it passes into the main ducting. In some systems, equipment, e.g. safety shut-off valves, is provided to ensure that an air mass flow sufficient for all de-icing requirements is supplied within pressure limits acceptable to duct and structural limitations.

3.2 The heat exchanger method of supplying warm air is employed in some types of aircraft powered by turbo-propeller engines. The heat exchanger unit is positioned so that exhaust gases can be diverted to pass between tubes through which outside air enters the main supply ducts. The supply of exhaust gases is usually regulated by a device such as a thermostatically controlled flap fitted in the ducting between the exhaust unit and the heat exchanger.

3.3 In a combustion heating system ram air is passed through a cylindrical jacket enclosing a sealed chamber in which a fuel/air mixture is burned, and is heated by contact with the chamber walls. Air for combustion is derived from a separate air intake and is supplied to the chamber by means of a blower.

4 DUCTING The type of ducting, materials used, methods of inter connection and disposition in an aircraft vary between de-icing systems, and reference should therefore always be made to the relevant aircraft Maintenance Manual for details.

4.1 Light alloy and stainless steel are materials normally used in construction, stainless steel being adopted principally in compressor bleed systems. Flanged and bolted end fittings, or band-type vee-clamps with interposed sealing rings are common methods of connecting duct sections together, and in some cases an additional means of sliding duct sections one end into the other and securing by adjustable clamps may be adopted.

4.2 In some installations in which ducting passes through the fuselage, joints between duct sections are sealed to prevent loss of cabin air pressure. Fuselage ducting may, in some types of aircraft, comprise an inner stainless steel duct surrounded by an outer fibreglass duct. The two ducts are approximately 13 mm (½ in) apart and the interspace is filled with glass wool to provide thermal insulation. The purpose of this ducting arrangement is to serve as a leak warning system by venting interspace air through venturis which operate pressure switches and a warning light.

4.3 Expansion and contraction of ducting is catered for by bellows or gimbal type expansion joints and in aircraft having variable incidence tailplanes and other moveable aerofoil surfaces such as leading edge slats and Kruger flaps, swivel joints and telescopic joints are fitted in the ducts supplying air to these surfaces.

4.4 In some installations, ducting in certain areas is lagged with a fire-resisting, heat-insulating material, normally fibreglass held in place by glass-cloth bound with glass cord.

5 TEMPERATURE CONTROL The control of the air temperature within ducting and leading edge sections is an important aspect of thermal de-icing system operation and the methods adopted depend on the type of system.

5.1 In a typical compressor bleed system, control is effected by temperature sensing units which are located at various points in the leading edge ducting and by valves in the main air supply ducting. The sensing units and valves are electrically interconnected so that the valves are automatically positioned to regulate the flow of heated air to the system thus maintaining the temperature within a predetermined range. Indications of air temperature conditions are provided by resistance type temperature sensing elements and indicators, temperature sensitive switches and overheat warning lights. On some aircraft the electrical supplies to the valves are interrupted by landing gear controlled relays when the aircraft is on the ground. Under these conditions, valve operation is accomplished by holding the system control switch to a 'TEST' position.

5.2 When heat exchangers are employed, temperature control is usually obtained by the use of adjustable flaps and valves to decrease or increase the supply of heating and cooling air passed across the exchangers. The method of controlling the flaps and valves varies with different aircraft, but a typical system incorporates an electric actuator, which is operated automatically by an inching device controlled by a temperature sensing element fitted in the duct on the warm air outlet side of the heat exchanger. In some systems, actuators are directly controlled by thermal switches, so that the flaps or valves are automatically closed when a predetermined temperature is reached. Indications of air temperature conditions are provided by resistance type temperature sensing elements and indicators, temperature sensitive switches and overheat warning lights.

5.3 In systems incorporating combustion heaters, the temperature is usually controlled by thermal cyclic switches located in the heater outlet ducts, so that when the temperature reaches a predetermined maximum the fuel supply to the heaters is automatically switched off.

6 INSTALLATION The arrangements for the installation of thermal de-icing system components depends primarily upon the type of system and also upon the particular type of aircraft. The information given in the following paragraphs is of a general nature only, and is intended as a guide to the procedures associated with the installation of principal components. Full details are contained in the Maintenance Manuals for specific aircraft types and reference must always be made to these documents.

6.1 **Heat Exchangers.** Before installation, heat exchangers should be inspected to ensure that no foreign matter has entered the various connections, that there are no visible cracks or other damage and that ram air passages are free from obstruction. In some installations, exhaust gas and hot air ducts must be assembled to a heat exchanger prior to its installation.

6.1.1 Heat exchangers must be adequately supported during installation to prevent fouling of ducting, or other adjacent components and parts of the aircraft structure.

6.1.2 The fore-and-aft and transverse clearances for mounting flanges and bolts should be checked to ensure that these are within the limits specified in the relevant Maintenance Manuals. Mounting bolts should be tightened to appropriate torque values.

6.1.3 New sealing gaskets and O-rings should be fitted to the joints between system ducts, ram air inlet and outlet flanges, and exhaust gas inlet and outlet flanges. This is also essential whenever a joint is broken down for any reason. All joints should be correctly aligned and in tightening the appropriate nuts, bolts or clamps, care should be taken that distortion of the connection flanges and damage to brazed joints of a heat exchanger does not occur through overtightening. Nuts, bolts or clamps should be locked in the appropriate manner specified in the relevant aircraft Maintenance Manual.

NOTE: Particular care must be taken when making connections between engine exhaust units and heat exchangers to ensure that exhaust gases cannot enter the main ducting of the de-icing system. If the ducting has leaks, gases may be introduced into the cabin of the aircraft resulting in dangerous levels of carbon monoxide concentration (see Airworthiness Notice No. 40).

6.1.4 If disturbed during installation of a heat exchanger, flaps or valves should be tested and adjusted as necessary. Moveable parts should operate freely throughout their full range of travel.

6.2 **Combustion Heaters.** Before installation, combustion heaters should be inspected for evidence of damage and, when necessary, pressure tested in the manner prescribed in the manufacturer's Maintenance Manual to ensure that no fuel or combustion products can leak into the air supply of the system (see Airworthiness Notice No. 40).

6.2.1 Heaters should be installed in the manner specified in the Maintenance Manual concerned, taking care that air and fuel leakages do not occur at duct joints or connections.

6.2.2 Equipment associated with the heating system such as flow valves, air regulators, thermostatic devices and ducts should be correctly interconnected, and mechanical movements, flows and temperature settings checked and adjusted.

6.2.3 After the installation of a heater the system should be ground tested in the manner specified in the revelant aircraft Maintenance Manual.

NOTE: Unburnt fuel or fuel vapour should not be allowed to accumulate within the combustion system or aircraft particularly during component functioning tests (see Leaflet AL/3-8).

6.3 **Ducting.** The methods of installing ducting vary between de-icing systems and it is therefore necessary to refer to the relevant aircraft Maintenance Manual for details of the procedure to be carried out.

6.3.1 The following summary serves as a guide to some important aspects common to installation procedures:—

(a) Ducting should be inspected externally and internally for cleanliness, signs of damage and security of end fittings.

(b) New sealing gaskets and O-rings should be fitted between jointing faces of duct end fittings. This is also essential whenever a joint is broken down for any reason. The jointing faces should also be checked for excessive ovality or gapping.

(c) When fitting band-type vee-clamps, the sealing rings must be correctly positioned to ensure that the seal bears evenly against, and is compressed by, the adjacent joint flange.

(d) Band-type vee-clamps should be lubricated with the lubricant prescribed in the Maintenance Manual and torque-tightened to the loads specified.

(e) In some installations requiring the supply of hot air to moveable aerofoil surfaces, flexible couplings are used to join duct sections and are sealed by twin sealing rings between inner and outer sleeves of the coupling. When such a coupling or associated duct section is to be replaced it is important to fit new sealing rings in pairs.

(f) When installing sections of ducting supplying air to moveable aerofoil surfaces, care must be taken to ensure that sealing rings are correctly positioned with respect to swivel joints to permit full freedom of movement and to prevent leakage of air.

(g) New locking washers should be fitted to bolts which secure flanged type end fittings.

(h) When assembled on ducts, silicone rubber sleeves should be in a free condition, i.e. they should not be twisted, stepped or collapsed.

(j) Bedding tape or metal clips must be correctly located between rubber sleeves and adjustable clamps to prevent damage to the sleeves when tightening the clamps.

(k) Lagging, where fitted, should be inspected to ensure freedom from tears, damage and evidence of deterioration.

(l) Electrical bonding leads must be properly secured and tested electrically.

NOTE: Information on bonding and testing is given in Leaflet **EEL/1-6.**

(m) Expansion bellows, gimbal joints, sliding clamps or swinging link assemblies where installed, should be checked for full and free movement.

(n) In installations employing ducting having both inner and outer sections, threaded blocks are normally incorporated for attaching the ducting to the aircraft structure. When installing such ducting it is essential that the correct bushes, washers and bolts are assembled in the appropriate positions on the mounting bracket to prevent penetration of the inner duct skin by the mounting bolt.

(o) After replacement of a duct, the disturbed joints and appropriate section of ducting should be tested for leaks in the manner described in the relevant aircraft Maintenance Manual.

NOTE: The pressures specified for test purposes must not be exceeded and adequate safety precautions must be taken when inspecting ducts under pressure.

6.4 **Temperature Control Components.** The method of controlling the air temperature within the ducting of a system and within wing and tail unit leading edge sections, varies between systems and aircraft types; relevant Maintenance Manuals must therefore be consulted for the appropriate procedures for installing components. The details given in the following paragraphs are of a general nature only.

6.4.1 Temperature sensing elements for control and indication purposes should be inspected before installation for cleanliness, signs of damage and should be checked for proper functioning. New sealing rings, gaskets and retaining washers, as appropriate, should be fitted.

6.4.2 In some types of aircraft, the temperature control system employs a sensing element and a control valve which after bench setting are given the same serial number and must always be installed as a matched pair.

6.4.3 Cables interconnecting components must be of the rating specified by the manufacturer. All connections should be checked against the relevant wiring diagrams, and plugs, sockets and terminal screws properly secured.

6.4.4 All valves should be inspected for cleanliness, signs of damage and freedom of movement. New sealing rings and gaskets, as appropriate, should be fitted between valve jointing faces and ducting.

6.4.5 Before installation, functional checks should be carried out on electric actuators employed for the operation of butterfly valves, jet pipe flaps etc., to ensure that limit switches are correctly adjusted at the extremes of valve travel.

6.4.6 In certain systems deriving hot air from an engine compressor stage, shut-off valves of the electro-pneumatic type are employed. When installing these valves care must be taken to ensure that pressure sensing lines are undamaged and that they are correctly and securely coupled to the valve connecting unions.

6.4.7 Certain valves are often marked with arrows to indicate the direction of flow, particular care is therefore necessary to ensure that they are installed in correct relation to the flow.

6.4.8 The attachment of valves to their respective mountings and duct sections must be securely made and torque loadings strictly observed.

6.4.9 Electrical bonding leads must be properly secured after the installation of a component.

6.4.10 Mechanical linkages between electric actuators, inching control units, butterfly valves and flaps should be correctly adjusted to ensure that, after installation of a component, all movements are free and within the required range of travel. Where specified, linkages, exposed surfaces of actuator plungers, etc., should be lubricated with a low temperature grease.

6.4.11 On completion of the installation of a component associated with temperature control, an in-situ functional test should be carried out in accordance with the procedure specified in the relevant aircraft Maintenance Manual. Any limitations as to the duration of complete system functional checks must be strictly observed.

7 INSPECTION AND MAINTENANCE The information given in the following paragraphs on inspection, maintenance and functional testing, is only of a general nature and should be read in conjunction with Maintenance Manuals and approved Maintenance Schedules for the components and aircraft concerned.

7.1 **Heat Exchangers.** These units should be inspected for security of attachment to the aircraft structure, security of duct connections, evidence of engine exhaust gas leaks, evidence of overheating, and freedom from damage.

NOTE: Careful examination of connections is necessary to ensure that no leakage of exhaust gases into the main ducting of the de-icing system can occur (see Airworthiness Notices Nos. 40 and 41).

7.1.1 The external surfaces of a heat exchanger matrix must be clean and the ram air passages free from obstruction. If dirt or other forms of contamination are found, the surface and air passages should be cleaned by means of an air blast applied in a direction opposite to the normal air flow.

7.1.2 If a matrix has not been satisfactorily cleaned due to the contamination being excessive or hardened on to the surfaces, or if internal contamination or leakage is suspected, the heat exchanger should be removed for cleaning and repair and replaced by a serviceable unit.

7.1.3 Heat exchangers should be pressure tested at the periods and at the test figures recommended in the approved Maintenance Schedule.

7.2 **Combustion Heaters.** Heaters should be examined for security. The fuel system should be carefully checked for evidence of leakage and drain pipes checked to ensure freedom from obstruction. At the specified inspection periods, igniter plugs should be cleaned, and heaters should be subjected to a pressure test in accordance with the procedure laid down by the manufacturer.

7.2.1 Electrical wiring and associated electrical components should be checked for security, loose connections, chafing of insulation, etc. The sheath of the igniter plug cable should be examined for any possible indications of arcing, evident by burning or discolouration of the sheath.

7.2.2 Filters, air and fuel regulating devices, safety devices (e.g. overheat switches, fuel cut-off valves, etc.), and all controls should be inspected, adjusted and tested as required by the approved Maintenance Schedule.

7.2.3 System operation should be checked at the periods specified in the approved Maintenance Schedule and in the manner prescribed in the relevant aircraft Maintenance Manuals.

7.3 **Ducting.** All ducting should be inspected for security of attachment to the relevant parts of the aircraft structure, freedom from damage and overheating. Attention should be paid to weak and critical areas most likely to be found around bends and bifurcations where the gauge may be locally reduced by deformation during manufacture.

7.3.1 Joints between duct sections, and adjustable clamps should be secure and where appropriate tightened to specified torque values. Expansion bellows, flexible couplings and gimbal joint assemblies should be examined for freedom from cracks, distortion, corrosion and damage. Checks should also be made for free movement and, where necessary, manufacturing clearances should be checked to ensure they are within the limits specified for the installation.

7.3.2 Rupture disc and blow-out disc assemblies, where fitted, should be inspected for security and freedom from damage and a check made to ensure that the blow-out disc lies flush with the aircraft skin. In the event that a rupture disc has operated (indicated by protusion of the blow-out disc), or if there is any cause to suspect the application of excessive duct pressure, the rupture disc assembly must be replaced and the duct inspections detailed in the aircraft Maintenance Manual carried out. It should be noted that manual re-setting may require the replacement of a shear device which forms part of the blow-out disc assembly.

7.3.3 When specified, ducts should be tested for leaks in the manner prescribed in the relevant aircraft Maintenance Manual. The test pressures and rate of leakage should not exceed the limits quoted for the system.

NOTE: Adequate safety precautions must be taken when inspecting duct sections under pressure.

7.3.4 It is usually more convenient to test a complete duct system by dividing it into sections and applying a recommended pressure separately and in sequence. The sections should be selected so that all critical joints are subjected to the test pressure; advantage being taken of stop valves, non-return valves, etc., where these provide convenient boundaries between sections.

7.3.5 Air leaks can be detected by sound and where ducts are lagged, leaks are sometimes revealed by discoloration and holes blown in the lagging material. If there is any difficulty in locating leaks, the soap and water method is recommended.

7.3.6 Lagging should always be properly secured and free from oil, hydraulic fluids, etc.

7.4 **Temperature Control Components.** All components should be inspected for security of mounting, mechanical and electrical connections, signs of damage, deterioration of electrical cables, etc.

7.4.1 Moveable flaps, linkages and actuators associated with engine exhaust units and with heat exchangers, should be inspected for freedom of movement and where specified, lubricated with the oil or grease recommended in the relevant aircraft Maintenance Manual. Inter-connecting linkages, flap hinges, etc., should be checked for excessive play and evidence of lost motion.

7.4.2 Maintenance of valves, inching control units, etc., associated with temperature control is usually confined to inspection for cleanliness, security of mounting, ducting attachments and, where applicable, security of electrical connections, functioning tests and lubrication specified in the particular component Maintenance Manual.

7.4.3 Sliding or rotating parts of valve assemblies should be free from scores, damage or excess static friction. The maximum effort required to move a valve should be checked when necessary and should not exceed the figure recommended by the manufacturer. Valve seats and valve faces should be kept free of dust or traces of lubricant.

7.4.4 Temperature sensing elements, indicators and overheating warning devices should be checked for proper functioning and that the correct indications appropriate to system operating conditions are obtained. In the event that the pointer of an indicator moves to a position beyond maximum scale reading, the power supply should be switched off immediately and a continuity check of the sensing element and cables carried out, as this fault is an indication of an open circuit in the temperature sensing signal line.

7.4.5 The combined operation of components comprising a temperature control system should be checked during specified ground tests to ensure that they respond correctly to the selected operating conditions. The test procedures which must be carried out at the periods specified in the approved Maintenance Schedule vary, and the extent to which a system can be tested may, in some cases, be limited, particularly in relation to the duration of a test and the air temperature to be attained in leading edge sections. On the other hand, full-range temperature control of a system in some aircraft may be checked on the ground. Reference should be made to the relevant aircraft Maintenance Manual for the procedure to be adopted and limitations to be observed.

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AIRCRAFT

ICE PROTECTION

GROUND DE-ICING OF AIRCRAFT*

1 INTRODUCTION This Leaflet gives general guidance on the removal of frost, ice and snow from aircraft before flight. In-flight de-icing is dealt with in Leaflets **AL/11-1, AL/11-2, AL/11-4** and **AL/11-5**.

2 GENERAL

2.1 The presence of frozen deposits on an aircraft may be the result of direct precipitation (rain, snow, frost etc.,) or accretion of frost or ice on external surfaces of integral fuel tanks after prolonged flight at high altitude, or accumulations on the landing gear and forward surfaces or undersurfaces following taxying through snow or slush.

2.2 Any deposits of ice, snow or frost on the external surfaces of an aircraft may drastically affect its performance. This can be due to reduced aerodynamic lift and increased aerodynamic drag resulting from the disturbed airflow over the aerofoil surfaces, or due to the weight of the deposit over the whole aircraft. The operation of an aircraft may also be seriously affected by the freezing of moisture in controls, hinges and microswitches, or by the ingestion of ice into the engine. Furthermore, since the in-flight de-icing system may not become effective until the aircraft is established in the climbout, the measures taken to remove frozen deposits on the ground must also be such as to provide adequate protection during the initial stages of flight.

2.3 Neither the use of currently available Freezing Point Depressant (FPD) types of de-icing/anti-icing compounds, nor the use of manual techniques of de-icing with such compounds should be thought of as producing reliable anti-icing qualities for a definable period of time because the number of variables involved make it impractical to estimate that time. Only in the sense that under certain conditions FPD anti-icing compounds are known to be effective in retarding the formation of frost, snow or ice may they be considered to have anti-icing qualities for a period of time thus making the process of de-icing simpler and in many cases obviating the need for further de-icing or treatment during that period. It is emphasised, however, that the need for a close inspection of an aircraft prior to take-off still remains.

*CAP 512, entitled Ground De-icing of Aircraft is also available from CAA Printing and Publication Services, PO Box 41, Cheltenham, Glos. GL50 2BN Price £1.45 + 45p postage and packing. This CAP covers the text of this Leaflet, together with operational aspects and common practices or suggested practices for safe cold weather operation and general information relating to ground and flight operations in conditions conducive to aircraft icing.

2.4 The aircraft de-icing systems are designed to remove or prevent the accretion of ice on a specific area of the wings, tail and engine nacelles in flight and would not normally be effective in removing deposits which have accumulated while the aircraft is stationary. Their use on the ground may, in some instances, also cause a different type of unsatisfactory situation by melting parts of the deposit which would then freeze elsewhere. The use of cabin heating to remove deposits from the fuselage is also not recommended for the same reason.

2.5 When aircraft are moved so as to be under cover during inclement weather, any melted snow or ice may freeze again when the aircraft is subsequently moved into sub-zero temperatures. Complete protection could be provided by placing aircraft in heated hangars, but due to the size of modern transport aircraft and the need to meet schedules involving quick turnround times this is not often practicable. Removal of frost, ice and snow from aircraft is therefore often necessary and maintenance crews need to be familiar with the methods of ground de-icing in current use.

2.6 There are two main types of de-icing/anti-icing fluids:–

(a) **Type I fluids (unthickened).** These fluids have a high glycol content and a low viscosity. The de-icing performance is good, however, they provide only limited protection against refreezing.

(b) **Type II fluids (thickened).** These fluids have a minimum glycol content of approximately 50% and due to the thickening agent have special properties which enable the fluid to remain on the aircraft surfaces until take-off. The de-icing performance is good and, in addition, protection is provided against refreezing and/or build-up of further accretions, when exposed to freezing precipitation.

3 PRE-FLIGHT PREPARATION

3.1 The whole aircraft should be inspected to ensure that it is free from deposits of frost, ice and snow. When necessary, a de-icing fluid should be used. The objectives of using such fluids are to achieve effective removal of any frost or ice and to provide a measure of protection against any further formation. Only fluids approved for the purpose should be used.

3.1.1 The ability of the fluid to achieve the above objectives under varying atmospheric conditions is dependent upon the correct mixture strength and methods of application, both of which should be strictly in accordance with recommended procedures. For example, while fluid diluted with water may effectively remove ice, its ability to prevent further formation will be significantly reduced, and under certain conditions the fact that the aircraft surfaces are wetted may actually enhance the accumulation of wet snow.

3.1.2 Where adequate advice on approved fluids, mixture strength and methods of application is not given in the relevant aircraft Maintenance Manuals, guidance should always be sought from the aircraft manufacturer and from the suppliers of the fluid. The following information is only intended as general information and should not be used to override that which is contained in the aircraft Maintenance Manuals.

3.1.3 Advances in the composition of de-icing fluids have led to the production of a dual purpose anti-icing barrier fluid (DTD 900/4907) which is capable of removing ice and snow and delaying deposits re-forming. When used as a de-icing agent, this fluid should be mixed with the required volume of water and applied at a temperature of approximately 70°C by the method described in paragraph 5.2. It is however, strongly recommended that refractometer readings be taken so that the precise concentration of the solution can be determined.

NOTE: Pocket refractometers are available which permit on-site measurement of fluid concentration as a refractive index which can be converted to fluid/water proportions accurately by means of a chart.

3.1.4 Table 1 gives a guide to some typical maximum times during which the residual film of fluid may be effective in providing protection from re-freezing. It must be appreciated, however, that the period of protection will vary dramatically, depending upon the severity of the particular condition. Visual checks of the aircraft external surfaces are therefore always required to confirm the actual condition of the aircraft in extreme conditions of snow and freezing rain.

TABLE 1

GUIDELINE TO HOLDOVER TIMES

Ambient temper-ature °C	Weather conditions					Probable safe period of protection			
	Steady snow	Frost	Freez-ing fog	Freez-ing rain	Rain	Kilfrost ABC 100%	Kilfrost ABC or Hoechst 1704 + water 70/30	Kilfrost ABC or Hoechst 1704 + water 60/40 or 50/50	Any other approved fluid + water
+3 and above	*					4 hours	3 hours	2 hours	1 hour
+3 to zero	*					2 hours	1¼ hours	45 mins	15 mins
		*				10 hours	6 hours	4 hours	1½ hours
			*			3 hours	2 hours	1½ hours	30 mins
				*		45 mins	20 mins	15 mins	10 mins
					*	1 hour	45 mins	30 mins	15 mins
zero to –5	*					1 hour	40 mins	30 mins	15 mins
		*				8 hours	5 hours	3 hours	1½ hours
			*			2 hours	1¼ hours	1 hour	30 mins
				*		45 mins	20 mins	15 mins	5 mins
–5 to –10	*					1 hour	40 mins	30 mins	15 mins
		*				8 hours	5 hours	3 hours	1½ hours
			*			1½ hours	1 hour	45 mins	30 mins
–10 and below	*					1 hour	40 mins	–	20 mins
			*			1½ hours	1 hour	–	20 mins

NOTE: Kilfrost ABC is normally available in a solution of 50/50, 60/40 or 70/30. It may be difficult to get stronger solutions at short notice unless the temperature conditions at the aerodrome involved are below limits for that solution mix (see Table 2).

TABLE 2

LOWER TEMPERATURE LIMITS

Mixture strength (Glycol/water)	Kilfrost ABC	Hoechst 1704	Mil. Spec. Fluids 8243
30/70	–	–	–11°C
40/60	–	–	–18°C
50/50	–7½°C	–7½°C	–35°C
60/40	–10°C	–10°C	–
70/30	–13°C	–13°C	–
100%	–28°C	–28°C	–

4 FROST DEPOSITS AND METHODS OF TREATMENT

4.1 A deposit of frost is best removed by the use of a frost remover or, in severe conditions, a de-icing fluid (e.g. Kilfrost ABC or similar proprietary fluids). These fluids normally contain either ethylene glycol and isopropyl alcohol or diethylene glycol (or propylene glycol) and isopropyl alcohol, and may be applied by spray or by hand. The process is not lengthy, as one application is usually sufficient, provided that it is applied within the two hours prior to flight.

NOTES: (1) De-icing fluids may adversely affect glazed panes or the exterior finish of aircraft, particularly when the paint is new. Only the type of fluid recommended by the aircraft manufacturer should therefore be used and any instructions relating to its use should be strictly observed.

(2) De-icing fluids, particularly those with an alcohol base, may cause dilution or complete washing out of oils and greases from control surface bearings, etc., allowing the entry of water which could subsequently freeze, jamming controls. Spray nozzles should not, therefore, be directed at lubrication points or sealed bearings and an inspection of areas where fluid may be trapped is usually necessary. The Maintenance Schedule may specify relubrication in these areas whenever de-icing fluids are used.

4.2 Frost may also be removed from aircraft surfaces using a mobile unit capable of supplying large quantities of hot air through a delivery hose and nozzle. The air is blown on to the wings, fuselage and tail surfaces and either blows away or melts any frost deposits. Operators using this equipment should ensure that any melted frost is deied up and not allowed to accumulate in hinges, microswitches, etc., where re-freezing could occur.

5 ICE AND SNOW DEPOSITS AND METHODS OF TREATMENT Probably the most difficult deposit to deal with is deep wet snow when ambient temperatures are slightly above freezing point. This deposit should be removed with a brush or squeegee, care being taken not to damage aerials, vents, stall warning vanes, pitot probes, vortex generators, etc., which may be concealed by the snow. Light dry snow in sub-zero temperatures should be blown off whenever possible; the use of hot air is not recommended, since this would melt the snow, which would then freeze and require further treatment. Moderate or heavy ice and residual snow deposits should be removed with a de-icing fluid, which may be successfully applied to any aircraft by spraying; in severe cnditions it may be necessary to spray a final application immediately before flight. The aircraft nose and cockpit canopy should normally be left dry to ensure that the windscreen does not become contaminated with fluid which could cause smearing and reduced vision. Windscreens should be cleared by wiping with an alcohol-soaked cloth or by use of the windscreen anti-icing system.

NOTES: (1) No attempt should be made to remove ice deposits or break an ice bond by force.

(2) It is essential that removal of deposits proceeds symmetrically.

5.1 **Cold Fluid Spray.** A cold fluid spray is the simplest method of applying de-icing fluid, but suffers from several disadvantages which must be considered in relation to the particular circumstances.

5.1.1 In very severe conditions one sprayed application of cold fluid may not be sufficient to remove all the ice and snow; brushing or rubbing thickly iced areas is usually necessary, followed by a second or even third application of fluid. As the ice and snow melts, the fluid is diluted, becomes less effective and is prone to freezing again quite quickly. This may have serious consequences if the diluted fluid is allowed to run into control surface and landing gear mechanisms. Under these conditions the cold spray method may be both prolonged and expensive.

5.2 **Hot Fluid Spray.** Many airline operators have dispensed with the use of cold spraying techniques except at small airports and in an emergency. They have adopted a hot fluid spraying system which was developed specifically to reduce turnround times and to inhibit the bonding of ice and smow to aircraft surfaces for a period of time. The equipment used consists of a static unit, in which quantities of both water and de-icing fluid are heated, and a mobile unit which houses an insulated tank, a pump, an hydraulically-operated boom-mounted platform and several spray lances.

5.2.1 In this system hot fluid is pumped from the static unit to the insulated tank on the mobile unit, the proportions of water and de-icing fluid being adjusted to suit prevailing weather conditions. The mobile unit is then driven to the site of operations, the optimum number and disposition of unitsbeing found by experience on a particular aircraft type.

5.2.2 The fluid is normally sprayed on at a temperature of 70°C and a pressure of 700 kN/m^2 (100 lbf/in^2), holding the nozzle close to the aircraft skin to prevent heat losses. Heat is transferred to the aircraft skin, thus breaking the ice bond, and large areas of ice may be flushed away by turning the nozzle sideways. In this way, time is saved and the dilution of fluid with ice and snow reduced to a minimum. The film of fluid left on the aircraft skin, being only slightly further diluted, is effective in preventing ice re-forming.

NOTE: Overheating, in the de-icing rig, of most de-icing fluids will result in a gelled formation being deposited on the aircraft which will not shear off on take-off and may, therefore, have an adverse aerodynamic effect.

5.2.3 **Hot Water De-Icing.** Hot water de-icing should not be carried out at temperatures below –7°C, and the second step must be performed within three minutes of the beginning of step 1, if necessary area by area.

(a) **Step 1.** Snow and ice is initially removed with a jet of hot water at a maximum temperature of 95°C.

(b) **Step 2.** A light coating of de-icing fluid is then immediately applied to the aircraft to prevent re-freezing.

5.3 **High Pressure Sprays**

5.3.1 High pressure sprays used for de-icing are capable of causing damage to pitot-static probes and other sensing devices. A carelessly directed spray could also result in the ingress of a considerable quantity of fluid into engine intakes, drains or vents, possibly resulting in cabin smoke or malfunction of an associated aircraft system. Where covers or bungs are provided they should be fitted during de-icing operations. Where this is not possible care must be taken to prevent direct impingement of the spray on any vents or probes.

5.3.2 High pressure sprays can also cause erosion of the aircraft skin and some aircraft manufacturers recommend a maximum impingement pressure which is quoted in the appropriate Maintenance Manual and should not be exceeded.

5.4 **De-icing of Aircraft with Engines Operating**

5.4.1 Aircraft 'taxi-through' de-icing facilities are presently being used which de-ice aircraft with the engines operating. Winter environmental conditions and the manner of application create potentially unsafe conditions if an incorrect de-icer solution is inadvertently sprayed into the engine/APU inlets or contacts the exhausts when the engines or APU are operating. APU and engine bleeds should be closed during such operations to minimise the risk of contamination of the cabin environment.

5.4.2 De-icing fluids have a flashpoint of 139 to 156°C in their undiluted state which is within the engine/APU operating range. The numerous de-icing fluids available also include some which have toxic characteristics that could affect personnel or passengers if ingested by the air-conditioning system.

5.4.3 Some aircraft manufacturers issue instructions which contain precautions concerning fluids and techniques for de-icing aircraft with engines operating. A safety hazard could exist if the manufacturer's instructions are not followed.

5.4.4 Safeguards should include procedures which ensure that de-icing fluids are diluted below critical flashpoints and that such fluids are prevented from entering air ducts, air-conditioning systems, and engines/APU inlets or exhaust.

5.4.5 Fire and emergency equipment should also be readily available at all times.

6 ANTI-ICING MEASURES

6.1 When used as an anti-icing agent, the FPD fluid shuld be sprayed onto the aircraft cold and undiluted, either before the onset of icing conditions or after hot de-icing has been carried out. This will leave a film of fluid approximately 0·5 mm (0·020 in) thick on the surfaces sprayed and give protection overnight in all but the most severe weather conditions. The fluid prevents ice and snow from sticking to the aircraft skin and given time will melt any fresh precipitation. Newly fallen snow may be quickly removed by blowing, and heavy ice deposits, such as those produced by freezing rain, may be removed by a light and economical spray of hot fluid. Excess fluid will shear off during the take-off run (but see paragaph 5.2.2 Note).

NOTE: FPD compound should not be applied to windscreens or essential glazed panels as it will severely restrict vision.

6.2 On some aircraft not equipped with an aerofoil de-icing system, the use of a de-icing paste may be specified. This paste is intended to prevent the accumulation of frozen deposits which may result from inadvertent flight into icing conditions. When spread smoothly by hand over the leading edges of the wings and tail unit the paste presents a chemically active surface, on which ice may form but may not bond. Any ice which does form may ultimately be blown off in the airstream.

6.2.1 The paste should be reactivated before each flight in accordance with the manufacturer's instructions.

WARNING: It is important to note that de-icing pastes do not constitute an approved method of de-icing otherwise unprotected aircraft for intended flights into known or forecast icing conditions.

7 INSPECTION AFTER DE-ICING OPERATIONS It is important to carry out an inspection of an aircraft after completion of de-icing operations. The aircraft should also be continually monitored between de-icing and departure to ensure no further ice build-up has occurred. The presence of ice in certain areas may not be obvious to personnel handling the de-icing equipment.

NOTE: The effective duration of anti-icing fluids depends on concentration/temperature of application, volume of snow and ice, etc., subsequent ambient temperature and time.

7.1 All external surfaces should be examined for signs of residual snow or ice, particularly in the vicinity of control surface gaps and hinges. This is especially important where control surfaces are sealed by 'curtains' of the Westland-Irvine type. Drainage or pressure sensing holes and radiator honeycombs should be checked to ensure that they are not blocked. Where it has been necessary to physically remove a layer of snow all protrusions and vents should be examined for signs of damage.

7.2 Where possible, control surfaces should be moved by hand to ascertain that they have full and free movement. Where this is not possible the pilot's controls should be gently operated, bearing in mind that power operated controls exert considerable force on the control surface and could cause damage if any part of the circuit is frozen. If any restriction is found, the control cables, pulleys, fairleads, hinges, etc., should be examined and any frozen deposits treated with de-icing fluid until smooth control operation is achieved.

7.3 The landing gear mechanism, doors, bays and wheel brakes should be inspected for snow or ice deposits, and the operation of uplocks and microswitches checked. In very sever conditions it is possible for the tyres to become frozen to the ground; they may be freed by the application of warm air to the ice (not the tyre) and the aircraft should then be moved to a dry area.

7.4 Snow or rain can enter jet engine intakes after flight and freeze in the compressor when the engine has cooled. If compressors cannot be turned by hand for this reason, the engine should be blown through with hot air immediately before starting, until the rotating parts are free.

7.5 The low temperatures associated with icing conditions may also introduce problems apart from those associated with the clearance of precipitation.

7.5.1 Contraction of metal parts and seals can lead to fluid leakage and particular attention should be given to landing gear shock sbsorber struts and hydraulic jacks.

7.5.2 Tyre and shock absorber strut pressures reduce with temperature and may require adjustment in accordance with the loading requirements.

8 **TECHNICAL LOGS** An entry should be made in the Technical Log as required by British Civil Airworthiness Requirements, Section A, Chapter **A6-8**, unless an alternative company procedure has been agreed by the CAA.

AL/11-4

Issue 2

June 1986

AIRCRAFT

ICE PROTECTION

WINDSCREEN DE-ICING AND ANTI-ICING SYSTEMS

1 INTRODUCTION This Leaflet gives details of operating principles and general guidance on the installation and maintenance of windscreen de-icing and anti-icing systems employing fluids and electrical heating elements. It should be read in conjunction with the Maintenance Manuals and operators Maintenance Schedules for the type of aircraft concerned. Reference should also be made to Leaflet **AL/7-10,** Glass Windscreen Assemblies, for information on the construction, installation and maintenance of windscreens.

2 FLUID DE-ICING SYSTEM The method employed in this system is to spray the windscreen panel with a methyl-alcohol based fluid. The principal components of the system are a fluid storage tank, a pump which may be a hand-operated or electrically-operated type, supply pipe lines and spray tube unit. Figure 1 illustrates the interconnection of components based on a typical aircraft system in which fluid is supplied to the spray tubes by two electrically-operated pumps. The system may be operated using either of the pumps or both, according to the severity of icing.

3 ELECTRICAL ANTI-ICING SYSTEM This system employs a windscreen of special laminated construction heated electrically to prevent, not only the formation of ice and mist, but also to improve the impact resistance of the windscreen at low temperatures (see Leaflet **AL/7-10** paragraph 3.1.2).

3.1 The film-type resistance element is heated by alternating current supplied from the aircraft's electrical system. The power required for heating varies according to the size of the panel and the heat required to suit the operating conditions. Details of these requirements are given in the relevant aircraft Maintenance Manual.

3.2 The circuit embodies a controlling device, the function of which is to maintain a constant temperature at the windscreen and also to prevent overheating of the vinyl interlayer which would cause such permanent damage as vinyl 'bubbling' and discolouration (see also Leaflet **AL/7-10** paragraphs 5.1.6 and 5.1.7). In a typical anti-icing system shown schematically in Figure 2, the controlling device is connected to two temperature sensing elements laminated into the windscreen. The elements are usually in the form of a fine wire grid, the electrical resistance of which varies directly with the windscreen temperature. One sensing element is used for controlling the temperature at a normal setting and the other is used for overheat protection. A system of warning lights and, in some cases, magnetic indicators, also forms part of the control circuit and provides visual indications of circuit operating conditions, e.g. 'normal', 'off' or 'overheat'.

3.2.1 When the power is applied via the system control switch and power relay, the resistance element heats the glass. When it attains a temperature pre-determined for normal operation the change in resistance of the control element causes the control device or circuit to isolate, or in some cases to reduce, the power supply to the heater element. When the glass has cooled through a certain range of temperature, power is again applied and the cycle is repeated. In the event of a failure of the controller, the glass temperature will rise until the setting of the overheat sensing element is attained. At this setting an overheat control circuit cuts off the heating power supply and illuminates a warning light. The power is restored and the warning light extinguished when the glass has cooled through a specific temperature range. In some systems a lock-out circuit may be incorporated, in which case the warning light will remain illuminated and power will only be re-applied by cycling the system control switch to 'OFF' and back to 'ON'.

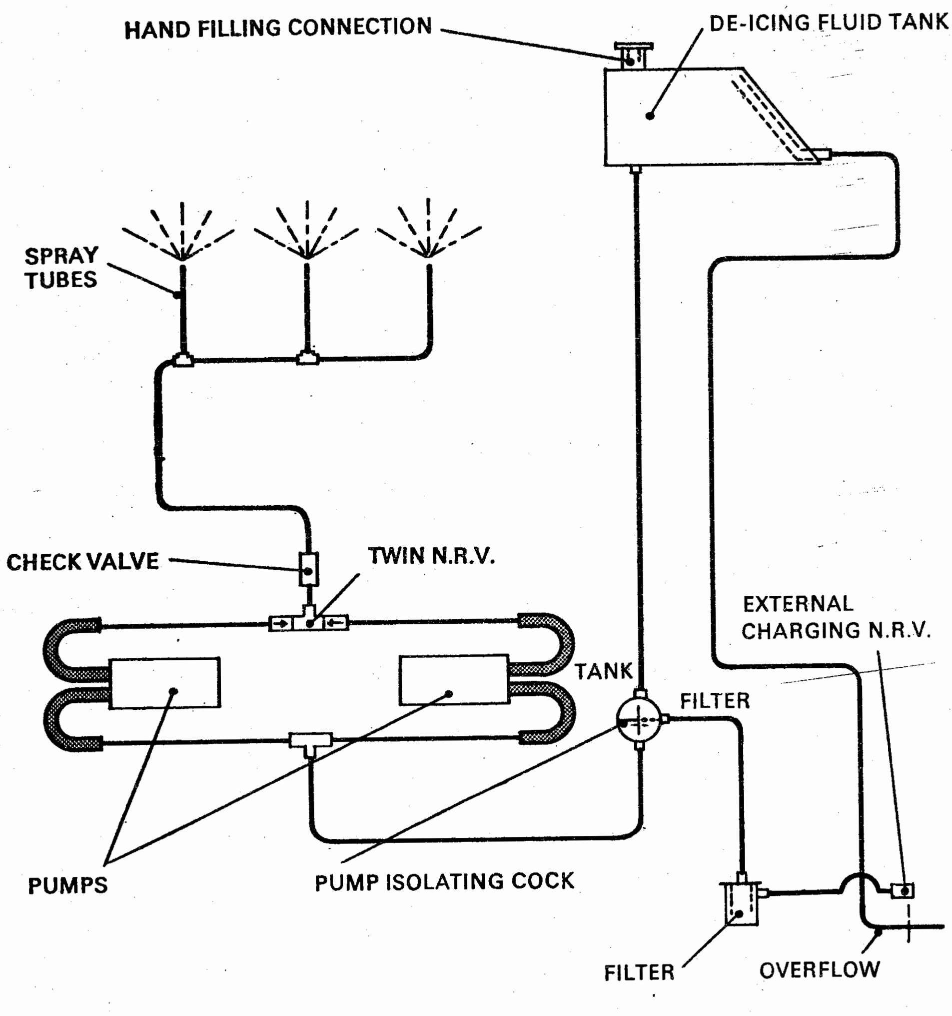

Figure 1 TYPICAL FLUID DE-ICING SYSTEM

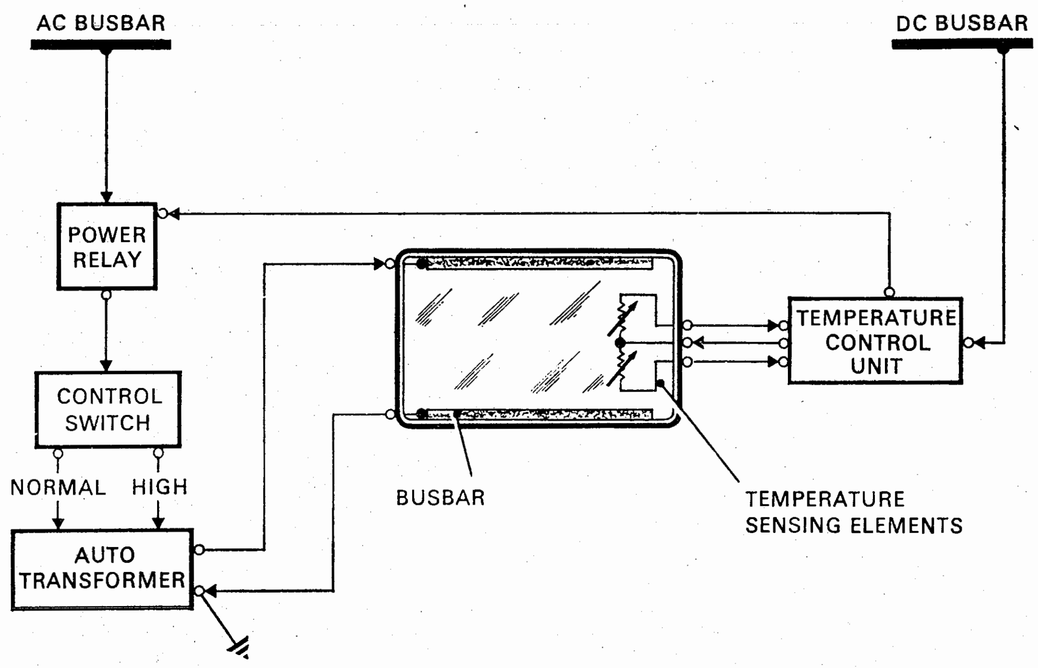

Figure 2 TYPICAL ELECTRICAL ANTI-ICING SYSTEM

(a) In addition to the normal temperature control circuit it is usual to incorporate a circuit which supplies more heating power under severe icing conditions when heat losses are high. When the high power setting is selected, the supply is switched to higher voltage output tappings of an auto transformer which also forms part of an anti-icing system circuit thus maintaining the normal operating temperature. The temperature is controlled in a manner similar to that of the normal control temperature circuit.

(b) For ground testing purposes, the heating power supply circuit may also be controlled by landing gear shock-strut microswitches in such a way that the voltage applied to the resistance elements is lower than that normally available in flight.

4 INSTALLATION AND MAINTENANCE Details of the installation methods and maintenance requirements for a particular aircraft system will be found in the Maintenance Manual and approved Maintenance Schedules for the aircraft concerned. The information given in the following paragraphs is intended as a guide and should be read in conjunction with relevant Maintenance Manuals and approved Maintenance Schedules. Reference should also be made to Leaflets **AL/3-13, AL/3-14** and **AL/3-15** which deal with the installation of pipelines and supply tanks, and Leaflets **EEL/1-6** and **EEL/3-1** for guidance on the installation of electric cables and testing of circuits.

4.1 **Fluid De-icing Systems.** The installation and maintenance of components and pipelines of fluid de-icing systems is, in general, a straightforward procedure and only requires checks to ensure security of attachment to appropriate parts of the aircraft structure, signs of fluid leakage, security of connections and wirelocking where necessary. After installation of a component and at the periods detailed in the aircraft approved

Maintenance Schedule, the tank contents should be checked and replenished with the specified fluid as necessary. The system should also be tested to ensure proper functioning and checks made for fluid leakage at the connections of the various components. Fluid filters, where fitted, should also be inspected for cleanliness.

4.1.1 **Tank Replenishment.** A tank is normally filled by hand through a filler neck in the tank, but in some systems an external charging connection (see Figure 1) is provided for the purpose of pressure filling. An isolating cock at the charging connection location is fitted in the line between tank and pumps and has a third connection which must be coupled to the charging connection before filling. A hand pump should be used for pressure filling to avoid excessive pressure build-up within the tank. On completion of a tank replenishment process, filler caps or blanking plugs must be replaced and correctly secured, isolating cocks returned to their normal operating condition and wirelocked.

NOTE: Care should be taken to avoid spillage of fluid during tank replenishing, and drips should be removed immediately. In a system employing a tank having an overflow pipe a receptacle should be placed at the pipe outlet to catch any fluid.

4.1.2 **Testing of Systems.** With the tank filled with de-icing fluid the pump, or pumps, should be operated and a check made that an even amount of fluid discharges from the spray unit, and is directed on to the panels. Receptacles should be positioned to catch the fluid and any spillage should be removed immediately. The system pipelines and couplings should be checked for fluid leakage. On satisfactory completion of all checks the fluid tank should be replenished.

4.2 **Electrical Anti-icing Systems.** Before installation, the electrical resistance of the conducting film and the temperature sensing elements should be measured to ensure that it is within the limits specified in the relevant aircraft Maintenance Manual. The resistances of conducting films may, in some cases, have to be matched by selective assembly. In certain types of aircraft an indication of conducting film resistance is also given by a code number etched in the corner of the glass near the busbar terminals.

4.2.1 The power supply and temperature sensing circuit cables should be identified in accordance with the system wiring diagram and connected to their appropriate terminals. The terminals on the windscreen and cable end connections should be checked for contamination such as grease or paint before making connections. This check applies particularly to sensing circuit terminals since contamination could increase the circuit resistance, signalling to the control unit that the windscreen was continuously hot thereby stopping the power supply.

4.2.2 Auto transformers are provided with several voltage output tappings which permit the voltage to be varied appropriate to heating element resistance, e.g. the resistance increases with age, and so it would be necessary to increase the applied voltage. Cables must therefore be connected to the transformer tappings detailed in the relevant Maintenance Manual, to ensure correct operating temperatures and adequate protection against ice.

4.2.3 The type of temperature control unit varies between types of aircraft and system; it is therefore necessary to check part numbers to ensure that a unit is correct for the supply voltage and sensing element circuit resistance requirements. In some units potentiometers, or fine adjustment resistances, are provided to vary the temperature controlling point. These are preset and must not be disturbed after installation of the unit.

4.2.4 At the periods specified in the approved Maintenance Schedule, all components should be checked for security of attachment, security of electrical connections and for evidence of any damage. System functioning checks should also be carried out.

4.2.5 **Testing of Systems.** The method of testing varies between individual systems; reference should therefore be made to relevant aircraft Maintenance Manuals for details of procedure to be adopted, specific test equipment required and also for any precautions to be observed. There are, however, aspects of testing and certain precautions which are of a standard nature, and these are summarised for guidance as follows:—

(a) In general, test procedures are principally concerned with the checking of the electrical resistance of heating films and temperature sensing elements, checking of the voltages applied at selected system operating conditions, e.g. 'normal', 'low' and 'high' settings of a system control switch and also checking of insulation resistance between circuits.

(b) Electrical power should always be applied initially at low intensity and the windscreen allowed to warm up gradually thus minimising the effects of thermal shock stresses.

(c) When carrying out resistance and voltage checks of some anti-icing systems it is necessary to isolate the overheat sensing element circuit. In such cases, the period of time during which power is applied to the heating elements must be kept to a minimum to avoid overheating of the windscreens.

(d) In systems incorporating electrically heated direct vision and other side windows, the circuits to these windows must be checked at the same time as the windscreen anti-icing system checks.

(e) During ground testing attention should be paid to the effect of ambient temperature and strong sunlight on the behaviour of temperature control systems. Ambient temperatures approaching those of the normal operating temperature of windscreens will result in a very brief application of power, followed by no power for a considerable period. In some instances power will not be applied at all. It is possible, therefore, to be misled into believing that a serviceable system is malfunctioning. Where it is necessary to carry out system tests and checks in such conditions, it is recommended that the aircraft be positioned in the shade or in a hangar if practicable, and also that cool wet cloths be applied to the windscreens thereby lowering their temperature prior to switching on the power. Bearing in mind thermal shock stresses, the use of ice should be avoided.

AIRCRAFT

ICE PROTECTION

FLUID DE-ICING SYSTEMS

1 INTRODUCTION This Leaflet gives general guidance on the installation and maintenance of fluid systems used in certain types of aircraft, for de-icing wings and tail units. It should be read in conjunction with Maintenance Manuals and approved Maintenance Schedules; such documents providing details of construction, major servicing and test procedures relevant to specific aircraft installations and components.

2 GENERAL In systems of this type, a de-icing fluid is drawn from a storage tank by an electrically driven pump and fed through micro filters to a number of porous metal distributor panels. The panels are formed to the profiles of the wing and tail unit leading edges into which they are fitted. At each panel the fluid passes into a cavity, and then through a porous plastic sheet to a porous stainless steel outer skin. As the fluid escapes it breaks the bond between ice and the outer skin and the fluid and ice together are directed rearward, by the airflow, over the aerofoil.

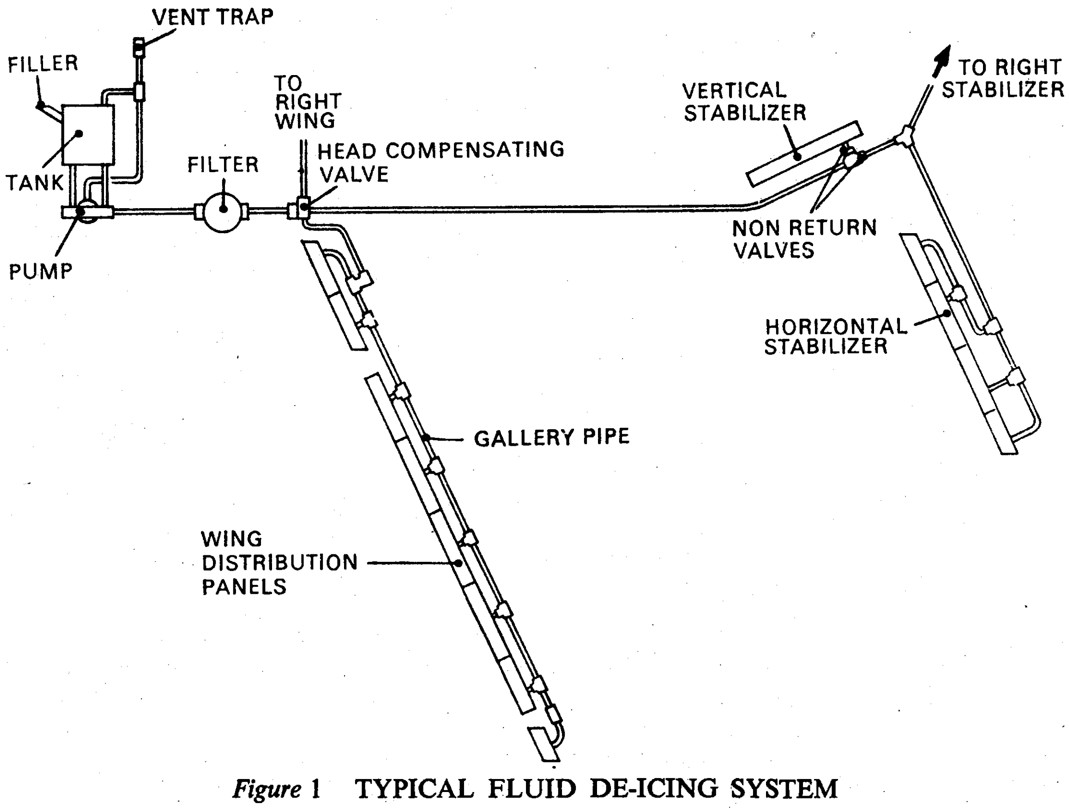

Figure 1 TYPICAL FLUID DE-ICING SYSTEM

2.1 The interconnection of components of a typical fluid de-icing system is shown in Figure 1. The head compensating valve is fitted in some types of aircraft to correct for variations in system pressure (head effect) due to differences in level between the wings, horizontal and vertical stabilisers. The non-return valves prevent back flow when the system is inoperative. Nylon pipelines are usually used throughout the system; those for the main fluid supply being of 8 mm ($\frac{5}{16}$in) inch outside diameter and those for connections to individual distributor panels of 4·7 mm ($\frac{3}{16}$ in) outside diameter.

2.2 A sectional view of a typical distributor panel is shown in Figure 2. The connector contains a metering tube which is accurately calibrated to provide the required rate of fluid flow through the distributor. In some aircraft the metering of fluid to the distributor panels is done via proportioning units containing the corresponding number of metering tubes.

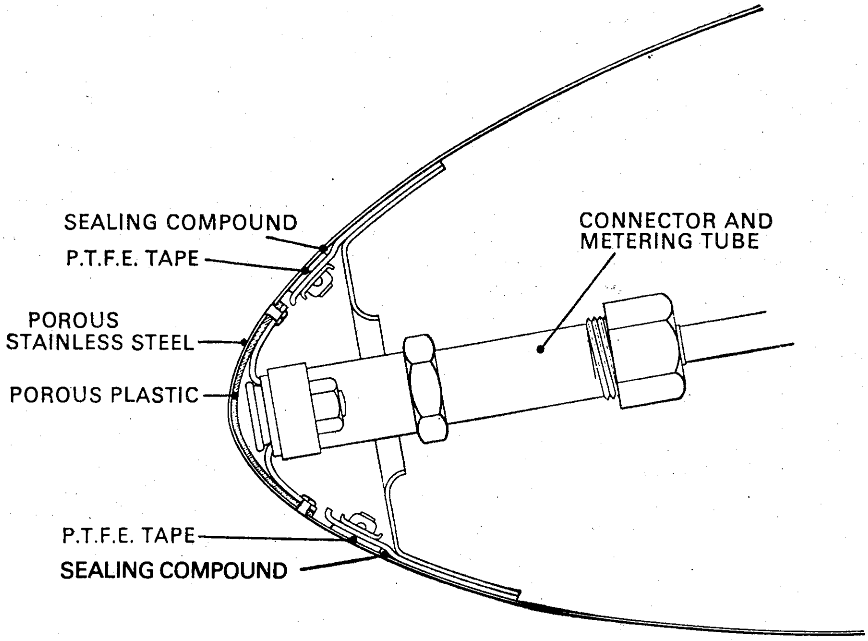

Figure 2. SECTION OF A TYPICAL DISTRIBUTOR PANEL

2.2.1 To prevent electrolytic corrosion, plastic sealing strips are interposed between the stainless steel panel and the metal used in the aerofoil structure. In some installations (see Figure 2) an epoxy resin sealing compound is used, and to facilitate the removal of a panel it is sprayed along its edges with a thin coating of polytetrafluourethylene (p.t.f.e.) to act as a release agent. In addition, a strip of p.t.f.e. tape may be laid along the mating surfaces of the aerofoil structure.

3 INSTALLATION AND MAINTENANCE Details of the installation methods and maintenance requirements for a particular aircraft de-icing system will be found in the Maintenance Manual and approved Maintenance Schedule for the aircraft concerned. The information given in the following paragraphs is intended as a guide and should be read in conjunction with such manuals and schedules. Reference should also be made to

Leaflets **AL/3-13, AL/3-14** and **AL/3-15** which contain information relevant to the installation of pipelines and supply tanks, and Leaflets **EEL/3-1** and **EEL/1-6** for guidance on the installation of electric cables and testing of circuits.

3.1 **Distributor Panels.** Before installation of a distributor panel the part number should be checked to ensure that it is the correct type for the aircraft. Where aerofoils are not symmetrical odd part numbers usually indicate a left-hand component and even numbers right-hand. A check should also be made for signs of corrosion, damage and deformation of the panel profile. Panels which are to be sealed by an epoxy resin compound should also be checked to ensure that the coating of p.t.f.e. release agent is undamaged.

3.1.1 New seals should be fitted to the pipe union of the panel and the pipeline securely coupled and wire-locked. The system pump should be switched on to prime the distributor panel and a check made on the pipe coupling for signs of fluid leakage.

NOTE: Care should be taken to prevent de-icing fluid from running along the surfaces of aerofoils and adjacent parts of the structure.

3.1.2 On satisfactory completion of the leakage check, the de-icing pump should be switched off and the distributor panel secured to the structure in the manner specified for the installation. Attachment screws must be tightened evenly; during tightening, checks should be made to ensure that no distortion of the panel takes place.

3.1.3 After installation of a panel, a check should be made to ensure that a smooth and continuous profile, free from high spots or depressions, is maintained both chordwise and spanwise. Where specified, special shims may be fitted under a distributor panel to maintain a smooth profile.

NOTE: After installing distributor panels on some types of aircraft, a test flight must be carried out to check the stall characteristics.

3.1.4 When an epoxy resin compound is required for sealing a panel-to-wing joint, it must be applied uniformly to maintain a smooth and continuous profile. Care must be taken to prevent the compound coming into contact with the porous surface of the panel.

3.1.5 Metering tubes are removeable items and are calibrated according to panel part numbers in order to achieve the correct flow rate at the appropriate locations. It is essential therefore, that when it is necessary to remove and refit a metering tube it should first be identified with its distributor panel. A new rubber sealing grommet must be fitted and the distance from the end of the metering tube checked to ensure that it corresponds to the value given in the relevant aircraft Maintenance Manual.

3.1.6 Dirt accumulated on the panels in service should be removed with a clean water spray and soft brush. A mild detergent and water solution may also be used.

NOTE: The surfaces of distributor panels must not be cleaned with polishing materials or solvents.

3.1.7 During repainting of an aircraft, distributor panels should be masked with a non-adhesive material attached to the panels at the top and bottom edges only, by masking tape.

3.1.8 Care must be taken to avoid damaging the panels, particularly when refuelling. The refuelling hose must not be allowed to rest on, or vibrate against, the wing leading edge.

3.2 **Fluid Storage Tank.** Before installation, the tank should be inspected for signs of damage and interior cleanliness, and the tank supporting structure checked to ensure that it is in a suitable condition to receive the tank. With the tank accurately positioned it should be firmly secured by the mounting straps or mounting bolts as appropriate to the type of tank. Blanks should be removed from all pipe unions, new sealing rings fitted and the pipelines connected and wire-locked.

3.2.1 In a system utilising a tank with an electrical fluid contents indicating system the insulation resistance between the tank and earth should be checked to ensure that it is within the value specified in the relevant aircraft Maintenance Manual. The attachment of the tank transmitter unit and cable connections should be checked for security. Indicating systems should be checked and adjusted in the manner specified in the relevant Maintenance Manual.

3.2.2 After the installation of a tank, and whenever system priming operations and test procedures are carried out, the tank contents should be checked and replenished with the specified fluid as necessary. Replenishment of a tank is normally carried out by hand through a filler connection in the tank itself. Before refitting the filler cap, the sealing washer should be checked for serviceability and replaced as necessary. Strainers, when fitted, should be checked for serviceability and cleanliness.

NOTES: (1) The specification number of the fluid should be stencilled on the structure above the tank filler aperture.

(2) Care should be taken to avoid spillage of fluid during tank replenishing, and drips should be removed on completion.

3.3 **Pumps.** Before installing a pump it should be inspected for signs of damage, and checks made that the part number of the pump is correct for the particular installation. An electrical power supply at the specified voltage should be connected to the pump motor and a functioning check carried out.

NOTE: The inhibiting fluid should be retained in the pump for the functioning check, the duration of which should not exceed the figure specified for the particular type of pump. Dry running of a pump is not permissible.

3.3.1 On completion of the functioning check, the pump should be drained of inhibiting fluid and secured to its mounting. New sealing rings should be fitted to the pump and pipeline connections and the union nuts tightened to the specified torque values and wire-locked. The tank should be filled and the pump connections checked for signs of fluid leakage.

3.3.2 Electrical connections and pump bonding lead must be securely made and the pump operated to check that fluid is delivered to the distributor panels. If fluid is not pumped through the system the pump should be switched off immediately and the cause of the fault investigated and rectified.

3.3.3 If a pump is to be removed from an aircraft for a period exceeding 10 days, it must be inhibited with fluid to Specification DTD 5540B and all pipe connecting unions blanked off with protection caps.

3.4 **Pipelines and Couplings.** Pipelines should be supported by clips spaced not more than 457·2 mm (18 in) apart. Where there is more than one pipe in a run the pipes should be strapped together at approximately every 152·4 mm (6 in).

3.4.1 The ends of nylon pipes are connected to their respective unions by an olive and a sealing ring. Before connecting a pipe the olive must be inspected to ensure that it is firmly clenched to the pipe; the pipe should extend approximately 6·3 mm (0·25 in) beyond the clenched end of the olive. A new sealing ring must be fitted over the end of the pipe and to butt against the olive, and after the pipe is inserted into its coupling, the ring must be carefully packed into the recess.

NOTE: An olive must be fully clenched as a separate operation before the introduction of the sealing ring. Any attempt to clench the olive with the ring in position will destroy the ring and prevent the olive from locking correctly on to the pipe. Sealing rings must be correctly located and not twisted or damaged.

3.4.2 Pipelines should not be crushed or kinked and the minimum bend radii should comply with the dimensions specified in the relevant Maintenance Manual.

3.5 **Proportioning Units.** Before installing proportioning units a check should be made that they are of the correct type. Units are identified in two ways; by the part number which includes a variation number relating to the calibration, and by a description of the aircraft type and location for which each unit is calibrated.

3.5.1 Pipelines should be checked to ensure that the outlets of the proportioning units are connected to their respective distributor panels in the correct sequence.

3.5.2 If a metering unit becomes blocked it should be removed and its tubes cleaned with compressed air. During re-assembly of the unit the sealing washer and locating key must fit correctly in the manifold.

3.6 **Filters.** After installation, the system should be operated until fluid flows from the filter outlet connection or, if provided, from a bleed screw hole. The pump should then be switched off and the filter outlet connection or bleed screw as appropriate, refitted.

3.6.1 The filter element must be renewed at the period specified in the approved Maintenance Schedule. At the time of element renewal the other component parts of the filter should be thoroughly washed in warm water using a soft brush. On re-assembly of the filter, new sealing washers and rings should be fitted, the unit bled and checks made for signs of leakage.

3.7 **Priming and Testing.** After the installation of a component in the de-icing system and at the periods specified in approved Maintenance Schedules, priming and functional testing of the system should be carried out in the manner specified in the relevant aircraft Maintenance Manual. In general, the procedures are straightforward and usually require a check to ensure that the tank is full and that, when the pump is operated, fluid flows out from each of the distributor panels.

3.7.1 On completion of the tests, all pipeline connections should be checked for signs of fluid leakage and the tank replenished with fluid (see also paragraph 3.2.2). Any fluid which may have run on to the structure adjacent to distributor panels, should be washed off with water. Fluid should also be washed from the surfaces of the distributor panels by means of a water spray.

3.8 **Inhibiting of Systems.** For certain types of aircraft operating under hot dry climatic conditions, it may not be necessary to use the de-icing system. In such cases the system should be drained of de-icing fluid and inhibited with fluid to Specification DTD 5540B in the manner prescribed in the relevant aircraft Maintenance Manual. If prolonged storage of an aircraft is necessary the de-icing system should also be similarly drained and inhibited.

AL/11-6

Issue 1.

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AIRCRAFT

ICE PROTECTION

ICE DETECTION SYSTEMS

1 INTRODUCTION This Leaflet gives brief details of the operating principles, and guidance on the installation and maintenance, of ice detection systems. This information is not related to any particular aircraft installation and should, therefore, be read in conjunction with the relevant aircraft Maintenance Manuals and Maintenance Schedules. Information on associated subjects is contained in Leaflets **AL/11-1**—Pneumatic De-icing Systems, **AL/11-2**—Thermal (Hot Gas) De-icing Systems, **AL/11-4**—Windscreen De-icing and Anti-icing Systems, **AL/11-5**—Fluid De-icing Systems, and **AL/10-1**—Pitot Static Systems. The regulations regarding the use of ice detection equipment is contained in Chapter D4—7 of British Civil Airworthiness Requirements.

1.1 Ice Detection Systems use one of the following methods of detecting and assessing the formation of ice.

(a) **Ice Accretion Method.** Ice is allowed to accumulate on a probe which projects into the airstream and in doing so operates a warning system.

(b) **Inferential Method.** Atmospheric conditions conducive to the formation of ice are detected and continuously evaluated to operate a warning system.

NOTE: The inferential method of ice detection is not usually employed in series aircraft, but is used extensively in wind tunnels and on flight trials for aircraft certification.

2 THEORY OF ICING Icing on aircraft is caused primarily by the presence of super-cooled water droplets in the atmosphere. If the droplets impinge on the forward facing surfaces of an aircraft, they freeze and cause a build up of ice which may seriously alter the aerodynamic qualities. This applies particularly to small objects, which have a higher catch rate efficiency than large ones, as small amounts of ice will produce relatively bigger changes in shape. The actual amount and shape of the ice build up depends on surface temperature, which results from an energy balance arising from heat input from viscous or kinetic air heating, kinetic heating by water droplets and the latent heat of fusion, and losses from evaporation or sublimation, convection and by warming the impinging droplets.

2.1 Three different situations arise, depending on whether the surface temperature is less than, equal to or greater than 0°C. When the temperature is less than 0°C all the impinging water droplets are frozen, and when it is above 0°C none are frozen. However, for a particular set of atmospheric conditions and altitude it is found that there is quite a wide aircraft speed range over which the energy balance gives a skin temperature of 0°C and this energy balance occurs at one end of the speed range by all the droplets freezing and at the other by none freezing. The potential "catch rate" or "impingement rate" and the actual icing rate are thus not simply related in this region. The "no icing hazard" speed depends, therefore, upon the free water content of the atmosphere as well as the temperature and altitude. For severe conditions it is about the maximum speed of subsonic aircraft. The final influencing factor of note is that icing does not occur above about 12 000 m (40,000 ft) since the droplets are all frozen and in the form of ice crystals and will not adhere to the aircraft's surface.

3 TYPES OF ICE DETECTOR HEADS

3.1 **Pressure Operated Ice Detector Heads.** These consist of a short stainless steel or chromium plated brass tube, which is closed at its outer end and mounted so that it projects vertically downwards from a portion of the aircraft known to be susceptible to icing. Four small holes are drilled in the leading edge of this tube, and in the trailing edge are two holes of less total area than those of the leading edge (Figure 1). A heater element is fitted to allow the detector head to be cleared of ice. In some units of this type a further restriction to the air flow is provided by means of a baffle mounted through the centre of the tube.

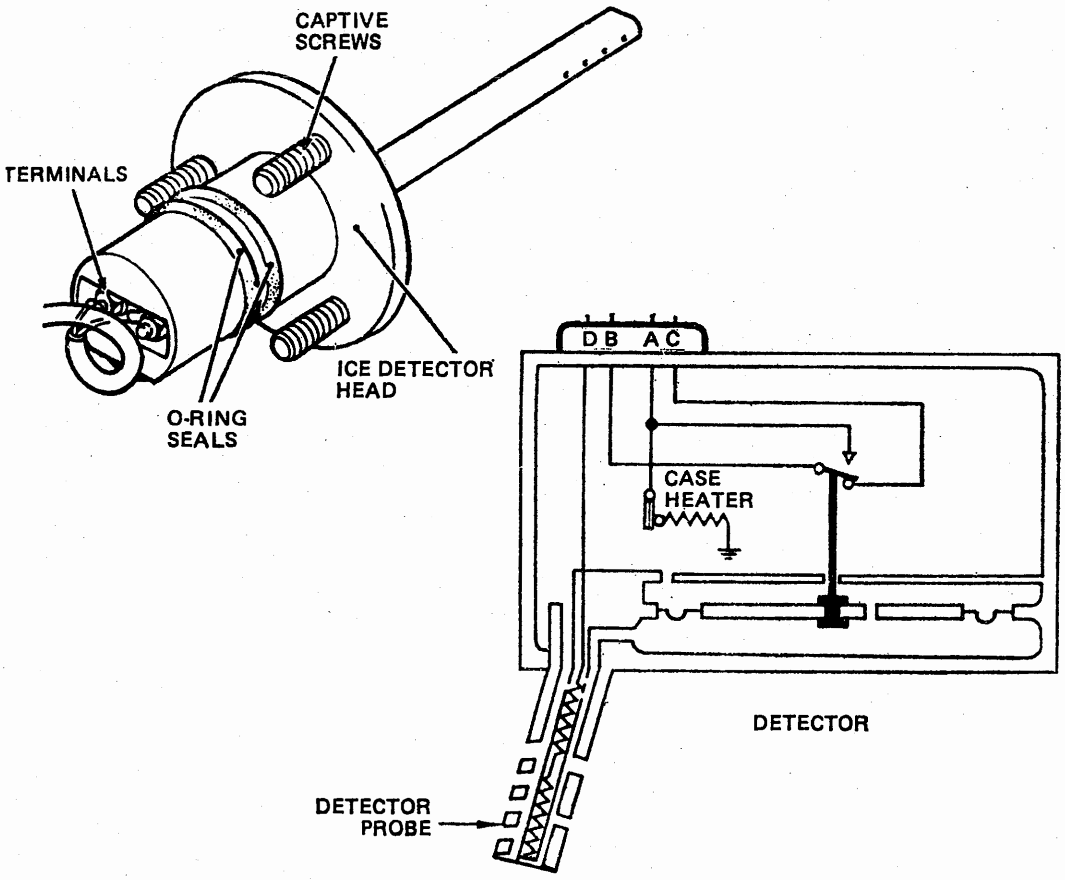


Figure 1 PRESSURE OPERATED ICE DETECTOR HEAD

3.1.1 When, in normal flight, pressure is built up inside the tube by the airstream, this pressure is then communicated, by tubing, to the capsule of an electro-pneumatic relay tending to expand it and separate a pair of electrical contacts. When icing conditions are met, ice will form on the leading edge and close off the holes. As the holes in the trailing edge will not be covered by ice the airstream will now tend to exhaust the system, collapsing the relay capsule and so closing the relay contacts. Generally these contacts operate in conjunction with a thermal device, to illuminate a warning indicator in the flight compartment and to switch on the heater in the detector head; the latter clears the head of ice and is then switched off allowing continued detection of icing conditions. This cycling will continue until such time that the icing conditions no longer exist.

3.2 **Hot Rod Ice Detector Head.** This consists of an aluminium alloy oblong base (called the plinth) on which is mounted a steel tube detector mast of aerofoil section, angled back to approximately 30° from the vertical, mounted on the side of the fuselage, so that it can be seen from the flight compartment windows. The mast houses a heating element, and in the plinth there is a built-in floodlight (Figure 2).

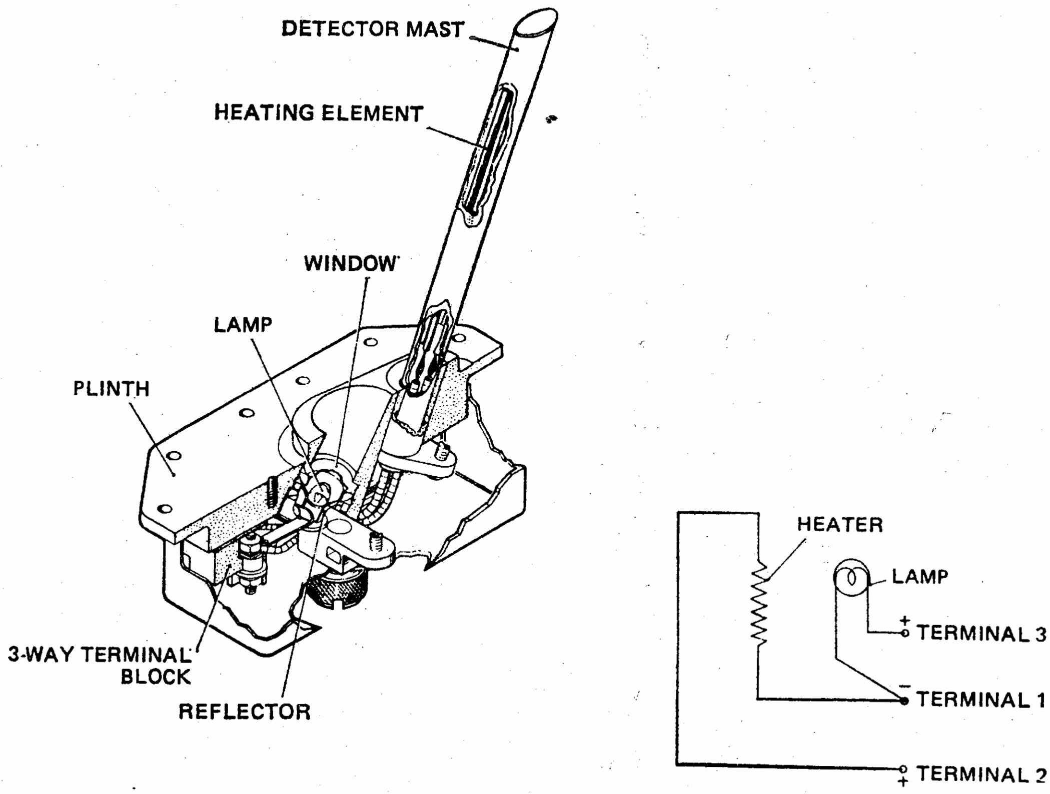


Figure 2 HOT ROD ICE DETECTOR HEAD

3.2.1 The heating element is normally off and when icing conditions are met ice accretes on the leading edge of the detector mast. This can then be observed by the flight crew. During night operations the built-in floodlight may be switched on to illuminate the mast. By manual selection of a switch to the heating element the formed ice is dispersed for further observance.

3.3 **Serrated Rotor Ice Detector Head.** This consists of a serrated rotor, incorporating an integral drive shaft coupled to a small a.c. motor via a reduction gearbox, being rotated adjacent to a fixed knife-edge cutter (Figure 3). The motor casing is connected via a spring-tensioned toggle bar to a micro-switch assembly. The motor and gearbox assembly is mounted on a static spigot attached to the motor housing, and together with the micro-switch assembly, is enclosed by a cylindrical housing. The detector is mounted through the fuselage side so that the inner housing is subjected to the ambient conditions with the outer being sealed from the aircraft cabin pressure.

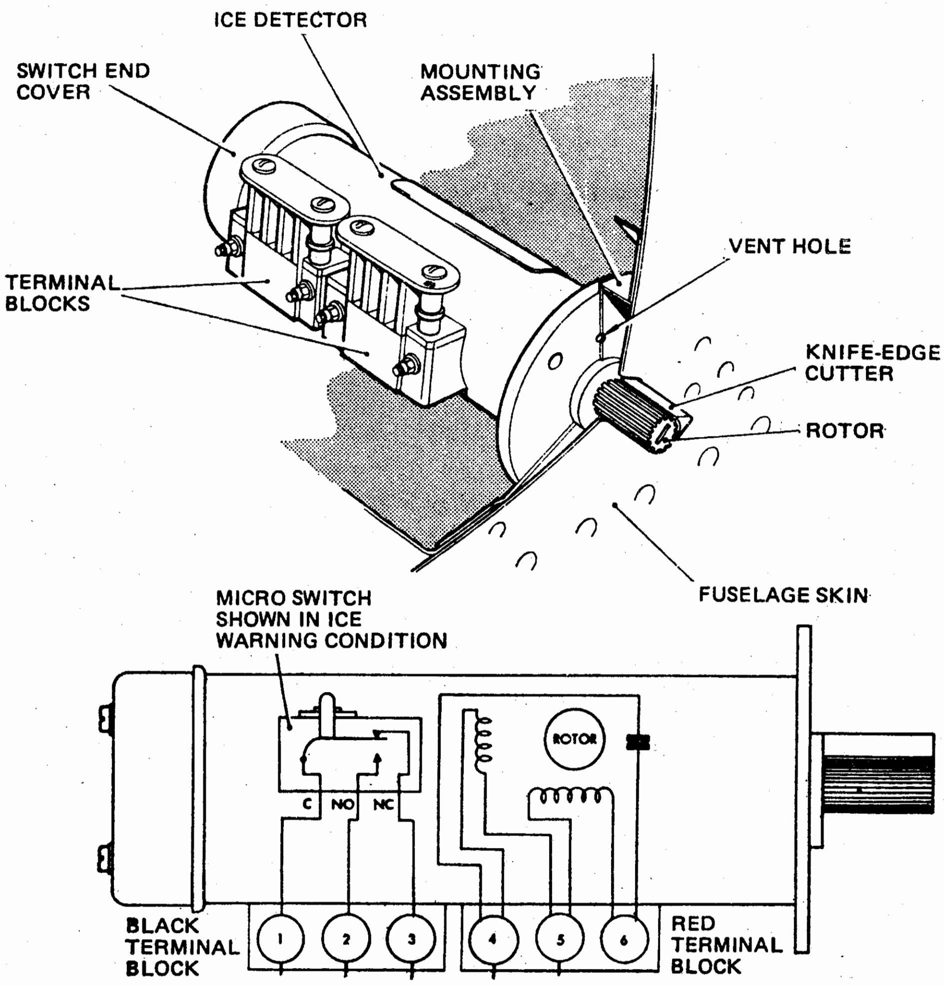


Figure 3 SERRATED ROTOR ICE DETECTOR HEAD

3.3.1 The serrated rotor on the detector head is continuously driven by the electrical motor so that its periphery rotates within 0·050 mm (0·002 in) of the leading edge of the knife-edge cutter. The torque therefore required to drive the rotor under non-icing conditions will be slight, since bearing friction only has to be overcome. Under icing conditions, however, ice will accrete on the rotor until the gap between the rotor and knife edge is filled, whereupon a cutting action by the knife edge will produce a substantial increase in the required torque causing the toggle bar to move against its spring mounting and so operate the micro switch, to initiate a warning signal. Once icing conditions cease, the knife-edge cutter will no longer shave ice, torque loading will reduce and allow the motor to return to its normal position and the micro switch will open-circuit the ice warning indicator.

3.4 **Vibrating Rod Ice Detector Head.** This ice detector senses the presence of icing conditions and provides an indication in the flight compartment that such conditions exist. The system consists of a solid-state ice detector and advisory warning light. The ice detector is attached to the fuselage with its probe protruding through the skin (Figure 4). The ice detector probe (exposed to the airstream) is an ice sensing element that ultrasonically vibrates in an axial mode of its own resonant frequency of approximately 40 KHz.

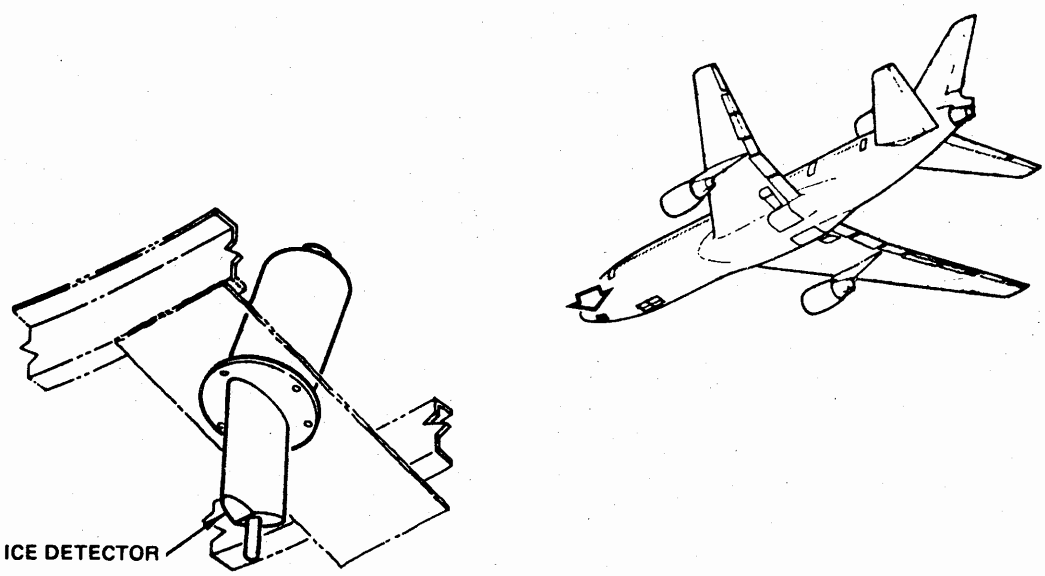


Figure 4 VIBRATING ROD ICE DETECTOR HEAD

3.4.1 When ice forms on the sensing element, the probe frequency decreases. The ice detector circuit detects the change in probe frequency by comparing it with a reference oscillator. At a pre-determined frequency change (proportional to ice build-up), the ice detector circuit is activated. Once activated, the ice warning light in the flight compartment is illuminated and a timer circuit is triggered. The operation of the time circuit switches a probe heater on for a set period of time to remove the ice from the probe. After the timer has timed out, it switches off the ice warning indicator and returns the system to a detector mode, providing that icing conditions no longer exist. If, however, a further ice warning signal is received during the timer period, the timer will be re-triggered, the warning light will remain on and the heater will again be selected on. This cycle will be repeated for as long as the icing conditions prevail.

3.5 **Ice Formation Spot Light.** Many aircraft have two ice formation spot lights mounted one each side of the fuselage, in such a position as to light up the leading edges of the mainplanes, when required, to allow visual examination for ice formation (Figure 5).

NOTE: In some aircraft, this may be the only method of ice detection.

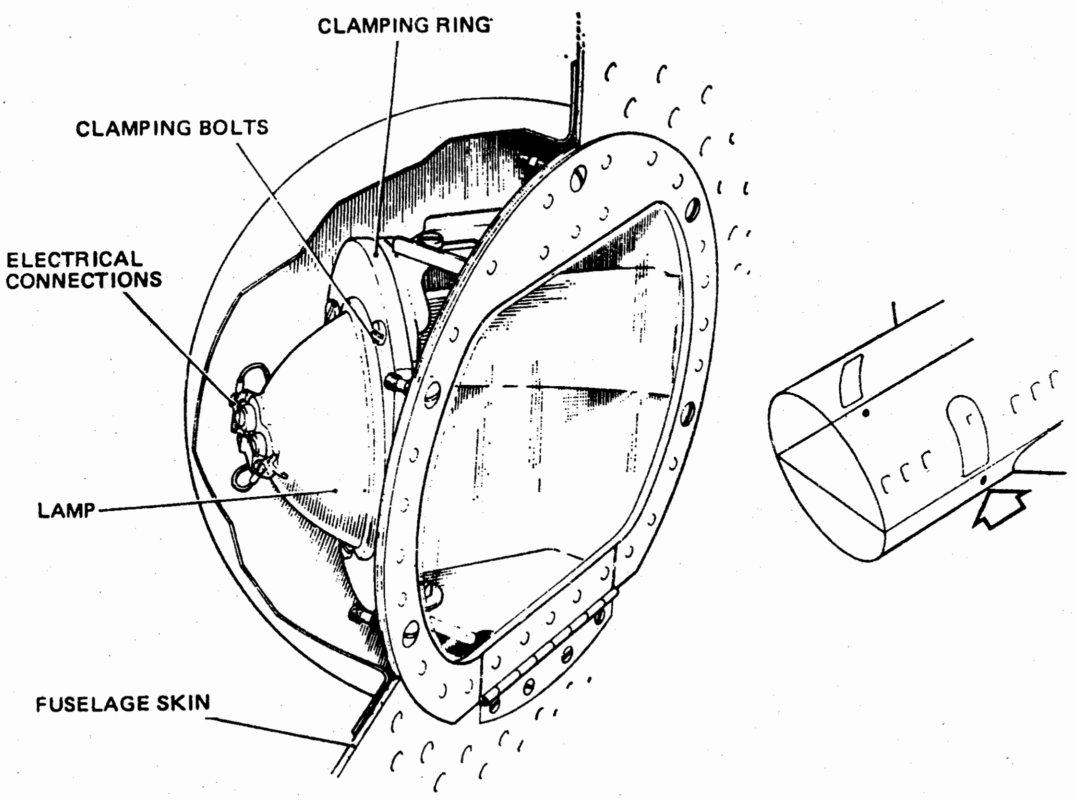


Figure 5 ICE FORMATION SPOT LIGHT

4 INSTALLATION AND MAINTENANCE The efficiency of any detection system depends on the suitable positioning of the detectors and on the proper maintenance of all components within the system. For details of particular installations reference should be made to the relevant manuals for the aircraft concerned; information given in the

following paragraphs serves as a general guide to typical maintenance practices. Reference should also be made to Leaflets **EEL/3-1** and **EEL/1-6** for guidance on the installation of electric cables and testing of circuits, respectively. As some ice detection systems require the use of static pressure for the operation of their associated equipment (which may be an independent static vent or the pitot-static system of the aircraft), reference should also be made to Leaflet **AL/10-1**—Flight Instruments—Pitot-Static Systems.

4.1 **Installation**

4.1.1 Before fitting a new detector head the part number should be checked, the head inspected for cleanliness or damage, and a new sealing gasket should be fitted. Where possible an electrical check should be carried out to ensure that continuity and insulation resistance are within the limits quoted in the relevant Maintenance Manual. Testing should be carried out at normal room temperature (20°C), since an elevated temperature would result in different readings being obtained.

4.1.2 The end fittings of each detector head, and other components in the system, are protected by caps during storage. These caps should only be removed for testing purposes or immediately before installation. New sealing washers must be fitted whenever a pressure or static pipe line is broken and all parts must be perfectly clean and dry. Coupling nuts should be tightened to the appropriate values, using two spanners to prevent twisting of the pipes or capsule.

4.1.3 Electrical connections to the units may be made by terminal posts, or by plugs and sockets; whichever type is used care must be taken to ensure that the contacts are clean. The correct torque loading tool should be used, if called for by the Maintenance Manual.

4.1.4 **Bonding.** The methods of testing and inspection will vary with different types of aircraft and the equipment fitted; reference, therefore, must be made to the appropriate Maintenance Manuals for detailed information. Each test requires specified equipment and care should be taken that it is correctly used. Further information on bonding will be found in Leaflet **EEL/1-6.**

4.1.5 **Torque Testing of Serrated Rotor.** The functional testing of the serrated rotor ice detector head is carried out with the use of a torque tester of the type specified by the relevant aircraft Maintenance Manual. Care should be taken so that sufficient torque only is applied to cause the warning system to operate but not enough to stall the motor as this may cause overheating with a subsequent electrical failure (see Figure 6).

4.1.6 **Leak Testing of Pressure and Static Lines.** Ice detector systems that are pressure operated and which require a source of static pressure must be tested for leaks after the installation of any component parts, at any time system malfunctioning is suspected, and at periods specified in the aircraft Maintenance Schedule. The method of testing consists basically of applying pressure and suction to detector heads and static vents, respectively, by means of a special leak tester and coupling adapters, and noting that there is no leakage, or that the rate of leakage is within the permissible tolerances prescribed for the system. Leak tests also provide a means of checking that a system is functioning correctly. Specific applications of the basic method of leak testing and the type of equipment recommended depend on the type of aircraft and its ice detector system, and as these are detailed in relevant manufacturer's and aircraft Maintenance Manuals, reference must always be made to these documents.

There are, however, certain aspects of the procedures and precautions to be observed which are of a standard nature, and these are summarised for guidance as follows:—

(a) Pressure and suction must always be applied and released slowly to avoid damage to capsules.

(b) If two static vents are interconnected, one vent should be blanked off before testing is commenced.

(c) When fitting leak tester adapters to detector heads, care must be taken not to apply loads which tend to disturb their setting.

(d) When carrying out a leak test on a system that uses the aircraft static pressure system an apparent leak will be indicated by the dropping back of the altimeter pointer until the system stabilises.

(e) On completion of tests which have necessitated the blanking-off of various sections of a system, a check must be made that all blanking plugs and adapters have been removed.

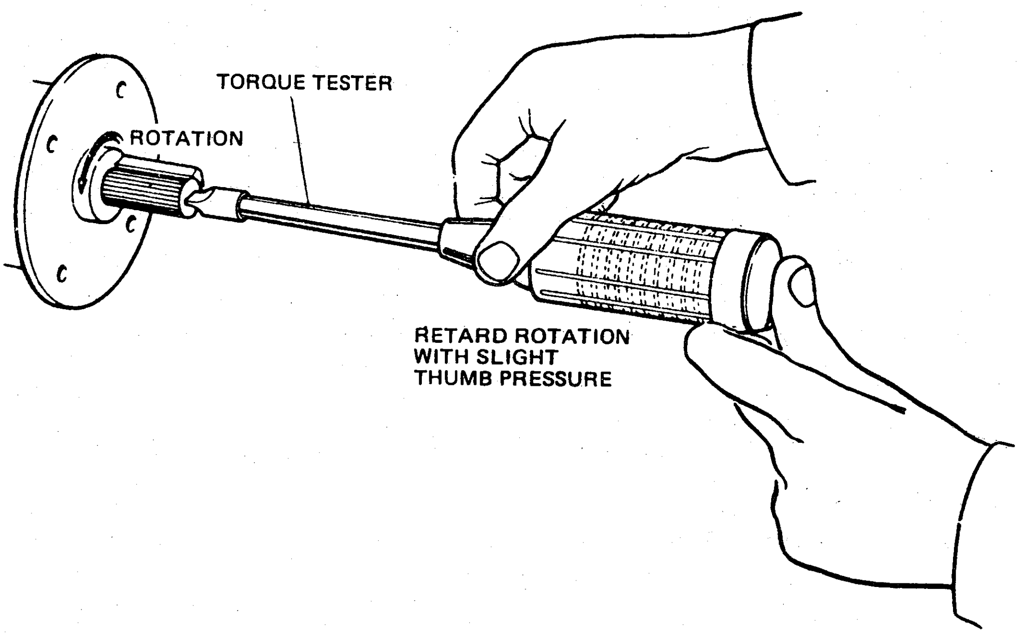


Figure 6 TORQUE TESTING OF SERRATED ROTOR ICE DETECTOR HEAD

4.1.7 When the installation has been completed, operation of the system should be checked in accordance with the relevant aircraft Maintenance Manual, including leak testing as appropriate.

4.2 **Inspection**

4.2.1 **Acceptance Checks.** All components should be examined externally for damage which may have occurred in transit, and sealing caps should be removed to ensure that threads and coupling connections are clean and internal parts undamaged. All caps and protective devices must be refitted for storage unless the components are to be installed immediately. Some components can be bench checked by means of special test sets or fixtures; others should be tested for continuity and insulation resistance, where appropriate. Procedures for the electrical checks vary between installations and reference should be made to the relevant aircraft Maintenance Manual for details of the test requirement for a particular component.

4.2.2 **Function Test.** In view of the difficulty of producing icing conditions, functional tests are mainly related to all other parts of the installation, other than the detector head, except for the head heater unit, with which extreme care should be taken because of the high temperatures that can be obtained. Particular note should be given to the isolation of associated de-icing and anti-icing systems so that possible damage may be avoided.

4.2.3 **Periodic Checks**

(a) At the intervals prescribed in the approved Maintenance Schedule all components should be examined, in situ, for security of attachment, damage, corrosion or deterioration. Any damage found on detector heads should be compared with the limits laid down in the relevant manuals and components replaced with new ones as necessary. Parts with acceptable physical damage should be given an electrical check to ensure that functioning characteristics and, where applicable, the insulation resistance remains satisfactory. All cable and piping should also be examined for chafing and security of attachment.

(b) When required by the Maintenance Schedule or when serviceability is suspect, components should be removed, so that they may be properly cleaned and inspected. New sealing gaskets should always be fitted on installation.

NOTE: The time interval between these checks varies considerably and is based on experience gained with each particular aircraft installation. On some aircraft, detector heads are only removed when unserviceable.

5 MAINTENANCE OF ICE DETECTOR SYSTEMS The following paragraphs detail the maintenance generally necessary on ice detector systems and their major components, and should be read in conjunction with the Maintenance Manuals for the type of aircraft and equipment concerned.

5.1 **Detector Heads.** These should be inspected for security of mounting and signs of distortion. Checks should also be made that electrical connections at terminal blocks are secure and the insulation of cables does not show signs of cracking or chafing. The pressure entry and exit holes, and if applicable the static holes, should be inspected to ensure that they are unobstructed.

NOTE: The size of pressure inlet, exhaust, static and drain holes is aerodynamically critical and they must never be cleared of obstruction with tools likely to cause enlargement or burring. In the absence of a special clearing technique, which may be obtained from the manufacturer's or aircraft Maintenance Manual, the use of a stiff non-metallic brush is recommended, taking care not to displace debris into the system and cause obstructions.

5.1.1 **Electrical Checks.** Heating elements should be checked for functioning by ensuring that detector heads commence to warm up when switched on until they are just too hot to hold with the bare hand. The current should then be switched off and the insulation resistance measured, while the head is hot, using the specified tester. The head should then be allowed to cool and the insulation resistance measured again. The resistance values obtained should not be less than those quoted in the relevant Maintenance Manual.

5.1.2 **Leakage Tests.** The method of checking for leaks differs with the various types, and in each case the procedures given in the relevant manual should be followed (see paragraph 4.1.6).

5.1.3 **Protective Covers.** If the aircraft is to be left standing for prolonged periods, e.g. during overnight parking or hangar maintenance checks, detector heads should be covered with a moulded protective sheath or cover to prevent the entry of foreign matter and contamination by water or other liquids. Any protective sheath or cover should be able to 'breathe', and extreme care should also be taken to ensure that the system heater is not operated. The sheath or cover should be of a prominent colour and have a streamer attached to it to attract attention should a take-off be attempted before removal of the sheath.

5.1.4 **Static Vents.** Static vent plates should be inspected to ensure that exposed surfaces are free from scratches, indentations, etc., and that holes are unobstructed and their edges free from burrs and other damage. Mud and dirt should be removed from exposed surfaces with a 'lint-free' cloth to ensure that particles of material are not rubbed off into vent holes. Protection of static vents during long standing periods of the aircraft is effected by blanking the vent holes with special vent plugs. If plugs made from rubber are used they should be able to 'breathe' otherwise pressure differentials can build up, causing the system to operate when power is applied. They should also be periodically inspected for signs of cracking or fracture. This is important since, if part of a fractured rubber plug remains in the vent when the plug assembly is thought to be removed, incorrect operation of the detector will result. The plugs should be of a prominent colour and have a streamer attached, to attract attention should a take-off be attempted before removal of the plugs.

5.1.5 **Pipelines.** Pipelines should be checked to ensure freedom from corrosion, kinking and other damage, and that the pipes are securely clamped and their connections tight and locked. Flexible hoses should be carefully inspected for security and evidence of kinking, twisting, deterioration (particularly at the joints between hose and connectors) and other defects. At the periods specified in the aircraft Maintenance Schedule the pressure and static systems should be drained at each of any provided draining points, and pipes disconnected from the equipment and blown through with clean, dry, low-pressure air. To avoid contamination of the adjacent equipment and structure, a suitable container should be placed at the draining points for the collection of water.

Issue 1.

14*th May*, 1976.

AIRCRAFT

ENGINES

PISTON ENGINE DESIGN AND CONSTRUCTION

1 INTRODUCTION This Leaflet is the first in a series of Leaflets which cover the principles of operation, design, construction and maintenance of aircraft piston engines, such as are used in civil aircraft throughout the world. This Leaflet deals with the general principles of operation, the design features and constructional details of typical aircraft engines.

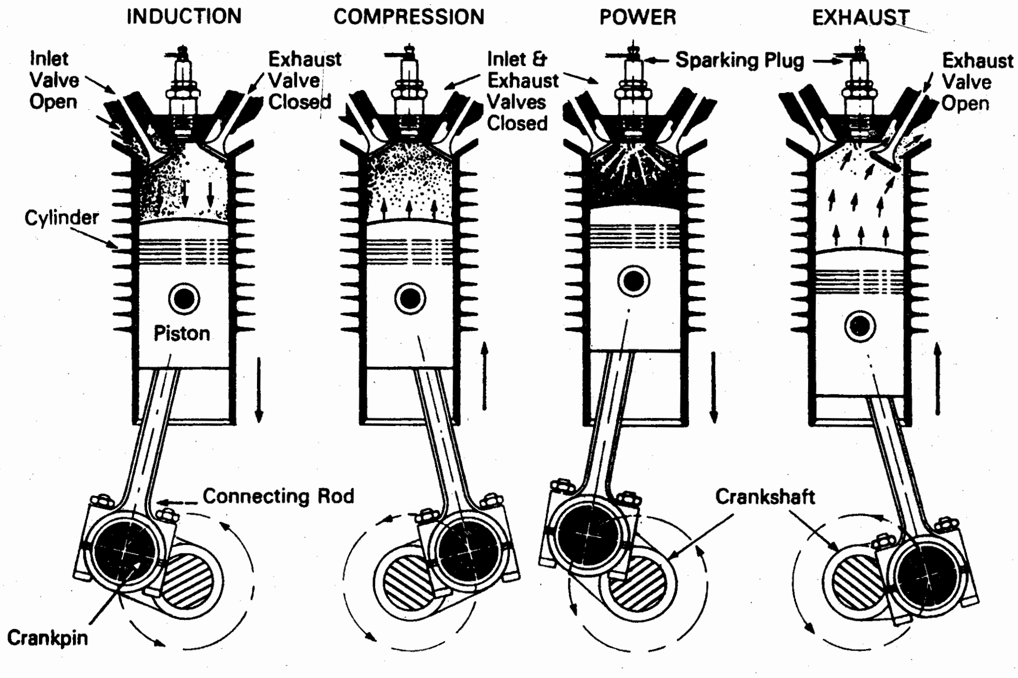


Figure 1 OPERATION OF FOUR-STROKE CYCLE

2 PRINCIPLES OF OPERATION A piston (or reciprocating) engine is a device for converting the heat energy of a fuel into mechanical energy, by internal combustion. The principles which govern the relationship between pressure, temperature and volume in a gas, are stated in the Laws of Boyle and Charles, and these principles are applicable to the operation of a piston engine. Boyle's Law states that, for a given mass of gas at constant temperature, the volume of the gas varies inversely as its pressure, and Charles' Law states that, at constant pressure the volume of a gas varies directly as its absolute temperature.

In a piston engine, a fuel/air mixture is drawn or forced into a cylinder, compressed, and ignited, thus increasing temperature and pressure; this pressure acts on a piston and forces it down the cylinder. The linear movement of the piston is converted into rotary movement by the engine mechanism. Piston engines are designed to operate on a "2-stroke" or "4-stroke" cycle, but since the vast majority of aircraft engines operate according to the latter, this Leaflet deals solely with the 4-stroke or "Otto" cycle, which is named after its inventor (Figure 1).

2.1 The movement of the piston from its highest to its lowest position in a cylinder is known as a "stroke", and corresponds to one half of a revolution of the crankshaft. Two upward and two downward strokes make up the complete cycle, and the purpose of each stroke, together with theoretical valve movement, is described below.

2.1.1 **Induction Stroke.** When the piston is at the top of its stroke, an "inlet" valve in the cylinder head is opened, and as the piston travels down to the bottom of its stroke, a combustible mixture of fuel and air is drawn into the cylinder. The valve closes when the piston reaches the bottom of the stroke.

2.1.2 **Compression Stroke.** As the piston travels up to the top of its stroke both the inlet valve and the "exhaust" valve are closed and the combustible gas is compressed in the cylinder.

2.1.3 **Power Stroke.** As the piston commences its second downward stroke the combustible mixture is electrically ignited (by means of a magneto and sparking plug, see Leaflet **EL/3-9**) and the gas expands, thus building up pressure and forcing the piston down.

2.1.4 **Exhaust Stroke.** The exhaust valve in the cylinder head now opens, and as the piston continues its second upward stroke the burnt gases are forced out through the exhaust port to atmosphere. At the completion of this stroke the exhaust valve is closed.

2.2 Because there is only one power stroke in the cycle, a single cylinder engine is dependent upon the inertia of the rotating parts to carry it over the other three strokes. When weight is not a major problem (e.g. on stationary engines and automobile engines), a large, heavy flywheel is often fitted to the end of the crankshaft to provide the necessary inertia and to smooth out the impulses. With aircraft engines the propeller acts as a flywheel and the multiplicity of cylinders (generally between 4 and 18) provides regular power strokes, but nevertheless small balance weights or vibration dampers may be required.

2.3 The theoretical 4-stroke cycle is very inefficient, for several reasons, and must be modified to produce acceptable power. The main factors which necessitate these modifications are, inertia of the gases, burning rate of the fuel/air mixture, and the ineffective crank angle, the last being defined as the angular position of the crankshaft when, for a large angular movement of the crankshaft at both ends of the stroke, the linear movement of the piston is small. Ideally, best power would be produced by varying the valve timing (i.e. the times at which the valves open and close in relation to the crankshaft position) according to the rotational speed of the engine, but the mechanism necessary would result in such increased weight and complication that the valves of an aircraft engine are usually timed to provide the greatest efficiency at cruising speed. The actual timing of the valves on a particular engine is often illustrated in the form of a diagram, known as a Valve Timing Diagram, such as is shown in Figure 2. The terms Top Dead Centre (TDC) and Bottom Dead Centre (BDC) are used to define the positions of the crankshaft when the piston is exactly at the top or bottom of its stroke, respectively.

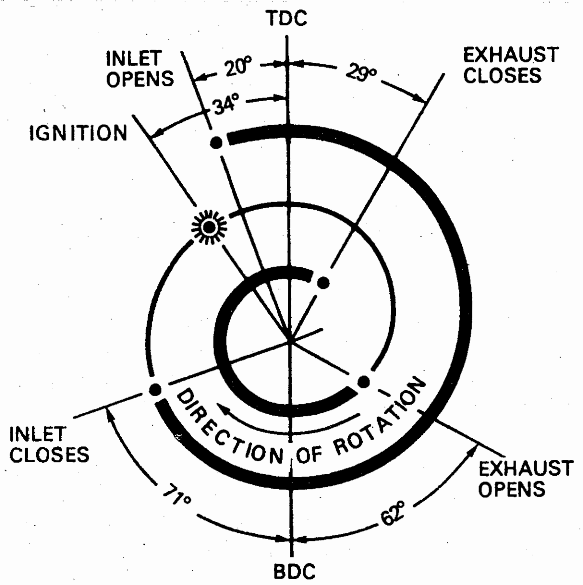


Figure 2 VALVE TIMING DIAGRAM

2.3.1 For the induction stroke, the opening of the inlet valve is initiated before TDC to ensure that it is partially open when the piston commences its downward stroke, so reducing the lag between the piston and the gases.

2.3.2 The inlet valve closes after BDC, to take advantage of the inertia of the incoming gases and fill the cylinder as completely as possible. Movement of the piston for a short period after BDC, is insufficient to oppose the incoming gases before the valve closes.

2.3.3 Although the fuel/air mixture burns quickly, combustion is not instantaneous. The ignition is therefore arranged to occur before TDC at the end of the compression stroke, so that maximum pressure is achieved shortly after TDC on the power stroke.

2.3.4 The exhaust valve opens before BDC on the power stroke, when most of the expansion due to combustion has taken place, and further useful work is limited by the ineffective crank angle. Residual gas pressure initiates scavenging of the burnt gases through the exhaust port.

2.3.5 The exhaust valve closes after TDC, to make use of the inertia of the outgoing gases to completely scavenge the cylinder, and to assist in overcoming the inertia of the incoming gases.

2.3.6 The number of degrees of crankshaft movement by which valve opening precedes BDC or TDC is known as "valve lead", and the number of degrees of crankshaft movement by which valve opening follows BDC or TDC is known as "valve lag". The period when both inlet and exhaust valves are open together is known as "valve overlap".

NOTE: Although the valves are opened and closed at specific crankshaft positions, regardless of engine speed, it should be noted that the ignition timing may be varied according to engine speed and mixture strength. The ignition timing included on the Valve Timing Diagram represents the fully advanced position.

2.4 The main components of an engine are described in detail in paragraph 6 and are illustrated in Figures 4 to 13.

3 ENGINE DESIGN FEATURES The aims of an engine designer can be either to produce as much power as possible for a given engine size or weight, or to produce as small and light an engine as possible, with a given power output. In either case this means producing an engine with the best possible power/weight ratio, but reliability and cost are also very important factors to be considered. The power produced by an engine results from the burning of a fuel/air mixture in the cylinders, the greater the weight of mixture burnt the greater will be the amount of energy released. The power produced in the cylinders is initially used to overcome internal friction and to drive accessories such as pumps and generators, and the remainder is available to drive the propeller.

3.1 **Engine Power.** There are a number of ways of increasing the power output of an engine, but these may be resolved into three main methods. These are, increasing the volume of the cylinders, increasing combustion pressure, and increasing the engine speed. The strength and weight of the components used in an engine are the main factors limiting the power produced.

3.1.1 **Increased Volume.** The obvious way to increase the volume of the cylinders is to increase their actual size. However, increasing the size of the cylinders would also mean increasing the size, and therefore the weight, of the reciprocating and rotating parts of the engine, and a point will be reached when the forces on these parts will approach the limits of strength of the materials used. The rate of acceleration of the pistons, and their speed of movement, will increase as the length of stroke increases, and stresses will become very high. Inertia forces on the crankshaft will also increase with cylinder size. These factors place a physical limit on the size of the cylinders, and the method normally adopted to increase volume above this limit is to increase the number of cylinders. This method also has its limitations, however, resulting mainly from increased complexity, which may affect reliability.

3.1.2 **Increased Pressure.** There are two ways of increasing pressure in a cylinder. One method is to increase the compression ratio (i.e. the ratio of the total volume of the cylinder with the piston at BDC, to its volume with the piston at TDC). This produces a higher pressure in the cylinder at the end of the compression stroke, and the force exerted on the piston during combustion will also be greater. The second method is to increase the weight of charge drawn into the cylinder during the induction stroke. The weight of charge drawn into the cylinder during the induction stroke compared with the weight of charge which will fill the swept volume (i.e. the volume of the cylinder between the TDC and BDC positions of the piston) at standard temperature and pressure, is known as volumetric efficiency, and is expressed as a percentage. Volumetric efficiency may be increased by mechanically raising the pressure of the mixture fed to the inlet valve (i.e. supercharging), or, to a more limited extent, by careful design of the induction passages, ports and valves, so as to present as little hindrance as possible to the flow of gases. An increase in volumetric efficiency produces higher pressures in the cylinder throughout the complete cycle of operations; a greater weight of fuel/air mixture being burnt in a given time, and more energy being released by combustion. The extent to which compression ratio and manifold pressure (i.e. induction pipe pressure) can be raised, is limited by the strength of the materials used in the engine, and a factor known as detonation (paragraph 3.1.4).

3.1.3 **Increased Speed.** An increase in engine speed will also result in the burning of a greater weight of fuel in a given time, and will therefore result in the production of more power. However, the higher centrifugal forces, and other stresses set up in the engine, necessitate stronger components, with a disproportionate increase in weight. Again the strength of the materials is the limiting factor.

3.1.4 **Detonation.** In the normal combustion process, a flame front spreads out from the ignition point, and continues burning until all the combustible mixture is consumed. If the temperature of the gases prior to ignition is high, then depending on the characteristics of the fuel, the temperature may be raised sufficiently after ignition to a point where, instead of the mixture burning at a controlled rate, combustion spreads with almost explosive force. This is known as detonation, and produces a rapid rise in pressure within the cylinder, which is capable of causing physical damage to the cylinder, piston and connecting rod. The provision of fuels with good anti-detonation properties has permitted the use of higher compression and supercharger ratios, but, since the act of compressing a gas also raises its temperature, both these factors have to be limited. Alternatively, a means of cooling the mixture before it enters the cylinder may be used for operation at high power settings.

NOTE: A defect known as pre-ignition may also produce results similar to those caused by detonation. With pre-ignition, the gases in the combustion chamber are ignited by incandescent material such as carbon particles, or an overheated exhaust valve, before the proper spark is due to occur. This may cause gas pressure to be applied to the piston before it reaches TDC, and may result in damage to the piston or connecting rod.

3.1.5 **Thermal Efficiency.** The ratio of the power produced by an engine to the power theoretically available in the fuel, is known as the thermal efficiency. Whilst this can be improved by careful design of the combustion chamber, valves and ports, to obtain efficient combustion, its value is primarily dictated by the basic cycle and the compression ratio. In practice the thermal efficiency of an engine is approximately 30%, the remaining energy being lost through the exhaust, or wasted in heating the engine.

3.2 **Engine Layout.** Individual designers have adopted different methods of arranging the cylinders on an aircraft engine to achieve a particular power output. The different arrangements are illustrated in Figure 3, and are explained in paragraphs 3.2.1 to 3.2.3. Air-cooled in-line, horizontally-opposed, and radial engines, are all widely used on civil aircraft because of their general reliability and economy. Liquid-cooled Vee engines were widely used on military aircraft because of their high power output and low frontal area, but are rarely found on civil aircraft.

3.2.1 **In-line Engines.** In-line engines usually have four or six cylinders arranged in an upright or inverted row along the crankcase; it is not usual to have more than six cylinders, because of the difficulty of cooling the rear cylinders and the length of the crankshaft which would be required. In a four-cylinder engine, four power strokes occur every two revolutions of the crankshaft, and must be evenly spaced to provide smooth running. With the arrangement shown in Figure 3(A), the firing order could be 1,3,4,2 or 1,2,4,3. The camshaft, which is a shaft having a cam for each valve in the engine, would be driven from the crankshaft at half engine speed, and would operate the valves by means of push rods, and rockers as illustrated in Figure 7. Each of the eight cams (two to each cylinder) would be located on the camshaft to open and close an inlet or exhaust valve in relation to the particular firing order and the valve timing prescribed for that engine. If the engine had six cylinders, there would be six power strokes every two revolutions of the crankshaft, and a cylinder would have to fire every 120° of crankshaft movement. This would necessitate a crankshaft with throws (i.e. the offset portions of the crankshaft containing the crankpins) arranged as shown in Figure 3(B). Suitably arranged cams would be provided on the camshaft, which would still be driven at half engine speed. The firing order of a six-cylinder engine is generally 1,4,2,6,3,5, but a different order could be used, and the crankshaft throws could be arranged differently.

NOTE: The cylinders of British engines are usually numbered commencing from the propeller end of the engine, but engines of American manufacture are often numbered in the opposite direction.

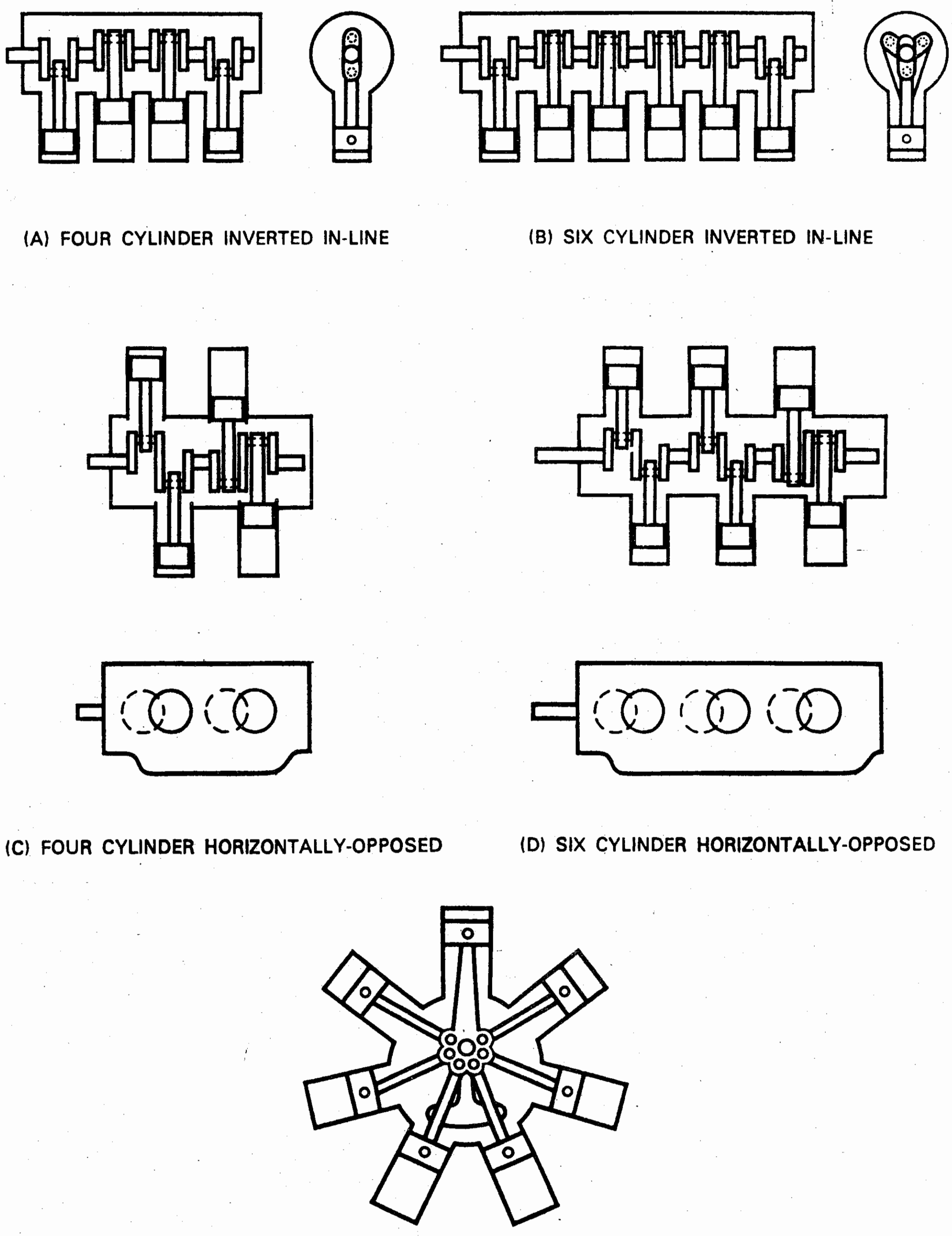


Figure 3 ENGINE CYLINDER ARRANGEMENTS

3.2.2 **Horizontally-opposed Engines.** The cylinders of a horizontally-opposed engine (usually four or six) are arranged in horizontal banks on opposite sides of the crankcase. Most engines have individual connecting rods operating on separate crankpins, thus the cylinders are staggered as shown in Figure 3(C). A single camshaft is located either above or below the crankshaft, and is driven at half engine speed to operate the valves in both banks of cylinders. On some engines the inlet valve cams are shared by opposing cylinders, so that the camshaft of a six-cylinder engine may have a total of nine cams, six separate exhaust cams and three shared inlet cams. To minimize the length of the engine, a four-cylinder engine may have three main (crankshaft) bearings and a six-cylinder engine may have four. Because six firing strokes occur every two revolutions of the crankshaft of a six-cylinder engine, the throws of the crankshaft must be arranged at 120° to each other. In the four-cylinder engine illustrated in Figure 3(C) the firing order would normally be 1,3,4,2, and the firing order of the six-cylinder engine illustrated in Figure 3(D) would normally be 1,4,5,2,3,6, but different firing orders would be possible on engines with different crankshaft and cam arrangements.

3.2.3 **Radial Engines.** A radial engine has an odd number of cylinders (usually not more than nine) arranged radially around the crankcase (Figure 3(E)). If greater power is required, two banks of cylinders are used, each cylinder in the rear row being located midway between two front row cylinders to ensure adequate cooling. The crankshaft of a radial engine has only one throw for each bank of cylinders, and all the connecting rods are attached to the single crankpin via a master rod (Figure 9); this fact also dictates the firing order of the engine. On a seven-cylinder engine a firing stroke is required every $\frac{360° \times 2}{7} = 102\frac{6}{7}°$ of crankshaft movement, and since the angle between cylinders is $51\frac{3}{7}°$, the firing order can only be alternate cylinders in the direction of rotation, i.e. 1,3,5,7,2,4,6. To balance the heavy mass of the master rod assembly, counterweights are fitted to the crankshaft, and it is also usual to fit vibration dampers to minimize the effects of any residual vibration. On engines with two banks of cylinders, the crankshaft throws are arranged at 180° to each other.

(a) Except for sleeve-valve engines (paragraph 6.7.1) the valves are operated by a cam drum (Figure 4), which is concentric with, and driven by, the crankshaft. The cam drum has two rows of cams, one for the inlet valves and one for the exhaust valves. On seven-cylinder and nine-cylinder engines, there are four equally-spaced cams in each row, and the drum rotates at $\frac{1}{8}$ engine speed; on three-cylinder and five-cylinder engines, two equally spaced cams on each row, with the drum rotating at $\frac{1}{4}$ engine speed, would be suitable.

(b) Taking a seven-cylinder radial engine as an example, when the inlet valve on No. 1 cylinder is open, the next inlet valve to open is on No. 3 cylinder (since this is the next cylinder in the firing order). The cams are 90° apart and the drum must, therefore, rotate through an angle of $12\frac{6}{7}°$ (the angle between No. 1 and No. 3 cylinder is $102\frac{6}{7}°$) in the direction of rotation to open the required valve on No. 3 cylinder. Speed of rotation of the cam drum must be $12\frac{6}{7} \div 102\frac{6}{7} = \frac{1}{8}$ engine speed (operation of the cam drum on a seven-cylinder engine is illustrated in Figure 4). On a nine-cylinder engine the spacing of the cylinders is 40°, and successive valves open every 80° of crankshaft movement. Since the cams are 90° apart, the cam drum must rotate in the opposite direction of rotation to the crankshaft, but still at $\frac{1}{8}$ engine speed $\left(\frac{90 - 80}{80} = \frac{1}{8}\right)$.

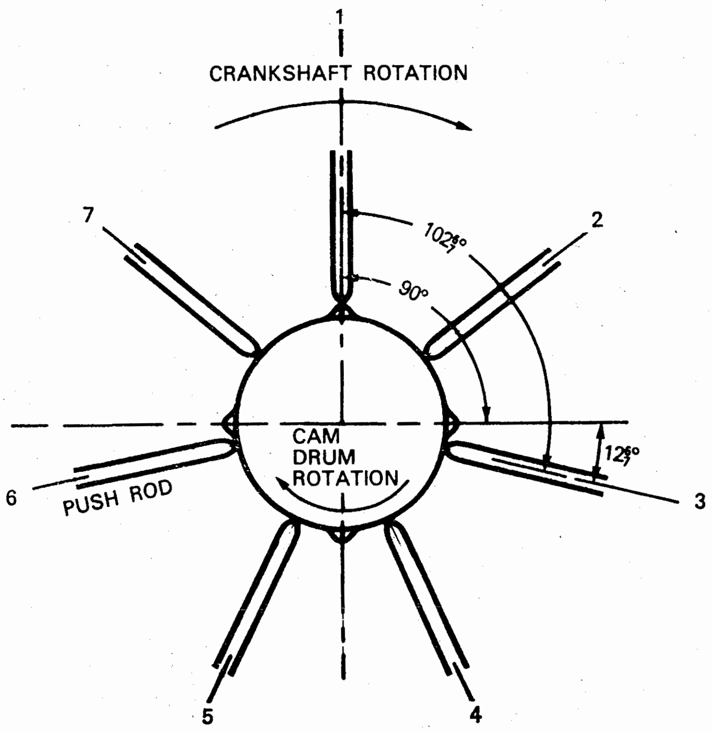


Figure 4 RADIAL ENGINE CAM DRUM OPERATION

4 COOLING Approximately one-third of the energy produced by burning fuel in the engine cylinders manifests itself as heat which is not converted to power. If this heat were not dissipated, some of the engine components in direct contact with the combustion process would quickly reach a temperature at which distortion and reduction in strength would take place, and the engine would fail. Some of the heat is rejected with the exhaust gases but the remainder must be dissipated so as to maintain the working parts of the engine at a temperature which will ensure that the materials are not adversely affected. However, a minimum temperature must be maintained to assist proper lubrication and to provide good fuel evaporation. There are two main methods of cooling, by liquid or by air, but some internal parts are also cooled by heat transference through the medium of the lubricating oil.

4.1 In liquid-cooled engines the cylinders are surrounded by a water jacket, through which liquid (normally a mixture of ethylene glycol and water) is passed to absorb and remove excess heat. The jackets are part of a closed system, which also includes an engine-driven pump and a radiator which projects into the airstream. Some systems are provided with a thermostatically controlled radiator shutter, by means of which a suitable coolant temperature is maintained during flight. Liquid cooling has been used mainly on military aircraft engines, but a few examples may still be found on civil aircraft.

4.2 With air-cooled engines, all those parts of the engine which need to be cooled (mainly the cylinders) are provided with fins, the purpose of which is to present a larger cooling surface to the air flowing round them. The size of the fins is related directly to the quantity of heat to be dissipated, thus the fins on the cylinder head have a greater area than those on the cylinder barrel. Baffles and deflectors are fitted round the cylinders to ensure that all surfaces are adequately cooled, and the whole engine is cowled to direct airflow past the cylinders and to reduce drag. The exit path from the cowling is generally provided with gills or flaps, by means of which the mass air flow may be adjusted to control cylinder temperatures. Because air-cooling is simple and little maintenance is required, air-cooled engines are used in the majority of piston-engined aircraft.

5 LUBRICATION Where there is movement between parts which are in contact (e.g. rotary or reciprocating motion), a film of oil is provided between the surfaces to reduce wear and to minimize friction. Crankshaft, camshaft and other plain bearings in the engine are fed with oil under pressure from an engine-driven pump; oil escaping from these bearings, or sprayed through oil nozzles, is directed onto the underside of the pistons to provide lubrication and cooling of the pistons and cylinder walls; other parts of the engine are lubricated by the oil mist which exists inside the crankcase. On most engines the valve rocker mechanism is pressure lubricated, but on some the rocker bearings are greased by hand at pre-determined intervals, and on certain inverted engines the rocker covers are filled with oil, to splash-lubricate the mechanism. The methods of providing lubrication to individual components are described in paragraph 6.

5.1 In some light aircraft engines the oil required for lubrication is housed in a sump, which is attached directly to the bottom of the crankcase. The pressure pump draws its supply through a tube, the open end of which is in the bottom of the sump, and the oil, after circulation through the engine, drains back into the sump. In some engines the supply from the pump passes through an oil cooler, whilst on others the sump is finned on the outside, and cooling air is directed over it. This method of lubrication is known as a "wet sump" system.

5.2 In other engines the oil is stored in a separate tank, which may be fixed to the engine, or mounted on the engine bulkhead. Oil is supplied through rigid and flexible pipes to the pressure pump, and, after circulating round the engine, drains into a small sump. A separate engine-driven scavenge pump empties this sump, and returns the oil, via an oil cooler, to the tank. The capacity of the scavenge pump is greater than that of the pressure pump, so that the sump is kept empty and the oil in the tank is maintained at a satisfactory level. This method of lubrication is known as the "dry-sump" system.

5.2.1 With a dry-sump system, the scavenge pump, being of greater capacity than the pressure pump, will draw in air with the oil in the sump, and this may result in frothing in the tank. If this air were drawn in by the pressure pump, inefficient lubrication of the bearings would result, and steps are usually taken to prevent this from happening. By passing the oil across a de-aerator tray in the tank, or, in some instances by pressurizing the tank, frothing is reduced to a minimum. Air separates further as the oil stands in the tank before being drawn out by the pressure pump.

5.3 **Filters.** During its passage through the engine, the lubricating oil picks up minute particles of metal resulting from engine wear, and carbon particles resulting from the combustion process and heating of the engine. These particles could cause damage to the bearing surfaces if they were not removed from the pressure oil supply, and filters are fitted to keep the oil in a clean condition. A pressure filter is fitted between the pressure pump and the engine, and usually consists of a container, which houses a paper or cloth filter element through which the oil must pass. This filter is changed at regular intervals. A scavenge filter is usually a coarse wire-mesh type filter, fitted in the sump to prevent large metallic particles from damaging the pumps. In addition, a wire mesh filter is often fitted to the tank filler opening, to exclude foreign matter when the oil tank is being replenished.

6 ENGINE COMPONENTS

6.1 **Bearings.** Plain, ball or roller bearings may be used at various positions in an engine, depending on the magnitude and direction of the load which they are required to accept.

6.1.1 Plain bearings have a greater load-bearing capacity than either ball or roller bearings, and are generally used in a place where the radial load is high. A plain bearing usually consists of a pair of semi-circular steel shells which are lined with a non-ferrous alloy; this in turn may be faced with a white metal. In most cases each half of the bearing is pegged or otherwise located to prevent rotation in its support, and receives its oil supply through drillings in the supporting member. Some plain bearings, such as those fitted to the crankpins on radial engines, are completely circular and fully-floating, and oil is supplied to both sides of the bearing, thus providing two bearing faces. Although plain bearings are generally fitted in positions where the load is mainly radial, plain bearings can be made capable of accepting axial loads, and are sometimes used to transmit the propeller thrust. In these cases the bearing has a flange on each side, which forms a bearing face normal to the shaft axis, and limits axial movement. Plain bearings must be pressure lubricated in order to maintain an oil film between the mating parts, and prevent damage to their surfaces.

6.1.2 Ball bearings are used in many places where radial loads are light, and where axial positioning is important. Heavy roller bearings are used as main crankshaft bearings on radial engines, and ball bearings are frequently used as thrust bearings on propeller shafts and on the crankshafts of direct-drive engines (see Leaflet **BL/6-14** for the various types of rolling bearings). Ball and roller bearings do not, generally, require pressure lubrication, and are frequently lubricated by splash; however, oil jets may be used in locations where lubrication is particularly critical.

6.2 **Crankcases.** The crankcase is, usually, the largest single component of an engine. It provides the mounting faces for the cylinders, reduction gear, sump, and accessories, supports the crankshaft, provides oilways for the lubricating oil, and carries the mountings for attachment of the engine to the airframe. A crankcase is, therefore, of complicated shape, and it is usually cast from aluminium or magnesium alloys, which provide the strength and rigidity required, without unnecessary weight. Some crankcases are in two or more parts, which are bolted and dowelled together. A typical crankcase for a horizontally-opposed engine is illustrated in Figure 5, which shows that the two halves are joined at a vertical plane passing through the crankshaft centreline. With radial engines the join is on the plane normal to the crankshaft centreline and passing through the centres of all cylinders in one bank, each portion of the crankcase supporting one of the main bearings.

6.2.1 Studs are fitted to the crankcase for the attachment of all components, except that in the case of horizontally-opposed engines with staggered cylinders, the positions of some cylinder holding-down points coincide with the main bearing supports, and through-bolts are used at these locations.

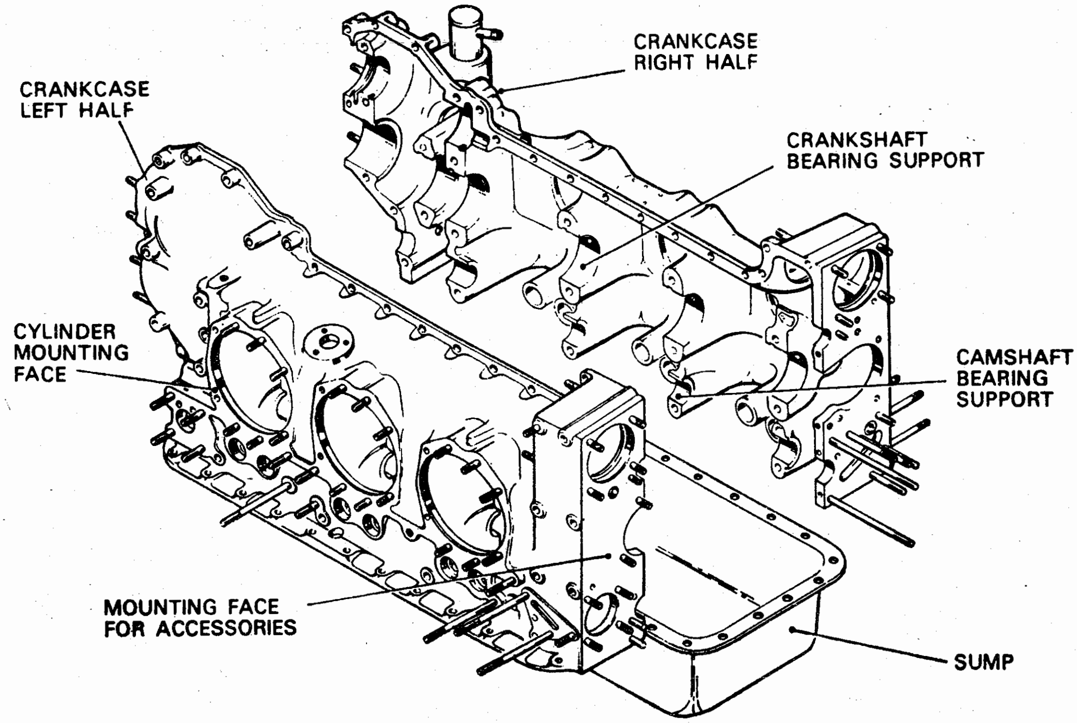


Figure 5 CRANKCASE AND SUMP OF HORIZONTALLY-OPPOSED ENGINE

6.2.2 The sump may be considered as part of the crankcase, and may be a casting in light alloy, or may be fabricated from sheet steel. The sump contains a drain plug, and may also house the scavenge filter. A dip-stick, housed in the crankcase, provides a means of checking the sump oil level.

6.2.3 All crankcase face joints are sealed to prevent oil leakage, but a vent at the top of the crankcase is ducted overboard to relieve internal pressure. In general, cylinder mounting flanges are sealed with an "O" ring, sump joint faces are sealed with a cork or composition gasket, and other joint faces are sealed with paper gaskets or jointing compound.

6.3 **Crankshafts.** The crankshaft is the heaviest single component of the engine, and is usually forged from an alloy steel in order to resist the high stresses imposed during operation. The crankshafts of in-line and horizontally-opposed engines are machined from a single forging, with hollow crankpins and journals, and drilled webs to provide passageways for the lubricating oil. The crankshaft of a single-row radial engine is generally made from two forgings, and that of a two-row radial engine from three forgings, the separate parts being joined at the crankpins; this is because of the difficulty of providing a split bearing capable of accommodating all the connecting rods on a single crank pin. Typical crankshafts are illustrated in Figure 6.

6.3.1 Lubricating oil is ducted from the oil pressure pump, through crankcase oil passages, to each of the crankshaft main bearing supports. This oil passes through holes in the bearings to lubricate the journals, and through radial holes in the journals into the hollow shaft. From there it flows through drillings in the webs to the connecting rod big-end bearings, and then escapes from these bearings to be thrown by centrifugal force into the pistons and cylinders. On some engines, oil jets at the crankshaft main bearings spray oil into the cylinders. At its front end, a crankshaft may have a flange or splined portion to which the propeller is attached, or it may be internally splined in order to drive the propeller reduction gear through a quill shaft; the quill shaft is designed to twist under torsional loads so as to smooth out the power impulses. A gear or a quill shaft is generally attached to the rear end of the crankshaft, for the purpose of driving the camshaft and accessories, but some of these may be driven from the propeller reduction gear.

6.4 **Cylinders.** A cylinder must, generally, provide the hard bearing surface on which the piston slides, must be strong enough to resist the pressures produced by the combustion of the mixture, and must dissipate the heat produced in the combustion chamber. Aluminium alloy has good strength and heat-dissipation properties and is generally used for cylinder heads, but its surface is not hard enough to resist abrasive wear, and therefore the cylinder barrels are generally made from a steel alloy. An exception is the sleeve-valve engine, in which the piston operates inside a steel alloy sleeve, and aluminium alloy is used for the cylinder barrel. Poppet valve guides and rocker bearings (Figure 7) are made from bronze or similar material, and the valve seats are made from steel in order to resist the hammering of the valves. Sparking plugs may be fitted into bronze inserts, which are screwed and pegged into the cylinder head, but in some engines thread inserts are used, and are installed directly into the head.

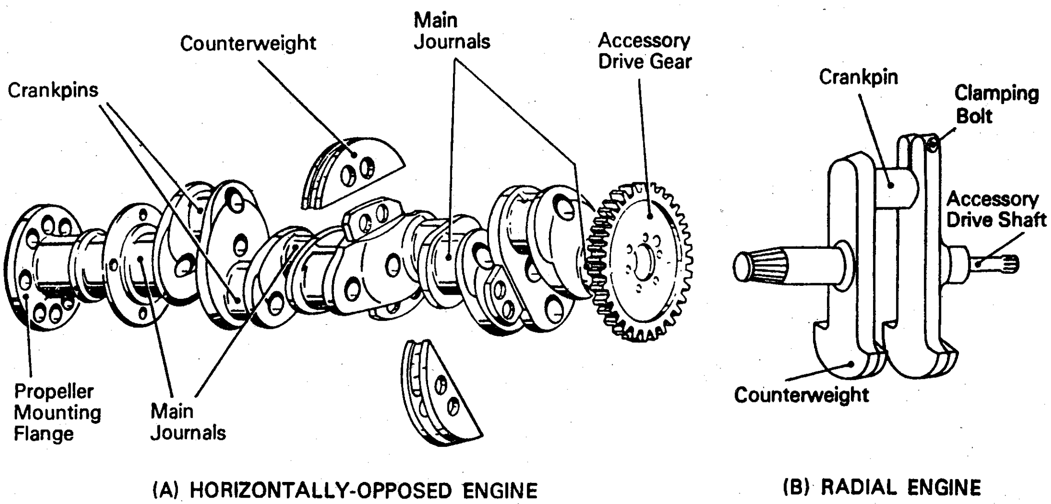


Figure 6 TYPICAL CRANKSHAFTS

6.4.1 On air-cooled engines, which invariably have individual cylinders, the cylinder head and barrel are finned to present a large cooling surface to the airflow, the spacing and size of the fins depending on the amount of heat which must be dissipated. The cylinder head is usually screwed and shrunk onto the barrel to make a permanent assembly, but on some engines the head may be removable and bolted to the cylinder barrel or secured by studs extending from the crankcase. A copper gasket between the head and barrel prevents gas leakage.

6.4.2 On water-cooled in-line engines, the one-piece aluminium-alloy cylinder block has a detachable head, and steel liners in which the pistons operate. The whole assembly is attached to the crankcase by studs or bolts which pass right through the head and block, a copper gasket preventing gas leakage between the liners and head, and a flexible seal round each liner preventing coolant leakage from the block. Coolant flowing round the liners, and through passageways in the head, absorbs and removes excess heat.

6.4.3 Lubrication of the cylinder bores is generally by oil mist and spray from the connecting rod bearings, but oil jets at the crankshaft bearings may be used. Cylinder bores are often honed in such a manner as to result in a pattern of microscopic grooves which permit the retention of a small quantity of oil on the walls.

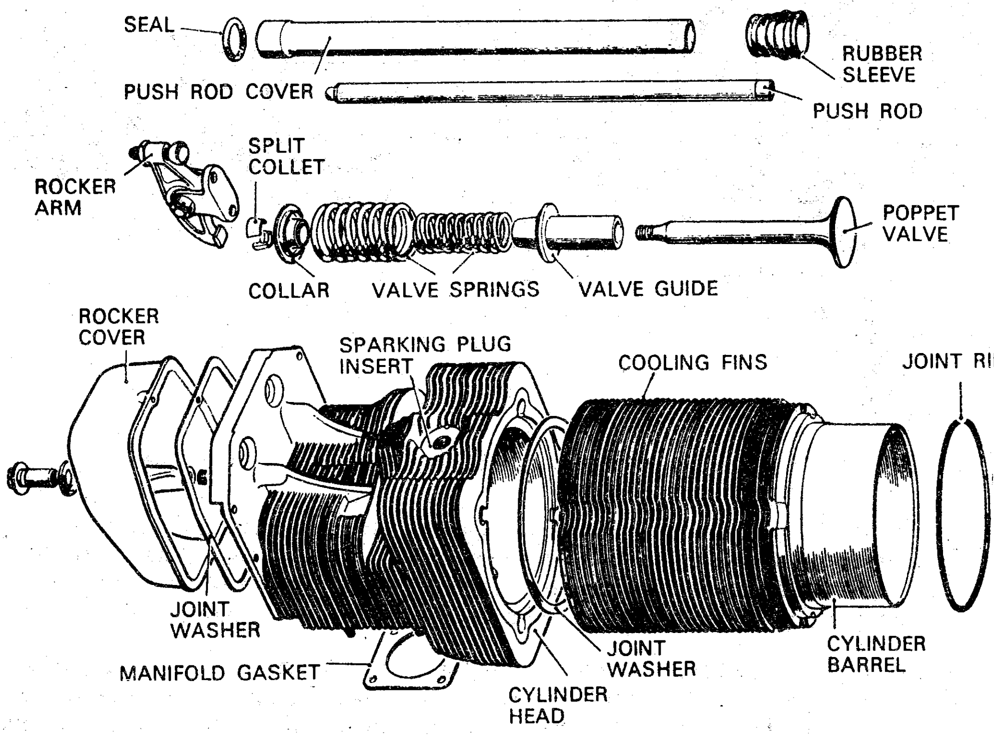


Figure 7 CYLINDER ASSEMBLY

6.4.4 The rocker bearings (and, in the case of some in-line engines, the overhead camshaft bearings) are usually pressure-lubricated by oil ducted from the crankcase, and the splash oil released from these bearings is used to lubricate the valve stems, guides and springs. In some small engines the rocker arms oscillate in roller bearings which are hand lubricated at specified intervals, whilst on inverted engines the rocker cover may be partially filled with oil, to splash lubricate all the cylinder head components. A typical air-cooled cylinder is shown in Figure 7.

6.5 **Connecting Rods.** Connecting rods convert the reciprocating motion of the pistons to the rotary motion of the crankshaft. They require considerable strength and rigidity, and are generally aluminium alloy or steel forgings of "H" section. On horizontally-opposed and in-line engines, the bearing at the crankpin end (big end) is usually a split plain bearing similar to those used at the crankshaft main bearings (Figure 8). The connecting rod small end is usually fitted with a bronze bush and attached to the piston with a hollow steel gudgeon pin (Figure 8). On radial engines only one connecting rod (the master rod) in each bank of cylinders is mounted directly on to the crankpin (Figure 9), and usually has a fully-floating bearing (paragraph 6.1.1). The connecting rods on the other cylinders (known as articulated rods) are connected to flanges on the master rod big-end by hollow steel wrist pins, which are similar to the gudgeon pins at the connecting rod small end. Big-end bearings are pressure lubricated through drillings in the hollow crankpins, from the main oil pressure supply, and small-end (and wrist pin) bearings are usually lubricated by splash oil through holes in the connecting rods.

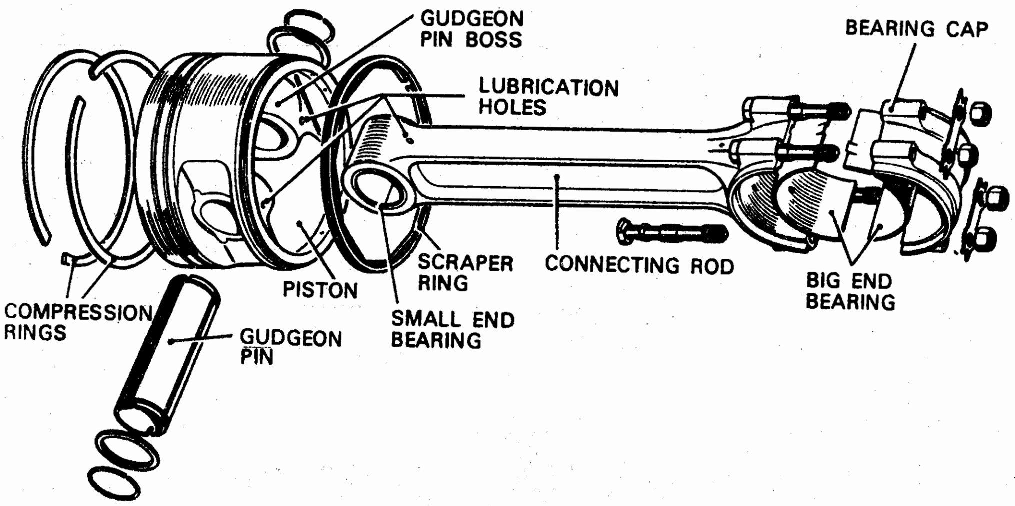


Figure 8 CONNECTING ROD AND PISTON ASSEMBLY

6.6 **Pistons.** Pistons are subjected to high pressures and temperatures, and to rapid accelerations and decelerations. They must, therefore, be strong yet light, and capable of conducting away some of the heat generated in the combustion chamber; they are generally machined from forgings of high strength aluminium alloy.

6.6.1 Pistons are attached to their connecting rods by means of a gudgeon pin, which is often free to rotate in both the piston and connecting rod, and may be supported in bronze bushes fitted to an internal boss on each side of the piston; axial movement of the gudgeon pin is usually prevented by a circlip fitted at each end, or by an end pad of soft metal, which bears against the wall of the cylinder.

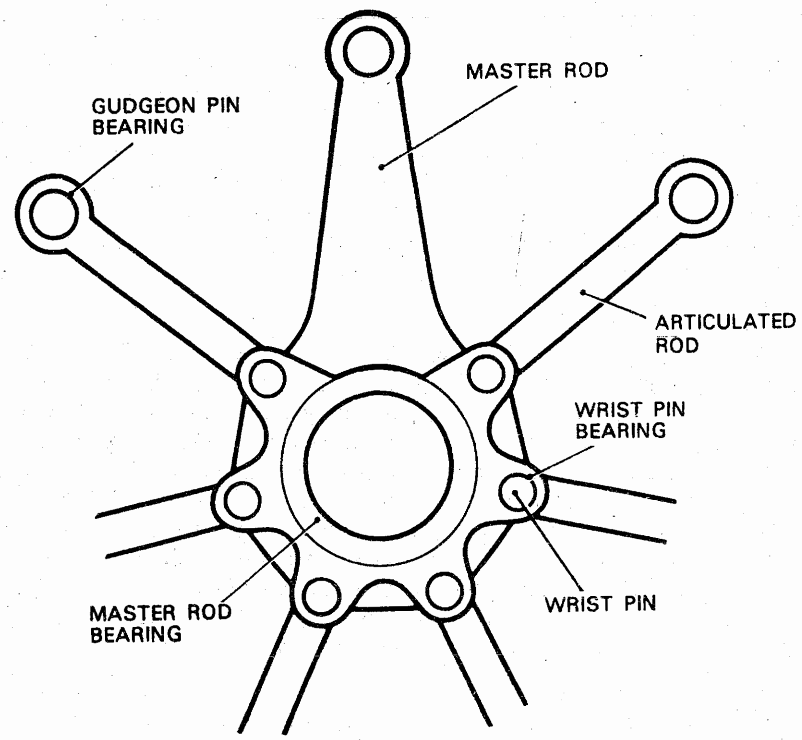


Figure 9 RADIAL ENGINE CONNECTING RODS

6.6.2 Since a piston, being made from aluminium alloy, expands more than the cylinder barrel (which is normally steel alloy), a working clearance between these components is essential, and, in order to prevent gas leakage from the combustion chamber, a number of piston rings are fitted into grooves in the piston. These rings are generally made from cast iron or alloy steel, are split to permit assembly, and have a gap between their ends to allow for expansion; a side clearance between the groove and ring is also essential. Rings are often free in their grooves, and are assembled with the gaps of alternate rings spaced 180° apart, but in some cases rotation is prevented by a peg in the piston ring groove. Compression rings are designed to prevent gas leakage from the combustion chamber, and are generally fitted above the gudgeon pin, whilst scraper rings (also known as oil control rings) are designed to remove oil from the cylinder walls, and are generally fitted below the gudgeon pin.

6.6.3 Piston heads may be flat or slightly domed for strength, or may be concave in order to provide a combustion chamber which is as nearly spherical as possible. In some cases it may also be necessary to have recesses in the head of the piston, to provide clearance for the open valves when the piston is at the top of the exhaust stroke.

6.6.4 Lubrication of the gudgeon pin bearings is provided by splash oil, through holes drilled in the gudgeon pin bosses, and drainage of the oil removed from the cylinder walls by the piston scraper rings, is provided by radial holes drilled through the piston from the base of the piston ring grooves.

6.7 **Valves**

6.7.1 **Sleeve Valves.** On a few engines, the inlet and exhaust ports in the cylinder are opened and closed by means of a cylindrical sleeve fitted between the cylinder barrel and the piston. The sleeve, of hardened steel, is driven by a crank, which is geared to the crankshaft, and ports in the sleeve uncover the cylinder inlet and exhaust ports at the appropriate times. Timing of the opening and closing of the ports is fixed by the gear train and the position and shape of the ports in the sleeve, and no adjustments are possible. The main advantage of this method is reputed to be the increased volumetric efficiency resulting from the lack of obstruction to the incoming and outgoing gases.

6.7.2 **Poppet Valves.** These valves (Figure 7) are fitted to the majority of aircraft piston engines; they operate under arduous conditions and may be made from a variety of steel alloys. Exhaust valves, which are subjected to the highest temperatures, often have a larger diameter stem than inlet valves, the stem being hollow and partially filled with sodium to transfer heat away from the valve head. Valve heads are ground to form a face which mates with the valve seat and forms a gas-tight seal. The ends of the valve stems are grooved to secure a split collet, which holds the spring retaining collar in position, and are hardened at the tip to provide a bearing surface for the rocker arm. Each valve is closed by two or more coil springs, which are concentrically mounted and coiled in opposite directions; the fitting of two or more springs having different vibration frequencies prevents the valve from bouncing on its seat when it closes.

(a) Valve stems slide in valve guides fitted in the cylinder head, which are generally lubricated by splash from the rocker gear. The inner ends of the valve guides are often fitted with a seal, to prevent the leakage of oil into the inlet and exhaust ports of the cylinder.

6.8 **Valve Operating Mechanism.** Poppet valves are opened by a mechanical linkage from the cam shaft or cam drum, and closed by the valve springs. As the appropriate cam is rotated, its lobe pushes a tappet, which in turn activates a push rod, which transmits movement to the rocker arm; the rocker arm pivots on its bearing and pushes on the end of the valve stem to open the valve. When the cam has passed its point of maximum lift, the valve springs return the mechanism to its original position and close the valve. This type of mechanism is generally used on horizontally-opposed and radial engines, and also on some in-line engines (Figure 7). On other in-line engines the camshaft is mounted on the cylinder heads, and operates directly on the rocker arms to open the valves; these are known as "overhead camshaft" engines.

6.8.1 **Camshafts.** Camshafts are fitted to all horizontally-opposed and in-line engines, and are driven through spur or bevel gearing from the crankshaft, at half engine speed. They are made from alloy steel and are supported in plain bearings which are pressure lubricated from the engine oil system. The cams are shaped and positioned so as to open and close their associated valves at the correct time, and their faces are hardened to provide a good bearing surface.

6.8.2 **Cam Drums.** Cam drums are used in most radial engines, and have two rows of cams (one for the inlet valves and one for the exhaust valves). They are made from steel, and are mounted on a bearing around the front of the crankshaft and driven, by a gear train from the crankshaft, at the required speed and in the required direction of rotation (paragraph 3.2.3). The cam drum bearing is generally pressure lubricated by the engine oil system.

6.8.3 **Tappets.** The purpose of a tappet is to transfer the motion of a cam to its associated push rod. Tappets may be fitted either directly into the crankcase or in bronze guides in the crankcase. They are often purely mechanical devices comprising a rod with a hardened pad or roller at the cam end, and a hardened socket at the push rod end. To ensure that the valves close properly when the engine is running, in spite of expansion of the cylinder, a means of adjustment is provided to enable a predetermined clearance to be maintained in the valve operating mechanism when the valve is closed; this is known as tappet clearance. Most modern light aircraft engines are fitted with hydraulic tappets (Figure 10). This type of tappet consists basically of a body and a plunger, with an internal spring and non-return valve, and a push rod socket. During operation, pressure oil supplied to the tappet is picked up by a groove round the body when the tappet is near the outer end of its stroke. This oil lubricates the tappet bearing surface and enters the plunger reservoir through a port in the plunger wall; it then passes through the push rod socket and hollow push rod to lubricate the rocker mechanism. If clearance is present in the valve operating mechanism when the tappet is resting on the cam dwell, the spring in the tappet body pushes the plunger outwards to eliminate this clearance, the non-return valve opening to allow oil to pass into the body reservoir. As the cam lobe commences to push on the tappet, the non-return valve closes and a hydraulic lock is formed, transmitting motion to the push rod. In this way clearance is eliminated from the mechanism; valve closure is unaffected, since the force applied by the tappet spring is much less than that of the valve springs.

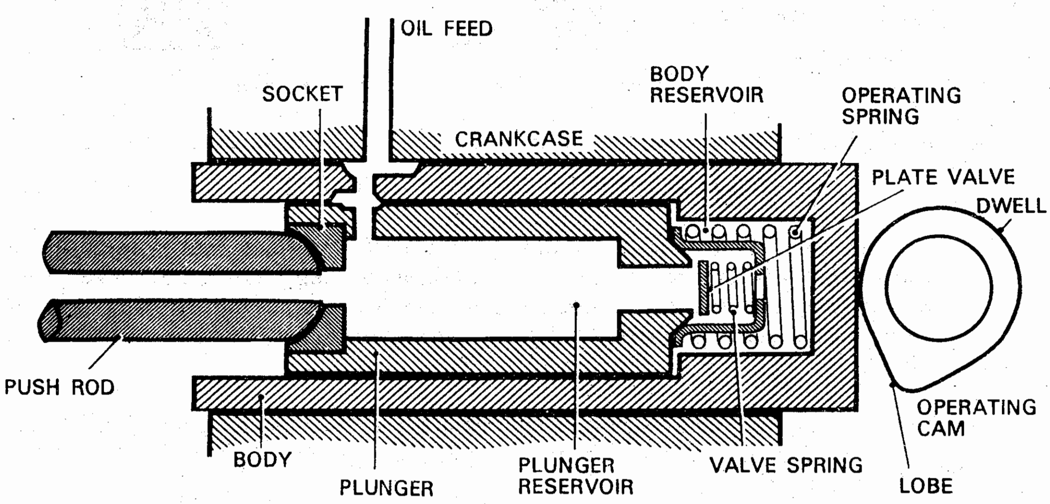


Figure 10 HYDRAULIC TAPPET

6.8.4 **Push Rods.** Push rods are usually steel tubes, with hardened steel fittings at each end to mate with the tappet and rocker arm. These fittings are usually drilled to allow lubricating oil to pass to the rocker arm. The push rods are surrounded by push rod covers, which may be steel or aluminium alloy tubes, and which are fitted with seals at the cylinder head and crankcase; the crankcase seal usually being spring-loaded to permit assembly.

6.8.5 **Rockers.** A rocker arm pivots on a steel shaft, which may be held in mountings in the cylinder head or in pedestals which are bolted to the cylinder head. Rocker arms are generally made from alloy steel, with a hardened face at the valve end, and an adjusting screw with hardened socket at the push rod end. On some engines, mounting and adjustment are by means of a ball or roller pivot bearing, which is mounted in an eccentric bush. Oil from the hollow push rod is often fed through the drillings in the rocker arm to lubricate the rocker arm bearing. On other engines the rockers may be lubricated as described in paragraph 5.

6.9 **Propeller Reduction Gear.** The purpose of a reduction gear is to reduce engine speed to a speed suitable for efficient operation of the propeller. The various types of reduction gears are illustrated in Figure 11. Epicyclic (sometimes known as "planetary") reduction gears are always used on radial engines, and spur gear reduction gears are generally used on in-line engines, but either type may be fitted to horizontally-opposed engines.

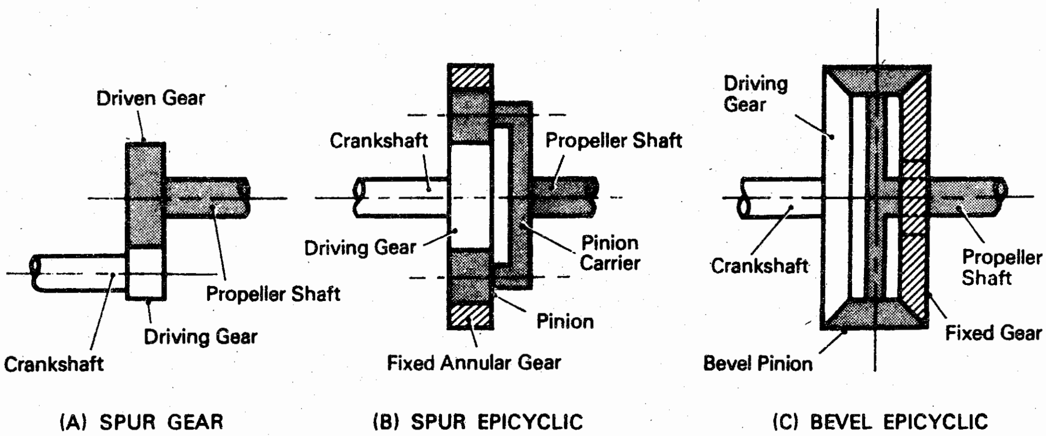


Figure 11 REDUCTION GEAR TYPES

6.9.1 A propeller shaft is normally supported in roller bearings, and propeller thrust is transferred to the engine by means of a ball thrust bearing. On some small engines, however, the propeller may be supported in plain bearings, the thrust being taken by a thrust washer placed between a flange on the propeller shaft, and one of the bearing supports.

6.9.2 Lubrication of plain bearings is by pressure feed from the normal engine lubrication system, and lubrication of ball and roller bearings, and of gears, is by oil spray nozzles and splash.

6.10 **Accessories.** A number of components such as magnetos, oil pumps, fuel pumps, starter and engine speed indicator drive, are required for normal operation of the engine, and, in addition, accessories such as hydraulic pumps, pneumatic pumps and electrical generators may be required to power the aircraft systems. All these components are driven at a suitable speed by gearing from the engine crankshaft, and are generally attached to the engine crankcase. In some cases, however, the aircraft system components are fitted to a remotely mounted gearbox, which is driven by an extension shaft from the rear of the engine crankshaft. Accessories are often coupled to their driving gears by means of a quill shaft, which is designed to shear in the event of failure of the accessory, thus preventing damage to the engine. Lubrication of accessory drive plain bearings is generally by lubrication system pressure, through ductings in the crankcase, and of ball and roller bearings, by crankcase splash; remotely mounted gearboxes are generally self-contained, the casing being partially filled with oil, and lubrication effected by splash.

6.11 **Pumps.** Mechanically driven pumps may be used for a number of purposes on an engine; centrifugal pumps are used to circulate coolant, gear-type pumps are used to provide oil at high pressure for engine lubrication, and diaphragm pumps are sometimes used to supply fuel to the carburettor. Other types of pumps are used to power various aircraft systems, and these are described in the appropriate Leaflets.

6.11.1 **Centrifugal Pumps.** A centrifugal pump consists of an impeller, which is rotated inside a housing. The working fluid rotates with the impeller, and centrifugal forces acting on this fluid cause it to flow to the outside of the housing, and more fluid is drawn into the eye of the impeller. This provides a low pressure circulation through the system, and, since it is not a positive displacement pump, neither a pressure relief valve nor a by-pass is required.

6.11.2 **Gear Pumps.** These pumps consist of two meshing gears, which rotate in a close-fitting housing (Figure 12). One gear is driven from the engine, and as it rotates it carries the other gear round with it, and fluid is carried round the casing between the gear teeth. These pumps are known as positive displacement pumps, a definite volume of fluid being delivered for each revolution of the gears. Any restriction in the delivery line (such as will normally be provided by the bearings) will result in a build-up of pressure, and a relief valve is required. Relief valves are adjusted to maintain a predetermined pressure on the delivery side of the pump, and any excess fluid is by-passed to the inlet side of the pump or to the sump; in some engines a second relief valve is fitted after the main pressure relief valve, to provide a low-pressure lubrication system for certain components. Engine oil pressure and scavenge pumps are generally driven by a common shaft and mounted in adjoining housings, the gears of the scavenge pump being longer than those of the pressure pump to ensure complete scavenging of the sump.

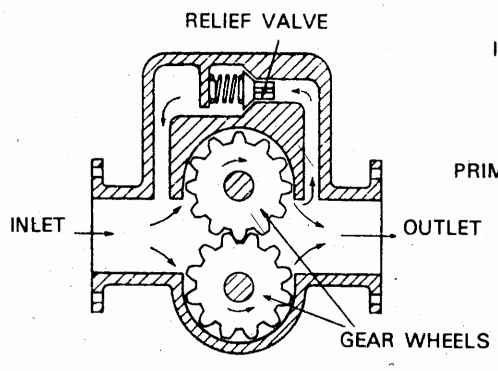


Figure 12 GEAR PUMP

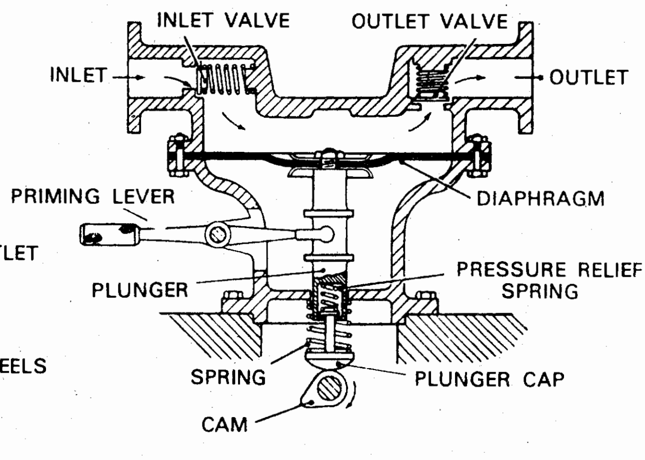


Figure 13 DIAPHRAGM PUMP

6.11.3 **Diaphragm Pumps.** In a diaphragm pump, a rotating cam in the engine acts indirectly on a diaphragm (usually of rubberized fabric), and causes it to reciprocate. This motion, in conjunction with lightly spring-loaded inlet and outlet valves, can be used, for example, to pump fuel to the carburettor. In the pump illustrated in Figure 13, a spring keeps the plunger cap in contact with the cam, and a second spring, inside the plunger, limits the delivery pressure by restricting the movement of the diaphragm. Construction of these pumps varies in detail, and in some pumps a filter bowl is suspended below the pump, the inlet valve being located inside the filter; in other pumps the plunger may be operated indirectly by a cranked lever.

7 POWER CALCULATION AND MEASUREMENT

7.1 **Indicated Power.** The power developed in an engine cylinder can be calculated from the cylinder dimensions and the average pressure on the piston during the power stroke. The force exerted on the piston will be the average pressure multiplied by the area of the piston, and the work done (force x distance) will be this force multiplied by the length of the stroke. The power developed in the cylinder can then be calculated by multiplying the work done by the number of power strokes (N) per unit time. In the case of a single cylinder engine, "N" will be the crankshaft rotational speed divided by 2, and in the case of a multi-cylinder engine "N" will be the crankshaft rotational speed $\times \frac{\text{no. of cylinders}}{2}$.

When using Imperial units, power is usually quoted in horsepower (hp) (1 hp = 33,000 ft lbf/min) and when using SI units, power is usually quoted in kilowatts (kW) (1 hp = 0·746 kW). Thus the Indicated Power of an engine can be calculated from the formula:—

$$\frac{PLAN}{33{,}000}\text{ hp} \quad \text{or} \quad \frac{PLAN}{60{,}000}\text{ kW}$$

where P = pressure on piston (lbf/in^2 or N/m^2)
L = length of stroke (ft or m)
A = area of piston (in^2 or m^2)
N = number of power strokes/min.

7.1.1 For any particular engine the cylinder capacity is fixed, so that a constant (k) could be used to replace all the invariable quantities in the formula for Indicated Power, which could then be simplified to:—

$$\frac{P \times \text{rev/min}}{k}$$

where k is $\frac{33{,}000}{L \times A \times \frac{1}{2}\text{ no. of cylinders}}$ or $\frac{60{,}000}{L \times A \times \frac{1}{2}\text{ no. of cylinders}}$ as appropriate.

It can then be seen that Indicated Power for a particular engine varies directly as the cylinder pressure and the engine speed, an increase in either giving an increase in Indicated Power.

7.2 **Brake Power.** The Brake Power, or shaft power, of an engine is the power actually delivered to the propeller, and represents the Indicated Power reduced in quantity by the power required to overcome friction and to drive the engine accessories. Power used internally is known as Friction Power, and the relationship between Brake Power and Indicated Power, expressed as a percentage, is known as the Mechanical Efficiency of the engine.

7.2.1 The output of an engine is obtained by measuring the torque of the propeller shaft. When calculating the work done on the piston (paragraph 7.1) work was taken as force x distance (in a straight line); when measuring the work done by the propeller shaft, the torque can be thought of as a force "F" acting at a distance "r" from the axis of the shaft (Figure 14). If the system rotates once, the force can be regarded as having travelled one circumference of a circle of radius r, i.e. work done per revolution $= F \times 2\pi r$ or, as torque $=$ Fr, then work $=$ torque $\times 2\pi$. Brake Power can then be calculated if the speed of rotation is known. Using Imperial units the Brake Power becomes:—

$$\frac{\text{torque (lbf ft)} \times 2\pi \times \text{rev/min}}{33{,}000}\ \text{hp}$$

and using SI units it becomes:—

$$\frac{\text{torque (N m)} \times 2\pi \times \text{rev/min}}{60{,}000}\ \text{kW}.$$

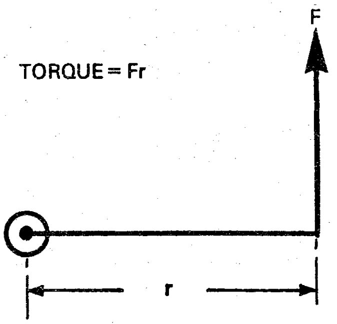


Figure 14 TORQUE MEASUREMENT

Again, using a constant (C) for the invariable quantities, Brake Power becomes $\frac{\text{torque} \times \text{rev/min}}{C}$, and it can be seen that it varies directly with torque and engine speed.

7.3 **Mean Effective Pressure.** The average pressure exerted on the piston during the power stroke is known as the Mean Effective Pressure (MEP). The actual pressures can be measured, and are generally reproduced on an Indicator Diagram similar to the one shown in Figure 15. The shaded areas represent work done on the piston during the induction and power strokes, and the unshaded areas below the curve represent work done by the piston during the compression and exhaust strokes. The sum of the shaded areas, less the sum of the unshaded areas, represents useful work, and when this area is confined to the power stroke, the pressure co-ordinate becomes the Indicated MEP (IMEP), and may be used for calculating Indicated Power (paragraph 7.1). IMEP, therefore, has a definite relationship to Indicated Power, and, in a similar way, is composed of components representing Friction Power and Brake Power. These components are known as Friction MEP (FMEP) and Brake MEP (BMEP), and can be used for calculating Friction Power and Brake Power respectively. Similarly, if Indicated Power and rev/min are known, IMEP can be calculated

$$\left(\text{IMEP} = k \times \frac{\text{Indicated Power}}{\text{rev/min}}\right),$$

and if Brake Power and rev/min are known, then BMEP can be calculated

$$\left(\text{BMEP} = k \times \frac{\text{Brake Power}}{\text{rev/min}}\right).$$

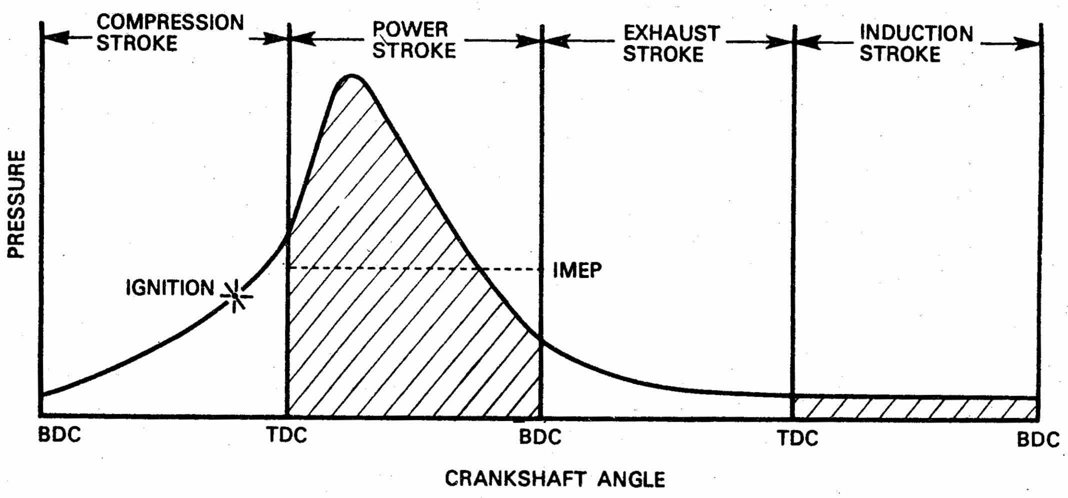


Figure 15 INDICATOR DIAGRAM

7.4 **Power Control.** Engine operation must be confined within cylinder pressure and crankshaft speed limitations, which are determined by the manufacturer. Various combinations of these parameters could be used to produce any particular power output, and the most economical would be the use of low rev/min to minimize friction and high cylinder pressures to produce the power required. On most engines, since cylinder pressure is related to manifold pressure, adequate control is provided by operating within prescribed manifold pressure and rev/min limitations, but on large engines where economy is particularly vital, closer control of cylinder pressure becomes necessary. IMEP is related directly to peak cylinder pressure and to Indicated Power, so that control of IMEP would ensure operating at safe cylinder pressures; however, Indicated Power is difficult to measure and other means must be used.

7.4.1 FMEP varies according to peak cylinder pressure and internal power requirements (different supercharger ratios, etc.), and can be measured throughout the engine speed range. The relationship between BMEP and IMEP can, therefore, be determined for any operating conditions, and since Brake Power can easily be measured by fitting a torquemeter (paragraph 7.5) to the engine, operation at safe cylinder pressures can be achieved by imposing BMEP limitations for the various operating conditions.

7.4.2 Manufacturers conduct tests to ascertain the BMEP which is equivalent to the maximum safe cylinder pressure for any set of operating conditions, and also provide sets of tables showing the range of BMEP and rev/min setting which will give particular power outputs. The pilot may then select the power settings for the power output he requires, ensuring that the BMEP is within the limit prescribed for the particular operating conditions. Alternatively, using the formula

$$\left(\text{BMEP} = \text{k} \times \frac{\text{Brake Power}}{\text{rev/min}}\right),$$

the pilot may calculate the rev/min necessary to achieve the power he requires at maximum permissible BMEP.

7.4.3 Any rapid reduction in rev/min when operating at maximum BMEP, would result in the cylinder pressure limit being exceeded. When adjusting power, therefore, manifold pressure should be reduced before decreasing rev/min, and rev/min should be increased before raising manifold pressure.

7.5 **Torquemeters.** Propeller shaft torque is generally measured at the reduction gear. As the crankshaft gear rotates, it drives the propeller pinions, and these exert a thrust on the fixed gear teeth, tending to rotate the fixed gear in the opposite direction to the crankshaft gear; this thrust is directly proportional to power output. To measure the thrust applied to the fixed gear, the gear is allowed to float, and is attached to the structure through pistons and oil-filled cylinders, as shown in Figure 16. Engine oil pressure to these cylinders is boosted by a torquemeter pump, and each cylinder is fitted with a bleed back to the engine oil system.

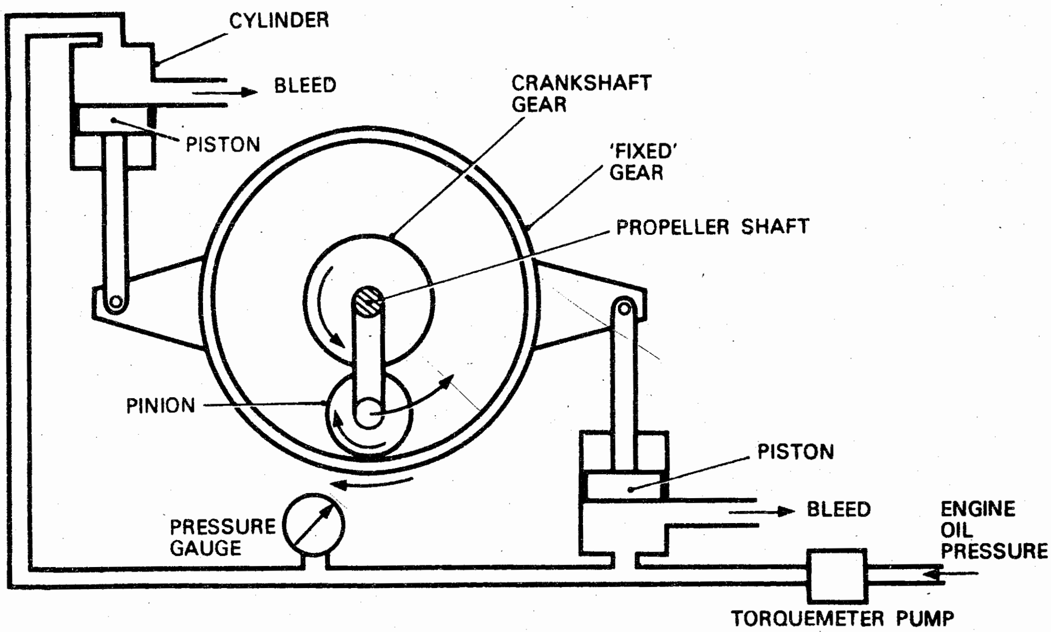


Figure 16 TORQUEMETER SYSTEM

7.5.1 **Operation.** At low engine power, thrust on the "fixed" gear is at a minimum and the bleed port is fully open, resulting in a low oil pressure in the system and a low reading on the torquemeter pressure gauge. As power is increased the thrust on the "fixed" gear increases, and the pistons are forced further into their cylinders. The bleed ports are reduced in size by movement of the pistons, and the oil pressure in the system increases to balance the thrust on the fixed gear. The torquemeter gauge may be calibrated directly in BMEP, or in units of oil pressure.

Issue 1.

3rd December, 1976.

AIRCRAFT

ENGINES

PISTON ENGINE CARBURATION SYSTEMS

1 INTRODUCTION This Leaflet deals with piston-engine fuel requirements, and the methods used to provide a satisfactory supply of combustible mixture to the cylinders under all operating conditions. The storage of fuel and the supply of fuel to the engine are dealt with in Leaflets **AL/3-15** and **AL/3-17,** respectively.

2 FUEL The fuel used in piston engines is a hydrocarbon fuel, with a composition of approximately 85% carbon and 14% hydrogen by weight. When the fuel is mixed in suitable proportions with air, and ignited, the carbon and hydrogen combine with the oxygen in the air and form carbon dioxide and water vapour; the nitrogen in the air, being an inert gas, is chemically unchanged, but performs the useful function of slowing down the combustion process and maintaining acceptable combustion temperatures.

2.1 The most important qualities required in a fuel are outlined in paragraphs 2.1.1 to 2.1.4 below.

2.1.1 **Anti-knock Rating.** This is an indication of the resistance afforded by the fuel to the onset of detonation. It is explained in Leaflet **EL/1-1,** that an increase in power can be obtained by increasing cylinder pressure, but that this can cause detonation. It is important, therefore, that the fuel has good resistance to detonation in order to enable satisfactory engine power to be developed.

2.1.2 **Calorific Value.** This is a measure of the amount of heat which can be obtained from a given weight of fuel. This is important in an aircraft, since the weight of fuel carried will limit the payload. The calorific value of a given volume of fuel is also of significance, as in some cases the fuel tank capacity may be a limiting factor.

2.1.3 **Volatility.** This is the tendency of a fuel to evaporate. Volatility should be high enough to permit easy starting under cold atmospheric conditions, but not so high that vapour will form in the pipelines and pumps at high temperatures and/or low pressures, and interrupt fuel flow or upset the metering system.

2.1.4 **Corrosive Effects.** A fuel must not be corrosive to any components in the engine or fuel system.

2.2 Although fuels of various grades have been available in the past, and have been specified for use in particular engines, there is a tendency for fuel companies to reduce the number of grades available, to standardize on Grade 100L (dyed green) or Grade 100LL (dyed blue), which both contain a small quantity of tetraethyl lead to assist in preventing detonation and are covered by Specifications D Eng RD 2485 and 2475 respectively. The problems associated with the use of these fuels in engines which were designed for use with non-leaded fuel, or fuel with a lower lead content, are outlined in CAA Airworthiness Notice No. 70.

3 MIXTURE REQUIREMENTS Air and fuel vapour will burn if mixed in the ratios of between approximately 8 : 1 and 20 : 1 by weight. However, complete combustion will only occur at a ratio of approximately 15 : 1 (i.e. all the hydrogen and carbon in the fuel, and all the oxygen in the air will be used up), and this is known as the chemically-correct, or stoichiometric, mixture, which produces the highest combustion temperatures. With weaker mixtures (i.e. those containing less fuel), and richer mixtures (i.e. those containing more fuel), the excess air or fuel will absorb some of the heat of combustion and lower the temperature of the burning gases.

3.1 Although the chemically-correct mixture strength would theoretically produce the highest temperature, and therefore power, in practice mixing and distribution are less than perfect and this results in some regions being richer and others being weaker than the optimum strength; this variation may exist between one cylinder and another. A slight excess of fuel does not have much effect on power since all the oxygen is still consumed and the excess of fuel simply serves to reduce slightly the effective volumetric efficiency; in fact its cooling effect can be to some extent beneficial. Weak mixtures, however, rapidly reduce power since some of the inspired oxygen is not being utilized, and this power reduction is much greater than that resulting from slight richness. It is, therefore, quite common to run engines (when maximum power rather than best fuel economy is the objective) at somewhat richer than chemically-correct mixtures (e.g. about 12·5 : 1) to ensure that no cylinder is left running at severely reduced power from being unduly weak.

3.2 A mixture which is weaker than the chemically-correct mixture, besides burning at lower temperatures, also burns at a slower rate (because of the greater proportion of inert gas in the cylinder). Power output thus decreases as the mixture is weakened, but, because of the increase in efficiency resulting from cooler burning, the fall in power is relatively less than the decrease in fuel consumption. Thus the specific fuel consumption (i.e. the weight of fuel used per horsepower per hour) decreases as mixture strength is weakened below 15 : 1. For economical cruising at moderate power, air/fuel ratios of 18 : 1 may be used, an advance in ignition timing being necessary to allow for the slower rate of combustion.

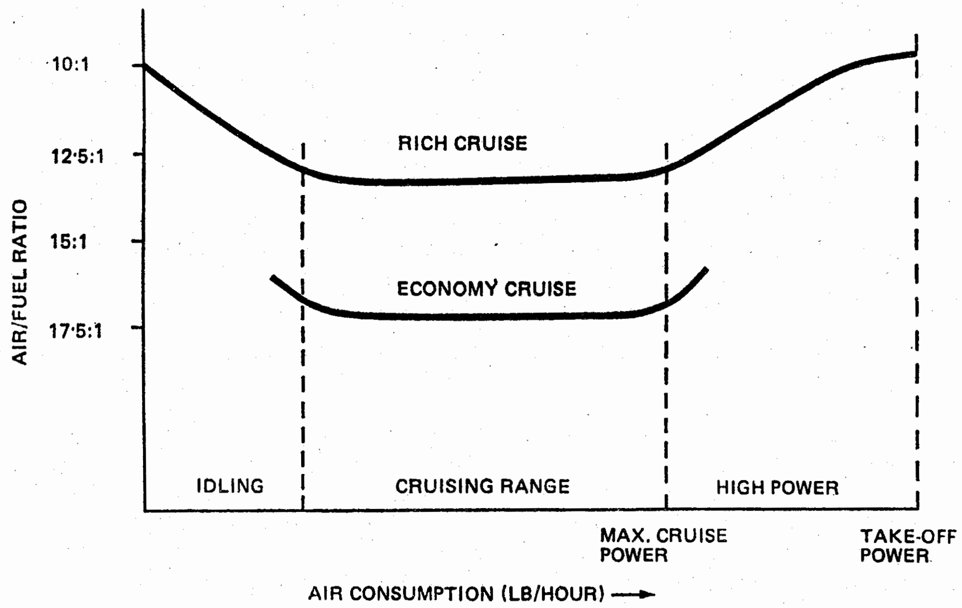


Figure 1 TYPICAL MIXTURE REQUIREMENTS

3.3 At high power settings, the increase in engine speed and cylinder pressure results in an increase in mixture temperature, and this could lead to detonation. Cooling may be provided by using excess fuel, an air/fuel ratio as low as 10 : 1 often being used at maximum power. This excess fuel, other than acting as a coolant, is otherwise wasted, because there is no oxygen available to burn it.

3.4 A richer mixture is also required at low engine speeds. The valves are timed to provide efficient operation at high engine speeds, and at low speeds the exhaust gas velocity is much less, with the result that exhaust gases are left in the cylinder during the period of valve overlap. This residual gas results in dilution of the incoming mixture, which must be progressively enriched as speed is decreased, in order to maintain smooth running.

3.5 The mixture requirement is, therefore, dependent upon engine speed and power output. A typical air/fuel mixture curve is shown in Fig. 1, and Fig. 2 illustrates the relationship between fuel consumption and power.

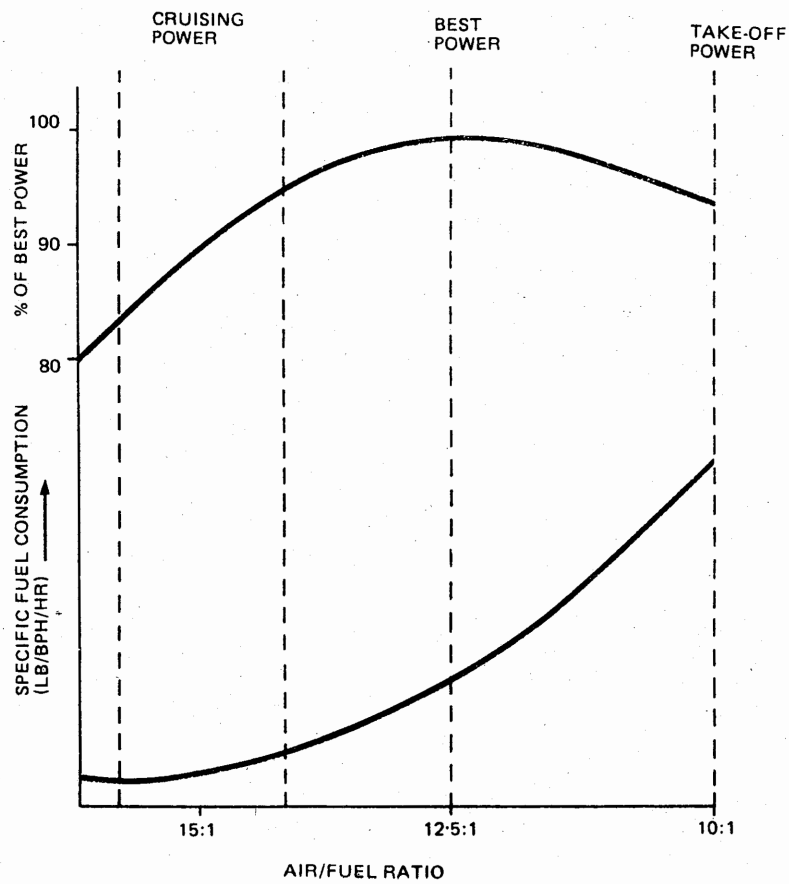


Figure 2 FUEL CONSUMPTION AND POWER

3.6 Fuel is supplied to the engine as a liquid, but must be burnt as a mixture of fuel vapour and air; a number of engine and carburettor design features are, therefore, aimed at producing thorough atomization and mixing of the charge.

3.6.1 Initial atomization of the fuel in a float-chamber carburettor is achieved in a diffuser or discharge nozzle, by mixing the air and fuel before they pass into a venturi, but in other carburation systems the fuel is forced through a discharge nozzle under positive pressure, and better atomization is achieved.

3.6.2 Vaporization is often assisted by warming the induction passages, by designing the engine so that much of the induction manifold is either submerged in hot oil in the engine sump, or is surrounded by an exhaust-heated jacket.

3.6.3 On some engines the fuel/air mixture passes through a distribution impeller, which is attached to the crankshaft and rotates at engine speed. This has the effect of thoroughly mixing the fuel and air, and assisting in vaporization.

3.7 The carburation system must control the air/fuel ratio in response to throttle setting, at all selected power outputs from slow-running to full throttle, and during acceleration and deceleration; it must function at all altitudes and temperatures in the operating range, must provide for ease of starting and may incorporate a means of shutting off the fuel to stop the engine. The float-chamber carburettor (paragraph 4) is the cheapest and simplest arrangement and is used on many light aircraft; it is very prone to carburettor icing, however, and may be affected by flight manoeuvres. The injection carburettor (paragraph 5) is a more sophisticated device and meters fuel more precisely, thus providing a more accurate air/fuel ratio; it is also less affected by flight manoeuvres, and is less prone to icing. The direct- (or port-) injection system (paragraph 6) provides the best fuel distribution and is reputed to be the most economical; it is unaffected by flight manoeuvres and is free from icing.

3.7.1 Any of these carburettor types may be fitted with a manual mixture control, by means of which the most economical cruising mixture may be obtained. However, in order to assist the pilot in selecting the best mixture, some aircraft are fitted with fuel flowmeters, exhaust gas temperature gauges or exhaust gas analysers.

4 FLOAT-CHAMBER CARBURETTORS In a float-chamber carburettor (Fig. 3), airflow to the engine is controlled by a throttle valve, and fuel flow is controlled by metering jets. Engine suction provides a flow of air from the air intake, through a venturi in the carburettor, and thence to the induction manifold; this air speeds up as it passes through the venturi, and a drop in pressure occurs. Fuel is contained in a float chamber, which is supplied by gravity, by an electrical booster pump or by an engine-driven fuel pump, and a constant level is maintained in the chamber by the float and needle-valve. Where fuel pumps are used, a fuel pressure gauge is included in the system to provide an indication of pump operation. Air intake or atmospheric air pressure acts on the fuel in the float chamber, which is connected to a fuel discharge tube located in the throat of the venturi. The difference in pressure between the float chamber and the throat of the venturi, provides the force necessary to discharge fuel into the airstream. As airflow through the venturi increases so the pressure drop increases, and a higher pressure differential acts on the fuel to increase its flow in proportion to the airflow. The size of the main jet in the discharge tube determines the quantity of fuel which is discharged at any particular pressure differential, and therefore controls the mixture strength. The simple carburettor illustrated in Fig. 3 contains all the basic components necessary to provide a suitable air/fuel mixture over a limited operating range. A number of alterations are necessary, however, in order to provide for all the requirements of an aircraft engine, and these are discussed in paragraphs 4.1 to 4.5.

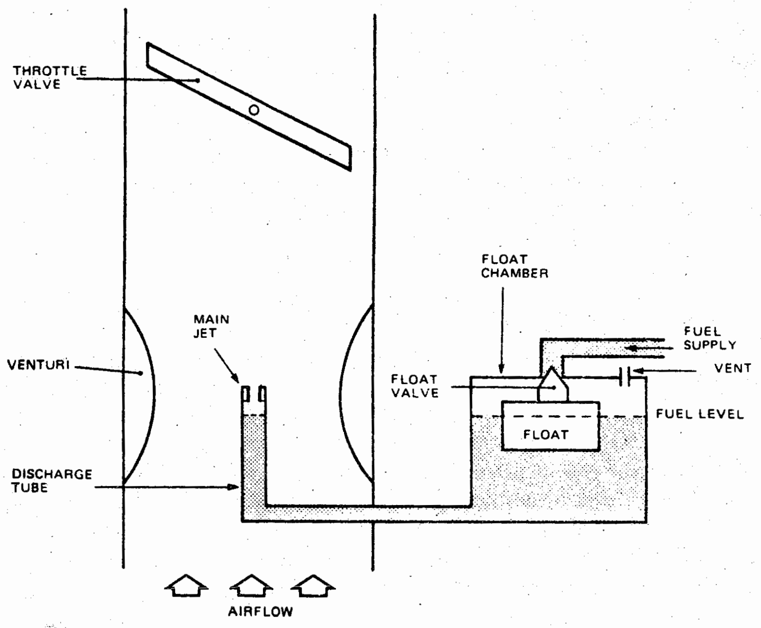


Figure 3 SIMPLE CARBURETTOR

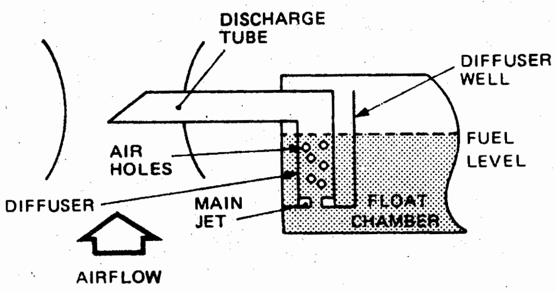


Figure 4 DIFFUSER

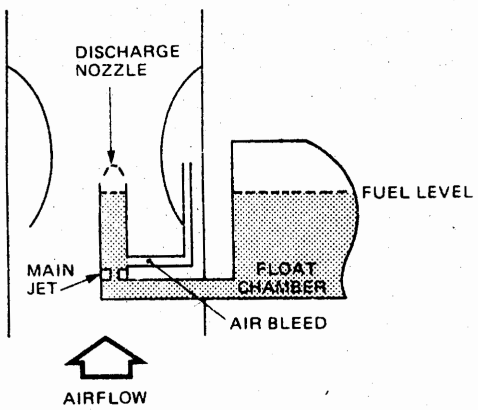


Figure 5 AIR BLEED

4.1 **Main Metering System.** As engine speed and airflow through the venturi increase, the proportion of fuel to air rises as a result of the different flow characteristics of the two fluids. To overcome this effect, some carburettors are fitted with a diffuser such as is illustrated in Fig. 4. As engine speed is progressively increased above idling, the fuel level in the diffuser well drops, and progressively uncovers more air holes. These holes allow more air into the discharge tube, and by reducing the pressure differential prevent enrichment of the air/fuel mixture. The process of drawing both air and fuel through the discharge tube also has the effect of vaporizing the fuel more readily, particularly at low engine speeds. On carburettors not fitted with a diffuser, air at atmospheric pressure is bled into the discharge tube, and produces similar results; the air bleed method is illustrated in Fig. 5.

4.2 **Idling.** When the engine is idling, the air velocity through the venturi is too low to provide an adequate discharge of fuel. However, the air passing through the gap between the throttle valve and the wall of the throttle body has sufficient velocity to provide the necessary reduction in pressure. One or more small holes are drilled through the wall at this position, and ducted to the float chamber; an air bleed is incorporated in this duct, to provide a mixture of air and fuel to an idling jet. On some carburettors the idling mixture is adjusted by varying the total quantity of mixture discharged into the airstream, whilst on others a fuel metering jet is placed in the idling duct, and adjustment is obtained by varying the air bleed. A cut-off valve may be fitted to the duct, to enable the engine to be stopped. A typical idling system is shown in Fig. 6.

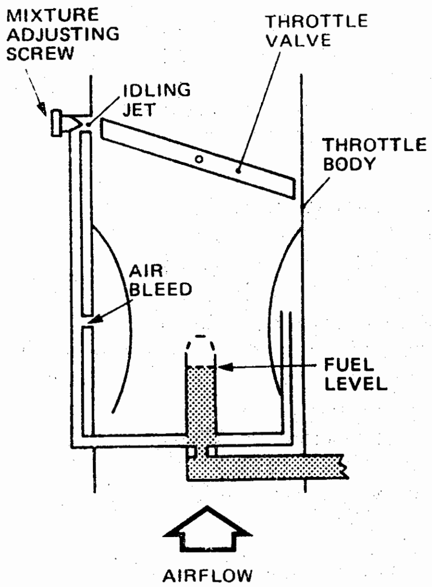


Figure 6 IDLING SYSTEM

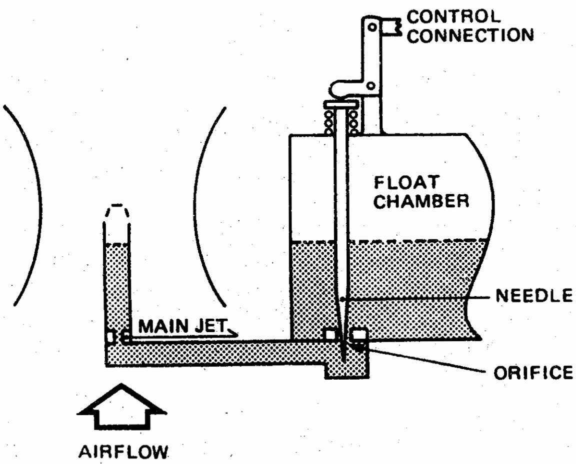


Figure 7 NEEDLE-TYPE MIXTURE CONTROL

4.3 **Mixture Controls.** The pressure drop at the venturi is a measure of air mass flow and is proportional to $d \times v^2$ (where d is air density and v is air velocity). Fuel mass flow resulting from the pressure drop in the venturi is proportional to $D \times V^2$ (where D is fuel density and V is fuel velocity). At constant density therefore, v^2 and V^2 are both proportional to the pressure drop, and changes in fuel mass flow will be proportional to changes in air mass flow (engine speed), except as noted in paragraph 4.1. At constant air velocity however, the pressure drop in the venturi is directly proportional to changes in air density, whilst fuel mass flow, being of constant density, remains proportional to $\sqrt{}$pressure drop; changes in air density therefore, produce less than proportional changes in fuel flow. This results in a progressive increase in richness with increased altitude, which would be unacceptable for economic operation. Float-chamber carburettors are normally fitted with a manual mixture control, which is used for correcting the enrichment resulting from decreased air density, and also for leaning (weakening) the mixture for economical cruising. The carburettors fitted to some large engines have automatic mixture control for altitude.

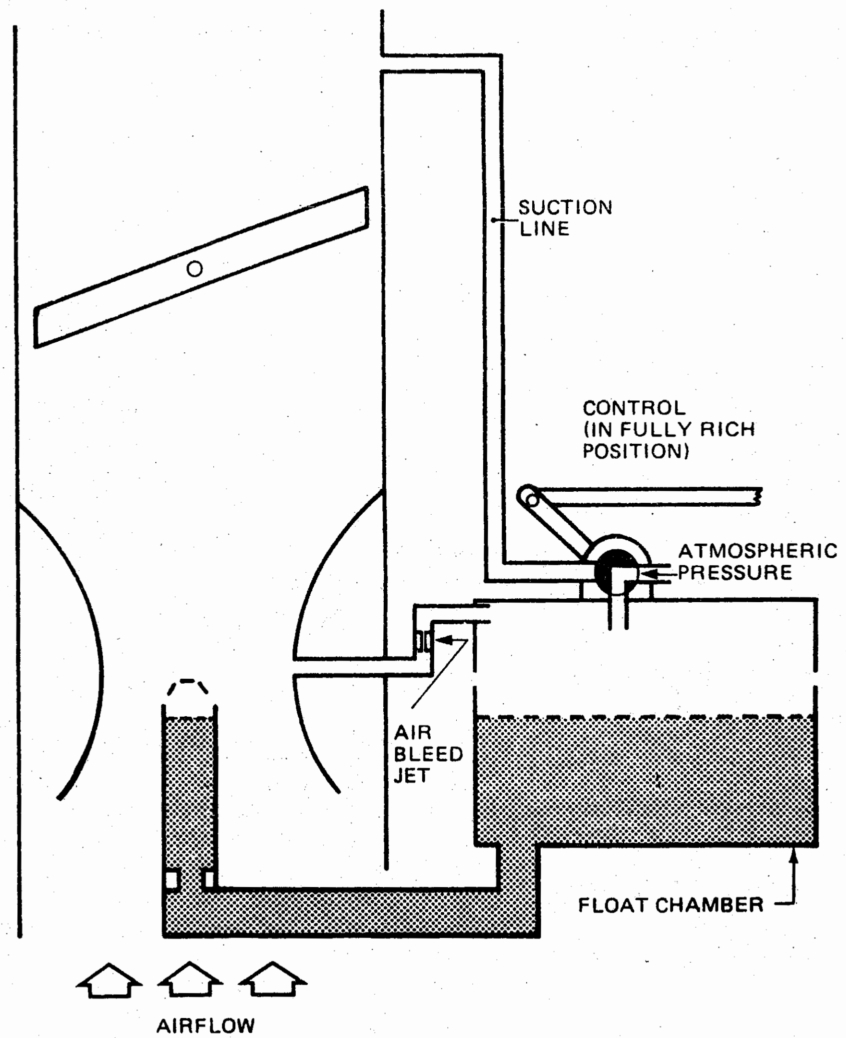


Figure 8 AIR BLEED MIXTURE CONTROL

4.3.1 With a needle-type mixture control, such as is illustrated in Fig. 7, a cockpit lever is connected to a needle valve in the float chamber. Movement of the cockpit lever raises or lowers the needle and varies fuel flow through an orifice to the main jet. The position of the needle, therefore, controls the mixture strength, and in the fully-down position will block fuel flow to the main jet, thus providing a means of stopping the engine.

4.3.2 The mixture control shown in Fig. 8 operates by controlling the air pressure in the float chamber, thus varying the pressure differential acting on the fuel. A small air bleed between the float-chamber and the venturi tends to reduce air pressure in the float-chamber, and a valve connected to a cockpit lever controls the flow of air into the float chamber. When this valve is fully open the air pressure is greatest, and the mixture is fully rich; as the valve is closed the air pressure decreases, thus reducing the flow of fuel and weakening the mixture. In the carburettor illustrated the valve also includes a pipe connection to the engine side of the throttle valve; when this pipe is connected to the float-chamber by moving the cockpit control to the 'idle cut-off' position, float-chamber air pressure is reduced and fuel ceases to flow, thus stopping the engine.

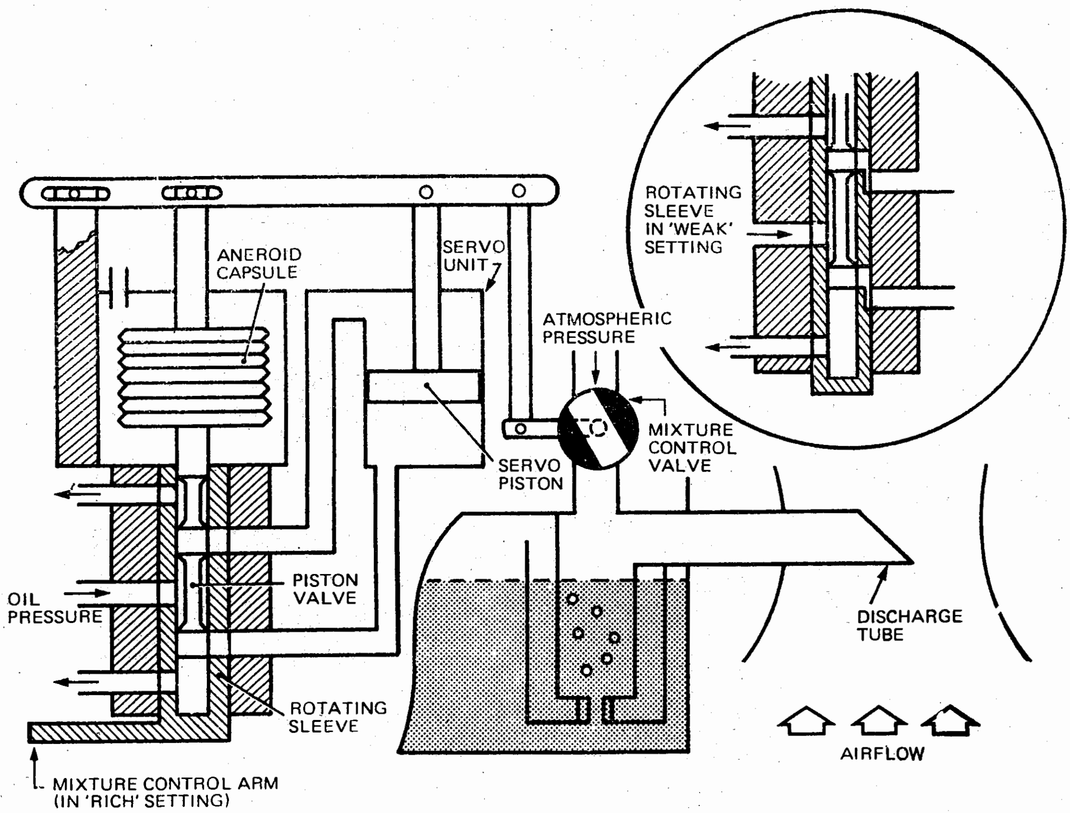


Figure 9 AUTOMATIC MIXTURE CONTROL

4.3.3 An automatic mixture control usually consists of an aneroid capsule, which controls the position of a valve admitting atmospheric pressure into the mixture discharge tube; this action alters the pressure difference between the venturi and the float-chamber, thus varying fuel flow. Fig. 9 illustrates a mixture control which uses engine oil pressure to position the mixture control valve according to atmospheric pressure. The aneroid-capsule chamber is open to atmosphere, and, as altitude increases, the capsule expands and lowers the piston valve. The piston valve directs oil to the lower side of the servo piston, which moves upwards in the servo unit; oil from above the servo piston returns through the piston valve to the scavenge line. The servo piston is connected to the mixture control valve and to the top of the aneroid capsule, and while opening the control valve also raises the aneroid capsule and piston valve, until the piston valve regains its neutral position and blocks oil flow to the servo unit. The reverse situation occurs as atmospheric pressure increases. The linkage is set by the manufacturer so that movement of the servo piston is proportional to changes in atmospheric pressure, and opening of the mixture control valve is proportional to fuel flow requirements.

(a) In this system, the mixture normally supplied is in accordance with the rich curve shown in Fig. 1. Economical cruising is obtained by resetting the neutral position of the piston valve, so that the servo piston adopts a higher position in the servo unit, irrespective of altitude. A sleeve around the piston valve is provided with two sets of holes, so that when the sleeve is rotated 90° (by movement of a two-position cockpit control), a second pair of holes is brought into line with the ducts leading to the servo unit. These holes are so formed that when their outlet points are lined up with the servo unit ducts, their inlet points (inside the sleeve) are situated higher up the sleeve, as shown in the small sketch in Fig. 9. The piston valve must, therefore, be moved to a higher position before it can block the servo unit ducts, and this results in an upward movement of the servo piston, which alters the position of the mixture control valve to give a weaker mixture.

(b) The cockpit controls are so arranged that, as power is increased above the cruising range, the mixture lever is automatically moved to the rich setting.

4.4 **Power Enrichment.** At power settings above the cruising range, a richer mixture is required to prevent detonation. This rich mixture may be provided by an additional fuel supply, or by setting the carburettor to provide a rich mixture for high power and then bleeding off float-chamber pressure to reduce fuel flow for cruising.

4.4.1 Fig. 10 illustrates a carburettor with an additional needle valve, which may be known as a power jet, enrichment jet, or economizer. The needle valve, which is connected to the throttle control, is fully closed at all throttle settings below that required to give maximum cruising power at sea-level, but as the throttle is opened above this setting the needle valve opens progressively until, at full throttle, it is fully open. On some engines the power jet is operated independently of the throttle, by means of a sealed bellows which is actuated by manifold pressure. In this way high-power enrichment is related to engine power rather than to throttle position.

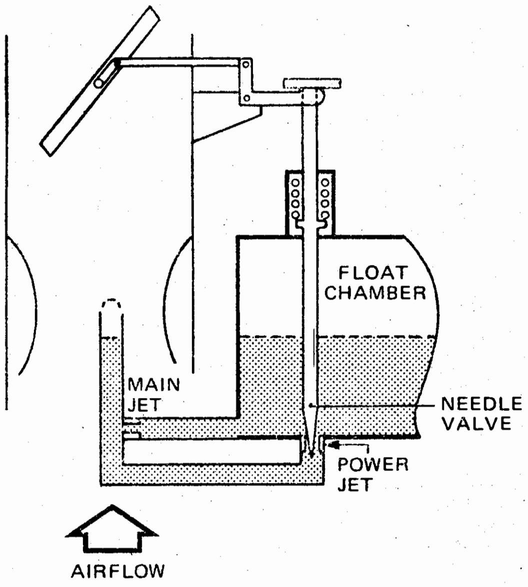


Figure 10 POWER JET

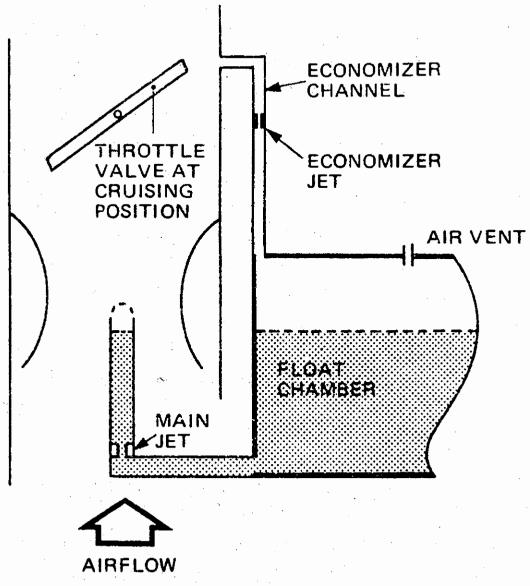


Figure 11 BACK-SUCTION ECONOMIZER

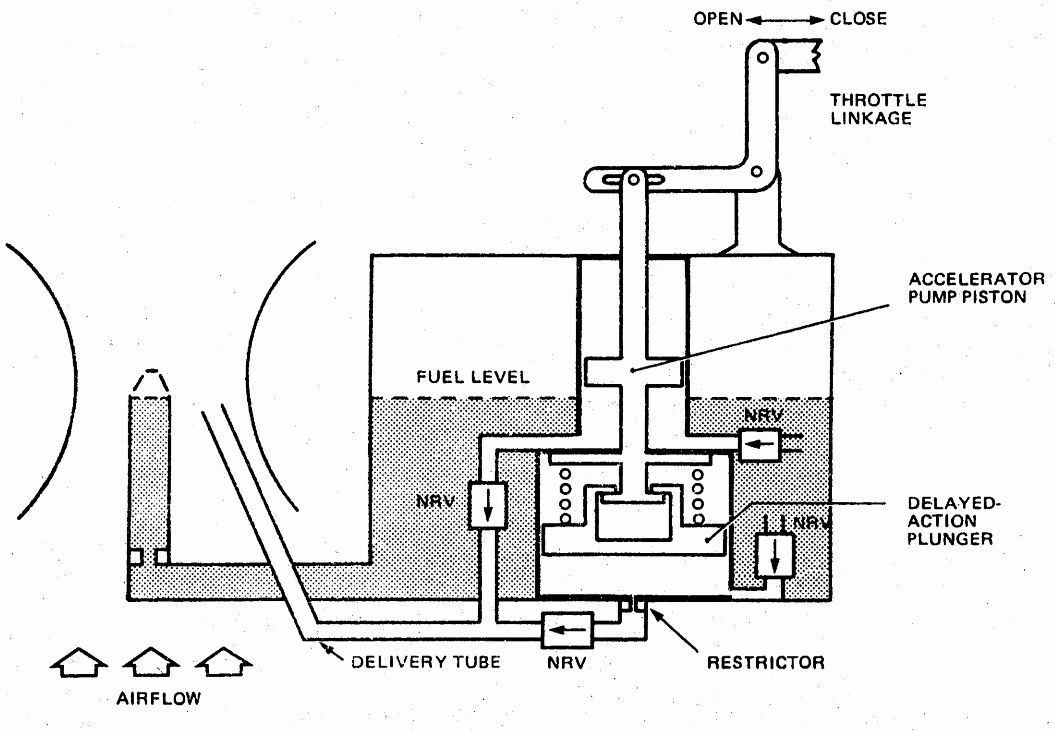


Figure 12 ACCELERATOR PUMP

4.4.2 An air-operated economizer (known as a back-suction economizer) is illustrated in Fig. 11. When the throttle valve is at a high power setting, the pressure of air flowing past the valve is only slightly below atmospheric pressure, and will have little effect on air pressure in the float chamber; thus a rich mixture will be provided. As the throttle is closed to the cruising position, air flowing past the throttle valve creates a suction, which is applied to the float-chamber through the economizer channel and air jet. The reduced float-chamber pressure reduces fuel flow through the main jet to provide the economical mixture required for cruising.

4.5 **Acceleration.** If the throttle valve is opened quickly, airflow responds almost immediately and a larger volume of air flows through the carburettor. The fuel metering system, however, responds less quickly to the changing conditions, and a temporary weakening of the mixture will occur before fuel flow again matches airflow. This condition is overcome by fitting an accelerator pump, which is linked directly to the throttle and forces fuel into the venturi whenever the throttle is opened. In some pumps a controlled bleed past the pump piston allows the throttle to be opened slowly without passing fuel to the engine; in other pumps an additional delayed-action plunger is incorporated to supply an additional quantity of fuel to the engine for a few seconds after throttle movement has ceased. The latter type of pump is illustrated in Fig. 12.

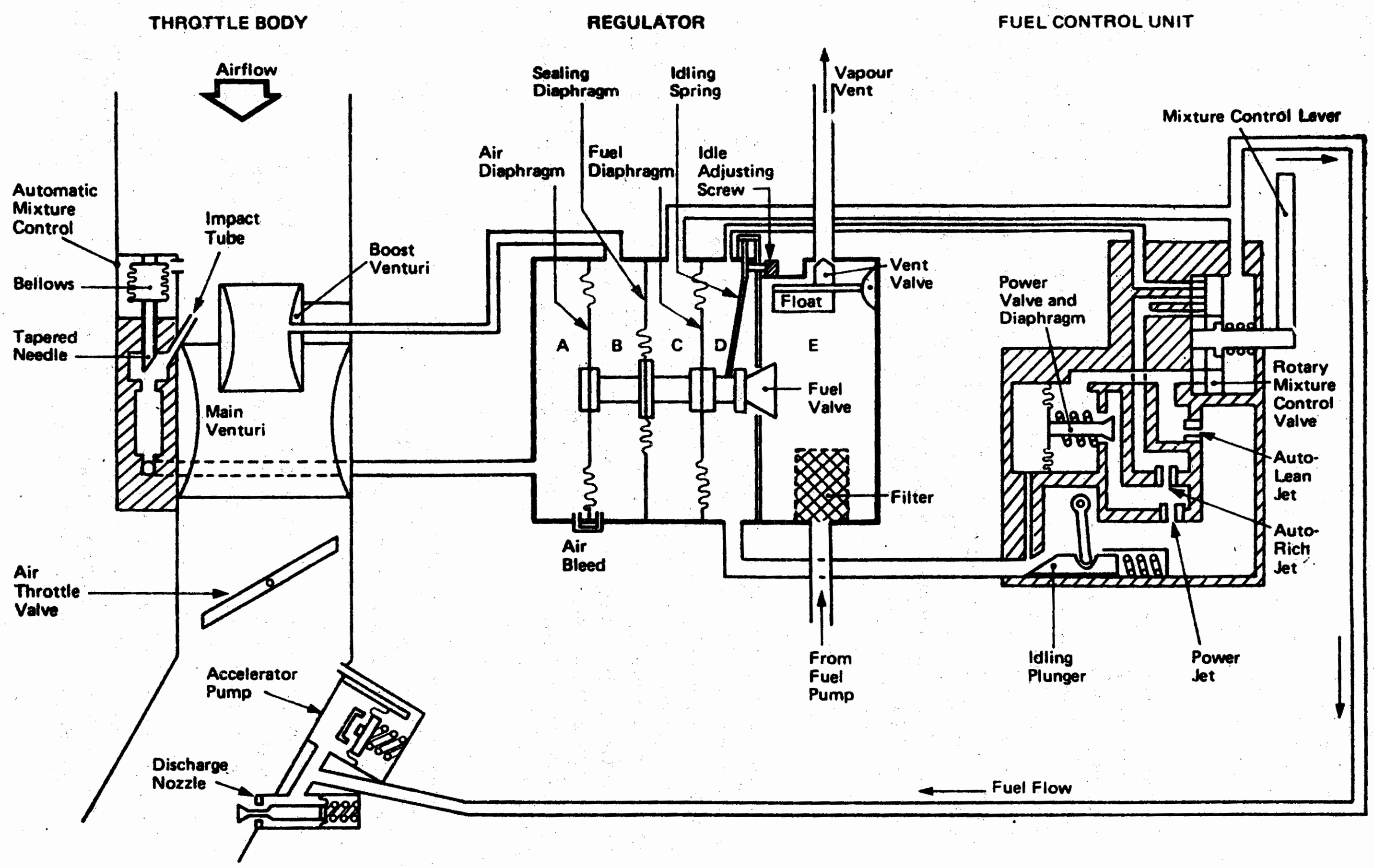
5 INJECTION CARBURETTORS These carburettors do not have a vented float-chamber, and do not rely on venturi suction to discharge fuel into the airstream; they provide a pressurized, closed system, which meters fuel according to airflow and mixture strength requirements, and sprays it into the induction manifold, downstream of the throttle valve. The various components in the system normally include an air throttle valve, an engine-driven pump, a pressure regulator, a fuel control unit, an automatic mixture control, an accelerator pump and a discharge nozzle; these components combine to provide for all the air/fuel mixture requirements of the engine. A typical injection carburettor is illustrated in Fig. 13.

5.1 **Throttle Body.** This unit contains the throttle valve, discharge nozzle, accelerator pump, venturis and automatic mixture control, and provides various connections to the regulator and fuel control unit.

5.1.1 **Throttle Valve.** Unlike the throttle valve on a float-chamber carburettor, the throttle valve on an injection carburettor controls only the airflow to the engine. Since no fuel passes the throttle valve, there is less likelihood of carburettor icing.

5.1.2 **Discharge Nozzle.** The discharge nozzle contains a spring-loaded valve and diaphragm. The valve opens when metered fuel pressure acting on the diaphragm is sufficient to overcome spring pressure, and acts as a relief valve to hold the pressure in the discharge line relatively constant, regardless of fuel flow.

5.1.3 **Accelerator Pump.** The accelerator pump is automatic in operation, and supplies additional fuel during rapid throttle opening.


THROTTLE BODY
REGULATOR
FUEL CONTROL UNIT
Airflow
Sealing Diaphragm
Idling Spring
Vapour Vent
Mixture Control Lever
Air Diaphragm
Fuel Diaphragm
Idle Adjusting Screw
Automatic Mixture Control
Impact Tube
Boost Venturi
Vent Valve
Bellows
Float
Power Valve and Diaphragm
Tapered Needle
A
B
C
D
E
Fuel Valve
Rotary Mixture Control Valve
Main Venturi
Auto-Lean Jet
Filter
Air Bleed
Auto-Rich Jet
Air Throttle Valve
Accelerator Pump
From Fuel Pump
Idling Plunger
Power Jet
Discharge Nozzle
Fuel Flow

5.1.4 **Venturis.** The throttle body contains two venturis, the smaller, or 'boost', venturi discharging into the throat of the main venturi. This arrangement provides a larger pressure drop than could be obtained with a single venturi. A number of impact tubes are arranged around the top of the main venturi, and provide air-intake pressure to the regulator. The purpose of the venturis is to measure airflow through the throttle body.

5.1.5 **Automatic Mixture Control.** This unit contains a sealed bellows, which responds to changes in air pressure and temperature. It is connected to a tapered needle in the duct supplying air intake pressure to the regulator, and provides the means of automatically varying fuel flow with changes in air density.

5.2 **Fuel Pumps.** The engine-driven fuel pump is generally a positive-displacement type pump, with a capacity in excess of the maximum fuel requirements of the engine. Since the carburettor relies on fuel being supplied at a positive pressure, an electrically-operated booster pump is also included in the fuel system, both to supply fuel in the event of failure of the engine-driven pump and for use during engine starting. A fuel pressure gauge is fitted to provide an indication of pump operation.

5.3 **Regulator.** The regulator is attached to the throttle body, and is designed to regulate the pressure drop across the jets in the fuel control unit according to airflow through the throttle body. It consists of two pairs of chambers, each pair being separated by a flexible diaphragm. Referring to Fig. 13, chamber A is ducted to air-intake pressure, chamber B is ducted to boost-venturi suction, chamber C is ducted to metered fuel pressure and chamber D is supplied by unmetered fuel pressure. The air and fuel diaphragms, and the sealing diaphragm between chambers B and C, are all attached to the stem of the fuel valve, which is opened or closed by the air and fuel forces in the four chambers. Fuel is delivered from the fuel pump to chamber E of the regulator, which also contains a filter and vapour vent valve. The vent valve allows any vapour in the fuel to escape and return to the aircraft tanks, thus preventing it from upsetting the balance of the carburettor.

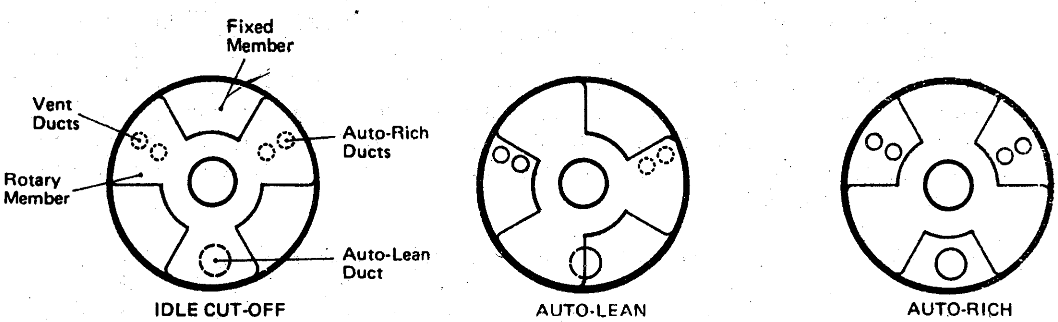


Figure 14 ROTARY MIXTURE CONTROL VALVE

5.4 **Fuel Control Unit.** The fuel control unit is attached to the regulator, and contains all the metering jets and valves. The manual mixture-control lever is connected to a rotary mixture-control valve, which determines which jets are in operation. The valve consists of a stationary member, with ducts leading to the auto-rich and auto-lean jets, and a rotating member which covers or uncovers the ducts according to its position. A pressure-operated valve opens the passage from the power jet, and a plunger connected to the pilot's throttle, adjusts fuel flow in the idling range. It should be noted that if two holes or jets are connected in series, it is the smaller jet or hole which, combined with the pressure drops across the jets, controls fuel flow. Operation of the mixture control is illustrated in Fig. 14.

5.4.1 With the manual mixture control lever in the 'idle cut-off' position, all the fuel passages in the rotary valve are blocked, and no fuel flows to the engine.

5.4.2 With the manual mixture control lever set to 'auto-lean', the largest passage in the rotary valve is partially uncovered, and fuel flows past the idling plunger, through the auto-lean jet and mixture control valve to the discharge nozzle. Fuel flow depends on the size of the auto-lean jet, and on the difference in pressure between the metered and the unmetered fuel.

5.4.3 With the manual mixture control lever set in the 'auto-rich' position, all the fuel passages through the mixture control valve are uncovered, and fuel flows past the idling plunger, through both the auto-lean and auto-rich jets, through all holes in the rotary valve and to the discharge nozzle. When the power valve is opened, additional fuel flows through the power jet and the large hole in the mixture control valve. Fuel flow in this setting depends on which jets are in operation, and on the difference in pressure between the metered and unmetered fuel.

5.5 **Basic Operation.** The difference in pressure between chambers A and B in the regulator, is dependent upon the difference between intake pressure and boost-venturi suction. This pressure difference will increase with airflow through the engine, and will result in movement of the air diaphragm and opening of the fuel valve. With the fuel valve open, fuel will flow into chamber D, through the metering jets in the fuel control unit, back to chamber C in the regulator, and thence to the discharge nozzle. When pressure in chamber C and the discharge line reaches a predetermined value, the discharge nozzle valve will open and fuel will be discharged into the induction manifold. The unmetered fuel pressure in chamber D will always be greater than the metered fuel pressure in chamber C, because of the restriction of the jets, and the fuel diaphragm will move in opposition to the air diaphragm to close the fuel valve. However, the pressure in chamber D will decrease as the fuel valve closes, and a balanced condition will be reached when air and fuel forces are equal. In this condition, fuel flow through the jets will be in proportion to the difference in pressure between chambers C and D. Since the pressure difference across the fuel diaphragm is equal to the pressure difference across the air diaphragm, fuel flow will be proportional to, and governed by, the airflow through the throttle body, and the engine will be supplied with the correct basic air/fuel mixture at all engine speeds.

5.5.1 Alteration of the mixture control setting will change the fuel flow, and alter the pressure drop across the jets. The diaphragm and fuel valve assembly will reposition to maintain the pressure drop established by the particular airflow, resulting in a change in mixture strength according to the size of the jets in operation. Similarly, any change in fuel pump pressure or fuel pressure at the discharge nozzle would affect the balanced condition of the diaphragm assembly and would be followed by a corrective movement of the fuel valve.

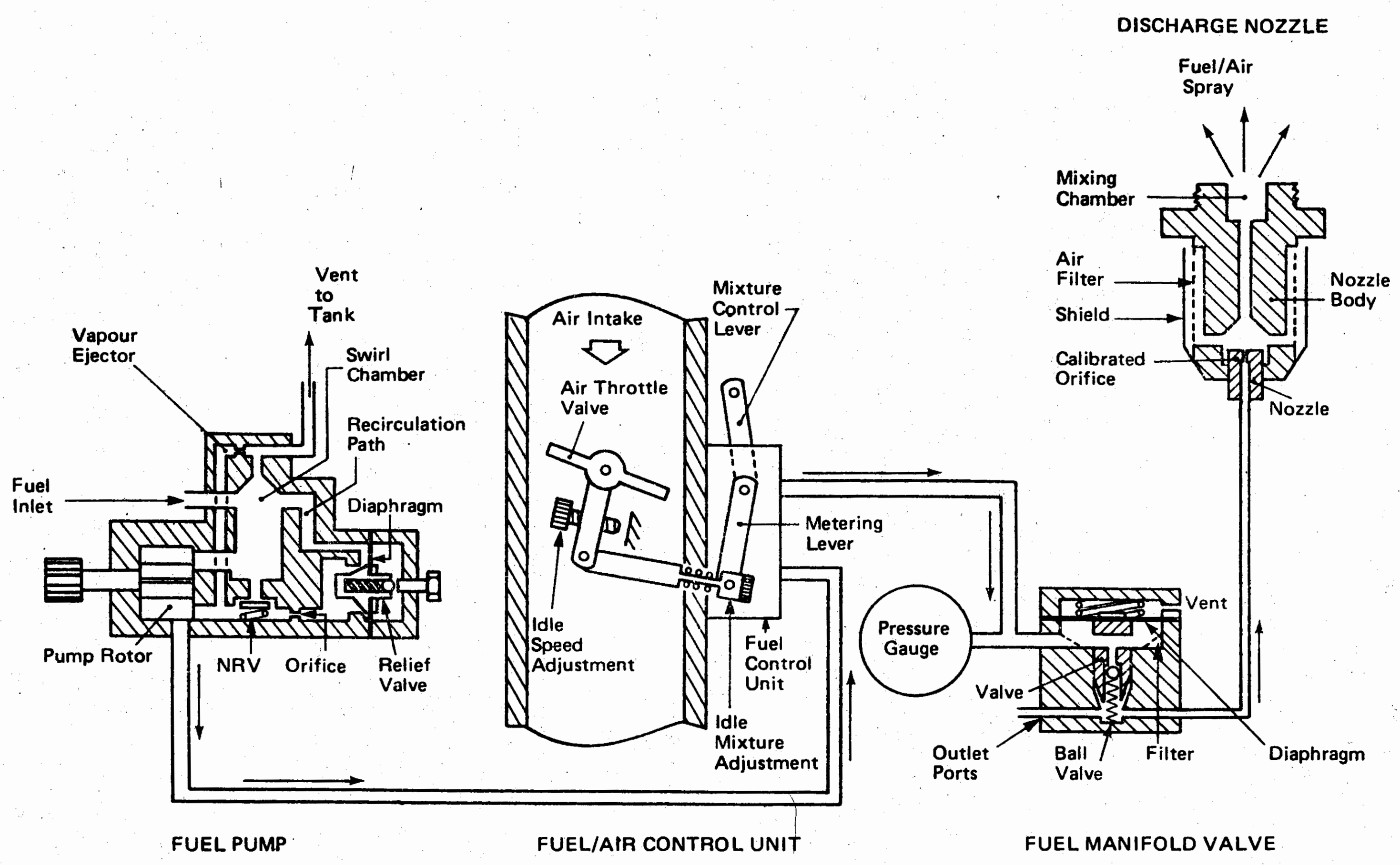
5.6 **Idling.** At very low engine speeds, airflow through the throttle body is insufficient to provide an effective pressure drop through the boost venturi, and is unable to regulate fuel flow. To overcome this problem, a spring is attached to the fuel valve stem in chamber D, and holds the fuel valve off its seat at idling speeds. Fuel may then flow through chamber D to the fuel control unit, where the idling plunger, which is connected to the pilot's throttle, meters fuel flow for the first few degrees of throttle opening. At larger throttle openings the idling plunger is withdrawn from the fuel passage and has no effect on fuel flow.

5.7 **Mixture Control.** The manually-operated mixture control varies fuel flow according to engine operating conditions and was described in paragraph 5.4. Automatic correction of fuel flow for changes in air density (temperature and pressure) is provided by the automatic mixture control. A small air bleed between chambers A and B in the regulator causes a slight but continuous flow of air from the impact tubes to the boost venturi, thus providing the means of controlling the pressure in chamber A, and thereby regulating fuel flow. At sea level the bellows is fully compressed and the tapered needle is withdrawn from the air passage leading to chamber A; full intake pressure acts on the air diaphragm, so that fuel valve opening and fuel flow are at the maximum for the particular airflow condition. As the aircraft climbs and atmospheric pressure decreases, the bellows expands and inserts the tapered needle into the air passage, thus restricting the flow of air into chamber A, and reducing the differential pressure across the air diaphragm. As a result the fuel valve closes slightly and fuel pressure is adjusted to match air pressure, thus reducing fuel flow through the jets to maintain the required mixture strength.

5.8 **Acceleration.** A number of different fully-automatic accelerator pumps may be used with injectors; a single-diaphragm pump is illustrated in Fig. 13, and operation of this type is explained below.

5.8.1 Air pressure on the engine side of the throttle valve varies according to throttle position, being lowest when the throttle is at the idling position and progressively increasing as the throttle is opened. This air pressure is ducted to the rear of the accelerator-pump diaphragm. At small throttle openings air pressure and fuel discharge-nozzle pressure are sufficient to overcome the force of the spring and withdraw the diaphragm, allowing the pump fuel chamber to fill. When the throttle is opened, the air pressure increases and the spring is able to force the diaphragm forward, discharging fuel to the nozzle. This fuel, added to the normal metered fuel flow, is sufficient to overcome any temporary weakening of the mixture.

6 DIRECT FUEL INJECTION Direct fuel injection is often employed on aircraft piston engines, but is of the low-pressure, continuous-flow type rather than the intermittent-flow type commonly used on diesel engines, in which calibrated quantities of fuel are injected into the cylinders at a particular time in the operating cycle. In the low-pressure, continuous-flow method, fuel is sprayed continuously into the inlet port of each cylinder; the advantages claimed for the method are low operating pressure, good fuel distribution, freedom from icing problems and the ability to use a pump which does not have to be timed to the operating cycle. Some fuel injectors operate on similar principles to the injection carburettor described in paragraph 5, with a distribution system replacing the discharge nozzle, but a different method of operation is used on some engines, and this latter method is described in paragraph 6.1 to 6.6.


DISCHARGE NOZZLE
Fuel/Air Spray
Mixing Chamber
Air Filter
Shield
Calibrated Orifice
Nozzle Body
Nozzle
Vent to Tank
Vapour Ejector
Swirl Chamber
Recirculation Path
Fuel Inlet
Diaphragm
Pump Rotor
NRV
Orifice
Relief Valve
Air Intake
Air Throttle Valve
Mixture Control Lever
Metering Lever
Idle Speed Adjustment
Fuel Control Unit
Idle Mixture Adjustment
Pressure Gauge
Vent
Valve
Outlet Ports
Ball Valve
Filter
Diaphragm
FUEL PUMP
FUEL/AIR CONTROL UNIT
FUEL MANIFOLD VALVE

6.1 In this system, the size of a variable orifice is controlled according to the position of the air throttle valve, and the pressure of fuel passing through this orifice is controlled according to engine speed. Mixture strength is varied by a manually-operated control, which adjusts the fuel pressure for altitude or operating conditions, as necessary. Because of the method of operation of the injector, no special idling arrangements are required and a separate priming system for engine starting is unnecessary. The main components in the system are a fuel pump, a fuel/air control unit, a fuel manifold (distribution) valve, and discharge nozzles for each cylinder. In addition, a normal throttle valve controls airflow to the engine, and a fuel pressure gauge is fitted to enable mixture adjustments to be made. The system is illustrated in Fig. 15.

6.2 **Fuel Pump.** The fuel pump is a positive-displacement, vane-type pump, which is driven by gearing from the engine crankshaft; total pump output is, therefore, proportional to engine speed. The pump supplies more fuel than is required by the engine, and a recirculation path is provided; a calibrated orifice and relief valve in this path ensure that the pump delivery pressure is also proportional to engine speed. Fuel enters the pump through a swirl chamber in which vapour is separated from liquid fuel; the vapour is ejected from the pump by a jet of pressurized fuel, and returned to the fuel tank. When the pump is not operating, a spring-loaded valve in the base of the swirl chamber allows fuel under positive pressure to by-pass the pump, so allowing an electrically-operated booster pump to be used for engine starting and in an emergency. The booster pump is often a two-speed pump, providing a low pressure for normal back-up use, and a high pressure for use in the event of main fuel pump failure.

6.3 **Fuel/Air Control Unit.** This unit is mounted on the intake manifold and contains three control elements.

6.3.1 The air throttle assembly contains the air throttle valve, which is connected to the pilot's throttle lever and controls airflow to the engine. The intake manifold has no venturi or other restriction to airflow.

6.3.2 The fuel control unit is attached to the air throttle assembly, and controls fuel flow to the engine by means of two rotary valves. One valve, the metering valve (Fig. 16), is connected to the air throttle, and by means of a cam-shaped end face controls fuel flow to the fuel manifold valve according to the position of the air throttle; thus fuel flow is proportioned to air flow and provides the correct air/fuel ratio. The second valve, the mixture valve (Fig. 17), is connected to the pilot's mixture control lever, and by means of a contoured end face, bleeds off fuel pressure applied to the metering valve. Thus the air/fuel ratio can be varied from the basic setting of the metering valve, as required by operating conditions. A fuel pressure gauge in the system indicates metered fuel pressure, and, by suitable calibration, enables the mixture to be adjusted according to altitude and power setting (paragraph 6.6).

6.4 **Fuel Manifold Valve.** This valve is located on the engine crankcase, and is the central point for distributing metered fuel to the engine. It contains a spring-loaded diaphragm to which a valve is attached. When the engine is stopped, the spring forces the diaphragm down, and seats the valve in the bore of the valve body; all the outlet ports are closed, and no fuel can flow to the engine. As fuel pressure builds up (as a result of engine rotation or booster pump operation) and overcomes spring force, the valve lifts and opens all the ports to the discharge nozzles simultaneously. The ball valve ensures that the ports are fully open before fuel starts to flow.

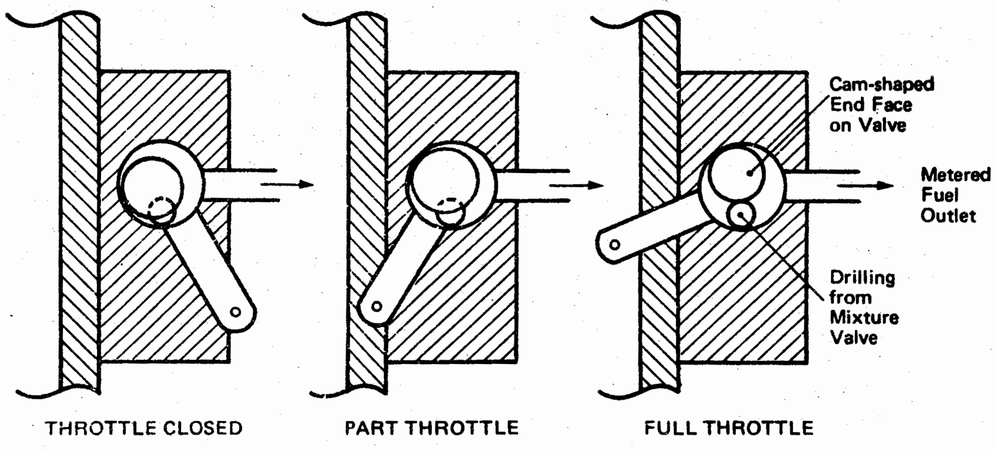


Figure 16 METERING VALVE

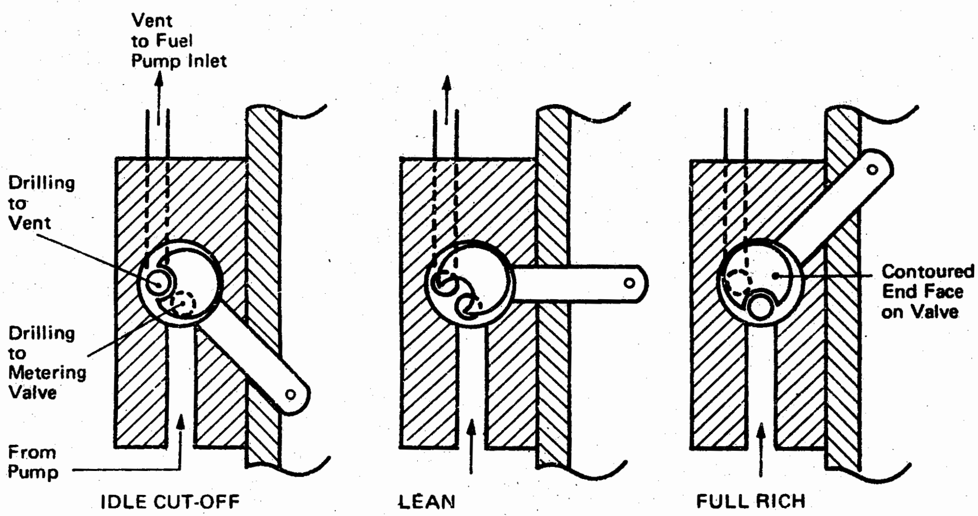


Figure 17 MIXTURE VALVE

6.5 **Discharge Nozzle.** A fuel discharge nozzle is located in each cylinder head, with its outlet directed into the inlet port. A nozzle, with a calibrated orifice, fits into the nozzle body and directs fuel through a central bore. Radial holes in the body allow air to be drawn in through a cylindrical filter which surrounds the body (at ambient air pressure on a normally-aspirated engine and at manifold pressure on a supercharged engine), and this air is mixed with the fuel before it sprays into the inlet port. Nozzles are calibrated in several ranges, and are fitted to individual engines as a set, each nozzle in a set having the same calibration.

6.6 **Pressure Gauge.** A pressure tapping is taken from the metered fuel pressure line to operate a fuel pressure gauge. Since the mixture strength depends on the pressure of the fuel passing through the metering valve, the gauge reading is proportional to fuel flow and may be used when adjusting mixture strength to suit flight conditions.

6.6.1 Fig. 18 illustrates a fuel pressure gauge which is marked for use with a normally-aspirated engine, and has two ranges of pressures. The take-off segment is used for take-off and climb, and is calibrated in thousands of feet of altitude; the cruise segment is marked with maximum and minimum lines for each of a range of power settings. The fuel pressure is adjusted by means of the mixture control lever, and during take-off is set according to the airfield height, and this compensates for reduced air density. During cruising flight, fuel pressure is first set to the highest line for the power being used, and this gives best power; when engine temperatures have stabilized, the fuel pressure is then reduced to the minimum line, and this increases the air/fuel ratio to give economical cruising. For ground running, the mixture lever is left in the fully-rich position.

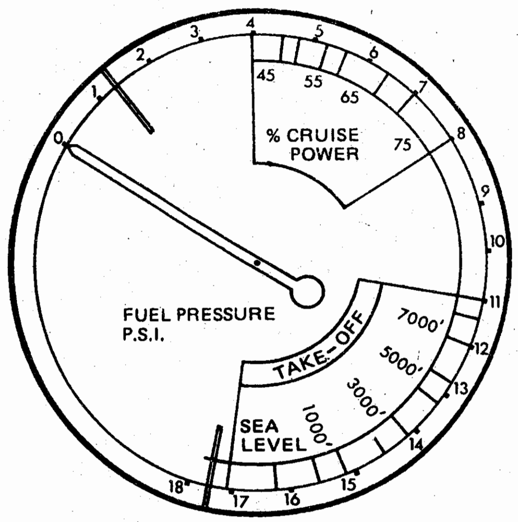


Figure 18 FUEL PRESSURE GAUGE

6.6.2 With a turbocharged engine, fuel flow at any particular power setting remains constant at all altitudes, so that the fuel pressure gauge is calibrated solely in units of pressure or flow. The correct mixture strength is obtained by adjusting the mixture control to give the fuel pressure or flow recommended for the particular flight conditions.

7 ENGINE ICING Icing encountered on aircraft piston engines may be classified into two distinct types, impact icing and carburettor icing. These are formed in different ways but may occur in ambient temperatures between +25°C and —15°C; below —15°C any ice which forms is too dry to adhere to the intake or throttle-body wall. Engine icing may be encountered when an aircraft is flying in cloud, rain or snow, or even in clear air provided that the humidity is sufficiently high; it may also be encountered when running an engine on the ground in similar atmospheric conditions. An air-intake temperature gauge is often fitted to provide a warning of icing conditions.

7.1 **Impact Icing.** This is caused by water droplets freezing on impact with the intake, throttle-body wall or impact tubes, and is most likely to occur at temperatures of 0°C to —7°C. Ice can build up round the air intake and disturb airflow to the carburettor, thus upsetting the air/fuel ratio and causing loss of power and even complete stoppage of the engine. Protection against this form of icing is provided by fitting a gapped ice-guard, or by providing an alternative air intake which is sheltered from the direct airflow.

7.1.1 A gapped ice-guard consists of a coarse wire-mesh screen mounted in front of the air intake, the gap between the screen and intake providing a passage for air should the screen become blocked with ice or snow.

7.1.2 Where a permanent mesh screen or air filter is fitted in the intake an alternative intake is usually provided. This may be manually operated or in the form of a spring-loaded door in the intake duct, which opens into the engine compartment. If the intake or filter becomes blocked with ice, engine suction opens the door automatically, and warm air is drawn into the engine.

7.2 **Carburettor Icing.** The restriction to airflow caused by the venturi and throttle valve, by increasing the velocity and reducing the pressure of the air, also reduces its temperature (Boyles Law). In addition, vaporization of the fuel also cools the air and throttle-body walls, and further reduces the temperature. When the temperature of the air passing through the carburettor is reduced below 0°C, any moisture in the air forms into ice and builds up on the venturi and throttle valve. This ice further reduces the area through which the air must pass, and thus worsens the situation. Rough-running, loss of power, jamming of the throttle valve and eventual stoppage of the engine may result. Carburettor icing may develop in any type of carburettor in air temperatures below +25°C, but is less likely to occur with direct fuel injectors since the fuel is injected downstream of the throttle valve and venturi. Protection against carburettor icing is usually effected by supplying warm air to the carburettor, or by heating the carburettor.

7.2.1 A hot-air intake may be provided, through which air, taken from regions adjacent to heated parts of the engine, e.g. an exhaust pipe muff, is ducted to the carburettor. The pilot's control may be a two-position control selecting the source of air, or may be a multi-position control which progressively bleeds more hot air into the intake duct.

7.2.2 On some earlier carburettors, the throttle-body wall and throttle valve are hollow, and form passages through which engine oil is pumped. This warms the carburettor sufficiently to prevent icing, and assists in fuel vaporization.

7.2.3 Use of a manually-selected hot-air intake is usually restricted to operation below 80% power; the prolonged use of hot air at higher power settings could result in detonation.

8 **AIR FILTERS** Dust and grit in the atmosphere could cause serious damage to a piston engine by entering the engine through the air intake and being drawn into the cylinders, thus causing excessive wear to the cylinder walls and pistons. Dust and grit could also collect in the carburettor and upset the air/fuel mixture by clogging air and fuel passages. To prevent this from happening, most engines have an air filter in the air intake, through which all air is drawn during normal operation. Air drawn in through the alternative air intake in icing conditions is not filtered, but because of the sheltered position of the intake, the air is less likely to be contaminated.

8.1 On some older aircraft the normal engine air intake has no filter, so that full advantage may be taken of ram effect to increase engine power. In these cases a separate filtered intake may be provided, and is used during flight at low altitude to prevent dust and grit from affecting the engine. A flap in the intake duct controls the source of air and is operated by a control in the cockpit.

9 **PRIMING SYSTEM** To avoid unnecessary cranking when starting a cold engine, a quantity of neat fuel is supplied to the induction manifold so that a rich fuel/air mixture is drawn into the cylinders as soon as the engine begins to rotate. The fuel may be supplied in a number of ways, depending on the type of carburettor.

9.1 Some carburettors are fitted with a means of overfilling the float chamber, and this often takes the form of a manually-operated plunger, which presses down on the float. This action allows the fuel level to rise, and results in fuel flowing from the discharge nozzle into the induction manifold.

9.2 On carburettors which are fitted with a throttle-operated accelerator pump (Fig. 12), the action of opening the throttle will result in fuel being sprayed into the induction manifold, thus priming the engine.

9.3 In many cases a separate priming system is installed on the engine. This comprises a priming pump (hand- or electrically-operated), which draws fuel from one of the fuel tanks, and discharges it through a system of priming pipes and nozzles to a number of points in the induction manifold.

9.4 With fuel injection systems no separate priming system is generally required. By switching on the fuel booster pump, fuel is sprayed into the cylinder inlet ports as soon as the mixture lever is moved out of the idle cut-off position.

9.5 In order to avoid flooding an engine with neat fuel, a drain is fitted to the lowest point in the induction manifold or supercharger casing, to drain off any surplus fuel which may have collected.

10 **INSPECTION AND MAINTENANCE** Because of the many variations within the three main types of carburettors, the inspection and maintenance requirements may vary considerably. However, sophisticated test rigs are usually required to set-up a carburettor over its complete range of operation, and, therefore, adjustments without the rigs are usually limited to those affecting the idling speed, idling mixture strength, fuel pressure, and the mechanical connections between the carburettor and the pilot's controls. Individual components in some carburettor systems may be removed for cleaning or repair, and in some cases the renewal of damaged diaphragms in a regulator, accelerator pump or manifold valve may be permitted.

10.1 **Routine Inspections and Maintenance.** Routine inspections and maintenance are intended to check the security of the carburettor and its components, the correct operation of the operating controls, the cleanliness of the air and fuel passing through the carburettcr, and the supply of a correct mixture to the cylinders.

10.1.1 The cleanliness of the air and fuel is of the utmost importance to the satisfactory operation of a carburettor. Dust in the air could build up on the venturi, impact tubes and air passages, and affect the metering action of the carburettor; similarly, any contamination of the fuel could restrict or block fuel jets and again affect proper metering. Cleanliness of the air and fuel filters is of the utmost importance, therefore, and regular inspection and cleaning are specified in the appropriate Maintenance Schedules. However, depending on the operating environment of the aircraft, more frequent checks may be advisable.

10.1.2 A further cause of incorrect mixture may be leakage at the inlet manifold joints or at the joint between the carburettor and the inlet manifold. On a supercharged engine such leakage may be evident by signs of blowing at the leakage points, and on a normally-aspirated engine by excessively weak mixtures at low engine speeds.

10.1.3 Air leakage into the intake system upstream of the carburettor will not directly affect the mixture, although it may allow dirt to enter with the airstream, but leakage of hot air into the normally cold intake will affect engine power. In this latter respect alternative air intake flaps with magnetic catches are particularly prone to unsatisfactory operation, through failure to remain positively in the intended position.

10.1.4 To ensure continued satisfactory operation, and depending on the carburettor type, the routine checks prescribed in an approved Maintenance Schedule, will normally include the following:—

(a) Check carburettor or injector components for fuel leakage and security, and for tightness and locking of attaching bolts and nuts.

(b) Check all connections on fuel, priming and vent pipes, for security and freedom from leaks, and ensure that the pipes are securely clipped and free from damage.

(c) Check inlet manifold for leaks or damage, and for tightness and locking of attaching nuts and bolts.

(d) Check intake duct seals for condition and proper fit, and alternative air flap for fit, wear, security and positive action.

(e) Check intake duct for damage, and for satisfactory connection to carburettor.

(f) Check all engine controls for full and free movement, locking, security and correct operation.

(g) Remove float chamber drain plug, and flush out sediment by operation of the electrical booster pump or gravity feed, as appropriate.

(h) Check that intake or supercharger drains are clear.

(j) Remove and clean air filter.

(k) Remove and clean fuel filters in the carburettor and fuel pump.

(l) Refit, tighten and lock any parts removed during maintenance work.

(m) Check idling mixture and engine speed.

(n) Check operation of priming pump, and connections for security and freedom from leaks.

(o) Open the drain tap in the fuel filter bowl, drain off a quantity of fuel into a glass jar and inspect for water and sediment. If excessive free water is found, proceed as outlined in Leaflet **AL/3—17.**

10.2 Cleaning of Filters

10.2.1 **Dry Air Filters.** A dry filter element should be carefully removed from its casing, and shaken or tapped on a hard surface to remove all loose dirt; the casing should be cleaned by wiping with a lint-free cloth moistened in solvent, and should be dried before refitting the element. On no account should the element be washed in any liquid. If any damage is found, the element should be discarded and a new element should be fitted.

10.2.2 **Oil-wetted Air Filters.** A filter of this type should be thoroughly washed in solvent to remove all oil and dirt, then checked for satisfactory condition. When completely dry, the filter should be immersed for a few minutes in oil of the recommended grade, then allowed to drain thoroughly before refitting it to the engine.

10.2.3 **Fuel Filters.** Fuel filters in the carburettor and fuel pump should be cleaned by flushing in solvent, then dried with dry compressed air. Brushes and rags should not be used for cleaning filters.

10.3 **Idling Adjustment.** Because of small changes in compression and ignition which may affect engine operation, the idling mixture and speed may occasionally require adjustment. This adjustment is also important to operation outside the idling range, since fuel may still be drawn through the idling jet at power settings in the cruising range. An excessively rich idling mixture will result in sooting of the plugs, whilst an excessively weak idling mixture will prevent satisfactory acceleration. Most carburettors are adjusted to provide an idling mixture which is slightly richer than the 'best power' mixture, but some injector systems are adjusted to the 'best power' mixture, or slightly weaker.

10.3.1 In order to adjust the idling mixture and speed, the engine should be warmed up until the oil and cylinder (or coolant) temperatures are in the normal operating range, and the ignition should be checked at the power setting recommended for the particular engine to ensure that the engine is operating satisfactorily; where appropriate, the propeller should be in fully fine pitch and the mixture set to fully rich. In some instances it may be advisable to withdraw the idling-speed stop to adjust the mixture, and set the required speed with the throttle lever; this will save the need for continual adjustment of speed after a change of idling mixture. Between adjustments the engine should be run for a short period at a moderate power setting, to prevent oiling of the plugs.

10.3.2 On a float-chamber carburettor, the throttle should be closed to give normal idling speed, and the idling mixture screw turned to richen the mixture until the engine runs roughly or 'rolls' from over-richness. The screw should then be turned in the opposite direction until the engine runs roughly from leanness, and this will show the range of adjustment within which the best-power mixture and idling mixture lie. From the lean position the screw is then turned to richen the mixture until just after the position at which maximum engine speed is obtained. The setting should then be checked after increasing power to clear the engine, and the throttle stop should be adjusted to give the specified engine idling speed. Several alterations to the mixture screw may be necessary before the idling mixture is correct, and each alteration of the mixture will affect the idling speed.

10.3.3 On a carburettor fitted with a mixture control and cut-off lever, a different method of adjustment may be used. With the engine idling at the correct speed, the mixture lever should be moved smoothly into the idle cut-off position, and any changes in engine speed or manifold pressure should be noted. With a correct idling mixture, an initial increase in engine speed (5 to 60 rev/min, depending on the installation) and decrease in manifold pressure (approximately ¼ in.Hg) will occur as the mixture becomes leaner, before the engine stops firing. A larger rev/min increase indicates that the mixture is too rich, and a smaller increase, or no increase, indicates that the mixture is too lean. Care must be taken during the check to ensure that the mixture lever is returned to the fully-rich position as soon as engine speed starts to fall and manifold pressure starts to rise. As with the float-chamber carburettor, a number of adjustments may be necessary before the correct mixture strength is obtained and it will usually be necessary to re-adjust the idling speed.

10.3.4 With an injection system the idling mixture is altered by adjusting the length of the linkage between the air throttle valve and the metering valve. Idling speed should be set first then the method described in paragraph 10.3.3 should be used to adjust the idling mixture. With an injection system the mixture supplied to the cylinders may be affected by the condition of the air filters in the discharge nozzles, and if difficulty is experienced in setting the idling mixture these filters should be examined and, if necessary, cleaned by washing in solvent.

10.3.5 If idling is erratic, the throttle linkage should be checked for play, and it should be ensured that the idling speed adjusting-screw contacts the throttle stop on the carburettor before the throttle lever reaches its fully-closed position. If the idling mixture is excessively lean, the induction manifold joints, sealing gaskets, and priming connections should be checked for signs of damage or leakage.

10.3.6 When the idling adjustments have been completed and rechecked, any locking which has been disturbed should be renewed, and any cowlings or panels which have been removed to obtain access should be refitted.

10.4 **Removal and Installation.** It may occasionally be necessary to remove and refit a carburettor or some of the separate components in a carburation system, because of damage, excessive wear or incorrect operation. Individual installations will vary in detail and the particular requirements of each installation will be included in the approved Maintenance Manual for the aircraft concerned, but the procedures and precautions to be observed will generally be similar to those outlined in paragraphs 10.4.1 to 10.4.4.

10.4.1 **Carburettor Removal.** Before removing a carburettor, the fuel supply cock should be closed and suitable containers should be made available to prevent major spillage of fuel into the engine compartment when the fuel pipes are disconnected. Any electrical circuits to the engine should be made safe by tripping the circuit breakers or removing the fuses, as appropriate. Precautions must also be taken during removal of the carburettor (particularly a down-draught carburettor), to prevent any foreign material from entering the induction manifold, intake duct or supercharger, since this could result in physical damage to the engine. The following procedure should normally be adopted:—

(a) Disconnect throttle and mixture control linkage at the carburettor and, where appropriate, the linkage to the supercharger control unit. In some cases it may be advisable to secure these control linkages to adjacent structure, so as to prevent interference with carburettor removal and refitting.

(b) Disconnect the fuel inlet pipe, vapour return pipe and pressure gauge connection, as appropriate. If a new carburettor is not being fitted immediately, these pipes should be suitably blanked and any spilled fuel should be mopped up.

(c) Secure the throttle valve in the closed position, then disconnect the intake duct from the carburettor and remove the intake air screen.

(d) Remove the nuts and washers securing the carburettor to the engine, then carefully remove the carburettor and joint gasket. A protective cover should immediately be secured over the mounting flange on the engine, to prevent the entry of foreign matter.

10.4.2 **Carburettor Installation.** A new or replacement carburettor should be examined before being fitted to an engine, to ensure that it is the correct type for the particular engine, that it is undamaged, and that all locking is correctly fitted and secure. The throttle valve operating lever may have to be positioned to suit the particular installation, and should be temporarily secured in the closed position to prevent the entry of foreign matter into the engine. The carburettor should then be fitted as follows:—

(a) Remove protective cover from the engine mounting flange and inspect the induction passages for foreign matter.

(b) Place the joint gasket in position, ensure that any bleed holes in the flange match up with corresponding holes in the gasket, then position the carburettor and tighten the attaching nuts to the prescribed torque.

(c) Remove the blanks from the fuel and vent pipes, inspect the threads for condition and connect to the carburettor. Only fuel-soluble oil should be used on the threads of the connections; the use of hard-drying sealants should be avoided.

(d) Remove the temporary restraint from the throttle valve and check the throttle and mixture levers on the carburettor for full and free movement. Reconnect the control linkage to the carburettor and check operation (paragraph 10.4.3).

(e) Flush the carburettor by selecting the fuel cock on, switching on the booster pump, and opening the mixture control valve until fuel, free from preservative oil, is discharged from the manifold or supercharger drain. Carburettors in which flexible diaphragms are used to control fuel flow should be allowed to stand for at least eight hours before running the engine, in order to soak the diaphragms and make them more flexible; to save time, this procedure may be carried out before installing the carburettor on the engine.

(f) Lock all controls and connections as required.

(g) Check operation of carburettor by running the engine (paragraph 10.5) and adjust the idling mixture as necessary (paragraph 10.3). After closing down the engine, inspect the installation for leaks and rectify as necessary.

10.4.3 **Control Settings.** When the control linkage to a carburettor is reconnected, its adjustment must be checked to ensure correct operation of the engine.

(a) The throttle valve must have full movement between the stops on the carburettor which limit its movement at the idling and fully-open positions. To make sure that this occurs, the pilot's throttle lever must have clearance at both ends of the quadrant in which it operates; this clearance is often referred to as 'spring-back' and ensures that vibration of the engine does not affect the position of the throttle valve. On most light aircraft the linkage should be adjusted so that there is an equal clearance at both ends of the quadrant, but on aircraft with long control runs the positions of the various pulleys and levers may be set by rigging pins or angular markings, and the rods and cables should be adjusted to suit these positions. The controls should be checked for full and free movement, and any looseness or excessive play in the linkage should be corrected by adjustment or renewal of parts. When connected and checked, the adjustments and connections should be locked in the appropriate manner.

(b) Mixture controls which do not have marked positions should be adjusted in the same way as throttle controls, to give clearance in the quadrant at the fully-rich and fully-lean positions. Mixture controls which have detents on the carburettor and marked positions on the quadrant, should be adjusted so that the position of the mixture valve agrees with the position of the control lever. Mixture controls should be checked for looseness or play, and faults should be corrected in the appropriate manner. Locking should be renewed as appropriate.

(c) On carburettors fitted with a separate idling cut-out control, the linkage is usually in the form of a cable, which is spring-loaded to the 'running' position. The cable should be adjusted so that a small movement of the control is necessary before the cut-out begins to operate.

(d) On those carburettors which have linkage from the throttle valve to a super-charger control unit, the linkage to this unit will not normally have been altered. Where necessary, the setting-up procedure will be specified in the approved Maintenance Manual, and any adjustments necessary should be carried out during engine runs.

10.4.4 **Individual Components.** Removal and installation of individual components such as injector nozzles, accelerator pumps, fuel pumps, priming pipes, etc., is usually permitted by the manufacturer, and is generally straightforward. Care is necessary to prevent damage to rigid pipes and couplings when making or breaking connections, and blanks should be used whenever a component is removed. After replacement of a component, the engine should be run to check the satisfactory operation of the carburation system (paragraph 10.5), and inspected for fuel leakage. In some instances adjustments may be necessary (e.g. adjusting fuel pressure after changing a fuel pump) and these should be carried out in accordance with the manufacturer's instructions.

10.5 Whenever a carburettor, injector, or major component in the system is changed, an engine run should be carried out to verify correct fuel metering. The following should be confirmed:—

(a) The engine should start smoothly when hot or cold.

(b) At normal operating temperatures, idling should be smooth and steady.

(c) Rapid acceleration and deceleration are prohibited on some engines, but acceleration and deceleration within the limitations of the particular engine should be checked as being smooth, and without hesitation or any tendency to stop or run roughly.

(d) The engine should run smoothly at any power setting likely to be encountered in flight.

(e) Any interconnection between the throttle and mixture controls, or between the throttle and the alternative air intake controls, should function as intended.

(f) A full-power check or reference power check (see Leaflet **EL/3-15**) should be carried out to confirm that normal power is being produced.

NOTES: (1) Excessive ground running should be avoided since the engine will not be adequately cooled when the aircraft is stationary.

(2) Running at those engine speeds at which engine/propeller resonant vibrations may occur, and concerning which there may be cockpit placards or warnings in the Flight Manual, should be avoided.

10.6 **Storage.** A carburettor which has been removed from an engine, should be protected from deterioration before being placed in storage. All fuel should be drained out, and the fuel chambers and passages should be filled with preservative oil; the carburettor should then be rocked and rotated to distribute the oil over all the internal surfaces. Injection carburettors should be filled with oil by connecting an oil supply line to the fuel inlet and pumping in oil under pressure with the throttle valve fully open and the mixture control fully rich; on no account must the maximum permitted pressure be exceeded. After draining out surplus oil, all openings should be securely blanked and the throttle valve should be locked in the closed position. The carburettor should then be wrapped in greaseproof paper, and packed in a suitable carton or crate to protect it from damage. A label should be affixed to the carton, giving details regarding type of carburettor, reason for and date of removal, and any other details relevant to it.

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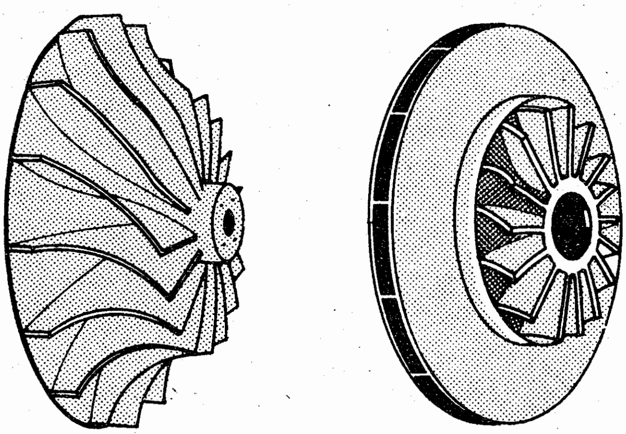
AIRCRAFT

ENGINES

PISTON ENGINE SUPERCHARGERS

1 INTRODUCTION This Leaflet deals with the methods used to increase the power of a piston engine, or to increase the altitude at which sea-level power can be maintained.

2 GENERAL The power output of an engine depends basically on the weight of mixture which can be burnt in the cylinders in a given time, and the weight of mixture which is drawn into each cylinder on the induction stroke depends on the temperature and pressure of the mixture in the induction manifold. On a normally-aspirated engine the pressure in the induction manifold at full throttle is slightly less than atmospheric pressure because of intake duct losses, and the manifold pressure decreases with any increase in altitude. Power output, therefore, decreases with altitude, although some of the loss is recovered in better scavenging of the cylinders as a result of reduced back pressure on the exhaust. In order to increase engine power for take-off and initial climb, and/or to maintain engine power at high altitude, the manifold pressure must be raised artificially, and this is done by supercharging.



(A) SINGLE-SIDED IMPELLER (B) FULLY-SHROUDED IMPELLER

Figure 1 SUPERCHARGER IMPELLERS

2.1 Where a supercharger is used to increase sea-level power, rather than to maintain normal power up to a high altitude, the engine will need to be strengthened in order to resist the higher combustion pressure. For superchargers capable of producing maximum power at high altitude, a control system is necessary to prevent excessive pressure being generated within the engine at low altitude.

2.2 Centrifugal impellers (Fig. 1) are used for superchargers on aircraft engines and may be driven by either internal or external means; in some installations a combination of both is used. Internally-driven superchargers are driven by gearing from the engine crankshaft, and externally-driven superchargers (known as turbo-superchargers or turbochargers) are driven by a turbine which is rotated by the exhaust gases. The methods of operation and control of these two types are quite different, and are dealt with separately in this Leaflet.

3 CENTRIFUGAL IMPELLERS Centrifugal impellers are used because they are comparatively light, are able to run at high speed, will handle large quantities of air, and are reliable.

3.1 A centrifugal impeller is, in effect, a fan which, when rotated at high speed, causes the air between the vanes to be flung outwards under centrifugal force. The air receives kinetic energy as it flows outwards between the vanes, and, as the cross-section of its path increases, some of this energy is converted into pressure energy. The proportion of pressure gained in the impeller depends on the impeller's diameter, speed of rotation, and the shape of the vanes.

3.2 The air leaves the impeller with considerable tangential and radial velocity and passes into a diffuser, which consists of a number of vanes fixed between the walls of the supercharger casing. The angle of the diffuser vanes is initially parallel to the path taken by the air leaving the impeller, and the curvature of the vanes guides the air into a volute casing, or manifold ring, in such a way as to minimize turbulence, which would impede the flow and increase temperature. The diffuser vanes form divergent passages, which decrease the velocity and increase the pressure of the air passing through them.

3.3 The action of compressing the air rapidly increases its temperature, and reduces some of the increase in density which results from the increased pressure; this loss of density may be partially recovered either by passing the air through a heat exchanger or by spraying the fuel into the eye of the impeller so that vaporization will reduce air temperature. Other losses are caused by friction, air leakage, and buffet at the inlets to the impeller and diffuser. Friction losses may be reduced by using a shrouded impeller (Fig. 1 (B)), and buffet losses may be reduced by using curved inlet vanes on the impeller, and by careful design of impeller tip clearance to suit the impeller's speed of rotation. Air leakage is caused by the pressure difference across the impeller tending to produce a reverse flow of air; this is minimized by ensuring that clearances between stationary and rotating parts are kept as small as possible, but leakage cannot be completely eliminated.

3.4 At a particular speed of rotation a centrifugal supercharger increases the pressure of air passing through the impeller in a definite ratio. Physical constraints limit the speed of rotation and size of an impeller, and so limit the compression ratio and, consequently, the power output or maximum operating altitude of the engine to which it is fitted. Compression ratios between 1·5 : 1 and 3 : 1 are generally obtainable, and any further compression necessary would have to be obtained by fitting two impellers in series.

4 INTERNALLY-DRIVEN SUPERCHARGERS Internally-driven superchargers are generally used on medium- and high-powered piston engines (approximately 250 bhp and above), and are fitted downstream of the throttle valve. In the past the superchargers of high-powered engines have often been driven at two speeds in order to save power at low altitudes, and have also been fitted with two impellers working in series in order to raise the overall compression ratio; some of these engines are still in use, but current engines generally employ a single impeller driven at a fixed ratio to the crankshaft (usually between 6 : 1 and 12 : 1). This type of supercharger is usually capable of maintaining sea-level manifold pressure up to an altitude of 5000 to 10,000 feet, depending on the gear ratio, at Rated Power settings. In Fig. 2 the power curves of a single-speed, single-stage supercharged engine are compared with a normally-aspirated but otherwise identical engine.

NOTE: Rated Power, or Maximum Continuous Power, is the maximum power at which continuous operation is permitted. Take-off Power, and in some instances Climbing Power, may have a time limitation.

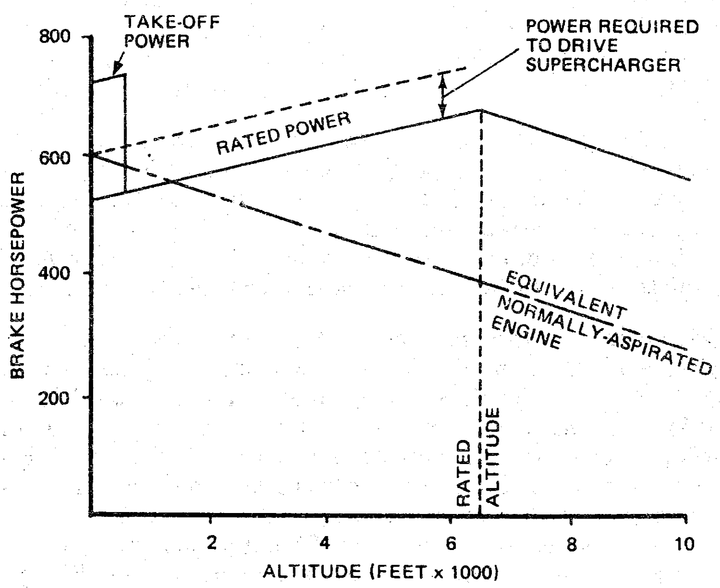


Figure 2 POWER CURVES—SINGLE-SPEED SUPERCHARGER

4.1 The power developed by the normally-aspirated engine is at a maximum at sea-level, and progressively decreases as altitude is increased. The power developed by the supercharged but otherwise identical engine, at the same speed and manifold pressure, is less than that of the normally-aspirated engine at sea-level, and this power loss represents the power required to drive the supercharger. However, as height is increased, the power developed by the supercharged engine at constant throttle settings, increases as a result of the decreased temperature of the atmosphere. The decreased temperature increases the density of the air, and thus a greater weight of air is pumped into the cylinders for the same manifold pressure. Decreased air pressure also causes less back-pressure on the exhaust, thus improving scavenging of the cylinders.

4.1.1 At sea-level the throttle valve in the supercharged engine must be partially closed, so as to restrict manifold pressure and prevent excessive cylinder pressures, but as the aircraft climbs the throttle valve must be progressively opened (either manually or automatically) to maintain this manifold pressure. Eventually a height is reached where the throttle is fully open, and this is known as full-throttle height; above this height power will fall off as with the normally-aspirated engine. Since the effect of the supercharger depends on the speed of rotation of the impeller, each power setting will have a different full-throttle height according to the engine speed and manifold pressure used; the full-throttle height at Rated Power settings is known as Rated Altitude.

4.2 **Supercharger Drives.** A shaft, splined into the rear of the crankshaft, provides the initial drive to the supercharger impeller and often also drives a number of accessories and transmits the drive from the starter motor to the engine. Such a shaft may incorporate a spring-drive unit, which transmits the drive through intermediate gears to the impeller pinion, and the impeller pinion may also include a centrifugal clutch.

4.3 **Supercharger Controls.** Since a supercharger is designed to compress air and provide sea-level pressure, or greater, in the induction manifold when atmospheric pressure is low, excessive manifold pressures could be produced when atmospheric pressure is high. It is necessary, therefore, to restrict throttle opening below full-throttle height, and, to relieve the work load on the pilot, this is often done automatically.

4.3.1 An aneroid capsule, which expands or contracts under varying pressure, is normally used in any system designed to control manifold pressure. The capsule (or in some cases a stack of individual capsules) is enclosed in a chamber connected to supercharger outlet pressure, and is attached to a servo valve to control the flow of pressure oil to a servo piston. The servo piston is connected to the throttle linkage so as to adjust throttle valve opening and thus control and limit manifold pressure.

4.3.2 A fixed-datum control, such as is illustrated in Fig. 3, is designed to prevent manifold pressure exceeding the Rated Power setting. When the engine is started, the throttle valve is only slightly open and manifold pressure is low; the capsule expands, lowering the servo valve and directing pressure oil to the underside of the servo piston, which moves to the top of its cylinder. As the throttle lever is advanced, the manifold pressure rises until the capsule has contracted sufficiently to lift the servo valve and block the flow to the servo piston; this is the neutral position of the valve and coincides with Rated Power. If the throttle lever is advanced further, the manifold pressure will increase and the capsule will contract, lifting the servo valve and directing pressure oil to the top of the servo piston. This action moves the servo piston downwards, closing the throttle valve until manifold pressure has returned to the rated value and the servo valve has returned to its neutral position. When climbing at Rated Power settings, the decreasing atmospheric pressure results in a lower supercharger outlet pressure, and the capsule gradually expands, progressively opening the throttle valve until full-throttle height is reached. In order to enable maximum power to be obtained during take-off, a means of overriding the control unit is required; this is often in the form of a calibrated leakage from the capsule chamber which is activated by linkage to the throttle lever. The main disadvantage of the fixed-datum system is that it has no effect on the throttle valve at power settings below Rated Power, and the throttle lever must be continually adjusted when climbing or descending at a lower power. There is also some "lost motion" of the throttle lever, which is greatest at sea level and decreases with altitude, and this means that the mixture enrichment required at high-power settings must be obtained by pressure-controlled devices rather than by the use of jets which are controlled by throttle movement (see Leaflet **EL/1-2**).

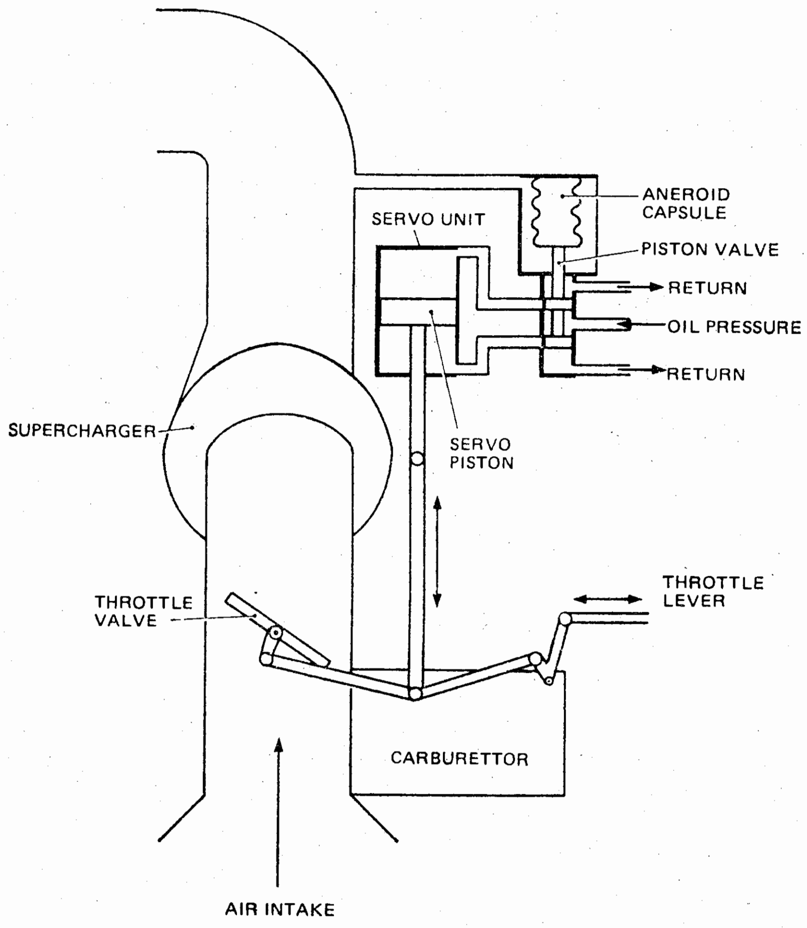


Figure 3 MANIFOLD PRESSURE CONTROL

4.3.3 A method used to overcome the deficiencies of the system described in paragraph 4.3.2, is the variable-datum control which is illustrated in Fig. 4. A cam connected to the throttle lever controls the datum setting of the aneroid capsule; as the throttle lever is closed from the fully-open position, the cam rotates and allows the capsule to rise under spring pressure. Thus the neutral position of the servo valve varies according to throttle lever position, and enables the capsule to exercise control at whatever manifold pressure is selected by the throttle lever. There is no lost motion in the throttle lever, and adjustment of the throttle valve to compensate for changes in atmospheric pressure is carried out automatically at any power selected by the throttle lever.

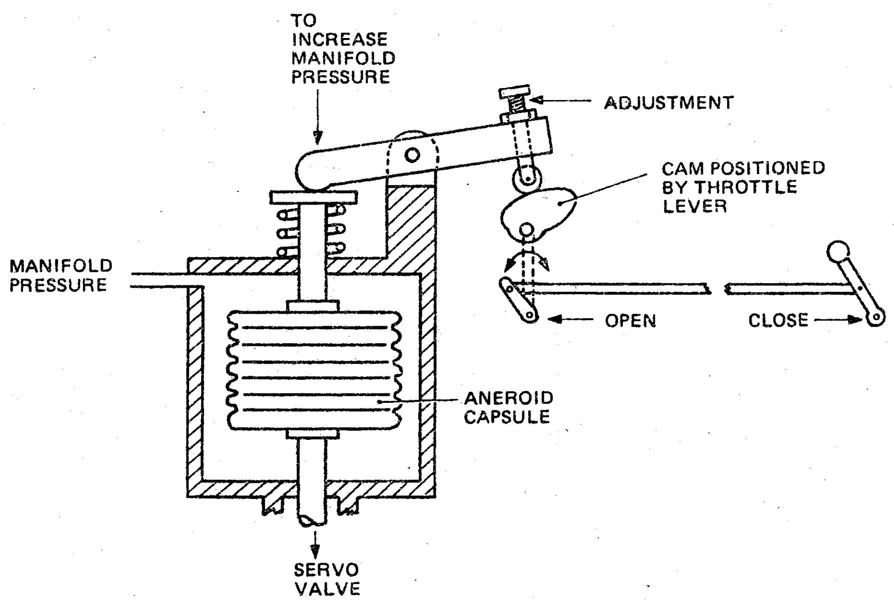


Figure 4 VARIABLE DATUM CONTROL

4.3.4 When an engine is operating in the idling range the induction pressure is very low, and a reversal of flow may occur in which air or exhaust gases are drawn into the induction manifold during the period of valve overlap. This would produce an increase in pressure in the manifold, which would be communicated to the capsule chamber and, on engines fitted with a variable-datum control, would have the effect of closing the throttle valve. This would effectively prevent any acceleration, and with this type of control the cam is so contoured and adjusted that the throttle lever is the sole means of controlling the throttle valve in the idling range.

5 EXTERNALLY-DRIVEN SUPERCHARGERS The main differences between an internally-driven and an externally-driven supercharger are in the method of driving the impeller and in the fact that the latter delivers compressed air to the throttle and carburettor. Externally-driven superchargers are powered by the energy of the engine exhaust gases and do not directly lower the power output of the engine; they are generally known as turbo-superchargers or turbochargers. Some turbochargers are designed to maintain approximately sea-level air pressure in the engine air intake up to a high altitude, and are known as Altitude Turbochargers. Others are designed to provide an intake pressure which is higher than sea-level pressure, and thus produce a higher power output at all altitudes than would be available from an unsupercharged engine, and these are known as Ground Boosted Turbochargers. The former type may be fitted without significant engine design changes to normally-aspirated engines in order to maintain sea-level power up to a high altitude, but the latter may only be fitted to engines which are designed to withstand the higher stresses imposed by the higher combustion pressures.

A few large engines with internally-driven superchargers are also fitted with a turbocharger, which is used to increase the altitude at which a given power can be developed; because of the increased air temperature arising from the two stages of compression, it may be necessary to fit an intercooler between the turbocharger and the carburettor.

5.1 A turbocharger consists of a turbine wheel and an impeller fitted on a common rotor shaft, the bearings for which are contained within a bearing housing and are lubricated by oil from the engine. The turbine and compressor casings are attached to the bearing housing and are connected to the exhaust and intake systems respectively; the compressor is shielded from the heat of the turbine, and intake or external air is ducted between the two casings to remove excess heat. The turbocharger is not necessarily an integral part of the engine, but may be mounted on the engine or on the fireproof bulkhead, and shielded from combustible fluid lines in the engine bay. A typical turbocharger is illustrated in Fig. 5, and a turbocharged engine installation is illustrated in Fig. 6.

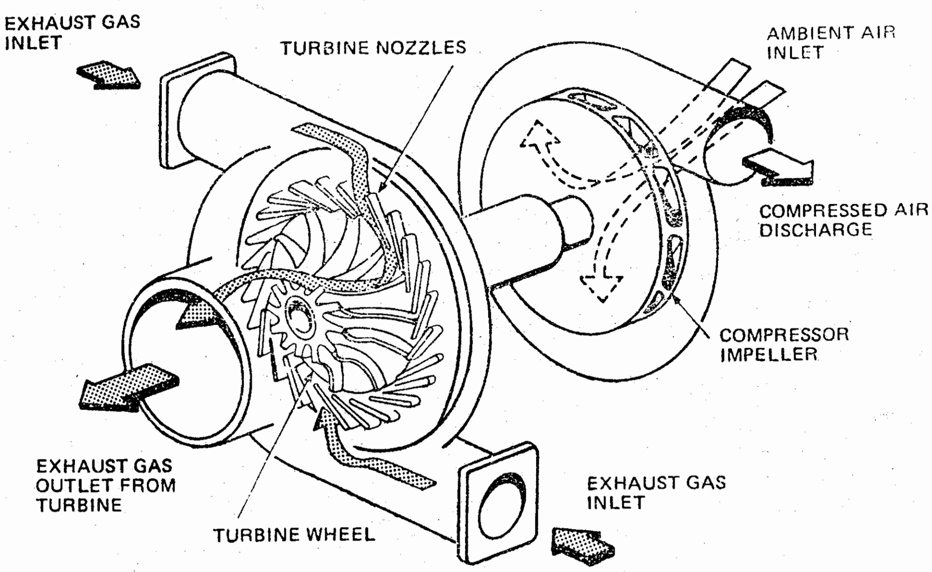


Figure 5 TYPICAL TURBOCHARGER

5.1.1 Exhaust gases are ducted to the turbine casing, where they pass through nozzles and impinge on vanes on the turbine wheel, causing it to rotate; the gases then pass between the vanes and are exhausted overboard. Since the impeller is attached to the same shaft as the turbine wheel it also rotates, drawing in air from the intake duct and throwing it outwards at high velocity through diffuser vanes in the compressor casing; these vanes convert the velocity energy into pressure energy, and the compressed air is delivered to the engine.

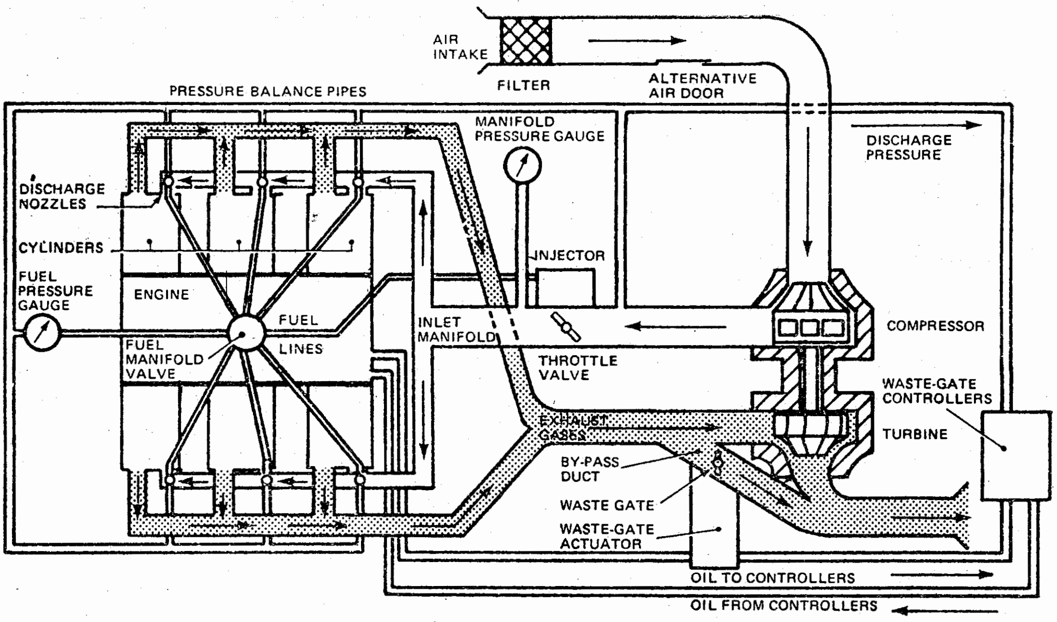


Figure 6 TURBOCHARGER INSTALLATION

5.2 For any particular power output the turbocharger delivers a fixed weight of air to the engine in a given time, and, since the density of air decreases with altitude, a greater volume of air is compressed and the impeller rotates faster at high altitude than it does at low altitude. Therefore, some form of control over compressor output must be provided, and this is done by varying the quantity of exhaust gas passing to the turbine. A turbine by-pass, in the form of an alternative exhaust duct, is fitted with a valve (known as a waste gate) which shuts or regulates the degree of opening of the by-pass. When the waste gate is fully open nearly all the exhaust gases pass directly to atmosphere, but as the waste gate closes gases are directed to the turbine, and the maximum rotor speed is achieved when the waste gate is fully closed. The waste gate may be controlled manually by the pilot, but in most turbocharger systems automatic controls are fitted to prevent over-boosting the engine.

5.3 In an automatic control system, the waste gate is mechanically connected to an actuator (Fig. 7), the position of which depends on the opposing forces of a spring and engine oil pressure. Spring force tends to open the waste gate and oil pressure tends to close it. Engine oil pressure is fed to the actuator through a restrictor, and the waste gate controllers are placed in the return line. When a controller opens the return line, oil flows through the actuator and controller back to the engine sump, and pressure in the actuator falls. The extent to which the oil pressure will fall depends on the size of the restrictor and the size of the bleed through the controllers; the larger the bleed the lower the oil pressure will drop. Thus oil pressure in the actuator is controlled to regulate the position of the waste gate according to engine requirements. Various types of controllers may be used to vary waste-gate actuator oil pressure, and these are discussed in paragraphs 5.3.1 to 5.3.5.

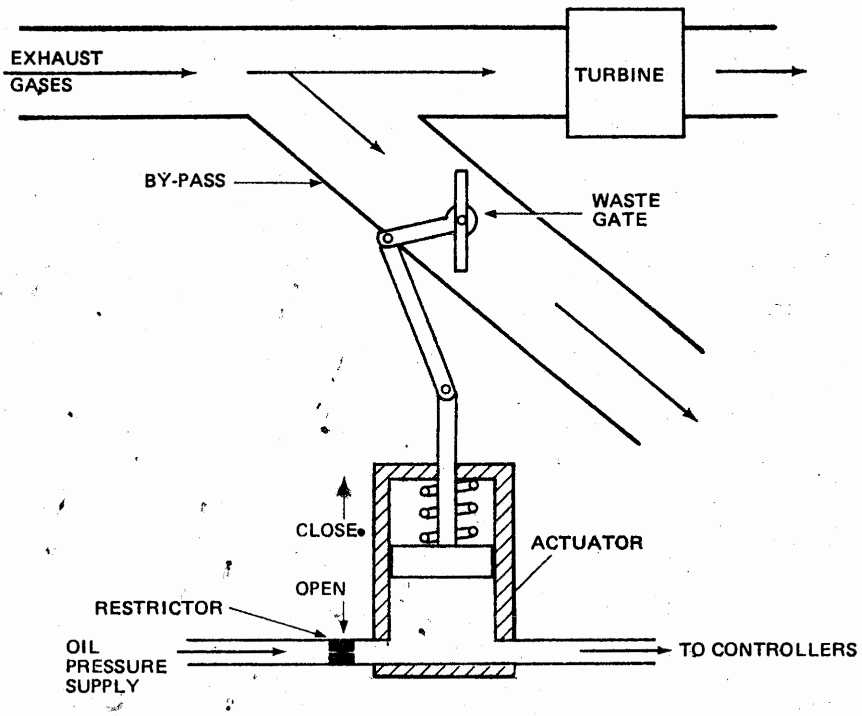


Figure 7 OPERATION OF WASTE GATE

5.3.1 Some simple turbocharger systems use a single controller, called an Absolute Pressure Controller, which is designed to prevent supercharger outlet pressure from exceeding a specified maximum; this type of controller is illustrated in Fig. 8. At low power settings full oil pressure is applied to the waste-gate actuator, which closes the waste gate and diverts all exhaust gases through the turbine. As the throttle is opened, engine speed increases, and more exhaust gas passes through the turbine; this results in an increase in the speed of rotation of the turbine and impeller, and produces a higher supercharger outlet pressure which is communicated to the capsule chamber in the Absolute Pressure Controller. When the controlling supercharger outlet pressure is reached, the capsule is compressed sufficiently to open its bleed valve and thus to bleed off oil pressure from below the waste-gate actuator piston. The piston moves down under spring pressure and starts to open the waste gate, diverting exhaust gas from the turbine and reducing its speed. Thus at high power settings at low altitude the waste gate is almost fully open, but as the aircraft climbs and more air has to be compressed it is gradually closed until, at critical altitude (equivalent to Rated Altitude on an internally-driven supercharger) it is fully closed. Above this height both manifold pressure and power output will decrease, even though the turbocharger is operating at its maximum speed.

NOTE: Since the speed of the impeller increases with altitude, the temperature of the charge will also increase, and this will reduce power output for a given manifold pressure and engine speed. Engine oil and cylinder temperatures will also increase as a result of the higher combustion temperatures.

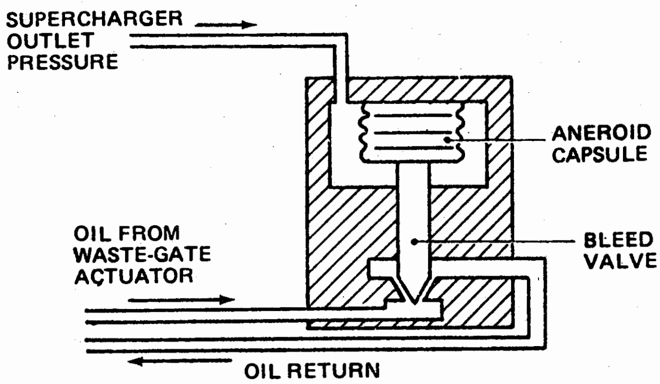


Figure 8 ABSOLUTE PRESSURE CONTROLLER

5.3.2 A variation of the single controller is the Variable Pressure Controller (see Fig. 9), which is similar in operation to the variable datum control described in paragraph 4.3.3 for internally-driven superchargers. A cam, operated by linkage to the throttle control lever, adjusts the datum of the valve in the Variable Pressure Controller, so controlling the degree of opening of the waste gate and producing a manifold pressure which is related to the power selected by the throttle lever. Operation of this system is otherwise similar to the operation of the Absolute Pressure Controller.

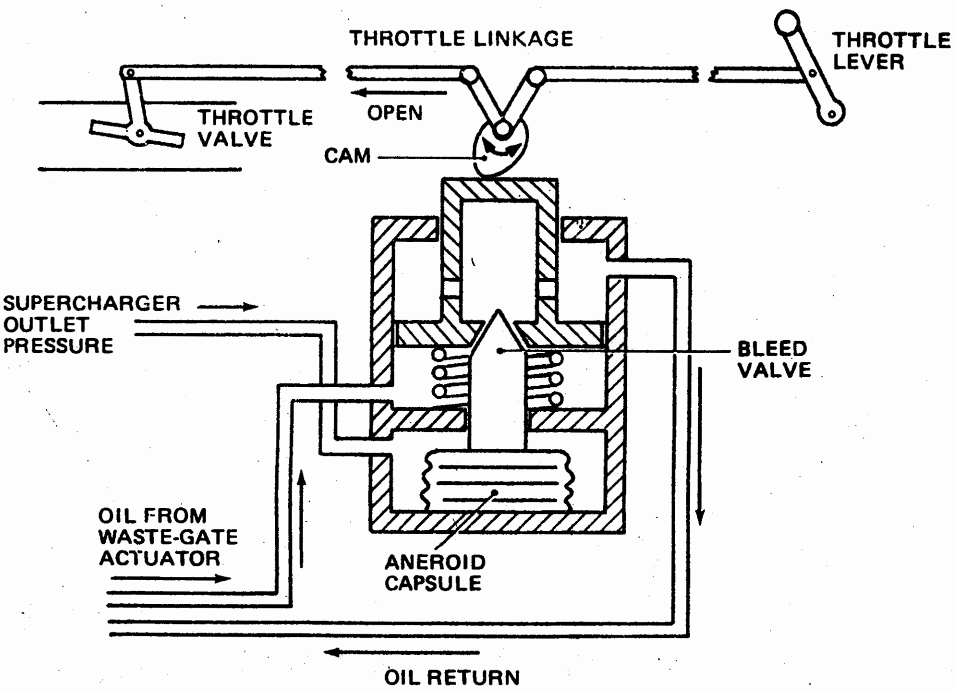


Figure 9 VARIABLE PRESSURE CONTROLLER

5.3.3 On some Ground Boosted Turbochargers a dual-unit control system is used to adjust waste-gate actuator oil pressure; the units are the Density Controller and the Differential Pressure Controller, which are installed as shown in Fig. 10.

(a) The Density Controller is designed to prevent the supercharger output from exceeding the limiting pressure; it regulates oil pressure only at full throttle and up to the turbocharger's critical altitude. The capsule is filled with dry nitrogen and is sensitive to both temperature and pressure changes. Contraction or expansion of the capsule varies the quantity of oil bled from the waste-gate actuator and repositions the waste gate, thus maintaining a constant density at full throttle.

(b) The Differential Pressure Controller controls the waste gate at all positions of the throttle other than fully open. A diaphragm divides a chamber which has supercharger outlet pressure on one side and inlet manifold pressure on the other side, thus responding to the pressure drop across the throttle valve. The bleed valve is fully closed at full throttle, when the pressure drop is least, and gradually opens as the throttle is closed and the pressure drop increases. The controller thus opens the waste gate as the throttle is closed, and reduces supercharger outlet pressure in accordance with the power selected.

(i) Any variation in power caused by slight changes in temperature or engine speed will result in a change in exhaust gas flow which will affect turbine speed. This may produce an unstable condition, known as 'bootstrapping', or hunting, of the manifold pressure as the control system attempts to reach a state of equilibrium. This condition is smoothed out by the Differential Pressure Controller, which reacts quickly to changes in the pressure drop across the throttle valve, and reduces the effects of small power changes.

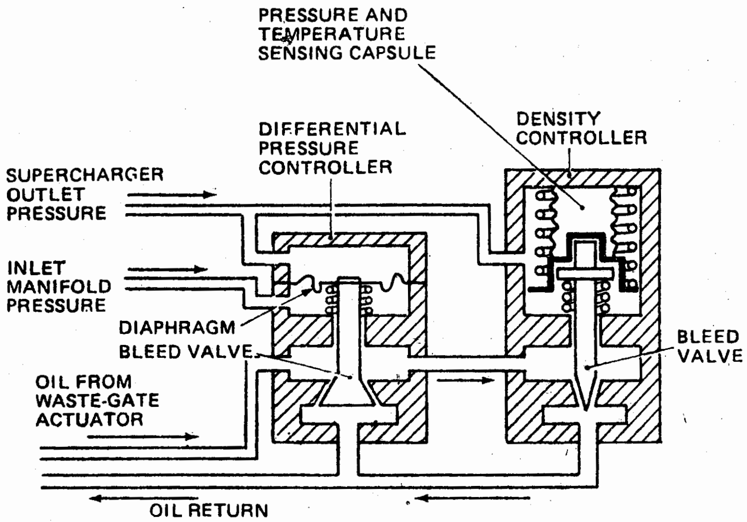


Figure 10 DUAL-UNIT CONTROL SYSTEM

5.3.4 On some Ground Boosted Turbochargers three separate controllers are used; two of these control the waste gate up to the turbocharger's critical altitude and the third controls the waste gate above critical altitude. This system is illustrated in Fig. 11.

(a) An Absolute Pressure Controller is used to control the supercharger outlet pressure below critical altitude. Operation of this unit is as described in paragraph 5.3.1.

(b) A Rate Controller is fitted to control the rate at which supercharger outlet pressure will increase, thus preventing overboosting the engine initially when the throttle is opened. Both sides of a diaphragm in the unit are connected to supercharger outlet pressure, but the opening to the lower chamber is fitted with a restrictor. If supercharger outlet pressure increases at too high a rate, air pressure will increase more quickly above the diaphragm than it does below it, because of the presence of the restrictor. The downward force on the diaphragm opens the bleed valve, bleeding oil pressure from the waste-gate actuator and opening the waste gate. Thus the rate of increase of supercharger outlet pressure is controlled, regardless of the rate of acceleration of the engine.

(c) As altitude is increased, the supercharger has to rotate faster and compress more air to maintain maximum power, and this results in an increase in the temperature of the air delivered to the engine. This rise in temperature could eventually reach a point where detonation would occur, and is controlled by placing limits on the maximum manifold pressure which can be used above a specified altitude (often 16,000 ft). Whilst it is possible to operate within these limitations, by retarding the throttle lever above the specified altitude, a Pressure Ratio Controller can be fitted to limit supercharger outlet pressure automatically. This controller contains a chamber which is open to atmospheric pressure, and at the specified altitude a capsule in the chamber will have expanded sufficiently to contact the stem of a bleed valve. As the aircraft climbs above this altitude the valve is opened by an increasing amount, and gradually increases the bleed from the waste-gate actuator to reduce supercharger outlet pressure at a set ratio to the atmospheric pressure (normally 2·2 : 1).

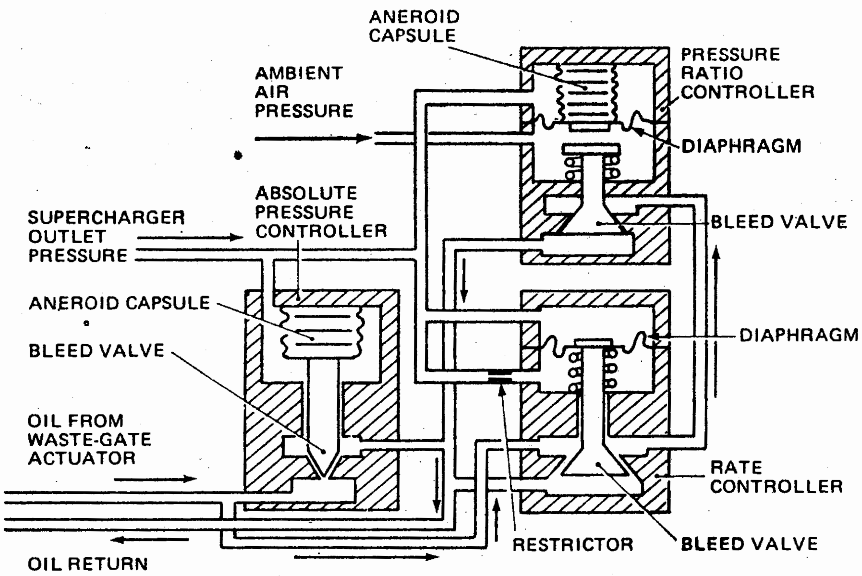


Figure 11 TRIPLE-UNIT CONTROL SYSTEM

5.3.5 On some aircraft a manifold pressure relief valve is fitted in the compressor discharge duct, to prevent overboosting of the engine during rapid acceleration, and in the event of failure of the controllers or sticking of the waste gate. The valve is usually a simple poppet type valve, which is adjusted to relieve the supercharger discharge pressure to atmosphere whenever the controlled maximum pressure is exceeded. A manifold pressure relief valve is usually fitted in conjunction with an Absolute Pressure Controller or a Variable Pressure Controller.

5.4 Turbocharger systems are very sensitive to changes in exhaust gas flow, and automatic controls take time to reach a state of equilibrium. It is important, therefore, that the throttle and propeller controls are operated slowly and that time is allowed for the control system to settle down.

6 INSPECTION AND MAINTENANCE Internally-driven superchargers, being contained within the engine casing and handling only clean air, generally require no attention between engine overhauls; however, the air intake filter must be cleaned at the times specified in the approved Maintenance Schedule, and the control linkage should be checked for security and operation, and lubricated as required. To ensure that only clean oil passes to the clutch units, some engines are also fitted with a device, known as a centrifuge, which is driven from the supercharger gear train and removes sludge from the oil by centrifugal force; this centrifuge should be removed for cleaning at the intervals specified in the approved Maintenance Schedule. If failure of the supercharger or its drive train should occur, the engine must be removed for repair or overhaul, but if system components such as an automatic manifold pressure control unit or an interconnected carburettor are changed, the linkage may have to be adjusted to obtain the required manifold pressure according to throttle position; details concerning the adjustment of particular components should be obtained from the relevant Maintenance Manual. An externally-driven supercharger, however, has a more severe operating environment; the turbine is subjected to the hot and corrosive exhaust gases, and the compressor and lubrication system may be subjected to heat from the turbine. Dirt, dust, carbon deposits, and ineffective lubrication, may all have adverse effects on turbocharger operation, and output may also be affected by incorrect engine oil pressure, or leaks in the intake or exhaust ducting. The inspection and maintenance requirements of a turbocharger are, therefore, more rigorous, and are outlined in paragraphs 6.1 to 6.6; these operations are typical of those required on the turbocharger installations on many light aircraft.

6.1 **Periodic Inspections.** At the periods specified in the approved Maintenance Schedule, the following inspections should be carried out.

(a) Remove and clean the intake air filter (Leaflet **EL/1-2**) and inspect for damage. If the element is damaged is must be renewed.

(b) Inspect the turbocharger mountings and the connections to the intake and exhaust ducting, for security and locking.

(c) Inspect all ducting in the intake and exhaust systems for gas leaks, and all oil and drain connections for oil leaks.

NOTE: Constant leakage from a drain line indicates a leaking seal, and the affected unit should be removed and checked in accordance with the relevant Overhaul Manual.

(d) Check the turbine insulation blanket (shield) for condition and security.

(e) Run the engine and check the turbocharger for vibration and unusual scraping or whining noises. Vibration could result from unbalanced accumulations of dirt or carbon on the rotors, whilst unusual noises could be indicative of bearing failure or incorrect running clearances. Any vibration or unusual noises would necessitate removal and overhaul of the turbocharger.

(f) Disconnect the inlet duct from the compressor and remove the compressor housing. Check the compressor impeller for nicks, cracks, bent or broken vanes, and signs of rubbing. Check for a build-up of dust and dirt and remove any deposits with a lint-free cloth moistened in solvent.

(g) With the compressor housing removed, check the axial play of the impeller shaft by pushing the shaft in both directions and rotating the impeller manually. Physical contact between the turbine wheel or impeller and their housings will require removal of the turbocharger, in order to adjust or replace the bearings.

(h) With the overboard exhaust duct removed, check the turbine wheel for excessive carbon build-up, nicks, cracks, and bent or broken vanes.

(j) Check the waste-gate/actuator linkage for security, free movement and correct operation, and clean as necessary.

(k) Remove the controllers to enable them to be checked for internal leakage in accordance with the appropriate Overhaul Manual.

(l) Remove the oil filter in the supply to the turbocharger and controllers, and clean in solvent.

(m) Check the engine breather pipe for obstruction.

(n) Before returning an aircraft to service after an inspection has been carried out, all items which have been removed must be refitted, all bolts and nuts must be tightened to the appropriate torque values, and locking must be renewed as appropriate. If parts have been disturbed, an engine run should be carried out to check the operation of the system.

6.2 **Bearing Checks.** When called for in the Maintenance Schedule, or when incorrect operating clearances are suspected, the radial and axial play in the rotor bearings should be measured. This may usually be carried out 'in situ', but on some installations, because of insufficient clearance in the engine bay, it may be necessary to remove the turbocharger. The intake and exhaust ducts should be disconnected from the turbocharger, and a dial test indicator (DTI) should be used to measure the bearing clearances; a mounting fixture for the DTI will usually be required.

6.2.1 To measure the radial clearance in the bearings the centre housing drain pipe should be removed and the DTI should be mounted so that its spindle (fitted with an extension rod of suitable length) protrudes through the oil drain hole and rests on the centre of the rotor shaft. By moving the shaft towards and away from the DTI in the direction of its travel, and applying equal pressure at both ends of the shaft, the total radial clearance will be indicated and should be within the limits specified by the manufacturer.

6.2.2 To measure axial clearance in the bearings the DTI should be mounted so that the tip of its spindle rests on the end of the rotor shaft, with its direction of travel along the axis of the rotor shaft. By moving the shaft axially in both directions the total axial clearance will be indicated and should be within the limits specified by the manufacturer.

6.2.3 If bearing clearances are found to be excessive, the turbocharger should be removed for overhaul.

6.3 **Rotor Shaft Binding.** If running clearances appear to be satisfactory, but sluggish or low-powered engine operation is apparent and difficulty is experienced in rotating the turbocharger rotor by hand, the cause may be deposits in the turbine shaft seal ring area. These deposits are caused by water vapour accumulations, and occur during the early life of a turbine, before combustion products have formed a protective coating on seal surfaces. In order to remove these rust deposits, the exhaust outlet duct from the turbine should be removed, and an approved penetrating oil should be sprayed behind the turbine wheel. After leaving this to soak for at least ten minutes it should be possible to turn the rotor by hand, but light taps with a soft mallet on the end of the rotor shaft may be necessary in some cases. After refitting the exhaust duct an engine power check should be carried out to confirm turbocharger output.

6.3.1 A further cause of rotor shaft binding may be the accumulation of carbon deposits on the turbine wheel and in the turbine housing. These deposits build up during the life of a turbocharger and cannot easily be removed; the turbocharger should be removed for cleaning and overhaul.

6.4 **Exhaust Leaks.** Whilst exhaust gas leakage in a normally-aspirated engine may have serious safety aspects, the leakage of exhaust gas from a turbocharged engine is much more serious, because of the pressure differential which exists between the inside and outside of the exhaust pipes, particularly at high altitude. The turbine itself is usually shielded to contain any leaking exhaust gases, but the ducts from the cylinders to the turbine contain a number of separate pipes, gaskets and expansion joints, leakage from which could produce a flame in the engine bay and have serious consequences; in addition, leakage will reduce the gas pressure on the turbine and thus reduce its maximum output. Regular inspections of the exhaust system are, therefore, very important to safety.

6.4.1 Exhaust gas leakage is usually indicated by sooty streaks on the exhaust piping and joints, or by signs of overheating of adjacent parts and shields. Cracks are most often found at welds, changes of section or clamping points, and an inspection should include a check for broken or missing parts such as attachment clips, and the tightness of any clamping bolts. Exhaust pipes should also be checked for evidence of physical damage, since uneven internal surfaces can produce hot spots, and these could lead to scaling and cracks.

6.5 **Removal and Replacement of Components**

6.5.1 **Turbocharger.** A turbocharger may be mounted on the engine, on the engine bulkhead, or on a component in the exhaust system, and is connected to the intake and exhaust systems and to the engine lubrication system. Removal is usually straightforward and involves removal of the turbine heat shielding, and disconnection of the various ducts, oil pipes, stays and attachment bolts as necessary; however, precautions must be taken to prevent the ingress of debris into the oil system and into the intake and exhaust ducts where it could, if undiscovered, be subsequently drawn into the turbocharger or engine and cause damage. Ducts and pipes should, therefore, be blanked immediately they are disconnected, and the blanks should remain in position until the item is re-connected. A new or replacement unit should be examined to ensure that it is the correct type, that it is undamaged, and that the rotor rotates without binding or scraping. When installing the turbocharger the blanks should be removed and the intake and exhaust ducts should be inspected for debris immediately before re-connection. New washers, O-rings or gaskets should be used where appropriate, and high temperature anti-seize compound should be used on all threads which are heated by the exhaust gases. Proper fit of ducts and pipes should be checked, and any special dimensional requirements stipulated in the approved Maintenance Manual for couplings and expansion joints, should be met. Fasteners should be torque loaded to the required values and properly locked, and when installation is complete the engine should be run to check turbocharger operation. An inspection for gas and oil leaks should be carried out after the engine run.

6.5.2 **Waste gate and Actuator.** The waste gate and actuator are usually adjusted together during assembly, and are considered as a single unit. When either component becomes unserviceable, both should be changed, and adjustment should not be attempted without a suitable test rig. The unit is usually bolted onto an exhaust manifold flange and may usually be removed, complete with exhaust discharge duct, after disconnecting and blanking the oil pipes and drain. A new gasket should be used when refitting the unit, the threads of the attachment bolts should be lubricated with high temperature anti-seize compound, and fasteners should be torque loaded and locked as appropriate. A ground run should be carried out to check waste gate operation.

6.5.3 **Controllers.** Removal and installation of most controllers is straightforward, and usually entails only removal or refitting of the oil and air pressure sensing pipes and the mounting bolts; the precautions outlined in paragraph 6.5.1 regarding the blanking of open pipes and the tightening and locking of fasteners should be taken. The Absolute Pressure Controller and the Variable Pressure Controller, however, may require adjustment after installation. The former may be adjusted to set the limiting manifold pressure, but the latter, being connected to the throttle linkage, must be adjusted to control manifold pressure over its whole range of operation. Two adjustments are provided on the Variable Pressure Controller; one is the initial (low) setting of the valve when it contacts the cam dwell (Fig. 9) and the other is the position of the cam to obtain maximum manifold pressure (high setting). The exact method of adjustment varies between aircraft and the appropriate procedure should be obtained from the relevant Maintenance Manual. Operation of the controllers should be confirmed by engine runs.

6.6 **Testing Turbocharger Operation.** Whenever major components in the turbocharger system are changed or incorrect operation is suspected, the engine should be ground tested, and if necessary air tested, to confirm proper operation and to enable any faults to be correctly diagnosed.

6.6.1 The ground test normally consists of ensuring that take-off rev/min and manifold pressure can be obtained at full throttle, but depending on the types of controller fitted, additional checks may be required. After starting and warming-up the engine to normal operating temperatures and pressures the following checks should be carried out:—

(a) With the propeller in fully-fine pitch, slowly open the throttle control and check that take-off rev/min and manifold pressure are obtained. The manifold pressure should be watched carefully as engine power increases, to ensure that the limiting pressure is not exceeded. Excessive pressure could result from failure of the manifold pressure relief valve to open, or from failure of the rate controller to control acceleration. Failure to obtain maximum power may be caused by induction or exhaust leaks, low oil pressure in the waste-gate actuator, or a sticking waste gate.

(b) If a Variable Pressure Controller is fitted, a gauge which registers supercharger discharge pressure should be connected to the test ports provided on the controller, before starting the engine; this gauge is used to check the low setting of the controller. Two different combinations of rev/min and manifold pressure are prescribed for this check in the approved Maintenance Manual, and these should be set-up during the ground run. The supercharger discharge pressures recorded at these settings should be noted, and should be within the limits prescribed by the manufacturer.

6.6.2 The flight test is designed to check all aspects of turbocharger operation and control. The full test is detailed in the relevant Maintenance Manual, and varies according to installation and types of controllers fitted.

(a) The turbocharger should maintain maximum power from take-off to critical altitude. An early fall-off in power may be caused by induction or exhaust system leaks, 'coking' of the turbine, or incorrect setting of the manifold pressure relief valve. Incorrect manifold pressure, either high or low, may result from incorrect operation of the Density Controller, Absolute Pressure Controller or Variable Pressure Controller.

(b) 'Bootstrapping' is checked by flying at a specified altitude then reducing engine speed until manifold pressure starts to fall, indicating that the waste gate is closed. The manifold pressure, engine rev/min and outside air temperature at this point should be noted, and a slight increase in rev/min should not produce bootstrapping. The power settings and outside air temperatures at which bootstrapping may occur, are stated in the relevant Maintenance Manual.

(c) Operation of the manifold pressure relief valve or the Rate Controller is checked by opening the throttle rapidly during level flight at a specified altitude. The increase in manifold pressure produced by this acceleration should be within the limits specified in the Maintenance Manual.

(d) The Differential Pressure Controller is checked by climbing above the altitude at which maximum manifold pressure is permitted. The fall in manifold pressure with increased altitude should be in accordance with the specified limits.

Issue 1.

18*th May*, 1977.

AIRCRAFT

ENGINES

PISTON ENGINE INSTALLATIONS

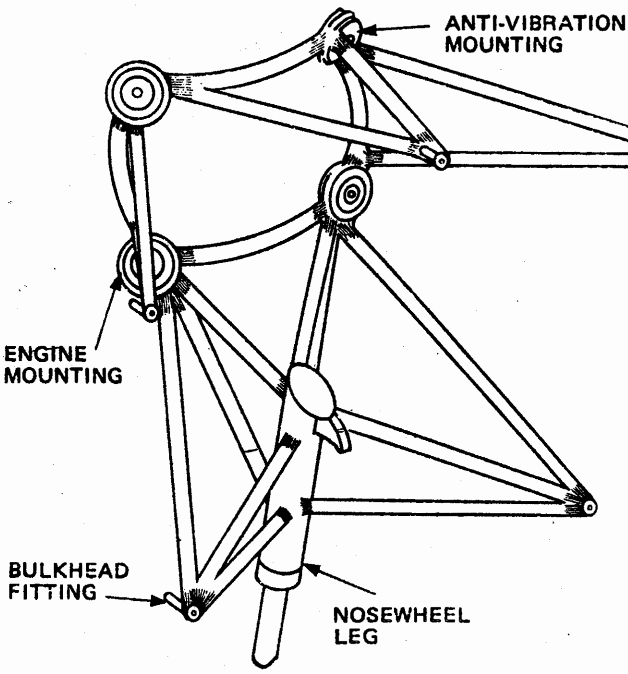
1 INTRODUCTION This Leaflet deals with the systems and components required for the installation of a basic piston engine into an aircraft fuselage or nacelle. It also includes the maintenance aspects not previously covered in Leaflets **EL/1-2** and **EL/1-3**. The topics discussed are as follows:—

Para.	Topic	Para.	Topic
2	Engine Mountings	8	Instrumentation
3	Controls	9	Starters
4	Air Intake System	10	Oil Coolers
5	Exhaust System	11	Removal and Installation
6	Cooling	12	Routine Maintenance
7	Access	13	Non-Routine Inspections

2 ENGINE MOUNTINGS Radial engines, and most horizontally-opposed engines, are generally mounted in a tubular framework such as is illustrated in Figure 1. This welded framework is rigidly attached through the fireproof bulkhead to the fuselage or nacelle structure, and connected through a vertical mounting ring and flexible mountings to the engine. In some cases the fuselage or nacelle monocoque structure is continued forward and connects to the mounting ring to which the engine is attached. In-line engines, and some horizontally-opposed engines, may be mounted in bearers which provide four attachment points in a substantially horizontal plane. The bearers are often welded tubular cantilever structures running down each side of the engine and attached through the bulkhead at the rear, but may also be an extension of the lower fuselage or nacelle structure; the cantilever method facilitates the installation and removal of the engine, particularly if it is fitted with a turbocharger or other large accessories at the rear.

2.1 **Flexible Mountings.** The engine is usually attached to the mounting ring, bearers, or airframe structure, by means of flexible vibration isolators; these are specially designed for each engine and mounting position, and transfer propeller thrust to the airframe but limit the transfer of propeller or engine vibrations. The load is transmitted through rubber in shear or compression, and a typical mounting for a horizontally-opposed engine is illustrated in Figure 2.

3 CONTROLS Linkage between the cabin controls and the engine provides for operation of the throttle, mixture control, propeller governor, and oil or air temperature-control flaps or gills. On light aircraft this linkage is usually mechanical, but in some cases the temperature-control flaps are electrically actuated and may be automatically controlled.



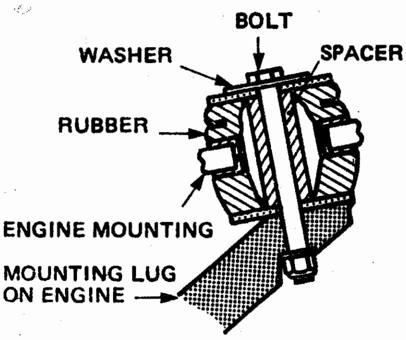


Figure 1 ENGINE MOUNTING FRAME *Figure* 2 ANTI-VIBRATION MOUNTING

3.1 Mechanical connection between the cabin controls and the engine can be by various methods, such as rods and levers, pulleys and cables, cable contained within rigid or flexible conduit, or, in the case of controls which are only used infrequently (such as a slow-running cut-out), by means of a single-acting cable and return spring.

3.1.1 The rod and cable ends terminate in a fork-end or eye-end fitting, for connection to the associated lever or control, and these afford the means of adjusting the linkage so that movement of the cabin control lever corresponds to engine control movement. When pulleys and cables are used the cable ends are joined by turnbuckles, which are used to adjust cable tension. Initial setting of the linkage is usually by placing the cabin and engine controls in the required positions, then adjusting the length of the connecting linkage to suit these positions; the inspection holes in the end fittings should be used to check that sufficient thread is engaged to provide a safe connection. In some cases rigging pins or graduated quadrants may be used to fix the positions of the levers or pulleys in the system, before connecting the rods and cables. Positive locking such as split pins or locking wire are used on all parts which, if not properly secured, could loosen and lead to disconnection of the linkage.

3.2 Electrically-powered actuators usually take the form of a screw jack, which is driven through a reduction gear by an electric motor. The direction of rotation of the motor depends on the current direction, and this is controlled by a switch. When automatic operation is provided, the manual switch is by-passed and current is directed to a temperature switch, which then controls operation of the actuator.

4 AIR INTAKE SYSTEM The air intake system comprises a smooth-walled duct from the outer surface of the engine cowling to the carburettor or injector, and generally includes an air filter and alternative air door (see Leaflet EL/1-2); the duct may be separate from the cowling or, particularly in the case of radial engines, an integral part of the upper or lower portions of the cowling. The duct entrance is usually located at the front of the engine cowling where the airstream provides some ram effect, and the duct may pass over or under the engine, depending on whether an updraught or downdraught carburettor is fitted. On light aircraft the air filter is usually located at the front of the duct and, in normal circumstances, filters all incoming air; operation of the alternative air door may be either manual or automatic. Joints and mating surfaces in the air intake are sealed to prevent air leakage, and often include a flexible bellows type of joint at the carburettor to accommodate engine flexing and vibration.

5 EXHAUST SYSTEM An exhaust system is designed to carry the exhaust gases from the engine cylinders and discharge them safely outside the fuselage or nacelle skin. In addition, the exhaust pipes may be used as a source of warm air for the carburettor during icing conditions, and to provide cabin heating. A typical exhaust system for a horizontally-opposed engine is illustrated in Figure 3.

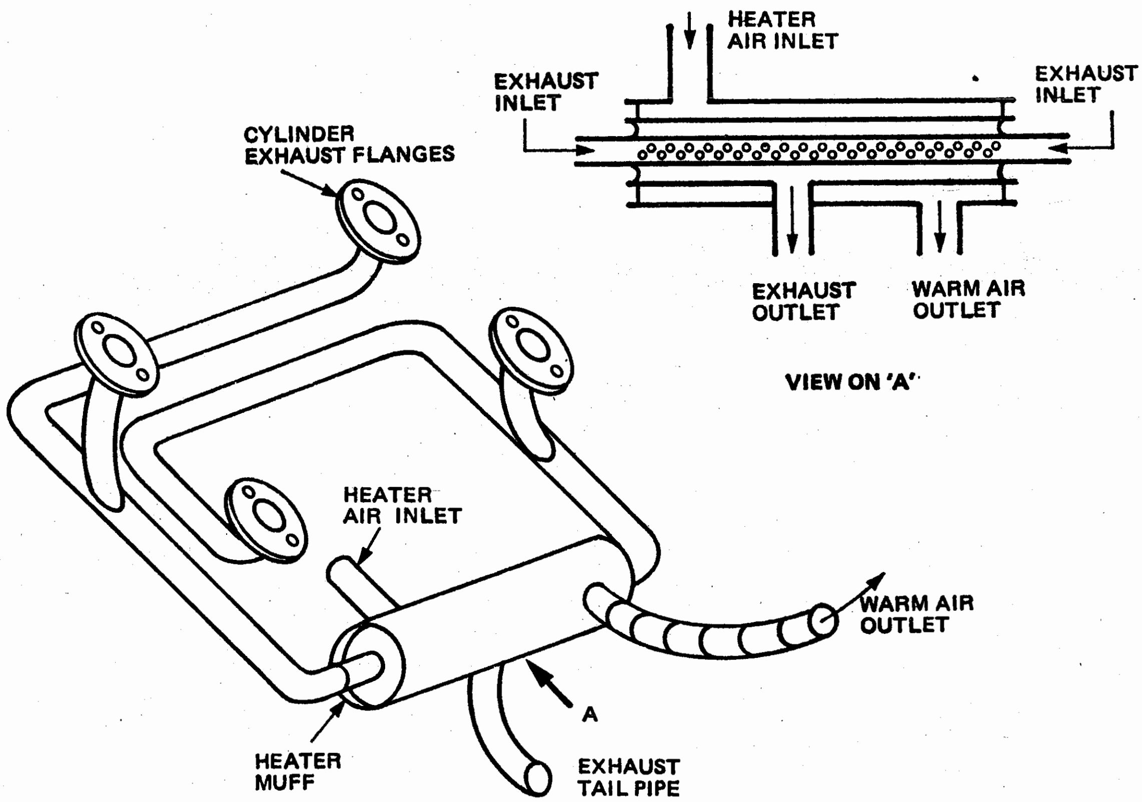


Figure 3 TYPICAL EXHAUST SYSTEM

5.1 On a horizontally-opposed engine, individual pipes from the cylinders (stack pipes) are fed into a muffler (silencer), and a tail pipe leads the exhaust gases to atmosphere. The muffler is generally surrounded by a detachable jacket, which is fed by ram air from an intake at the front of the engine, and exhausts into the cabin heating system. Warm air for the carburettor may be drawn from a scoop adjacent to the muffler.

5.2 On radial engines the individual pipes from each exhaust port are fed into an exhaust collector ring, which is a large diameter pipe surrounding the engine, and usually contained within the engine cowling. One or more tail pipes from the collector ring lead the exhaust gases to atmosphere, and often incorporate a heater muff to supply warm air to the cabin.

5.3 On some installations the exit for cooling air from the engine bay is through a duct known as an augmentor, and by discharging exhaust gases into this duct, a better cooling air flow is induced through the engine compartment.

5.4 An exhaust system consists of a number of components, most of which are made from sheet steel parts welded together, and connected by clamps or slip joints to their adjacent parts. With normally-aspirated or internally-supercharged engines the exhaust system is usually connected rigidly to the engine, but when a separately mounted turbocharger is fitted, flexible couplings are also used in the exhaust ducting. Because of the temperature and corrosive nature of the exhaust gases (maximum temperatures and pressures being experienced on turbocharged engines), many parts of the system have a limited life and require regular inspection for leakage, cracks, and damaged or broken parts, in order to ensure that the exhaust gases are contained within the exhaust system (see also Leaflet **EL/1-3**). Inspection is particularly important on those installations which use a cabin heater muff, since any gas leakage into the heater system could introduce carbon monoxide into the cabin, with fatal effects on passengers and crew; a similar effect could result from poor sealing of the engine bulkhead or the introduction of exhaust gas through unsealed seams or openings in the aircraft skin.

6 **COOLING** The cowlings on an air-cooled engine are designed to provide a streamlined shape round the engine and so reduce drag, and to provide adequate cooling by forcing air to flow between the cylinder cooling fins.

6.1 On a horizontally-opposed engine, cooling-air is admitted through an aperture on each side of the propeller spinner and passes to the top of the engine and cylinders. The space between the top cowling and the cylinders is sealed at the sides and rear by baffles attached to the engine, and air entering through the front of the cowling is compressed in this space. This increase in pressure forces air past the cylinders, where inter-cylinder baffles direct it between the cylinder cooling fins to remove excess heat, and discharge it into the lower part of the engine bay (Figure 4). Apertures at the rear of the pressurized compartment direct air through the oil cooler, into the alternative hot-air intake, and through blast tubes to cool specific components such as the magnetos, generator and sparking plugs. Cooling air is finally exhausted at the rear of the engine cowling, the size of the exit controlling the flow of air over the cylinders, and thus the engine temperature. On some light aircraft the exit is of fixed size and is designed to provide adequate cooling during all normal flight operations, but many aircraft are fitted with flaps which can control the amount of air released from the engine compartment, thus enabling engine temperatures to be controlled. These cooling flaps may be mechanically operated by linkage to a lever in the cabin, but are often operated by electric actuators (paragraph 3.2).

6.2 A radial engine is usually contained within a cylindrical cowling which directs air into the face of the engine while maintaining a streamlined flow external to the engine. Baffles attached to the cylinders ensure that the air passes between the cylinder cooling fins and the air is finally exhausted through the gap between the cowling and the nacelle structure. The rear edge of the cowling is fitted with movable gills, which open to increase the flow of cooling air and close to reduce it; they are usually electrically operated.

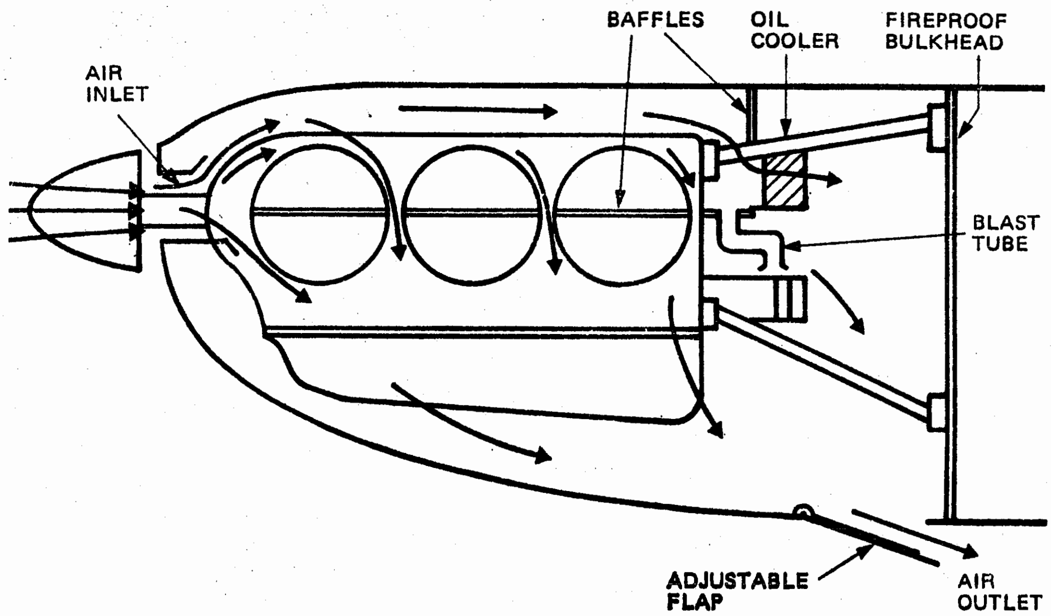


Figure 4 TYPICAL COOLING SYSTEM

6.3 The cooling arrangements for a particular engine are designed to ensure satisfactory cooling during flight, when the forward speed of the aircraft produces an adequate flow of cooling air. When an engine is being run on the ground the only airflow to the engine is produced by the propeller, and in most cases this is not sufficient to provide adequate cooling of all parts of the engine. Unless otherwise stated in the relevant Maintenance Manual, therefore, ground running, particularly at high power, must be kept to a minimum, and careful watch must be kept on both cylinder and oil temperatures.

6.4 Cracked or broken cylinder-cooling fins are generally repaired by cutting away the damage to form a smooth contour, but the size of the fin area which can be removed is limited, since it reduces the cooling area available. Care should be taken not to exceed the limitations imposed by the manufacturer, concerning the number, position and area of any repairs to cylinder cooling fins.

7 ACCESS In order to provide a means of carrying out the various servicing tasks required on an engine it is necessary to provide access openings in the cowling, the type of opening usually depending on the frequency at which access is required.

7.1 On a horizontally-opposed engine access to the oil filler cap, which is required daily or before flight, is often obtained by means of a hinged side panel, which is secured by quick-release fasteners, but may be by means of a small similarly-secured panel in the cowling, located immediately adjacent to the oil filler cap. Access to less frequently serviced items is usually obtained by removing large panels, which may be attached by threaded or quick-release fasteners to the cowling structure.

7.2 Radial engines may also have access panels attached by quick-release fasteners or screws at the rear of the engine for access to the ancillaries, but the main cylinder cowlings are generally in two or three parts, which are positioned by cylinder head mountings and secured together by quick-release fasteners. On some large radial engines a 'clam-shell' type of cowling is used which, when opened, provides access to the complete engine.

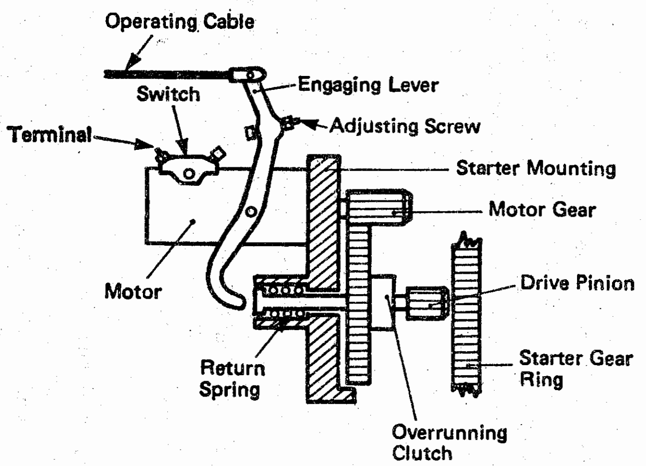
7.3 The maintenance of a smooth airflow over the engine is most important (see also Leaflet **AL/7-11**), and great care is necessary when removing or refitting access panels. Bent corners or other damage to these panels could cause excessive drag or prevent cooling of the engine. Quick-release fasteners should also be treated with care, particularly on panels which are frequently removed; fasteners which are loose or poorly positioned should be adjusted or renewed as appropriate.

8 INSTRUMENTATION Instruments located on the instrument panel in the cabin provide constant indications of certain parameters of engine operation. Numerical marking on the instruments is often combined with colour to indicate minimum, maximum or normal readings, but on some light aircraft the numerical markings are omitted. The parameters which may be covered are engine speed, oil pressure, oil temperature, cylinder head temperature, manifold pressure, fuel flow, fuel pressure, air intake temperature and exhaust gas temperature. Operation and maintenance of engine instruments are dealt with fully in Leaflet **AL/10-3.**

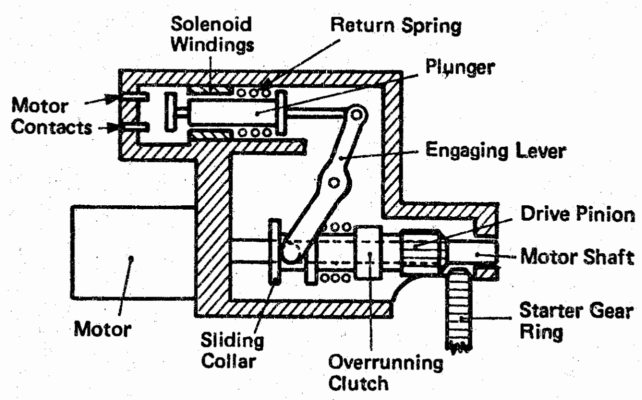
9 STARTERS The normal method of starting a piston engine is by means of a direct-cranking electric starter motor, which may be engaged with the engine either manually or automatically. The starters on some horizontally-opposed engines turn the crankshaft by engaging the starter pinion gear with a large-diameter starter gear ring attached to the forward end of the crankshaft, whilst others are connected through a clutch arrangement to gearing in the rear cover. On radial engines the starter is usually attached to the rear cover, and engages the crankshaft by means of a starter jaw similar to that described in Leaflet **EL/3-12** for the electric starters used on turbine engines.

9.1 Figure 5 (a) illustrates a typical manually-engaged starter motor. A gear on the end of the armature shaft meshes with a larger gear, which is attached to an overrunning clutch and drive pinion. The drive pinion assembly is free to move axially into engagement with the starter gear ring, and is spring-loaded to the disengaged position. The starter control is attached to the engaging lever, and when it is pulled the engaging lever pushes the drive pinion into engagement with the starter gear ring. At the end of its travel the engaging lever operates the starter switch to supply electrical power to the motor. When the engine starts, the overrunning clutch disengages the drive pinion from the motor, and when the starter control is released the drive pinion assembly is disengaged from the starter gear ring by spring pressure. The starter-switch operating stud on the engaging arm must be adjusted so that the drive pinion is fully engaged before electrical power is supplied to the motor.

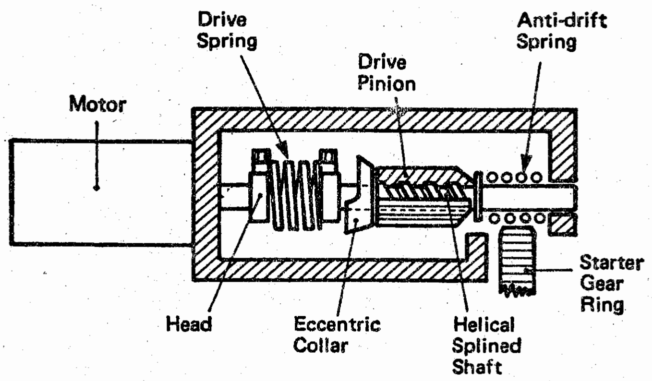
9.2 Figure 5 (b) illustrates a method of engagement which is similar to that described in paragraph 9.1, but in this case the engaging arm is operated by a solenoid. The overrunning clutch and drive pinion slide on helical splines on the armature shaft and are moved into engagement when electrical power is supplied to the solenoid. Final movement of the solenoid makes the connection to supply electrical power to the motor, and when the starter switch is released the spring surrounding the solenoid extends to disengage the drive pinion.



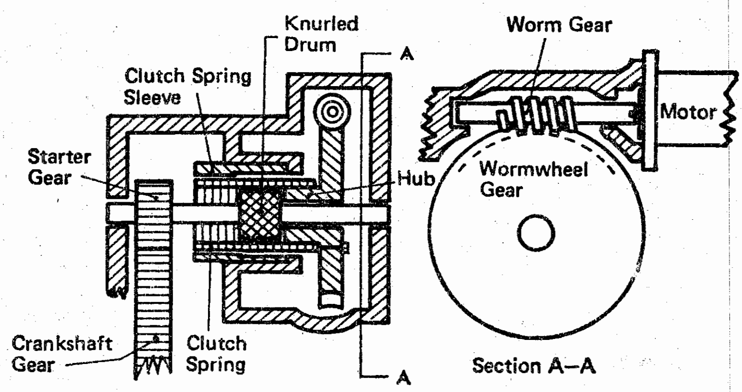
(A) MANUAL ENGAGEMENT



(B) SOLENOID ENGAGEMENT



(C) BENDIX DRIVE



(D) SPRING CLUTCH DRIVE

9.3 Figure 5 (c) illustrates a method of automatic engagement of the starter known as a Bendix drive. The head is keyed to the armature shaft and the drive spring transmits torque to the drive shaft and pinion assembly. The pinion runs on helical splines on the drive shaft, and is normally held out of engagement with the starter gear ring by an anti-drift spring. When electrical power is applied to the motor the armature turns, and because of its inertia the pinion moves axially along the drive shaft into engagement with the starter gear ring, and turns the engine. When the engine starts, the pinion rotates faster than the starter drive shaft and is forced back along the helical splines out of engagement with the starter gear ring. When electrical power to the motor is cut off, the anti-drift spring holds the pinion in the disengaged position.

9.4 Figure 5 (d) illustrates the use of a worm gear and clutch to transmit starter-motor torque to the crankshaft. A tang on the end of the armature shaft engages a slot in the worm gear shaft, which rotates the wormwheel. As the wormwheel turns, a clutch spring mounted on its hub is tightened to grip a knurled drum on the starter gear shaft and transmits torque to a gear on the end of the crankshaft. When the engine starts and the starter gear shaft rotates faster than the wormwheel drum, the clutch spring returns to its normal position and disengages the knurled drum from the wormwheel.

10 OIL COOLERS Except for some small engines which have wet sump systems and others which have the oil tank located in the slipstream, most engines are fitted with a cooler to remove excess heat from the engine lubricating oil. In an oil cooler the oil is passed through a block of finned tubes, which present a large surface area to the cooling airflow. With horizontally-opposed engines the cooler is usually located at the front or the rear of the engine, and is cooled by the airstream. Front-mounted coolers are cooled directly by air entering the engine cowling, whilst rear-mounted coolers are cooled by air passing through an aperture in the rear cylinder cooling baffle; in some cases the airflow may be reduced by fitting a blanking plate to the cooler, so as to prevent over-cooling during cold weather.

10.1 Most oil coolers are fitted with a thermostatically-controlled by-pass valve, which regulates oil temperature within specified limits. When the oil is cold the valve blocks flow through the oil cooler and all oil flows directly to the engine. When the oil reaches a temperature high enough to require cooling, the valve begins to open the passage through the cooler and close the by-pass, thus reducing the temperature of the oil delivered to the engine.

11 ENGINE REMOVAL AND INSTALLATION There are many reasons why an engine may have to be removed from an aircraft and replaced by a new or overhauled engine. These may include expiry of the prescribed life of the engine, failure of bearings or other internal components, shock loading of the propeller shaft, and excessive vibration not attributable to propeller unbalance. The procedures which should normally be followed when removing and installing an engine are outlined in paragraph 11.1 to 11.5, but particular installations may demand additional operations and reference should always be made to the relevant Maintenance Manual.

11.1 The method adopted when changing an engine depends on the type of engine and the requirements of the particular operator. With most light aircraft the bare engine is changed, transferring accessories from the old engine to the replacement as appropriate, but some commercial operators prefer to hold one or more 'quick engine change assemblies' (QECA) in stock, to minimize the time the aircraft is out of service. A QECA generally consists of an engine complete with accessories, baffles, cowlings and mounting structure, which has the minimum number of attachments to the aircraft and which can be removed and installed in a few hours. The use of a QECA is generally confined to large radial engines, and the aircraft structure must be specially designed to be compatible with them. Paragraphs 11.2 to 11.5 apply mainly to changing a bare engine but the precautions and tests may also be applicable to a QECA.

11.2 **Removal of Engine from Airframe.** Before commencing to remove an engine from an aircraft, all electrical supplies to the engine should be disconnected (preferably by removing the batteries) and the fuel supply to the engine should be turned off. A crane or lifting tackle, and an engine sling of adequate capacity and of the correct design should be available for lifting the engine, and should be inspected for serviceability before use. Drip trays should be placed under the engine, and suitable receptacles made available to catch draining fluids. The main undercarriage wheels should be chocked front and rear to prevent the aircraft from moving, and, on aircraft with a nosewheel landing gear, it may be necessary to support the rear fuselage at the rear jacking or trestling point, to prevent the aircraft from tipping on its tail when the engine is removed. Aircraft with a tailwheel landing gear should be placed in the rigging position. The propeller should then be removed and the propeller shaft fitted with a blanking sleeve; if the propeller is to be fitted on the replacement engine it should be inspected for damage and corrosion, placed in a suitable rack or stand, and protected from dust or other foreign matter, but if it is to be sent for repair or overhaul it should be prepared for storage (Leaflet **PL/1-1**). In order to remove the engine, the operations listed in paragraphs 11.2.1 to 11.2.8 should normally be carried out.

11.2.1 The engine cowlings should be removed to gain access to the engine disconnection points, and should be inspected for cracks, dents and other damage, and the security and operation of the fasteners.

11.2.2 All lubricating oil should be drained from the engine, oil cooler and oil tank, and the drain plugs refitted.

11.2.3 All engine controls should be disconnected at the engine end, the attaching parts refitted to prevent their being lost, and the control runs secured to adjacent structure to prevent damage when the engine is changed.

11.2.4 Disconnection of electrical cables is usually made at the engine components concerned, such as the starter, generator, or magneto, and the end connectors should be covered with moistureproof tape to protect them from dirt and moisture; cable ends should be identified to assist reconnection and loose cables should be temporarily secured to adjacent structure to protect them from damage. On some engines the electrical cables are disconnected at plug and socket assemblies or junction boxes on the fireproof bulkhead, and are removed with the engine; these connections should be protected by blanking until the replacement engine is installed.

NOTE: The magneto lead earths the magneto primary circuit through the associated cabin switch. Without this lead the magneto is live, and as a safety precaution the sparking plug leads should be removed before the earth lead is disconnected.

11.2.5 Various types of pipe connections are used on the system pipes running between the engine and the airframe. Flexible pipes with union nuts are generally used to connect the engine component concerned to a fitting on the fireproof bulkhead, so as to take up engine vibration; in some cases self-sealing bulkhead couplings (Leaflet **BL/6-15**) are used, to prevent the system from losing fluid when the disconnection is made, and to minimize the need for bleeding when the system is reconnected. In other systems hose connections are used to join pipelines which are not subject to high internal pressures. Pipes should be disconnected and, where applicable, drained of fluid, then blanked to prevent the entrance of extraneous matter, and temporarily tied out of the way of the engine.

11.2.6 Other disconnection points will depend on the engine installation, and may include intake ducts and exhaust pipes, heater pipes, priming pipes, drain pipes and tachometer flexible cables. In addition, some engines may be fitted with temperature bulbs and pressure transmitters in the oil system, which are connected by capillary tubing to the associated cabin instruments. When removing these connections from the engine, care should be taken to bend or twist the capillaries as little as possible, and they should only be moved sufficiently to prevent fouling the engine when it is removed. In some cases it may also be necessary to remove the carburettor in order to clear the engine mounting; in these cases the engine intake manifold should be blanked as soon as the carburettor is removed.

11.2.7 When all controls, pipes and cables between the engine and airframe have been disconnected and secured clear of the engine, the engine sling should be attached to the engine lifting points, and the crane should be positioned and attached to the sling. The engine should then be lifted just sufficiently to remove its weight from the bearers, and the bearer bolts should be removed after checking that they are free to rotate and are not taking any strain. Depending on the type of mounting, the engine should be lifted or moved slowly away from the mounting, and guided clear of the airframe structure. Once clear, the engine should be lowered into an engine stand and prepared for storage (Leaflet **EL/3-14**).

11.2.8 If the engine is being changed because of internal failure, the lubricating oil may have become contaminated. Accessories lubricated by engine oil, such as a variable-pitch propeller and propeller governor, and the oil cooler, should also be sent for overhaul. The oil tank and pipelines remaining in the airframe, should be removed and thoroughly flushed before being connected to the replacement engine.

11.2.9 With the engine removed from the engine bay, the mounting frame and other fixed parts are readily accessible for inspection and should be checked for corrosion, scratches, dents and other damage, which should be made good before the replacement engine is installed. Similarly, the opportunity should be taken to visually inspect all pipes, cables, controls, fire detection and extinguishing equipment, and other components in the engine bay, for security, corrosion and damage, and to repair or renew parts as necessary.

NOTE: If one anti-vibration mounting has been found unserviceable, it is advisable to consider changing the whole set, otherwise the effectiveness of vibration damping may be reduced.

11.3 **Preparation of Replacement Engine.** An engine required for installation in an aircraft should be removed from its packing case, mounted in an engine stand, and built up to the standard required for the particular installation.

11.3.1 External corrosion-preventative compound should be washed off as necessary, at the same time ensuring that any breather orifices in such accessories as magnetos and injectors remain unobstructed. The engine should be inspected for signs of corrosion and damage, which may have occurred during storage or transit. The dehydrator plugs should be removed from the cylinders, and a careful inspection for corrosion should be made in any cylinders in which these plugs indicate, by their colour, the presence of moisture. Internal inhibiting oil should be drained out through the sparking plug holes, the crankshaft being turned several revolutions while the oil is draining. Any excess oil in the cylinders (particularly the lower cylinders of a radial engine) should be removed with a syringe. Unless suitable for engine running, the inhibiting oil should be drained from the crankcase and sump by removing the sump drain plug, and the oil filters should be removed and cleaned in solvent. When draining is completed the dehydrator plugs or dummy sparking plugs should be temporarily replaced to prevent the ingress of foreign matter, and the sump drain plug and filters should be refitted and locked as appropriate.

11.3.2 Blanking plates should be removed from the mounting faces provided for any accessories which have to be fitted, and the faces should be inspected for corrosion and damage. In some cases engine accessories (such as the carburettor) may have been removed from the engine and packed separately in the engine packing case; these should be inspected for corrosion and damage, and fitted on the engine, or, if this is not possible, retained in their cartons until the engine has been installed in the airframe. In other cases (except as noted in paragraph 11.2.8 and provided sufficient hours remain), accessories may have to be transferred from the old engine; these should be inspected for damage and excessive wear, and, where appropriate, the operating times should be recorded in the engine log book. When installing accessories, new gaskets or seals should be used where appropriate, and the attaching parts should be tightened and locked as specified in the relevant Maintenance Manual. Care should be taken to remove any silica gel bags which have been used during storage, particularly those which may have been placed in the air intake passage.

11.4 **Installation of Engine.** When the engine bay has been cleaned and inspected, and any necessary repairs or replacements have been carried out, the engine should be attached to the sling and crane, and carefully lifted out of the engine stand and moved into its mounting position in the airframe. The engine must be steadied whilst being moved, and must be guided past any obstructions, to mate with the bearers and other connections such as the exhaust tail pipe. The correct anti-vibration mountings should be assembled at each position on the mounting frame, and the engine should be accurately aligned with the mountings, so that the bearer bolts slide in easily; the bolts should then be tightened in the sequence and to the torque values specified by the manufacturer, and locked in the appropriate manner. The engine sling may then be removed and, where appropriate, bonding strips fitted across the mountings.

11.4.1 The sequence for connecting the pipes, ducts, controls and cables to the engine may not be important, but the quickest and most satisfactory sequence will normally be given in the relevant Maintenance Manual. The general precautions which should be taken when making these connections are outlined in paragraphs 11.4.2 to 11.4.8.

11.4.2 Carburettor controls should be connected and adjusted as outlined in Leaflet **EL/1-2**, and the propeller control should be connected as outlined in Leaflet **PL/1-1**; they should be checked, locked and lubricated as appropriate. Other controls, such as those for the hot-air intake and cabin heater, should be connected so that the flap or valve position corresponds to the position of the operating lever in the cabin, closes and opens fully, and operates smoothly.

11.4.3 Electrical connections should be clean before assembly, and must be effectively locked, and the associated cable or conduit should have sufficient slack to allow for engine vibration. Sparking plugs should be installed, with new washers, and the plug leads connected. The magneto earth leads should be connected after ensuring that the ignition switches are in the off position.

11.4.4 The exhaust system should be connected using the correct type of nuts or clamps, and new gaskets should be fitted to the cylinder exhaust flanges. Where ball or expansion joints are fitted, these should be adjusted to the dimensions specified in the relevant Maintenance Manual, so as to prevent gas leakage or binding when the pipes expand during engine operation; the joints should be lubricated with graphite grease when specified. If the exhaust piping from the old engine is being re-used, it should be inspected for cracks, dents, pinholes and other damage, and attaching parts should be checked for serviceability.

11.4.5 Before connecting flexible pipes with threaded end-fittings to the engine, the blanks should be removed and the threads should be inspected for cleanliness and condition; the routeing of the pipes should be as originally fitted and should enable the pipes to retain their natural shape. System fluid or engine oil, as appropriate, may be used to lubricate the threads of the end fittings prior to assembly. Care must be taken not to twist a flexible pipe, and the hexagon on the fixed end fitting should be used to hold the pipe whilst the nut is tightened. Low-pressure hose should be inspected for damage, particularly at the positions where the hose clips are fitted, and should not be twisted when it is fitted; the hose clips should be checked for smooth operation.

11.4.6 When a hydraulic pump is refitted, it will need to be bled before starting the engine. This is normally carried out by pressurizing the reservoir (Leaflet **AL/3-21**) and opening the pump bleed valves until bubble-free fluid is discharged. The reservoir should then be topped-up and re-pressurized as necessary.

11.4.7 Before connecting the intake duct to the engine, the intake filter should be cleaned (Leaflet **EL/1-2**) and the duct should be inspected for cleanliness and freedom from foreign objects. It is important that there are no leaks in the intake ducting, and the seals fitted at the filter, hot-air flap and carburettor flange should be checked for effectiveness.

11.4.8 The aircraft Maintenance Manual may specify a clearance between the fixed structure in the engine bay and the engine, or parts attached to the engine. This clearance should be checked and any adjustments necessary should be carried out, but the re-routeing of pipes, hoses, controls and cables should be carefully controlled, and must not restrict movement caused by engine vibration, place a strain on connections or supports, or result in further chafing.

11.4.9 When the engine has been completely installed, the oil tank (or sump) should be filled with clean oil, the aircraft batteries should be reconnected, the carburettor or injector should be flushed and bled (Leaflet **EL/1-2**), and the propeller should be refitted (Leaflet **PL/1-1**). The lubricating system should then be primed in preparation for ground running, and the cowlings should be refitted.

NOTE: If a new propeller is being fitted it will be necessary to check that it is the correct type (Airworthiness Notice No. 4) and that, in the case of a variable pitch propeller, the fine and coarse pitch stops are correctly set (see relevant aircraft data sheets).

(a) The method of priming the oil system varies between different engines, but basically the aim is to ensure that all bearing surfaces have a film of oil on them when the engine is started for the first time. A priming rig is connected to the inlet side of the oil system, either by disconnecting a pipeline or by using the oil pressure gauge transmitter union, and oil (preferably hot) is pumped through the engine under pressure, using the pump or pressurized container on the rig. The sump drain plug is usually removed in order to drain off the oil which has passed through the engine, and it is usually recommended that the engine is turned by hand whilst priming is being carried out. The engine should normally be run within four hours after priming the oil system.

11.5 **Engine Testing.** Before starting an engine the cowlings should be fitted, the aircraft should be faced into wind and securely chocked, the brakes should be applied, and suitable fire extinguishers should be made available. When starting a new engine it is advisable to use an external power supply rather than the aircraft batteries, and this should be connected to the aircraft. The method of starting will vary according to the type of carburettor and the engine installation, and the procedure recommended by the aircraft manufacturer should be followed. Engine speed should be kept as low as possible until the oil pressure has built up to a prescribed value in a given time. If the minimum oil pressure is not achieved within the specified time the engine must be stopped and the cause determined. The engine should then be warmed up until the recommended minimum cylinder and oil temperatures are reached. At this power setting the magnetos should be checked for a dead cut (by momentarily switching off both magnetos), then the engine should be stopped and inspected for fuel and oil leaks. The engine cowlings should then be refitted, the engine started, and the following checks carried out as appropriate and in accordance with the manufacturer's instructions.

(a) Exercise the propeller several times by operation of the pitch control lever, to ensure that it is filled with oil and is operating properly.

(b) Check the operation of the magnetos at the recommended power settings.

(c) Carry out an engine power check (Leaflet **EL/3-15**).

(d) Open up to full power and check the maximum engine speed. Correct by means of the constant speed unit adjustment as necessary.

(e) Check the carburation over the full power range (Leaflet **EL/1-2**).

(f) Check operation of the supercharger (Leaflet **EL/1-3**).

(g) Check operation of all engine-operated systems. This may include checking battery-charging rate, hydraulic pressure and system operation, pneumatic pressure and system operation, vacuum pressure, and operation of the instruments and de-icing boots. The maintenance of the correct fuel pressure over the full power range should also be checked, to ensure correct operation of the engine-driven pump.

(h) Close the throttle and check the idling speed and mixture strength (Leaflet **EL/1-2**).

(j) Cool the engine by running it at approximately 1000 rev/min for a short period, or until the cylinder head temperature is within limits, then close it down.

NOTE: Prolonged ground running at high power settings must be avoided, since the cylinders are not adequately cooled when the aircraft is stationary.

11.5.1 After the ground run, the engine should be inspected for gas, fuel or oil leaks, and any adjustments found necessary during the run should be carried out. It will usually also be found necessary to replenish the oil system, since some of the oil from the tank will now occupy the sump and pipelines.

11.5.2 The results of the engine run, including the manifold pressure and engine speed obtained during the power check, and the drop in engine speed obtained during the magneto checks, together with any adjustments carried out, should be recorded in the engine log book.

12 ROUTINE MAINTENANCE In order to guard against malfunction or failure of an engine and its associated equipment, a programme of inspection and maintenance is carried out in accordance with a schedule approved by the CAA. The engine and component manufacturers stipulate the work which should be carried out to maintain their particular products in a satisfactory condition, and the combined inspection and maintenance requirements for the complete engine installation are included in the Maintenance Schedule for the particular aircraft. The bulk of the items will normally be repeated at intervals of 100 flying hours, but some items may be carried out more frequently and some less frequently. The following paragraphs indicate the work required for a typical light-aircraft engine installation.

12.1 **Lifed Items.** The engine itself must be removed for overhaul after a specified number of flying hours (see Airworthiness Notice No. 35), the time depending on its proven reliability; a new type of engine normally has an initial overhaul life which is capable of being extended as experience is gained during its operation. Some components (such as the alternator) may also have to be removed for overhaul after a specified time, but these "lives" are usually arranged to coincide with the engine life. Other components may have to be replaced at more frequent intervals, depending on their condition.

12.2 **General Condition of Engine.** The general condition of an engine should be checked after each routine inspection, by carrying out an engine run as outlined in paragraph 11.5. At less frequent intervals a compression check should be carried out on all cylinders, to determine the condition of the cylinders, pistons and valves. Various methods of carrying out this check are outlined in Leaflet **EL/3-15,** but the particular manufacturer's recommendations should be followed. If any particular cylinder shows excessive loss of compression, that cylinder should be replaced with a serviceable component; it is not normally necessary to change the engine because of cylinder unserviceability.

12.3 **Basic Engine.** The crankcase, sump and reduction gear casing, should be inspected for damage, cracks, corrosion and oil leaks, and the security and locking of attaching parts. The cylinders should be checked for damaged fins, corrosion, cracks, security and locking of attaching parts, oil leaks at the cylinder base, rocker covers, and push-rod covers, and gas leaks at the barrel/head joint and at the inlet and exhaust pipe flanges. Any apparent gas/oil leaks at the barrel/head joints should be checked carefully, to ensure that they result from oil seepage and are not the beginning of barrel/head separation. Any damaged paintwork should be repaired according to the manufacturer's instructions, and oil leaks should be rectified as appropriate.

12.4 **Cowlings and Baffles.** Cowlings should be cleaned and checked for cracks, distortion, condition of any rubbing strips attached to them, and loose or unserviceable fasteners. The interior of the cowlings should be inspected for evidence of chafing against engine structure, accessories or baffles; the cowlings should be repaired as necessary, and adjustments should be made to the chafing parts, to provide clearance. Baffles should be checked for cracks, security, and condition of any sealing strips attached to them. Cracks may normally be repaired by welding or patching, but temporary repairs may be effected by drilling the ends of the cracks. Fasteners which are not fully effective should be renewed. Paintwork should be made good in accordance with the manufacturer's instructions and the particular paint scheme.

12.5 **Engine Mountings.** The engine mounting framework should be carefully inspected for cracks, corrosion, distortion, and security of attachment to the airframe. The flexible mountings should be inspected for condition and security; some sag may occur during service, and if this reduces the clearance between engine parts and the structure below the minimum figure specified, it is usually permitted to add spacers to restore the clearance. Damage to the mounting frame and paintwork must be repaired.

12.6 **Intake Duct.** The ducting to the carburettor or injector air intake should be inspected for cracks, corrosion and security, and the condition of the seals at the air filter, carburettor, and, where fitted, the hot-air flap (see also Leaflet **EL/1-2**). Any controls provided for filtered air or hot air should be checked for correct operation and for full and free movement, and the connections in the control run should be checked for wear and correct locking. Alternative air flaps which are operated by differential air pressure and are held in position by magnetic catches, should be inspected carefully, as they are more prone to wear and failure, particularly when the magnetic catches lose their effectiveness. The air filter should be cleaned regularly (Leaflet **EL/1-2**).

12.7 **Exhaust System.** Because of its operating environment, cracking and wear of parts of the exhaust system are inevitable, and frequent inspections are usually specified in the relevant Maintenance Schedule. All parts of the exhaust system should be inspected for security, warping, cracks, dents, and evidence of gas leakage, particularly at clips, slip joints, V-clamps, bellows and heater muffs. Damage may often be repairable by welding, but when carrying out such repairs, extreme caution is necessary to maintain the original contour, since any disruption to the smooth flow of exhaust gas will result in a hot spot, and lead to early failure at that point. Renewal of damaged parts is preferable to repair, and new gaskets or seals should always be fitted.

12.7.1 Attention is drawn, in Airworthiness Notice No. 40, to the dangers inherent in the use of heating systems which employ an exhaust heat-exchanger to heat the air entering the cabin. A thorough inspection of these systems should be carried out at the specified intervals and whenever carbon monoxide contamination is suspected. In some cases the heating jacket on the muffler is detachable, and can be completely removed to enable a thorough inspection to be made for signs of leakage from the exhaust section of the muffler. In other cases a pressure test may be recommended, and this is carried out by blanking the outlet from the heater jacket and applying air pressure through the inlet; with the air supply shut off, there should be no leakage from the heater jacket.

12.8 **Oil System.** Internal lubrication of the engine is of vital importance, and the oil quantity should be checked daily or prior to each flight. Oil should be changed regularly (usually at 50 or 100 hour intervals) by draining the sump and tank (preferably when the oil is hot) and refilling the system with new oil to the correct specification. Oil screens (wire-mesh filters) should be cleaned and filter elements changed at the specified intervals, but on removal should be inspected for the presence of metal particles, which would indicate internal failure in the engine. The oil-cooler air passages should be checked for blockage and cleaned as necessary, and all parts of the oil system should be checked for cracks, security, chafing, leaks and damage during the routine inspection.

12.9 **Engine Fuel System.** The fuel system in the engine bay, including flexible pipes, injector distribution pipes, carburettor, pump, and filter, should be checked for leakage under pressure, and should be inspected for security, chafing and damage; some engine fuel components also have tell-tale drains from shafts, seals and diaphragms which facilitate checks for internal failure.

12.9.1 The main fuel filter should be drained before flight, daily, or after refuelling, as specified in the relevant Maintenance Schedule, in order to remove sediment and to drain off any water which may have accumulated. A small amount of water will often be removed from the filter or tank drains, but if the amount is excessive the fuel system should be checked as outlined in Leaflet **AL/3-17.**

12.9.2 All filters associated with the fuel system should be removed and cleaned at the specified intervals, and when required by unsatisfactory engine operation. Fuel filters should be cleaned by washing in solvent and blowing dry with compressed air, but the air filters fitted to injector nozzles may not be detachable and are often cleaned with the nozzle, by ultrasonic methods.

12.9.3 Throttle and mixture controls should be checked for full and free movement, for correct locking, and for signs of play or lost motion resulting from excessive wear.

12.9.4 Operation of the engine fuel system should be checked during engine runs. Any adjustments found to be necessary should be carried out (Leaflet **EL/1-2**).

12.10 **Electrical System.** All major components in the electrical system should be checked for condition and security. The generator and starter brushes should be checked for wear, their bearings for play, and their connections for security and locking as appropriate; the alternator drive belt, where fitted, should be checked for condition and tension. The magneto timing and contact breaker gap should be checked and the cam pad should be lubricated (Leaflet **EL/3-9**). Ignition switch leads should be checked for condition and security (Leaflet **EL/5-2**), and the sparking plugs should be removed, cleaned and tested (Leaflet **EL/5-1**). All wiring harnesses and conduits should be checked for security and condition.

12.11 **Pipes.** Rigid pipes should be inspected for security of attachment to the airframe or engine, for cracks, dents, corrosion and chafing, and for signs of leakage. Bonding strips fitted across hose joining rigid pipes should be checked for condition and security. All flexible hoses should be inspected for deterioration, kinks, chafing, security and correct installation, without twists or unnecessary bends. The life of flexible hoses should also be checked, and they must be rejected at the end of this time regardless of their apparent condition. Firesleeves such as are fitted to flexible fuel and oil hoses, should be checked for deterioration, and should be renewed if they are cut, chafed or frayed, or have become impregnated with fuel or oil.

NOTE: Further information on flexible hoses is contained in Leaflet **AL/3-13.**

12.12 **Lubrication.** A diagram is provided in most light-aircraft Maintenance Manuals, indicating the method and frequency of lubrication of various parts of the aircraft, and the types of lubricant to be used. As far as the engine installation is concerned, lubrication is generally confined to the application of oil or grease to the various working parts. These include the lever pivots, rod ends and bearings in the throttle, mixture, air filter, and cabin-heat control linkages, and the links and hinges on filter doors, hot-air intake doors, and cooling-air exit flaps. In addition, the rocker covers of some inverted engines may need filling with engine oil, whilst the rocker bearings of some radial engines may require lubrication by means of a grease gun. Dirt, grit and old lubricant should be wiped off before applying the new oil or grease, and any excess should be removed.

12.13 **Fireproof Bulkhead.** Damage to a fireproof bulkhead, or ineffective sealing of pipes, mounting structure or controls passing through the bulkhead, could result in exhaust fumes passing into the wing or fuselage, and in the case of an engine fire, in the spreading of the fire to the airframe structure, with possible catastrophic results. The fireproof bulkhead should be examined very carefully for cracks and other damage, and for signs of ineffectiveness of the seals or sealing compound used; any faults should be corrected in accordance with the relevant Maintenance Manual.

13 NON-ROUTINE INSPECTIONS Operating limitations on the rotational speed and manifold pressure of an engine are imposed to ensure that the engine is operated within design parameters. There are times, however, when these limitations may be exceeded, through either a mechanical fault or mishandling, and the engine must be inspected to determine whether it is still satisfactory for continued operation. The inspections necessary following overspeeding or overboosting of the engine, and also after a shock-loading of the engine, are included in paragraphs 13.1 to 13.3. The inspections which are required following a lightning strike or static discharge damage are included in Leaflet **AL/7-1.**

13.1 **Overspeeding.** Operation at engine speeds higher than the rated speed (or take-off engine speed when this is specified), can cause rapid wear of highly-stressed parts, and, if the speed is high enough, serious damage or failure can occur. The inspections required by the engine manufacturer are normally contained in the Maintenance Manual or in Service Bulletins, but the inspections outlined in paragraphs 13.1.1 to 13.1.4 are typical of those required on light-aircraft engines.

13.1.1 **Momentary Overspeed up to 2%.** No special inspections are normally required for a momentary overspeed of 2% of the rated engine speed, but the cause should be determined and corrected, and an entry should be made in the engine log book.

13.1.2 **Overspeeding up to 5%.** The following inspections should be carried out following an overspeed of up to 5% of rated speed, and if satisfactory the engine may be returned to service.

(a) Drain all oil from the engine lubrication system, remove all filters and inspect for metal particles.

(b) Carry out a cylinder compression check (Leaflet **EL/3-15**).

(c) Using a suitable inspection instrument (e.g. a borescope), examine the cylinder walls for scoring, which may have been caused by broken piston rings.

13.1.3 **Overspeeding between 5% and 10%.** Repeated momentary overspeeds or short periods of operation at 5% to 10% higher than rated speed may produce excessive wear in the valve train. A routine 100 hour inspection should be carried out, and the following checks should also be made. Any parts which are found to be unserviceable must be renewed before the engine is returned to service.

(a) Check all filters for metal particles.

(b) Using a suitable inspection instrument, examine the cylinder walls for scoring, and the valves and seats for distortion or damage.

(c) Examine the rockers, valves, valve guides and springs for condition.

(d) Rotate the engine by hand to check the full and free movement of all parts in the valve train.

(e) On a turbocharged engine, inspect the turbine wheel and compressor for damage, and the bearings for excessive wear (Leaflet **EL/1-3**).

13.1.4 **Overspeed higher than 10%.** Any overspeed in excess of 10% above rated speed will require removal of the engine for overhaul in accordance with the manufacturer's instructions.

13.2 **Overboosting.** On a supercharged engine, overboosting is possible through a mechanical fault (in the control system) or through mishandling, and may result in excessive pressures in the cylinders and overstressing of the working parts of the engine. The inspections which are generally required by engine manufacturers, following overboosting, are outlined in paragraphs 13.2.1 to 13.2.3.

13.2.1 **Overboosting not exceeding 2 inHg (1 lbf/in²).** A momentary overboost which does not exceed 2 inHg does not require any special inspections, but the cause should be determined and corrected, and the relevant details should be entered in the engine log book.

13.2.2 **Overboosting not exceeding 5 inHg (2½ lbf/in²).** An overboost not exceeding 5 inHg which is of short duration (i.e. less than 10 seconds) will require a routine 50 hour inspection to be carried out, and the following checks to be made. Provided that no damage is found, the engine may be returned to service.

(a) Inspect cylinders for cracks around base flange, the sparking plug holes and in the head.

(b) Examine oil filters for metal particles.

(c) Inspect sparking plugs for cracks, and for loose or damaged electrodes.

13.2.3 **Overboosting exceeding 5 inHg (2½ lbf/in²).** If the overboosting exceeds 5 inHg, or is of long duration, the engine must be removed from the aircraft, and overhauled in accordance with the manufacturer's instructions.

13.3 **Shock-loading.** When sudden stoppage of an engine occurs, through, for example, the propeller striking the ground, damage to the engine is likely to occur. The extent of the damage is very difficult to assess, however, and may bear no relationship to engine speed or to the forward speed of the aircraft; damage is most likely to be incurred by the propeller shaft, the engine bearers, the crankshaft counterweights and the crankcase bearing webs. The propeller shaft and engine bearers can be examined for damage, and a limited inspection of the internal parts of an engine can be made by removing one or more cylinders, but satisfactory crack detection is not possible with the engine assembled. Most manufacturers, therefore, recommend that any incident of sudden engine stoppage is sufficient to warrant removal of the engine for complete disassembly and inspection.

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AIRCRAFT

ENGINES

PISTON ENGINE OVERHAUL—DISMANTLING, CLEANING AND CRACK DETECTION

1 INTRODUCTION

1.1 This Leaflet is the first of a series on piston engine overhaul; it gives general guidance on the preliminary stages of overhaul and on methods of crack detection suitable for various engine components. It should be read in conjunction with the other Leaflets of the series and the appropriate Overhaul Manuals. Reference should also be made to the manufacturer's technical instructions for details of all modifications and special inspections applicable at overhaul, bearing in mind that the overhaul lives of engines depend to a great extent on the modification standard to which they are rebuilt.

1.2 The series deals mainly with the overhaul of low-power, air-cooled engines but does not aim to provide a complete guide to those engaged on this work. The procedures and practices for the overhaul of such engines are well established, but the purpose of the Leaflets is to draw the attention of individual engineers to a number of important points rather than to restate this practice in full. The series includes those parts of British Civil Airworthiness Requirements which are relevant to the overhaul of piston engines and explains how overhauled engines should be tested to comply with the Requirements.

1.3 The rest of the series consists of Leaflet **EL/3-2,** which covers top overhaul and gives the CAA's recommendations for testing after top overhaul; Leaflet **EL/3-3** dealing with inspection during complete overhaul; Leaflet **EL/3-4** dealing with inspection during engine assembly, and Leaflets **EL/3-5** to **EL/3-8** which cover engine testing after complete overhaul. Ignition equipment is covered in Leaflets **EL/3-9, EL/5-1** and **EL/5-3,** and the general principles of operation, construction, and maintenance of typical aircraft piston engines are covered in Leaflets **EL/1-1** to **EL/1-4.**

2 EQUIPMENT Engine overhaul should not be attempted unless the equipment and workshop facilities available are adequate. Special tools, rigs and stands are required for each engine type, and an accurate surface table and a full range of precision measuring instruments are essential. For the non-destructive examination of engine parts, electro-magnetic flaw detection equipment is required in the case of ferrous materials, and provision for making oil and chalk or penetrant dye checks is required in the case of light alloys.

2.1 Precision equipment, such as the surface table, micrometers, vernier calipers and plug gauges, should be treated with care. They should be checked periodically to ensure that their accuracy is within the limits specified in the relevant specifications of the British Standards Institution. Each item should have a history card on which a record of each check is entered.

2.2 When doubt exists regarding the condition of an engine part, it may be desirable to subject it to a more searching examination for concealed flaws than is possible with normal workshop equipment. In this case it should either be referred to an approved test laboratory for examination by X-ray, ultrasonic or surface hardness tests or the part should be renewed.

3 **INSPECTION RECORDS** During overhaul work a systematic and methodica inspection of all the parts removed should be made and a record of the condition and, where applicable, the dimensions of all parts examined at each stage of the inspection should be entered on an Inspection Report.

3.1 Before dismantling an engine, the log book should be checked so that speclal attention can be given to items which may have caused defects. The total running times of "lifed" components should also be checked and replacements should be obtained for components which have completed their approved running lives.

3.2 During the inspection, all items should be classified into one of three categories—serviceable, repairable or scrap. Scrap parts should be clearly marked with red paint or should be destroyed to prevent further use. All parts affected by modification action should be clearly labelled and segregated for appropriate attention.

3.3 A record should be kept of all rectifications made during the overhaul. If the nature of the work is such that it affects the fits and clearances of the assembled engine, a special note should be made to recheck the clearances at the final assembly. The renewal of bushes which affect the meshing of gears is a typical case.

3.4 All fits and clearances should be recorded and checked against the schedule given in the manufacturer's manual. The schedule usually gives the data under four headings:

(a) "Dimensions New" are the drawing sizes to which the parts are made.

(b) "Permissible Worn Dimensions" indicate the limits to which parts may be worn and yet be refitted for a further period of service. However, it may be found that some manufacturers use the term in a different sense and advise renewing all parts found to be worn to dimensions described under this heading.

(c) "Clearance New" gives the minimum and maximum working clearance obtainable with new parts when assembled.

(d) "Permissible Worn Clearance" is the limit of working clearance permissible between any two parts assembled together.

NOTE: Parts which are not worn beyond permissible limits may nevertheless cause permissible worn clearances to be exceeded when the parts are assembled.

4 **INSPECTION BEFORE DISMANTLING** Before the commencement of dismantling and cleaning, engines received for overhaul should be examined externally and a preliminary inspection report should be prepared. Inspection at this stage provides an opportunity of discovering defects that might be obscured by subsequent cleaning.

4.1 The general external examination for condition should be made with the engine secured to the correct type of stand, except where a top overhaul is to be made without removing the engine from the airframe. Evidence of oil leaks should be investigated; any oil seepage should be traced to its source. A visual inspection for cracks should be made; cracks, blown joints at cylinder heads, damaged face joints, etc., are often indicated by dark lines and local seepage. The controls should be checked for incorrect operation and for wear and lost movement.

4.2 If any engine apertures are discovered unblanked it should be remembered that foreign matter may have entered the engine. This may cause damage if the engine is turned during dismantling.

4.3 The engine should be drained of oil and the filters should be examined for metal deposits which could be an indication of possible damage to bearings or pistons. When it is required to identify metal particles found in the scavenge filters, they should be washed in ether and filtered on to a clean sheet of blotting paper. With the aid of a strong lens, they should be separated from any carbon particles by the use of tweezers. For their precise identification the following tests can be applied.

4.3.1 A magnet should be used to separate the ferro-magnetic particles from the other metals. The magnet will pick up cast iron, carbon steels, certain alloy steels and some stainless steels, but not austenitic stainless steels, white metal, copper, magnesium or aluminium alloys.

4.3.2 Magnetic particles can be identified by placing a number in a beaker and pouring a small quantity of nitric acid (sp. gr. 1·20) over them. The acid should then be heated to just below its boiling point and held there until the cessation of chemical action. Stainless steel will not be attacked, but the acid will turn yellow or light brown if the particles are of carbon steel and dark brown if they are of cast iron.

4.3.3 If bronzes cannot be picked out by the colour of the copper in them, they too can be identified by a nitric acid test. In this case the acid should be poured on to the particles but should not be heated until the chemical reaction ceases. The acid should then be boiled for 2 to 3 minutes. If a white precipitate is formed, the metal is a bronze.

4.3.4 Other alloys can be identified by their reactions when attacked by particular chemicals. Thus magnesium alloys are violently attacked by saturated copper sulphate solution, aluminium and its alloys by a 20% caustic soda solution (the solution will become clear if the metal is aluminium but a grey or black precipitate will be evident if it is aluminium alloy), whilst white metal will dissolve slowly in nitric acid leaving black particles in a pale green solution.

5 DISMANTLING To avoid damage and distortion to the engine components, it is essential that the correct extractors and special tools are used at each stage of dismantling. As items are removed, they should be placed on properly designed stands or in storage bins and should be identified so that they can be reassembled without difficulty.

5.1 The dismantling sequence in the manufacturer's manual should be followed at all times. Pistons, valves, valve springs and collets should be grouped with their associated cylinders so that the effects of any damage can be traced on all related parts.

5.2 Cylinders can generally be pulled off by hand, but, if they are stiff, wedges should not be driven under the flanges to free the crankcase joint. Alternate rocking and pulling will usually free a cylinder, but, for cylinders with integral heads, a last resort is to place the cylinder in question on compression stroke, fill the combustion chamber with oil and fit dummy plugs. A partial turn of the crankshaft will then free the joint.

5.3 Seized gudgeon pins should not be drifted out but should be withdrawn with a special extractor—if one is provided in the tool kit. If no extractor is available the piston should be expanded by the application of heat. This can be done by wrapping the piston in rags soaked in boiling water or by immersing the piston in a can of hot oil.

5.4 When dismantling radial engines, guard plates should always be fitted as each cylinder is removed. The cylinder containing the master connecting-rod should be removed last to avoid collapse of the connecting-rod assembly. This prevents such faults as:

(a) An oil scraper ring springing out of a cylinder and locking the whole assembly.

(b) The crankshaft balance weights fouling the skirts of the pistons.

(c) The articulating rods damaging the crankcase cylinder sockets.

NOTE: If only the master cylinder is being removed, the master rod should be positioned at Top Dead Centre (TDC) before removing the cylinder and the crankshaft and rod should not be moved again until the cylinder has been replaced.

5.5 When unbolting crankshaft and connecting-rod bearing caps, a check should be made to ensure that they are correctly numbered and precautions should be taken to mark the actual positions of bearing shells in case they are to be used again. At this stage the torque loading of the cap nuts should be checked by first slackening them off and then torque-loading them back to positions that give the same split pin hole alignment. Where the torque required to do this is less than that specified by the engine manufacturer, stretch of the bolt or stud is indicated. After this check, dismantling should proceed with every precaution being taken to avoid damaging the shaft, rods or bearing shells.

6 INSPECTION BEFORE CLEANING All components and parts should be inspected before cleaning, otherwise useful evidence of defects and the behaviour of the engine whilst in service may be removed. Defects of an unusual nature should be reported to the manufacturer and to the CAA.

6.1 Brown or black patches on cylinder walls and piston skirts often indicate piston "blow-by." This is caused by combustion gases leaking past worn piston rings, over-wide piston ring gaps or gaps which are all in alignment.

6.2 Where valve seat inserts are provided, looseness or displacement of the seats is often more readily detected before the cylinder head is cleaned.

6.3 Scores in cylinder walls, on gudgeon pins, shaft journals, crank pins and valve stems can often be traced to poor oil filtration. Gritty substances in the oil become embedded in the softer metal of the pistons and bearings and score the harder material. Evidence of the presence of harmful solids is often found in the oily deposits found inside the hollow crank pins.

6.4 Many small parts such as piston rings, circlips, locking washers, split pins, gaskets and jointing washers are renewed when an engine is overhauled, but, before they are discarded, they may yield evidence regarding the functioning of the particular assemblies with which they were associated.

7 CLEANING Only cleaning agents suitable to the particular materials of the parts to be cleaned should be used. Care is necessary to ensure that no dimensional changes or deterioration of surface finish is caused by cleaning.

7.1 The most satisfactory method of removing oil and grease from most engine parts is trichloroethylene degreasing (Leaflet **BL/6-8**). However, the temperature of the degreasing plant may cause disturbance of shrink-fits, so, unless a keeper can be fitted to prevent this, components incorporating shrink-fitted parts should be cleaned by some other method.

7.2 When trichloroethylene plant is not available or is unsuitable for a particular job, soap solutions or proprietary cleaning agents are recommended. For certain steel and aluminium-alloy components a satisfactory cleaning solution which will remove carbon and sludge as well as grease, can be made up in the following proportions:

Cresol	25 litres	(5½ gallons)
Water	423 litres	(93 gallons)
Hard yellow soap	3·6 kg	(8 lb)

The parts should be soaked in this solution for two hours at a temperature of 55°C to 65°C.

NOTES: (1) Paraffin should only be used to clean components containing parts which may be harmed by the above methods, e.g. white metal bearings.

(2) Certain chlorinated proprietary cleaners give off vapours which are slightly toxic. If they are used, the precautions applicable to trichloroethylene should be taken.

7.3 The use of abrasive materials and wire brushes should generally be avoided. Particles of emery or carborundum are easily trapped in inaccessible corners and may later give trouble when the engine is in service. Sand blasting is sometimes recommended for the removal of old paint from the fins of air-cooled cylinders but should only be used if great care has been taken to exclude the sand from valve ports, plug apertures, etc. The use of chemical paint removers is preferred.

7.4 Hard carbon deposits can be removed using special dry blasting techniques. The most suitable types of grit for dry blasting are plastics pellets or processed natural materials such as crushed fruit pips or shells.

8 INSPECTION AFTER CLEANING The following is a summary of essential points which should be included in the inspection procedure.

8.1 The surface finish of all stressed parts should be examined for such defects as tool marks, sharp corners, pitting, etc., which might provide starting points for fatigue cracks.

8.2 An examination should be made for cracks around such points as mounting feet, flanges or bosses, reinforcing webs, stud and bolt holes, bearing housings and in the vicinity of all stud holes and changes of section. Internal threads and holes drilled through castings can be inspected with the aid of a borescope or similar inspection instrument.

8.3 All studs and bolts should be checked for signs of stretching; they should be straight and their threads should be undamaged. All bolt and stud holes should be undamaged and all studs remaining in position should be checked for tightness. The peening of countersunk locking screws, core-plug dowels, balance weight plugs, etc., should also be checked for effectiveness.

9 CRACK DETECTION To avoid unnecessary work, crack detection tests should be made immediately after cleaning. Whilst each engine component should be inspected for cracks by visual examination, it is nearly always necessary to use a non-destructive aid to ensure that small fatigue cracks are not missed. Information on the various non-destructive flaw detection methods is given in Leaflets **BL/8-1** to **BL/8-8.** This paragraph gives general guidance on the application of crack detection and other processes to the inspection of engine parts, but, since these parts are of widely-differing shapes and materials, the selection of the most suitable crack test is not always easy. On occasions it is advisable to apply two or three different methods to prove that an individual part is free from defects.

9.1 **Crankcases and other Castings.** For castings of aluminium alloy the oil and chalk method of testing (Leaflet **BL/8-1**) is recommended, whilst the fluorescent penetrant method (Leaflet **BL/8-7**) is usually more satisfactory for magnesium alloys. The fluorescent penetrant method will generally give better definition of porosity in castings made from either group of alloys and should therefore be used on all items where detection of porosity is important. For certain components, e.g., cylinder heads and induction elbows, a pressure test may also be specified. The test pressure and method of application should be obtained from the appropriate manufacturer's manuals.

9.2 **Pistons.** Both the oil and chalk method and the fluorescent penetrant method of crack detection are suitable for most pistons but some manufacturers recommend an etch inspection for the skirt and reinforcing ribs. Inspection by etching should be made as follows:

9.2.1 The etching solution should be prepared in the following proportions:

Sulphuric acid	200 c.c.
Sodium Fluoride	28·35g (1 oz)
Water	1800 c.c.

A solution of 50% nitric acid in water is also required to remove the black smut deposited by the etching solution.

NOTE: Whenever dilute acid solutions have to be prepared, the acid should always be added to the water and not vice-versa.

9.2.2 The piston to be tested should be free from grease and carbon. To expand any tiny cracks it should first be immersed in hot water, after which it should be placed with crown downwards and the etching solution should be poured into it. The solution should then be swabbed over the whole of the inside surface of the piston and over the lower rim of the skirt. About four minutes should be allowed for the etching to proceed.

9.2.3 After four minutes the piston should be drained and immediately afterwards should be washed thoroughly in clean running water. The nitric acid solution should then be swabbed over the treated area, after which the washing should be repeated. Finally the piston should be immersed in methylated spirit and dried with warm air.

9.2.4 The piston should then be inspected for cracks, pitting and signs of corrosion, using a powerful magnifying lens or a binocular microscope. Particular attention should be paid to the reinforcement ribs, gudgeon pin bores and piston ring grooves.

9.3 **Steel Parts.** Non-magnetic steels can be tested satisfactorily by either fluorescent or non-fluorescent penetrant dyes, but electro-magnetic crack detection is recommended for all ferro-magnetic parts. In many cases the engine manufacturers specify the electro-magnetic technique and test amperage that should be used to suit the shape and nature of each part to be tested. If guidance on these matters is not included in the manufacturer's manual, the following points should be considered.

9.3.1 Amperages to suit particular parts commonly range from 350 to 1000 depending on the size of the part, but higher amperages are sometimes required to show up specific faults such as grinding cracks. It is often necessary to check individual components at several different amperages to ensure that all flaws are detected.

9.3.2 The majority of shafts and gears should be tested by both the current flow and magnetic flow methods, but the geometry of some items makes them suitable for one method only. Tests should be carried out at different current settings, and using portable cracks and flux detectors, to establish a satisfactory technique for each component (Leaflet **BL/8-5**).

9.3.3 To check small parts in situ and to make local checks on awkwardly shaped parts, it is advantageous to use portable detectors of the semi-permanent magnet type. The manufacturers of these detectors generally supply a white spray for application to the area under test before the magnetic ink is brushed on: the white surface gives a better indication than would otherwise be obtained.

9.3.4 During all electro-magnetic crack detection tests, care is necessary to avoid local burning of the part being examined. Burning can be caused by excessively high current or by local concentration of current due to faulty or unsuitable electrodes. Overheating from these causes does not always leave visible evidence on the surface of the metal, even though its mechanical properties may have been impaired; when this trouble is suspected, the part should be submitted to an approved laboratory for hardness tests on the affected area.

9.3.5 It is essential that all parts be demagnetised at the conclusion of the tests. Neglect of this precaution will cause ferrous swarf to cling to the parts and may affect the reading of the aircraft magnetic compass.

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AIRCRAFT

ENGINES

PISTON ENGINE OVERHAUL—TOP OVERHAUL

1 INTRODUCTION

1.1 This Leaflet is the second of the series dealing with engine overhaul and gives general guidance on the inspection of cylinders, pistons and valve gear during top overhaul and on the testing of small air-cooled engines after top overhaul.

NOTE: Although the leaflet deals primarily with top overhaul, paragraphs 3 to 7 apply equally to inspection during complete overhaul.

1.2 Although top overhaul is not generally specified as a periodic overhaul in the Engine Maintenance Schedule, it is sometimes necessary to remove one or more cylinders in order to rectify particular defects or to maintain the required performance of the engine: the term "top overhaul" is therefore applied in this Leaflet irrespective of the number of cylinders removed.

2 GENERAL It is often unnecessary to remove an engine from its airframe to carry out a top overhaul, although removal may be advisable if accessibility is limited.

2.1 The oil filters should be checked before removing the cylinders and any metal particles found should be identified by the methods described in Leaflet **EL/3-1.** If the origin of such particles is traced to cylinder defects, it may be possible to restore the serviceability of the engine during top overhaul, but if there is evidence that the engine has been damaged by the circulation of metal, it should be completely dismantled.

2.2 If only a limited top overhaul is to be done, it is important to ensure that an accurate diagnosis has been made and that the defective cyclinders have been correctly identified. To this end a compression check on each cylinder is a useful guide, whilst visual inspection of the combustion space, conducted with the aid of suitable optical equipment, may reveal defects to the experienced eye. Cavity viewing instruments (variously known as endoscopes, borescopes or introscopes) can be inserted through the plug apertures; these devices incorporate their own illumination and project a magnified image of the surfaces within their view to an external eyepiece.

3 CYLINDERS Guidance on the removal and dismantling of cylinder assemblies is given in Leaflet **EL/3-1.** After cleaning, cylinders should be inspected for corrosion, broken fins, internal scoring, "ridging," pitting, cracks, signs of overheating and, in the case of internally-chromed bores, for adhesion of the chromium plating.

3.1 If fins are cracked or broken, the manufacturer's repair scheme should be consulted to determine whether the cylinder should be classified as repairable or scrap. If it is repairable, small cracks at the edges of the fins can be arrested by drilling a 1·5 mm ($\frac{1}{16}$ in) diameter hole at the extremity of the crack. Broken edges of fins should be filed smooth and blended into the general contours of the fins after which the total reduction of fin area should be estimated and compared with the maximum reduction permitted by the manufacturer.

3.2 The valve guides should be checked for freedom from scores, tightness of fit, and, using either a slip gauge or an internal micrometer of the retracting anvil type, for wear and ovality. Unserviceable valve guides should be renewed, the extraction of the old guide being made with the correct extractor. Some manufacturers recommend machining away the external portion of the valve guide with a step drill, after which the guide may be withdrawn into the cylinder; this avoids damage to the cylinder if the guide is distorted or burnt inside the cylinder head. The new guide should be pressed into position, a soft metal plug being interposed between the guide and press to avoid damaging the guide. An alternative way of fitting a guide is to use a draw-bolt rig; it is bad practice to attempt to drift a new guide into a cylinder head. The bore of the guide should then be reamed to the specified diameter, the reaming operation being done by a succession of light cuts. Each stage of reaming should be checked by using a 'GO' and 'NO GO' plug gauge.

NOTE: When inserting a new valve guide it is common practice to heat the cylinder head in an oil bath before inserting the guide.

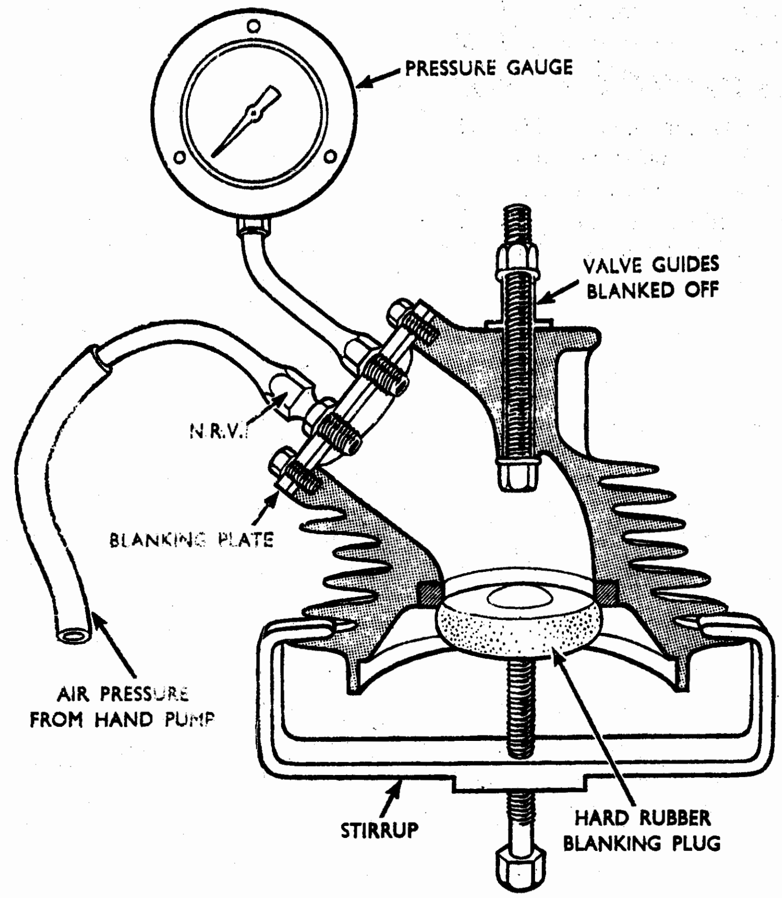


Figure 1 **PRESSURE TESTING VALVE SEAT INSERTS**

3.3 If a new valve guide has been fitted, the corresponding valve seat should be lightly refaced with a cutter or grinder to true it up to the new guide. Valve seats should also be refaced if they show signs of uneven wear, ridges or pitting, although the extent to which this can be done on stellited exhaust valve seats is very limited. After refacing, the valve seat should be checked with the valve-seat gauge provided in the engine tool kit; this gauge usually resembles a poppet valve with four segments cut from the rim. The valve seat has been cut to its maximum permissible limit when the outside diameter of the gauge coincides with the largest diameter of the seat.

NOTE: The action to be taken in the case of over-cut valve seats depends on the type of seat; cylinder heads with inserted valve seats should be returned to the manufacturer for new seats to be fitted, but those with integral seats should be scrapped.

3.4 A pressure test is often specified as a check on the tightness of inserted valve seats. A method of blanking and pressurising a typical cylinder head is illustrated in Figure 1. The valve guide and seat should be plugged to withstand an applied air pressure of 480 to 550 kN/m^2 (70 to 80 lbf/in^2) and, when this pressure has been reached, the head should be immersed in hot water. Leaks will be indicated by bubbles escaping from the joint between the valve seat insert and its housing.

3.5 The sparking plug inserts should be secure and free from signs of excessive burning, pitting or damaged threads. Plug inserts are usually screwed and shrunk in position and are then locked by a dowel. This makes their removal difficult without special facilities, hence manufacturers often advise that cylinder heads with damaged inserts should be returned to them for renewal of the insert. If this procedure cannot be adopted, the dowel should be drilled out and the cylinder head should then be expanded in a can of hot oil before unscrewing the insert.

3.6 The cylinder bore should be checked with an internal micrometer, comparator or cylinder bore gauge for wear, ovality and lack of parallelism. The greatest diameter should be within the permissible worn dimension. The bore should be checked at the thrust and non-thrust faces at the top, centre and bottom of the piston stroke, bearing in mind that some bores are slightly tapered to allow for differential expansion. Whilst honing of the bore is usually adequate to remove light scores or pitting, bores which have worn oval or out of parallel, or which are more seriously scored or pitted, should be reground. After regrinding it is essential to ensure that the maximum permitted diameter of the bore has not been exceeded. Manufacturers often specify one or two stages of regrinding, which usually necessitates the fitment of oversize pistons.

3.7 Detachable cylinder heads should be checked for distortion by placing them on a surface table and, while pressing them down firmly by hand, attempting to insert feelers between the flat on the underside of the head and the table. The spigot joint between the cylinder head and the cylinder barrel should be checked with engineers' marking. Provided it is not outside the permissible limits, a poorly-fitting spigot joint can be trued up by skimming the cylinder head on a lathe or by lapping the head on to an old cylinder barrel. The maximum amount of material that can be removed by skimming is specified by the manufacturer; the removal of more may reduce the volume of the combustion space by an impermissible amount.

4 **VALVES** Valves should be checked for wear, ovality and stretch, for profile (using a profile gauge), for loose or cracked end plugs, and for burned, cracked or distorted valve faces.

4.1 Valves that are bowed, stretched, distorted, excessively scored or which show signs of fretting at the collet grooves should be renewed. If the stem is only lightly scored it is permissible to polish it lightly with fine grade emery cloth, after which its diameter should be measured with a micrometer. Bow of the valve stem is checked by mounting the valve between vee-blocks and positioning a dial test indicator (DTI) so that it contacts the centre of the stem. The valve should then be turned through one revolution and the DTI reading noted.

4.2 To remove pitting from valve faces and to ensure that they are concentric about the axes of the valve stems, valves are normally refaced at overhauls on a refacing grinder. Except in the case of valves which have an included angle difference between the valve face and the valve seat, refaced valves should be lapped to their seats with a fine carborundum powder followed by "Crocus" powder and oil. Valves which have a different angle to their seats should be checked with engineers' marking against the valve face gauge provided in the tool kit.

4.3 After grinding and lapping, the thickness of the valve head should be checked. This is measured from the bottom of the valve head to the lower edge of the valve face, and if it has been reduced beyond the limits quoted in the Schedule of Fits and Clearances the valve must be renewed.

4.4 The valve springs should be inspected for pitting, cracks or chafing. A simple rig should be constructed so that the length of the spring can be measured when the spring is compressed by a specified load. After reassembly, tests to determine the load required to open each valve may also be specified.

4.5 On the completion of all overhaul work on the valve assemblies, they should be reassembled, preferably to the cylinders from which they were removed. Finally, the leak-tightness of the valve seatings should be checked by filling either the valve ports or the combustion space with paraffin and noting that there is no leakage past the valve over a reasonable period.

5 PISTONS This paragraph gives guidance on dimensional checks and the assembly and fitting of piston rings. Crack detection tests on pistons are covered in Leaflet **EL/3-1.**

5.1 Pistons should be carefully inspected for damage to the piston-ring grooves, lands or skirts, and the oil holes should be inspected for cleanliness. The piston skirt should be checked for diameter, ovality and taper, micrometer readings being taken as follows:—

(a) At the top and bottom of the thrust face.
(b) At the top and bottom of the non-thrust face.
(c) At all lands above and between the piston rings.

5.2 The gudgeon-pin diameter should be measured at a number of points along the length of the pin, and the corresponding bores of the pistons should also be measured to determine the clearance of each pin in its bore. The most accurate tool for measuring bore diameters is a pneumatic gauge but if this instrument is not available a slip-gauge is an acceptable alternative. The fit in the small end of the connecting rod should be checked in a similar manner. If the worn dimensions and clearances are within limits, the original pin can be used again but new circlips must be fitted on reassembly. If the wear is beyond the permitted maximum, action should be taken in accordance with the manufacturer's salvage scheme.

5.3 It should be remembered that one or more cylinders may have been ground over-size on previous overhauls, in which case oversize pistons and rings will have been fitted. Since it is customary to renew all rings during overhaul, care must be taken that the correct size rings are fitted to each piston. The ring gaps should be checked by placing the rings in the recommended positions in their respective cylinder bores and squaring them up with their pistons. The gaps can then be checked with feeler gauges or with a 'GO' and 'NO GO' gap gauge. If adjustment is required, the gap can be increased by filing with a smooth file, care being taken to keep the gap square and free from burrs.

5.4 After new piston rings have been correctly gapped to their cylinder bores, they should be fitted to their pistons to check the clearance between the ring and the walls of the ring groove. If this clearance is too small there is danger that expansion of the ring will cause it to break or seize on the cylinder wall. Parallel-sided rings which are over-thick can be reduced by rubbing them on a dead flat surface to which a sheet of fine emery cloth has been fixed, the ring being sprung into a special holding tool with a suitable retaining groove. Tapered piston rings must not be rubbed down in this manner.

5.5 When fitting piston rings it should be ensured that they are all the correct way up (usually with the part number uppermost) and that the gaps are positioned according to the manufacturer's instructions; care should be taken to prevent the corners from scratching the piston. The piston should then be oiled to protect it from corrosion. Although most manufacturers only supply pistons that are within permissible weight tolerances and can therefore be fitted without any special weight precautions, piston weight variations may be critical in the case of a few engine types. When this is the case, the pistons should be weighed carefully and should then be selectively fitted in accordance with the manufacturer's instructions.

6 CONNECTING RODS This paragraph describes the inspection of connecting rods during top overhaul. Tests on connecting rods during complete overhaul are covered in Leaflet EL/3-3.

6.1 The surface condition of connecting rods is of great importance and a careful check should therefore be made for scores, nicks or signs of overheating. On some engines the rods may be checked for bow using a straight-edge and feeler gauges, but in most cases this will not be possible without removing the rods from the engine.

6.2 Using a torch, the external condition of the big ends should be inspected through the crankcase apertures. Top overhaul provides an opportunity for checking the end-float of the big-end bearings, either by inserting feeler gauges or by use of a DTI on the small end; if this is found to be excessive, further investigation is necessary.

7 TAPPETS, PUSH-RODS AND ROCKERS

7.1 Push-rods should be examined for dents, bending or looseness of end fittings, and the ball ends and sockets for wear and fretting. When push-rod springs are fitted, the manufacturers sometimes recommend that checks for spring length and strength be made after reassembly of the valve gear and cylinders. These checks are made with the valves closed but without the push-rod oil tubes fitted. Afterwards the oil tubes, which should be free from dents or cracks, should be assembled with new oil seals fitted at each end.

7.2 Rocker brackets require careful inspection for cracks, the penetrant dye method being recommended. The rocker arms should have been tested for excessive play before they were dismantled, but in any case the bearings and fulcrum pin should be measured to determine the amount of wear. Some manufacturers provide oversize ball bearings which can be fitted if the bore for the rocker bearing is enlarged or, as an alternative means of restoring the fit, allow the bores to be reduced by copper deposition.

7.3 Rocker arms with hardened end pads should be examined for wear of the pads. Light stoning to remove signs of fretting is permissible but badly-worn pads should be renewed. The threads of adjustable ball ends or contact pads should be in good condition. At the final stage of assembly the adjustment should be set to give the specified valve clearances.

8 REASSEMBLY General guidance on the reassembly of piston engines is given in Leaflet EL/3-4 but the following points should be noted before any engines are tested after top overhaul.

8.1 Engines which are not going to be run within seven days after reassembly should be protected against corrosion; guidance on suitable methods of protection is given in Leaflet **EL/3-14.**

8.2 Before any attempt is made to start and run an engine after reassembly, it is essential that warm oil be circulated round the engine to prime the oil-ways and bearings. A priming rig with a built-in heater is recommended for this operation, although the oil can be warmed before it is poured into the priming rig tank. If the engine is not run within three hours of priming, it should be reprimed.

8.3 To avoid hydraulic locking, the crankshaft should be turned through at least two revolutions by hand immediately before the engine is to be started. If there is any abnormal resistance to turning, rotation should not be continued until the lowest spark plug in each cylinder (or, on radial engines, one plug from each of the lowest two cylinders) has been removed.

9 TESTING AFTER TOP OVERHAUL After top overhaul it is essential that ground running tests be made to establish that the engine is functioning correctly and that the performance is satisfactory. The extent of the ground running necessary depends on whether parts have been renewed; if no parts have been renewed or if "run-in" parts only have been used to replace original parts, the ground run procedure should be that normally followed to re-establish the reference rpm. If new parts which have not previously been run-in have been fitted, they should be run-in according to a recognised procedure and the engine power should be assessed by comparing the rpm obtained before and after the top overhaul under corresponding conditions. Instructions for testing piston engines after top overhaul are sometimes, but not always, included in the Overhaul Manual for the engine concerned. When they are not available, e.g., in the case of foreign-built engines, the procedure outlined in paragraphs 9.1 to 9.7 should be used.

9.1 **Conditions of Test.** Testing after parts have been renewed during top overhaul should be done with the engine installed in the airframe, with the flight propeller and all accessories and cowlings fitted, and with the normal complement of engine instruments. If a cylinder head temperature gauge is not part of the installation, one should be provided for the test, the thermocouple being connected to the appropriate stud on what is normally the hottest-running cylinder. Alternatively, if there is no suitable stud, a ring-type thermocouple can be used at one of the sparking-plug positions.

9.2 To obtain the maximum cooling, the aircraft should be headed into wind. Corrections for wind speed are not practicable and therefore ground testing should be avoided as far as possible in conditions of strong wind.

9.3 **Starting and Warming Up.** After taking the normal precautions in regard to chocks, brakes, etc., the engine should be started and warmed up in the usual way. During the warming-up period, particular note should be taken of the oil pressure, cylinder head temperature and (if an oil temperature gauge is provided) the oil temperature; if the temperatures rise rapidly to above the permitted maximum continuous temperatures, or if the oil pressure is incorrect, the engine should be stopped and the cause should be investigated.

9.4 **Running-in Procedure.** When the oil temperature has reached the minimum opening-up temperature specified for the engine type and the oil pressure has stabilised, the engine speed should be increased by uniform increments of rpm over four or five stages. The engine should be run for 5 minutes at each stage, provided there is no overheating. If overheating occurs, it may be necessary to fit an oversize cooling scoop or to substitute a test fan for the flight propeller.

NOTE: If a test fan is fitted to improve cooling during running-in, it must be replaced by the flight propeller before making the power check detailed in paragraph 9.8.

9.5 The magnetos should be tested at each stage of incremental running by switching OFF each magneto in turn. The maximum rpm drop permitted for the engine type may be exceeded during these tests but, provided the drop is not excessive and it is within limits during the subsequent power check, no action need be taken at this point.

NOTE: For certain engine/propeller combinations, there are restrictions on running at particular rpm because of induced vibration. Vibration periods must be avoided by running the engine only at speeds above or below those at which vibration is known to occur.

9.6 When the final stage of incremental running has been reached, usually at about two-thirds throttle opening, the engine should be run for about 15 minutes, subject of course to the engine temperature limitations not being exceeded. If the engine has a variable-pitch propeller, it should be exercised at this stage. When the propeller control lever is moved to the minimum rpm position, a drop in engine speed should occur. Afterwards the lever should be returned to the maximum rpm position to ensure that the propeller blades are against the fine pitch stop, note being taken that the original rpm are restored.

9.7 **Helicopter Engines.** Although the test procedure for engines installed in helicopters is basically the same, the following special provisions apply:

9.7.1 The helicopter must be firmly anchored to the ground, using the holding-down procedure specified in the Service and Instruction Manual for the helicopter concerned. Before starting an engine in a helicopter, the engine should be turned through four or five revolutions on the hand-turning gear to ensure that the rotor clutch is out of engagement and that there is no hydraulic locking.

9.7.2 When warming up the engine, the rotor should be engaged as soon as the oil reaches the minimum permissible temperature for opening up. In the case of helicopters with automatic clutches, this entails opening up the throttle until the engine is driving the rotor. Helicopter engines should be run for as short a time as possible under "no load" conditions.

9.7.3 Before making the power check (paragraph 9.8), collective pitch has to be selected and this means that the helicopter will endeavour to rise and will strain against its tetherings. The fuselage will also have a tendency to rotate in the opposite direction to the rotor and this should be countered by manipulation of the rudder pedals.

9.8 **Power Check and Reference RPM.** The power check is made by running the engine under conditions which permit the observed rpm to be compared with rpm previously accepted for the same engine when it was run under corresponding conditions. The procedure differs according to whether the engine is normally aspirated or supercharged, since the effects of barometric pressure changes must be taken into account in the latter case (Leaflet **EL/3-8**).

NOTE: The procedure given in the following paragraphs should also be applied whenever a propeller is changed.

9.8.1 Normally-aspirated engines are tested at full throttle and, where a variable pitch propeller is fitted, with maximum fine pitch selected. The changes in barometric pressure affecting engine power are considered to be balanced by changes in propeller load, so that only a temperature correction is necessary. This correction factor may be obtained from a graph supplied by the engine constructor or, if this is not available, from the graph shown in Figure 1 of Leaflet **EL/3-8.** The observed full throttle speed multiplied by the correction factor will give the corrected speed.

9.8.2 The magnetos should be checked again at the specified rpm and the oil pressure and engine temperatures should be noted. The engines should not be run at full throttle for periods longer than are necessary to make these observations; thus, when they have been noted, the throttle should be eased back to a low rpm position (usually 1000) to allow the engine to cool off before it is shut down.

9.8.3 **Supercharged Engines.** The standard method of checking the power of a supercharged engine during a ground run is to run the engine at a specified constant manifold pressure with the propeller on its fine pitch stops, and to compare the rpm obtained under these conditions with the reference rpm established previously when the engine was run at the same manifold pressure. However, the comparison has little value unless both the observed rpm and the reference rpm are corrected to common temperature and barometric conditions, normally the conditions at sea-level on a standard day (101·3 kN/m^2 (29·92 in Hg) and 15°C). A method sometimes used to establish a reference rpm consists of noting the indication of the manifold pressure gauge before the engine is started and then noting the rpm registered when, with the engine running, the same manifold pressure is indicated. On subsequent runs an approximate check on engine power is possible by comparing the rpm obtained at this manifold pressure with the reference rpm. However, the more accurate method given in the following paragraphs is recommended after top overhaul, or after other major adjustments or replacements have been made on the engine.

9.8.4 After top overhaul the reference rpm should be re-established so that there is a rough datum for the detection of any subsequent falling-off in power. Since the disturbance of the engine will invalidate any previously established reference rpm, the results obtained will only give an approximate indication of any power changes caused by the top overhaul.

9.8.5 To establish the reference rpm, the throttle should be opened until the Maximum Take-off manifold pressure is reached and then closed until the manifold pressure stabilises at the pressure used on previous occasions to establish reference rpm for the particular engine. (The engine manufacturers sometimes recommend a specific manifold pressure for the engine type, usually about 36 inHg). The rpm should drop off as the throttle is brought back from the take-off position, thus indicating that the propeller is on its fine pitch stops. When the rpm and manifold pressure have stabilised, the rpm should be carefully recorded. The barometric pressure and local air temperature at the time of test should be recorded at the same time. The engine should then be shut down by the usual procedure.

9.8.6 The rpm observed during the above test must now be corrected to the conditions at sea-level on a standard day. To do this reference should be made to the charts in Figures 2 and 3, which may be used for all types of supercharged piston engines. These charts do not allow for design variations between different engine types but are sufficiently accurate for ground testing. The charts should not be confused with those of Leaflet **EL/3-8.** They should be used as follows:

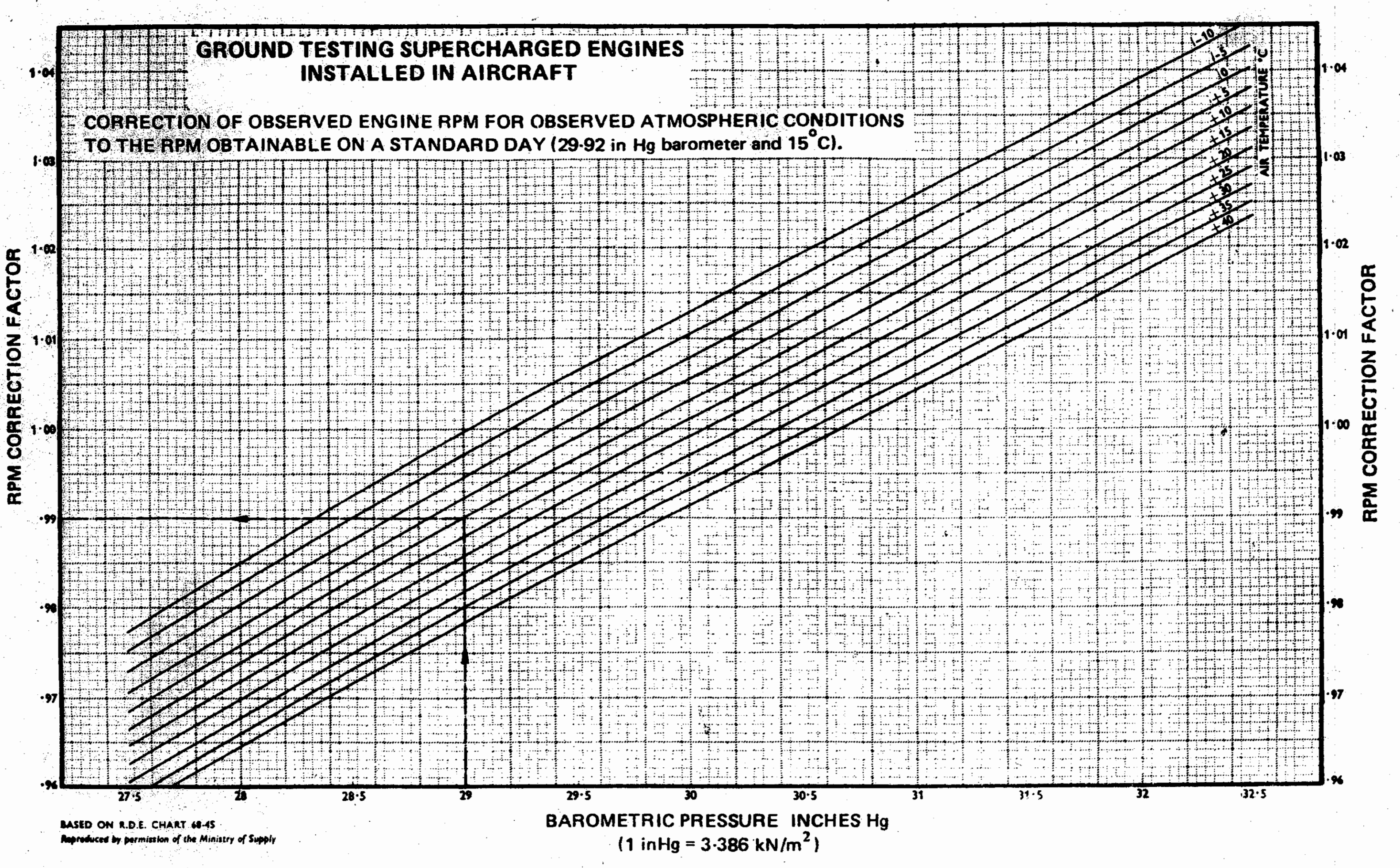
(a) Find the barometric pressure of the day on the horizontal scale of Figure 2 and project a vertical line from this point to intersect the oblique curve corresponding to the observed air temperature. Project a horizontal line from the point of intersection to the vertical scale and read off the rpm correction factor.

(b) The correction can be made by multiplying the observed rpm by this correction factor but, for convenience, the result may be obtained from Figure 3. To use Figure 3, read off the correction factor from the vertical scale and project a horizontal line from it; then read off the observed rpm from the horizontal scale and project a vertical line from it until the two lines intersect. The relationship of the point of intersection to the curves on the chart indicates the amount of rpm which must be added to or subtracted from the observed reading to give the corrected result.

EXAMPLE:—If the observed rpm are 2600 on a day when the barometric pressure is 29 in Hg and the air temperature is +10°C, the correction factor from Figure 2 is ·99. The intersection of the lines corresponding to 2600 rpm and ·99 correction factor on Figure 3 gives a value of approximately 25 rpm to be deducted from the observed results. The corrected rpm is therefore 2575, and this is the reference rpm which should be used as a standard for subsequent power checks made on the same engine.

9.9 **Acceptance Limits.** The rpm observed during the power check on a normally-aspirated engine, or the reference rpm established for a supercharged engine, should be compared with the figures obtained during previous checks made before the top overhaul. When assessing the results allowances have to be made for differences of environment such as wind strength, the proximity of buildings, etc., but in general the rpm values should be an improvement on those previously obtained. In any case the rpm should not be lower by more than about 3%. Differences greater than this may be taken as an indication that the power has fallen by an amount which warrants investigation and rectification. When satisfactory results have been obtained, the reference rpm established during the test should be recorded in the Engine Log Book.

10 AFTER TEST The exact procedure to be adopted after the completion of the test given in paragraph 9 should be determined by the number of items which have been renewed and the results of the power check. The following paragraphs give general guidance covering a number of typical cases.


GROUND TESTING SUPERCHARGED ENGINES
INSTALLED IN AIRCRAFT
CORRECTION OF OBSERVED ENGINE RPM FOR OBSERVED ATMOSPHERIC CONDITIONS
TO THE RPM OBTAINABLE ON A STANDARD DAY (29·92 in Hg barometer and 15°C).
AIR TEMPERATURE °C
−10
−5
0
+5
+10
+15
+20
+25
+30
+35
+40
RPM CORRECTION FACTOR
1·04
1·03
1·02
1·01
1·00
·99
·98
·97
·96
27·5
28
28·5
29
29·5
30
30·5
31
31·5
32
32·5
BAROMETRIC PRESSURE INCHES Hg
(1 inHg = 3·386 kN/m²)
BASED ON R.D.E. CHART 68-45
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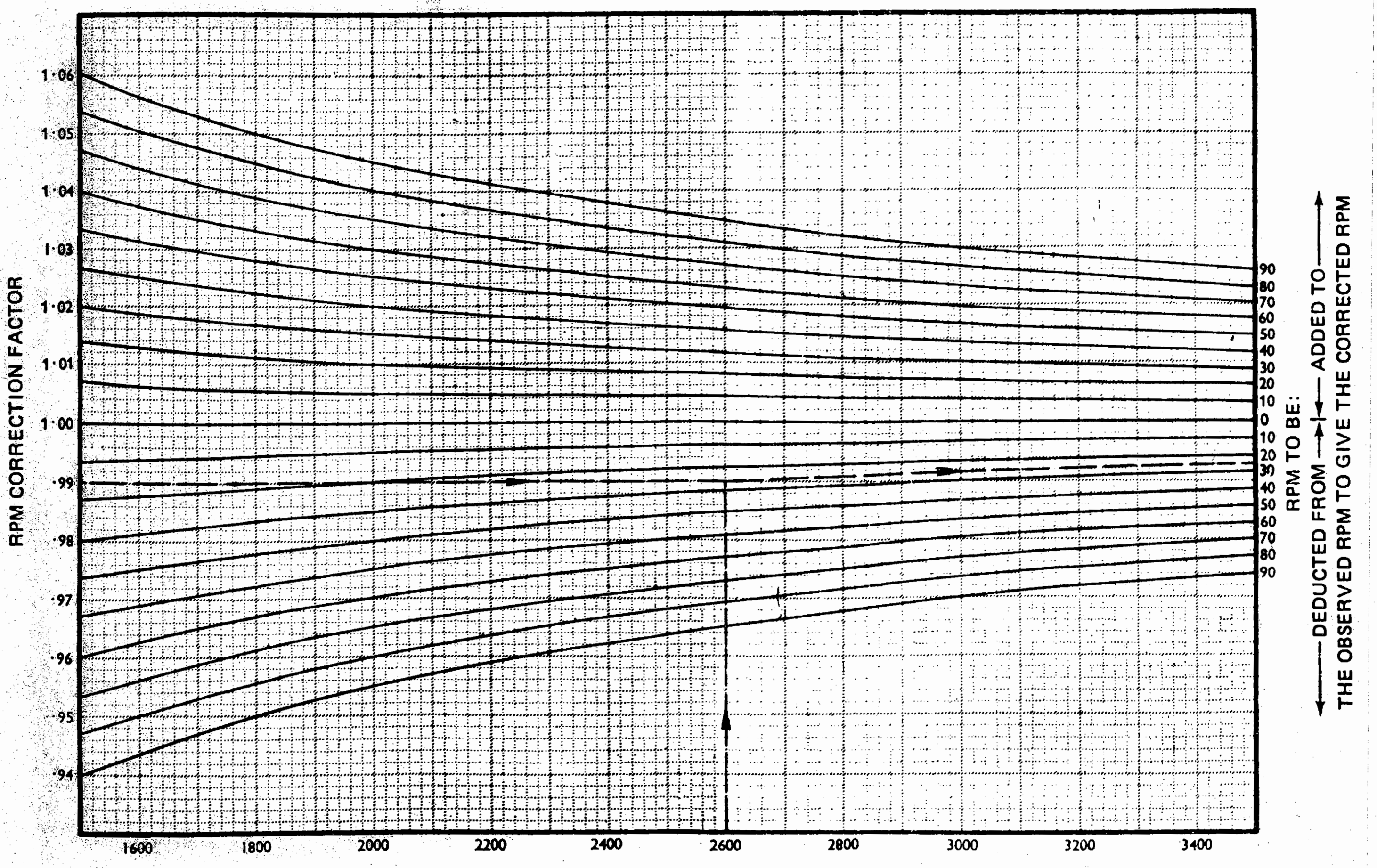
GROUND TESTING SUPERCHARGED ENGINES INSTALLED IN AIRCRAFT

CORRECTION OF OBSERVED ENGINE RPM USING RPM ATMOSPHERIC CORRECTION FACTOR



BASED ON R.D.E. CHART 68-45

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10.1 Provided that all aspects of the test run were satisfactory, after-test dismantling should not be necessary unless specified by the engine manufacturer. If the test run was not satisfactory, components which were renewed during the overhaul may require examination.

10.2 If cylinders have been removed a second time for an after-test examination, a final test should be made after reassembly. The final test should be as follows:

10.2.1 The engine should be started and warmed up until a safe oil temperature is reached. It should then be opened up until the throttle is about two-thirds open and a 10-minute proof run should be made. An ignition check should be made by switching OFF each magneto in turn.

10.2.2 A power check should then be made as described in paragraph 9.8. In the case of supercharged engines, the observed results should be corrected by means of the charts in Figures 2 and 3 and the results should be compared with the reference rpm established by the first power check. The new results become the reference rpm for future checks.

10.3 After testing engines which have received a top overhaul, the pressure and scavenge oil filters should be removed and examined for metal deposits. If metal is found it should be identified and, depending on the metal and quantity present, a decision should be made on whether further engine running and filter examination is necessary, or whether the engine should be dismantled for further investigation. If further test running is to be made, the oil tank and cooler should first be drained, flushed and refilled.

10.4 In cases where the results of the power check have not been satisfactory or where valves and valve seats have been changed or rectified, a compression check should be made.

10.5 Finally, the sparking plugs should be retightened, the tappet clearances should be checked and adjusted as necessary, and the tightness of the cylinder holding-down nuts should be checked. The appropriate details of the top overhaul and subsequent tests should then be entered in the Engine Log Book.

Issue 2.

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AIRCRAFT

ENGINES

PISTON ENGINE OVERHAUL—COMPLETE OVERHAUL

1 INTRODUCTION This Leaflet is the third of the series dealing with engine overhaul and gives general guidance on the inspection of such parts as casings, shafts, bearings, gears and manifolds during complete overhaul. The inspection of cylinders, pistons and valve gear is dealt with in Leaflet EL/3-2.

2 CRANKCASES AND OTHER STRUCTURAL CASTINGS Crankcases, reduction gear cases, top, front and rear covers are subjected to static and dynamic loads which can cause cracks or slight distortion. Small cracks do not always necessitate the scrapping of castings but the manufacturer's guidance should always be sought regarding the amount of cracking which can be considered acceptable. Distortion is usually revealed by making checks on the machined faces of castings. Other points to be examined include all inserts, dowels and studs for condition and tightness, all stud and bolt holes for elongation and burring, and all mating surfaces for signs of fretting.

2.1 Torque reaction from the rotating crankshaft sometimes results in slight distortion of the crankcases of in-line engines. One check which is sometimes of value in showing up distortion is to fit an accurately-ground mandrel in the crankshaft position and, after tightening down the bearing caps, ensure that it can be turned freely. Such mandrels are often used for checking the alignment of the bearing bores after they have been bored, but can be used at this stage before the bearings are overhauled.

2.2 The upper and lower machined faces of an in-line crankcase should be checked for flatness with a straightedge and feeler gauges. The straightedge should first be laid lengthways along the machined flanges of the crankcase joint and then checks should be made with it laid across the crankcase in line with each main bearing station. If distortion is suspected, the studs can be removed and the machined faces can be checked again on a surface table. Another way of testing for distortion is to mount a dial test indicator (DTI) in a scribing block and run it along the machined flanges with the button of the DTI in contact with the bearing alignment mandrel.

2.3 The mating surfaces of castings which bolt on to the crankcase should be checked for flatness, either by using a surface table and engineers' marking or else by mounting them so that they can be measured for flatness with a DTI. The latter method is recommended for faces with protruding studs. Any high spots should be removed with a flat scraper, after which the mating surfaces should be placed together with marking on one surface. Further scraping may be necessary to obtain at least an 80% transfer of marking—which is about the minimum necessary to give a reasonable guarantee that each joint will be leakproof. On no account should machined faces be lapped with grinding paste or abrasives.

2.4 The crankcases of radial engines should be checked at the front and rear machined faces for flatness and parallelism, the bearing housings afterwards being checked for alignment and concentricity. Particular methods of carrying out these inspections will vary from engine to engine according to the design of the crankcase, and in some cases special jigs may be necessary for supporting DTIs and other measuring instruments.

2.5 If the cylinder barrels have caused fretting in the crankcase apertures, the remedial action should be in accordance with the approved salvage scheme. On some engines a repair can be effected by removing the cylinder holding down studs and counter-boring the apertures, after which shims have to be used to restore the original compression ratio.

3 CRANKSHAFTS In addition to a magnetic crack detection test, crankshafts should be carefully examined with a magnifying lens for scores and nicks. Particular attention should be given to splines, from which signs of fretting, corrosion or chipping should be removed by light stoning followed by a polish with fine emery cloth. Dimensional checks should then be made as follows:

3.1 The wear, ovality and taper of the crankpins and journals should be determined before any attempt is made to check for bow, twist or parallelism, otherwise misleading results may be obtained. As shown in Figure 1, readings should be taken with a vernier gauge or micrometer at points 90° to each other around the circumference at two or three stations along the length of each pin and journal; it is not sufficient to measure only at the central points between the crankwebs. If the dimensions are less than the permissible worn dimensions, the crankshaft can probably be trued up by regrinding.

3.2 Twist, bow and parallelism should be checked with the crankshaft supported by vee-blocks on a surface table at the front and rear journals. Twist should be considered over the whole length of the crankshaft: on a four-throw crankshaft with parallel-sided webs it can be detected by first ensuring that the rear crankweb is horizontal and then checking that a zero reading is obtained when a DTI, preset on the rear crankweb, is passed over each web in turn. In the case of a six-throw crankshaft, or any shaft with oval-shaped webs, it is necessary to check for twist and parallelism on the crankpins. Bow should be checked on the central journal, where it will be half the difference between the maximum and minimum dial indicator readings obtained when the crankshaft is turned through one revolution. The reason for this is made clear in Figure 1.

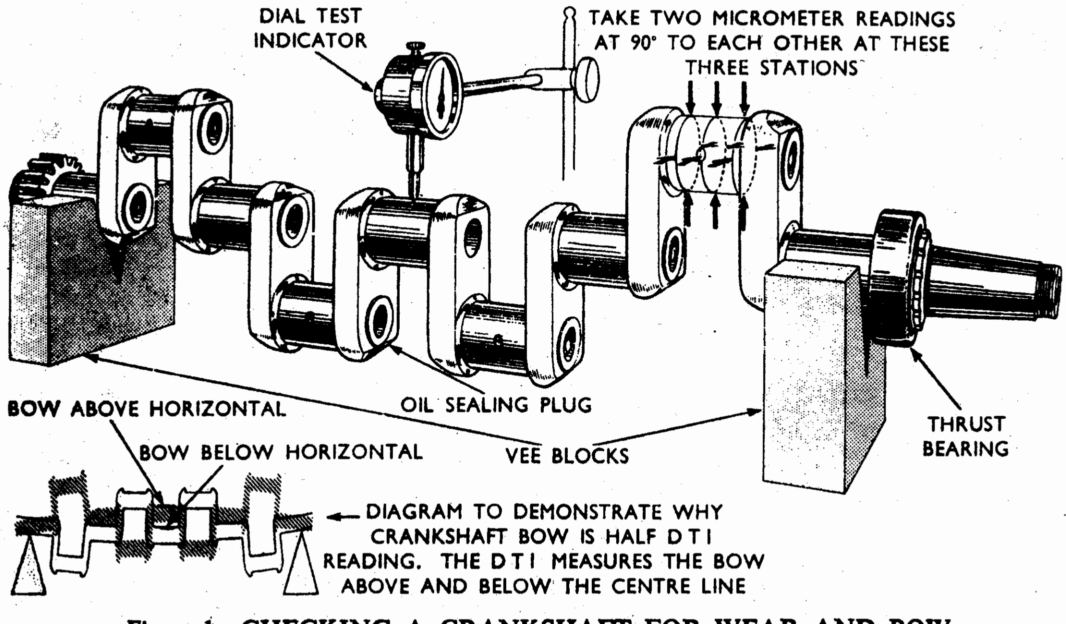

Figure 1 CHECKING A CRANKSHAFT FOR WEAR AND BOW

3.3 If vibration dampers are fitted to the crankshaft, they should be checked for security of attachment but should only be dismantled if defects are apparent or if dismantling is particularly specified. If they are removed for one of these reasons, the hardened steel bush in the crankweb lug should be crack tested. A small portable semi-permanent magnet type detector is suitable for this purpose. On reassembly, the securing screws must be renewed, the ends of the new screws being locked by peening.

3.4 The nose end of the crankshaft should be checked for distortion by turning the shaft through one revolution with a DTI in contact with the small end of the taper. This test is particularly important if the engine has been shock-loaded. A shock-loaded crankshaft may have suffered damage from twisting, bending or cracking. Bending will be indicated by lack of concentricity at the nose end and may be associated with cracking at the junction of the journals and webs.

3.5 After the inspection of the crankshaft is completed, the oil sealing plugs, provided they are in good condition, should be refitted and the crankshaft should be subjected to an oil pressure test to verify that they are oil tight. The oil holes in the journals and crankpins should be blanked off with rubber seals and metal clips, except that one should be fitted with a union for introducing the oil, and a pressure of 550 to 690 kN/m^2 (80 to 100 lbf/in^2) should be applied unless otherwise specified by the engine manufacturer.

4 BEARINGS

4.1 If the manufacturer does not recommend automatic replacement, the main and big-end bearing shells should be examined for condition of the bearing metal; inclusion of grit on the surface of white metal and wear and distortion are reasons for rejection. The adhesion of the bearing metal to its shell should be checked, and the quickest method of doing this is by means of the penetrant dye method described in Leaflet **BL/8-2.** If penetrant dyes are not available, the bearing can be immersed in oil at a temperature of 105°C for 15 minutes. It should then be removed from the oil and thoroughly dried, after which a mixture of French chalk and methylated spirit should be brushed over it. If, after a three-hour cooling period, staining of the chalk is evident, lack of adhesion is indicated and the bearing should be rejected.

4.2 Lead-silver bearings, lead-bronze bearings and thin-walled bearings with silver-lead-indium coatings should be checked for damage to the surface coating, signs of chemical attack, porosity and adhesion. Discoloration can be removed from silver-lead-indium surfaces by burnishing with a hardwood pencil stick.

4.3 The bearing housings and the bearing shells should be examined for signs of fretting. If fretting has occurred, relative movement between the shell and its housing is indicated and may be due to incorrect torque tightening of the bearing attachment nuts. Fretting may also be associated with enlargement of the dowel holes in the bearing shell or oversize bore in the bearing saddle.

4.4 Ball and roller bearings should be examined for signs of corrosion, pitting of the balls or rollers, cracks or scores, and excessive radial or axial movement of the inner race relative to the outer. Fretting marks on the outer race indicate that movement in the bearing housing is taking place: similar marks in the bore of the inner race indicate a loose fit on the shaft. A simple rig for checking the axial movement of ball bearings consists of a clamp made of mild steel with vee-shaped cut-outs arranged so that bearings of various sizes can be accommodated. The DTI is positioned to contact a bolt which is tightened down on to the inner race. The race is checked by moving the bolt up and down and measuring the end float on the DTI. Radial movement may be checked by a rig consisting of a base plate with the threaded end of a bolt protruding from it. The bearing should be placed over the bolt and the inner race clamped to the base plate by a circular plate and wing nut. The radial movement of the outer race relative to the inner can then be measured with a DTI. The outer race should be lightly gripped with one hand and moved only in a plane parallel to the movement of the DTI button.

5 CAMSHAFTS AND CAMRINGS

5.1 Camshafts should be checked for signs of flaking or chipping; minor roughness can be blended out with a stone. Using a profile gauge, the journals can then be checked for wear and ovality and the cams for profile. The shaft should then be checked for bow in the usual way by placing the shaft on vee-blocks on a surface table with a DTI in contact with its centre. The shaft should be turned through one revolution to obtain the maximum and minimum readings and the bow will be half the difference between the two readings.

5.2 The most practical way of testing the camshaft for twist is to reassemble it to the engine and compare the valve opening angles at the front and rear end of the shaft. The lift of the cams should also be checked when the engine is being reassembled.

5.3 Camrings for radial engines should be tested for flatness on a surface table. When checking the cam profiles it should be remembered that the cams may not be symmetrical in shape for design reasons. Minor scores on the profiles may be removed by light stoning but serious chipping necessitates renewal. Timing and lift should be checked after reassembly.

6 CONNECTING RODS

6.1 The bearings and housings at each end of a connecting rod should be checked for wear and ovality before the tests for bow and twist are made. For the latter tests the bearing shells should be removed and closely fitting mandrels should be used to mount the rods as shown in Figure 2. Figure 2 shows the method of setting up a rod to check for twist between the big and small ends; the jack is used to ensure that the centres of the two mandrels are in line when checked with the scribing block. With the connecting rod absolutely horizontal, any difference in DTI readings taken at equal distances each side of the small end will indicate the degree of twist.

6.2 Whilst the connecting rod is mounted as shown in Figure 2, it can also be checked for bending. The distance between the two mandrels should be measured on each side of the rod at points equidistant from the centre line of the rod; the two measurements should be the same.

6.3 Bore alignment should be checked with the bearing shells removed and again, using a different pair of mandrels, with them in position. For these tests the rod, supported by the lower mandrel resting on vee-blocks, should be vertical and the DTI should be passed across the small end mandrel at equal distances from the centre of the small end.

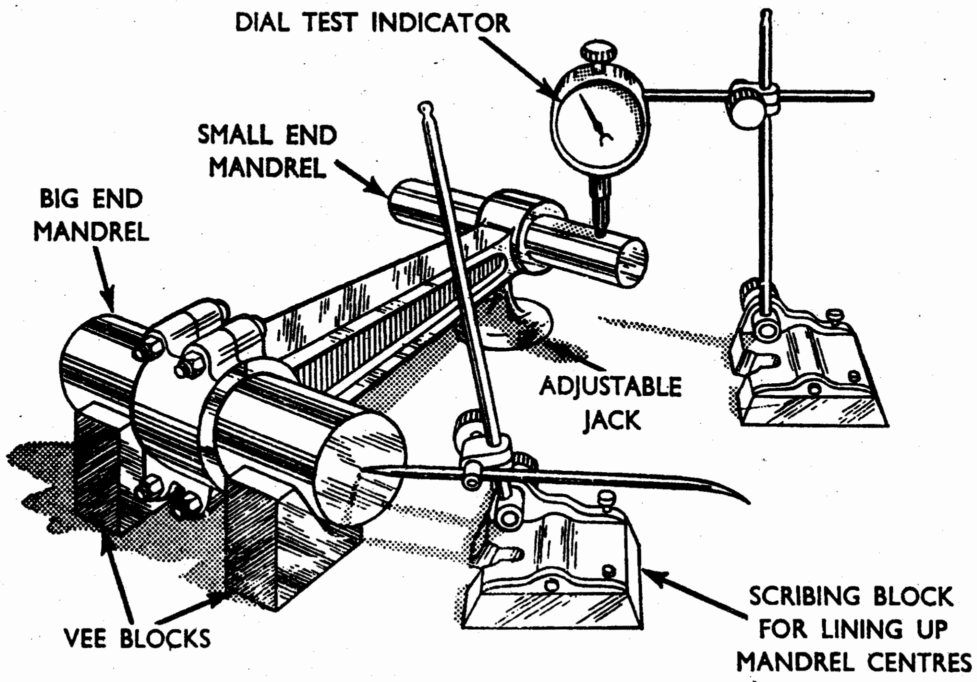

Figure 2 CHECKING A CONNECTING ROD FOR TWIST

6.4 After the rod has been tested for bow and twist with the bearing shells removed and after it has been verified that the big and small bores are in alignment with them removed, it may be found that bore alignment is not obtained when the bearing shells are replaced. This probably indicates that the bore of the big end bearing metal is out of true and may necessitate changing the bearing shells even if they are within the prescribed limits of wear and ovality.

6.5 Before refitting connecting rods they should be cleaned and, if specified for the particular engine type, reprotected as required by the manufacturer. If connecting rods are renewed, it may be necessary to check the weights and balance of the new rods. This should be done in accordance with the manufacturer's instructions. Some manufacturers recommend weighing each rod with its associated piston as a complete assembly.

7 GEARS

7.1 In addition to the magnetic crack detection tests covered in Leaflet EL/3-1, gears should receive a careful visual examination with the aid of a magnifying lens. Minor roughness on the teeth may be stoned out, but wear affecting the contact faces cannot be rectified.

7.2 Timing and reduction gears of the spur type should be checked for concentricity with a DTI. The most important check is between the axis of rotation and the pitch circle, since this is where most of the loading, and therefore the maximum wear, occurs.

7.3 Each tooth should be inspected along its full length for parallelism with the axis of the gear, since the bearing of a gear may wear unevenly and, in some cases, the gear itself may tend to slew out of its intended plane of rotation with consequent irregular wear on the teeth.

8 SUPERCHARGERS The impeller, shafts and gears of superchargers are subjected to severe running stresses and require careful examination for cracks during overhaul. Generally, these components should be tested by both the current flow and magnetic flow methods (Leaflet **BL/8-5**).

8.1 Impellers should be examined for nicks and indentations, for erosion of the vanes and cavity floors, and for fretting at the splines in the bore. The backlash between these splines and the matching splines on the impeller shaft should then be measured. With the impeller assembled to its shaft and with the shaft bearings mounted on suitable supports, a test for excessive "wobble" or "swash" should be made. To do this a DTI should be mounted so that its button is in contact with the backplate of the impeller near its periphery and the impeller should then be turned so that any deviation of the DTI reading can be observed and recorded.

8.2 Impeller drive gears are accurately balanced by the manufacturer and this balance may be disturbed when gear teeth are stoned to remove minor defects. A static balance test should therefore be carried out before supercharger drives are reassembled. A simple method of doing this is to mount each gear on a mandrel and place the mandrel across a pair of knife edges. If the gear wheel is in balance, it will not turn of its own accord from any position in which it is set. If it is out of balance, the manufacturer's instructions should be consulted to determine the position from which metal may be removed to restore the balance.

8.3 An important feature of the inspection of any supercharger is the determination of the backlash and end float of the various gear and shaft assemblies. The Schedule of Fits and Clearances will give details of each measurement which has to be determined.

8.4 If the impeller, its shaft or any parts which have been dynamically balanced with the impeller assembly are rejected during the inspection, the complete assembly fitted with the new parts must be rebalanced. This must be done on a dynamic balancing machine and it is customary to return the impeller assembly to the manufacturer for rebalancing.

9 OIL PUMPS

9.1 Increase in the end float of a gear-type oil pump permits the oil to be forced back to the suction side of the pump. To check for end float the pump should be completely assembled, mounted on a jig and positioned on a surface table; with a DTI rigidly bolted to the pump case so that its button contacts the end of the pump spindle, the end float can then be measured by raising and lowering the spindle to the limit of the clearance between the driving gear and its end bushes. The end float of the driven gear should then be checked using an extension rod to contact the DTI button. Excessive float should be corrected by renewing the bushes of both gears, this also being the remedy if the diametral clearance is excessive.

NOTE: Taking up the end float by reducing the length of the pump body should never be attempted since this upsets the pump output and precludes the replacement of parts on future occasions.

9.2 The diametral clearance of the gears should be checked by inserting a pair of feeler gauges between opposing sides of each gear and the pump housing. To check the backlash a pointer should be mounted on the spindle of the driven gear so that it contacts the button of a DTI. It is usual to make the point of contact at a distance along the pointer double the pitch-circle radius of the gear and then to take the backlash as half the DTI reading obtained when the driven gear is rocked against the fixed driving gear.

9.3 The piston and bore of the relief valve, if this is of the plunger type, should be checked for scores and freedom of movement. Relief valve or reducing valve springs should be renewed when necessary; no attempt to pack them up with washers should be made unless this method of adjustment is specifically recommended by the manufacturer.

9.4 All oil pump and oil filter bodies should be pressure tested for leaks at 1½ times their normal working pressure.

10 MANIFOLDS Induction and exhaust manifolds must be free from cracks, porosity and corrosion, particular attention being given to welds at flanges and joints. Flanges should be checked on a surface table with feeler gauges for freedom from distortion; it is important that their condition should be good to ensure leakproof joints when the manifolds are reassembled to the engine.

10.1 Induction manifolds should be pressure tested at the pressure specified in the appropriate Manual; typical pressures are 130 to 170 kN/m^2 (20 to 25 lbf/in^2) for the manifolds of non-supercharged engines and 345 kN/m^2 (50 lbf/in^2) for the manifolds of supercharged engines. All the apertures should be blanked off for the test, one of the blanking plates having a pressure gauge attachment and a Schrader valve connection for introducing compressed air.

10.2 When the manifold is pressurised, a leak test should be made to check for cracks and porosity. A simple test can be made by immersing the manifold in hot water and looking for bubbles. An alternative method is to whiten the exterior of the manifold with a mixture of French chalk and methylated spirit and to insert a small quantity of a 50/50 mixture of engine oil and paraffin in the interior before pressurising. The paraffin mixture will then be forced from any flaws in the manifold walls and will stain the white surface.

10.3 Leaflet AL/3-8 draws attention to fire risks that can arise from damaged exhaust pipes and manifolds. Fluorescent or penetrant dye tests should be made on these items to find cracks but the high temperatures to which they are subjected may cause intergranular corrosion without any obvious external evidence. To test for this defect each exhaust manifold should be tested over its entire length for increase in magnetic permeability. Whilst the use of a permeability detector is recommended, the tendency of a horseshoe magnet to adhere to any part of the manifold can be taken as sufficient grounds for rejection.

11 REPAIR It is outside the scope of this leaflet to deal in any detail with repairs and rectifications since these vary from engine to engine and are covered in the approved salvage scheme for the engine type. On the completion of approved repairs, the inspector responsible for certifying that they have been carried out correctly should verify the following points:

(a) That the dimensions of all repaired parts correspond to the dimensions specified on the repair drawings.

(b) That all oil-ways and similar passages are free from burrs, swarf and foreign matter. Pressure tests and oil flow tests must be made as specified by the manufacturer and should be witnessed by the responsible inspector.

(c) That any heat treatments or protective processes have been carried out in accordance with approved specifications and that the condition of parts which have received such treatments has been assessed by appropriate inspection and tests.

(d) That all detail assemblies have been correctly put together and that all locking is satisfactory. The fit of split pins is important; they should always be tight in their holes and those fitted to rotating parts should preferably be at right angles to the direction of rotation.

(e) That full particulars of all repair work done are duly recorded as prescribed in Chapter A4—2 of British Civil Airworthiness Requirements.

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AIRCRAFT

ENGINES

PISTON ENGINE OVERHAUL—INSPECTION DURING ASSEMBLY

1 INTRODUCTION This Leaflet is the fourth in the series dealing with piston engine overhaul and gives guidance on the reassembly of engines which have been overhauled in accordance with the recommendations of Leaflets **EL/3-1, EL/3-2** and **EL/3-3.**

2 GENERAL Before reassembly commences, it should be verified that details of the dimensions and condition of all components have been recorded as detailed in Leaflet **EL/3-1.**

2.1 All engine parts should receive a final examination for cleanliness before reassembly commences. Scrupulous cleanliness is of course essential at all times during reassembly and care must be taken to ensure that no foreign objects find their way into the engine. All apertures should be blanked off until the appropriate connections are made to them.

2.2 Systematic inspection at each stage of reassembly is necessary to ensure that all mating parts are accurately aligned and fitted, that all locking is in accordance with approved methods, and that the torque-loadings, clearances, etc., are those recommended by the manufacturer. If new parts have been fitted they should receive particular attention, details of their part numbers, fits and clearances, and, if applicable, weights being entered in the Overhaul Records.

3 FITTING BEARINGS The first stages of reassembling an engine involve fitting the main bearings to the crankcase and the big-end bearings to the connecting rods. The majority of the information in the following paragraphs relates to the main and big-end bearings for in-line engines, most of which consist of steel-backed shells lined either with white metal, lead-bronze or some special combination of bearing metals. However, paragraph 3.1 gives some information on ball and roller bearings and is therefore applicable to the main bearings of radial engines, as well as to the thrust bearings of in-line engines.

3.1 With ball and roller bearings two fits are of importance, that of the outer race in the bearing housing and that of the inner race on the shaft. In neither case should the clearance be such that relative movement of the races can occur; if the clearance is excessive it may be permissible to reduce it, either by building up the external diameters of the races by the electro-deposition of chrome or nickel, or by building up the bore of the bearing housing by an approved method. Before attempting such salvage schemes the general condition of the bearing should be re-assessed since it is preferable to renew rather than repair a partially worn bearing. In some cases the engine manufacturers specify that all main ball and roller bearings must be renewed at each complete overhaul of the engine.

3.2 Shell type bearings must be assembled the right way round and in the correct order and must be a good fit in their housings in the crankcase, big ends and bearing caps. To ensure this, a check with engineers' marking should be made. Care should be taken to ensure that the shells are not held proud by poorly fitting dowels or keys, otherwise oil under pressure may force the bearing hard against the shaft. Salvage schemes usually make provision for fitting oversize dowels where the dowel hole has been enlarged.

3.3 On some engines the "nip" of the bearings should be checked by assembling the caps on to the complete bearings and tightening the holding-down bolts to the correct torque value. All the nuts should then be released a little until resistance to rotation ceases, when the nip of the cap on the bearing can be measured by running feelers around each side of the cap. In the case of white-metal or other thick-walled bearings, too large a gap, i.e. excessive nip, can be corrected by rubbing down by an equal amount the edges of each half-shell, using fine emery paper laid on a flat surface such as a piece of plate glass. Thin-walled bearings should be selectively fitted to give the required nip.

NOTE: The bearing housings of horizontally-opposed engines are part of each crankcase half, and provided the crankcase has been checked for distortion on a surface table, bearing shells do not normally need to be checked for "nip" during assembly.

3.4 The diametral clearance of each shell type bearing on its corresponding crankpin or journal should be checked by micrometer measurements. It is essential that the specified minimum clearance all round the shaft is obtained to ensure the maintenance of an oil film when the engine is running. A further check can be made by assembling the shaft and bearing with engineers' marking, tightening down to the specified torque value and rotating the shaft so that the high spots are marked. If the clearance is inadequate or if less than 80% surface bearing contact is obtained, the bearings (provided they are not of the thin-walled type) should be trued up with a bearing boring bar. After boring, the radii at the edges of each bearing must be recut, using the special tools supplied by the engine manufacturer. In some instances, hand scraping may be used to remove high spots from the bearing surface but it is a more tedious method and requires more skill than boring.

NOTE: The practice of measuring the diametral clearance by strips of paper or lead wire is not recommended as it may cause damage to the bearings. However, an exception is made in the case of certain thin-walled bearings which, because of their springiness, are tested with thin strips of oiled paper.

3.5 Some salvage schemes permit the fitting of replacement bearing shells which are oversize on their outside diameters. These are used in instances where the bores of the bearing housings are found to be malaligned or damaged by fretting, corrosion, etc. The bores are first machined out to take the appropriate oversize bearing (there are often three or four stages of oversize allowed), after which the bearings are fitted and the diametral clearance is checked as in paragraph 3.4.

3.6 If the crankshaft has been ground because the journals were oval or worn, the bearing shells should be replaced with shells which are undersized on their internal diameters. The bearings may require boring to ensure that they are correctly aligned and to obtain the correct diametral clearance at each journal. After boring, the bearing radii must be recut and the width of each bearing should be reduced by means of the appropriate cutter so that the side clearances between the bearings and the crankwebs are left slightly smaller than those specified in the Schedule of Fits and Clearances. This means that enough metal is left on the width of each bearing for a final cut to correct these clearances after the crankshaft has been centralised.

3.7 After boring, the bearings should be examined for concentricity, i.e. the bearing metal should be of equal thickness all round the walls of the shells. Lack of concentricity may indicate distortion of the crankcase.

3.8 Thin-walled bearings are a special case and cannot be bored; if they are in any way unsatisfactory in respect of nip, alignment or clearance, they should be renewed.

3.9 When the bearing clearances and alignment have been correctly adjusted, it should be verified that the oil holes are correctly aligned. The journal bearing caps should be fitted to the crankcase with the shells in position and then oil should be pumped through the oil galleries of the crankcase to check that all oilways are clear.

4 FITTING THE CRANKSHAFT The sequence of assembly varies according to the type of engine; the crankshaft of a radial engine is usually mounted on a special stand and the crankcase is assembled around it, whilst it is the crankcase of an in-line engine which is first mounted, the crankshaft and connecting rod assembly being offered to it. With horizontally-opposed engines one half of the crankcase is mounted on its side in a stand, the crankshaft and connecting rod assembly is lowered into position, and the other half of the crankcase is then assembled and secured.

4.1 In the majority of cases the crankshaft should be supported on a stand whilst the connecting rods are fitted, but there are one or two engine types in which the crankshaft is first installed in the crankcase. In either case the big-end cap nuts should be tightened down in the sequence recommended by the manufacturer, each nut being correctly torque loaded but not locked at this stage. Centralisation checks should then be made so that the bearings can, where specified, be machined to give the required side clearance.

4.2 The first check at this stage of reassembly is for crankshaft end float and main bearing side clearance. The crankshaft must be married to the crankcase for these checks, all the main bearing caps being tightened down to the correct torque value. The test for end float is made by tapping the crankshaft fore and aft; generally no end float is allowed and if any is detected it will be necessary to remove the crankshaft and change the front thrust race. The side clearances at the main bearings should now be checked with feeler gauges. If it is found that they are incorrectly distributed fore and aft, it will probably be possible to make a correction by fitting shims between the shoulder at the front of the crankshaft and the inner track of the thrust-race; the shims will not affect the end float but will reposition the crankwebs relative to the bearings.

NOTE: Horizontally-opposed engines often have plain thrust bearings, and crankshaft end-float is usually checked by inserting feelers between the faces of the thrust bearing and the cheeks of the adjacent crankshaft webs.

4.3 When the crankshaft has been centralised, the width of the main bearing shells should be reduced as necessary to give the correct side clearances. These clearances are sufficiently generous to allow for expansion of the crankcase relative to the crankshaft.

4.4 Final adjustment of the width of the big-end bearing shells should be made after the centralisation of the small ends has been checked. In the case of in-line engines, the small end check is made by assembling the crankshaft, complete with connecting rods, to the crankcase and then fitting the pistons and cylinders. The side clearances at the small ends can then be measured by inserting feeler gauges through the top or bottom of the crankcase and into the cylinder bores. If the check has to be made on a radial engine, it is usually necessary to fit the pistons and cylinders one at a time, removing each one as it is checked so that access can be obtained to the next through the adjacent cylinder apertures. Equal clearances should be obtained each side of each small end, and the clearances themselves should be within the limits specified in the Schedule of Fits and Clearances. If the connecting rods are not central between the gudgeon pin bosses, the connecting rods must be taken off again. They should then be mounted in a jig so that the width of the big-end bearing shells can be trimmed with the appropriate cutter. The rods can be centralised by removing metal from the side of the bearing which is on the same side as the smallest clearance found at the small end of each rod.

4.5 When the small-end clearances have been corrected and the widths of the big-end bearing shells have been cut to final dimensions, the connecting rods should be assembled to the crankshaft and all bolts and nuts should be tightened down and split-pinned. The nuts must be torque-loaded to the specified value and thereafter must not be slackened back to align the split pin holes. If the holes do not align, the nuts should be taken off again and reduced on their underfaces by rubbing them on an emery-covered block. After the connecting rods have been finally tightened, a check for freedom from binding should be made by moving each rod to the vertical position and checking that it falls slowly but freely when released.

4.6 The crankshaft complete with connecting rods should next be married to the crankcase again and all the main bearing caps should be tightened down with a torque spanner. The order of tightening is important; for a typical in-line engine it is usually middle, end and intermediate caps in that order.

4.7 An oil pressure test on the crankcase and crankshaft assembly is necessary to detect leaks from the oil seals, to ensure that the oil passages are free and to distribute oil through all the galleries and oilways. With some kinds of in-line engine, this test is carried out by substituting a specially prepared top or bottom cover for the normal crankcase cover. The special cover is cut away to permit observation of the interior of the engine during the test. Double the normal oil pressure is usually specified for this test and the crankshaft should be rotated whilst the pressure is applied.

5 FITTING SHAFTS AND GEARS It is not possible to give detailed guidance on checking shafts and gears because the pattern of these varies so much from engine to engine. For this reason the following paragraphs deal with general principles rather than specific applications.

5.1 The camshafts of small in-line engines are usually housed within the crankcase and are installed before the crankshaft is replaced. The clearances at the camshaft bearings must be within limits; if they are excessive, it may be permissible to correct them by fitting new bearing bushes. New bushes usually require reaming to size and sometimes it is necessary to drill oil holes after the bushes are in position. All swarf must be carefully cleared away and the bushes must be generously smeared with engine oil before the camshaft is fitted. When the shaft is fitted, it must be checked for end float and for freedom of rotation. End float is usually measured with feelers between the shoulder on the shaft and the rear bearing.

5.2 After an internal camshaft has been installed, the tappets and guides should be replaced and correctly aligned with their respective cams. A check for tappet alignment can be made by coating the tappet rollers or shoes with engineers' marking, rotating the camshaft and checking the transfer of marking to the cams. A 90% transfer is desirable and can usually be obtained by slackening off the tappet guide retaining nuts (the studs pass through clearance holes) and re-aligning the tappets.

5.3 All gears and gear trains should be checked for backlash before and during assembly to the engine. Backlash should be checked at more than one position on each gear, the maximum possible number of combinations of gear position being the ideal.

5.4 Checks on end float are usually specified after the installation of cam rings, layshafts, quillshafts, gears, etc. In some cases feeler gauges can be used for these checks, but sometimes it is necessary to mount a DTI in a convenient position for measuring end float. Adjustment of end float is usually obtained by packing with shims or washers, but these must only be used when and where specified by the manufacturer. At all times during the assembly of drives and gears, it is necessary to ensure that each item is inserted in its correct order, is facing the correct way, is free to rotate without binding and is locked with new locking devices of the correct type.

6 ASSEMBLY OF COVERS AND ANCILLARIES

6.1 When assembling sumps, top, front or rear covers or supercharger casings, their location, and the alignment of any bearings integral with them, should be checked before the holding-down nuts are tightened. After a top cover or sump has been placed on a crankcase, a check should be made with feeler gauges for any indications of 'holding-off' at the face joint. When it has been verified that the cover or casing is a good fit at the case, the nuts on the studs and bolts should be tightened in a predetermined order.

6.2 Reduction gears are usually built up as complete sub-assemblies before they are offered to the engine. The separate spindles, gears and washers are normally given group numbers so that all the components of a particular planet-gear group can be reassembled in their original positions. Certain teeth on intermeshing gears will probably be marked to indicate the particular positions in which they have to be meshed together. On completion of the prescribed backlash and end float checks, the reduction gear assembly should be submitted to an oil flow test. Special adapters will have to be fitted to introduce the oil into the rear end of the propeller shaft. It should then be pumped at a pressure one and a half times the normal engine oil pressure, whilst a check is made that it emerges freely from the planet gear spindles and sun gear. If the propeller shaft is of the kind which feeds oil to a variable pitch propeller, the oil flow through the oilways from the constant-speed unit mountings should also be checked and the oil feed sleeves should be examined for leaks. When fitting a reduction gear assembly to an engine, it should be carefully aligned, preferably with the axis of the engine vertical, to ensure that there is no strain on the case when the bolts are tightened.

6.3 Superchargers are also built up in a similar manner to reduction gears as complete sub-assemblies, although the drives and gears will probably have to be mounted on the rear of the engine before the supercharger case is offered up. Great care is necessary to ensure that all bearings, cones, oil seals, washers, etc., are assembled in the correct order and facing the right way, and at all times during the assembly and checking of superchargers it is essential that close attention should be paid to the manufacturer's instructions. Concentricity checks are normally made on the impeller by rotating it with a DTI mounted so that its button is in contact with the tips of the vanes. The clearance between the impeller back plate and the front case of the impeller is usually measured by inserting a depth gauge through a suitably positioned hole in the back plate. Other checks specified will vary according to the particular design of supercharger but in most cases will include an oil flow check.

6.4 When assembling such items as pumps, starters and generators to an engine, only gaskets and washers approved for use on the engine concerned should be used, since any variation of thickness of these items may result in damage to the driven unit or to the driving gear of the engine. Only jointing compounds of the types specified by the manufacturer are to be used, and care must be taken that only sufficient is applied to cover the faces of the joint without any excess to be squeezed out when the joint is tightened. In particular it is necessary to ensure that jointing compound cannot enter fuel pumps or carburettors, where it could cause obstruction, or oilways, where it would restrict the oil flow.

7 FITTING PISTONS AND CYLINDERS

7.1 When refitting piston rings, thin metal strips should be used to enable them to be manoeuvred into their grooves without breaking them. Generally all piston rings are renewed at overhaul but if the original rings are to be refitted, they should be replaced in the grooves from which they were originally removed. Care must be taken that all rings are fitted correctly; this is obviously important with unsymmetrical scraper rings, but some types of compression rings are also marked to indicate that they must be installed with a particular side towards the crown of the piston.

7.2 The procedure for fitting cylinders is much the same for all air-cooled engines. The appropriate connecting rod should first be turned to the top and the piston should then be assembled to it. New gudgeon pin circlips should be fitted, where appropriate, using the circlip fitting tool provided in the tool kit. The piston ring gaps should then be equally spaced on the piston and the ring compressor sleeve should be fitted. The cylinder bore should be well oiled, a new sealing ring should be fitted over the spigot and the cylinder should be slid over the piston until the piston is completely within the bore. After removal of the ring compressor, the cylinder should be pushed right home. If the cylinder barrel is of the type that screws into the crankcase, the threads should be engaged carefully and the cylinder should be screwed right home before the next one is fitted.

7.3 When copper cylinder head washers are to be fitted at cylinder head to barrel joints, it is an advantage to anneal them before fitting. To do this they should be heated for 5 minutes to a red heat by any convenient method that will ensure a uniform temperature of approximately 600°C, and should then be quenched in cold water.

7.4 When the cylinder heads of an in-line engine have been placed in position and secured by finger-tightening the holding-down nuts, an alignment check should be made with a straightedge laid across the machined faces of the valve ports. The nuts should then be tightened down evenly and a final check should be made to confirm that the alignment has not been disturbed.

8 VALVE AND MAGNETO TIMING Since the procedure to be adopted in timing the valves will depend on the engine type, only a few remarks of a general nature can be made in this leaflet. Magneto timing and synchronisation is covered in Leaflet **EL/3-9.**

8.1 Valve timing should not be commenced until the valve clearances have been set to the timing clearances recommended by the manufacturer. To allow for cylinder expansion when the engine is running, the clearances should be reset to the normal running clearances on completion of the timing operations.

8.2 After the crankshaft has been set to the required position by aligning the appropriate marks on the timing disc with a fixed pointer, the camshaft and valve gear should be set so that the No. 1 exhaust valve is just about to open. Without moving either the crankshaft or camshaft, the two are then linked together by inserting the appropriate shaft or gear. The link is usually designed on a vernier principle so that a fine adjustment may be obtained if the initial timing does not give the exact opening times specified in the Overhaul Manual.

9 OTHER ASSEMBLY WORK The overhaul and fitting of carburettors, fuel pumps, boost control units, etc., is not covered in this series of leaflets but detailed instructions will be found in the appropriate Service and Instruction Manual. Guidance on the testing and inspection of fuel and oil pipes is given in Leaflets **AL/3-13** and **AL/3-14**, and information on various other engine accessories and components is contained in other Civil Aircraft Inspection Procedures Leaflets.

9.1 Sparking plugs are not usually fitted until the engine is prepared for running and thus dummy plugs should be fitted to exclude dirt from the cylinders. Leaflet **EL/5-1** covers the cleaning and overhaul of plugs and gives the precautions to be taken when refitting them.

9.2 When the main assembly work has been completed the engine should be subjected to a systematic inspection to ensure that all nuts have been correctly tightened, that all locking is satisfactory and that the engine controls have been correctly adjusted. When this inspection is completed, the cylinder cooling baffles should be fitted. Care is necessary during the fitting of baffles and airscoops otherwise the cooling of the engine may be adversely affected.

10 AFTER OVERHAUL On completion of the inspection of an overhauled engine, the inspection records should be completed and signed by the responsible inspector or licensed aircraft engineer. The requirements for recording overhaul and repair work are given in Chapter A4—2 of British Civil Airworthiness Requirements and further guidance is given in Leaflet **BL/1-10.** Before being released for installation in an aircraft, the engine must be tested in accordance with the CAA's requirements for testing piston engines after overhaul. These requirements are given in Section C of British Civil Airworthiness Requirements and those parts relevant to the testing of small air-cooled engines are reprinted in the subsequent Leaflets of this series.

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AIRCRAFT

ENGINES

PISTON ENGINE OVERHAUL—TEST REQUIREMENTS FOR OVERHAULED ENGINES

1 INTRODUCTION This Leaflet is the fifth in the series dealing with piston engine overhaul. After an engine has received a complete overhaul it must be tested as prescribed in Section C of British Civil Airworthiness Requirements; this Leaflet includes certain parts of the Requirements which are relevant to the testing of the low-power, air-cooled engines covered by the series. There are no requirements in Section C for testing piston engines after top overhaul but the CAA's recommendations are given in Leaflet **EL/3-2.**

1.1 The test procedure prescribed for piston engines after overhaul includes an Endurance Test followed by a strip examination and a Final Test during which the performance is determined. Engine manufacturers in the United Kingdom prepare Test Schedules and instructions which are approved by the CAA for use when testing particular engine types. These schedules are based on the appropriate schedule from the Requirements (Schedule 1 or Schedule 2 of this Leaflet) and the Engine Technical Certificate. Persons or approved organisations responsible for the overhaul and testing of aero-engines should obtain copies of these schedules from the manufacturers or, in the case of engines for which such schedules are not available, should compile their own and submit them to the CAA for approval.

1.2 Leaflets **EL/3-6** and **EL/3-7** give guidance on dynamometer testing and fan testing respectively, and, in each case, include the applicable acceptance conditions prescribed in Section C of the Requirements. Leaflet **EL/3-8** contains the performance corrections to be applied during dynamometer testing and also explains the correction procedure to be used during the calibration of test fans.

2 APPLICABILITY OF OVERHAULED ENGINE TESTS

2.1 Overhauled engines intended for use in aircraft for which a certificate of airworthiness is sought must be submitted to the tests prescribed in the schedule appropriate to the engine, except that the CAA will consider alternative methods and conditions where it is satisfied that, for technical reasons, those prescribed in the Requirements cannot be complied with.

2.1.1 The schedule appropriate to the engine depends on whether the engine is rated in accordance with the Requirements in force before or after the 18th November, 1946. Schedule 1 prescribes the tests for engines with ICAO ratings, i.e. engines rated after the above date, and Schedule 2 prescribes the tests for engines with pre-ICAO ratings. Any alternative methods and conditions which necessitate departure from the appropriate basic schedule in the Requirements will be incorporated in the manufacturer's schedule and will be individually approved for that engine type only.

2.1.2 The Requirements for testing overhauled piston engines intended for installation in helicopters are the same as for engines intended for use in fixed-wing aircraft, except that the engines must be tested in the attitude in which they will be installed in the helicopter, and wherever reference is made to Maximum Take-off Power this shall be taken to read Maximum One-hour Power.

2.2 The tests are presented in two groups, the first constituting an Endurance Test intended primarily as a loading check of the engine and an indication of the power performance and fuel and oil consumptions, and the second group a Final Test made, after dismantling, inspection and reassembly, to determine the performance of the engine prior to acceptance.

2.3 All test equipment must be of an approved type and the test bench must be equipped with an approved range of instruments to enable accurate indication of the relevant test data specified in the test schedule appropriate to the engine. The instruments and all measuring equipment must be calibrated periodically and thereafter checked for accuracy at regular intervals, as agreed with the CAA.

3 TEST CONDITIONS The Requirements state that the tests shall be run in the sequence given in the schedule and in accordance with the general requirements prescribed for engine testing and the particular requirements prescribed for testing overhauled engines. Both the general and the particular requirements in which the test conditions applicable to the testing of low-power, air-cooled engines are prescribed, are included in the following paragraphs.

3.1 **Artificial Humidity.** No artificial means of increasing the humidity of the ambient air shall be employed.

3.2 **Fuel and Oil.** Fuel and oil as approved for the prototype engine (unless otherwise agreed by the CAA) shall be used for all tests. The CAA may require a check of the specific gravity of the fuel and oil to be made. The CAA may also require representative samples of the fuel and oil to be taken for analysis.

3.3 **Controls and Adjustments**

3.3.1 Such automatic controls as may be provided shall be in operation.

3.3.2 Adjustments (i.e. variable devices not intended to be varied in flight or ground handling) shall be set prior to each test in accordance with the manufacturer's instructions.

3.3.3 Controls (i.e. variable devices which are intended for use during flight or ground handling) shall be operated in accordance with the manufacturer's instructions.

3.3.4 Adjustments shall be checked and unintended variations from the original settings recorded—

(a) At each strip examination.

(b) When adjustments are reset because the nature of a test clearly demands it.

(c) As required by instructions relating to specific tests.

3.3.5 The manufacturer's instructions referred to in 3.3.2 and 3.3.3 shall be those which are incorporated (with such minor alterations as the CAA may permit) in the Overhaul Manual for the engine type.

3.4 **Engine Parts Replacement during Test.** If, as a result of the tests, replacement of any major component or part is necessary, the test shall be repeated unless otherwise agreed by the CAA.

3.5 **Temperatures.** Cooling conditions shall be controlled so that for each running condition the declared maximum operating temperatures for inlet oil or cylinder head temperatures (measured on the hottest cylinder) are maintained throughout the stage, except that for runs of not more than five minutes duration such temperatures need be maintained for one minute only. A tolerance of $\pm 5°C$ shall not be exceeded on the cylinder head temperature and of $\pm 3°C$ on the oil temperature.

3.6 **Engine Accessories.** Engine accessory drives, other than those essential to the satisfactory functioning of the engine, shall be suitably loaded by slave accessories or by a suitable brake, or by rig tests. Accessories not essential to the satisfactory functioning of the engine need not be fitted during the Final Test.

3.7 **Test Fans which may be used.** When an engine is to be tested using a fan, the type of fan to be used shall first have been approved by the CAA as being suitable for the particular type of engine and test cell, and the particular fan to be used shall have been satisfactorily calibrated on an engine of known power in the test cell in which it is to be used in accordance with the instructions issued by the engine manufacturer.

3.8 **Engine Performance Assessment with Test Fans.** When tests are made using fans, the rpm obtained is used as an indication of the power obtained except when approved torquemeters form part of the engine being tested. If there is no torquemeter, no attempts shall be made to quote the output in terms of power and no specific fuel consumption shall be assessed.

3.9 **Limitations not simultaneously attainable when using Test Fans.** If when using a test fan the maximum manifold pressure and crankshaft rotational speed appropriate to the conditions of the tests cannot both be obtained concurrently, the individual periods of the test shall be run at whichever limitation is reached first, except that during the stages to be run at Maximum Cruising or Maximum Continuous Power the observed power of the engine in each supercharger gear shall be not less than 90% of the established Maximum Cruising or Maximum Continuous Power for the Type engine at sea-level respectively.

4 OBSERVATIONS

4.1 Throughout the tests observations shall be made as prescribed in the Observations column associated with the stage or test. The numbers entered in the Observations columns shall be interpreted in accordance with the code given in 4.3.

NOTE: Where the letters N.A. appear in the code it signifies that the observation prescribed in British Civil Airworthiness Requirements against this code number does not apply to the testing of the low-power, air-cooled engines with which this series of Leaflets is concerned.

4.2 Engine operating conditions shall be allowed to stabilise before observations are taken. In particular, during the rating tests observations taken less than 3 minutes after a change in engine operating conditions shall not be included in the performance curves.

4.3 **Test Observations Code**

Ref. No.	Observation	Standard Units
1	Crankshaft rotational speed	rpm
2	Manifold pressure	kN/m^2 or kPa (inHg)
3	Main oil pressure	kN/m^2 or kPa (lbf/in^2)
4	Auxiliary oil pressure	kN/m^2 or kPa (lbf/in^2)
5	Oil pressure at inlet to pump	kN/m^2 or kPa (lbf/in^2)
6	Fuel pressure at inlet to carburettor or injector	kN/m^2 or kPa (lbf/in^2)
7	N.A.	
8	N.A.	
9	N.A.	
10	N.A.	
11	Oil inlet temperature	°C
12	Oil outlet temperature	°C
13	N.A.	
14	N.A.	
15	Cylinder temperature	°C
16	Cooling air temperature (in front of engine)	°C
17	Cooling air speed (or pressure difference)	m/s or kN/m^2 or kPa (mile/h or inH_2O)
18	N.A.	
19	N.A.	
20	Oil circulation rate	litre/h (gal/min)
21	Oil consumption	litre/h (pint/h)
22	Fuel consumption	kg/h or litre/h (lb/h or pints/h)
23	Air intake temperature	°C
24	Power developed	kW (BHP)
25	Exhaust back-pressure	kN/m^2 or kPa (lbf/in^2)
26	Test-house barometer	kN/m^2 or kPa (inHg)
27	Air intake pressure	kN/m^2 or kPa (inHg)
28	Temperature of air passing propeller or test fan	°C

5 GENERAL CONDITIONS

5.1 Each stage of the Tests shall be run non-stop. In the event of a stop occurring during any stage, the stage shall be repeated unless the CAA considers this to be unnecessary. The CAA reserves the right to require the complete test to be repeated if an excessive number of stops occurs.

5.2 Throughout each stage of the Tests, the crankshaft rotational speed and manifold pressure shall be maintained at, or as near as possible to, the declared maximum values appropriate to the engine operating conditions prescribed. The CAA may require a repeat run if, for any reason, the observed crankshaft rotational speed and manifold pressure deviate by more than $\pm 1\frac{1}{2}\%$ from the declared maximum values.

6 ENDURANCE TEST

6.1 The Endurance Test of the Schedule appropriate to the engine shall be made with the engine either fitted with a propeller or test fan, or coupled to a dynamometer or other approved means of absorbing the power output of the engine. In the event of a propeller or test fan being used, the CAA may be prepared to accept such deviation from the test conditions as may be necessary to enable one propeller or test fan only to be used. The engine manufacturers or overhaulers shall, in agreement with the CAA, establish the equivalent standards of performance (e.g. fuel consumption, oil consumption, etc.) to meet any such deviations.

6.2 Where any of the Engine Rating conditions of Stages 7, 8, 10 and, where applicable, 10a are similar, one run only need be made at the particular conditions, except that the run shall be repeated in each supercharger gear.

7 STRIP EXAMINATION Upon completion of the Endurance Test, the engine shall be dismantled for examination. The extent of any deviation from the complete strip examination which may be permitted will be decided by the CAA after due consideration of the quantities, and functional and inspectional standards of the initial batches of engines. After inspection, the engine shall be rebuilt for submission to the Final Test.

8 FINAL TEST

8.1 The Final Test of the Schedule appropriate to the type of engine shall be made with the engine either fitted with a test fan or mounted on a dynamometer test bench.

8.2 Where, due to the limitations of a test fan, standard test conditions cannot be attained, the engine overhauling agency shall, in agreement with the CAA, establish the equivalent standards of performance (i.e. fuel consumption, oil consumption, etc.).

8.3 Where any of the Engine Rating conditions of Stages 7, 8, 10 and 10a are similar, one run only need be made at the particular conditions, except that the run shall be repeated in each supercharger gear.

9 ACCEPTANCE CONDITIONS Apart from the general running standard of each engine and its ability to satisfactorily complete the tests laid down in the Requirements, the specific standards of performance appropriate to the engines tested shall be attained to the satisfaction of the CAA. These standards are given in Leaflet **EL/3-6** for dynamometer tested engines and in Leaflet **EL/3-7** for fan tested engines.

10 CERTIFICATE OF COMPLIANCE A Certificate of Compliance should be issued for each aircraft engine after the overhaul and testing have been satisfactorily completed.

SCHEDULE I

OVERHAULED PISTON ENGINES

TESTS FOR ENGINES RATED IN ACCORDANCE WITH THE REQUIREMENTS IN FORCE ON AND AFTER 18th NOVEMBER, 1946 (ICAO RATINGS)

1 GENERAL Detailed requirements associated with the tests of this schedule are given in the text of this Leaflet, acceptance conditions are given in Leaflets **EL/3-6** and **EL/3-7** and correction formulae in Leaflet **EL/3-8.**

2 ENDURANCE TEST

Stage	Duration	Operating Conditions	Observations (See paragraph 4 of text)
1	—	Engine run-in light under its own power and then opened up in incremental stages of speed and load until Maximum Continuous Power is attained. Duration and conditions of speed and load for the various stages as agreed by the CAA.	
2	—	Tuning and preliminary tests of the fuel metering and ignition systems, and any other tests considered necessary by the CAA to ensure satisfactory operation of the engine up to, and including, Maximum Continuous Power. The tests shall be repeated in each supercharger gear.	
3	2 Hours	Maximum Continuous Power. Running equally divided between the supercharger gears.	Every 15 mins. 1, 2, 3, 8, 11, 14, 15, 22, 24. Beginning and end 4, 6, 7, 9, 13, 17, 23, 25, 28. At beginning 26. Throughout 21. During this Stage 20*.
4	30 Mins.	Maximum Weak-mixture Power. In the case of a supercharged engine having more than one supercharger gear, the running shall be in the low gear.	Beginning and end 4, 6, 7, 9, 13, 17, 23, 25, 28. At beginning 27. Throughout 21. At end 1, 2, 3, 8, 11, 14, 15, 22, 24.

***If acceptable alternative evidence of oil circulation rate is available, the CAA will waive this observation.**

Stage	Duration	Operating Conditions	Observations
5	5 Mins.	Minimum rpm for Weak-mixture Cruising and Maximum Weak-mixture manifold pressure, or full throttle. In the case of a supercharged engine having more than one supercharger gear, the running shall be in low gear. NOTE: If the engine is being tested with a propeller or a fan which limits the rpm or manifold pressure of this Stage to unrepresentative values, the Stage shall be run at the same operating conditions as for Stage 4.	Beginning and end 4, 6, 7, 9, 13, 17, 23, 25, 28. At beginning 27. Throughout 21. At end 1, 2, 3, 8, 11, 14, 15, 22, 24.
6	—	Further tuning and checks of the fuel metering and ignition systems, and any other tests considered necessary by the CAA to ensure satisfactory operation of the engine at the high power loading checks. The tests shall be repeated in each supercharger gear.	
7	5 Mins.	Maximum Continuous Power. The test shall be repeated in each supercharger gear.	Once 1, 2, 3, 6, 8, 9, 11, 14, 15, 22, 23, 24, 25, 28.
8	5 Mins.	Maximum Continuous Power conditions and full throttle with reduced air intake pressures (applicable to supercharged engines only—supercharger compression ratio check). The test shall be repeated in each supercharger gear.	” ”
9	5 Mins	Maximum Take-off Power conditions and full throttle with reduced air intake pressures (applicable to supercharged engines only—supercharger compression ratio check). The test shall be repeated in each supercharger gear, if applicable.	” ”
10	5 Mins.	Maximum Take-off Power.	” ”
11	—	Three supercharger gear change cycles (in the case of supercharged engines having more than one supercharger gear) at Maximum Continuous Power. If automatic gear changing is provided for, the gear changes shall be made under conditions approved by the CAA.	

Stage	Duration	Operating Conditions	Observations
12	—	Three accelerations, from slow running conditions up to the declared Maximum Take-off Power conditions in low supercharger gear. The test shall be repeated up to Maximum Continuous Power conditions in each other supercharger gear.	
13	—	Three hot starts effected by each of the means of starting provided on the engine.	

3 STRIP EXAMINATION As prescribed.

4 FINAL TEST

Stage	Duration	Operating Conditions	Observations
1	—	Three starts, one from cold, effected by each of the means of starting provided on the engine, unless otherwise agreed by the CAA.	
2	—	Engine run-in light under its own power and then opened up in incremental stages of speed and load until Maximum Continuous Power is attained. Duration and conditions of speed and load for the various stages as agreed by the CAA.	
3	—	Tuning and preliminary checks of the fuel metering and ignition systems, and any other tests considered necessary by the CAA to ensure satisfactory operation of the engine up to, and including, Maximum Continuous Power. The test shall be repeated in each supercharger gear.	
4	30 Mins.	Maximum Continuous Power. In the case of a supercharged engine having more than one supercharger gear, the running shall be in the low gear.	Every 10 mins. 1, 2, 3, 8, 11, 14, 15, 22, 24. Beginning and end 5, 6, 7, 9, 13, 17, 23, 24, 28. At beginning 26. Throughout 21. During this Stage 20*.
5	5 Mins.	Maximum Continuous Power in each supercharger gear other than the low gear.	Once 1, 2, 3, 6, 8, 9, 11, 14, 15, 22, 23, 24, 25, 28.

*If acceptable alternative evidence of oil circulation rate is available, the CAA will waive this observation.

Stage	Duration	Operating Conditions	Observations
6	—	Further tuning and checks of the fuel metering and ignition systems, and other tests considered necessary by the CAA to ensure satisfactory operation of the engine at the high power performance checks; these shall include slow running, accelerations as in Stage 12 of the Endurance Test, single ignition check at Maximum Take-off Power and at Maximum Continuous Power in each supercharger gear, and one supercharger gear change at Maximum Continuous Power.	
7	5 Mins.	Maximum Continuous Power. The test shall be repeated in each supercharger gear.	Once 1, 2, 3, 6, 8, 9, 11, 14, 15, 22, 23, 24, 25, 28.
8	5 Mins.	Maximum Continuous Power conditions and full throttle, with reduced air intake pressure (applicable to supercharged engines only—supercharger compression ratio check). The test shall be repeated in each supercharger gear.	,, ,,
9	5 Mins.	Maximum Take-off Power conditions and full throttle with reduced air intake pressures (applicable to supercharged engines only—supercharger compression ratio check). The tests shall be repeated in each supercharger gear, if applicable.	,, ,,
10	5 Mins.	Maximum Take-off Power.	
11	—	A selection of at least five rpm settings (as agreed by the CAA) at Maximum Weak-mixture Power manifold pressure, to enable a power/rpm curve to be drawn. The curve shall be obtained in each supercharger gear. NOTE: This Stage may be waived when it is rendered impracticable by the engine being tested with a fan.	**At each speed 1, 2, 8, 22, 23, 24, 25. Once during downward portion and once during upward portion of curve 6, 9, 11, 14, 15. Once 17.**
12	—	Where the Final Test has been made with fuel containing tetra-ethyl-lead an agreed anti-corrosion treatment of the parts exposed to combustion shall be carried out on completion of the test.	

SCHEDULE 2

OVERHAULED PISTON ENGINES

TESTS FOR ENGINES RATED IN ACCORDANCE WITH THE REQUIREMENTS IN FORCE BEFORE 18th NOVEMBER, 1946 (PRE-ICAO RATINGS)

1 GENERAL Detailed requirements associated with the tests of this schedule are given in the text of this Leaflet, acceptance conditions are given in Leaflets **EL/3-6** and **EL/3-7** and correction formulae in Leaflet **EL/3-8.**

2 ENDURANCE TEST

Stage	Duration	Operating Conditions	Observations (See paragraph 4 of text)
1	—	Engine run-in light under its own power and then opened up in incremental stages of speed and load until Maximum Cruising Power is attained. Duration and conditions of speed and load for the various stages as agreed by the CAA.	
2	—	Tuning and preliminary tests of the fuel metering and ignition systems, and any other tests considered necessary by the CAA to ensure satisfactory operation of the engine up to, and including, Maximum Cruising Power. The tests shall be repeated in each supercharger gear.	
3	2 Hours	Maximum Cruising Power. Running equally divided between the supercharger gears.	Every 15 mins. 1, 2, 3, 8, 11, 14, 15, 22, 24. Beginning and end 4, 6, 7, 9, 13, 17, 23, 25, 28. At beginning 26. Throughout 21. During this Stage 20*.
4	30 Mins.	Maximum Weak-mixture Power. In the case of a supercharged engine having more than one supercharger gear, the running shall be in the low gear.	Beginning and end 4, 6, 7, 9, 13, 17, 23, 25, 28. At beginning 27. Throughout 21. At end 1, 2, 3, 8, 11, 14, 15, 22, 24.

*If acceptable alternative evidence of oil circulation rate is available, the CAA will waive this observation.

Stage	Duration	Operating Conditions	Observations
5	5 Mins.	Minimum rpm for Weak-mixture Cruising and Maximum Weak-mixture manifold pressure, or full throttle. In the case of a supercharged engine having more than one supercharger gear, the running shall be in the low gear. NOTE: If the engine is being tested with a propeller or a fan which limits the rpm or manifold pressure of this Stage to unrepresentative values, the Stage shall be run at the same operating conditions as for Stage 4.	Beginning and end 4, 6, 7, 9, 13, 17, 23, 25, 28. At beginning 27. Throughout 21. At end 1, 2, 3, 8, 11, 14, 15, 22, 24.
6	—	Further tuning and checks of the fuel metering and ignition systems, and any other tests considered necessary by the CAA to ensure satisfactory operation of the engine at the high power loading checks. The tests shall be repeated in each supercharger gear.	
7	5 Mins.	Maximum Climbing Power. The test shall be repeated in each supercharger gear.	Once 1, 2, 3, 6, 8, 9, 11, 14, 15, 22, 23, 24, 25, 28.
8	5 Mins.	Maximum Climbing Power and full throttle with reduced air intake pressures (applicable to supercharged engines only—supercharger compression ratio check). The test shall be repeated in each supercharger gear.	" "
9	5 Mins.	Maximum Take-off Power conditions and full throttle with reduced air intake pressures (applicable to supercharged engines only—supercharger compression ratio check). The tests shall be repeated in each supercharger gear, if applicable.	" "
10	5 Mins.	Maximum Take-off Power.	" "
10a	5 Mins.	Emergency Cruising Power. The test shall be repeated in each supercharger gear.	" "
11	—	Three supercharger gear change cycles (in the case of supercharged engines having more than one supercharger gear) at Maximum Climbing Power. If automatic gear changing is provided for, the gear changes shall be made under conditions approved by the CAA.	

Stage	Duration	Operating Conditions	Observations
12	—	Three accelerations, from slow running conditions up to Maximum Take-off Power conditions in low supercharger gear. The test shall be repeated up to Maximum Climbing Power conditions in each other supercharger gear.	
13	—	Three hot starts effected by each of the means of starting provided on the engine.	

3 STRIP EXAMINATION As prescribed.

4 FINAL TEST

Stage	Duration	Operating Conditions	Observations
1	—	Three starts, one from cold, effected by each of the means of starting provided on the engine, unless otherwise agreed by the CAA.	
2	—	Engine run-in light under its own power and then opened up in incremental stages of speed and load until Maximum Cruising Power is attained. Duration and conditions of speed and load for the various stages as agreed by the CAA.	
3	—	Tuning and preliminary checks of the fuel metering and ignition systems, and any other tests considered necessary by the CAA to ensure satisfactory operation of the engine up to, and including, Maximum Cruising Power. The test shall be repeated in each supercharger gear.	
4	30 Mins.	Maximum Cruising Power. In the case of a supercharged engine having more than one supercharger gear, the running shall be in the low gear.	Every 10 mins. 1, 2, 3, 8, 11, 14, 15, 22, 24. Beginning and end 4, 6, 7, 9, 13, 17, 23, 25, 28. At beginning 26. Throughout 21. During this Stage 20*.
5	5 Mins.	Maximum Cruising Power in each supercharger gear other than the low gear.	Once 1, 2, 3, 6, 8, 9, 11, 14, 15, 22, 23, 24, 25, 28.
6	—	Further tuning and checks of the fuel metering and ignition systems and other tests considered necessary by the CAA to ensure satisfactory operation of the engine at the high power performance checks; these shall include slow	

*If acceptable alternative evidence of oil circulation rate is available, the CAA will waive this observation.

Stage	Duration	Operating Conditions	Observations
		running, accelerations as in Stage 12 of the Endurance Test, single ignition check at Maximum Take-off Power and at Maximum Climbing Power in each supercharger gear, and one supercharger gear change at Maximum Climbing Power.	
7	5 Mins.	Maximum Climbing Power. The test shall be repeated in each supercharger gear.	Once 1, 2, 3, 6, 8, 9, 11, 14, 15, 22, 23, 24, 25, 28.
8	5 Mins.	Maximum Climbing Power conditions and full throttle with reduced air intake pressures (applicable to supercharged engines only—supercharger compression ratio check). The test shall be repeated in each supercharger gear.	,, ,,
9	5 Mins.	Maximum Take-off Power conditions and full throttle with reduced air intake pressure (applicable to supercharged engines only—supercharger compression ratio check). The tests shall be repeated in each supercharger gear, if applicable.	,, ,,
10	5 Mins.	Maximum Take-off Power.	
10a	5 Mins.	Emergency Cruising Power. The test shall be repeated in each supercharger gear.	,, ,,
11	—	A selection of at least five rpm settings (as agreed by the CAA) at Maximum Weak-mixture Power manifold pressure, to enable a power/rpm curve to be drawn. The curve shall be obtained in each supercharger gear. NOTE: This Stage may be waived when it is rendered impracticable by the engine being tested with a fan.	At each speed 1, 2, 8, 22, 23, 24, 25. Once during downward portion and once during upward portion of curve 6, 9, 11, 14, 15. Once 17.
12	—	Where the Final Test has been made with fuel containing tetra-ethyl-lead, an agreed anti-corrosion treatment of the parts exposed to combustion shall be carried out on completion of the test.	

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AIRCRAFT

ENGINES

PISTON ENGINE OVERHAUL—DYNAMOMETER TESTING OF OVERHAULED ENGINES

1 INTRODUCTION

1.1 After an aero-engine has received a complete overhaul, the tests prescribed in Section C of British Civil Airworthiness Requirements may be made with the engine either fitted with a test fan or mounted on a dynamometer test bench. This Leaflet gives guidance on testing low-power, air-cooled engines when coupled to dynamometers and includes the acceptance conditions required by the CAA when overhauled engines are tested by this method.

1.2 The Leaflet is the sixth of a series dealing with piston engine overhaul and, like the rest of the series, does not aim to provide a complete guide to approved inspection organisations engaged in aero-engine overhaul. The particular purpose of this Leaflet is to give students and individual engineers an outline of engine test procedure and to draw attention to a number of points of special importance. Before actual tests are attempted on engines which are to be released in accordance with CAA Requirements an approved Engine Test Schedule must be available. All overhaul work on such engines must be in accordance with the manufacturer's instructions given in the Overhaul Manual and all tests must be made as prescribed in the Engine Test Schedule for the particular type.

1.3 The Requirements relating to the testing of small air-cooled piston engines after overhaul are reprinted in Leaflet **EL/3-5**, except that the prescribed acceptance conditions are included in this Leaflet **(EL/3-6)** and the prescribed formulae for performance corrections in Leaflet **EL/3-8.** Guidance on the testing of overhauled engines by means of test fans, and the prescribed acceptance conditions when engines are tested by this method, are given in Leaflet **EL/3-7.**

2 GENERAL The tests made after overhaul consist of an Endurance Test followed by a strip examination, and a Final Test during which the performance is determined. The CAA sometimes permits relaxation of the Requirements for complete strip examination, but the extent of any deviation must be approved by the CAA.

2.1 The method of testing an engine on a dynamometer test bench enables the engine output to be determined in terms of brake power, whereas this is not practicable when the engine is tested with a fan or flight propeller unless the engine incorporates a torquemeter of known accuracy or the torque reaction on the engine mounting can be measured with exactitude.

2.2 Since the engines with which this series of Leaflets is concerned are not usually fitted with torquemeters, their performance after overhaul is most often assessed by testing them when fitted with calibrated test fans, in which case, as explained in Leaflet **EL/3-7,** the corrected rpm obtained under specified conditions is taken as a measure of the engine performance. However, before an engine can be so tested, the test fan itself must be calibrated in the test cell to be used, on an engine, the performance of which has been determined on a dynamometer test bench.

3 **TEST PLANT** A dynamometer is a heavy machine which must be rigidly mounted. This fact and the necessity of making adequate arrangements for water, electricity, fuel and oil supplies, for exhaust gas disposal, for drains, for silencing and for ventilation means that dynamometer testing is usually performed in a permanent test house. It is beyond the scope of this Leaflet to describe such a test house in detail but attention is drawn, in the following paragraphs, to a number of important features:

3.1 A dynamometer test bench consists of a mounting for the engine, a coupling shaft for interconnecting the engine to the dynamometer, a fan and the necessary ducting for cooling the engine, a starting system for the engine, the necessary controls and instruments for operating the engine and measuring its performance, and systems for supplying the engine with fuel and oil and the dynamometer with water. In the case of supercharged engines a depression box should be provided for the air intake so that altitude conditions can be simulated when specified in the Engine Test Schedule.

3.2 When an engine is mounted on the test bench, care should be taken that the engine propeller shaft is in exact alignment with the shaft of the dynamometer, but the coupling should not be completed until the zero setting of the torque measuring equipment has been checked. Guidance on the procedure for this check is given in paragraph 4.

3.3 The coupling shaft between the engine and dynamometer must be specially designed. It must be light in weight, properly supported and in perfect dynamic balance. Cardan shafts incorporating two universal joints are normally used; they should be inspected before the start of the test to ensure that they have not been disturbed in any way that could upset their alignment or dynamic balance.

3.4 All test and measuring equipment must be of an approved type. All instruments should be calibrated periodically and thereafter should be checked for accuracy at regular intervals by an organisation approved for the purpose. Measuring equipment should also be checked at regular intervals, the check periods to be agreed with the CAA. Engine speed indicators should be checked with a stop watch against a revolution counter and, during tests, cross-checks should be made by measurement of the engine speed using a "Hasler" type instrument.

3.5 Before commencing the test, the oil filter elements in the feed lines should be either cleaned or renewed. Oil tanks should be drained and flushed at intervals of approximately 100 hours' running time.

3.6 Before checking oil consumption or oil circulation, the oil temperature must be stabilised at the check temperature specified in the appropriate test schedule. To obtain this condition, the test plant must be provided with suitable means of heating or cooling the oil as required. If the heating is accomplished with an electric immersion heater there is danger of damaging the chemical structure of the oil, since the surface temperature of this type of heater can rise to high values when the flow rate of the oil is low. It is therefore recommended that the oil is heated via a heat exchanger, using steam at a controlled pressure if a source is available but otherwise using a circulating water supply as a means of conveying heat from an immersion heater to the oil.

3.7 Engine oil consumption can be checked by either of the following methods:

(a) Readings of oil volume should be taken from a graduated sight glass fitted externally to the oil tank. The readings should be recorded each 15 minutes during the prescribed stages of the test schedule and the difference between the initial and final readings can be used to calculate oil consumption in litre/h (pint/h).

(b) On an engine which has a "wet sump" lubrication system, the oil should be drained out and weighed at the end of the running-in period, replaced in the engine, then drained out and weighed again after the Endurance Test. The difference between these weights will enable the oil consumption to be calculated.

3.8 The fuel pressure gauge connection should be made at the inlet to the carburettor or fuel injector. A fuel flowmeter calibrated in litre/h or kg/h (pints/h or lb/h) must be tapped into the fuel supply line and readings must be taken as called for in the test schedule appropriate to the engine.

3.9 To avoid unscheduled stoppages during the test, all pipe connections should be properly made and all pipes should be adequately supported. The test bench controls should be checked for alignment and range of movement and the engine baffles and cowlings should be firmly secured.

3.10 Measurements of the exhaust back pressure should be made as close to the engine as possible but, where more than one manifold is provided because of the cylinder configuration, the pressure at each silencer connection should be checked and the mean reading obtained. If it is inconvenient to measure the pressure from each connection throughout the test, the pressure tapping with the value closest to the mean reading may be used.

4 TYPES OF DYNAMOMETER There are three principal types of dynamometer commonly used for the testing of aero-engines, the hydraulic type, the electrical (direct-current) type and the eddy-current type. With all types, the engine under test is directly coupled to the rotor shaft of the dynamometer, which can be loaded to obtain the desired engine speed. The dynamometer absorbs the power output of the engine and, in doing so, experiences a torque reaction on its own casing. It is by measurement of this torque reaction that the brake power of the engine is determined; it can be calculated from a simple formula which takes into account the torque reaction and the rpm of the dynamometer rotor.

$$\text{Brake Power} = \frac{\text{torque (Nm)} \times 2\pi \times \text{rpm}}{60{,}000}\ \text{kW} \quad \text{or} \quad \frac{\text{torque (lb ft)} \times 2\pi \times \text{rpm}}{33{,}000}\ \text{BHP}$$

4.1 **Hydraulic Dynamometers.** A part sectioned view of a typical hydraulic dynamometer is illustrated in Figure 1. The shaft of this machine carries a rotor which has a series of semi-elliptical cups separated by vanes; the rotor runs between two sets of similar cups formed in the casing. Water at constant pressure is fed into the casing. Rotation of the shaft circulates this water by centrifugal force around the orbits formed by the opposing pairs of moving and static cups, the water thus absorbing the power fed into the machine by the engine under test. The shaft is supported in the casing by ball bearings and the casing itself is mounted on trunnion bearings which allow it to rotate in response to torque reaction. The reaction on the casing is balanced, and the rotation of it constrained, by a system of weights and levers and a spring balance which, when correctly preset, indicates the load due to torque. The loading on the engine can be reduced by adjusting a pair of shrouds, known as sluice gates, so that they progressively mask the rotor cups from the cups in the casing, and can be increased by the reverse process. The type illustrated is a non-reversible dynamometer but reversible types are also made. The latter have two rotors and two sets of casing vanes, one to work clockwise and the other anti-clockwise.

NOTE: The following instructions are applicable when the testing is done with a Non-reversible Froude Type D.P.Y. dynamometer. Since this dynamometer is the type most widely used for testing small aero engines, these instructions have been included as an example. Should any other type of hydraulic dynamometer be employed, instructions for its use must be obtained from the manufacturer.

4.1.1 Before coupling an engine to the dynamometer, the static balance of the weighing apparatus should be checked. This is done in the following way:—

(a) Adjust the inlet and outlet water valves so that there is a steady flow of water through the dynamometer.

(b) A dashpot prevents oscillations of the torque lever arm from being transmitted to the spring balance. When the spring balance is being checked the dashpot should be freed by setting its adjusting nut to zero.

(c) Remove all loose balance weights from the end of the lever arm, leaving the fixed static weight in place.

(d) If the lever arm is not in a position slightly above the bottom stop on the bedplate, the adjustment on the interconnection to the spring balance should be reset. The adjustment should be checked by raising the lever arm which should cause the pointer of the spring balance to make one revolution before the lever arm touches the top stop in the spring balance column.

(e) By moving and locking the small sliding weight on the lever arm, the pointer of the spring balance should then be reset to zero. The dynamometer is then ready for the test and the engine should be coupled to it, care being taken to ensure exact alignment of the engine and dynamometer shafts.

(f) A final check should be made by alternately lifting and depressing the lever arm by hand, when the pointer should settle down to zero and it should be possible by depressing the lever arm to move the pointer a few degrees to the minus side of zero, without causing stiffness or binding. The adjusting nut of the dashpot should then be screwed down so that the by-pass will be partially closed, although final adjustments must be made when the engine is running.

NOTE: If the spring balance does not register sufficient load to balance the output of the engine under test, the load may be increased by adding extra balance weights. These are marked with figures representing the correct weight which must be added to the load registered on the spring balance and the sum of weights and registered load will then represent the factor W in the formula given in paragraph 4.1.3 for calculating Brake Power.

4.1.2 Before starting an engine coupled to a non-reversible dynamometer, the water inlet valve should be fully opened but the outlet valve should only be opened slightly. As prescribed in the Requirements, the Engine Test Schedules (Leaflet EL/3-5) specify that engines under test should be run-in under their own power with an initial light load. For starting purposes it is advisable to close the sluice gates to minimise the load on the engine; afterwards, as the engine is opened up in incremental stages, the load should be progressively increased by opening the sluice gates, to maintain the operating conditions to those agreed for each stage by the CAA. As the engine power is increased the water outlet valves should be adjusted so that they pass sufficient water to keep the water temperature at a reasonable level; about 60°C is satisfactory.

4.1.3 It has been stated that the power of the engine can be found if the torque and the rpm of the rotor are known. The torque is calculated by multiplying the length of the lever arm by the effective weight lifted. Since the lever length, the value of π and the power conversion factor are all constant, the simplified formula given below can be used. The formula introduces a constant K known as the dynamometer constant, which has a value determined for each type of dynamometer by its manufacturer. The value of K, which varies with the length of the lever arm, is stamped on the name-plate of each dynamometer. The formula is therefore:

$$\text{Brake Power} = \frac{W \times N}{K}$$

where W = net weight lifted by dynamometer
N = rpm of rotor
K = dynamometer constant

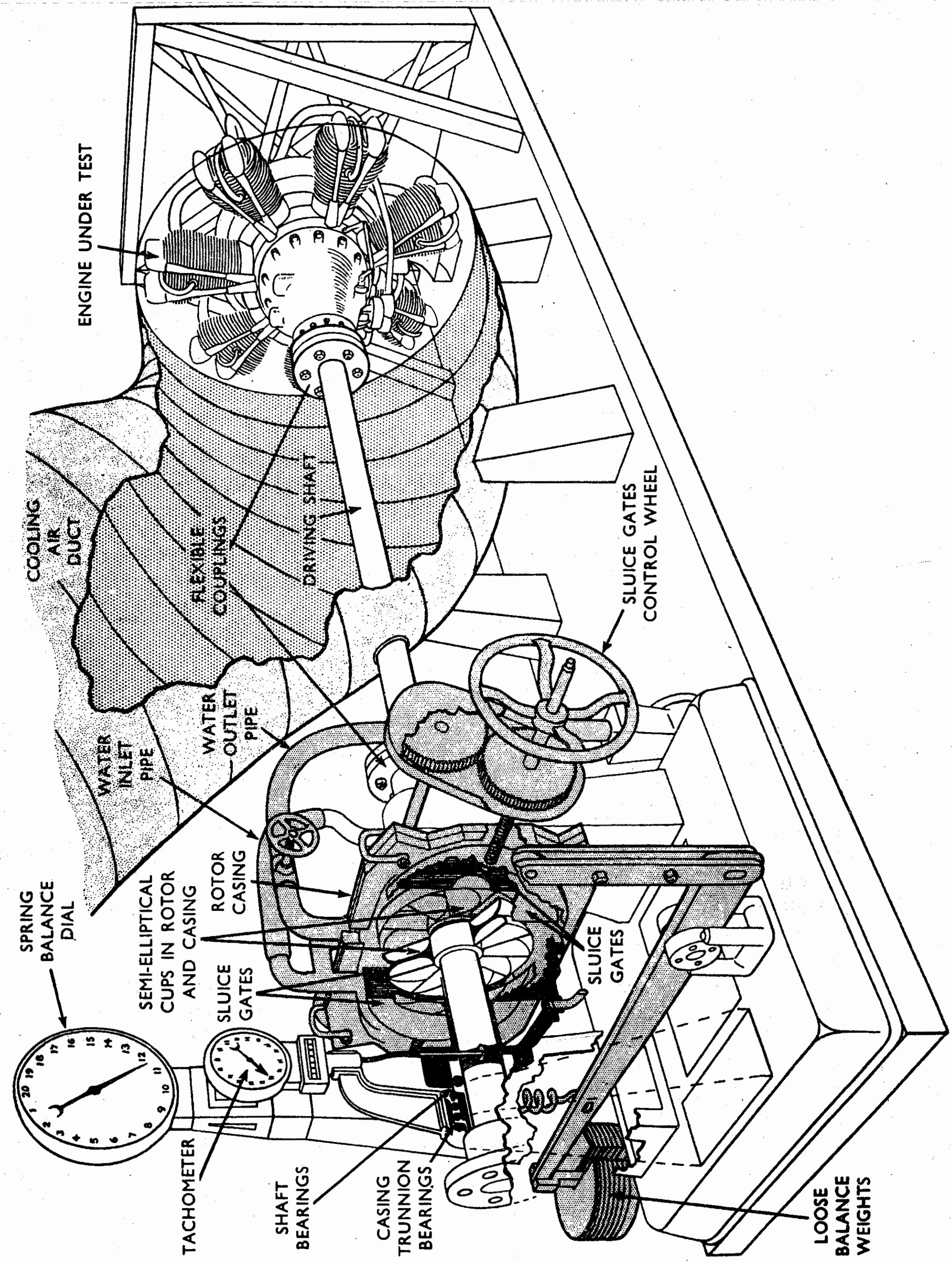

Figure 1 RADIAL ENGINE COUPLED TO FROUDE HYDRAULIC DYNAMOMETER

4.2 **Electrical Dynamometers.** The type of electrical dynamometer usually supplied for the testing of small engines consists of a generator designed so that it will also function as an electric motor. Thus when supplied with electrical power it can be used for running-in a newly-assembled engine or when driven by an engine under test it generates electrical energy. The first of these functions is not normally applicable to overhauled aero-engines, which are run-in under their own power, but it does provide a means of measuring the power required to overcome the internal resistance of an engine when this information is required. The armature shaft of a typical electrical dynamometer is carried by bearings in the casing of the machine and the casing is itself carried in co-axial bearings which allow it to swivel in the same direction of rotation as the shaft. When an engine is driving the armature shaft with the dynamometer connected to an electric circuit, the turning moment is resisted by a combination of bearing friction, electro-magnetic reaction and air resistance. These three loads each tend to rotate the casing, to which is attached a lever arm and weighing apparatus similar to that of a hydraulic dynamometer. The magnitude of the total force acting on the casing is indicated on a spring-balance dial, which enables the engine power to be found by the method given in paragraph 4.1.3.

4.3 **Eddy-current Dynamometers.** The single frame electrical dynamometer described in paragraph 4.2 is not designed to absorb high powers and therefore an eddy-current dynamometer is more often used for testing engines which develop over 150 kW (200 BHP). An eddy-current dynamometer is an electrical machine in which the rotor is constructed with a number of coarse teeth which act as magnetic poles. The rotor turns inside a stator which incorporates one or more field coils excited by a small amount of direct current, so that during rotation concentrations of magnetic flux are produced at each pole of the rotor. The flux concentrations induce eddy-currents in the stator and it is these which resist the rotation of the rotor and therefore load the engine under test. The degree of power absorption is controlled by regulating the amount of excitation of the main field coils. The engine power is converted into heat by the braking effect of the machine and cooling water has therefore to be circulated to conduct the heat away. In this type of dynamometer the water outlet temperature should not exceed 60°C but if possible it should be limited to 50°C as this will help to reduce the possibility of internal scale formation. As with the hydraulic and electric types of dynamometer, the engine power is found by measuring the torque reaction exerted on the stator casing. The casing is mounted on trunnion bearings which allow some freedom of oscillation and attached to the casing is a lever arm which operates weighing gear. The engine power is found by the method given in paragraph 4.1.3.

4.4 **Dynamometer Plant for Helicopter Engines.** British Civil Airworthiness Requirements prescribe that engines intended to be installed in helicopters should be tested in the attitude in which they will be mounted in the airframe (Leaflet **EL/3-5**). Thus when the axis of rotation of the crankshaft is to be vertical in service, one solution is to provide a right-angled gearbox to couple the engine to the dynamometer. The dynamometer itself can be of any type capable of absorbing the power output of the engine, but the brake power readings obtained from it must be corrected for the power absorbed by the gearbox. (This information is usually obtainable from the manufacturer of the gearbox.) Since helicopter engines are not always provided with integral reduction gears, a right-angled gearbox may be designed with a reduction ratio to assist in matching the engine speed to the characteristics of the dynamometer. If required, hydraulic dynamometers can be made to run directly coupled to helicopter engines without the introduction of a gearbox, and in addition special dynamometers can be made to suit vertical or any other shaft inclination desired. In some special cases both dynamometer and engine can be arranged on a swivel to give variable adjustment of shaft inclination. The test bench may also be designed so that the engine is provided with an external source of cooling air since, if it drives its own cooling fan, it may be necessary to make allowance for the power absorbed by the fan.

5 TEST RUNNING AND OBSERVATIONS After the engine has been coupled to the dynamometer and the preparations for starting and running have been completed, the engine should be tested strictly in accordance with the approved Test Schedule appropriate to the type. The observations made during the tests should be recorded on properly prepared test log sheets. During the tests attention should be given to the following points:

5.1 The engine should be tuned according to the instructions in the approved Test Schedule. The observed fuel flowmeter readings must be corrected to standard conditions; formulae and/or charts for this purpose are normally provided with the schedules supplied by engine manufacturers. Likewise, the fuel flow acceptance limits (see paragraph 6.1.2) are normally quoted in the same source.

5.2 At each stage of test running, a careful watch should be kept for signs of defects and such undesirable behaviour as excessive oiling, vibration, breather discharge or detonation.

5.3 Single ignition checks should be made and the power drop measured. As each magneto is switched OFF, the engine load should be reduced, e.g., by opening the sluice gates on a hydraulic dynamometer, so that the rpm is restored to that obtained with both magnetos operating. The differences in power output between operation with single and dual ignition should be recorded on the log sheets.

5.4 Stage 11 of the Final Test calls for a power/rpm curve to be drawn at the Maximum Weak-mixture Power manifold pressure. To obtain this curve the engine should be run over the range of rpm specified in the Test Schedule. The resultant curve should be smooth; if it is not so and any of the points plotted diverge to any appreciable extent, the readings should be rechecked.

5.5 If, after rechecking, it is necessary to adjust or replace any component or part, the test, or portions of it, will have to be repeated, unless otherwise agreed by the CAA.

6 ACCEPTANCE CONDITIONS The acceptance conditions for overhauled engines tested on a dynamometer test bench are prescribed in Section C of British Civil Airworthiness Requirements and are repeated in the following paragraphs. Apart from the general running standard of each engine and its ability to satisfactorily complete the tests detailed in the relevant schedule, the specific standards of performance of 6.1 or 6.2, as appropriate, must be obtained to the satisfaction of the CAA.

6.1 **Engines Rated in accordance with the Requirements in force on and after 18th November, 1946 (ICAO Ratings)**

6.1.1 **Power.** The corrected Maximum Take-off Power shall be not less than 96% of the declared Maximum Take-off Power. Also, in the case of a supercharged engine, the corrected power at the declared full throttle altitude at Maximum Take-off Power and Maximum Continuous Power conditions, as derived from the tests of Stages 7, 8, 9 and 10 of the Final Test, shall be not less than 96% of the declared power. Alternatively, the sum of the ratios of the corrected sea-level power and the corrected supercharger compression ratio (at 15°C) at Maximum Take-off and Maximum Continuous conditions to the established values for the prototype engine shall be not less than 1·96. These conditions shall be met in each supercharger gear.

NOTE: For the assessment of the supercharger performance, it is recommended that a chart should be prepared, for each supercharger gear, showing the absolute pressure which would be required at the air intake of the engine, with a supercharger compression ratio at 15°C equal to that quoted in the Engine Technical Certificate, when running at full throttle at the Take-off and Maximum Continuous manifold pressures (Take-off and Maximum Climbing for engines with pre-ICAO ratings). The chart, a specimen of which is reproduced in Leaflet **EL/3-8,** should cover a suitable range of rpm and air intake temperatures. The performance of the supercharger under test will be measured by comparing the observed air intake pressure with that determined from the chart.

6.1.2 **Fuel Consumption.** The fuel consumption at all sea-level rating conditions shall be within the limits quoted in the engine specification or technical certificate.

6.1.3 **Oil Consumption.** The mean oil consumption obtained from the tests of Stages 3 and 4 of the Endurance Test and Stage 4 of the Final Test, shall be within the declared limits. In the event of the engine not being able to comply with this requirement during the tests of Stages 3 and 4 of the Endurance Test, it shall be rejected for rectification and re-submission to the Endurance Test. Alternatively, the endurance running of Stages 3 and 4 of the Endurance Test may be extended up to a maximum of an additional 2 hours, until the consumption falls within the required limits over a period of at least 30 minutes duration. The consumption shall be checked in each supercharger gear. As a further alternative, where the applicant is of the opinion that the oil consumption can be improved by adjustment during strip examination, the endurance portion of the Final Test may be extended by the addition of a run limited to a minimum of 1 hour at the declared Maximum Continuous Power conditions. The running shall be equally divided between the supercharger gears. During the period of oil consumption measurement, ignition checks, or operation of any accessory or any other test or adjustment which may affect consumption, shall be avoided. The oil consumption in each supercharger gear shall be reasonably consistent.

6.1.4 **Accelerations.** Accelerations shall be smooth and free from hesitation or other signs of fuel-metering trouble.

6.1.5 **Single Ignition Check.** The power drop when running with single ignition shall not exceed the declared maximum.

6.1.6 **Cleanliness.** The engine shall be free from leaks at all joints and connections, etc.

6.2 **Engines Rated in accordance with the Requirements in force before 18th November, 1946 (pre-ICAO Ratings).** The acceptance conditions for these engines are the same as those in paragraph 6.1 except that Maximum Climbing Power should be substituted wherever reference is made to Maximum Continuous Power.

Issue 2.

December, 1978.

AIRCRAFT

ENGINES

PISTON ENGINE OVERHAUL—FAN TESTING OF OVERHAULED ENGINES

1 INTRODUCTION

1.1 After an aero-engine has received a complete overhaul, the tests prescribed in Section C of British Civil Airworthiness Requirements may be made with the engine either fitted with a test fan or mounted on a dynamometer test bench. This Leaflet gives guidance on testing low-power, air-cooled piston engines by means of test fans and includes the acceptance conditions required by the CAA when overhauled engines are tested by this method.

1.2 This Leaflet is the seventh of a series dealing with piston engine overhaul. Since the engines with which the series is concerned are more often tested by the fan method than on a dynamometer test bench, this Leaflet gives fairly detailed information on the methods used for choosing test fans to suit particular engines and for calibrating test fans. It also draws attention to a number of other points of special importance. Before tests are attempted on engines which are to be released in accordance with CAA Requirements, an approved Engine Test Schedule (see paragraph 2) must be available. All overhaul work on engines must be in accordance with the manufacturer's instructions given in the Overhaul Manual, and all tests must be made as prescribed in the Engine Test Schedule for the particular type.

1.3 The Requirements relating to the testing of small air-cooled piston engines after overhaul are reprinted in Leaflet **EL/3-5,** except that the prescribed acceptance conditions are included in this Leaflet and the prescribed formulae for performance corrections in Leaflet **EL/3-8.** Leaflet **EL/3-8** also incorporates a set of correction charts for use during test fan calibrations. Guidance on the testing of overhauled engines on dynamometer test benches, and the acceptance conditions prescribed when engines are tested by this method, are given in Leaflet **EL/3-6.**

2 GENERAL The test procedure prescribed for piston engines after overhaul includes an Endurance Test followed by a strip examination, and a Final Test during which the performance is determined. Engine manufacturers in the United Kingdom prepare Test Schedules and instructions which are approved by the CAA for use when testing particular engine types. As explained in Leaflet **EL/3-5,** these schedules are based on the appropriate basic schedule from Section C of the Requirements and the Engine Technical Certificate.

2.1 Although the Requirements recognise two basic methods of testing piston engines after overhaul, the test fan method, because of its lower cost, is most frequently used for testing the smaller engines. This method entails fitting the engine with an approved type of test fan which is calibrated to absorb the power output of the engine at a specified rpm. Since torquemeters are not usually fitted to the small engines with which this Leaflet is concerned, the rpm obtained when running with a calibrated fan is used to indicate the engine power. However, the results obtained can be grossly inaccurate unless exceptional care is exercised in the application of the method.

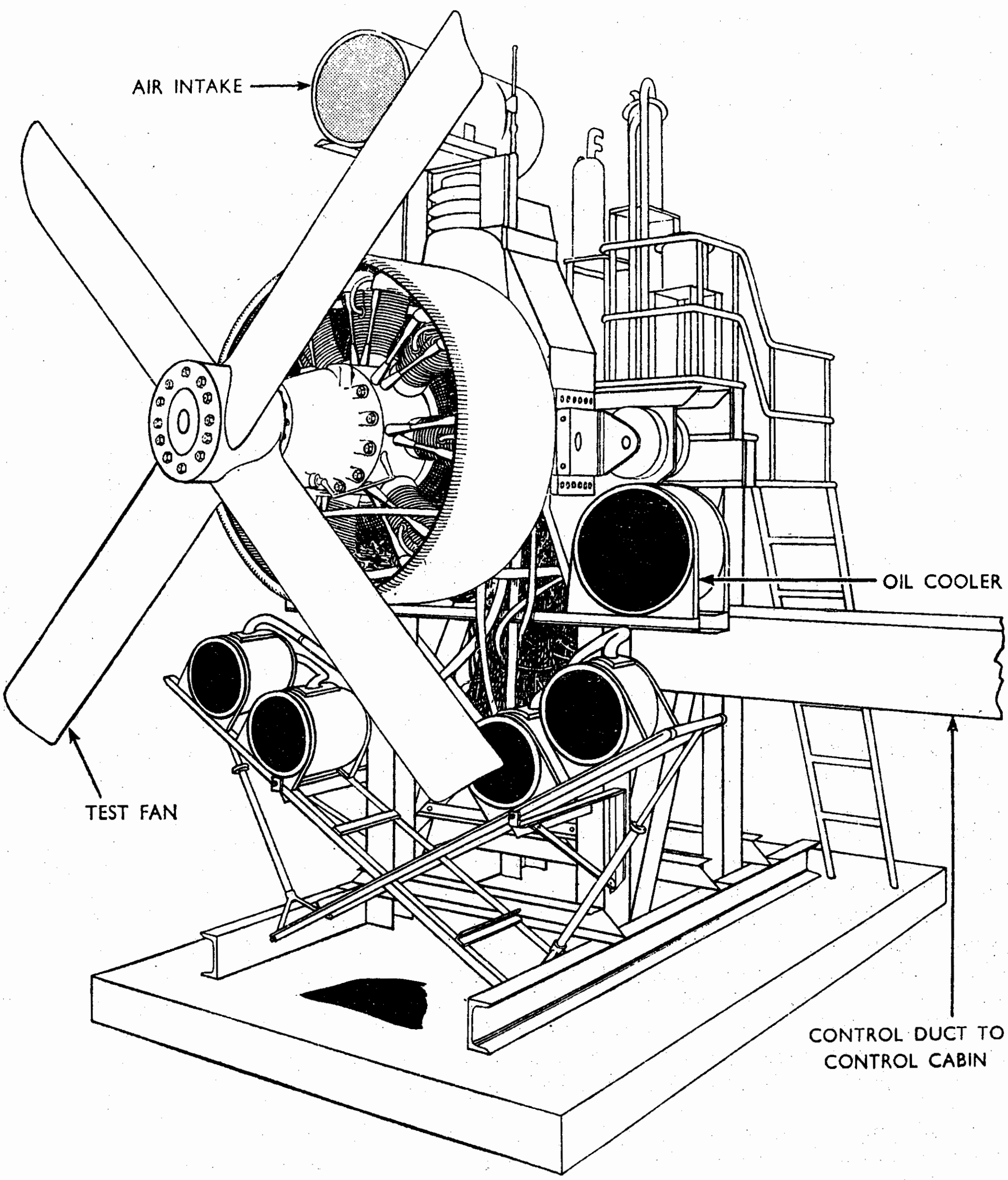

Figure 1 AERO-ENGINE TEST BENCH FOR FAN TESTING

2.2 Since it is a requirement that helicopter engines be tested in the attitude in which they will be installed in the helicopter, engines which are intended to be installed with the axis of rotation either vertical or inclined from the horizontal may be tested on a dynamometer test bench specially designed for the purpose (Leaflet **EL/3-6**). However, tests on such engines are often run with the engine loaded by a paddle-bladed fan, in which case it is sometimes necessary to change the paddles to suit conditions at the various stages of the test run. Thus paddles of one diameter ('A' plates) may be specified for running at Maximum Continuous Power conditions and paddles of a different diameter ('B' plates) for running at Maximum Take-off Power conditions. Whilst paddle-bladed fans are calibrated in a similar manner to aerofoil-bladed fans, the technique of rendering them 'heavy' or 'light' is of course different.

3 FAN TESTING The fan method of testing an aero-engine consists of running the engine on a test bench with a calibrated test fan fitted instead of a flight propeller, the fan providing the means of loading the engine during the test. To assess the engine power output, the rpm of the overhauled engine when loaded with the test fan must be compared with the rpm which would be developed by the type engine loaded with the same fan and run on the same test bed under the same conditions.

3.1 **Test Plant.** The engine to be tested should be mounted on a test bench which should be provided with the complete oil, fuel and electrical systems required for starting and running the engine, and, in the case of supercharged engines, with equipment for reducing the pressure of the air supplied to the engine intake so that altitude conditions can be simulated when specified in the engine test schedule. A suitable type of test bench for small engines is shown in Figure 1; it can be adapted for either radial or in-line engines. Whichever type of engine is fitted, adequate provision must be made for cooling it. This may necessitate fitting an oversize cooling scoop to in-line engines. Testing should normally be done in a specially designed building, preferably located so that the engines under test inhale air which is free from excess moisture or industrial contaminants. However, some test stands for the testing of small engines are of a mobile type and, in favourable atmospheric conditions, may be used in the open air. In all cases the test bench must be approved by the CAA.

3.2 **Test Instruments.** The test bench should be equipped with an approved range of instruments to enable accurate indication of the relevant test data specified in the test schedule appropriate to the engine. The instruments and all measuring equipment should be calibrated prior to fan calibration and should afterwards be checked for accuracy at regular intervals, as agreed with the CAA. An additional revolution counter which will serve as a master for checking the continuous reading rpm indicator must also be available; an instrument approved for this purpose is the "Hasler", which is a hand-held indicator of great accuracy incorporating its own chronometer. In accordance with the Test Observations Code given in the Requirements (see Leaflet **EL/3-5**), the following continuous reading instruments are required for the testing of small air-cooled engines:

Instrument	**Calibration**
1. Engine speed indicator	rpm
2. Manifold pressure gauge	kN/m² or kPa (inHg)
3. Main oil pressure gauge	kN/m² or kPa (lbf/in²)
4. Auxiliary oil pressure gauge	kN/m² or kPa (lbf/in²)

Instrument	Calibration
5. Pump inlet oil pressure gauge	kN/m² or kPa (lbf/in²)
6. Fuel pressure gauge	kN/m² or kPa (lbf/in²)
7. Oil temperature gauges (inlet and outlet temperatures)	°C
8. Cooling air temperature gauge	°C
9. Cooling air speed indicator (or cooling air differential pressure gauge)	m/s or kN/m² (mile/h or inH_2O)
10. Stop watch for checking oil circulation rate	Seconds
11. Cylinder head temperature gauge	°C
12. Fuel flowmeter	kg/h or litre/h (lb/h or pints/h)
13. Air intake temperature gauge	°C
14. Exhaust back pressure gauge	kN/m² or kPa (lbf/in²)
15. Test house barometer	kN/m² or kPa (inHg)
16. Air intake pressure gauge	kN/m² or kPa (inHg)
17. Fan air temperature gauge	°C

3.3 **Test Plant Oil System.** The instructions given in Leaflet **EL/3-6** for cleaning and heating test bench oil systems and for measuring oil consumption and oil circulation are also applicable when an engine is to be tested with a fan.

3.4 **Instrument and Pipe Connections.** The provisions of paragraphs 3.8, 3.9 and 3.10 of Leaflet **EL/3-6** are also applicable when an engine is to be tested with a fan.

4 CHOICE OF TEST FAN The type of test fan to be used when testing a particular type of engine must have been agreed with the engine manufacturer and approved by the CAA; the criteria determining the choice include the power dispersal characteristics of the fan, the ability to withstand the blade stresses imposed during prolonged bench running, and the cooling requirements of the engine. There are two main groups of fans: fixed-pitch fans, and variable-pitch fans controlled by a constant-speed governor.

4.1 **Fixed-pitch Test Fans.** Fixed-pitch fans may be sub-divided into two types: those which have one pitch that cannot be altered and those which have an adjustable pitch which can be locked at predetermined pitch settings. These two types of fans are usually designed and calibrated to absorb the Maximum Continuous Power of the engine when it is running at Maximum Continuous rpm under standard sea-level conditions and it is also essential that they should not allow the engine to overspeed at the Maximum Take-off manifold pressure.

4.1.1 Fans with unalterable pitch settings are specially made with square-tipped blades of laminated wood construction. The blades are made wide to provide maximum power absorption and maximum engine cooling with minimum blade tip diameter. Because design limitations and variations in test conditions make it impossible to predetermine the exact diameter required to absorb a given power, the blades are supplied oversize and have to be individually calibrated by successively removing material from the blade tips until the required power absorption is obtained. This operation is known as "cropping".

4.1.2 To crop a fan, thin slices are sawn from the tips of each wooden blade, care being taken to ensure that equal amounts are removed from each tip and that all sharp corners are rounded off. After each cropping, the fan must be rebalanced before it is replaced on the engine. On completion of cropping, the cropped blades should be protected against deterioration by applying the approved finish to the bare ends. If the blades are overcropped by a small amount, or are found to be absorbing too little power for any other reason, it may be permissible to make the fan "heavy" by adding spoilers to the blades. The advice of the fan manufacturer should be sought on the method of spoiling appropriate to a particular type of fan.

4.1.3 The power absorption characteristics of a fixed-pitch fan with adjustable-pitch settings are varied by altering the pitch of the blades. The blade pitch is usually altered by resetting stops incorporated in the hub of the fan, and these should be adjusted in accordance with the instructions of the manufacturer of the fan. If the rpm obtained during calibration are too high, the blades should be moved towards coarse pitch; if the rpm are too low, they should be moved towards fine pitch.

4.2 **Variable-pitch Test Fans.** Variable-pitch test fans controlled by a constant-speed governor can be operated at a fixed, predetermined position, e.g. on the fine or coarse pitch stop, and also at variable settings under the control of the governor. Fans of this type are calibrated by adjusting their pitch stops so that the power of the engine at Maximum Take-off manifold pressure is absorbed without over-speeding when the engine is running under standard sea-level conditions. Such fans must also be able to absorb the Maximum Continuous engine power when constant speeding or running against a stop with the engine running under Maximum Continuous conditions.

4.3 **Flight Propellers.** A flight propeller may be approved as a test fan if the engine cooling provided is adequate and the propeller is able to withstand the more severe stresses which occur in the blades when operated under static instead of flight conditions. Once a metal flight propeller has been used as a test fan it must not again be used for flight purposes.

NOTE: Experience has shown that, unless a cable-suspended test rig is used, metal flight propellers are seldom satisfactory for prolonged test bed running.

4.4 **Method of Determining Fan Type Required.** If doubt exists as to whether a fixed-pitch or variable-pitch fan should be used for a particular engine type, the following method of determination may be used.

4.4.1 **Unsupercharged Engines.** The power/rpm curve at full throttle under standard sea-level conditions should be copied from the Engine Technical Certificate and marked at points corresponding to 90% and 97% of the maximum rpm. As shown in Figure 2, the point of Maximum Continuous power and rpm (the calibration point) should also be marked and a fan power absorption curve should be drawn through it to cut the full throttle curve. The fan power absorption curve is drawn on the assumption that the power varies with the cube of the rpm. The rpm indicated at the point of intersection of the two curves should lie between 90% to 97% of the maximum rpm. If it fails to do so, the point of Maximum Continuous power and rpm may be adjusted by $\pm 2\%$ of the rpm value and a cube law curve may be drawn through this adjusted point. If it is possible to bring the absorption curve to intersect the full throttle curve between the 90% to 97% rpm range by the $\pm 2\%$ adjustment, the engine may be tested with a fixed-pitch fan; if not, a variable-pitch fan should be used.

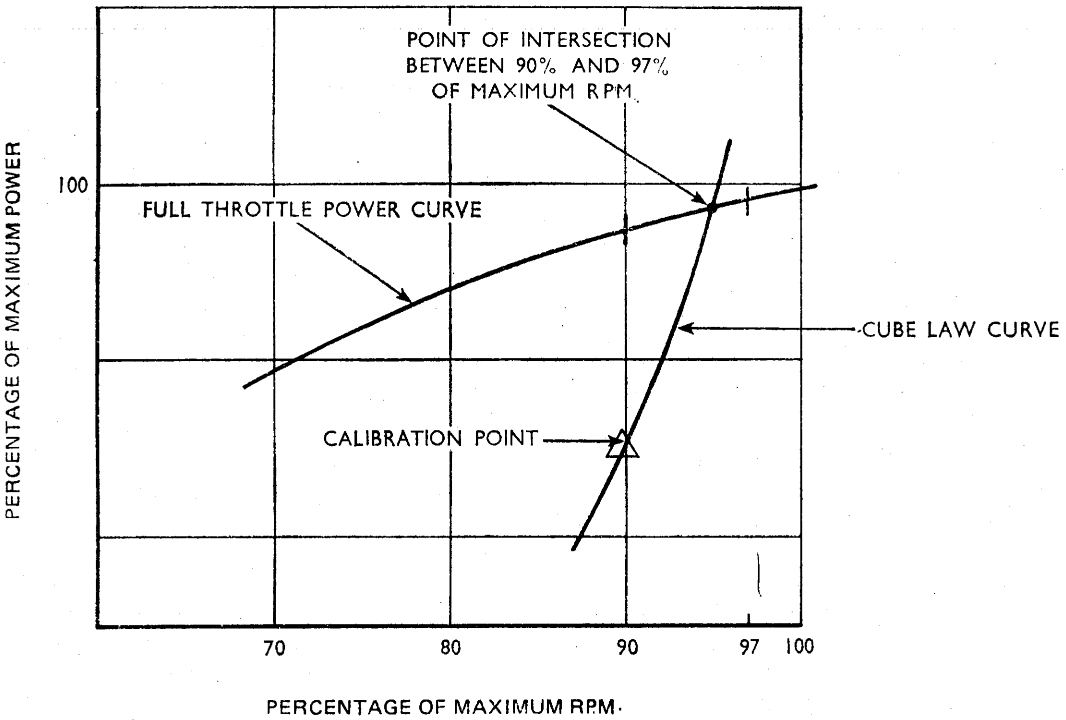

Figure 2 DETERMINATION OF TYPE OF TEST FAN REQUIRED FOR AN UNSUPERCHARGED ENGINE

4.4.2 **Supercharged Engines.** The procedure for supercharged engines with single speed superchargers is similar to that given in paragraph 4.4.1, except that the power/rpm curve at Maximum Take-off manifold pressure should be the curve obtained from the Engine Technical Certificate. Points corresponding to 90% and 97% of the maximum rpm should be marked on the Take-off power curve, and the power absorption curve, originating from the point of Maximum Continuous Power and rpm (the calibration point) should be drawn to intersect this power curve. If, after an adjustment of ±2% of the rpm value, the intersection of the two curves fails to be between 90% and 97% of the maximum rpm, a fixed-pitch fan would be unsuitable for the test.

4.4.3 **Variable-Pitch Fan Settings.** If the procedure given in paragraph 4.4.1 or 4.4.2, as appropriate, indicates that a fixed-pitch fan is unsuitable, a variable-pitch fan should be used. For the power check, one pitch stop of the variable-pitch fan should be set so that 97% of the Maximum Take-off rpm is obtained when running against this stop at Maximum Take-off manifold pressure (see Figure 3). To achieve this, separate engine runs should be made at Maximum Take-off manifold pressure to establish the speeds obtainable with the fan on its fine and coarse pitch stops respectively. The rpm obtained on each run should be marked on the Take-off power curve as an indication as to which stop, after adjustment, will give the fan pitch resulting in a fan power absorption curve passing through the 97% rpm point on the power curve. If the coarse pitch stop is used, the constant-speed unit (CSU) is set to the minimum rpm position and the fan will constant speed for a point below the absorption curve. If the fine pitch stop is used, the CSU control is set to the maximum rpm position and the fan will then constant speed for a point above the curve.

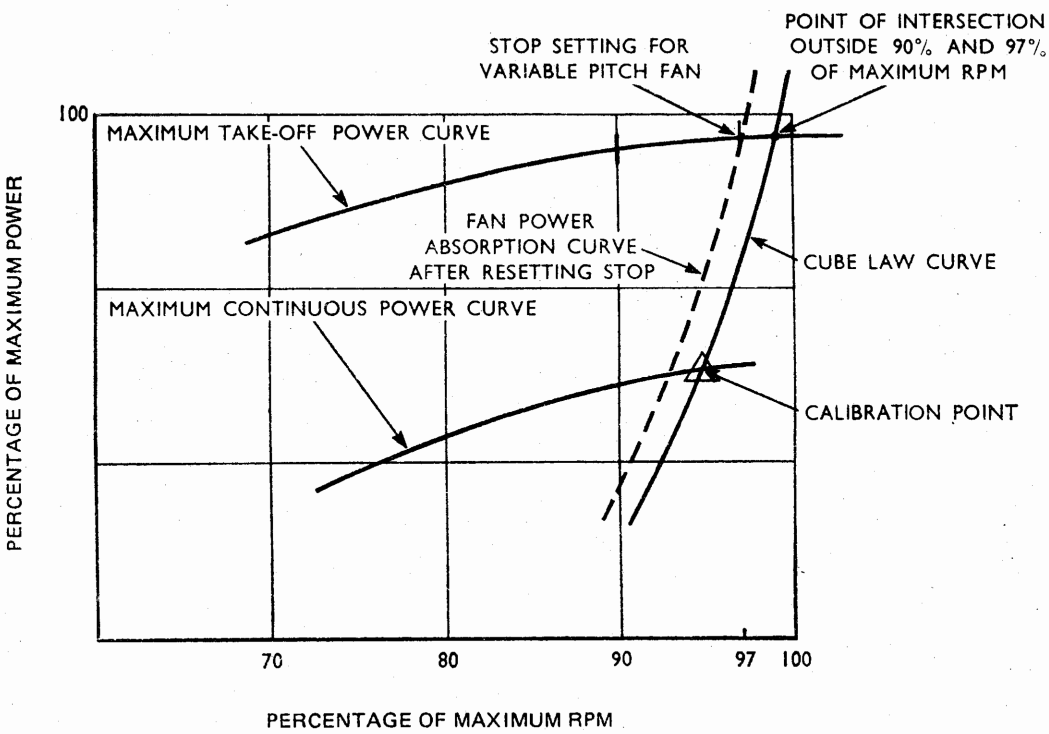

Figure 3 DETERMINATION OF TYPE OF TEST FAN AND PITCH SETTING REQUIRED FOR A SUPERCHARGED ENGINE

5 FAN CALIBRATION Before being used for testing overhauled engines, each test fan on each site must be calibrated on a new or recently reconditioned engine (hereinafter referred to as the "calibrated engine") which has not been run to any extent since its power output was last determined, for the purpose of fan calibration, on a dynamometer test bench. The calibration of the fan must be performed in the test cell in which the overhauled engines are to be tested, and unless it can be shown that changing from one test bench to another has no effect on fan performance, a separate calibration should be made each time the fan is used on a different bench. For preference the fan should be calibrated when the wind is unlikely to have any appreciable effect on results, but, if tests must be made when a strong wind is blowing, appropriate corrections may be made. The correction factors applied must be agreed by the CAA.

5.1 For an unsupercharged engine, the Full Throttle power curve of the calibrated engine must be available. In the case of a supercharged engine, the Maximum Take-off and Maximum Continuous constant manifold pressure curves, at standard sea-level atmospheric conditions, are required. An approved Test Fan Calibration Schedule for the engine type (obtainable from the engine manufacturers and normally included in the Engine Test Schedule), the power curves for the engine type (obtainable from the Engine Technical Certificate) and the appropriate correction curves (see Leaflet **EL/3-8**), must also be available.

5.2 Before commencing fan calibration, it is advisable to use an old engine to enable the test bed to be correctly set up. The calibrated engine should then be mounted on the test bench and primed with warm engine oil (see paragraph 7.1). The manufacturer may specify that a special cooling airscoop should be fitted for test bed running.

5.3 When a test fan is being calibrated, the engine temperatures and pressures should be as near as possible to those recorded when the engine was calibrated on the dynamometer.

5.4 The test fan power absorption characteristics are presented in the form of a cube law curve drawn on the assumption that, under constant atmospheric conditions, the power absorbed varies as the cube of the rpm. Consequently, if the power to be absorbed by the fan at one particular engine speed is known, a cube law curve showing the power/rpm relationship over a range of speeds may be drawn from calculated data. If such a curve is drawn through the power it should absorb at a particular speed so as to intersect the appropriate power curve for the calibrated engine, the value of rpm at the intersection is the rpm to be obtained from the fan after its blades have been cropped or its pitch stop finally adjusted.

5.5 In practice a tolerance of not more than ± 20 rpm has to be allowed, which necessitates drawing a cube law curve for the fan, after cropping or pitch adjustment, which is based on rpm values derived from the observed results corrected to standard sea-level conditions. The intersection of the actual fan power absorption curve and the appropriate engine power curve for the type engine then gives the "acceptance rpm" value for the test fan. The corrected values subsequently attained when overhauled engines are tested with the same fan on the same test bed should not be less than 98% of these values.

5.6 The acceptance rpm of the test fan on the particular test bed should be recorded and used as a reference whenever the fan is used for testing. At periods agreed with the CAA, each test fan should be weighed, its static balance should be checked, the blade angles should be measured at specified stations and the general condition of the fan should be assessed. At longer agreed periods, and whenever any change in the environment of the test cell is made or whenever distortion of the fan blades is suspected, the acceptance rpm should be re-checked by a repeat calibration.

6 FAN CALIBRATION PROCEDURE The procedure for calibrating a test fan for use in testing a particular type of engine varies according to whether the engine is supercharged or unsupercharged. In practice a specific method to suit the characteristics of each type of engine is recommended by the engine manufacturer and is included in the approved Engine Test Fan Calibration Schedule. The approved method must be used at all times, but an outline of the general principles of calibration procedure is given in the following paragraphs. Whilst the specimen procedures given are typical, they are not necessarily generally applicable to all engine types.

6.1 **Unsupercharged Engines.** Unsupercharged engines are generally tested with fixed-pitch fans and a typical calibration procedure is as follows:

6.1.1 Draw the power/rpm curves at full throttle for the calibrated engine and for the type engine, as shown in Figure 4.

6.1.2 Plot on the graph the test fan calibration point (obtained from data supplied by the engine manufacturer) and through it draw a cube law curve representing the power absorption characteristics of the fan. Extend this curve as necessary to intersect the full throttle curve for the calibrated engine. The point of intersection gives the corrected rpm to be attained, subject to a tolerance of ±20 rpm, when the test fan has been adjusted and the calibrated engine is running at full throttle.

EXAMPLE: If the calibration point is 142 kW at 2100 rpm, mark this point on the graph and then plot further points obtained by incremental increases of power and rpm. Since the power absorbed by the fan is assumed to increase with the cube of the rpm, the increments of power increase should be cubed thus:

$142 \times 1{\cdot}1^3$ against $2100 \times 1{\cdot}1 = 189$ kW/2310 rpm

and $142 \times 1{\cdot}2^3$ against $2100 \times 1{\cdot}2 = 245{\cdot}4$ kW/2520 rpm

The cube law curve is a line drawn from the calibration point through the points plotted to the full throttle curve of the calibrated engine.

6.1.3 The temperature correction chart (Leaflet **EL/3-8**) should now be used to find the corresponding value of rpm which should be obtained in the actual conditions of fan air temperature prevailing at the site.

6.1.4 With the calibrated engine fitted with the test fan and installed on the test bench in the cell for which the calibration is required, the engine should be run until normal running conditions have stabilised. It should then be opened up to full throttle and careful note taken of the rpm obtained. The rpm observed on the continuous reading rpm indicator should be cross-checked by means of the "Hasler" indicator.

6.1.5 To obtain the value of rpm determined by the method given in paragraph 6.1.3 (within ±20 rpm), the fan should be removed and the blades cropped or the pitch adjusted as necessary. This should be done in successive stages with trial runs and, in the case of cropped propellers, rebalancing between each stage. If a cropped test fan gives a higher speed than that aimed at, it should be made "heavy" in the manner approved by the fan manufacturer.

6.1.6 The fan should then be remounted on the engine and the engine should again be run at full throttle. When the required rpm are obtained, the observed values should be recorded. To obtain reliable results, two or three separate runs should be made and on each occasion the mean of three readings taken in stabilised conditions at 1 minute intervals should be taken as the observed rpm. The mean of the observed rpm readings should then be corrected to standard temperature conditions by means of the appropriate chart and the corrected value should be plotted on the full throttle curve for the calibrated engine. In the example shown in Figure 4, the rpm are higher than the value aimed at but are within the tolerance.

6.1.7 A cube law curve should now be drawn to pass through the point plotted by the method given in paragraph 6.1.6 for the corrected value of rpm. This curve should be extended as necessary to intersect the full throttle curve for the type engine and the point of intersection will give the acceptance rpm of the fan. This value should be recorded together with details of the direction and speed of the wind at the time of calibration. A report on the calibration, including details of the environment in which the fan was tested and the acceptance rpm established for it, should then be submitted to the CAA for approval.

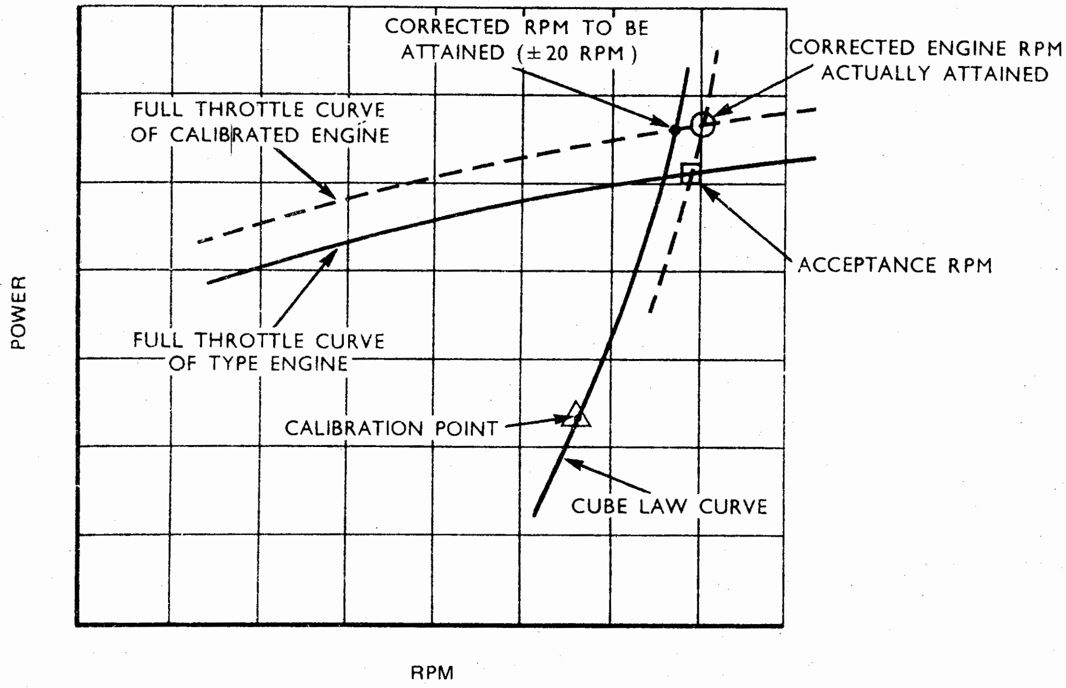

Figure 4 CALIBRATION OF FIXED-PITCH FAN FITTED TO UNSUPERCHARGED ENGINE

6.2 **Supercharged Engines.** Engines with single-speed superchargers are tested either with fixed-pitch fans or with variable-pitch fans, the type of fan required being determined by the method given in paragraph 4.4. Typical calibration procedure is as follows:

6.2.1 Draw the power/rpm curves for constant manifold pressure at Maximum Take-off, Maximum Continuous Power, and, if applicable, Maximum Weak Mixture Power for both the calibrated engine and the type engine, as shown in Figure 5.

6.2.2 For a fixed-pitch fan, plot on the graph the test fan calibration point (normally the point of Maximum Continuous power and rpm) and through it draw a cube law curve representing the power absorption characteristics of the fan. For a variable-pitch fan with governor control, plot the 97% rpm point of the type engine, as determined by paragraph 4.4.3, and draw the cube law curve through it. Extend the cube law curve as necessary to intersect the Maximum Take-off, Maximum Continuous Power and Maximum Weak Mixture constant manifold pressure curves for the calibrated engine. The point of intersection with the Maximum Take-off constant manifold pressure curve gives the corrected rpm to be attained, subject to a tolerance of ±20 rpm, when the test fan has been adjusted and the calibrated engine is running at the Maximum Take-off manifold pressure on a standard day.

6.2.3 The appropriate correction chart (Leaflet **EL/3-8**) should now be used to find the corresponding values of rpm to be obtained in the actual conditions of fan air temperature and atmospheric pressure prevailing at the site.

6.2.4 With the calibrated engine installed on the test bench and fitted with the test fan in the cell for which the calibration is required, the engine should be run until normal running conditions have stabilised. It should then be opened up to Take-off manifold pressure and careful note taken of the rpm obtained. A cross-check should be made by means of the "Hasler" indicator.

6.2.5 To obtain the value of rpm determined by the method given in paragraph 6.2.3 (within ± 20 rpm), the fan should be cropped or the pitch adjusted as necessary. The fan should then be remounted on the engine and the engine should be run at Take-off, Maximum Continuous and Maximum Weak Mixture manifold pressures in turn. Where applicable, the sequence of events for cropping the fan, and then running the engine fitted with the calibrated fan, should be the same as in paragraphs 6.1.5 and 6.1.6.

6.2.6 The rpm observed when the engine is running with the fan finally adjusted should be corrected to conditions at sea-level on a standard day. The corrected rpm at Take-off manifold pressure should be plotted on the Take-off Power curve for the calibrated engine and the corrected rpm for Maximum Continuous and Maximum Weak Mixture on the appropriate power curves. These points should be linked by a test fan power absorption curve of approximately cube law form drawn through them.

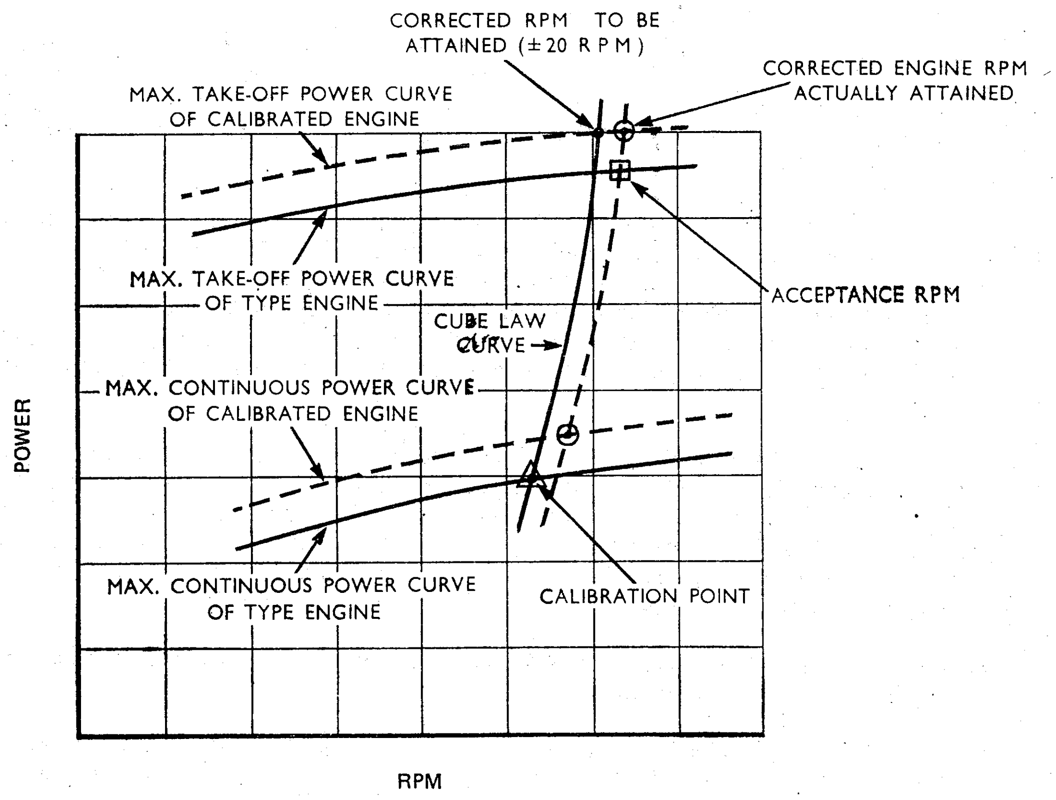

Figure 5 CALIBRATION OF FIXED-PITCH FAN FITTED TO SUPERCHARGED ENGINE

6.2.7 The fan power absorption curve should be extended as necessary to cut the Maximum Take-off Power curve for the type engine. The point of intersection gives the acceptance rpm of the fan. The points where the fan power absorption curve cuts the Maximum Continuous and Maximum Weak Mixture curves give rpm datum points which may be used, as recommended by the engine manufacturer, for engine tuning. These values should be recorded, together with details of the direction and speed of the wind at the time of the calibration. A report on the calibration, including details of the environment in which the fan was tested and the acceptance rpm established for it, should then be submitted to the CAA for approval.

7 USING THE CALIBRATED FAN After calibration, a test fan should only be used to test engines of the type for which it has been calibrated and in the particular cell in which the calibration has been made. If the environmental conditions of the test cell are changed, the fan must be recalibrated. The overhauled engine to be tested should be mounted on the test bench within the cell and the calibrated fan should be assembled to it: the engine should then be run according to the approved Test Schedule appropriate to the type of engine (see Leaflet **EL/3-5**).

7.1 Before starting the engine, its lubrication system should be primed with warm engine oil. The oil should be fed in under pressure whilst the engine is turned over by hand, care being taken to ensure that the oil is completely distributed through the bearings, gears and accessories drives. Should the engine not be run within three hours of priming it should be reprimed.

7.2 The engine should be correctly adjusted before the commencement of the test and a check should be made that the test plant controls have been correctly assembled. In the case of supercharged engines, the regulating valve of the depression box on the air intake should be fully open; in the case of normally-aspirated engines no depression box should be fitted.

7.3 After starting, the engine should be run-in according to the instructions in the Test Schedule approved for the engine type. Running-in is Stage 1 of the Endurance Test and the other stages should then follow in the sequence prescribed. During the test a suitable position for the thermometer which records the temperature of the air passing through the fan should be determined; a position between 2·5 to 4 metres (8 to 12 feet) forward of the engine and outside the arc of the fan usually proves satisfactory.

8 ACCEPTANCE CONDITIONS The acceptance conditions for overhauled engines when tested with a fan and the performance corrections to be made are prescribed in Chapter C2—5 of British Civil Airworthiness Requirements and repeated in the following paragraphs. Apart from the general running standard of each engine and its ability to satisfactorily complete the prescribed tests, the specific standards of performance of 8.1 or 8.2, as appropriate, must be obtained to the satisfaction of the CAA.

8.1 **Engines Rated in accordance with the Requirements in force on and after 18th November, 1946 (ICAO Ratings)**

8.1.1 The rpm obtained during the power check tests of the Final Test (Stage 10; and Stage 7 in respect of any other supercharger gears), when corrected to standard atmospheric conditions at sea-level, in accordance with paragraph 9, shall not be less than 98% of the acceptance rpm of the fan. Also in the case of a supercharged engine, the corrected supercharger compression ratio (at 15°C) obtained during Stages

8 and 9 of the Final Test and the corrected rpm obtained during the corresponding power check tests of the Final Test shall satisfy the following expression:

$$\frac{r_2}{r_1} + \left(\frac{N_2}{N_1}\right)^2 \text{ shall be not less than } 1{\cdot}96$$

where r_2 = supercharger compression ratio of the engine being tested at the observed rpm of the test.

r_1 = supercharger compression ratio of the standard engine at the observed rpm of the test as derived from the Engine Technical Certificate.

N_2 = corrected rpm obtained from the power check tests for engine being tested.

N_1 = acceptance rpm of the fan.

8.1.2 **Fuel Consumption.** In the case of overhauled engines tested with a fan, the fuel consumption shall be within the limits approved by the CAA.

8.1.3 **Oil Consumption.** The mean oil consumption obtained from the tests of Stages 3 and 4 of the Endurance Tests and Stage 4 of the Final Test, shall be within the declared limits. In the event of the engine not being able to comply with this requirement during the tests of Stages 3 and 4 of the Endurance Test, it shall be rejected for rectification and re-submission to the Endurance Test. Alternatively, subject to the agreement of the CAA, the endurance running of Stages 3 and 4 of the Endurance Test may be extended up to a maximum of an additional 2 hours, until the consumption falls within the required limits over a period of at least 30 minutes' duration. The consumption shall be checked in each supercharger gear. As a further alternative, where the applicant is of the opinion that the oil consumption can be improved by adjustment during strip examination, the endurance portion of the Final Test may, at the discretion of the CAA, be extended by the addition of a run limited to a minimum of 1 hour at the declared Maximum Continuous Power conditions. The running shall be equally divided between the supercharger gears. During the period of oil consumption measurement, ignition checks, or operation of any accessory or any other tests or adjustment which may affect consumption, shall be avoided. The oil consumption in each supercharger gear shall be reasonably consistent.

8.1.4 **Accelerations.** Accelerations shall be smooth and free from hesitation or other signs of fuel-metering trouble.

8.1.5 **Single Ignition Check.** The power drop when running with single ignition shall not exceed the declared maximum.

8.1.6 **Cleanliness.** The engine shall be free from leaks at all joints and connections, etc.

8.2 **Engines Rated in accordance with the Requirements in force before 18th November, 1946 (pre-ICAO Ratings).** The acceptance conditions for engines with pre-ICAO ratings are identical to those in paragraph 8.1, except that Maximum Cruising Power conditions should be substituted for Maximum Continuous Power conditions wherever these conditions are specified.

9 PERFORMANCE CORRECTIONS

9.1 The corrections used in order to convert the observed engine rpm to standard atmospheric conditions at sea-level, and to assess the performance of the supercharger where applicable, shall be approved by the CAA for each type of engine. These corrections shall be prepared in the form of charts (see Leaflet **EL/3-8**).

9.2 For the rpm correction the variation of power with rpm at Maximum Take-off manifold pressure (and at Maximum Climbing or Maximum Continuous manifold pressure in any other supercharger gears) shall be established and a chart giving the correction factor for a suitable range of atmospheric conditions shall be prepared. If variations in wind speed and direction can appreciably affect the power absorption characteristics of a fan in a particular test cell, suitable corrections may be established, but before being used they shall be approved by the CAA.

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AIRCRAFT

ENGINES

PISTON ENGINE OVERHAUL—CORRECTING ENGINE TEST RESULTS

1 INTRODUCTION

1.1 Section C of British Civil Airworthiness Requirements prescribes that all performance results obtained during the bench testing of aero-engines must be corrected to the conditions of temperature and pressure in the standard atmosphere. Correction formulae from the Requirements which are applicable to the testing of low-power, air-cooled engines are repeated in this Leaflet; other parts of the Requirements relevant to testing piston engines after overhaul are repeated in Leaflets **EL/3-5, EL/3-6** and **EL/3-7.**

1.2 This Leaflet also explains how to make corrections for the effects of prevailing atmospheric conditions during the calibration of test fans, and includes charts which may be used to make such corrections.

1.3 The Leaflet is the last of a series dealing with piston engine overhaul and should be read in conjunction with the other leaflets in the series, i.e. Leaflets **EL/3-1** to **EL/3-7.** In particular it is closely associated with Leaflets **EL/3-6** and **EL/3-7** which deal with the testing of overhauled engines by means of dynamometers and test fans respectively.

2 GENERAL Varying atmospheric conditions affect engine performance by an appreciable amount and corrections must therefore be made for deviations of atmospheric pressure and temperature from standard at the time of test. Humidity changes, whilst not generally as significant as pressure or temperature changes, also have an influence on the results and therefore a method of correcting for humidity is given in paragraph 3.3. If this method is not used, an alternative method approved by the CAA must be used. If the engine power is affected by deviation of cylinder temperature from the values prescribed in the test schedules, appropriate corrections may also be made, but the corrections must be approved by the CAA before use in the calculations.

3 ENGINES TESTED WITH A DYNAMOMETER When an engine is tested on a dynamometer test bench, the brake power is obtained from the products of the net weight lifted by the dynamometer and the rotational speed of the dynamometer rotor, divided by the dynamometer constant (Leaflet **EL/3-6**). This gives the observed brake power for the engine (power$_o$) and represents the particular power output of the engine under the conditions of air intake temperature, atmospheric pressure, engine manifold pressure and exhaust back pressure at the time of test. To ensure that the power of an engine is within the acceptance limits for the engine type, these results must be corrected to conditions which are standardised for all tested engines, namely to the sea-level conditions of pressure and temperature in the standard atmosphere. These are 101·325 kN/m² (29·92 inHg) and 15°C respectively.

3.1 **Power Correction Formulae.** The corrected brake power, P_c (BHP_c), of normally aspirated engines and supercharged engines in which there is no provision for inter-cooling, after-cooling or heating the charge before it enters the cylinders, is given by the formulae:—

S.I. Units

$$P_c = P_o \frac{(400 + t_o)\left(M_c - \frac{p_c}{R}\right)}{(400 + t_c)\left(M_o - \frac{p_o}{R}\right)}$$

Non-S.I. Units

$$BHP_c = BHP_o \frac{(400 + t_o)\left(M_c - \frac{p_c}{R}\right)}{(400 + t_c)\left(M_o - \frac{p_o}{R}\right)}$$

where P(BHP) = brake power, kW (horse-power)
t = air intake temperature, °C
M = manifold pressure, kN/m^2 (inHg)
p = exhaust back-pressure, kN/m^2 (inHg) = atmospheric pressure + any increase in pressure due to the test plant exhaust system. (In the examples given p is assumed to be equal to atmospheric pressure)
R = engine compression ratio

Friction Power (P_f or FHP) is given by the formulae:—

S.I. Units

$$P_f = 27 \times 10^{-16} \times N^2 \times d^2 \times l^2 \times n$$

Non-S.I. Units

$$FHP = 15 \times 10^{-10} \times N^2 \times d^2 \times l^2 \times n$$

where N = crankshaft rotational speed, rpm
d = cylinder bore, mm (in)
l = length of stroke, mm (in)
n = number of cylinders

Suffix "o" denotes an observed condition, corrected for instrument error only.
Suffix "c" denotes the condition in the required (sea-level atmospheric) atmosphere.

NOTES: (1) Standard sea-level atmospheric pressure = $1{\cdot}01325 \times 10^5$ N/m^2 = 1013·2 mbar = 29·92 inHg = 760 mmHg = 14·7 lbf/in^2.
(2) 1 kN/m^2 = 1 kPa = 10 mbar.
(3) 1 lbf/in^2 = 6·895 kN/m^2.
(4) 1 inHg = 3·386 kN/m^2.

3.1.1 **Unsupercharged Engines.** For an unsupercharged engine running at constant rpm at full-throttle, the manifold pressure is normally assumed to be atmospheric, which means that to correct the observed power to sea-level conditions the formulae can be written as follows:—

S.I. Units

$$P_c = P_o \frac{(400 + t_o)\left(101{\cdot}325 - \frac{101{\cdot}325}{R}\right)}{(400 + t_c)\left(p_o - \frac{p_o}{R}\right)}$$

Non-S.I. Units

$$BHP_c = BHP_o \frac{(400 + t_o)\left(29{\cdot}92 - \frac{29{\cdot}92}{R}\right)}{(400 + t_c)\left(p_o - \frac{p_o}{R}\right)}$$

EXAMPLE: If the full-throttle brake power of a particular engine (compression ratio 5·25:1) is observed to be 196 kW on a day when the air temperature is 17°C and barometric pressure is 1000 mbar (100 kN/m^2), then corrected to standard sea-level conditions the brake power would be:—

$$P_s = 196 \frac{(400 + 17)\left(101{\cdot}325 - \frac{101{\cdot}325}{R}\right)}{(400 + 15)\left(100 - \frac{100}{R}\right)}$$

$$= 196 \times 1{\cdot}005 \times 1{\cdot}013$$

$$= \underline{199{\cdot}54 \text{ kW}}$$

NOTE: Assuming the declared Maximum Take-off Power of the engine is 196 to 204 kW at sea-level, the result satisfies the acceptance conditions of BCAR.

3.1.2 **Supercharged Engines.** During the Endurance and Final Tests of a supercharged engine, the power output and the supercharger compression ratio are measured, the former with an unrestricted air intake and the latter with a restricted intake obtained by using a depression box fitted to the intake.

(a) **Power.** When correcting the power observed during a test run with unrestricted air intake to standard sea-level conditions at the same manifold pressure, the correction formula can be written:

S.I. Units

$$P_c = P_o \frac{(400 + t_o)\left(M_o - \frac{101{\cdot}325}{R}\right)}{(400 + 15)\left(M_o - \frac{p_o}{R}\right)}$$

Non-S.I. Units

$$BHP_c = BHP_o \frac{(400 + t_o)\left(M_o - \frac{29{\cdot}92}{R}\right)}{(400 + 15)\left(M_o - \frac{p_o}{R}\right)}$$

EXAMPLE: If the brake power of a particular engine, having a compression ratio of 6·5:1 and running at a manifold pressure of 41·3 inHg (140 kN/m²) is observed to be 348·5 kW on a day when the air intake temperature is 20°C and the barometric pressure is 1010 mbar (101 kN/m²), the corrected brake power will be:—

$$P_c = 348{\cdot}5 \frac{(400 + 20)\left(140 - \frac{101{\cdot}325}{6{\cdot}5}\right)}{(400 + 15)\left(140 - \frac{101}{6{\cdot}5}\right)}$$

$$= 348{\cdot}5 \times 1{\cdot}012 \times 0{\cdot}999$$

$$= \underline{352{\cdot}329 \text{ kW}}$$

(b) **Supercharger Compression Ratio.** The variation of supercharger compression ratio with variation of air temperature at constant air intake pressure is given by:

$$r_s = r_o \left(1 + k\,(t_o - t_s)\right) \text{ when correcting to a lower air temperature}$$

$$\text{and } r_s = \frac{r_o}{1 + k\,(t_s - t_o)} \text{ when correcting to a higher air temperature.}$$

In the above formulae the additional notation is used:

r = supercharger compression ratio
k = supercharger temperature constant for particular engine.

The supercharger compression ratio is determined during Stages 8 and 9 of each test by running the engine with the air intake restricted such that the throttle is fully open at Maximum Continuous (or Maximum Climbing) Power and at Take-off Power conditions respectively. With the throttle lever set to obtain the appropriate manifold pressure, the regulating valve on the intake depression box should be closed progressively until the boost control has fully opened the throttle. The corresponding air intake pressure should be found (see paragraph 4.3.1), and the ratio between the two pressures, $\frac{\text{Manifold Pressure}}{\text{Intake Pressure}}$ should then be corrected to sea-level temperature conditions in the standard atmosphere by means of the appropriate formula.

EXAMPLE: If when testing the above engine the observed manifold pressure at Maximum Continuous Power conditions is 140 kN/m², and the observed air intake pressure is 101 kN/m², the compression ratio will be:—

$$r_o = \frac{M_o}{P_o} = \frac{140}{101} = 1{\cdot}386$$

Assuming the value of 'k' for this engine is 0·001 under test conditions where the intake temperature is 20°C, the supercharger compression ratio corrected to the sea-level temperature of a standard day will be:—

$$r_c = 1{\cdot}386 \left[1 + 0{\cdot}001\,(20 - 15)\right] = 1{\cdot}386 \times 1{\cdot}005 = \underline{1{\cdot}392}$$

NOTE: Since the sum of the ratios of the corrected sea-level power and the corrected supercharger compression ratio to the values established in the Engine Technical Certificate is greater than 1·96, the results satisfy the acceptance conditions prescribed in BCAR.

$$\text{i.e.} \quad \frac{352{\cdot}329}{351} + \frac{1{\cdot}392}{1{\cdot}4} = 1{\cdot}004 + 0{\cdot}994 = \underline{1{\cdot}998}$$

3.2 **Power at Altitude**

3.2.1 When drawn on a relative density basis the variation of power with altitude at constant crankshaft rotational speed and manifold pressure may be given by a straight line between the power at sea-level and the power at the full throttle height.

3.2.2 The variation of power with height at constant crankshaft rotational speed and full throttle, when drawn on a relative density basis, may be a curve at high powers but at low powers this curve may be extended as a straight line to the negative friction horsepower at zero density.

3.3 **Humidity Corrections.** In order to determine power ratings in dry air, or conversely to determine the power output in given conditions of atmospheric humidity, the following corrections should be used unless more accurate data are available:

S.I. Units

$$P_e = \frac{P_o + P_f}{1 - xh} - P_f$$

Non-S.I. Units

$$BHP_e = \frac{BHP_o + FHP}{1 - xh} - FHP$$

where x is a factor depending on mixture strength

and h is the humidity, i.e., $\frac{\text{water vapour pressure}}{\text{barometric pressure}}$

NOTE: Since the effect of free water on power output is within ±1% over the range of water/air ratios normally encountered in operation, and the amount of free water is exceedingly difficult to measure, no corrections for free water need be made.

3.3.1 For constant fuel flow, the effect of humidity on air/fuel ratio is given by

$$Z_c = \frac{Z_o}{1 - h}$$

where Z = air/fuel ratio.

3.3.2 Table 1 gives values of x over a range of air/fuel ratios corrected to dry air conditions for air-cooled engines with fuel-metering systems which compensate for manifold pressure and charge temperature.

TABLE 1

Air/fuel ratio	9	10	11	12	13	14	15	16
Values of x	2·15	1·80	1·54	1·32	1·18	1·07	1·02	1·00

3.3.3 The following is the temperature correction which should be used in the case of air-cooled engines when the above-mentioned corrections for humidity are utilised:—

S.I. Units

$$P_c = \frac{P_o + P_f}{1 + C(t_c - t_o)} - P_f$$

Non-S.I. Units

$$BHP_c = \frac{BHP_o + FHP}{1 + C(t_c - t_o)} - FHP$$

where C is a constant determined for the appropriate dry air mixture strength.

3.3.4 Table 2 gives values for C over a range of air/fuel ratios corrected to dry air conditions.

TABLE 2

Air/fuel ratios	9	10	11	12	13	14	15	16
Values of C	·00167	·00181	·00195	·00207	·00216	·00224	·00226	·00228

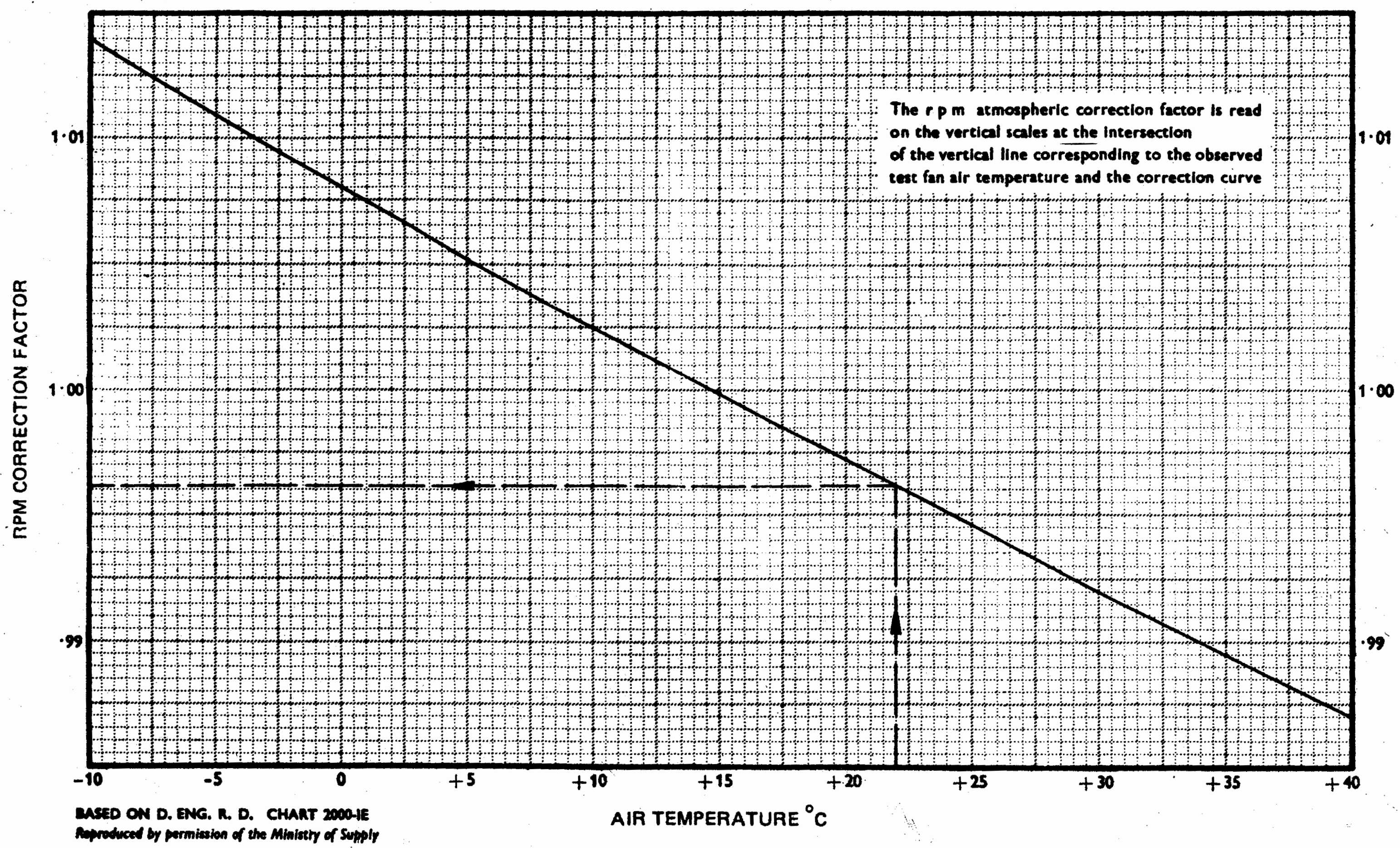
The value of C applicable to take-off conditions when water-methanol injection is used is 0·0022.

4 TEST FAN CALIBRATION CORRECTIONS During the calibration of engine test fans (Leaflet EL/3-7), the rpm obtained will be influenced by the conditions of atmospheric temperature and pressure prevailing at the site. Thus cold conditions have two contradictory effects; the engine power tends to increase because of the increased charge density but an increase in rpm is opposed by the increased power absorbed by the fan as a result of the denser air. The net result is that the observed rpm will be lower than under standard sea-level conditions. Corrections of observed rpm to conditions in the standard atmosphere should be made by means of suitable charts; charts suitable for particular engines are normally included by the manufacturer in the approved Test Schedule for the engine concerned. However, two charts, one for normally-aspirated engines and one for supercharged engines, each of which is suitable for a wide range of engines when testing at altitudes between sea-level and 1,000 feet, are included in this Leaflet and the following paragraphs explain their use.

NOTE: If engines are to be tested in cells at altitudes above 1,000 feet, specially prepared charts should be requested from the engine manufacturer.

ENGINE TESTING WITH PROPELLER TEST FANS

CORRECTION OF OBSERVED ENGINE RPM FOR OBSERVED TEMPERATURE CONDITIONS
TO THE RPM OBTAINABLE ON A STANDARD DAY



BASED ON D. ENG. R. D. CHART 2000-IE
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Figure 1

4.1 **Unsupercharged Engines**

4.1.1 When testing unsupercharged engines at full throttle it can be assumed that barometric changes affecting the engine power, and therefore tending to increase or decrease the engine rpm, are counterbalanced by the variation in fan loading. It is therefore necessary to correct for air temperature only and this can be done with the aid of the chart in Figure 1.

4.1.2 To use the chart, a vertical line should be projected from the observed air temperature point on the horizontal scale to the correction curve, and from the point of intersection a horizontal line should be projected to cut the vertical scale. This gives the rpm correction factor by which the observed rpm should be multiplied.

EXAMPLE: If the observed air temperature is +22°C, the rpm correction factor is 0·9962. If the observed rpm is 2650, the corrected rpm $= 2650 \times 0{\cdot}9962 = 2640$.

4.2 **Supercharged Engines**

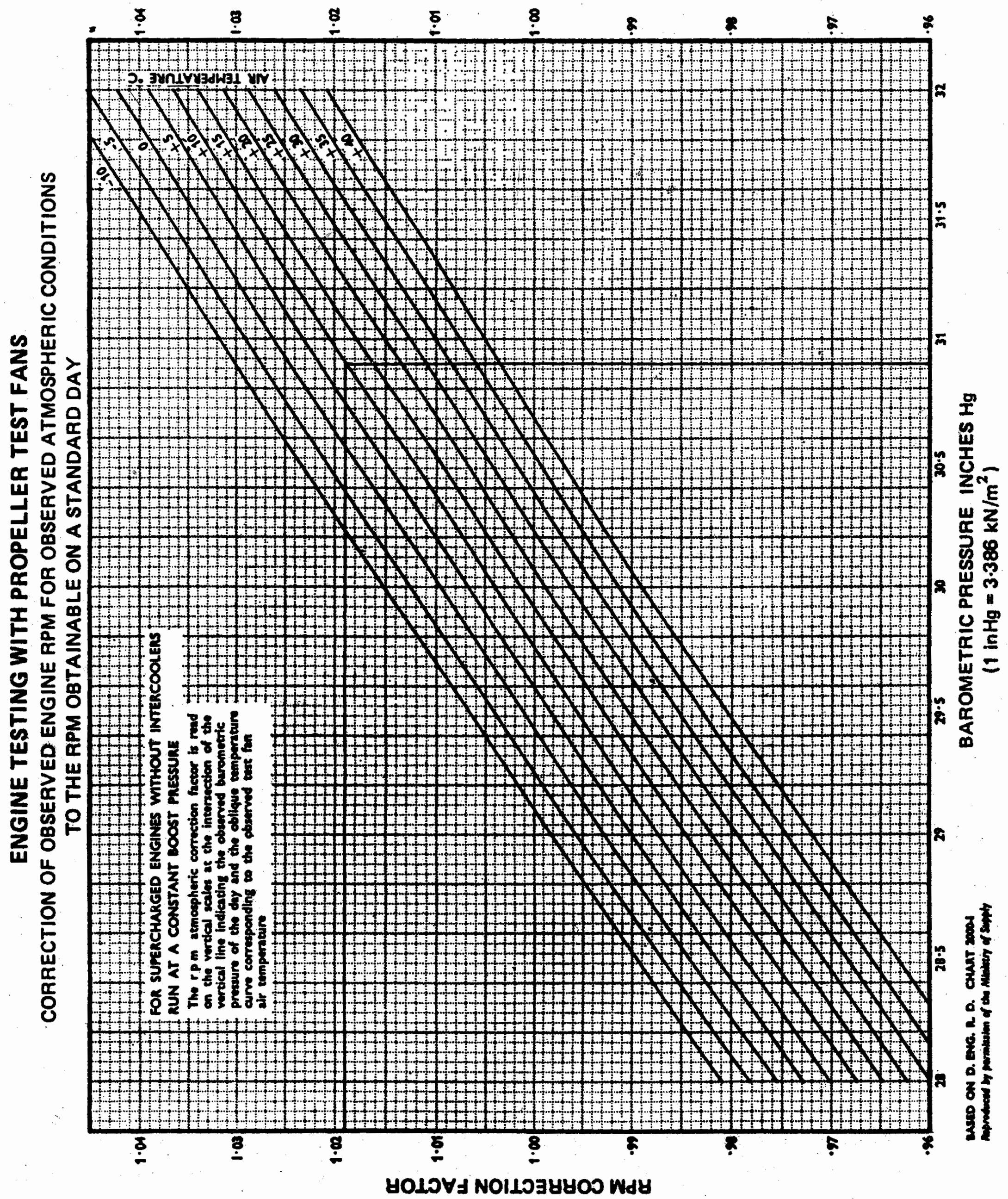
4.2.1 When checking the performance of a supercharged engine with a test fan, the engine is run at the required manifold pressure and the effects of barometric changes on engine adjustment are corrected by throttle adjustment. However, the fan loading will vary with the air density and corrections must therefore be made for barometric pressure as well as for air temperature. The fan air temperature, as recorded by the thermometer in the test cell, is assumed to be the same as the air intake temperature. The chart shown in Figure 2 can be used for correcting the rpm of a wide range of air-cooled supercharged engines.

4.2.2 The method of using the chart is to select the point corresponding to the observed barometric pressure on the barometric pressure scale and project a vertical line from this point until it intersects the curve corresponding to the observed air temperature. A horizontal projection from the point of intersection will give the rpm correction factor by which the observed rpm should be multiplied.

EXAMPLE: Referring to Figure 2, if the observed barometric pressure is 104·6 kN/m^2 (30·9 inHg) and the observed air temperature is +10°C, the rpm correction factor is 1·019. If the observed rpm is 2640, the corrected rpm $= 2640 \times 1{\cdot}019 = 2690$.

4.2.3 It sometimes happens that altitude-rated engines reach full throttle before the required manifold pressure can be obtained: either a low full throttle altitude rating, low atmospheric pressure or poor engine performance may be the cause. If, for any reason, a supercharged engine is run at full throttle during the power check (without, of course, exceeding the required manifold pressure), it should be corrected as though it were a normally-aspirated engine by the method given in paragraph 4.1.

4.3 **Supercharger Performance Corrections.** The requirements for testing piston engines after overhaul (Leaflet EL/3-5) prescribe that a supercharger compression ratio check shall be made whilst the engine is run at Maximum Continuous Power (or Maximum Climbing Power for Schedule II engines) and Maximum Take-off Power conditions with reduced air intake pressure. The supercharger performance is checked by running the engine at full throttle at the required rpm and manifold pressure with a restricted air intake and observing the absolute air intake pressure under these conditions. Since



ENGINE TESTING WITH PROPELLER TEST FANS
CORRECTION OF OBSERVED ENGINE RPM FOR OBSERVED ATMOSPHERIC CONDITIONS TO THE RPM OBTAINABLE ON A STANDARD DAY
FOR SUPERCHARGED ENGINES WITHOUT INTERCOOLERS RUN AT A CONSTANT BOOST PRESSURE
The r p m atmospheric correction factor is read on the vertical scales at the intersection of the vertical line indicating the observed barometric pressure of the day and the oblique temperature curve corresponding to the observed test fan air temperature
AIR TEMPERATURE °C
-10
-5
0
+5
+10
+15
+20
+25
+30
+35
+40
RPM CORRECTION FACTOR
1·04
1·03
1·02
1·01
1·00
·99
·98
·97
·96
28
28·5
29
29·5
30
30·5
31
31·5
32
BAROMETRIC PRESSURE INCHES Hg
(1 inHg = 3·386 kN/m²)
BASED ON D. ENG. R. D. CHART 2000-I
Reproduced by permission of the Ministry of Supply

Figure 2

the absolute air intake pressure is inversely proportional to the compression ratio, any difference in the ratio from standard will be shown by changes in the intake pressure. The compression ratio of a supercharger varies with the air intake temperature and with the tip speed of the impeller.

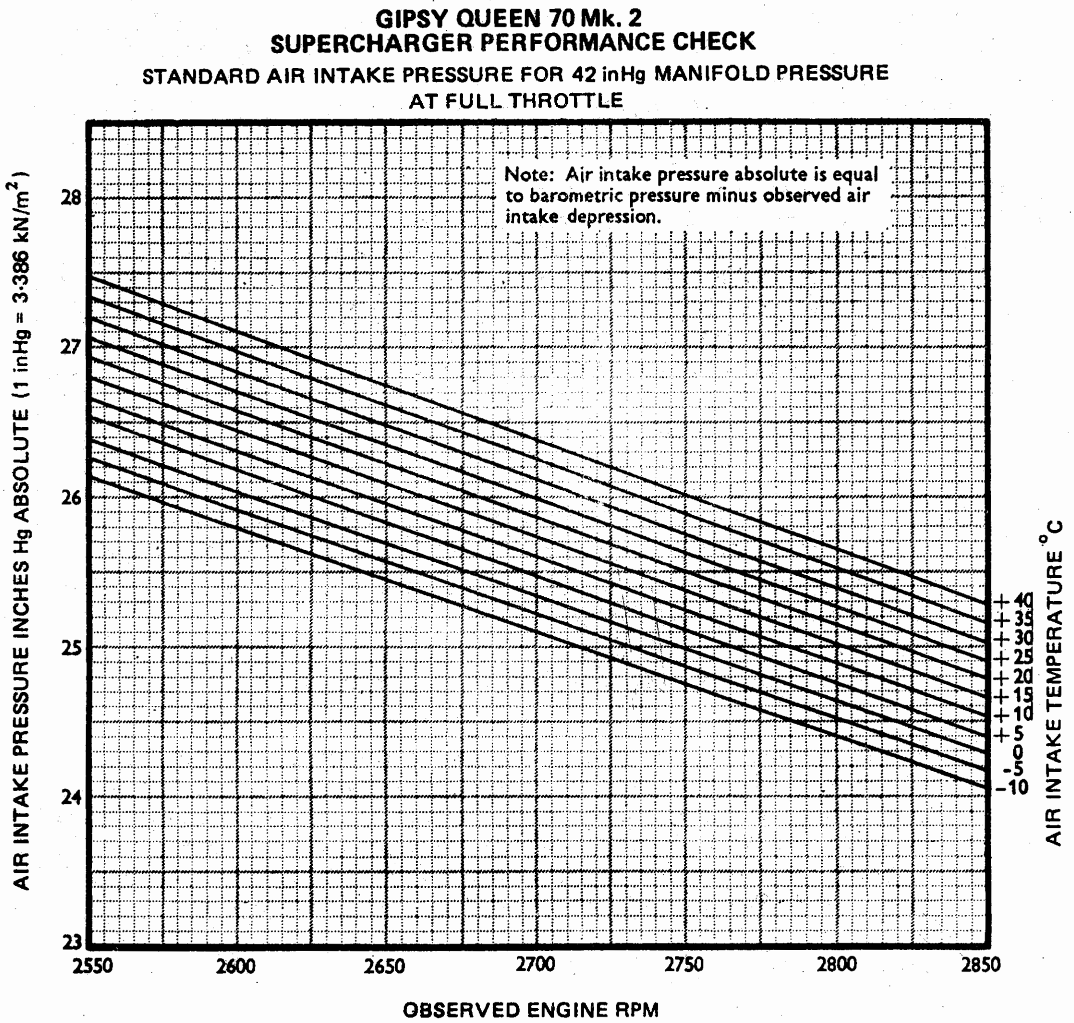


Figure 3

4.3.1 For each particular supercharged engine, it is usual for the engine manufacturer to prepare a supercharger performance correction chart based on the performance of the type-tested engine and to include this chart in the approved Test Schedule for the engine type. From the chart the absolute air intake pressure which should be obtained at the observed rpm and observed intake temperature can be determined. The performance of the supercharger can then be assessed by comparing this pressure with the absolute pressure actually observed in the intake of the engine under test. The observed air intake pressure is taken as the difference between the barometric pressure in the test cell and the pressure indicated on a depression gauge fitted to the depression box.

4.3.2 A specimen supercharger performance correction chart is shown in Figure 3; the chart illustrated is for the Gipsy Queen 70 Mk. 2 engine. To find the required absolute air intake pressure, the observed rpm should be read off on the horizontal scale and a vertical line should be projected from it to intersect the curve appropriate to the observed air intake temperature. A horizontal line projected from the point of intersection will give the absolute air intake pressure in inches of mercury.

4.3.3 If the observed absolute air intake pressure is greater than the figure obtained from the chart, the supercharger performance is below the performance of the supercharger of the standard engine as derived from the Engine Technical Certificate. The acceptance conditions for the performance of overhauled engines when tested with a fan (Leaflet EL/3-7) state that the corrected supercharger compression ratio (at 15°C) obtained during Stages 8 and 9 of the Final Test and the corrected rpm obtained during the corresponding power check tests shall satisfy the following expression:

$$\frac{r_2}{r_1} + \left(\frac{N_2}{N_1}\right)^2 \text{ shall not be less than } 1{\cdot}96$$

where r_1 = supercharger compression ratio of the standard engine at the observed rpm of the test as derived from the Engine Technical Certificate.

r_2 = supercharger compression ratio of the engine being tested, at the observed rpm of the test.

N_1 = acceptance rpm of the fan.

N_2 = corrected rpm obtained from the power check tests for engine being tested.

EXAMPLE: A Gipsy Queen 70 Mk. 2 engine is run at a manifold pressure of 42 inHg and at 2700 rpm with an air intake temperature of +5°C. If the barometer reading is 30 inHg and the depression gauge reading is 5 inHg, the observed air intake pressure is 25 inHg. Reading from the chart in Figure 3, the intersection of the vertical line corresponding to 2700 rpm and the curve for +5°C intake temperature gives an absolute intake pressure of 25·5 inHg

where $r_1 = \frac{42}{25{\cdot}5} = 1{\cdot}647$

$r_2 = \frac{42}{25} = 1{\cdot}68$

$N_1 = 2700$

and assuming $N_2 = 2680$

$$\frac{1{\cdot}68}{1{\cdot}647} + \left(\frac{2680}{2700}\right)^2 = 1{\cdot}02 + 0{\cdot}985 = \underline{2{\cdot}005}$$

EL/3-9

Issue 1.

23*rd June*, 1969.

AIRCRAFT

ENGINES

PISTON ENGINES—MAGNETOS

1 INTRODUCTION This Leaflet gives general guidance on the functioning, installation and maintenance of typical magnetos. It should be read in conjunction with the Maintenance Manual for the engine concerned.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet EL/5-3, Issue 1, 1st August, 1950. Information on the installation of sparking plugs is given in Leaflet EL/5-1 and on the installation and maintenance of ignition cables and harnesses in Leaflet EL/5-2.

2 BASIC PRINCIPLES OF A MAGNETO

2.1 A magneto consists basically of two parts, i.e. a generator and a transformer. It is based on the principles of electromagnetic induction summarised below.

2.1.1 When a conductor is moved through a magnetic field in such a way as to cut the lines of magnetic force, an electro-motive force (e.m.f.) is induced in that conductor. If the conductor circuit is closed then an electric current will flow.

2.1.2 Any conductor carrying an electric current generates a magnetic field concentric with the conductor, the strength of the field depending on the strength of the current.

2.1.3 Any change of magnetism, no matter how caused, when acting upon a coil of wire, induces into that wire an electric current. The strength of that current will depend on:—

(i) Strength of the magnet.

(ii) Rate of change of magnetism.

(iii) Number of turns of wire in the coil.

2.2 In a normal magneto two coils of insulated wire are wound round a soft iron core. The first or "primary" coil consists of a small number of turns (approximately 200) of relatively thick wire and the second or "secondary" coil consists of a large number of turns (approximately 10,000) of very fine wire. The soft iron core is subjected to an alternating magnetic flux either by being rotated between the poles of a permanent magnet or by the rotation of a magnet between suitably shaped shoes attached to the core. As the turns are cut by the magnetic flux a low voltage is induced in the primary coil, the current and therefore the magnetic field produced by it, being greatest when the rate of change of magnetic flux is greatest. At this point the primary circuit is broken and the magnetic field collapses round the secondary coil producing a high voltage current which is directed by a suitable conductor to the centre electrode of the sparking plug.

NOTE: Although an e.m.f. is built up in the secondary coil when the magnetic flux is increasing in the core, it is the rapid collapse of the magnetic field which produces the high voltage necessary to produce a spark at the sparking plug points.

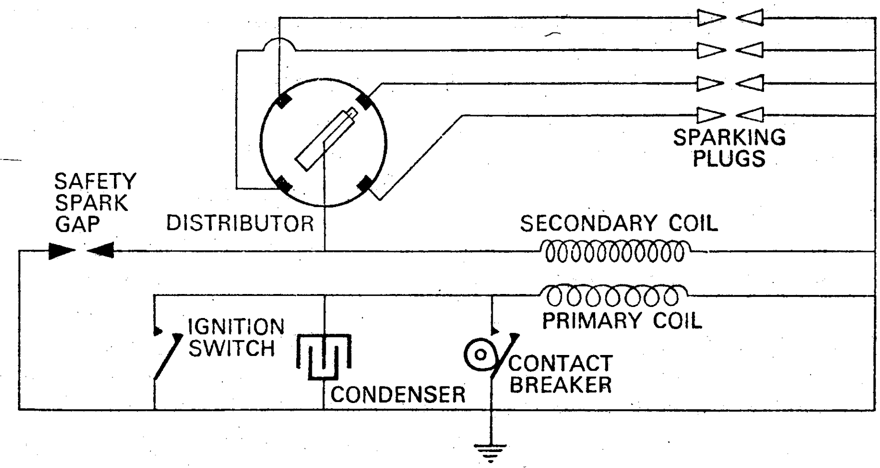


Figure 1 TYPICAL IGNITION CIRCUIT

3 CONSTRUCTION OF A MAGNETO Although the basic principle of operation of all magnetos is similar, the construction may vary considerably. They can, however, be divided basically into two types, i.e. the rotating armature magneto and the rotating magnet magneto.

3.1 **The Rotating Armature Magneto.** The assembly of the primary and secondary coils on a soft iron core discussed in paragraph 2 is known as the "armature". In the rotating armature magneto this is mounted on a shaft driven from the engine and rotated between the poles of a permanent magnet (*Figure* 2). As only two sparks are produced for each revolution of the armature, this type of magneto is normally used only on engines with up to six cylinders.

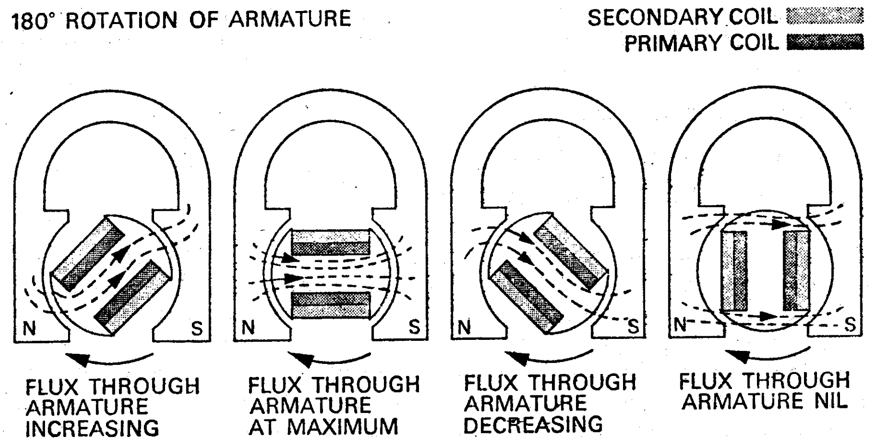


Figure 2 FLUX CHANGE IN ROTATING ARMATURE MAGNETO

3.2 **The Rotating Magnet Magneto.** The most usual type of "rotating magnet magneto" is the "polar inductor magneto" where the permanent magnets are actually stationary and soft iron inductors, mounted on a non-magnetic shaft driven from the engine, are used to guide the magnetic flux through the armature (*Figures* 3 and 4). Four sparks are produced for each revolution of the inductor shaft, making this type of magneto suitable for use on engines with more than six cylinders.

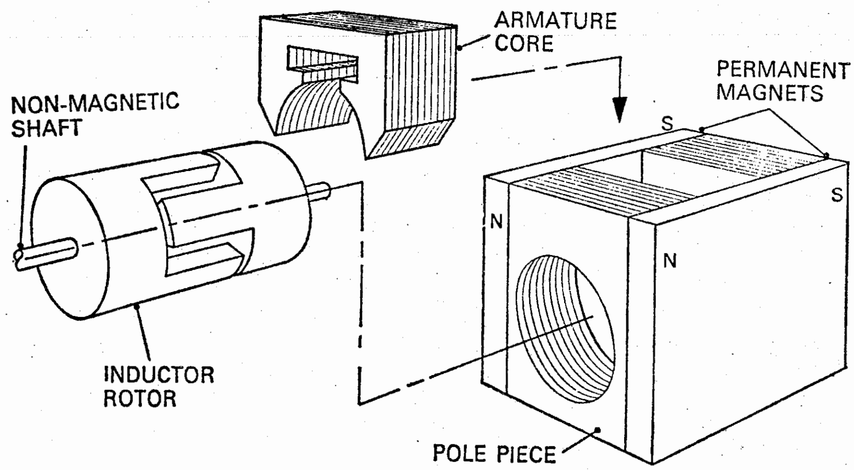


Figure 3 POLAR INDUCTOR MAGNETO

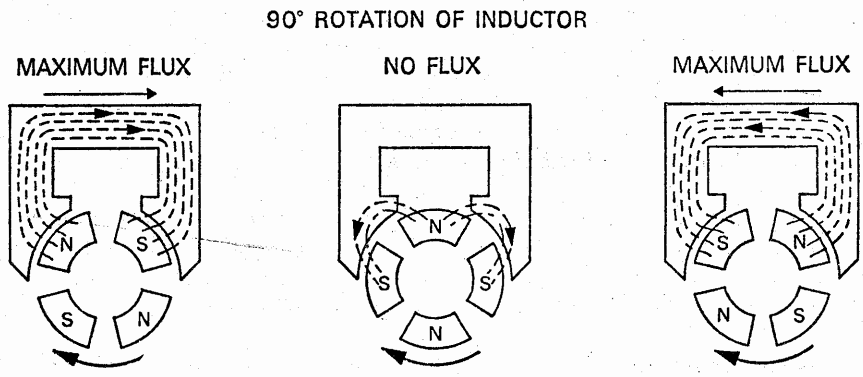


Figure 4 FLUX CHANGE IN A POLAR INDUCTOR MAGNETO

4 MAIN COMPONENTS OF A MAGNETO

4.1 The Armature. The armature consists of a soft iron core around which the primary and secondary coils are wound. With a rotating armature a means of transferring the electrical current to the static part of the magneto circuit, such as carbon brushes operating in slip rings, is provided. The armature core is usually laminated to reduce the build up of heat.

4.2 **The Contact-Breaker.** The contact-breaker is a mechanically operated switch which is timed to break the primary circuit when induced current in the primary coil is at a maximum.

4.2.1 On one type of rotating armature magneto, the contact-breaker is usually keyed on to the end of the armature shaft and rotates within a cam ring which is located concentrically round the shaft. As the contact-breaker assembly rotates, the breaker arm strikes each of the two cams in turn and breaks the primary circuit at the required moments.

4.2.2 On the polar inductor magneto, the contact-breaker assembly is normally stationary and the breaker arm is operated by a cam wheel attached directly to the distributor rotor. A separate cam lobe is provided for each of the engine cylinders.

4.3 **The Condenser.** The purpose of the condenser is to absorb the e.m.f. which tends to cause a spark to jump across the contact-breaker points as they begin to open. It ensures that the magnetic field collapses quickly and prevents rapid deterioration of the contact-breaker points due to arcing.

4.4 **The Permanent Magnet.** The magnet provides the necessary magnetic field to induce a current in the primary windings. Modern magnets are extremely powerful and are usually made from an alloy of aluminium, nickel and cobalt.

4.5 **The Distributor.** The purpose of the distributor is to ensure that the high voltage impulses produced in the secondary coil are conducted to the sparking plug in the appropriate engine cylinder in accordance with the firing order of the engine. Ignition of the gases is required in each engine cylinder once in every two revolutions of the crankshaft, thus the distributor has a segment for each cylinder arranged in firing order sequence and the rotating distributor arm is driven at half engine speed.

4.5.1 The distributor is usually an integral part of the magneto, the rotor being gear driven from the main magneto shaft. On some engines, however, the distributor assembly is remote from the magneto and the rotor is driven from an engine gear train or from a camshaft (which also rotates at half engine speed).

4.5.2 As sparking between the rotor and segments in the distributor is essential, the distributor casing is vented to prevent ionisation. The vent is fitted with a flameproof wire mesh screen to prevent combustion of inflammable gases round the engine.

4.6 **Impulse Starters.** During an engine starting sequence the magnetos are rotating only slowly and are not producing a strong enough spark to ensure combustion. Either one or both magnetos may be fitted with an impulse starter to overcome this failing. In one type of magneto fitted with an impulse starter, the drive from the engine to the armature shaft is through a spring loaded clutch device which flicks the armature through the positions at which a spark normally occurs, thus momentarily increasing the rate of rotation and the voltage generated. Once the engine is running, centrifugal weights in the impulse coupling overcome the springs and it operates as a normal "solid" drive shaft.

4.7 **Safety Spark Gap.** On some early magnetos a safety spark gap (see *Figure* 1) provided a means of discharging the secondary impulse to earth. It was provided to prevent damage to the armature in the event of a plug lead becoming detached.

5 ASSOCIATED COMPONENTS

5.1 **Booster Coils.** Where no impulse starter magneto is fitted, the weak spark produced during engine starting is supplemented by means of a booster coil, which takes its power from the aircraft batteries or external power supply, and is connected either to a booster coil switch or the engine starter switch.

5.1.1 High tension booster coils supply a "stream" of high tension impulses to a secondary or "trailing" brush in the distributor rotor arm which, due to its position, automatically retards the ignition timing.

5.1.2 Low tension booster coils supply a stream of low tension impulses to the armature primary windings either to augment or replace the voltage induced in the primary windings by the magnetic flux. On one type of magneto a second contact-breaker, retarded in relation to the main contact-breaker but connected in parallel with it, controls the supply of intermittent current from a low tension booster coil to the armature primary windings. Intermittent high tension current is therefore induced in the secondary coil and a stream of high tension impulses distributed to the sparking plugs.

5.2 **Ignition Switches.** Whenever a magneto is rotated sufficiently to open the contact-breaker points a spark will occur. All magnetos are therefore provided with an earthing wire, which is connected to the contact-breaker end of the primary coil and through a suitable switch to earth. Since this switch is connected in parallel with the contact-breaker, with the switch closed the effect of the opening and closing of the contact-breaker is by-passed and no spark can occur.

5.2.1 Some aircraft are provided with a separate toggle switch to control each magneto, the primary circuit being earthed when the switch is down. Many modern aircraft however are provided with a rotary four-position switch controlling both magnetos. A spring loaded position may also be provided for engine starter operation.

6 LOW TENSION MAGNETOS On some aircraft engines which consistently operate at high altitude, it has been found that the decreased atmospheric pressure leads to the breakdown of insulation within the magneto. The low tension ignition system in which the magneto produces only low voltage was designed to overcome these faults.

6.1 The magneto is similar to the polar inductor magneto described in paragraph 3.2, but does not embody a secondary coil. It is usual for the contact-breaker and condenser to be mounted in the distributor assembly.

6.2 Low voltage impulses from the magneto are distributed to individual secondary coils located near the sparking plugs. The secondary coils transform the current to the high voltage required at the sparking plugs.

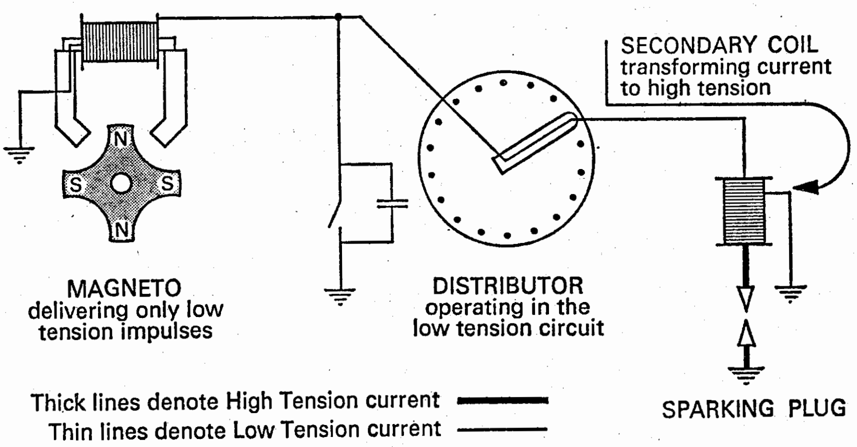


Figure 5 LOW TENSION IGNITION SYSTEM

7 INSTALLATION Prior to installation the magneto should be inspected for any defect which might have occurred during transit or storage. The contact-breaker cover, distributor cover and any blanking devices used for transit or storage should be removed and, as far as possible, an examination made for any signs of corrosion or dirt.

7.1 At all times when handling a magneto, such as during pre-installation checks, adequate precautions must be taken to keep all parts of the magneto clean. The working clearances of a magneto are small, and dust, swarf or filings may be drawn into the magneto by magnetic attraction and cause damage to the rotating parts or increase the resistance of contact points. The work-benches, shop equipment, and the vicinity in which magnetos are kept and maintained should therefore be clean. Any work such as filing, grinding, sawing, etc., which produces metallic dust or particles must not be permitted in the area.

7.1.1 It is important to ensure that the storage limiting period has not been exceeded and that the type of magneto is approved for the engine concerned.

7.1.2 On many engines slight variations exist between port and starboard magnetos. It is not unusual for the distributor covers to be handed and the direction of rotation to be different. Some engines may also have special starting devices fitted to one magneto only, such as an impulse starter or booster coil connection.

7.1.3 To prevent the build-up of cumulative errors when a single magneto is changed, it should be synchronised to the engine and not to the already installed magneto.

7.2 **Timing a Magneto.** Various methods are adopted by engine manufacturers for fitting and timing magnetos. The procedure specified in the appropriate engine Maintenance Manual should always be carefully followed. A typical timing procedure is outlined in the following sub-paragraphs.

7.2.1 To take up backlash in the engine drives to the magneto the engine should be turned in its direction of rotation (with some engines this may entail the use of a special friction clutch), until the cylinder on which the magneto is to be timed starts its compression stroke. To facilitate turning, a sparking plug can be removed from each cylinder. The engine should then be turned carefully until the magneto "fully advanced" mark on the moving part of the engine (e.g. on the crankshaft main driving gear), coincides with its related mark on a static part of the engine structure (e.g. on the gear case cover). The engine is then correctly set for the magneto to fire the cylinder concerned.

7.2.2 The spigot and mounting faces should be clean and free from burrs and, if applicable, an engine oil seal should be fitted. The magneto should be checked to ensure that, (a) the contact-breaker gap is correct, (b) it is fully advanced, (c) the distributor arm coincides with the distributor segment for the cylinder concerned, and (d) the contact-breaker points are just opening. The magneto should then be fitted to the engine, taking particular care to ensure that, when coupling-up the drive, the particular type of vernier adjustment is set so as not to disturb the magneto setting. At least two nuts or studs should be used to secure the magneto in position until a timing check is made.

7.2.3 The distributor cover should be removed from the magneto and the primary circuit lead disconnected from the contact-breaker. A lamp and battery should then be connected so that the battery and bulb are in series with the contact-breaker to earth. The timing can now be checked by turning the engine back about 30 deg. (ensuring impulse starter is not armed), then forward until the contact-breaker points open, indicated by the light going out; this should occur at the position shown by the timing mark. Small adjustments are possible by means of the vernier drive coupling. While turning the engine, the distributor rotor arm should be slightly restrained to to take up any backlash.

7.2.4 Where the timing of both magnetos is synchronised, a separate check for synchronisation should be made and the two lights should go out together at the correct timing position. For magnetos that are not synchronised, the timing of each magneto must be checked separately.

7.2.5 On magnetos where it is impracticable to isolate the primary winding from the contact-breaker points, the manufacturer may recommend the use of a proprietary timing indicator and, in some cases, the lamp will light when the points open (this is opposite to the normal lamp-battery timing indicator).

7.2.6 Before connecting the magneto to the ignition (earthing) switch, a check should be made to ensure satisfactory continuity and insulation resistance of the earth circuit. For the continuity test, one lead from a low voltage lamp-and-battery test set should be connected to the switch lead core and the other test lead should be connected to the screen. The lamp should be alight when the ignition switch is OFF and should go out when the switch is ON.

7.2.7 The insulation resistance of the ignition switch (earthing) lead should be checked with the type of insulation tester prescribed by the manufacturer. One lead from the tester should be connected to the magneto end of the ignition switch lead core and the other lead should be connected to the screen. With the ignition switch in the ON position the insulation tester reading should not be less than the minimum figure quoted in the Maintenance Manual.

7.2.8 When a magneto has been satisfactorily fitted and timed and the distributor cover complete with ignition harness has been fitted, it is important that the earthing switch connection is properly made and that the ignition switch is OFF. Unless this precaution is taken any rotation of the engine could cause a spark at the plug lead ends; if not connected to the plugs, this would create a fire hazard and, if connected with the switch at ON, there is a danger of the engine firing.

7.2.9 A check should be made to ensure that all securing devices and interconnecting linkages are secure and suitably locked and that controls operate in the correct sense through the full range of movement. It should also be ensured that the ignition harness connecting nuts are correctly engaged with the magneto adaptors and tightened to the specified torque loading.

8 MAINTENANCE The relevant publications for the engine concerned will specify the periodical inspections and maintenance operations for the magnetos.

8.1 During periodic maintenance, insulated and contact surfaces should not be cleaned until they have first been examined for any indications of high voltage discharge marks, erosion or other defects.

8.2 Only lubricant of the type recommended by the manufacturer should be used and the instructions regarding the periods and amount of lubricant required should be carefully followed.

8.3 Any excess lubricant near the contact-breaker points should be carefully cleaned off otherwise it may get on the points and cause arcing and burning.

8.4 **Contact-Breaker.** It is essential that the points should make good contact so that the primary winding current can build up freely. Special care should be taken to ensure that the points are making full contact and are free from oil, dirt, pitting or burning.

8.4.1 Unless specifically prohibited by the manufacturer, contact-breaker points should be cleaned with an approved solvent and then dried thoroughly with a jet of dry air; care is necessary to keep cleaning fluids away from the felt pads otherwise the lubricant will be dissolved. After cleaning, the contact-breaker gap should be checked.

8.4.2 When checking the contact-breaker gap it is important to ensure that this is accurately measured and adjusted. Any departure from the required gap will affect the internal timing of the magneto as well as the engine ignition timing, thus resulting in a weak spark and a loss of engine performance. The gap will vary with the type of magneto concerned (quite often between 0·009 in and 0·012 in) and this may be ascertained from the appropriate manual.

8.4.3 To check the gap clearance of points, the magneto should be turned in the direction of rotation until the heel of the rocker arm is riding on the top centre of the cam lobe; the points will then be fully open and can be checked with a clean feeler gauge. If excessive force is used when inserting the feeler gauge the contact-breaker spring will deflect and a false reading will be obtained.

NOTE: Before adjusting the gap the heel of the rocker arm should be checked for abnormal wear.

8.4.4 With some magnetos, especially where the contact-breaker points are made of tungsten, the use of a dial test indicator may be recommended. With a dial test indicator secured firmly to the magneto body and in a position that will permit the dial plunger to rest on the rocker-arm end, the magneto should be turned until the points are closed and the dial gauge set to zero. The magneto should then be turned, always in the direction of rotation, until the "points-fully-open" position is reached, the dial gauge indicating the gap clearance.

8.4.5 It is not uncommon for manufacturers to recommend that the contact-breaker gap should be checked on more than one cam lobe. On some magnetos, however, a master cam lobe may be specified for this check. If an excessive gap variation is noted between cam lobes this indicates uneven cam wear.

8.4.6 Adjustment of the gap should be made either by moving the base plate on which the fixed contact point is mounted or, in other cases where the actual contact point is threaded and clamped in its mounting arm, by screwing in or out as required. After any adjustment an engine check run must be carried out, following which it is essential to check carefully for security and locking of the parts disturbed.

NOTE: In some cases the magneto is earthed through the contact-breaker cover and if this is removed for any reason the magneto will be "live". On this type of magneto the plugs or leads should be removed before any servicing is carried out.

8.4.7 Correct spring pressure is essential (a) to prevent bouncing of the contact-breaker points, which could cause a bad electrical contact, or (b) to avoid excessive heel wear. The tension of the contact-breaker spring should be checked by opening the points with an accurate spring balance and noting the reading when the points open. To determine the exact moment when platinum points open, a 0·002 inch feeler gauge should be placed between the points prior to applying tension with the spring balance; when the feeler is released the reading should be noted. For tungsten points a timing indicator or lamp and battery must be used.

8.4.8 The spring balance should have an "L" shaped adaptor fitted so that it can be attached to the contact-breaker arm at the position required; the pull on the balance should be applied in the normal line of operation to ensure accurate results. The load at which the points should open will be specified in the appropriate manual.

8.4.9 The springs should be free from pitting, fretting, corrosion or discolouration; their contour should be smooth and free from kinks. Where auxiliary springs are fitted, they should be in line with the main spring and should lie flush along it, the free ends being slightly curled away from the main spring to prevent chafing.

8.5 **Distributor.** At the periods prescribed in the Maintenance Schedule the distributor should be removed for cleaning and inspection. It is important that all internal cleaning is carried out in accordance with the maker's recommendations. Leaded fuel must not be used for cleaning.

8.5.1 A visual check should be made for cracks or traces of tracking in the vicinity of the segments. If tracking has resulted in a breakdown of insulation, the distributor should be changed. However, if the traces of tracking can easily be removed by the normal cleaning process this should be satisfactory. It is essential that the moulding, especially between the segments, has a clean smooth surface. An insulation test may be specified by the manufacturer.

8.5.2 It is important that any gauze used in vent holes is clean and undamaged.

8.6 **General Maintenance Checks.** The following general points should also be checked during maintenance:—

(i) Carbon brushes or contacts should move freely in their guides and the spring pressures should be adequate to ensure good electrical contact. The contact surfaces should also seat satisfactorily.

(ii) Any other springs, in addition to the contact-breaker springs, should be checked for freedom from corrosion, pitting or fretting, and their strength should be adequate.

(iii) All connections should be tight and correctly made and all internal leads should be adequately supported.

(iv) If any fibre dust is found in the vicinity of the slow speed gear the reason for its presence should be investigated.

(v) Cam rings should be checked for cleanliness, corrosion or excessive wear.

(vi) Where applicable, variable timing devices should be checked for full and free movement and should be lubricated as necessary.

(vii) Impulse starters should be checked for condition and operation, and should be lubricated as necessary. Flexible vernier couplings should have the correct clearance to allow for expansion and should be free from oil soakage.

8.7 **Replacement of Parts.** Some parts may be changed during routine maintenance provided this is specified in the manufacturer's publication. After replacement and adjustment of the new part, a timing check may be necessary and an engine ground run should be made.

NOTE: On some small aircraft engines a sealed type of magneto may be fitted on which very little maintenance is possible. These magnetos are installed by setting the position of the engine crankshaft, fitting a special key to the magneto to lock the main shaft in a predetermined position and assembling the magneto to the engine. Further information may be obtained from the appropriate manufacturer's manual.

EL/3-10

Issue 2

June, 1984

AIRCRAFT

ENGINES

TURBINE ENGINES

1 INTRODUCTION This Leaflet gives general guidance on the inspection and maintenance of turbine engines in service. A brief description of these engines is also included to stress the reasons for careful inspection. Further information is contained in Leaflet **EL/3-11** Turbine Engine Fuel Systems.

2 GENERAL The gas turbine engine is basically of simple construction although the thermal and aerodynamic problems associated with its design are somewhat complex. There are no reciprocating components in the main assembly and the engine is therefore essentially free from vibration. Power is produced in a continuous cycle by compressing the intake air and passing it to the combustion section where fuel is added and burnt to provide heat. The expansion of the gases rearwards through the turbine produces the power necessary to drive the compressor, the residual energy being used to provide jet thrust or, in the case of turbo-prop engines, to drive a propeller. Propeller efficiency falls off rapidly above approximately 350 knots so that turbo-prop engines are normally used to power comparatively low speed aircraft. Faster aircraft use turbo-jet engines, by-pass or turbo-fan engines being favoured for high subsonic speeds because of their fuel economy and low noise level. After-burning, i.e. the burning of fuel in the jet pipe to provide additional thrust, is normally used only in military aircraft due to the large quantities of fuel consumed, but it may be used on civil supersonic aircraft for take-off and acceleration to supersonic flight.

2.1 **Limitations.** The power obtainable from a gas turbine engine is limited by the ability of the materials used in its manufacture to withstand the high centrifugal forces and high gas temperatures developed within the engine. The life of components in the 'hot' sections of the engine, i.e. combustion chambers, turbines and jet pipe, is also influenced by the number of temperature cycles to which they are subjected. It is mainly the construction of the turbines which decides the operating speeds and temperatures of the engine and although operation within these limits is often mechanically controlled, care must be taken to ensure that they are not exceeded either during ground running or in flight.

2.2 **Indicators.** Various conditions of the turbine engine must be known to enable satisfactory operation within limitations, and indicators are fitted to the aircraft instrument panel for this purpose. Their functions are explained in the following paragraphs.

2.2.1 **Engine Speed.** The speeds of the rotating assemblies must be known so that the centrifugal forces acting on the compressor and turbine rotors may be kept within safe limits. Propeller speed is also indicated when appropriate. Indicators are usually electrically operated (see Leaflet **AL/10-3**) and are calibrated to show revolutions per minute or a percentage of maximum rotational speed.

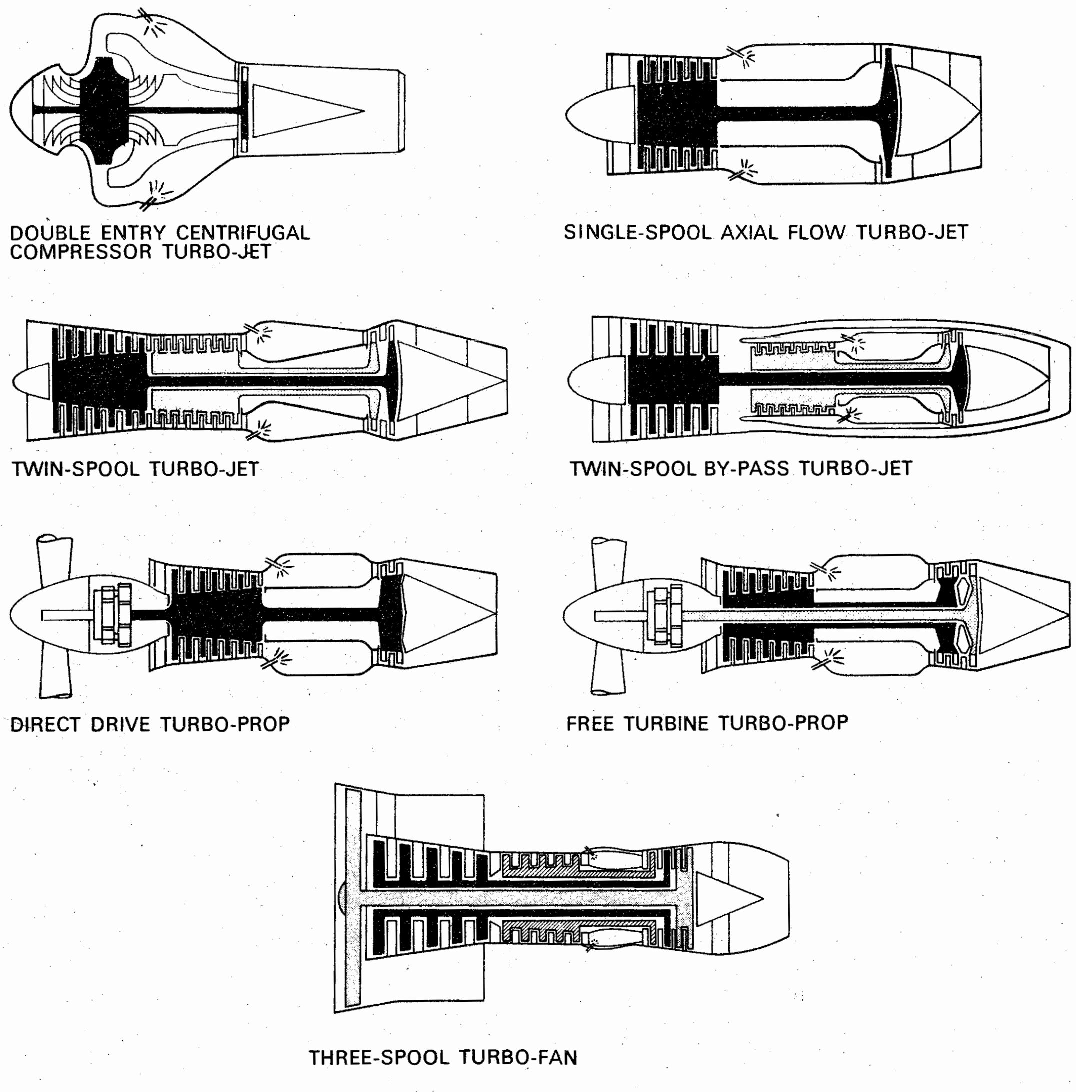


Figure 1 TYPICAL VARIATIONS IN GAS TURBINE DESIGN

2.2.2 **Turbine Gas Temperature.** Turbine gas temperature is a critical variable of engine operation but because of the high temperatures at the combustion chamber exit it is impractical to measure the actual temperature of the gas impinging on the turbine blades. The temperature drop across turbines is a known quantity, however, and temperature probes are often placed either in the stator blades aft of the first or second stage turbine or in the jet pipe. Indicated gas temperature limitations will thus differ considerably between engines and a low gas temperature limitation must not be taken as being less significant than a high one. Normally, a number of thermocouples are arranged radially around the engine with the mean temperature shown on a single indicator. This is known as the Exhaust Gas Temperature (EGT), Turbine Gas Temperature (TGT) or Jet Pipe Temperature (JPT) gauge, depending on the position of the probes.

2.2.3 **Power.** The power or thrust developed by an engine is not always directly proportional to gas temperature and rotational speed. Other factors such as ambient air pressure and temperature and forward speed also affect the power produced. 'Power' is measured in the form of thrust or torque and calibrated on an indicator which also acts as a power deficiency warning.

(a) The thrust of a turbo-jet engine is measured from the jet exhaust pressure. A commonly used indicator is the engine pressure ratio (EPR) gauge which measures the ratio of exhaust pressure to air intake pressure. Alternatively, a simple pressure gauge measuring jet pipe pressure is used. An accurate figure for comparison purposes is obtained by correcting for ambient temperature. In the case of a turbo-fan engine, the fan and exhaust pressures are measured.

(b) On turbo-prop engines the torque produced at the propeller shaft is measured because jet thrust is only a small proportion of the engine power. One particular type of torquemeter measures the oil pressure required to oppose the axial thrust of the helical teeth on the reduction gear, the gauge being calibrated in lbf/in^2.

2.2.4 **Vibration.** A turbine engine has a very low vibration level due to the accurate balancing of the rotating assemblies. Damage to the engine will usually be indicated by out of balance forces which are recorded on a vibration indicator. This instrument continually monitors the vibration level of the engine and takes the form of a milliammeter which receives signals through an amplifier from engine mounted vibration transducers.

2.2.5 **Other Indicators.** Gauges, warning lights or magnetic indicators are fitted to show fuel and oil system functions. Some multi-engine aircraft are fitted with a synchroscope to assist in synchronising engine speeds during flight.

3 MAINTENANCE

3.1 **Maintenance Requirements.** The maintenance required on a turbine engine in service is considerably less than that required on a piston engine and the overhaul life is much longer. This is mainly due to the lack of rubbing surfaces and low vibration. Overhaul lives of up to 15,000 hours are in current use and many engines are now being overhauled 'on condition' only.

3.1.1 An essential part of the maintenance of a turbine engine in service is the in-flight monitoring of indicators provided for certain critical parameters. This monitoring may be carried out by a flight crew member or by electronic recording apparatus and it has been found that a log of such readings provides a good basis for performance comparison and hence for judging engine condition.

3.1.2 Ground maintenance is a process of progressive visual inspection of the engine installation, adjustment to or replacement of components as required by reported defects, lubrication of working parts and replenishment of systems. Regular inspection for damage to compressor and turbine blades is particularly important. Minor repairs may be permitted within specified limits and the engine manufacturer may require periodic removal of certain components in the 'hot' section for detailed examination. Further disassembly is not normally permitted although certain engines are now designed with a view to 'modular' replacement, i.e. replacement of compressors, turbines or combustion chambers without removing the complete engine from the airframe.

4 INSPECTION The following paragraphs describe the inspections which are normally required by the engine manufacturer and specified in the appropriate Maintenance Schedule.

4.1 **General Precautions.** All turbine engines are susceptible to damage through the ingestion of foreign bodies. The axial flow type of compressor is particularly vulnerable to this type of damage and extreme care is necessary when carrying out an inspection of any part of the engine or adjacent structure to ensure that loose articles are not left where they may subsequently be drawn into the compressor. Clothing, buttons, caps, belts, pencils and tools are all items which, if left in intakes or engine cowlings, could cause damage necessitating removal of the engine. Intake and jet pipe covers should always be used when an aircraft is parked for any length of time and the intake area should be inspected for foreign objects or debris immediately prior to starting the engine.

4.2 **Air Intake.** The air intake passage leading to the compressor is designed to permit the required flow of air into the engine under all conditions of flight. Any damage or blockage in the air intake could affect engine performance.

4.2.1 All panels, fairings, fasteners, bolts and locking devices should be inspected for security of attachment, flush fitting or damage. Unserviceable items should be repaired or renewed.

4.2.2 Intake lips should be inspected for dents or other damage which could affect the airflow. Air bleeds or drain holes should be clear.

4.2.3 Pressure sensing probes, where fitted, should be inspected for security, cracks and corrosion.

4.2.4 Electrically heated anti-icing mats located in the air intake should be inspected for adhesion and damage. Controls for these heater mats may be automatic, continuous or cyclic and the manufacturer's manual should be consulted for details of a particular system before carrying out a functional or electrical resistance test.

4.3 **Compressors.** The compressor is an accurately manufactured and balanced component which may become damaged by hail, ice or foreign bodies. Inspection of the guide vanes and as many rows of stator and rotor blades as possible should be carried out with the aid of a mirror and strong spot light. (See also paragraph 4.8.)

4.3.1 **Superficial Damage.** Damage to aluminium, steel or titanium blades in the form of small dents, may be regarded as acceptable provided that it cannot result in the propogation of cracks and is within the limits defined in the manufacturer's manual.

4.3.2 **Impact Damage.** Impact damage caused by the entry of small metal parts can result in rejection of the engine as the damage may extend throughout the compressor. If thread or hexagon impressions are visible on the stator or rotor blades, the engine should normally be removed for strip examination.

4.3.3 **Reparable Damage.** Damage caused to the initial compressor stages by small stones or grit may be blended out within specified limits. A clean cloth should be placed round the blade being repaired to catch any swarf or filings removed during the blending process. File marks on blades should be removed with fine emery cloth and the blades inspected for cracks by a suitable penetrant-dye process (see Leaflet **BL/8-2**) immediately after the work and at regular intervals during the remaining life of the engine. Renewal of the anti-corrosive treatment may also be required.

4.3.4 Diagnosis of damage to later compressor stages may only be possible from the results of engine performance and running checks. Where limited engine stripping to facilitate inspection is permitted, procedures will be detailed in the appropriate Maintenance Manual.

4.3.5 **Compressor Washing.** When compressor blades become contaminated with dust and oil their efficiency is reduced and less power is developed by the engine. Manufacturers often specify compressor washing at regular intervals and when low torque or thrust readings, for which there is no apparent mechanical reason, are encountered. Washing is carried out by spraying kerosene into the air intake during a dry motoring run. This is allowed to soak for about 30 minutes and followed by spraying distilled or demineralised water into the intake during a second dry motoring run. Cabin heating and pressurising systems should be blanked off during these operations and the engine must be left to drain completely before subsequently being started. If a kerosene wash is not effective, certain manufacturers recommend repeating the wash with either kerosene or an approved cleaning solution.

NOTE: Dry cleaning of centrifugal compressor engines using a mild abrasive is sometimes recommended by engine manufacturers.

4.3.6 **Compressor Casing.** The compressor casing should be examined for signs of damage, gas or fluid leaks and the components for security of attachment. Any corrosion should be removed, the affected areas retreated and damaged paint renewed as necessary.

NOTE: Compressor casings are often manufactured from magnesium alloy which requires special anti-corrosive treatment, details of which will be given in the manufacturer's manual.

(a) Certain components attached to the casing may be fitted with 'witness' drains and these should be examined to ensure that the permitted leakage is not exceeded.

4.4 **Combustion Section.** Inspection of the internal features of the combustion chamber is not always possible in service, unless the engine is equipped for this, as described in paragraph 4.8. Where individual flame tubes are fitted the manufacturer may recommend their removal at specified intervals in order to carry out a detailed inspection for cracks or other heat damage. Removal of the flame tubes will permit an inspection of the nozzle guide vanes and high pressure turbine blades similar to that detailed in paragraph 4.5. In other cases the manufacturer often specifies an overhaul of the 'hot' section of the engine which is considered to be equivalent to the top overhaul of a piston engine. These inspections are often possible in situ, but, as radiographic or radio isotope crack detection methods are usually specified, it is often more convenient to remove the engine for inspection at a suitably equipped workshop.

4.4.1 Inspection during service is normally confined to an external examination of the combustion section as follows:

(a) Heat shields and lagging should be inspected for security, signs of burning or gas leakage. Any signs of overheating are an indication that internal damage may have occurred and further examination may be required.

(b) Fuel injectors should be inspected for security, damage or fuel leaks.

(c) The ignition system wiring should be inspected for signs of chafing, security and fluid contamination.

(d) Drain pipes should be inspected for security and must be free from blockage. A blocked combustion chamber drain pipe constitutes a potential fire hazard in certain circumstances. On some aircraft the drains are led to a common collector box which is emptied by suction during flight; these may require manual draining following a failure to start the engine.

4.5 **Turbine and Exhaust Section.** A strong spotlight and appropriate viewing equipment are necessary when inspecting the turbine and exhaust section (see also paragraph 4.8). All components should be carefully checked for damage, cracks or signs of metallic deposits.

4.5.1 Damage to turbine blades, other than slight pitting, is not usually acceptable. Damage to other components, including small cracks in jet pipes, is often permitted. Metallic deposits most likely to be found are aluminium, showing as a dull white or silver splatter, and titanium, which may be in the form of bright blue or golden speckles. Heavy deposits will necessitate removal of the engine for further examination but light deposits should be assessed in relation to engine performance before resorting to engine removal.

4.5.2 The jet pipes of turbo-prop engines are not so highly stressed as those of turbo-jet engines because there is little residual thrust left in the exhaust gases after the turbines have taken the power necessary to drive the propeller. Cracks or holes in these jet pipes may be repaired by patching with a similar material of the same gauge; electric resistance welding is usually specified to limit distortion. The manufacturer's manual should be consulted regarding the extent of repairs permitted and any subsequent limitation on time in service or inspection frequency.

4.5.3 Thrust reversers are often employed in large aircraft and should be subjected to an inspection similar to that carried out on jet pipes. It is particularly important that the doors or buckets used in thrust reversers should be flush with the jet pipe when retracted. Any projection will result in a 'hot spot', which will lead to distortion and cracking. Thrust reverser operating mechanisms should be checked for correct operation in accordance with the appropriate Maintenance Manual.

4.5.4 **Buried Engines.** Additional checks should be carried out on engines buried within the airframe structure as follows:

(a) Long jet pipes are often employed with buried engines and are lagged to prevent the transfer of heat to the surrounding structure. An inspection should be made to ensure that there are no gas leaks at the joint with the engine or cracks in the pipe itself, indicated by burning of the lagging material.

(b) Because of its length the jet pipe is suspended in such a way as to allow for considerable axial expansion. The fixed attachments should be checked for security and the expansion links for freedom of movement.

(c) The surrounding airframe structure should be inspected for signs of excessive heat such as discoloration or blistered paint. There should be adequate clearance from the jet pipe to permit the passage of cooling air.

4.6 **Oil System.** Most turbine engines have a closed cycle oil system similar to that used on piston engines. Rotor main bearings and all accessory drives and gears are pressure lubricated, scavenge oil being either drained in to a wet sump or returned to a tank mounted on the engine casing. The main compressor and turbine bearings on some engines are lubricated by a waste system which employs micro-pumps to provide a metered supply of oil to each bearing. The oil passes through the bearing and exhausts to atmosphere with the burnt gases. In this type of system both maximum and minimum permitted oil consumption figures are quoted.

4.6.1 Routine maintenance of the oil system consists of checking the level of oil in the oil tank and topping up as necessary with the appropriate type and grade of oil. When changing from one type of oil to another it may be necessary for the tank to be drained, partially refilled with the new oil and the engine run for approximately 15 minutes, exercising all oil operated controls as appropriate. The system should then be drained once more and refilled completely.

NOTE: Some synthetic oils used in turbine engines contain tri ortho cresyl phosphate or other additives which are highly toxic and should not be allowed to come into contact with the skin. It is recommended that suitable gloves should be worn by personnel continuously handling these oils.

4.6.2 Filters are provided in the oil system and should be removed for examination at the intervals specified in the Maintenance Schedule. Light metal swarf may be expected in new engines but a heavy deposit indicates a failure in the engine. Metal filters should be washed in kerosene and dried with compressed air before refitting, but 'throw-away' type paper filters should be renewed. It is also essential that the filter casing is flushed out to remove any residual contaminant.

4.6.3 Chip detectors and magnetic plugs are often fitted in the oil system and should be removed for examination at regular intervals. Some chip detectors can be examined in situ by the use of a 250 volt megger, with zero resistance between the centre of the detector and the casing indicating that sufficient metal particles are present to warrant removal and examination of the detector. This principle has been further extended so that detectors can provide an electrical signal for cockpit indication of particle build up, enabling in-flight monitoring and also automatic recording of necessary post-flight maintenance action.

4.7 **Engine Mountings.** Engine mounting structures are designed to allow for engine expansion and usually consist of a main trunnion to transmit engine thrust to the airframe and a secondary support to steady the engine. Turbo-prop engines are normally mounted in a tubular cage similar to that used on radial piston engines.

4.7.1 Turbo-jet engine mountings should be inspected for security, cracks and corrosion. Cracks are not acceptable and any corrosion must be removed and the component re-protected. The mountings are usually subjected to a detailed crack detection test whenever the engine is removed.

4.7.2 Tubular mounting structures should be inspected for dents, bowing, cracks or corrosion and a dimension check carried out whenever the engine is removed. Repairs are usually permitted within specified limits and the procedures in the appropriate Maintenance Manual should be followed.

4.7.3 When engines are subjected to shock loading as a result of a heavy landing or damage to a propeller, the engine mountings should be critically examined for cracks, bending, pulled rivets or other signs of distortion (buckled cowlings are a good indication of damaged mounting structures). The torque loading of bolts held in tension should also be checked; a low value indicates that the bolt has stretched and should be renewed. The mounting should be given a complete dimensional check and tested for cracks by the magnetic-flaw method (see Leaflet **BL/8-5**) following engine removal.

4.8 **Internal Inspection.** In addition to the checks detailed above for specific components some modern engines are provided with access holes at strategic positions through which an endoscope inspection can be carried out. By this means certain internal features such as combustion chambers and compressor or turbine blades can be examined without recourse to engine removal and stripping. (See Leaflet **BL/8-9**.)

5 ENGINE REMOVAL AND INSTALLATION New or reconditioned turbine engines are normally supplied as an Engine Change Unit (ECU), the Unit including the basic engine and the equipment which is common to the engines on the particular aircraft. Items which are 'handed' to suit the different engine positions such as jet pipes or engine mountings, and other items which are not fitted to all engines such as thrust reversers or hydraulic pumps, must be added to the ECU to make it into a complete power plant. The transfer of these components from the old power plant to the new ECU, when approved, must be recorded in the appropriate log books (see Leaflet **BL/1-10**). Similarly when new components are fitted to the ECU the entries must be made in the ECU log book. Engine installation details vary considerably between aircraft and it is not within the scope of this Leaflet to present detailed information on each. The following paragraphs may be taken to be typical of current practices and should be read in conjunction with the appropriate Maintenance Manual. Where the term 'engine' has been used in the text this may equally be taken to imply 'ECU' or 'Power Plant' as appropriate.

5.1 **Engine Removal.** Some aircraft may have to be jacked up and trestled when removing an engine. This is not often practicable with large multi-engine aircraft and other means are sought to ensure that the engine is at the same attitude when suspended from the sling as when installed in the airframe. Manufacturers may specify that the aircraft should be placed in a certain attitude (e.g. 1°30′ nose down) for engine removal and it is also sometimes necessary to add ballast weights to one side of an engine which is not symmetrical. These requirements will be stated in the aircraft Maintenance Manual.

NOTE: If the engine is not being replaced immediately it is sometimes recommended that ballast weights be fitted to the engine mountings to prevent airframe distortion.

5.1.1 **Preparation.** The aircraft should be prepared for engine removal as follows:

(a) Ensure that the landing gear ground lock pins are correctly fitted.

(b) Turn off the fuel supply to the engine being removed.

(c) Disconnect all electrical power to the engine being removed.

(d) Fit blanks to the engine air intakes and jet pipe.

(e) Position lifting gear.

(f) Prepare and position a suitable engine stand ready to receive the engine after removal.

5.1.2 **Safety Precautions.** The maximum safe working load of the lifting gear must exceed the weight to be lifted and the sling must be the correct one for the work being carried out (i.e. a sling designed to lift the bare engine must not be used to lift a complete power plant). The sling should be inspected for frayed wires, bent or worn shackles and any other damage likely to affect its serviceability. An aircraft undergoing engine change will rise or fall as the weight changes. All personnel working near the aircraft should be made aware of this and the proximity of trestles and stands checked to avoid structural damage.

5.1.3 **Removal.** Sufficient cowlings and panels should be removed to gain access to the engine disconnect points, engine slinging points and engine mountings. All system connections should then be broken, the open ends of pipes and electrical connectors being fitted with blanks to prevent the ingress of dust and dirt. Controls and cables should be temporarily secured to prevent damage; slave pulleys are sometimes provided in the nacelle to receive detached control cables. Locking wire, split pins, washers, nuts or bolts which have been removed should be carefully collected and taken away from the engine location. It is good practice to keep an inventory of tools used by the operators to check that none are left where they could cause damage.

NOTE: The electrical charge held by high energy ignition units can be lethal. After removing the LT input lead at least one minute should elapse before touching the HT output lead or igniter plug.

5.1.4 The engine sling should be fitted and the weight of the engine taken on the lifting gear, attaching ballast weights as necessary to level the engine. After a final check to ensure that all the connections are broken, the mountings should be disconnected and the engine lowered into the prepared stand.

5.1.5 Any components required for the replacement engine should be removed, together with the engine sling, and the engine prepared for storage or transit (paragraph 7).

5.2 **Engine Installation**

5.2.1 **Preparation.** With the engine in its stand an inspection should be made for any damage which could have occurred in transit. Components being installed on the engine should be inspected for serviceability, special note being taken of any lubrication or testing required by the manufacturer. The engine bay area should be thoroughly cleaned and inspected for damage and all engine connections inspected to ensure that no damage was sustained during engine removal. Engine mountings should be lubricated in accordance with the manufacturer's instructions.

5.2.2 The safety precautions appertaining to slings and lifting gear, outlined in paragraph 5.1.2 for removal, apply equally to installation and must be checked before commencing lifting operations.

5.2.3 **Installation.** The engine sling should be fitted and the engine lifted from the stand into the engine bay, connecting the mountings and torque loading the attachment bolts to the values quoted in the Maintenance Manual. When the engine is secured in position the sling should be removed and all systems reconnected, removing the blanks immediately before connecting each item. The high energy ignition units should not be connected until the engine is ready for ground running.

5.2.4 All bolts should be tightened to the recommended torque values and new gaskets, washers and locking devices fitted as necessary. Particular attention must be paid to the setting up of engine controls, the procedure for which will be found in the appropriate Maintenance Manual. A duplicate inspection of these controls is required (see Leaflet **AL/3-7** and BCAR Chapter **A5-3**).

5.2.5 **Priming.** The engine oil tank should be filled with the approved oil, and the oil and fuel systems primed. This is to ensure that all inhibiting oil is removed, that all pipelines are full and that the engine will not rotate in dry bearings when started.

(a) **Oil System.** Using the approved type of oil and a priming rig, the micro-pumps, gearbox and oil filters should be primed with the quantity of oil specified in the Maintenance Manual followed by replacement and locking of all unions, plugs and filler caps.

(b) **Fuel System.** As the aircraft booster pump is used for this operation, electrical power to the engine should be restored and the low pressure fuel cock opened. The booster pump should then be switched on and the appropriate bleed valves opened until clean bubble-free fuel is discharged. The bleed fuel should be collected in a suitable container and the bleed re-locked after use.

NOTE: It is common airline practice to cross-feed the fuel supply when bleeding. This ensures complete purging of the low pressure supply.

5.2.6 **Preparation for Starting.** To prove the engine installation before starting, the following procedure should be carried out:

(a) Check that the engine installation is clean and free from extraneous material, remove the intake and jet pipe covers and place drip trays under the engine.

(b) Open the low pressure fuel cock (LP cock) and the high pressure fuel cock (HP cock) and carry out a motoring run with the ignition system switched off. Check that oil and fuel pressures are indicated and that there are no leaks from the engine or adjacent pipelines.

(c) Allow the engine to drain and carry out a second motoring run with the HP cock closed.

(d) Allow the engine to drain once more then connect the leads to the high energy ignition units and refit all cowlings and panels.

5.2.7 The engine should then be started, all systems tested and adjustments carried out as necessary.

6 **GROUND RUNNING** The life of a turbine engine is affected both by the number of temperature cycles to which it is subjected and by operation in a dusty or polluted atmosphere. Engine running on the ground should therefore be confined to the following occasions:

(a) After engine installation.

(b) To confirm a reported engine fault.

(c) To check an aircraft system.

(d) To prove an adjustment or component change.

(e) To prove the engine installation after a period of idleness.

6.1 **Safety Precautions**

6.1.1 Turbine engines ingest large quantities of air and eject gases at high temperature and high velocity, creating danger zones both in front of and behind the aircraft. The extent of these danger zones varies considerably with engine size and location and this information is given in the appropriate aircraft Maintenance Manual. The danger zones should be kept clear of personnel, loose debris and equipment whenever the engines are run. The aircraft should be positioned facing into wind so that the engine intakes and exhausts are over firm concrete with the jet efflux directed away from other aircraft and buildings. Silencers or blast fences should be used whenever possible for runs above idling power. Additional precautions, such as protective steel plates or deflectors, may be required when testing thrust reversers or jet lift engines, in order to prevent ground erosion.

6.1.2 Air intakes and jet pipes should be inspected for loose articles and debris before starting the engine and the aircraft main wheels chocked fore and aft. It may be necessary to tether vertical lift aircraft if a high power check is to be carried out.

6.1.3 Usually on large aircraft one member of the ground crew is stationed outside the aircraft and provided with a radio headset connected to the aircraft intercom system. This crew member is in direct communication with the flight deck and able to provide information and if necessary warnings on situations not visible from inside the aircraft. Due to the high noise level of turbine engines running at maximum power it is advisable for other ground crew members to wear ear muffs.

6.1.4 A suitable CO_2 or foam fire extinguisher must be located adjacent to the engine during all ground runs. The aircraft fire extinguishing system should only be used in the event of a fire in an engine which is fully cowled.

6.2 **Starting.** There are many different types of turbine engine starters and starting systems, therefore it is not possible to give a sequence of operations exactly suited to all aircraft. The main requirements for starting are detailed in the following paragraphs.

6.2.1 An external electrical power supply is often required and should be connected before starting. Where a ground/flight switch is provided this must be set to 'ground' and all warning lights checked for correct operation.

6.2.2 Where an air supply is required for starting this should be connected and the pressure checked as being sufficient to ensure a start.

NOTE: If the electrical and air supplies are not adequate for starting purposes it is possible for a light-up to occur at insufficient speed for the engine to accelerate under its own power. This could result in excessive turbine temperatures and damage to the engine.

6.2.3 The controls and switches should be set for engine starting, a check made to ensure that the area both in front of and behind the engine is clear and the starter engaged. When turbine rotation becomes apparent the HP cock should be opened and the engine instruments monitored to ensure that the starting cycle is normal. When light-up occurs and the engine begins to accelerate under its own power, switch off the starter. If it appears from the rate of increase in exhaust or turbine gas temperature that starting limits will be exceeded the HP cock should be closed immediately and the cause investigated (see under 'Trouble Shooting' in the appropriate Maintenance Manual).

6.2.4 Once engine speed has stabilised at idling, a check should be made that all warning lights are out, the external power supplies disconnected and the ground/flight switch moved to 'flight'.

6.3 **Testing.** When a new engine has been installed a full ground test is necessary, but on other occasions only those parts of the test necessary to satisfy the purpose of the run need be carried out. The test should be as brief as possible and for this reason the aircraft Maintenance Manual specifies a sequence of operations which should always be observed. Records of the instrument readings obtained during each test should be kept to provide a basis for comparison when future engine runs become necessary.

6.3.1 Each aircraft system associated with engine operation should be operated and any warning devices or indicators in the cockpit checked against physical functioning. It may be necessary in certain atmospheric conditions to select engine anti-icing throughout the run and this should be ascertained from the minimum conditions quoted in the Maintenance Manual.

6.3.2 The particular tests related to engine operation are idling speed, maximum speed, acceleration, and function of any compressor airflow controls which may be fitted. Adjustments to correct slight errors in engine operation are provided on the engine fuel pump, flow control unit, and airflow control units. Observed results of the tests must be corrected for ambient pressure and temperature, tables or graphs being provided for this purpose in the aircraft Maintenance Manual. Adjustments may usually be carried out with the engine idling unless it is necessary to disconnect a control. In this case the engine must be stopped and a duplicate inspection of the control carried out before starting it again. An entry must be made in the engine log book quoting any adjustments made and the ambient conditions at the time.

6.4 **Stopping.** After completion of the engine run the engine should be idled until temperatures stabilise and then the HP cock closed. The time taken for the engine to stop should be noted and compared with previous times, due allowance being made for wind velocity (e.g. a strong head wind will appreciably increase the run-down time). During the run-down fuel should be discharged from certain fuel component drains and this should be confirmed. A blocked drain pipe must be rectified. When the engine has stopped, all controls and switches used for the run must be turned off and the engine inspected for fuel, oil, fluid and gas leaks.

6.4.1 After a new engine has been tested the oil filters should be removed and inspected (see paragraph 4.6.2) and after refitting these items the system should be replenished as necessary.

7 STORAGE AND TRANSIT All turbine engines which are to be either stored or shipped for overhaul should be packed in such a way as to prevent damage from corrosion or rough handling. The procedure to be followed is outlined below and should be observed irrespective of the condition of the engine.

7.1 **Fuel System Inhibiting.** The fuel used in turbine engines usually contains a small quantity of water which, if left in the system, could cause corrosion. All the fuel should therefore be removed and replaced with an approved inhibiting oil by one of the following methods:

7.1.1 **Motoring Method.** This should be used on all installed engines where it is convenient to turn the engine using the normal starting system. A header tank is used to supply inhibiting oil through a suitable pipe to the engine. A filter and an on/off cock are incorporated in the supply pipe, which should be connected to the low pressure inlet to the engine fuel system and the aircraft LP cock closed. After draining the engine fuel filter a motoring run should be carried out bleeding the high pressure pump and fuel control unit, and operating the HP cock several times while the engine is turning. Neat inhibiting oil will eventually be discharged through the fuel system and combustion chamber drains. When the motoring run is complete the bleeds should be locked, the oil supply pipe disconnected and all apertures sealed or blanked off.

7.1.2 **Pressure Rig Method.** This may be used on an engine which is installed either in the aircraft or in an engine stand. A special rig is used which circulates inhibiting oil through the engine fuel system at high pressure. The fuel filter should be drained and, where appropriate, the aircraft LP cock closed. The inlet and outlet pipes from the rig should be connected to the high pressure fuel pump pressure tapping and the system low pressure inlet respectively, and the rig pump turned on. While oil is flowing through the system the components should be bled and the HP cock operated several times. When neat inhibiting oil flows from the combustion chamber drains the rig should be switched off and disconnected, the bleed valves locked and all apertures sealed or blanked off.

7.1.3 **Gravity Method.** This is used when the engine cannot be turned. A header tank similar to the one used in the motoring method is required but in this case the feed pipe is provided with the fittings necessary for connection at several positions in the engine fuel system. The fuel filter should first be drained then the oil supply pipe connected to each of the following positions in turn, inhibiting oil being allowed to flow through the adjacent pipes and components until all fuel is expelled:

(a) High pressure fuel pump pressure tapping.

(b) Fuel control unit pressure tapping.

(c) Burner Manifold.

(d) Low pressure inlet pipe.

7.1.4 Components should be bled at the appropriate time and the HP cock operated several times when inhibiting the fuel control unit. All bleeds and apertures should be secured when the system is full of inhibiting oil.

7.2 **Packing.** The engine should be securely attached to its transportation stand, all blanks fitted and apertures taped over to prevent the ingress of moisture. A compartment is usually provided on the stand for the documents relating to the engine, and any other information considered relevant should also be included. If the engine has been removed because of suspected internal failure, any metal found in the filters, broken blades or other evidence should also be packed for examination during overhaul.

7.2.1 Engines are wrapped in a hermetically sealed moisture-proof bag which should be examined before covering the engine. Any large tears or holes should be repaired using the repair kit contained within the bag but small cuts may be repaired with adhesive PVC tape. Sponginess of the bag material is caused by contamination with oil or fluid and may sometimes be eliminated by washing with water. If the area remains tacky after washing the bag should be rejected.

7.2.2 Bags containing silica gel dessicant should be placed in the air intake and exhaust unit and attached at convenient positions around the engine. Approximately 14 to 18 kg (30 to 40 lb) of dessicant will be required depending on the size of the engine and the manufacturer may specify the use of VPI paper in addition (see Leaflet **BL/1-7**). A humidity indicator should then be placed in the bag where it can be easily seen and the bag sealed up. Where possible the humidity indicator should be inspected at frequent intervals to ensure that the condition of the air inside the bag is still 'safe' (i.e. the colour of the indicator is blue). If an 'unsafe' condition is shown (i.e. the colour of the indicator is lilac or pink) the bag should be inspected and repaired as necessary, and the dessicant renewed.

7.3 **Storage.** Complete engines and individual components should be kept in a clean, well-ventilated store with an even temperature of 10 to 20°C. Components should be stored in open racks in their original packing and rubber items kept away from strong sunlight, oil, grease or heat sources. Any dessicant packs attached to stored components should be checked frequently for moisture contamination.

7.3.1 With certain components (rubber seals, etc) the manufacturer may recommend that the number of components in a stack is limited to a specific number to prevent distortion.

7.3.2 Components which have a shelf life should be used in sequence, any which become time expired being removed for overhaul, test and repacking.

Issue 1.

10*th December*, 1969.

AIRCRAFT

ENGINES

TURBINE ENGINE FUEL SYSTEMS

1 INTRODUCTION This Leaflet describes the operation of typical turbine engine fuel systems and the maintenance normally carried out in service. Certain aspects of this subject are also dealt with in Leaflet **EL/3-10,** Turbine Engines.

2. GENERAL The fuel supplied to the combustion chambers of a turbine engine must be readily combustible and in a ratio with the mass air flow through the engine which will ensure efficient and economical operation under all conditions of flight.

2.1 **Turbine Fuels.** The fuels used in turbine engines must conform to rigid requirements to give optimum performance and safety. They must also be compatible with materials used in the fuel system components and provide adequate lubrication of working parts. The types most used in civil aircraft are to D. Eng. RD 2494 (AVTUR) or ASTM Spec. D1655 (Jet A or A-1) all of which are kerosene type fuels. A more easily produced fuel is D. Eng. RD 2486 (AVTAG) but as it is a more volatile wide cut gasoline its use is normally restricted to military aircraft.

2.1.1 One problem associated with kerosene fuels is the water taken into solution through the aircraft or storage tank venting system. This water may freeze at high altitude and result in the low pressure fuel filter becoming blocked with ice crystals. Fuel heaters are therefore necessary and are incorporated in most aircraft fuel systems upstream of the low pressure filter.

2.2 **Fuel System Operation.** The required engine speed is set by a throttle valve which passes a fixed amount of fuel to the spray nozzles (burners). Heat produced in the combustion chambers expands the gases rearwards to impinge on the turbine, resulting in rotation of the compressor/turbine assembly with the energy remaining in the gas stream providing engine thrust. An increase in fuel flow results in higher temperatures and increased gas expansion, producing higher engine speed, greater airflow and increased thrust.

2.2.1 The engine speed selected by the initial positioning of the throttle valve will be maintained provided that air intake conditions do not vary. Changes in altitude, air temperature and forward speed will affect mass air flow through the engine and a corresponding change in fuel flow is necessary to maintain the selected speed. In addition, any rapid throttle movements will uspet the air/fuel ratio due to the inertia of the compressor/turbine assembly. Automatic means are therefore necessary to relate fuel flow to mass air flow through the engine and to control maximum speed, idling speed and acceleration rate. A convenient means of achieving these functions is to control output from the fuel pump.

3 FUEL PUMP On some early turbine engines a constant displacement pump was used, the design of which ensured that pump delivery was always in excess of engine requirements. Excess fuel was bled back to the fuel tanks by means of a unit called a Barostat which was sensitive to changes in air intake pressure. Most modern British systems employ a pump of the variable stroke (swash-plate) type, a dual pump often being fitted on large engines to obtain high delivery rates.

3.1 The variable stroke pump is driven directly from the engine and consists of a rotating cylinder block in which a number of cylinders are arranged around the rotational axis. A spring-loaded piston in each cylinder is held against a non-rotating cam plate so that rotation of the cylinder block results in the pistons moving up and down in their respective cylinders. Conveniently placed ports in the pump body allow fuel to be drawn into the cylinders and discharged to the engine. The angle of the cam plate determines the length of stroke of the pistons and, by connecting it to a servo mechanism, delivery may be varied from nil to maximum pump capacity for a given pump speed.

3.2 The servo piston operates in a cylinder and is subjected to pump delivery pressure on one side and the combined forces of reduced delivery (servo) pressure and a spring on the other. A calibrated restrictor supplies pump delivery fuel to the spring side of the piston and this is bled off by the control system to adjust the piston position and hence the angle of the cam plate.

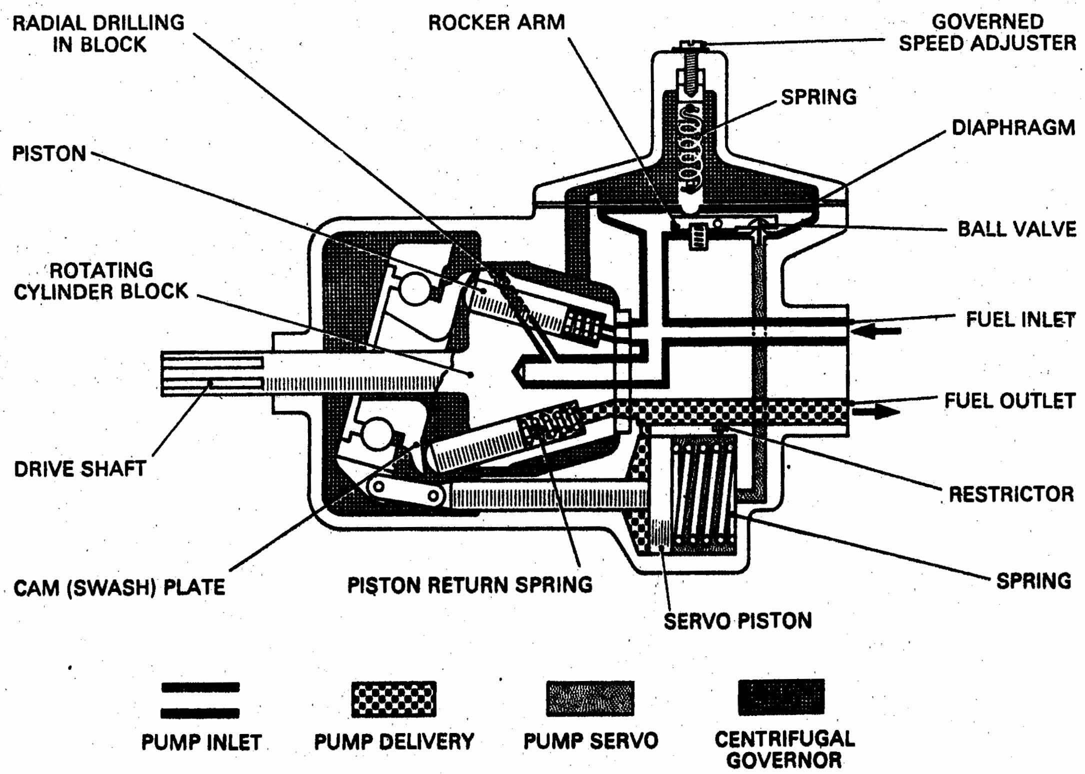


Figure 1. **TYPICAL HIGH PRESSURE FUEL PUMP**

4 FUEL PUMP CONTROL SYSTEMS Some engines are fitted with a control system which uses electronic circuits to sense changing fuel requirements and adjust pump stroke. Most engines however, use hydro-mechanical systems, with an electro-mechanical element to control maximum gas temperature and these are discussed in the following paragraphs.

4.1 **Pressure Control.** The quantity of fuel passing through a restrictor (the throttle valve) may be varied by increasing or decreasing the fuel pressure. In the pressure control system (Figure 2) fuel pressure is varied in relation to air intake pressure, decreasing with decreased mass air flow through the engine. Spill valves in the Barometric Pressure Control (B.P.C.), Acceleration Control Unit (A.C.U.) and pump governor, bleed off servo pressure to control pump stroke.

4.1.1 Under steady running conditions below maximum governed speed only the B.P.C. spill valve is open. A capsule subject to air intake pressure, contained in the B.P.C., controls the extent to which the spill valve is open. The bleed is arranged to increase as intake pressure decreases thus reducing servo pressure, pump stroke and fuel delivery pressure as altitude increases.

4.1.2 When the throttle is opened slowly, reduced throttle inlet pressure is transmitted to the B.P.C. and the spill valve closes to increase servo pressure and pump stroke. As pressure to the throttle is restored the B.P.C. spill valve again takes up its controlling position, and pump stroke, combined with increased pump speed, stabilises to give the output for the new throttle position. If the aircraft is in level flight the increasing speed will increase intake pressure and act on the B.P.C. capsule to further increase fuel flow to match the increasing mass air flow.

4.1.3 During rapid throttle opening, the action of the B.P.C. is restricted by the A.C.U. to prevent overfuelling. As the B.P.C. spill valve closes, increased fuel flow creates an increased pressure drop across the Metering Valve which is sensed by the A.C.U. fuel diaphragm. Movement of this diaphragm opens the A.C.U. spill valve to reduce servo pressure and limit overfuelling to the maximum amount which can be tolerated by the engine. As the engine accelerates, increasing compressor delivery pressure acting on the A.C.U. air diaphragm gradually closes the spill valve to permit greater acceleration at higher engine speeds.

4.1.4 Radial drillings in the fuel pump rotor direct fuel under centrifugal force to one side of a spring loaded diaphragm in the governor unit (Figure 1). When centrifugal force reaches a pre-determined value the diaphragm flexes sufficiently to open its spill valve and reduce servo pressure, thus limiting the amount of fuel delivered to the engine and so controlling engine speed.

4.2 **Flow Control.** In this system fuel pump delivery is controlled to maintain a constant pressure drop across the throttle valve regardless of engine speed. A common variation of the system is one in which a small controlling flow (proportional flow) is created with the same characteristics as the main flow and is used to adjust the main flow. A different type of spill valve known as a "kinetic" valve is used which consists of opposing jets of fuel at pump delivery pressure and servo pressure; a blade moving between the jets alters the effect of the high pressure on the low pressure. When the blade is clear of the jets, servo pressure is at maximum and moves the fuel pump to maximum stroke but as the blade comes between the jets servo pressure reduces to shorten pump stroke. The control elements which are housed in a single unit called the Fuel Control Unit (F.C.U.) are the Altitude Sensing Unit (A.S.U.), Acceleration Control Unit (A.C.U.), Proportioning Valve Unit (P.V.U.) and throttle, which sometimes also functions as a shut-off (H.P.) cock. The system is illustrated in Figure 3.

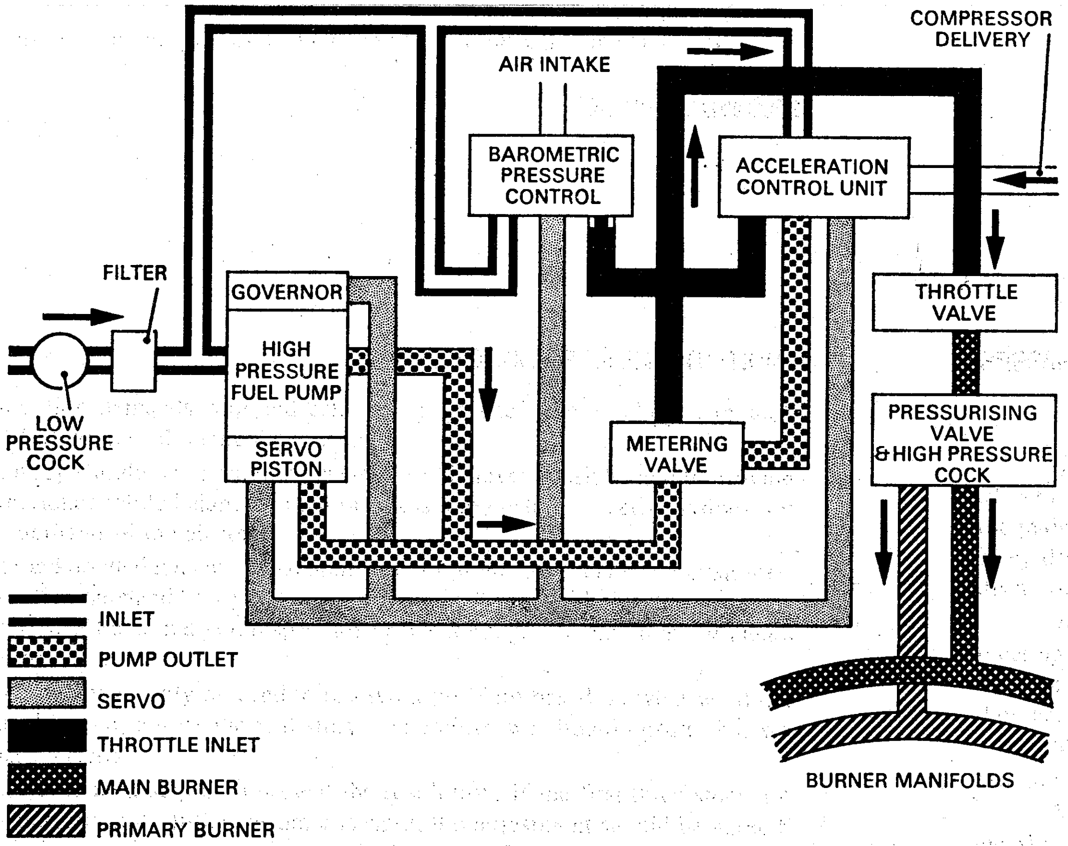


Figure 2. **PRESSURE CONTROL SYSTEM**

4.2.1 Under steady running conditions below governed speed, flow through two P.V.U. restrictors is proportional to flow through the throttle valve and the P.V.U. diaphragm is held open by spring pressure, allowing fuel to flow through the A.S.U. back to the pump inlet. The A.S.U. adjusts servo pressure in relation to this proportional flow by means of a kinetic spill valve.

4.2.2 When the throttle is opened slowly the pressure drop across the throttle valve and P.V.U. restrictors decreases and the P.V.U. diaphragm adjusts its position to reduce proportional flow through the A.S.U. This results in the A.S.U. spill valve closing slightly to increase servo pressure and therefore pump stroke, thus restoring the pressure difference across the throttle and P.V.U. restrictors.

4.2.3 Variations in air intake pressure are sensed by a capsule in the A.S.U. which adjusts its spill valve to decrease or increase servo pressure as required. The resulting change in proportional flow returns the A.S.U. spill valve to its controlling position.

4.2.4 During rapid throttle opening the sudden decrease in pressure drop across the throttle is sensed by the A.S.U. which closes its spill valve to increase pump stroke. The rapid increase in fuel flow, which would cause overfuelling, is restricted by means of a pressure drop diaphragm and metering plunger. This diaphragm is sensitive to the pressure drop across the metering plunger, the latter being located in the main

fuel line to the throttle valve. Rapid throttle opening increases the pressure drop across the plunger and at a fixed rate of overfuelling the pressure drop diaphragm flexes sufficiently to open its spill valve and override the A.S.U., maintaining a fixed pressure drop across the metering plunger. The metering plunger is, in effect, a variable area orifice and by means of a capsule in the A.C.U. sensitive to compressor delivery pressure, its position is controlled to increase the rate of overfuelling as engine speed increases. As the controlled overfuelling and engine speed increase, the pressure drop across the throttle valve is gradually restored until the proportional flow reaches a controlling value once more and the A.S.U. spill valve controls pump stroke.

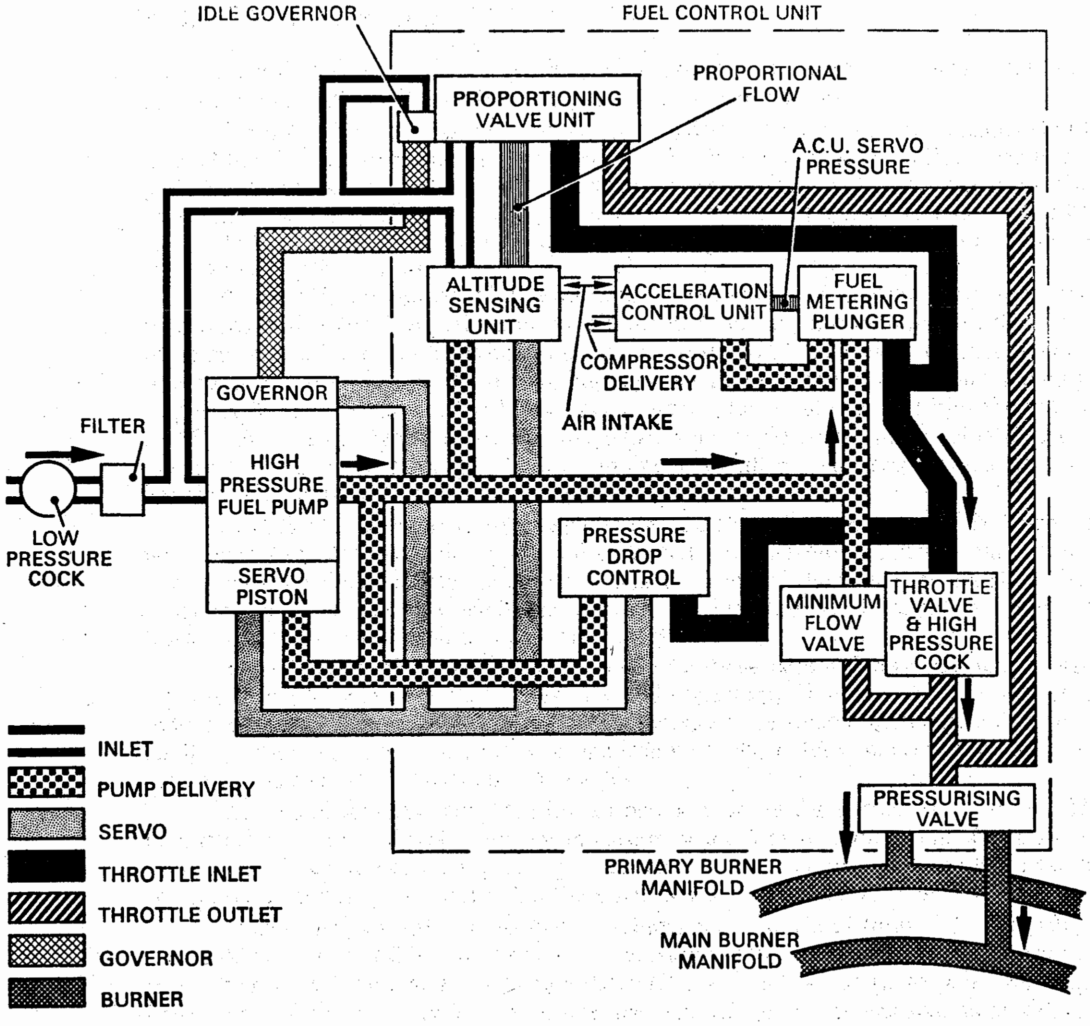


Figure 3. FLOW CONTROL SYSTEM

4.2.5 The maximum speed governor in the fuel pump is similar to that described in paragraph 4.1.4. Fuel under centrifugal force from the fuel pump also acts on a diaphragm in the P.V.U. to adjust the position of one of the restrictors and maintain proportional flow at a value suitable for idling.

4.3 **Combined Acceleration and Speed Control.** This fuel pump control system is contained within a single unit called a Fuel Flow Regulator, the fuel pump servo piston being operated by fuel pump delivery pressure opposed by main burner pressure and a spring. The system is illustrated in Figure 4.

4.3.1 Two rotating assemblies, each with a hollow valve and centrifugal governor, are driven from the engine by a gear train in the regulator and are known as the Speed Control Unit and the Pressure Drop Unit. The speed control valve is given axial movement by a capsule assembly under compressor delivery pressure and has a triangular hole known as the Variable Metering Orifice (V.M.O.). A non-rotating governor sleeve round this valve is given axial movement by the governor unit and restricts fuel flow through the V.M.O. Fuel from the pump outlet flows from the regulator body through the V.M.O. to the inside of the speed control valve and passes through the hollow valve to the pressure drop unit. The pressure drop valve is in the form of a hollow piston, moving axially under the force of fuel from the V.M.O. and governor flyweights, opposed by main fuel pressure. The pressure drop valve has an unrestricted outlet through the regulator body for primary burner fuel and a triangular outlet known as the Pressure Drop Control Orifice (P.D.C.O.) through which fuel flow to the main burners is restricted by the axial movement of the pressure drop valve.

4.3.2 Under steady running conditions the position of the speed control valve is fixed by the capsule assembly and the governor sleeve is held in a fixed axial position by the speed control governor. Pressure drop across the V.M.O. is sensed by the pressure drop valve which adjusts its position and the exposed area of the P.D.C.O. to supply the correct quantity of fuel in relation to engine speed.

4.3.3 When the throttle is opened slowly, spring loading on the speed control governor increases to move the governor sleeve and increase the V.M.O. area. Pressure drop across the V.M.O. decreases and this is sensed by the pressure drop valve which moves to increase the size of the P.D.C.O., the reduced system pressure difference acting on the pump servo piston to increase fuel flow to the engine. As the engine accelerates, the capsule in the speed control unit is compressed by increasing compressor delivery pressure and moves the speed control valve to further increase the size of the V.M.O. Balance is restored when centrifugal force acting on the speed control governor moves the governor sleeve to restore the system pressure difference.

4.3.4 The effect of rapid throttle movements is restricted by mechanical stops acting on the governor sleeve.

4.3.5 Changes in altitude or forward speed affect the capsule in the speed control unit which adjusts the position of the speed control valve to correct fuel flow.

5 **BURNERS** The purpose of the burners is to provide fuel to the engine in a suitable form for combustion. A burner with a single spray nozzle, although used on some early engines, is not suitable for large modern engines due to the widely varying fuel flow requirements for different flight conditions. If the orifice were of a size suitable for atomising fuel at low rates of flow the pressure required at take-off would be tremendously high, flow through an orifice being proportional to the square of the pressure drop across it.

5.1 One of the methods used to overcome this problem is the provision of a dual spray burner. The central orifice provides the fuel for low flow rates and a second annular orifice is used in addition for high flow rates. Distribution between the primary (low flow) manifold and the main (high flow) manifold is normally controlled by a pressure operated valve. In the case of the Fuel Flow Regulator, fuel flowing through the rectangular outlet from the pressure drop valve is always at a higher pressure than fuel flowing through the outlet from the P.D.C.O. and is used to supply the primary burner manifold.

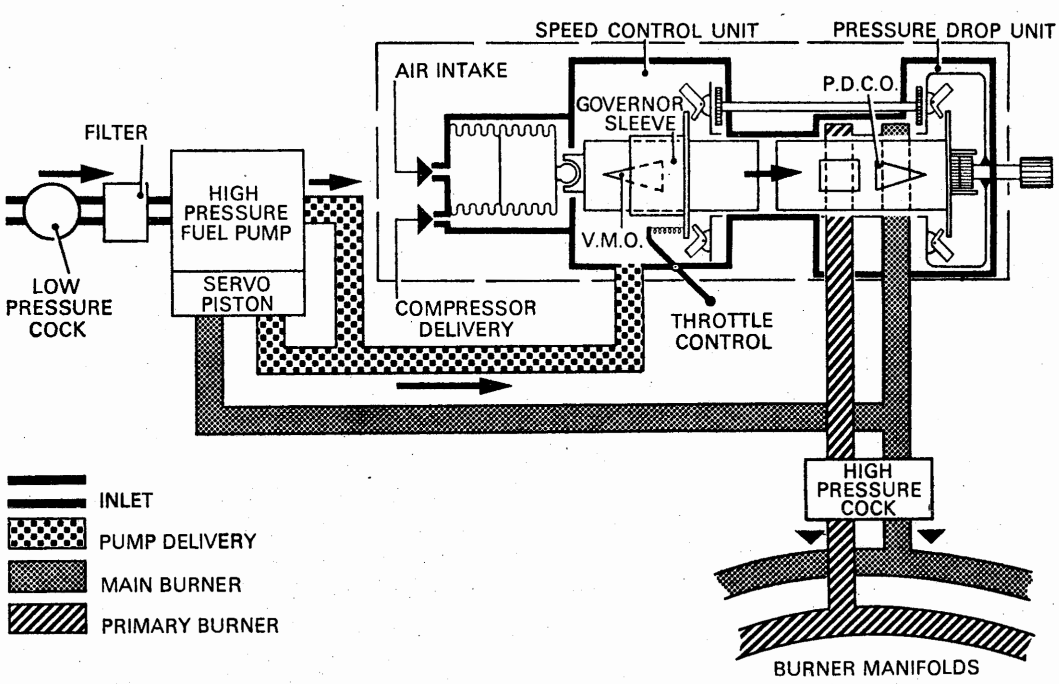


Figure 4. COMBINED ACCELERATION AND SPEED CONTROL SYSTEM

5.2 Another method used on some engines is known as the Vapourising Burner. Fuel is injected at low pressure into one end of a hollow "U" shaped tube located in the combustion chamber. It mixes with the primary air flow, is vapourised by the heat in the chamber and ejected upstream into the combustion zone. In this system a separate burner is necessary for engine starting.

6 ADDITIONAL CONTROLS In addition to the systems described in paragraph 4, additional controls are usually provided to prevent the engine from exceeding operating limitations.

6.1 **Turbine Gas Temperature Control.** Control of the maximum permitted turbine gas temperature is often exercised electrically. Signals from the T.G.T. thermocouples are amplified to either actuate a solenoid operated valve in the fuel system or reset the throttle linkage to reduce fuel flow to the burners. On engines which have different T.G.T. limitations for climb and take-off, a switch on the flight deck pre-sets the T.G.T. signal reference datum.

6.2 **Compressor Control**

6.2.1 In certain circumstances such as high forward speed and low ambient temperature it is possible to produce maximum power/thrust at less than maximum engine speed.

Under these conditions the engine could sustain damage due to high compressor delivery pressures and fuel flow is restricted by providing a bleed from the A.C.U. capsule chamber to atmosphere when compressor delivery pressure exceeds a predetermined value.

6.2.2 To prevent the low pressure compressor from exceeding its design speed a centrifugal governor driven from the low pressure shaft is often included in the fuel system. If design speed is exceeded the low pressure governor restricts the fuel flow in the main burner line and reduces both high and low pressure compressor speeds.

7 MAINTENANCE AND INSPECTION

7.1 General

7.1.1 Fuel systems normally operate at very high pressures and a leak from a connection could quickly become a potential fire hazard. Regular inspection of the complete system for security, bonding, freedom from leaks and correct positioning of drains is therefore very important. If a leak does develop the tightness of the connection should be checked but on no account should the recommended torque values be exceeded. If the leak persists the connection should be dismantled, the joint faces inspected for cleanliness, and the connection remade using new gaskets, washers or 'O' rings as appropriate. Pipes which are found to be twisted or damaged, particularly at the connections, must be replaced.

7.1.2 Lubrication of working parts should be carried out in accordance with the approved Maintenance Schedule using the type of lubricant recommended by the manufacturer. All excess oil or grease should be removed. Lubrication of gaskets, washers and 'O' rings is usually required during assembly of components. It is important that only the correct type of lubricant is used, as incorrect lubrication could cause rapid deterioration of the seals, resulting in fuel leakage with the attendant fire risk.

7.1.3 Whenever a component is replaced within the fuel system it is good practice to also clean the main fuel filter, especially where it incorporates a relief valve designed to open in the event of the filter becoming blocked. The surge of fuel on switching on the booster pump with a dry component in the line can open the relief valve and pass dirt into the system.

7.2 **Cleanliness.** Cleanliness of the fuel and fuel components is very necessary because of the small passages, restrictors and valves used in the system. Particular care should be taken to prevent the introduction of extraneous material such as water, dust or grit into the fuel tanks when refuelling an aircraft. Refuelling nozzles should be kept scrupulously clean. Filters which are incorporated in the supply line to the fuel pump and other small filters which may be fitted at the inlet connection of other components should be removed for examination at the intervals prescribed in the approved Maintenance Schedule. Except where renewable elements are used these filters should be thoroughly washed in kerosene and dried with compressed air before refitting. The low pressure fuel filter is normally provided with a drain valve for fuel sampling purposes.

7.2.1 When changing components all pipes and open passages should be blanked off immediately and the blanks removed only when the new component is ready to be fitted. New washers, gaskets or 'O' rings should always be refitted with new components.

7.3 Adjustments

7.3.1 **General.** Adjustments to the fuel system may be necessary when a new engine is installed, when a component is replaced or when incorrect operation of the system in flight is reported. Each component is bench tested before final approval and it is usual for the manufacturer to limit the extent to which adjustments can be made in service. If it becomes apparent that the permitted adjustment would be exceeded in order to achieve correct engine operation then the appropriate air and fuel pipes must be checked for leaks. If the required adjustment is still excessive it must be assumed that the component concerned is unserviceable and it should be replaced. A record of any adjustments made should be entered in the engine log book to provide a history of fuel system operation.

7.3.2 As air temperature, pressure and humidity all affect engine operation, any adjustments to the system must take account of ambient conditions and of the specific gravity of the fuel. Graphs or tables are provided in the appropriate Maintenance Manual showing the correction to be applied to a basic setting under different operating conditions. For example, when setting an idling speed, which may be 40% at standard atmospheric pressure of 1013 millibars, it may be necessary to reset the actual engine speed to 43.5% when the atmospheric pressure is only 950 millibars. On some engine installations it may also be necessary to disconnect or override other controls in order to make an adjustment. For example, when adjusting maximum governed speed it may be necessary to disconnect the Top Temperature Control (T.T.C.) or pressurise the air intake pressure sensing capsule in the B.P.C. to prevent their influence on the system from restricting fuel flow. Under these circumstances visual monitoring of instruments is vital to prevent exceeding J.P.T. limits. The appropriate Maintenance Manual lays down the procedure to be adopted when making an adjustment of this type.

7.3.3 **Mechanical Adjustments.** Adjustments to the idling speed, maximum governed speed and acceleration rate are usually by means of a screw and the effect of a set amount of rotation of the screw is usually quoted in the Maintenance Manual to avoid unnecessary engine running. Before making an adjustment the engine should be run for a sufficient length of time to stabilise engine temperatures and when altering power settings the controls should be operated carefully, and instruments kept under observation, to prevent exceeding operating limitations. This is particularly important after the installation of a new engine or component change. Adjusters must be relocked after use.

7.3.4 **Electronic Adjustments.** Some automatic engine controls are actuated by signals from the jet pipe thermocouples and require special test sets to check or correct their operation. Control is effected by comparing the thermocouple voltage with a datum voltage preset in an amplifier. Excessive temperatures produce an excess voltage and this is amplified to energise a relay in the T.T.C. circuit. This action operates a solenoid located either in the Fuel Bleed Valve or Flow Control Unit and restricts fuel flow to the engine. To adjust a control system of this type it is necessary to attach a special test set to the electrical circuit by means of a conveniently placed multi-pin plug and socket. The test set feeds a voltage to the circuit equivalent to that which would be supplied by the thermocouples at a specified gas temperature and any variations from the datum voltage may be reset by adjustment of resistors in the engine amplifier. Engine installations vary considerably in the layout of the automatic control systems and the appropriate Maintenance Manual should be referred to whenever it becomes necessary to check or adjust a specific system.

7.3.5 **Control Linkage.** The methods used to connect the pilots' controls to the engine throttle valve and the high and low pressure cocks are often very complex. The linkage normally includes cable and chain components in the flight deck and fuselage and a series of push/pull rods and levers leading to the engine bay. There are numerous connections in the installation and this can lead to 'lost motion' at the pilots' controls and irregular engine operation when wear takes place. The procedure for initially setting up the controls is laid down in the appropriate Maintenance Manual and the operation requires the use of rigging pins, datum marks, protractors and pointers. Re-adjustment may be required when wear in the connections causes slackness and insufficient travel of the control. At the periods specified in the Maintenance Schedule the linkage should be lubricated and inspected for security, locking, play and correct adjustment. Excessive wear should be eliminated by replacement of the affected parts.

NOTE: Whenever engine controls are disconnected an inspection in accordance with BCAR Chapter A5-3 is necessary.

7.4 **Pipes.** When changing fuel system components or pipes care is necessary to ensure that the pipes are not strained as this could result in the development of leaks due to the high fuel pressures in the system. Short rigid pipes are often used between components and special fitting instructions may be quoted in the Maintenance Manual. It may, for instance, be necessary to loosen or remove an adjacent component in order to fit a pipe. When installing a flexible pipe care must be taken to prevent the pipe from twisting when the connections are tightened. Before pipes are re-connected they should always be inspected for cleanliness and damage, especially at flared ends and nipples. Seals should be lubricated in accordance with the manufacturers recommendations and union nuts must be correctly locked. Whenever pipes have been disconnected the system should be bled (see paragraph 7.7).

7.5 **Fuel Pump.** It is possible to cause damage to the fuel pump when shutting down an engine in flight. Provided that the H.P. cock is closed first no damage will be caused by a windmilling engine but if the engine is stopped by closing the L.P. cock, or if the pump inlet is blocked in any way, the engine manufacturer usually specifies a time limit on engine windmilling as the pump will be running "dry" and damage may result. If this time limit is exceeded the pump must be changed and an inspection for contamination of the system downstream of the pump carried out. If metal deposits are found all system components must be changed and connecting pipes flushed out.

7.6 **Burners.** Due to their position in the combustion chambers, burners may become contaminated by deposits of carbon which could affect their operation. The deposit should be removed at the intervals laid down in the Maintenance Schedule. by either one of two methods depending on whether or not the burners can be removed from the installed engine. On no account should a wire brush be used to remove carbon, as any scratches will affect the spray pattern and result in hot spots in the combustion chamber.

7.6.1 In-situ cleaning, where approved, is carried out by connecting a pumping rig to the burner manifold feed pipe connection and pumping a set quantity of carbon solvent through the burners. After removing the pumping rig and reconnecting the feed pipe, the engine should be left for approximately two hours to give the solvent time to soften the carbon and then run for a short time to disperse the deposit.

7.6.2 When the burners are easily removed from the engine they should be completely immersed in a carbon solvent for two hours then thoroughly cleaned with an air/water gun, dried and dipped in de-watering oil. They may then be replaced in the engine or, if not required for immediate use, filled with inhibiting oil, blanked off and stored.

NOTE: Burners are often kept in sets and should only be replaced as individual components when permitted by the manufacturer.

7.7 **Bleeding.** Whenever a component is replaced or disconnected and instability in engine speed which could be attributed to air in the system is encountered, the fuel system should be bled. Fuel supply to the affected engine should be selected on and the low pressure cock and fuel pump turned on. Individual components should then be bled in turn commencing at the H.P. fuel pump and working downstream, each bleed valve being opened until bubble-free fuel is discharged, then the valve closed and locked. On some components a special bleed tool is provided and the discharged fuel should be caught in a container to avoid contamination of the engine bay.

8 STORAGE Preparation and storage of the complete engine is dealt with in Leaflet **EL/3-10** Turbine Engines. When it becomes necessary to store or return an individual component a similar procedure should be applied.

8.1 **Inhibiting.** Except for separate electrical parts all components removed from the fuel system should be inhibited as soon as possible to prevent internal corrosion. All fuel should be drained out and inhibiting oil poured in through the inlet connection until full. A blank should then be fitted and the component rotated, topping up through each outlet in turn and fitting blanks until it is completely full of oil and securely sealed. Drive shafts of pumps and fuel flow regulators should be turned while inhibiting and the throttle valve and H.P. cock operated several times to ensure complete distribution of oil. To check that the blanks are not leaking the part should be thoroughly dried and left for thirty minutes. Any leaking blanks should be replaced, the oil level topped up and a further test carried out until satisfactory results are obtained. Drive shafts should then be smeared with the recommended storage oil.

NOTE: **The inhibiting oil-can should contain a fine mesh filter to prevent the ingress of foreign material.**

8.2 **Packing.** All components, including the electrical ones which are not inhibited, should be wrapped in greaseproof paper, sharp edges being double wrapped, then enclosed in V.P.I. paper (see Leaflet **BL/1-7**) and secured with adhesive tape. The wrapped parts, together with a label giving details of the modification state, reason for return, etc., should be enclosed in a polythene bag, as much air as possible excluded and the bag heat sealed. Transport boxes are normally provided for all components and the wrapped part should be kept in one of these during storage. A label should be affixed to the box giving details of the contents, inhibiting date and storage life.

NOTE: **Certain electrical components require the attachment of a "Fragile" label on the transport box in addition to the normal identification label.**

8.3 **Storage Conditions.** Components should be stored in conditions that are dry and free from corrosive fumes. Components are best stored in racks but this may not always be possible; a double fuel pump, for example, may weigh up to 75 lb without its transport box and may more conveniently be stored at floor level but raised on blocks to permit the circulation of air.

8.3.1 Every six months the shafts of fuel pumps and fuel flow regulators should be rotated a few turns without removing them from the sealed bag. At the same time the part may be checked to ensure that the modification state is satisfactory and that no leaks have developed.

8.3.2 Some fuel system components may be given a maximum storage life. When this life has expired the components should be removed from storage and subjected to such overhaul and testing as may be specified by the manufacturer.

Issue 1.

15*th June*, 1970

AIRCRAFT

ENGINES

TURBINE ENGINE STARTER AND IGNITION SYSTEMS

1 INTRODUCTION This Leaflet deals with the starter and ignition systems in use on turbo-prop and turbo-jet aircraft. It is possible that other methods of starting may be used but the general principles outlined in this Leaflet are applicable. Detailed information on specific systems will be found in the appropriate manufacturer's manual. Information on the associated engine fuel systems will be found in Leaflet **EL/3-11** Turbine Engine Fuel Systems.

2 GENERAL Two separate systems are required to start a turbine engine, a means to rotate the compressor/turbine assembly and a method of igniting the air/fuel mixture in the combustion chamber. Ideally the process is automatic after the fuel supply is turned on and the starting circuit brought into operation.

2.1 **Starting Cycle.** The starter motor is capable of cranking the engine to a speed slightly higher than that at which sufficient gas flow is generated to enable the engine to accelerate under its own power. At an early stage in the cranking operation, igniter plugs in the engine combustion chamber are supplied with electrical power, followed by the injection of fuel when fuel pressure has built up sufficiently to produce an atomised spray. Light-up normally occurs at this point and the engine, assisted by the starter motor, accelerates to self-sustaining speed. The starter drive disengages when engine power begins to drive the starter and the engine accelerates to idling speed without further assistance. Power supplies to the starter and igniters are cancelled during this stage.

2.1.2 After selection, operation of the starter cycle is automatic but the engine speed and turbine gas temperature should be monitored to ensure that engine limitations are not exceeded. If necessary the starting operation may be stopped by closing the high pressure (H.P.) fuel cock and switching off the start master switch.

2.2 **Precautions.** If engine acceleration is retarded the possibility of a light-up occurring at a low engine speed would result in overfueling and high turbine gas temperature. Power supplies to the starter should always be checked before starting and must not be less than the minimum figure quoted in the aircraft Maintenance Manual. Facing the aircraft into wind will assist engine acceleration, particularly in the case of turbo-prop aircraft the propellers of which are normally provided with a special fine blade angle for starting and ground running.

2.3 **Cranking.** There are many different methods used to crank the engine to self-sustaining speed, depending on the operational requirements of the particular aircraft.

2.3.1 An air starter is most commonly used on passenger transport aircraft as this is an economical means of starting, causing the minimum disturbance to the passengers.

2.3.2 Electric starters are also commonly used and are fitted mainly to turbo-prop and small jet engines.

2.3.3 Where speed of starting is of the utmost importance, on fighter aircraft for instance, a cartridge or mono-fuel turbine starter is usually fitted. These methods are not used on civil aircraft however due to the high cost and the handling difficulties involved.

2.3.4 Certain operators may need to start the aircraft engines without outside assistance and specify the use of a hydraulic or air starter driven from an auxiliary power unit.

2.4 **Ignition.** On some early engines, a "torch igniter", which combined a sparking plug and fuel spray nozzle was used during starting, fuel being supplied by a priming pump controlled by the timer unit. The resulting flame was used to ignite fuel from the main burners. Although a separate spray nozzle is still used on some engines (i.e. those employing fuel vapourising burners—Leaflet **EL/3-11**), the normal fuel spray nozzles are generally used and ignition is achieved by means of a high energy ignition unit and surface discharge plug.

2.4.1 To provide automatic relighting in the event of flame extinction either a glow plug or continuously operating ignition system are used and manual relighting is accomplished by operating the ignition independently from the complete starter circuit. On some aircraft the ignition circuit is also connected to a stall warning device as a safeguard against flame extinction under stall conditions.

3 ELECTRIC STARTERS (FIGURE 1) The main components of an electric starter are a d.c. motor, a reduction gear, an overload clutch and a ratchet device to provide automatic engagement with and disengagement from the engine. These components may be included in the starter itself, or, except for the motor, form part of the engine gearbox. One particular engine is fitted with a starter/generator unit, the starter mode being engaged by applying an electric current to the field coils. In this case no special reduction gear, clutch or ratchet are required and the unit automatically reverts to the generation mode when generator output reaches a predetermined value.

3.1 **Engagement.** A common method of coupling the starter drive to the engine is by means of a jaw on the starter which moves axially into engagement with a similar jaw on the engine gearbox during initial starter rotation. Axial movement of this jaw is effected either by helical splines on the starter drive shaft or by the pressure of a solenoid operated push rod in the starter motor. Alternative methods of engagement are the ratchet drive and sprag clutch, in which the ratchet pawls or sprags rotate with the engine. Engagement and disengagement are effected centrifugally, engagement by the engine taking place whenever its speed falls below idling.

3.2 **Starting Cycle.** Operation of the starting cycle is normally controlled by either of two methods. On some aircraft the high initial starter current is used to engage an overspeed relay and hold-in solenoid; when the engine begins to accelerate under its own power, starter current decreases and the hold-in solenoid breaks the circuit automatically. On other aircraft a timer unit is employed which, by means of resistances, allows the full voltage to be progressively built up as starter speed increases. This prevents damage to the starter jaws through violent engagement and eliminates excessive loads on the starter motor in overcoming engine inertia. Electrical power is cut off either by an overspeed switch or at the end of the timed cycle.

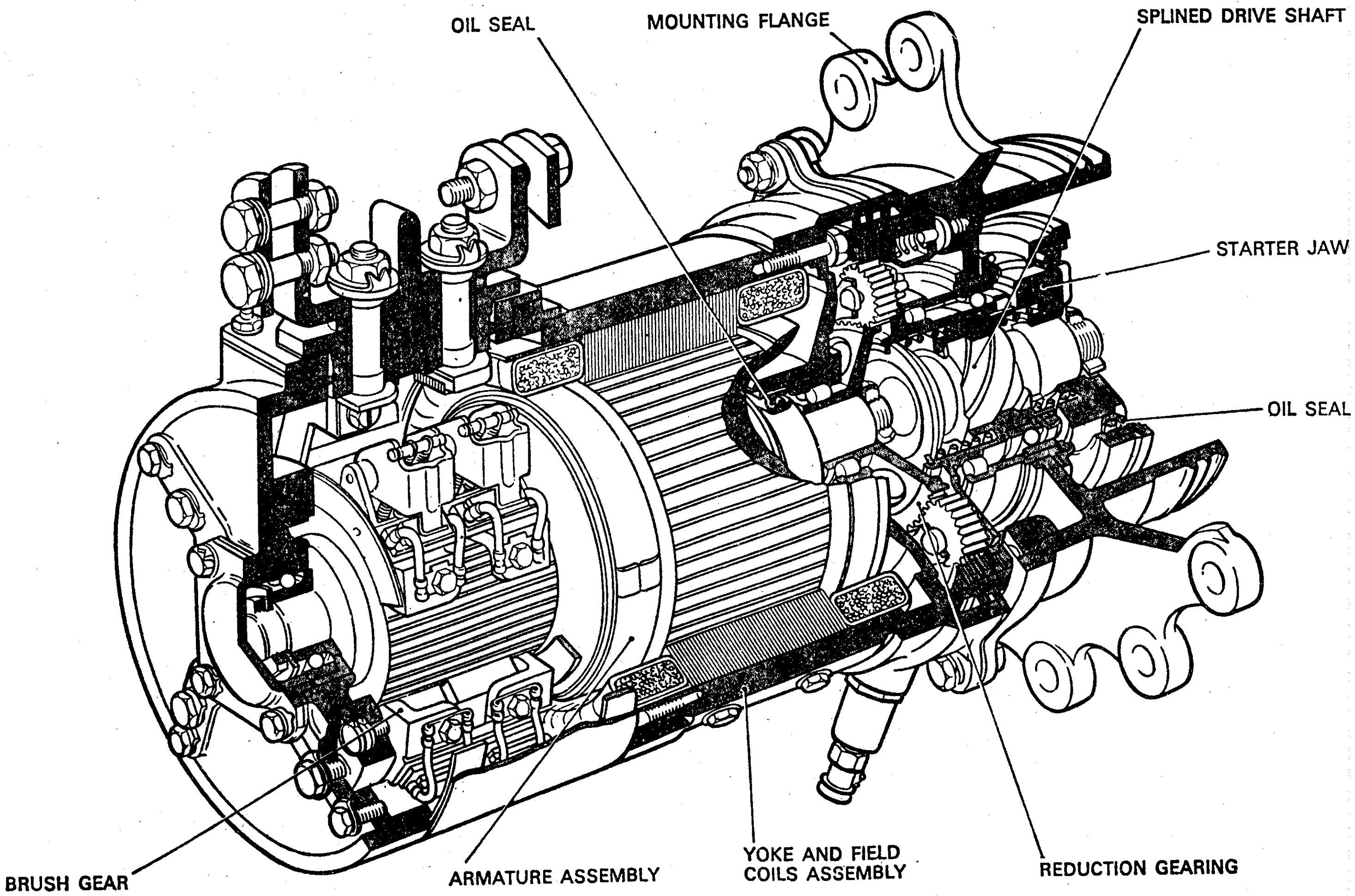


Figure 1 TYPICAL ELECTRIC STARTER

3.3 **Inspection.**

3.3.1 **Routine Inspection.** At the periods specified in the appropriate Maintenance Schedule the starter should be examined for serviceability as follows:—

(i) The starter should be inspected for security, external damage, cracks and oil leaks.

(ii) Brushes should be examined for freedom of movement and wear, and the commutator for scoring or other damage.

(iii) Leads should be secure and rubber grommets or sleeves should not be cracked or perished.

(iv) The gearbox oil level should be checked and topped up as necessary.

3.3.2 **Acceptance Checks on Replacement Starter.** An electric starter normally has an installed life at least equal to that of the engine to which it is fitted, subject to a possible calendar limitation. If replacement of the starter does become necessary the following checks should be carried out before installation:—

(i) The housing should be free from damage, cracks or corrosion.

(ii) Electrical resistance between the insulated terminal and the frame should be tested with a 250 volt insulation resistance tester and a reading of at least 500000 ohms obtained.

(iii) When applicable the axial movement of the starter jaw should be measured in accordance with the manufacturer's manual. The specified new washer or gasket must be fitted to the starter mounting flange to ensure satisfactory jaw engagement.

(iv) The brush inspection window cover should be temporarily removed in order to inspect the brushes for free movement, security and adequate spring pressure. All internal leads should be adequately supported and securely attached to the appropriate fitting.

3.3.3 After installation the starter gearbox should be filled with the recommended oil and a motoring run carried out to check starter operation.

4 AIR STARTERS (FIGURE 2) There are several different turbine engine starting systems which use a compressed air supply as a source of power and most transport aircraft are so designed that the engines may be started by alternative methods as a safeguard against lack of ground facilities.

4.1 Air impingement starting is a very simple method and represents a considerable saving in weight as compared with a normal starting system. An external air supply is connected to the engine and jets of air impinge directly onto the engine turbine to rotate it up to self-sustaining speed. No starter motor is required, the cranking operation being controlled by a simple ON/OFF cock and the ignition system by means of the normal relight circuit.

4.2 Air driven turbo starters are widely used and consist of a turbine wheel, reduction gear, clutch and driving shaft. Low pressure air (approximately 40 lb/in^2) impinging on the turbine produces the power required to turn the engine shaft. The air used for these starters may be obtained from an external supply, an auxiliary power unit in the aircraft or the compressor of a running engine. In addition, one engine of a multi-engined aircraft may be fitted with a "combustor" in which kerosene from the aircraft fuel tanks and air from a high pressure air supply (approximately 3000 lb/in^2) are ignited, the resulting gases impinging on the starter turbine at low pressure and high temperature.

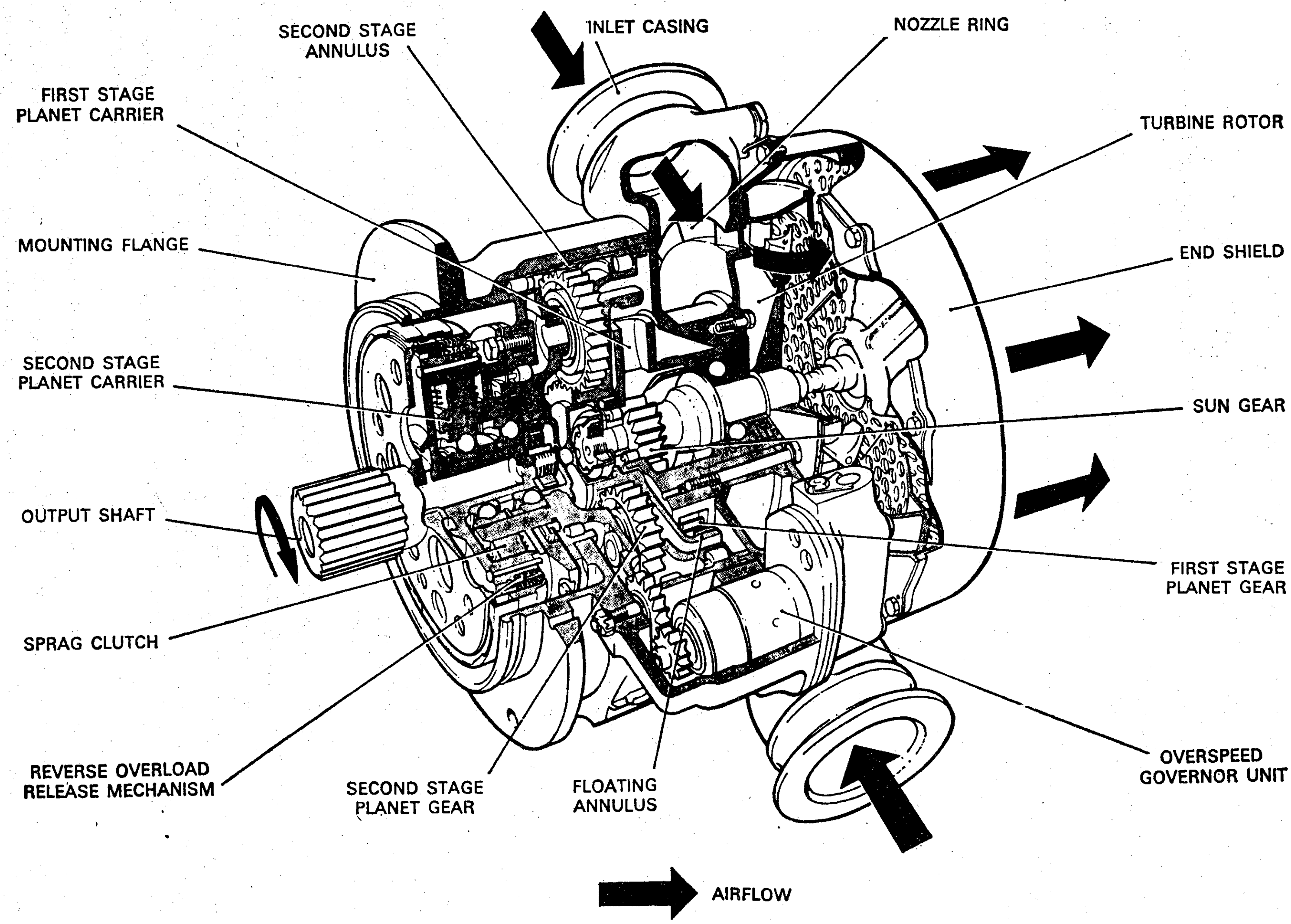


Figure 2 TYPICAL AIR STARTER

4.3 One particular British aircraft has a starter system which employs a Rootes type air motor instead of a turbine. In this case the air motor provides one input to the differential gear of the generator constant speed drive and during starting a sprag clutch engages to drive both engine and generator. When the engine reaches self-sustaining speed, the clutch disengages and air motor speed is controlled by varying the supply of air from the engine compressor. As engine speed increases, air motor speed decreases to maintain a constant speed drive to the generator.

4.4 **Inspection.** The inspections required on the starter motor itself are generally confined to ensuring that it is securely attached, free from damage or corrosion and that the gearbox contains the required quantity of oil. A certain amount of ducting is required with air starting systems however, particularly when air tapped from the engine compressors is also used for aircraft pneumatic purposes, and this, as well as the associated valves, must be regularly inspected. A typical system is shown in Figure 3.

4.4.1 Leaking ducts or incorrectly operating valves could cause malfunction, and in some cases damage to the associated starter or pneumatic system, and lead to loss of engine power. It is important to inspect these components for security, damage, chafing, corrosion or leaks, paying particular attention to sharp bends, connections, attachment points and positions where a duct runs through a panel or bulkhead.

4.4.2 When a leak is known to exist but is difficult to trace, metal pipes and joints should be brushed over with soapy water, and air at operating pressure applied to the inside of the duct; bubbles will indicate the position of a leak. The parts should be subsequently washed and dried to prevent corrosion. This method should not be used on flexible fabric ducts or pipes lagged with absorbent material such as asbestos. Contamination with oil or other fluids should also be avoided and surplus lubricants removed after servicing.

4.4.3 **Component Replacement.** The following inspection requirements should be satisfied whenever it becomes necessary to change an unserviceable item.

(i) The new component should be inspected for damage or corrosion, particularly on mating surfaces, and if possible its operation checked before installation.

(ii) On components with electrical mechanisms the insulation resistance between each pin of the electrical sockets and the case should be tested with a 250 volt insulation resistance tester, the minimum value required being 500000 ohms. The aircraft electrical supply should be disconnected by removing the appropriate fuse before installing a component of this type.

(iii) When the incorrect installation of a valve could cause malfunction or damage to the system, the component is usually designed so that it can only be fitted in one way. When this is not practical an arrow may be embossed on the casing to show the direction of main flow and it is important to take note of any such marking and refer to the Maintenance Manual when the installation procedure is not obvious.

(iv) "V" flange clamps are often used to connect components together and lubrication of the mating faces is sometimes required by the manufacturer. On other types of connection the use of jointing compound may be specified. All bolts should be torque loaded to the value specified in the Maintenance Manual.

(v) New washers, gaskets or seals should always be used when replacing a component in the system.

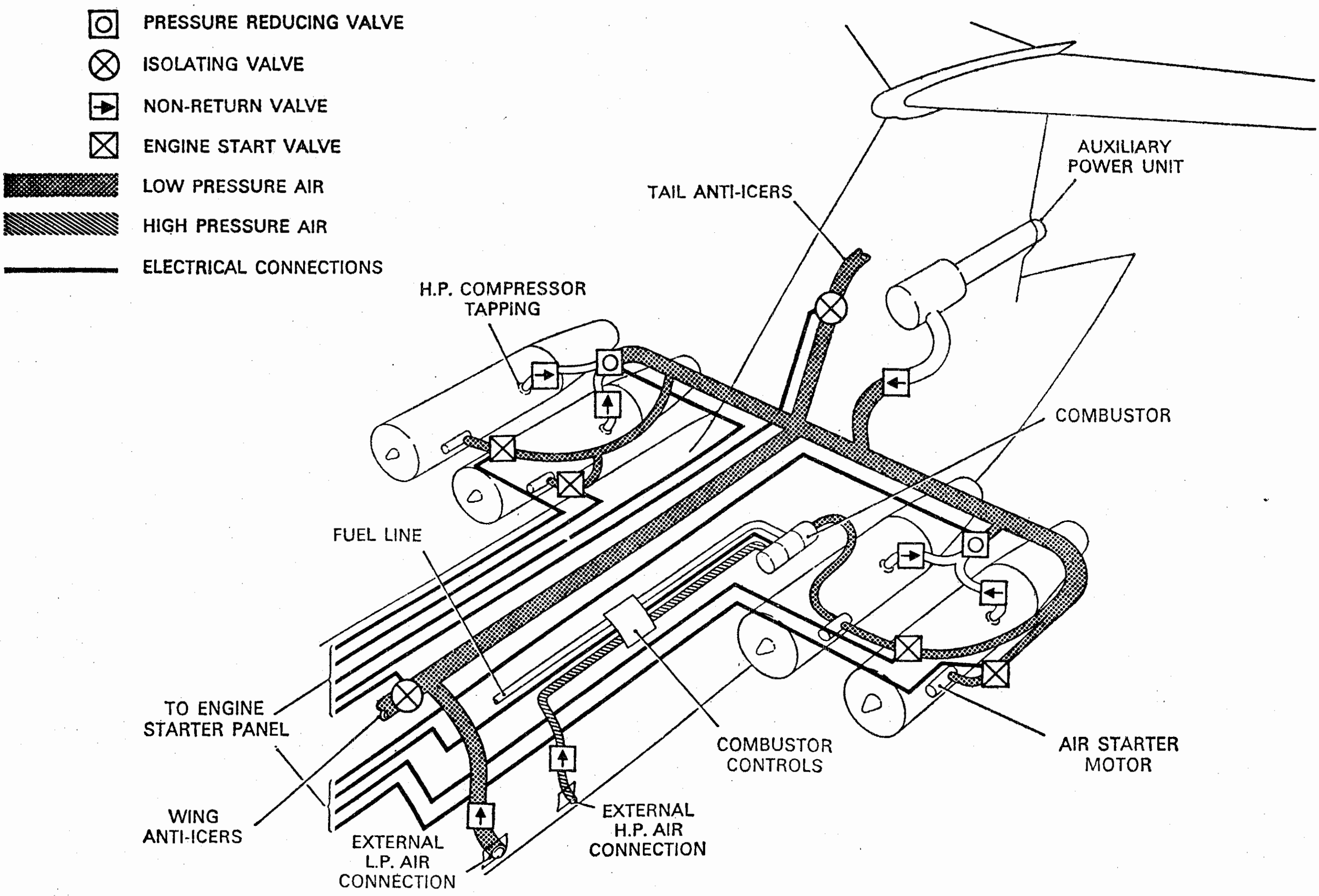


Figure 3 TYPICAL AIR STARTER SUPPLY SYSTEM

4.4.4 **Testing after Component Replacement.** Whenever a new component has been installed a functional check should be carried out to ensure correct operation of the system.

(i) Operation of the starter motor may be checked by carrying out a motoring run. During this test the operation of each valve should be checked against its indicated position and the engine speed obtained should be within the limits quoted in the Maintenance Manual.

(ii) If a valve concerned in the operation of both the starting and pneumatic systems is changed (e.g. an isolation valve), it will be necessary to start the engine and check the operation of both systems. Satisfactory cranking speed and pneumatic duct pressures should be obtained.

5 IGNITION SYSTEMS (FIGURE 4) The ignition system of a turbine engine must provide the electrical discharge necessary to ignite the air/fuel mixture in the combustion chamber during starting and must also be capable of operating independently from the starter system in the event of flame extinction through adverse flight conditions.

5.1 The electrical energy required to ensure ignition of the mixture varies with atmospheric and flight conditions, more power being required as altitude increases. Two independent 12 joule systems are normally fitted to each engine to provide a positive light up during starting but some engines have one 12 joule and one 3 joule system. The 3 joule system is kept in continuous operation to provide automatic relighting.

5.2 Where continuous operation of one system is not desirable, a glow plug is sometimes fitted in the combustion chamber where it is heated by the combustion process and remains incandescent for a sufficient period of time to ensure automatic re-ignition.

5.3 **High Energy Ignition Unit.** A 12 joule unit receives electrical power from the aircraft d.c. supply, either in conjunction with starter operation or independently through the "relight" circuit. An induction coil or transistorised h.t. generator repeatedly charges a capacitor in the unit until the capacitor voltage is sufficient to break down a sealed discharge gap. The discharge is conducted through a choke and h.t. lead to the igniter plug where the energy is released in a flashover on the semi-conducting face of the plug. The capacitor is then recharged and the cycle repeated approximately twice every second. A resistor connected from the output to earth ensures that the energy stored in the capacitor is discharged when the d.c. supply is disconnected.

NOTE: A 3 joule unit is usually supplied with l.t. alternating current but its function is similar to that described above.

5.3.1 The electrical energy stored in the high energy ignition unit is potentially lethal and even though the capacitor is discharged when the d.c. supply is disconnected, certain precautions are necessary before handling the components. The associated circuit breaker should be tripped, or fuse removed as appropriate, and at least one minute allowed to elapse before touching the ignition unit, high tension lead or igniter plug.

5.3.2 Ignition units are attached to the aircraft structure by anti-vibration mountings and the rubber bushes should be checked for perishing at frequent intervals. It is also important that the bonding cable is securely attached, making good electrical contact and of sufficient length to allow for movement of the unit on its mountings.

5.3.3 At the intervals specified in the appropriate Maintenance Schedule the unit should be inspected for signs of damage, cracks or corrosion. Bonding leads must be secure and the l.t. and h.t. ignition leads securely attached and locked.

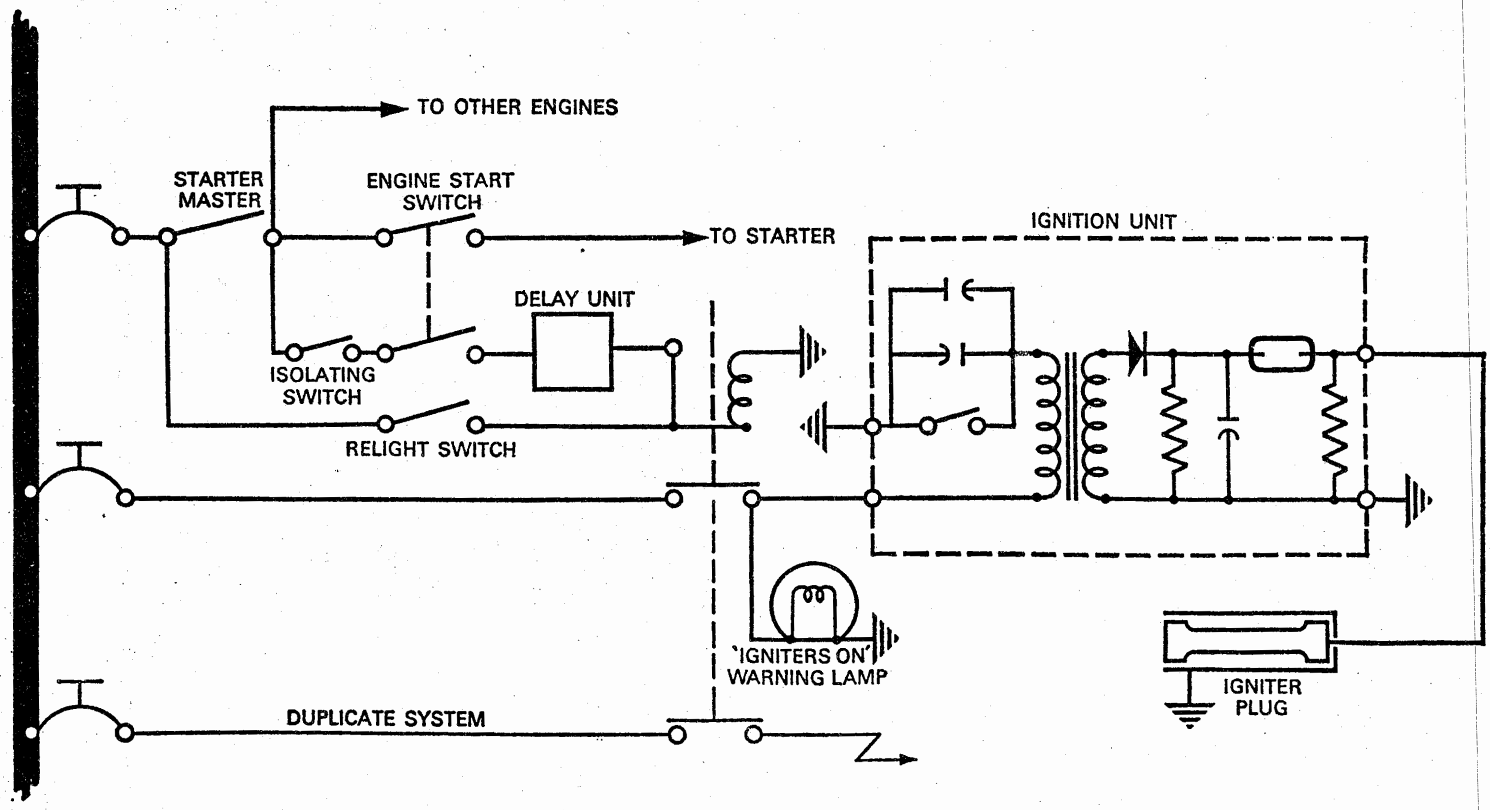


Figure 4 TYPICAL IGNITION SYSTEM

5.4 **Igniter Plug.** The igniter plug consists of a central electrode and outer body, the space between them being filled with an insulating material and terminating at the firing end in a semi-conducting pellet. A spring-loaded contact button is fitted at the outer end of the electrode. During operation a small electrical leakage from the ignition unit is fed through the electrode to the plug body and produces an ionised path across the surface of the pellet. The high intensity discharge takes place across this low-resistance path.

5.4.1 Igniter plugs should be inspected at frequent intervals for security, damage, gas leakage and secure attachment of the h.t. lead. When removed they should be inspected for heat damage, cracks and erosion of the pellet surface. Igniter plugs are not normally cleaned but if carbon deposits make inspection of the pellet impossible the carbon may be removed, care being taken not to damage the surface of the pellet.

5.4.2 When it is necessary to fit a new igniter plug the manufacturer sometimes specifies that the depth of penetration of the plug into the combustion chamber should be checked. This is accomplished by means of a special tool similar to a dummy plug and the adjustment is made by selecting a shim of appropriate thickness to fit under the igniter plug housing. A new sealing washer must be fitted when a plug is replaced.

5.4.3 Lubrication of plug threads is normally specified by the manufacturer and plugs should be torque loaded to the value stated in the appropriate Maintenance Manual.

5.5 **Ignition Lead.** The high energy ignition lead is used to carry the intermittent high voltage outputs from the ignition unit to the associated igniter plug. A single insulated core is encased in a flexible metal sheath and terminates in a spring-loaded contact button at each end. The end fittings usually incorporate a self-locking attachment nut.

5.5.1 Before installing an ignition lead the spring-loaded contact assemblies should be checked for freedom of movement and, where specified, an insulation resistance check carried out in accordance with the appropriate Maintenance Manual. The sheath should also be checked for fraying and the ceramic insulating sleeves for cracks or other damage. The manufacturer may specify the use of an anti-seize compound on the plug threads during fitting.

5.5.2 During service the leads should be inspected for security and damage. In particular the sheath should be examined in the vicinity of supporting clips for signs of chafing and over its whole length for signs of oil contamination.

5.6 **Testing.** Whenever an ignition component is changed or incorrect operation of the system is suspected a functional check may be made by operating the relight circuit.

5.6.1 The aircraft should be located in the open air and the engine inspected for signs of fuel or fuel vapour which, if present, must be dispersed before operating the ignition units. A suitable CO_2 fire extinguisher should be positioned adjacent to the engine before carrying out the test.

5.6.2 The high pressure fuel cock should be closed and the circuit breaker tripped (or fuse removed if appropriate) from each of the ignition circuits in turn whilst checking operation of the other. When the necessary switches are set for relighting, operation of the ignition system will be heard as regular clicking noises from the igniter plug as the electrical discharges occur and, on some aircraft, shown by illumination of an "igniters on" warning lamp on the flight deck.

5.6.3 If a component common to both the ignition and cranking systems is changed (e.g. a time delay unit), it is advisable to carry out an engine motoring run with the H.P. cock turned off, to check the normal d.c. circuit to the ignition units.

6 STORAGE Starters and ignition components should be stored in conditions that are clean, dry, warm and free from corrosive fumes. A temperature of 16°C (61°F) and humidity of 75% are often quoted by manufacturers as being ideal storage conditions.

6.1 **Starters and Ignition Units.** These components are transported in either a "tropical" or "commercial" pack. "Tropical" packing includes sealing the component with a suitable quantity of dessicant in a polythene bag and placing the bag in a padded wooden or cardboard box. Grease-resistant paper is used instead of a polythene bag for "commercial" packing. Components should be kept in their boxes during storage and when unpacked for use the packaging material should be retained. If the original material is not available a returned component should be packed in accordance with BS 1133 or equivalent specification

6.1.1 Starter gearboxes should be drained before packing and external threads and drive shafts coated with a rust preventative.

6.2 **Igniter Plugs.** Plug threads should be coated with a rust preventative and the plug wrapped in waxed paper or a polythene tube. It may then be placed in a cardboard box, either singly or with other plugs, and the box sealed.

6.3 **Ignition Leads.** These should be wiped with a cloth moistened with white spirit to remove any oil or grease, and the end connections blanked off. The leads should be placed in a natural position (i.e. not coiled or bent) on a flat shelf and covered with a dust cloth.

6.4 **Storage Life.** A specific storage life may be recommended for some components but igniter plugs and leads may normally be kept in storage indefinitely provided that storage conditions are ideal. Any component which has reached the end of its storage life must be subjected to such inspection and testing as may be specified to enable re-certification for a further period of storage.

EL/3-13

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AIRCRAFT

ENGINES

TURBINE ENGINES—ANTI-ICING SYSTEMS

INTRODUCTION This Leaflet gives general guidance on the installation and maintenance of the thermal systems employed for the anti-icing of the air intakes of turbine engines. It should be read in conjunction with the installation drawings, Maintenance Manuals and approved Maintenance Schedules for the engine and aircraft concerned.

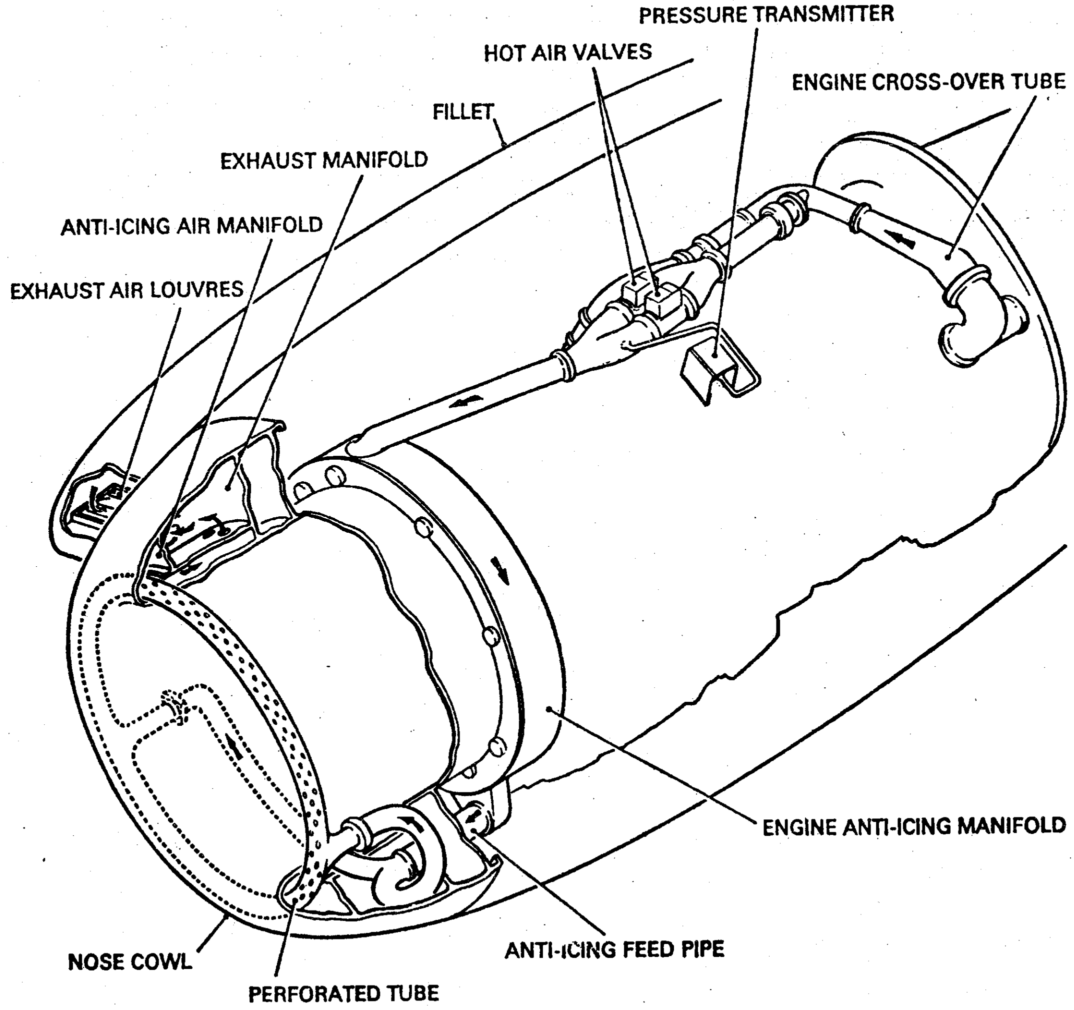

Figure 1 TYPICAL HOT AIR ANTI-ICING SYSTEM

2 GENERAL A gas turbine engine presents a critical icing problem and therefore requires protection against ice formation particularly at the air intake, nose bullet or fairing, and inlet guide vanes. Icing of these regions can considerably restrict the airflow causing a loss in performance and, furthermore, cause damage to the compressor as a result of ice breaking away and being ingested by the compressor. There are two thermal systems in use for air intake anti-icing; a hot air bleed system and an electrical resistance heating system, and although the latter is usually chosen for turbopropeller engines to provide protection for the propeller (see Leaflet **PL/1-4**), there are some examples where both systems are used in combination.

2.1 **Hot Air System.** In a hot air system the air is bled from the compressor and is fed via ducting into the air intake nose cowl, through the inlet guide vanes of the engine and also, in some engines, through the nose bullet. A typical system is illustrated in Figure 1. After circulating the intake cowl and guide vanes, the air is exhausted either to atmosphere or into the engine air intake. The flow of hot air is regulated by electrically operated control valves which are actuated by control switches on a cockpit panel. An air temperature control system is not usually provided in a hot air system.

2.2 **Electrical Heating System.** In an electrical heating system, heating elements either of resistance wire or sprayed metal, are bonded to the air intake structure. The power supply required for heating is normally three-phase alternating current. The arrangement adopted in a widely used turbopropeller engine is illustrated in Figure 2 as an example. The elements are of the resistance wire type and are formed into an overshoe which is bonded around the leading edge of the air intake cowl and also around the oil cooler air intake. Both anti-icing and de-icing techniques are employed by using continuously heated and intermittently heated elements respectively. The elements are sandwiched between layers of glass cloth impregnated with resin. In some systems the elements may be sandwiched between layers of rubber. The outer surfaces are, in all cases, suitably protected against erosion by rain, and the effect of oils, greases, etc. The power supply is fed directly to the continuously heated elements, and via a cyclic time switch unit to the intermittently heated elements and to the propeller blade elements (see also Leaflet **PL/1-4**). The cyclic time switch units control the application of current in selected time sequences compatible with prevailing outside air temperature conditions and severity of icing. The time sequences which may be selected vary between systems. For the system shown in Figure 2 the sequences are 'Fast', giving one complete cycle (heat on/heat off) of 2 minutes at outside air temperatures between —6°C and +10°C, and 'Slow', giving one complete cycle of 6 minutes at outside air temperatures below —6°C. An indicator light and, in some cases, an ammeter, are provided on the appropriate cockpit control panel to indicate correct functioning of the time switch circuit.

3 INSTALLATION AND MAINTENANCE Full details of the methods of installation and checks necessary for the inspection and maintenance of systems and associated components will be found in the relevant aircraft and engine Maintenance Manuals and approved Maintenance Schedules; reference must therefore be made to such documents. Reference should also be made to Leaflets **EEL/3-1** and **EEL/1-6** for guidance on the installation of electric cables and testing of circuits. The information given in the following paragraphs is intended only as a general guide to the installation and maintenance procedures normally required.

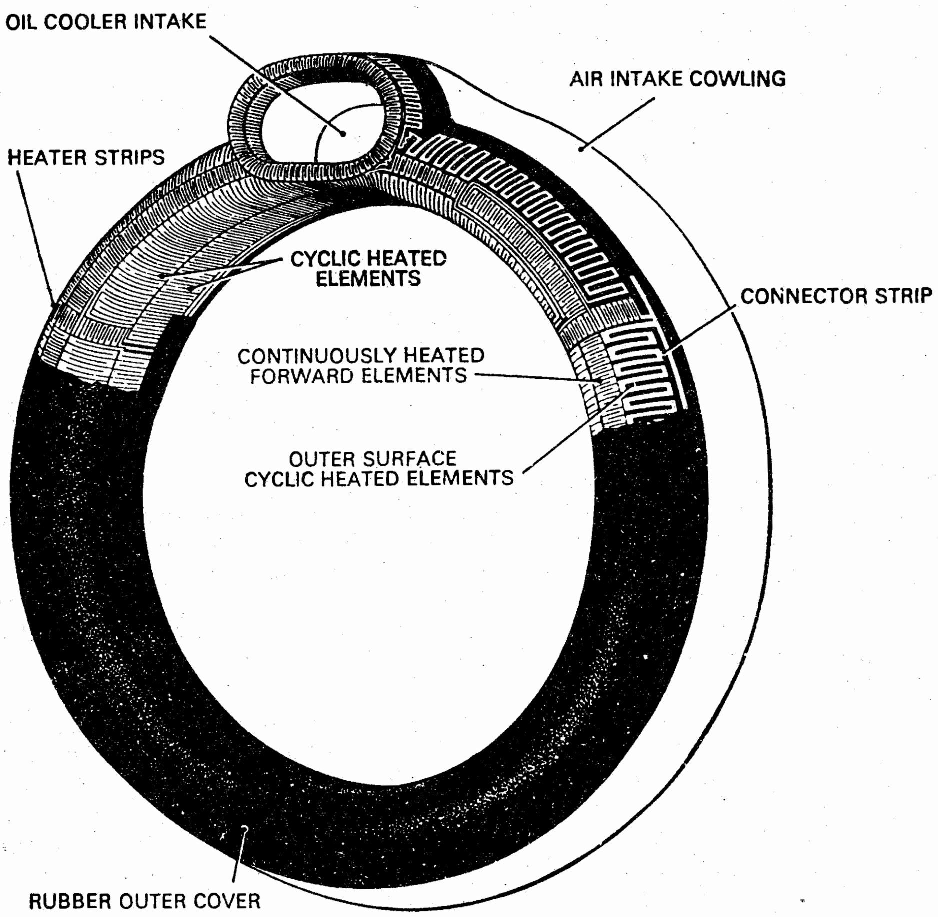

Figure 2 TYPICAL ELECTRICAL ANTI-ICING SYSTEM

3.1 **Hot Air Systems.** The installation and maintenance of components of hot air systems is, in general, a straightforward procedure which only requires checks to ensure security of attachment to appropriate parts of the aircraft structure, security of duct connections and wirelocking, where necessary. After installation of a component and at the periods detailed in the aircraft approved Maintenance Schedule, a system should be tested to ensure proper functioning and checks made for leakage at the areas disturbed. Some important aspects common to installation and maintenance procedures are given in the following paragraphs.

3.1.1 Ducts should be inspected externally and internally for cleanliness, signs of damage and security of end fittings.

3.1.2 During installation, ducts must be adequately supported at all times, and must not be allowed to hang from a joint or other component. There must be adequate clearance between ducts and adjacent structure and components.

3.1.3 In general, new seals should be fitted between jointing faces of end fittings of ducts and components such as control valves. This is also essential whenever a joint is broken down for any reason. The jointing faces should also be checked for excessive ovality or gapping.

3.1.4 Whenever possible ducting should be removed by disconnecting at a point where band-type vee-clamps are used. On some engines bolted spherical connections are employed and, unless it is absolutely necessary, the ducts should not be disconnected at these points since the connections will require special refitting.

3.1.5 Band-type vee-clamps should be lubricated with the dry-film lubricant specified in the Maintenance Manual and torque-tightened to the loads specified. The clearance between the flanges of fittings should be checked in order to ensure that the seal between the jointing faces of duct end fittings has been sufficiently compressed.

3.1.6 Expansion bellows type joints should be checked for full and free movement.

3.1.7 All sections of ducting should be properly aligned with each other and with other associated components. In most cases ducting passes through confined spaces and requires considerable care to ensure stress-free alignment at the joints before finally securing in place. Ducting should not be drawn into alignment by means of flange attachment devices. On some types of engine alignment is facilitated by locating a dowel in a hole. On others alignment is by means of coloured flashes painted on the ducts and components.

3.1.8 If a section of ducting or a component is removed and refitting is not being effected immediately, suitable blanks must be fitted to the open ends of ducts or other connections to prevent the ingress of foreign matter.

3.1.9 Where specified, ducts should be tested for leaks in the manner prescribed in the relevant aircraft and engine Maintenance Manuals. The test pressures and rate of leakage should not exceed the limits quoted.

NOTE: Adequate safety precautions must be taken when inspecting duct sections under pressure.

3.1.10 Control valves should be inspected for cleanliness, signs of damage and their insulation resistance and solenoid resistance values measured to ensure that they are within the limits specified in the Maintenance Manual. When installing valves particular care is necessary to ensure that they are positioned in correct relation to the air flow as indicated by an arrow on the body of the valve.

3.1.11 Cables interconnecting appropriate electrical components must be of the rating specified by the manufacturer. All connections should be checked against the relevant wiring diagrams, and plugs, sockets and terminal screws properly secured.

3.1.12 On completion of the installation of a duct section or component, and at the periods specified in the approved Maintenance Schedule, an in-situ functional test should be carried out. Any limitations as to the duration of the test and other precautions during engine ground running, must be strictly observed. A functional test consists principally of checking the air pressure supplied to the system at a specified engine speed, and checks on the function of associated controlling and indicating devices. Such checks and tests should be performed to a prescribed test schedule.

3.2 **Electrical Heating Systems.** In systems of this type, the overshoes are bonded to the air intake cowls, therefore removal and installation procedure are related to the cowls as combined units. The procedures are straightforward involving only the removal and refitting of setscrews which secure cowls to engine air intake casings, and the making and breaking of the electrical connections. In some cases the procedures also involve the connection and disconnection as appropriate, of fire extinguisher system spray pipes and oil cooler pipes and couplings at the rear face of the air intake cowl. Set-screws pass through steel insert and rubber bush assemblies and care should be taken to avoid losing these during removal. The bushes should be examined for wear and deterioration and renewed as necessary. Where specified, the clearance between the cowl diaphragm and engine air intake casing must be checked before finally securing the cowl, to ensure that it corresponds to the value specified in the engine Maintenance Manual. If the correct clearance cannot be obtained, the complete cowl assembly or diaphragm should be replaced by a serviceable item. Some important aspects common to inspection and maintenance procedures are given in the following paragraphs. These should be read in conjunction with the aircraft and engine Maintenance Manuals and approved Maintenance Schedules.

3.2.1 Cowls and electrical leads should be inspected for security and the overshoes inspected for blisters, gashes, exposure of the heating elements, signs of overheating and general deterioration.

NOTE: Overheating or a complete 'burn-out', can be caused through impact damage to the overshoe, defects in the heating elements or malfunction of the aircraft's electrical power supply to the heating elements.

3.2.2 The lacquer film on rubber covered overshoes should be examined for damage or deterioration and if either is evident the film should be touched-up or completely renewed as necessary, by using the repair kit supplied by the relevant manufacturer.

3.2.3 Checks on the continuity and resistance of the heating elements, and insulation resistance checks of the complete cowl assembly, must be carried out whenever an assembly has been changed or repairs effected and also at the prescribed inspection periods.

NOTE: The metal of air intake cowls is normally anodised and it is necessary to bare a small area to effect the 'earth' connection. On completion of the electrical checks, this area must be re-protected against corrosion.

3.2.4 Functional testing of a complete system must be carried out at the check periods specified in the approved Maintenance Schedule, when a system malfunction occurs, after replacement of an intake cowl or a system component such as a cyclic time switch, and also after any repairs to an overshoe. A functional test consists principally of checking that heating current is applied to the heater elements at the periods governed by the operation of the cyclic time switch and, as indicated by the system indicator light, and ammeter where applicable, to the systems. Tests and checks must be performed to a prescribed test schedule paying particular attention to any limitations on system operation and engine speeds during ground running.

NOTE: The power supply control circuit is usually routed through landing gear shock-strut micro switches so that on the ground the power is automatically reduced to prevent overheating. Therefore, whenever the aircraft is on jacks, or the micro switches are otherwise rendered inoperative, power should not be applied to the heating elements.

3.2.5 If blisters, gashes, exposure of the heating elements, general deterioration and lack of adhesion of either rubber or glass cloth covering is evident, the covering should be carefully cut open to permit examination of the heating elements. If the elements are not fractured or cracked and the rubber or glass cloth below the elements has not deteriorated, the areas affected may be repaired as a minor repair.

3.2.6 The heating element system is made up of a number of sections or pads and if any one of the sections has been fractured due to a localised burn-out or mechanical damage, a repair can be made by welding a portion of element in the appropriate section.

NOTE: The number of repairs in a section or pad is normally limited to one since the weld causes an increase in element resistance.

3.2.7 The repair methods to be adopted, and the nature of the work involved, depends largely on the extent of damage and also on the type of overshoe construction, i.e. glass cloth or rubber laminate. Repair schemes are therefore devised for each type and are usually classified according to the level of the repairs required, i.e. minor repairs which can be carried out in the normal overhaul workshops, or major repairs to be carried out by the manufacturer. Full details of these schemes are given in the Maintenance Manuals and Overhaul Manuals for the relevant type of engine and reference must always be made to these documents.

3.2.8 An air intake cowl assembly which has been damaged or has deteriorated to an extent outside repair standards specified in the Maintenance Manuals and Overhaul Manuals should be removed and replaced by a serviceable assembly.

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AIRCRAFT

ENGINES

STORAGE PROCEDURES

1 INTRODUCTION Under normal operating conditions the interior parts of an engine are protected against corrosion by the continuous application of lubricating oil, and operating temperatures are sufficient to dispel any moisture which may tend to form; after shutdown the residual film of oil gives protection for a short period. When not in regular service, however, parts which have been exposed to the products of combustion, and internal parts in contact with acidic oil, are prone to corrosion. If engines are expected to be out of use for an extended period they should be ground run periodically or some form of anti-corrosive treatment applied internally and externally to prevent deterioration.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet EL/10-1, Issue 1, 1st June 1949, cancelled 1st February 1968.

1.1 The type of protection applied to an engine depends on how long it is expected to be out of service, if it is installed in an aircraft, and if it can be turned.

1.2 This Leaflet gives guidance on the procedures which are generally adopted to prevent corrosion in engines but, if different procedures are specified in the approved Maintenance Manual for the particular engine, the manufacturer's recommendations should be followed.

1.3 The maximum storage times quoted in the Leaflet are generally applicable to storage under cover in temperate climates, and vary considerably for different storage conditions. Times may also vary between different engines, and reference must be made to the appropriate Maintenance Manual for details.

2 INSTALLED PISTON ENGINES If it is possible to run a piston engine which is installed in an aircraft and expected to be out of service for a period of up to one month, sufficient protection will be provided by running the engine every seven days, but if the period of inactivity is subsequently extended, continued periodic ground running would result in excessive wear and the engine should be placed in long term storage. The run should be carried out at low engine speed (1000 to 1200 rev/min), exercising the engine and propeller controls as necessary to ensure complete circulation of oil, until normal working temperatures are obtained. If the engine cannot be run for any reason, the manufacturer may recommend that it should be turned by hand or motored by means of an external power supply, but generally it will be necessary to inhibit the engine as described below.

2.1 **Long Term Storage.** When a piston engine is likely to be out of service for a period in excess of one month it must be treated internally and externally with a corrosion inhibitor. The treatments described below are normally considered satisfactory for six months but this may be extended to twelve months in ideal storage conditions. At the end of this period the engine should be prepared for service, given a thorough ground run and re-protected or, alternatively, removed from the aircraft and stored as described in paragraph 4.

2.1.1 **Internal Protection**

(i) **American Method**

(a) Drain the oil sump and tank and refill with storage oil as prescribed by the manufacturer.

(b) Run the engine at low speed (1000 to 1200 rev/min) until normal operating temperatures are obtained.

(c) Spray cylinder protective into the induction system until white smoke issues from the exhaust, then switch off the engine but continue spraying until rotation has ceased.

(d) Drain the oil sump and remove the filters.

(e) Remove the sparking plugs and spray a fixed quantity of cylinder protective into each cylinder while the engine is turned by hand. A further quantity should then be sprayed into the cylinders with the engine stationary.

(f) Fit dehydrator plugs in each cylinder and replace oil filters.

(g) Place a quantity of desiccant in the intake and exhaust and blank off all openings.

(ii) **British Method**

(a) Drain the oil sump and tank and refill with the storage oil recommended by the manufacturer.

(b) Run the engine at low speed (1000 to 1200 rev/min) until normal operating temperatures are obtained.

(c) Drain all oil from the system and remove filters.

(d) Remove sparking plugs and spray the specified quantity of cylinder protective into each cylinder while the piston is at the bottom of its stroke, at the same time spraying the valve springs and stems with the valves closed, and the valve heads and ports with the valves open. Also spray the valve rocker gear.

(e) Turn the engine at least six revolutions by hand, then spray half the previously used quantity of cylinder protective into each cylinder with the engine stationary.

(f) Replace oil filters and fit dehydrator plugs.

(g) Blank off all openings into the engine (intake, exhaust, breathers, etc.).

(h) Replenish oil tank to normal level with storage oil as specified.

(iii) **Special Requirements**

(a) Coolant systems should be drained and thoroughly flushed unless an inhibited coolant is used.

(b) Fuel system components such as fuel pumps, injectors, carburettors or boost control units also require inhibiting. This is done by draining all fuel and oil as appropriate, and refilling with storage or mineral oil as recommended by the manufacturer. Blanking caps and plugs should then be fitted to retain the oil.

(c) Auxiliary gearboxes should also be inhibited. The normal lubricating oil should be drained and the gearbox refilled with storage oil.

(d) If the propeller is removed the propeller shaft should be sprayed internally and externally with cylinder protective and correct blanks fitted.

2.1.2 **External Protection.** Exterior surfaces of the engine should be thoroughly cleaned with an approved solvent such as white spirit, by brushing or spraying, and dried with compressed air. Any corrosion should be removed, the area re-treated in accordance with the manufacturer's instructions and chipped or damaged paintwork renewed. The following actions should then be taken:—

(i) All control rods should be liberally coated with a general purpose grease.

(ii) Magneto vents should be covered.

(iii) Sparking plug lead ends should be fitted with approved transport blanks, exposed electrical connections masked and rubber components covered with waxed paper or mouldable wrap.

(iv) Spray holes in fire extinguisher pipes should, if possible, be blanked off, using polythene sleeving or waxed paper suitably secured.

(v) An approved preservative (normally lanolin or external air drying varnish) should be sprayed over the whole engine, in a thin even film.

2.2 **General Precautions.** It is most important that an installed stored engine should not be turned, since this would lead to removal of cylinder protective from the cylinder walls and possibly result in the formation of corrosion at those positions. Physical restraint is seldom practicable, particularly when a propeller is fitted, but warning notices should be fixed on the propeller and in the cockpit to prevent inadvertent rotation of the engine.

3 INSTALLED TURBINE ENGINES Installed turbine engines which are to be out of use for a period of up to seven days require no protection apart from fitting covers or blanks to the intake, exhaust and any other apertures, to prevent the ingress of dust, rain, snow, etc. A turbine engine should not normally be ground run solely for the purpose of preservation, since the number of temperature cycles to which it is subjected is a factor in limiting its life. For storage periods in excess of seven days additional precautions may be necessary to prevent corrosion.

3.1 **Short-term Storage.** The following procedure will normally be satisfactory for a storage period of up to one month.

3.1.1 **Fuel System.** The fuel lines and components mounted on the engine must be protected from the corrosion which may result from water held in suspension in the fuel. The methods used to inhibit the fuel system depend on the condition of the engine and whether it is installed in an aircraft or not, and are fully described in the appropriate Maintenance Manual and in Leaflet **EL/3-10.** On completion of inhibiting, the fuel cocks must be turned off.

3.1.2 **Lubrication Systems.** Some manufacturers recommend that all lubrication systems (engine oil, gearbox oil, starter oil, etc.) of an installed engine should be drained, and any filters removed and cleaned, while others recommend that the systems should be filled to the normal level with clean system oil or storage oil. The method recommended for a particular engine should be ascertained from the appropriate Maintenance Manual.

3.1.3 **External Treatment.** Exterior surfaces should be cleaned as necessary to detect corrosion, then dried with compressed air. Any corrosion should be removed, affected areas re-treated, and any damaged paintwork made good in accordance with the manufacturer's instructions. Desiccant or vapour phase inhibitor should be inserted in the intake and exhaust, and all apertures should be fitted with approved covers or blanks.

3.2 **Long term Storage.** For the protection of turbine engines which may be in storage for up to six months, the short-term preservation should be applied and, in addition, the following actions taken:—

(i) Grease all control rods and fittings.

(ii) Blank-off all vents and apertures on the engine, wrap greaseproof paper round all rubber parts which may be affected by the preservative and spray a thin coat of external protective over the whole engine forward of the exhaust unit.

3.2.1 At the end of each successive six months storage period an installed engine should be re-preserved for a further period of storage. Alternatively, the engine may be removed from the aircraft and preserved in a moisture vapour proof envelope.

4 UNINSTALLED ENGINES (PISTON AND TURBINE) Engines which have been removed from aircraft for storage, or uninstalled engines which are being returned for repair or overhaul, should be protected internally, and sealed in moisture vapour proof (MVP) envelopes. This is the most satisfactory method of preventing corrosion, and is essential when engines are to be transported overseas.

4.1 A piston engine should be drained of all oil, the cylinders inhibited as described in paragraphs 2.1.1 (ii), (d) to (h), drives and inside of crankcase sprayed with cylinder protective, and all openings sealed.

4.2 A turbine engine should be drained of all oil, fuel system inhibited, oil system treated as recommended by the manufacturer, and blanks fitted to all openings.

4.3 Particular care should be taken to ensure that no fluids are leaking from the engine, and that all sharp projections, such as locking wire ends, are suitably padded to prevent damage to the envelope.

4.4 The MVP envelope should be inspected to ensure that it is undamaged, and placed in position in the engine stand or around the engine, as appropriate. The engine should then be placed in the stand, care being taken not to damage the envelope at the points where the material is trapped between the engine attachment points and the stand bearers.

4.5 Vapour phase inhibitor or desiccant should be installed in the quantities and at the positions specified in the relevant Maintenance Manual, and a humidity indicator should be located in an easily visible position in the envelope. The envelope should then be sealed (usually by adhesive) as soon as possible after exposure of the desiccant or vapour phase inhibitor.

4.6 The humidity indicator should be inspected after 24 hours to ensure that the humidity is within limits (i.e. the indicator has not turned pink). An unsafe reading would necessitate replacement of the desiccant and an examination of the MVP envelope for damage or deterioration.

4.7 After a period of three years storage in an envelope the engine should be inspected for corrosion and re-preserved.

5 INSPECTION Engines in storage should be inspected periodically to ensure that no deterioration has taken place.

5.1 Engines which are not preserved in a sealed envelope should be inspected at approximately two-weekly intervals. Any corrosion patches should be removed and the protective treatment re-applied, but if external corrosion is extensive a thorough inspection may be necessary.

5.2 Envelopes on sealed engines should be inspected at approximately monthly intervals to ensure that humidity within the envelope is satisfactory. If the indicator has turned pink the envelope should be unsealed, the desiccant renewed and the envelope resealed.

6 EQUIPMENT AND MATERIALS

6.1 **Equipment.** The spraying equipment should be of a type approved by the engine manufacturer, and should be operated in accordance with the instructions issued by the manufacturer of the equipment. For inhibiting cylinders a special nozzle is required, and this should be checked immediately before use to ensure that the spray holes are unblocked. Correct operation of the spray gun may be checked by spraying a dummy cylinder and inspecting the resultant distribution of fluid.

6.2 **Materials.** Only the types of storage and inhibiting oil recommended by the manufacturer should be used for preserving an engine. American manufacturers generally recommend oils and compounds to American specifications, and British manufacturers generally recommend storage oil to DEF 2181, wax-thickened cylinder protective to DTD 791, turbine fuel system inhibiting oil to D. Eng. R.D. 2490, and external air drying varnish approved under a DTD 900 specification. Only approved alternatives should be used, and any instructions supplied by the manufacturer in respect of thinning or mixing of oils should be carefully followed.

6.3 **Blanks.** Approved blanks or seals should be used whenever possible. These are normally supplied with a new or reconditioned engine, and should be retained for future use. Pipe connections are usually sealed by means of a screw-type plug or cap such as AGS 3802 to 3807, and plain holes are sealed with plugs such as AGS 2108; these items are usually coloured for visual identification. Large openings such as air intakes are usually fitted with a specially designed blanking plate secured by the normal attachment nuts, and the contact areas should be smeared with grease before fitting, to prevent the entry of moisture. Adhesive tape may be used to secure waxed paper where no other protection is provided, but should never be used as a means of blanking off by itself, since it may promote corrosion and clog small holes or threads.

7 REMOVAL FROM STORAGE For an engine which was not installed in an aircraft during storage the installation procedure described in the appropriate Maintenance Manual should be carried out, followed by a thorough ground run and check of associated systems. For an engine which was installed in an aircraft during storage the following actions should be taken:—

(i) Remove all masking, blanks and desiccant.

(ii) Clean the engine as necessary, e.g. remove excess external protective and surplus grease from controls.

(iii) Ensure fire extinguisher spray pipe holes are clear.

(iv) Replace any components which were removed for individual storage, de-inhibiting as necessary.

(v) Drain out all storage oil, clean oil filters and refill with normal operating oil.

(vi) Piston engines; remove sparking plug blanks and turn engine slowly to drain excess oil from the cylinders, then fit plugs and connect leads. Turbine engines; prime the fuel system in accordance with the manufacturer's requirements (Leaflet **EL/3-10**).

(vii) Prime the engine lubricating oil system.

(viii) Start the engine and carry out a check of the engine and associated systems.

8 RECORDS Appropriate entries must be made in the engine log book giving particulars of inhibiting procedures or periodic ground running. Such entries must be signed and dated by an appropriately licensed engineer or Approved Inspector.

EL/3-15

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AIRCRAFT

ENGINES

PISTON ENGINES—OPERATION BEYOND RECOMMENDED OVERHAUL PERIODS

1 INTRODUCTION This Leaflet gives guidance on the procedures which are necessary for a small piston engine to be accepted as being in a condition which will allow completion of, or operation beyond, the recommended overhaul period under the terms of Airworthiness Notice No. 35.

2 GENERAL A piston engine which has reached the end of its normal overhaul period may be expected to have suffered some wear to cylinders, pistons, valves, bearings and other moving parts, but an engine which has been carefully operated and maintained may still be in a condition suitable for a further period of service.

2.1 Many factors affect the wear which takes place in an engine, the most important including the efficiency of the air intake filter, the techniques used in engine handling, particularly during starting, the quality of the fuel and oil used in the engine and the conditions under which the aircraft is housed when not in use. Conditions of operation are also relevant; the length of flights, the atmospheric conditions during flight and on the ground, and the type of flying undertaken. Many of these factors are outside the province of the maintenance engineer, but meticulous compliance with the approved Maintenance Schedule, and any instructions provided in the form of service bulletins or constructor's recommendations will undoubtedly help to prolong the life of an engine.

2.2 Airworthiness Notice No. 35 lays down certain conditions which must be fulfilled in order that an engine may be considered for—

(a) operation for the manufacturer's recommended overhaul period,

(b) operation beyond 10 years where the manufacturer's recommended overhaul period is conditional upon a minimum utilisation rate,

(c) operation for up to 120% of the recommended overhaul period, or

(d) in the case of engines installed in aircraft certificated in the Private Category with a Maximum Total Weight Authorised not exceeding 2730 kg, continuation in operation on an 'on-condition' basis.

2.2.1 The inspections and tests which may be necessary to assess the condition of an engine in compliance with Airworthiness Notice No. 35 are detailed in paragraphs 3 to 6.

3 EXAMINATION AND CHECKING OF ENGINE A number of items included in the normal scheduled maintenance of an engine may be repeated to determine the condition of an engine at the end of its normal overhaul period, and additional inspections may also be specified.

3.1 **External Condition.** The engine should be examined externally for obvious faults such as a cracked crankcase, excessive play in the propeller shaft, overheating and corrosion, which would make it unacceptable for further use.

3.2 **Internal Condition.** Significant information concerning the internal condition of an engine may be obtained from an examination of the oil filters and magnetic plugs, for metal particle contamination. These checks may be sufficient to show that serious wear or breakdown has taken place and that the engine is unacceptable for further service.

3.3 **Oil Consumption.** Since the oil consumption of an engine may have increased towards the end of its normal overhaul period, an accurate check of the consumption over the last 10 flying hours would show whether it is likely to exceed the maximum recommended by the constructor, should the overhaul period be extended.

3.4 **Compression Check.** Piston ring and cylinder wear, and poor valve sealing could, in addition to increasing oil consumption, result in a significant loss of power. A cylinder compression check is a method of determining, without major disassembly, the standard of sealing provided by the valves and piston rings.

3.4.1 On engines with a small number of cylinders a simple compression check may be carried out by rotating the engine by hand and noting the resistance to rotation as each cylinder passes through its compression stroke. The check should normally be made shortly after running the engine while a film of oil remains on the rubbing surfaces, to assist sealing and prevent scoring the working parts. If this is not possible, the constructor may recommend that oil is introduced into each cylinder and the engine turned through a number of revolutions before making the test.

(a) This method may be used to determine serious loss of compression on a single cylinder or the difference between the compressions of individual cylinders, but may not accurately show a similar partial loss of compression on all the cylinders of an engine.

(b) An alternative method, which will give a more accurate result, is to fit a pressure gauge (reading up to 1400 kPa (200 lbf/in^2)) in place of one sparking plug in each cylinder in turn and note the reading as the piston passes through top dead centre (TDC) on the compression stroke.

3.4.2 Another method of carrying out a direct compression test is by use of a proprietary type of compression tester equipped with a means of recording cylinder pressures on a graph card. One set of plugs should be removed immediately after an engine run, and the compression tester fitted to each cylinder in turn while rotating the engine by means of the starter motor. The effectiveness of combustion chamber sealing can be judged by assessment of the graph records obtained.

3.4.3 A further method of checking engine compression is the differential pressure test. In this test a regulated air supply (normally 560 kPa (80 lbf/in^2)) is applied to each cylinder in turn and a pressure gauge used to record the actual air pressure in the cylinder. Since some leakage will normally occur, cylinder pressure will usually be less than supply pressure and the difference will be an indication of the condition of the piston rings and valves. By listening for escaping air at the carburettor intake, exhaust and crankcase breather, a defective component may be located. As with the previous tests, it is usually recommended that the differential pressure test is carried out as soon as possible after running the engine.

NOTE: The crankshaft should be restrained during this test as, if the piston is not exactly at the end of its stroke, the test air pressure may be sufficient to cause rotation.

4 POWER OUTPUT OF AEROPLANE ENGINES The power developed by an aeroplane engine after initial installation is established in the form of a reference engine speed, which is recorded in the appropriate log book so that comparisons can be made

during subsequent power checks. The reference engine speed is the observed engine speed obtained using specified power settings and operating conditions, corrected, by means of graphs supplied by the engine constructor (or those contained in Leaflets **EL/3-2** or **EL/3-8** as appropriate), to the figure which would be obtained at standard sea-level atmospheric temperature and pressure; changes in humidity do not produce large changes of power and are ignored for the purpose of establishing a reference engine speed or subsequently checking engine power. Power checks should be carried out using the same power settings and operating conditions as when the reference engine speed was established, and should be corrected in the same way.

4.1 **Power Checks.** The majority of light aeroplane piston engines are air-cooled and rely on an adequate flow of air for proper cooling of the cylinders. This condition can only be obtained during flight, and ground runs should, therefore, be as brief as possible. Cooling can be assisted by facing the aircraft into wind, but high wind conditions must be avoided when making power checks, as they will seriously affect the results obtained. Before running the engine at high power the normal operating temperatures should be obtained (not the minimum temperatures specified for operation) and during the test careful watch should be kept on oil and cylinder temperatures to prevent the appropriate limitations being exceeded.

4.1.1 Normally-aspirated engines are tested at full throttle and, where a controllable-pitch propeller is fitted, with maximum fine pitch selected. The changes in barometric pressure affecting engine power are considered to be balanced by changes in propeller load, so that only a temperature correction is necessary. This correction factor may be obtained from a graph supplied by the engine constructor or, if this is not available, from the graph shown in Figure 1 of Leaflet **EL/3-8**. The observed full throttle speed multiplied by the correction factor will give the corrected speed.

4.1.2 Although normally-aspirated engines are often fitted with variable-pitch propellers, the engine speed obtained at full throttle is usually less than the governed speed and the propeller remains in fully fine pitch. With supercharged engines, however, the propeller is usually constant speeding at high power settings and small changes in power will not affect engine speed. The power of a supercharged engine is, therefore, checked by establishing a reference speed at prescribed power settings.

(a) Since a supercharged engine is run at a specified manifold pressure regardless of the atmospheric pressure, corrections must be made for both temperature and pressure variations from the standard atmosphere.

(b) The procedure is to run the engine until normal operating temperatures are obtained, open up to maximum take-off manifold pressure, decrease power until a fall in engine speed occurs (denoting that the propeller blades are on their fine pitch stops), then throttle back to the manifold pressure prescribed by the constructor and observe the engine speed obtained.

(c) The correction factor to be applied to the observed engine speed of a supercharged engine may be obtained from graphs supplied by the engine constructor or, if these are not available, from the graphs shown in Figures 2 and 3 of Leaflet **EL/3-2**.

4.1.3 Although the engine speed obtained during a check of engine power is corrected as necessary for atmospheric temperature and pressure, no correction is made for humidity, ambient wind conditions or instrument errors and, consequently, the corrected engine speed is seldom exactly equal to the reference speed even if engine condition is unchanged. However, engine power may usually be considered satisfactory if the corrected speed obtained during a power check is within 3% of the reference speed.

4.1.4 If it is not possible to assess power deterioration by means of a power check (e.g. due to fitting a different propeller), a rate-of-climb flight test should be carried out.

5 POWER OUTPUT OF HELICOPTER ENGINES The power developed by the engine of a single-engined helicopter is considered to be adequately checked during normal operations; any loss of power should be readily apparent. It is thus not considered necessary separately to check the power output of a helicopter engine specifically for the purpose of complying with Airworthiness Notice No. 35.

6 POWER LOSS If the power check (paragraph 4) or normal engine operation reveal an unacceptable loss of power or rough running, it may be possible to rectify this by carrying out certain of the normal servicing operations or by replacement of components or equipment. The replacement of sparking plugs, resetting of tappets or magneto contact breaker points, or other adjustments to the ignition or carburation systems, are all operations which may result in smoother running and improve engine power.

7 SERVICING If the engine proves to be suitable for further service, then a number of servicing operations will normally be due, in accordance with the approved Maintenance Schedule. Unless carried out previously (paragraph 6) these operations should be completed before the engine is returned to service.

8 LOG BOOK ENTRIES A record of the checks made, and any rectification or servicing work, must be entered and certified in the engine log book before the engine is cleared to service for its recommended or extended life under the provisions of Airworthiness Notice No. 35.

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AIRCRAFT

ENGINES

SPARKING PLUGS

1 INTRODUCTION This Leaflet gives guidance on the installation and maintenance of sparking plugs, and should be read in conjunction with the appropriate manufacturer's manuals.

2 GENERAL Sparking plugs are manufactured in a wide variety of shapes and sizes, each type being designed for use in a particular engine or range of engines, according to the operating conditions likely to be encountered and the design of the cylinder head. A typical modern sparking plug is illustrated in Figure 1.

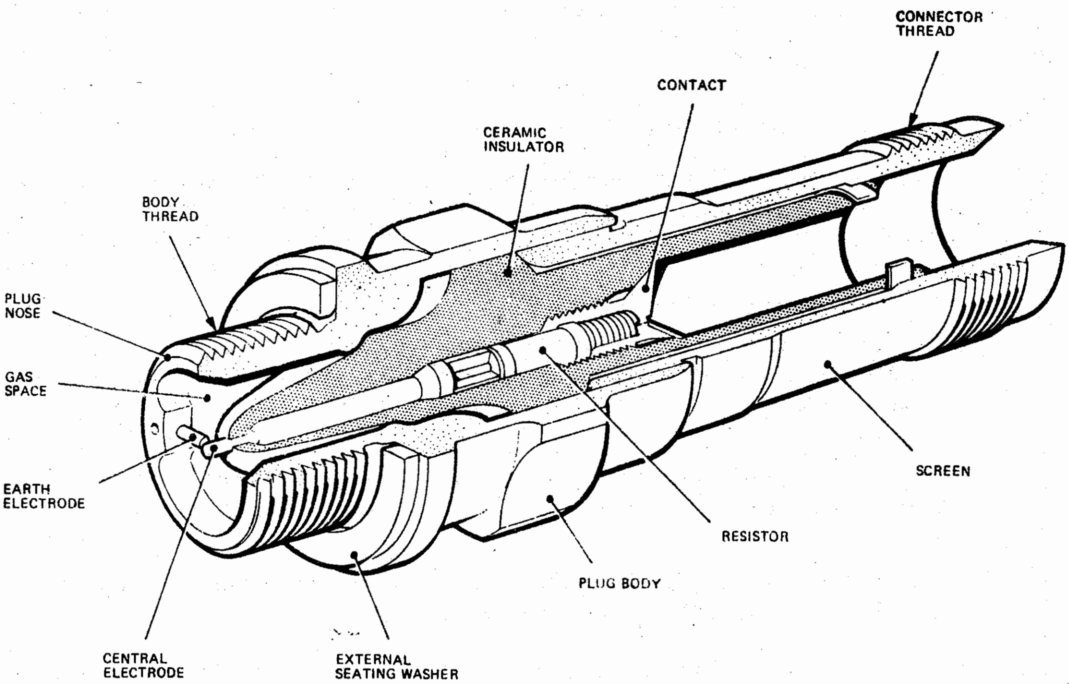

Figure 1 TYPICAL SPARKING PLUG

2.1 A sparking plug consists of a high tensile steel body which screws into the engine cylinder head, and a central electrode which is encased in a ceramic insulating material and secured inside the body. One or more earth electrodes protrude from the nose of the body towards the central electrode to form the spark gap, and the outer end of the central electrode terminates in a contact, which is connected to the magneto distributor via an ignition cable. A resistor interposed between the contact and the central electrode helps to reduce electrode erosion and electrical interference by eliminating current 'spikes' generated by the ignition system.

2.2 The earliest types of sparking plugs were often designed to be dismantled for cleaning and, because no radio equipment was fitted to aircraft, no electrical screening was provided. Later sparking plugs were fitted with suppression screens (as was the complete ignition system) and could still be dismantled for cleaning. The latest types of sparking plugs often have the screen tube brazed to the body and cannot be dismantled.

2.3 The screens on early sparking plugs were insulated with mica, but modern plugs generally incorporate a ceramic sleeve insulator which may be integral with or separate from the electrode insulator.

2.4 The ignition cable is secured to the sparking plug by means of a cable connector, and electrical contact with the central electrode is obtained through a spring attached to the end of the cable core (see Leaflet **EL/5-2**).

2.5 The types of sparking plugs approved for use in a particular engine are specified in the relevant manuals, and no other types should be used; for identification purposes the type number is always marked on a plug body. It is preferable for all plugs in an engine set to be of the same type and make.

3 FITTING SPARKING PLUGS

3.1 **Checks Prior to Fitting Sparking Plugs.** Before fitting new sparking plugs in an engine, all traces of inhibitor should be removed by swilling the nose of the plug in a solvent such as trichloroethane, and wiping the screen insulation with a soft lint-free cloth moistened in solvent. The plugs should then be thoroughly dried and the spark gap should be checked (see paragraph 9).

3.1.1 The correct type of external seating washers should be fitted to the plugs. Some washers are of the disposable type and should not be used more than once, but others, usually made of solid copper, can be re-used provided their condition is satisfactory.

3.1.2 Graphite grease, or the anti-seize compound specified, should be applied to the body threads sparingly, care being taken to ensure that the grease does not come into contact with the electrodes and does not contaminate the surfaces of the seating washers.

3.1.3 Just prior to actually fitting the plugs, a check should be made to ensure that the plug insert thread in the cylinder head is clean.

3.2 **Fitting Sparking Plugs.** It should be possible to screw the plug by hand into the cylinder head until the seating washer contacts the cylinder. If this cannot be done, it will probably be found that the plug insert thread is fouled with carbon or lead deposits, which should be removed by means of a thread cleaning compound of a type recommended by the plug manufacturer.

3.2.1 It is important that plugs should be tightened to the specified torque loading, using the correct spanner and torque wrench. They should not normally be fitted to a hot engine since the torque loading will alter when the engine cools. Over-tightening may tend to loosen or damage the plug inserts in the cylinder head, and under-tightening may result in loose plugs. In exceptional circumstances (e.g. when a plug has to be changed 'in the field' and a torque wrench is not available), a plug may be fitted without the use of a torque wrench provided that a suitable socket or box spanner is used and the length of the lever arm does not exceed the figures shown in Table 1.

TABLE 1

Plug size	Lever arm
12 mm	150 mm (6 in)
14 mm	200 mm (8 in)
18 mm	250 mm (10 in)

NOTE: It is important that side-loads should not be imposed on the outer end of a plug when it is being tightened, since the cable connector threads on a screened plug could be damaged or, in the case of an unscreened plug, the insulator could be damaged and render the plug unserviceable.

3.2.2 The cable connectors should be cleaned with a quick-evaporating cleaner such as white spirit before they are fitted to the plugs, and the threads of the connector nuts should be checked for condition. The presence of oil, dirt or moisture inside the screens could cause a breakdown int he insulation and affect operation of the plugs.

3.2.3 When fitting connector nuts to plug screens, care must be taken to ensure that the screen insulation is not damaged (particularly where mica insulation is used), and that the terminal seats correctly in the plug body. Connector nuts are often easily cross-threaded on plug screens and the connector should be pressed into the plug with one hand while tightening the nut with the other hand; the appropriate spanner should only be used for final tightening. Care should be taken not to overtighten connector nuts, as this may crack the insulation inside the plug screen or create distortion sufficient to affect the performance of the plug.

4 GROUND CHECK ON INSTALLED PLUGS The operation of installed sparking plugs should be checked by running the engine. The engine should be started and warmed up to the minimum operating temperatures before carrying out the check, and all relevant procedures and precautions detailed in the aircraft Maintenance Manual should be observed.

4.1 While warming up the engine each magneto should be switched off in turn to check that a drop in rpm is obtained while running on one magneto, and both magnetos should be momentarily switched off together to check that a dead cut is obtained. This will ensure that both magnetos are operating and can be earthed, and that the switch/switches is/are operating satisfactorily.

4.2 The plugs of inverted cylinders may sometimes cut out when the engine is first started. This may be caused by oil contamination, which will often clear as engine power is increased. However, it is important that the engine power should not be increased beyond that specified for warming-up until minimum operating temperatures are reached.

4.3 When the required temperatures are indicated, the engine should be opened up to the power specified for the magneto check. On normally-aspirated engines this will usually be at full throttle or at a specified rpm (with the propeller in fine pitch if appropriate), but with supercharged engines it will first be necessary to ensure that the propeller is on its fine pitch stops (if a propeller is constant-speeding the drop in power caused by switching one magneto off will be counteracted by the pitch-change mechanism and no rpm drop will be indicated), which is done by opening the throttle to a high power setting, then gradually closing the throttle until a drop in rpm is observed; the power can then be reduced to the setting specified for the magneto check.

4.4 A magneto check is carried out by switching off each magneto in turn and noting the differences between the rpm obtained when operating on both magnetos and those obtained when operating on each magneto separately. The maximum permissible drop in rpm, or the maximum permissible difference between the rpm obtained when operating on each magneto separately, are specified by the manufacturer. If the results of the check are outside these limits it will be necessary to investigate the cause.

4.5 If the magneto drop is excessive and cannot be cleared by further engine running the cause may be a plug which is not firing. If this is the case the magneto drop may also be accompanied by vibration when the 'good' plug is switched off. The faulty set of plugs should be removed and examined for oiling or damage.

4.6 With the majority of engines, rough-running will occur if both plugs in one cylinder are inoperative, although this may not be readily apparent with engines having a large number of cylinders. If rough-running is still apparent after an engine has warmed up, it should be shut down and the plugs removed for inspection; the engine should not be operated at high power.

5 FAULTS WITH AND FAULTS INDICATED BY SPARKING PLUGS A large proportion of engine faults originate in the combustion chambers and careful evaluation of the condition of sparking plugs removed from an engine will often provide an indication of a potentially serious fault. Faults which may be discovered as a result of the examination of sparking plugs are described in paragraphs 5.1 to 5.12.

5.1 **Plug Fouling.** The most common causes of malfunctioning of a plug are the accumulation of electrically conducting matter on the plug electrodes and insulation, and excessive electrode erosion (paragraph 5.12). Although some types of sparking plugs require frequent servicing to prevent these faults, others are so designed that they can be left installed for the overhaul life of the engine, and do not normally suffer from these defects.

5.2 **Loose Plugs.** If a sparking plug which was properly torque-loaded during installation is subsequently found to be loose, this may be an indication that pre-ignition (paragraph 5.3) or detonation (paragraph 5.4) has occurred and has resulted in excessively high pressures and temperatures in the cylinder.

5.2.1 A loose plug will not cool properly during operation and may overheat to such an extent that the ceramic insulation at the nose will become hot enough to ignite the mixture and cause pre-ignition.

5.2.2 When a loose plug is found, an examination should be made for damage to the piston and the exhaust valves. A compression check should be carried out and the cylinder head should be checked for evidence of distortion.

5.2.3 Both plugs in the affected cylinder should be checked for damage and for fusing or melting of the electrodes.

5.3 **Pre-ignition.** Pre-ignition is caused by the cylinder charge being ignited before the spark occurs at the plug points. It is caused by a hot spot in the cylinder, which may or may not be related to the plug (e.g. an abnormal deposit, burned valve, failed piston, or failure of the sparking plug nose ceramic). After pre-ignition has occurred the checks outlined in paragraphs 5.2.2 and 5.2.3 should be carried out.

5.4 **Detonation.** Detonation is caused by the spontaneous ignition of part of the mixture, due to an abnormally high pressure being created ahead of the advancing flame front. In contrast to normal progressive burning, it takes the form of an explosion and may result in excessive loads being applied to components. After detonation has occurred, checks as outlined in paragraphs 5.2.2 and 5.2.3 should be carried out.

5.5 **Mechanical Damage or Peening.** Mechanically damaged or peened electrodes indicate loose particles (e.g. small pieces of metal such as parts of broken piston-rings, etc.) moving around inside the cylinder. Such damage is not always readily apparent and the plugs may only appear to be badly oiled (paragraph 5.6). It is recommended that every badly oiled plug should be inspected carefully for evidence of electrode damage and, where doubt exists, the plugs should be washed and re-inspected.

5.6 **Oil Fouling.** A black oily deposit on the electrodes of a sparking plug may result from several causes. When only one plug in a cylinder is affected, it is usually the result of accumulated matter conducting the electrical impulse to earth and preventing the plug from firing. Oil fouling may also be caused by oil draining into the lower cylinders of an inverted or radial engine (paragraph 4.2), and could affect both plugs in a cylinder. When both plugs are contaminated by oil and this is found not to result from oil drainage, some sort of mechanical failure in the cylinder or a fault in the ignition system should be suspected, and an inspection should be carried out accordingly.

5.7 **Rich Mixture.** A soft furry black deposit on the electrodes often indicates an excessively rich mixture but may also be due to the engine idling for excessively long periods.

5.8 **Lead Deposit.** Lead deposit has the appearance of hard grey or brown globules, or a dark glaze on the insulator, and may build up in the gas space in the body. When the engine is running at high speed under load, with resultant high cylinder temperatures, the deposit tends to form a conductor which cuts out the plug. Plugs which have become severely lead-fouled may be difficult to clean and should be returned to the manufacturer for rectification.

5.9 **Flashover.** Foreign matter or moisture in the plug screen or connector, can reduce the insulation value between the central electrode and earth to such an extent that ignition voltages at high power settings may flash over the plug screen surface to earth and cause the plug to misfire; an excessively large spark gap will increase the possibility of this fault. Flashover is often difficult to detect visually, and the plug may have the appearance of oil fouling.

5.10 **Tracking.** Tracking can be caused by an electrically conducting deposit forming on an insulator, and may result from a hair-line crack. As with flashover, the defect may sometimes be confused with oil fouling.

5.11 **Sprayed Metal Deposits.** Sprayed metal deposits on the nose of a sparking plug can result from a number of causes and a thorough inspection of the combustion chamber should be made to determine the cause. If the deposit is confined to one cylinder it may be caused by a partially seized piston, but if all sparking plugs in an engine are contaminated the cause may be, for example, the supercharger impeller rubbing on its casing. It should be noted that incipient failures often release very small amounts of metal, and the plugs may have the appearance of being badly oil fouled.

5.12 **Weak Mixture or Advanced Ignition.** Premature erosion of electrodes and/or a white appearance of the insulator tips can be caused by either an excessively weak mixture or excessively advanced ignition. The timing and compression should be checked, as should the functioning of the carburettor or fuel injector.

6 REMOVAL OF SPARKING PLUGS Care is necessary when removing sparking plugs from an engine, to prevent damage to the plugs, cables and connectors.

6.1 The connector nut should be removed using the correct spanner and holding the elbow or other type of cable connector to prevent it from twisting. The connector should be withdrawn straight out of the plug screen, care being taken not to damage the screen insulation, particularly when this is made of mica.

6.2 Plugs may often be difficult to remove from the cylinder, and may require a greater torque for removal than for installation. This is usually caused by carbon which has formed on the end of the plug thread where it protrudes slightly into the combustion chamber.

6.2.1 Extreme care must be exercised when removing plugs which require more than the normal torque for their removal. A double-arm sparking plug spanner should be used to permit the use of both hands, thereby providing an even torque during turning; the liberal use of penetrating oil will also assist. Single-arm spanners should not be used, since it is difficult to avoid placing side loads on the plug threads and thus making removal more difficult; in extreme cases the plug threads could fracture, making a cylinder change necessary.

6.3 If new plugs are not to be fitted immediately, dummy plugs should be installed to prevent the ingress of foreign matter, and the ignition cables should be secured to adjacent structure to prevent damage to the connectors.

7 SERVICING OF SPARKING PLUGS Sparking plugs should be serviced strictly in accordance with the manufacturer's instructions, at the intervals specified in the Maintenance Schedule and whenever they are removed because of unsatisfactory operation. Older types of plugs are serviced at frequent intervals (usually every 100 hours of operation) but some modern plugs are designed with servicing periods equal to the engine life and need not be removed between engine overhauls provided their operation is satisfactory. The method of servicing will depend to a certain extent on whether the plug is 'detachable' (i.e. has a separate screen which is screwed into the plug body) or non-detachable (i.e. cannot be dismantled), but it should be noted that some detachable plugs are assembled

in a hot condition during manufacture to ensure a gas-tight seal, and are not considered detachable for servicing purposes.

NOTE: There are still a number of plugs with mica insulating material in service and these may be subject to attack from the lead which is present in aviation fuels. It is recommended that the insulation at the nose of these plugs should be inspected for deterioration at intervals of not more than 50 hours of operation.

7.1 **Inspection Before Servicing.** Before a plug is cleaned and tested, it should be inspected for obvious damage such as distortion, serious corrosion, chipped ceramic, cracks, and loose or fused electrodes. If any of these defects are present the plug should be discarded. Provided a plug has no obvious faults it should be serviced as outlined in paragraphs 7.2 or 7.3 as appropriate.

7.2 **Non-detachable Plugs**

7.2.1 **Degreasing.** Plugs should be degreased in a solvent such as trichloroethane, by the liquid or vapour methods but should not be completely immersed in the solvent. They should then be dried with a low-pressure dry air jet.

7.2.2 **Cleaning.** The nose of a non-detachable plug may be cleaned by sand blasting, by chemical cleaning or by vibratory cleaning. The method used will generally depend on the plug manufacturer's recommendations and on the equipment available. Cleaning should be carried out strictly in accordance with the relevant Maintenance or Overhaul Manual.

(a) **Sand Blasting.** Carbon and lead deposits can usually be removed by light sand blasting, but extreme care should be exercised to prevent 'scalloping' of the insulator and damaging of the electrodes. It is normally recommended that sand blasting should be limited to periods of not more than 5 seconds and that the plug should be rocked in a circular motion while blasting is in progress.

(b) **Chemical Cleaning.** Specially designed chemical cleaning equipment may be used when recommended, but, because the chemicals are corrosive, care must be taken to ensure that all traces are washed off after cleaning. The cleaning times and temperatures recommended for the process should be strictly adhered to, and only the specified chemicals should be used. Any stubborn deposits which remain after cleaning may be removed by light sand blasting as in (a).

(c) **Vibratory Cleaning.** A vibratory cleaner is illustrated in Figure 2, and employs a vibrating cutter blade which is entered into the nose of the plug to remove deposits. Only light pressure should be applied to the plug and care should be taken to avoid contact with the electrodes. Frequent checks on the condition of the plug should be made during cleaning, and any stubborn deposits should be removed by light sand blasting as in (a).

NOTE: After cleaning, all deposits should be removed with a low-pressure dry air jet, and the gas space should be inspected with the aid of a lens to ensure that no particles of sand, carbon or lead remain.

7.2.3 The outside of the plug body and threads should be cleaned with a fine steel wire hand-brush, care being taken not to brush the electrodes or insulator, and all loose material should be removed with a low-pressure dry air jet.

7.2.4 The inside of the plug screen should be cleaned by wiping with a lint-free cloth moistened in a quick-evaporating solvent such as white spirit. Particular care is necessary with mica insulation, and this should not be submerged in solvent or subjected to an air blast.

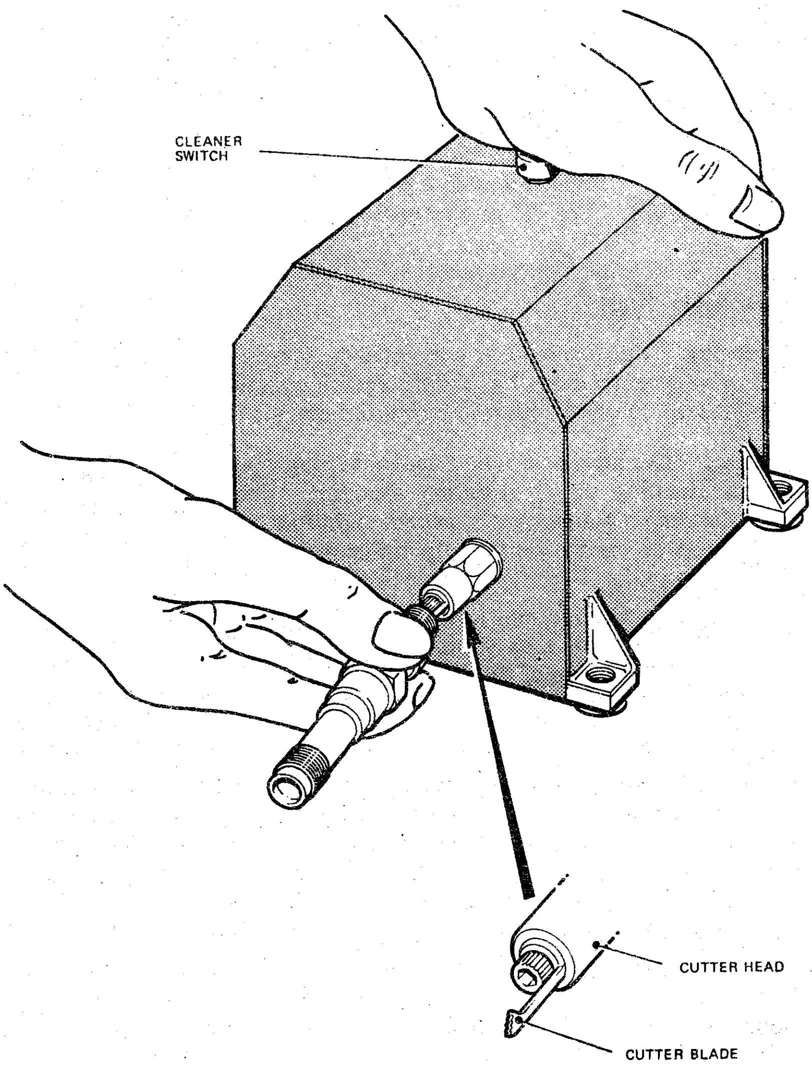

Figure 2 VIBRATORY CLEANER

7.3 **Detachable Plugs**

7.3.1 **Dismantling.** Detachable plugs should be dismantled using a ring type dismantling block and the appropriate ring spanner; they should not be held in a vice, as this could distort the plug body. If the threads are very tight, a penetrating oil should be applied and left to soak into the threads.

7.3.2 **Degreasing.** The plug body, screen, and centre assembly should be degreased as outlined in paragraph 7.2.1.

7.3.3 **Cleaning.** The outside of the plug body and screen should be cleaned with a fine steel wire hand-brush, and the plug body should be cleaned internally by light sand-blasting. Care must be taken during these operations to avoid damaging the electrodes, joint seating and threads.

7.3.4 The centre assembly and screen ceramic material should be cleaned with a lint-free cloth moistened in trichloroethane or white spirit. Any hard deposits on the nose ceramic may be removed by light sandblasting, but abrasives should not be used on the other ceramic material, as oil or dirt could adhere to the abraided surface and cause tracking (paragraph 5.10).

7.3.5 After cleaning, all parts should again be degreased and, except for mica screen insulation (which should be dried with a soft cloth), dried with a low-pressure dry air jet.

7.3.6 **Inspection.** After drying, the separate parts of the plug should be inspected as outlined in paragraph 8.

7.3.7 **Reassembly.** The seating faces of the plug body and centre assembly should be wiped clean and lightly smeared with oil; new sealing washers should be fitted. When fitting the centre assembly, the screen tube should be tightened lightly by hand and the centre assembly should be centrally located in the plug body. The screen should then be tightened to the specified torque, while holding the body in a dismantling block.

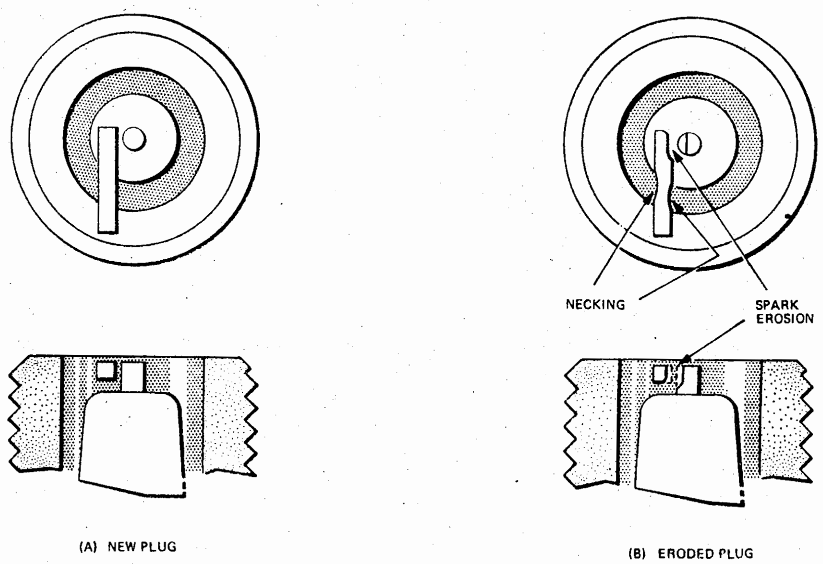

Figure 3 ELECTRODE EROSION

8 INSPECTION After cleaning, all plugs should be inspected as outlined in paragraphs 8.1 and 8.2.

8.1 **General Inspection.** All parts of a plug should be examined visually for cleanliness and for significant distortion, cracks, scores, dents, corrosion, damaged threads and worn or pitted plug washer seatings. Further cleaning may be carried out as necessary, but plugs which are found to have any of the other faults should be discarded.

8.2 **Electrode Inspection.** Electrodes should be examined for security and erosion (see Figure 3). Any plugs with loose electrodes, or with erosion exceeding the limits outlined in 8.2.1 and 8.2.2 should be discarded.

8.2.1 Using a new plug for comparison, the extent of erosion of the electrodes should be estimated. Unless otherwise specified in the relevant Manual, erosion at the sparking point which reduces the cross-sectional area of the electrodes by less than 50%, or which reduces the cross-sectional area of the earth electrode by 'necking' by less than 33%, is acceptable.

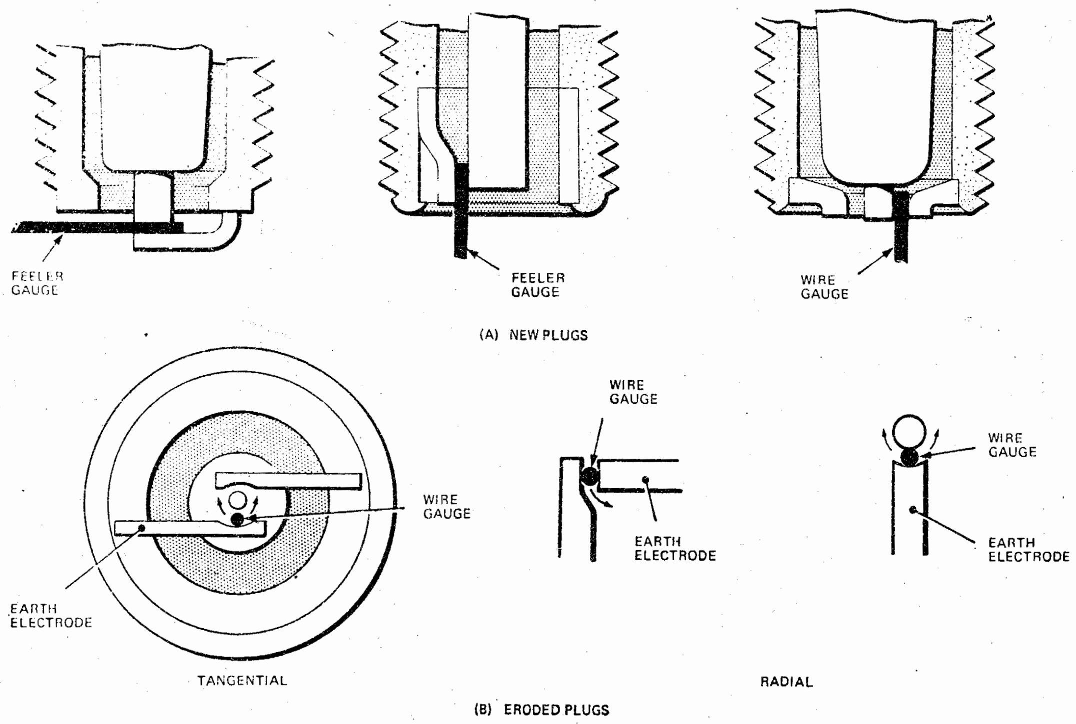

Figure 4 CHECKING THE SPARK GAP

8.2.2 On plugs which have a radial earth electrode, erosion will have the effect of increasing the spark gap. If the spark gap is found to exceed the maximum permitted setting, the plug should be discarded.

9 SPARK GAP SETTING Before testing plugs after servicing, and before fitting new plugs to an engine, the spark gaps should be checked and, except for plugs having radial electrodes (see paragraph 9.3), should be adjusted to the gap specified in the appropriate engine Maintenance Manual.

9.1 A standard feeler gauge may sometimes be used for checking new plugs (see Figure 4), but a wire-type gap gauge should always be used on plugs which have been serviced and new plugs on which the earth electrode has a concave surface.

9.2 Adjustment of the spark gap is achieved by bending the earth electrode (never the central electrode), and extreme care is necessary to prevent overstressing. Bending should be carried out in very small increments, using a suitable blunt tool and applying force only between the plug body and the earth electrode; no force should be applied to the central electrode. The gap should be checked after each bending operation to avoid the necessity for reverse bending; this is particularly important with iridium electrodes, which are comparatively brittle.

9.3 No adjustment is possible with plugs having a single radial earth electrode, and if the spark gap exceeds the maximum permitted value the plug must be discarded.

10 TESTING After a plug has been serviced, it should be tested in accordance with the manufacturer's insructions. A bench test cannot exactly reproduce conditions in the combustion chamber of an engine, and because of the many variables affecting the voltage/spark gap/air pressure relationship, the results of a test using a specified voltage and air pressure may bear little relationship to the performance of a plug installed in an engine. A bench test can, however, establish that the plug insulation is satisfactory and that all electrically conductive deposits have been removed during servicing. The spark test described in paragraph 10.1 is recommended by most manufacturers and the additional test as described in paragraph 10.2 may also be required.

10.1 **Spark Test.** This test should be carried out using ignition equipment specially designed for the purpose. Two main types of equipment are available, one providing a fixed voltage which is somewhat higher than the maximum voltage obtainable from an engine magneto, and the other fitted with a standard spark gap in parallel with the plug under test, which can be used to vary the voltage applied across the plug electrodes. A typical sparking plug tester of the former type is shown in Figure 5.

10.1.1 A test using the tester illustrated in Figure 5 should be carried out as follows:—

(a) Connect the tester to an electrical supply of the required voltage, and connect the bench air supply to the tester.

(b) Screw the sparking plug into the tester to finger tightness.

NOTE: Some air leakage is desirable as it allows ionised air to exhaust from the chamber and also helps to stabilise the air pressure.

(c) Connect the high voltage lead to the sparking plug.

(d) Press the test button for a few seconds and check that regular sparking occurs at the plug electrodes. If not, discard the plug.

(e) Open the air valve until the required test pressure is indicated on the tester pressure gauge.

NOTE: Although an air pressure of 550 kN/m² (80 lbf/in²) is generally considered to be satisfactory for most plugs, some manufacturers may stipulate a test air pressure which is related to the spark gap setting of the plug.

(f) Press the test button for a few seconds and check that regular sparking occurs at the plug electrodes. If not, discard the plug.

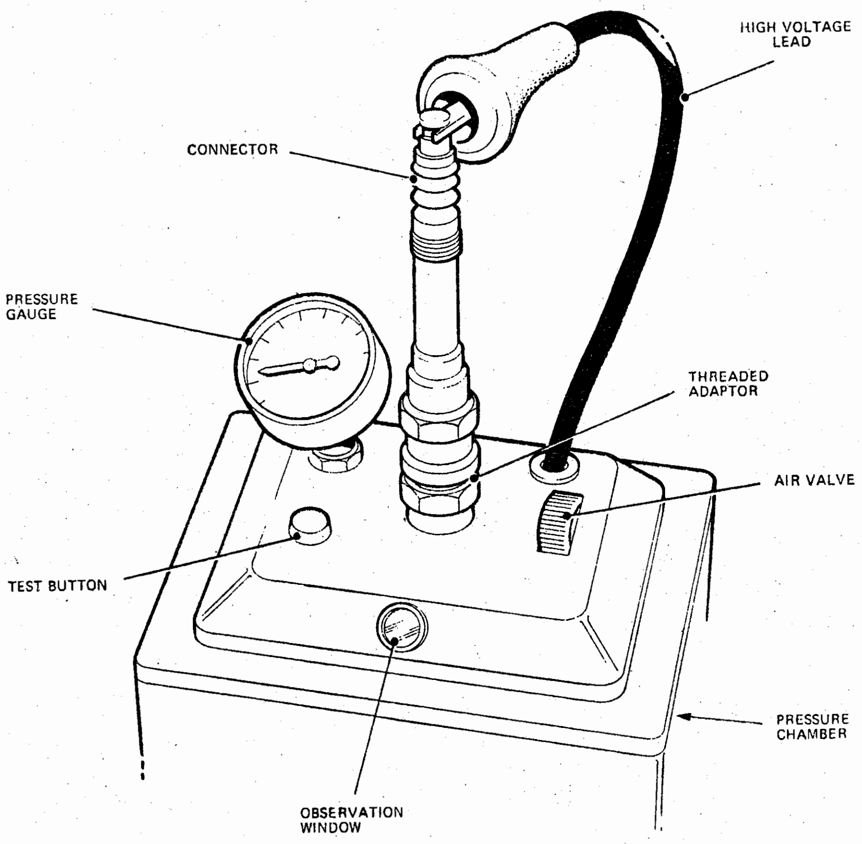

Figure 5 SPARKING PLUG TESTER

10.1.2 If a tester which is fitted with a standard spark gap is used, the gap should be set in accordance with the manufacturer's instructions before a test is carried out. During the test, sparking should occur only at the electrodes of the plug under test; if sparking at the standard spark gap occurs, an open circuit in the plug is indicated; if no sparking is evident a breakdown in plug insulation or a short circuit is indicated.

10.1.3 To check for cracked plug insulation some manufacturers recommend that the plug should be tested in the inverted position and a little water (with a wetting agent added) should be injected into the plug nose. When air pressure is applied during test the water will be forced into any cracks present and the plug will be short-circuited.

10.2 **Leakage Test.** A test for gas leakage may sometimes be specified, to ensure that the seal of a detachable plug or the joint in a non-detachable plug is satisfactory. The plug under test should be screwed into a pressure chamber, and immersed in a container of white spirit so that the liquid covers the joint. Air pressure in the chamber should then be raised to approximately 700 kN/m^2 (100 lbf/in^2) and any leakage will be indicated by bubbles in the white spirit.

11 STORAGE Sparking plugs which have been cleaned and tested should be inhibited against corrosion by coating the nose with a suitable storage oil and fitting thread protectors to the plug body and screen.

11.1 If the plugs are not intended for long term storage, they should be placed in racks and kept in a warm, dry place, preferably a heated cupboard, as a precaution against condensation.

11.2 Plugs which are required for long term storage or transit, should be packaged as follows:—

(a) Select a polythene tube of sufficient size, and cut off lengths suitable for containing one plug. Heat seal one end.

(b) Place a plug in each tube, and also insert an identification label in such a way that the details are visible.

(c) Extract excess air from the tube and heat seal the open end.

(d) Pack the plugs in layers in a strong cardboard box, with corrugated board between each layer.

(e) Close the box and seal with adhesive tape.

(f) Affix an identification and a certified serviceable label to the box.

11.3 Plugs should be stored in conditions which are clean, dry, of even temperature, well ventilated, and free from corrosive fumes.

EL/5-2

Issue 3.

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AIRCRAFT

ENGINES

PISTON ENGINE IGNITION CABLES AND HARNESSES

1 INTRODUCTION

1.1 The procedure outlined in this Leaflet gives general guidance on the installation and maintenance of fully screened high-tension ignition cables and cable harnesses. The information should be read in conjunction with the Maintenance Manual for the type of engine concerned.

1.2 To maintain efficient functioning, the cables and harnesses should be inspected, serviced and tested at the periods which are given in the Approved Maintenance Schedule. It is essential that the test equipment recommended by the manufacturer is used.

1.3 The following Leaflets contain information associated with the subject covered by this Leaflet and reference should be made to these as appropriate.

EL/3-9 Piston Engines—Magnetos

EL/5-1 Sparking Plugs

2 GENERAL

2.1 The flow of high tension current along the ignition cables from the magnetos to the sparking plugs results in unwanted electrical radiation which could, if not checked, result in interference with the aircraft radio equipment. Avoidance of interference is achieved by 'screening' the ignition cables by covering them with a metallic braiding which is connected to ground potential. It is also necessary to provide protection against mechanical damage, deterioration and contact with liquids; this is normally achieved either by enclosing the cables in a prefabricated 'ignition harness' (see Figure 1) or by providing an outer covering of neoprene or plastic tubing (see Figure 2).

2.1.1 All types of harness are basically the same in principle, but because of the proprietary nature of the manufacture, both the materials used and the arrangement of details may vary. The three main parts of a typical harness are as follows:—

(a) The body of the harness comprises a rigid metal duct which may be in several parts and may be joined by means of threaded joints. Materials commonly used for these ducts are brass, aluminium alloy, or corrosion resisting steel. The harness assembly is often attached to the engine by means of brackets soldered or brazed to the rigid duct.

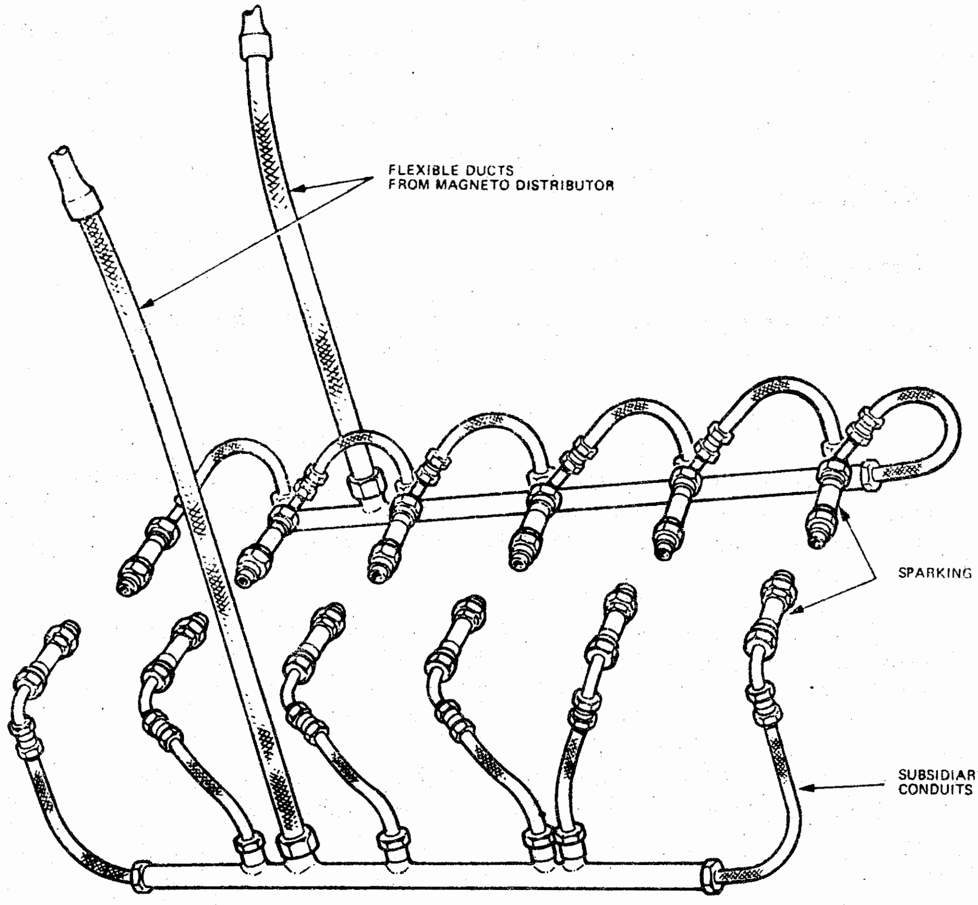

Figure 1 **IGNITION HARNESS FOR A TYPICAL SIX CYLINDER, IN-LINE ENGINE**

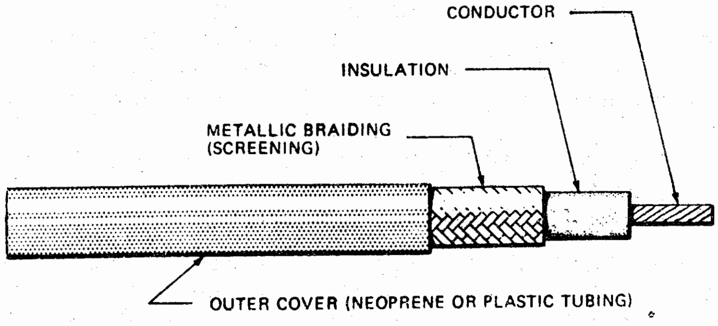

Figure 2 **IGNITION CABLE WITH PROTECTIVE COVERING**

(b) From the rigid duct, large diameter flexible ducts house the cables between the duct and the magneto distributors. These flexible ducts are usually made from a close mesh metallic braiding often of tinned copper or tinned phosphor bronze wire.

(c) The individual ignition cables, which are routed through individual apertures in the rigid duct, are covered with a similar braiding to that described in (b). The cable ends are fitted with metallic connectors for attachment to the sparking plugs and magneto distributors.

3 IGNITION HARNESSES

3.1 **Dismantling.** When a harness is removed from an engine and is awaiting dismantling, it should be properly stored so that it is not damaged either physically or by contact with oils or other liquids. The harness should be secured by its attachment brackets to a suitable stand so as to avoid distortion of the subsidiary conduits and ducts, which can easily result from the unsupported weight of the assembly. The sequence of dismantling should be as recommended in the manufacturer's publication, and will vary according to the type of harness.

3.2 Inspection of the Dismantled Harness

3.2.1 Every magneto distributor-block or harness connector assembly should be examined for freedom from cracks or signs of tracking. Where fitted, the carbon brush should be free from chips and excessive wear and should move freely in the guide under spring pressure.

3.2.2 The body of the harness should be free from cracks and dents, especially around the apertures and attachment brackets, which should also be in good condition. The threads of the couplings should be undamaged, and the nuts should be correctly fitted.

3.2.3 All flexible ducts and subsidiary conduits should be free from internal damage and wear caused by abrasion.

3.2.4 All ignition cable connections and plug terminal sleeves should be in good condition. These parts must be renewed if there are any signs of burning or tracking.

3.2.5 Any neoprene seals should be free from deformation and cracks.

3.2.6 Rubber sleeves and bushes which have deteriorated should be rejected and new ones should be fitted.

3.2.7 All sharp corners or irregularities liable to damage the covering of the cables should be removed, and all vents should be clear so that air may circulate freely.

3.2.8 The ducts of waterproof type harnesses may require pressure testing. This is usually carried out by blanking off all the outlet connections except the one to which an air pressure supply is connected. The pressure is then raised to the specified figure. Precise details of this test will be found in the manufacturer's Maintenance Manual.

3.3 Assembly

3.3.1 Before assembly, ducts and subsidiary conduits should be checked for obstructions, and all parts including cables and detail fittings should be clean.

3.3.2 The mating surface of all metal joints, including those formed by union-nuts and flanged-end fittings, should be free from enamel, lacquer or other protective treatments which will increase the electrical resistance across the joint.

3.3.3 All parts should be in good condition and should be inspected particularly after storage or transit. Screw threads and other jointing surfaces should be smooth and free from burrs.

3.4 **Cables**

3.4.1 The ignition cables should be assembled into the ducting in the proper sequence. The manner and sequence of assembly are usually so arranged that any one cable may be replaced without disturbing the other cables.

3.4.2 The cables should be fitted into the harness body through the main openings, and each cable pulled through its appropriate subsidiary opening with a small steel hook. When pulling, care should be taken to avoid damage to the body of the harness and the cables. In some cases a special silicone compound may be used as a lubricant to reduce fretting between cables.

3.4.3 Subsidiary conduits should be fitted together with all rubber or neoprene seals and grommets, and the cable connectors should be attached to the end of the ignition cables (see paragraph 3.5).

3.4.4 The cables should be re-adjusted so that the required lengths protrude from the body openings. The cables should be so arranged that correct orientation of the cables, sparking plug ends to distributor ends, has been ensured. The seals and, where applicable, the large diameter flexible ducts, should then be fitted to the body. After the flexible ducts have been tightened to the body of the harness, a check should be made to ensure that the cables protrude the correct distance.

3.5 **Cable Connectors**

3.5.1 When preparing the ends of the ignition cable for the terminal end fittings, only sufficient insulation should be cut from the cable to allow the specified amount of conductor to extend through. Extreme care should be taken not to cut any of the individual strands of the conductor when removing the insulation. Examples of ignition cable assembly details are illustrated in Figures 3 and 4.

3.5.2 The terminal sleeve should be maintained in a clean condition and free from scratches, otherwise a leakage to earth may occur and cause damage to the connectors and faulty operation of the sparking plug.

3.5.3 The terminal end connections should be securely attached; no looseness or end movement is permissible. The cable conductor should not be exposed under the terminal sleeve as this may cause an insulation loss under adverse conditions.

3.6 **Final Checks**

3.6.1 The attachment of all flexible ducts and subsidiary conduits to the harness body should be secure. The flexibility of the ducts and conduits should not be affected by the attachment of cable connectors, fittings or protective coverings.

3.6.2 The conductor should be in firm contact with the terminal connection points.

3.6.3 Spring-loaded terminal ends should have free movement throughout the full range of travel.

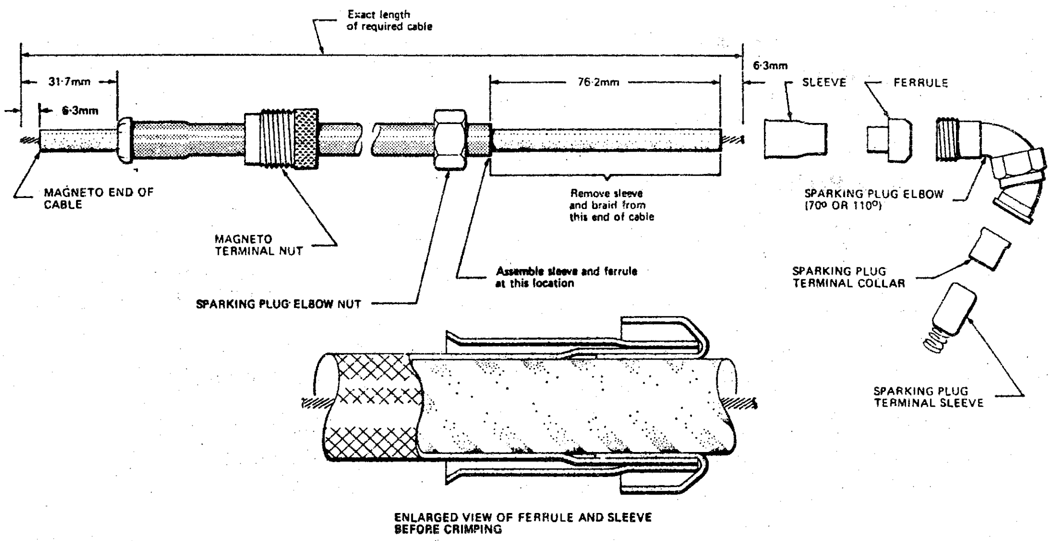

Figure 3 ASSEMBLY DETAILS OF IGNITION CABLES

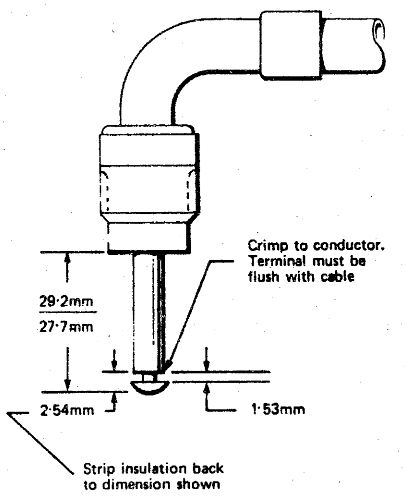

Figure 4 DETAILS OF TERMINAL CRIMP AT MAGNETO END OF IGNITION CABLE

3.6.4 All parts should be securely attached and correctly locked. A nut which has not been fitted correctly may cause an intermittent contact which could result in electrical interference.

3.6.5 Each cable end and subsidiary conduit, as applicable to the harness type, should be clearly identified.

3.6.6 The tests described in paragraph 4 should be applied after the harness is assembled.

3.7 **Fitting a Replacement Ignition Cable**

3.7.1 The cable connector, conduit and seals should be removed.

3.7.2 The cable should be disconnected at the magneto distributor-block and plug connector and a check made to ascertain from which direction the cable will pull out more easily.

3.7.3 The new cable should be secured and soldered to the end of the old cable to be pulled through the harness, and any ragged ends should be cleaned from the joint.

3.7.4 The defective cable should be pulled out, thus pulling the new cable into the harnesss.

3.7.5 After fitting a new cable, the tests outlined in paragraph 4 should be applied when all connections have been re-made.

4 TESTS

4.1 When the harness is completely assembled the tests detailed by the manufacturer should be carried out. The tests required may vary in detail with different harnesses but generally consist of continuity and insulation tests. It is important that good electrical contact is always made with the leads of test equipment.

4.2 **Continuity Test.** This test should be made with a low-voltage lamp and battery (e.g. 3·5 volts 0·4 amperes). The brilliance of the lamp must be checked before making the test so that the result may be compared.

4.2.1 One lead of the test equipment should be placed in good contact with a magneto distributor-block segment, the other connected to the appropriate sparking-plug terminal end and a slight tension applied to the lead under test. On pressing the test-button, a weak or flickering light of less brilliance than standard, or no light at all, would indicate a faulty connection, a broken wire or an incorrectly positioned lead.

NOTE: When a resistor is incorporated in a plug connector, the test equipment specified in the Maintenance Manual should be used instead of a lamp and battery.

4.2.2 If the continuity test indicates a defect, it should be located by first examining the connections and then the cable. Faulty ignition cables should be renewed as described in paragraph 3.7.

4.3 **Joint Resistance Tests.** In some instances the resistance of the joints in the harness screen should be measured with a suitable low reading ohmmeter or by a reading on a suitable millivolt meter across the joint when a known current is passed through it. The instrument used should be provided with prongs for making contact close to each side of the joint. The resistance of each joint should not exceed 0·0001 ohm.

4.4 **Insulation Tests.** The test equipment required for insulation tests will vary with the type of harness. In some cases the manufacturer may recommend an insulation resistance tester, but in other cases a spark gap test apparatus may be specified.

4.4.1 With the recommended insulation resistance tester a minimum acceptable reading in megohms will be specified. In general, it is desirable to obtain an "infinity" reading, but a lower reading may be expected from a harness which has been exposed to humid atmospheric conditions.

4.4.2 A spark gap tester is often specified by the manufacturer for testing ignition harnesses fitted to the larger types of engine. Briefly, the tester consists of a battery supplied induction coil designed to give the required voltage. A switch is interposed between the battery and the coil interrupter, and connected across the secondary terminal of the coil is a standard spark gap the points of which are set to discharge at the test voltage specified. Satisfactory insulation of the harness under test will be indicated by consistent sparking at the spark gap.

4.4.3 The sequence of operations for insulation tests recommended by the manufacturer should be carefully followed. For example, a test should be made between each cable in sequence and the remaining cables connected to the metal harness. A test should also be made between each cable and the other related cables connected together.

NOTE: When testing low-voltage ignition systems which have booster transformers fitted to the plug leads, care should be taken to adapt this test in accordance with the manufacturer's instructions.

5 ASSEMBLY TO ENGINE

5.1 The efficiency of the installation is dependent on the harness being fitted in such a manner that every point of contact with the engine makes a good and permanent electrical connection. All joints should be adequately tightened and locked to withstand the vibration encountered in service, thereby maintaining all parts of the harness at substantially the same potential.

5.2 During assembly to the engine, precautions should be taken to avoid damaging the ducts, subsidiary conduits and points of attachment.

5.3 All points of attachment should assemble freely to the supports without strain. Certain types of harness are manufactured as complete units and the respective sections must not be interchanged with those of other harnesses, since stress in the conduits and at points of attachment may occur when aligning the harness for final fitting.

5.4 When fitting the ignition cable connector to the plug screen, care should be taken to ensure that the lining of the screen is not damaged during the insertion of the terminal, and that the terminal seats correctly in the sparking plug. The effort applied to tighten the lead-end nut should not be excessive and the manufacturer often specifies the torque loading required. The plug leads should be positioned to clear exhaust systems and also correctly secured to prevent chafing and cutting. Guidance on the installation and testing of sparking plugs is given in Leaflet **EL/5-1.**

PL/1-1

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AIRCRAFT

PROPELLERS

CONSTRUCTION, OPERATION AND MAINTENANCE

1 INTRODUCTION This Leaflet gives general guidance on the construction, operation and maintenance of both fixed-pitch and variable-pitch propellers, such as may be fitted to many types of piston and gas turbine engines.

1.1 There are a number of propeller manufacturers, and many possible propeller/engine and engine/airframe combinations. For these reasons, there is a wide variety of propellers and propeller control systems. This Leaflet is not intended to cover all possible combinations, and should be read in conjunction with the appropriate aircraft and propeller manuals, from which information relating to a particular installation may be obtained.

NOTE: The relevant information previously published in Leaflet **PL/2—1,** Issue 1, 1st December 1962, is included in this Leaflet.

2 GENERAL A propeller is a means of converting engine power into propulsive force. A rotating propeller imparts rearward motion to a mass of air, and the reaction to this is a forward force on the propeller blades.

2.1 Each propeller blade is of aerofoil cross-section. As the blade moves through the air, forces are produced, which are known as thrust and torque, and which may be regarded as roughly equivalent to the forces of lift and drag produced by an aircraft wing. Thrust is the propulsive force, and torque the resistance to rotation, or propeller load. The magnitude of the thrust and torque forces produced will depend on the size, shape and number of blades, the blade angle, the speed of rotation, the air density and the forward speed.

2.2 Since each blade is of aerofoil cross-section, thrust will be produced most efficiently at a particular angle of attack, that is the angle between the chord line at a particular blade section and the relative airflow. This angle varies both with operating conditions and with the design camber of the blade sections, but, for a given blade and given in-flight conditions, it will be found to be relatively constant along the length of the blade. The rotational speed of a particular cross-section of a blade will increase with its distance from the axis of rotation, and, since the forward speed of all parts of the blade is the same, the relative airflow will vary along the blade, and it is, therefore, necessary to provide a decreasing blade angle from root to tip. The various terms relating to propeller operation are illustrated in Figure 1. This is a simplified diagram omitting inflow angles for clarity, but in practical designs these angles cannot be ignored.

2.2.1 The geometric pitch of a propeller is the distance which it should move forward in one revolution without slip; it is equal to $2\pi r \tan \theta$, where r is the radius (or station) of the particular cross-section, and θ is the blade angle at that point. Fixed pitch propellers are usually classified by their diameter and pitch, the pitch being related to the blade angle at $\frac{3}{4}$ radius, or other nominated station.

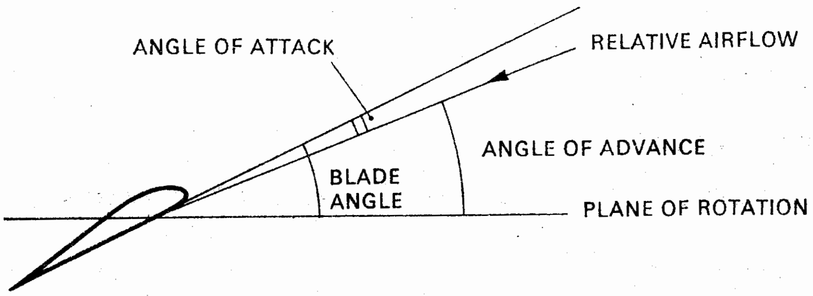

Figure 1 PROPELLER TERMS

2.3 Centrifugal, bending, and twisting forces act on a propeller during flight, and can be very severe at high rotational speeds. Propellers must be both strong enough to resist these forces, and rigid enough to prevent flutter. The main forces experienced are as follows:—

(a) Centrifugal forces which induce radial stress in the blades and hub, and, when acting on material which is not on the blade axis, also induce a twisting moment. Centrifugal force can be resolved into two components in the plane of rotation; one is a radial force parallel to the blade axis, and the other a force at 90° to the blade axis; the former produces radial stress, and the latter tends to turn the blade to a finer pitch. The turning effect is referred to as centrifugal twisting moment, and is illustrated in Figure 2; the wider the blade, the greater will be the twisting moment.

(b) Thrust forces which tend to bend the blades forward in the direction of flight.

(c) Torque forces which tend to bend the blades against the direction of rotation.

(d) Air loads which normally tend to oppose the centrifugal twisting moment and coarsen blade pitch.

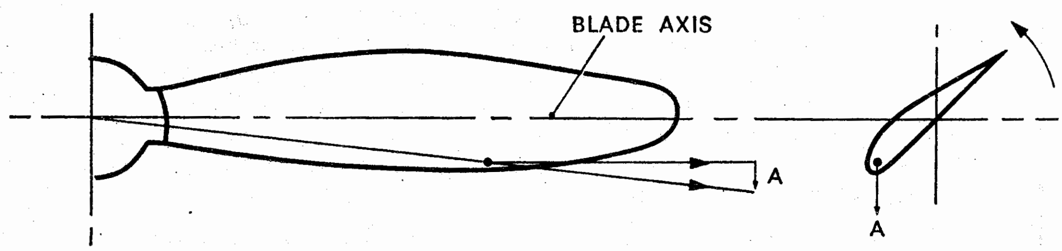

Figure 2 CENTRIFUGAL TWISTING MOMENT

2.4 The diameter of a propeller, and the number and shape of its blades, depend on the power it is required to absorb, on the take-off thrust it is necessary to produce, and on the noise-level limits which have to be met. High tip speeds absorb greater power than low tip speeds, but if the tip speed approaches the speed of sound, efficiency will fall, and this consideration limits practical diameter/rotational speed combinations. High tip speed is also the main source of propeller noise. Large diameters normally result in better performance than small diameters, and blade area is chosen to ensure that blade lift coefficients are kept in the range where the blade sections are efficient. Wide chord blades and/or large diameters lead to heavy propellers; increase in number of blades increases cost but reduces noise. The design of any propeller is, therefore, a compromise between conflicting requirements, and the features which are given prominence will vary from one application to another. Small two-bladed propellers, of suitable profile, are satisfactory for low-powered piston engines, but for high-powered piston or turbine engines, three, four, or five bladed, or contra-rotating, propellers are used, and are driven through a reduction gear to enable high engine power to be used at efficient propeller speeds.

2.5 **Propeller Balance.** A propeller is a rotating mass, and if not correctly balanced can produce unacceptable vibration. An unbalanced condition may be caused by uneven weight distribution, or by uneven air loads or centrifugal forces on the blades when the propeller is rotating. Even weight distribution is known as static balance; this is checked by mounting the propeller on a shaft between knife edges; or by use of a single-plane precision balancing machine. An unbalanced condition can be corrected by adding weight to the lighter blade(s) and/or removing weight from the heavier blade(s). Material may easily be removed from wooden propellers, but metal propellers are usually balanced by attaching weights to the blade hub or by adding lead wool to the hollow blade roots. If there are significant differences in form or twist between the blades on a propeller, vibration can result because the thrust and/or torque produced by the blades is uneven. Procedures for evaluating such differences, and for achieving aerodynamic balance, are often available for large propellers. In their absence, careful checking of the blade profiles, and adjustment of any deviations, may often eliminate vibration. It is possible for a propeller to be in perfect static and aerodynamic balance, but still suffer from dynamic unbalance when rotating. The cause of such unbalance is non-symmetrical disposition of mass within the propeller, or non-symmetrical mounting of the propeller. Such unbalance can be corrected by adding balance weights, but this may be a lengthy procedure, involving repeated runs with the propeller installed on the aircraft. Propellers are balanced after manufacture, and whenever repairs, or overhaul, have been carried out, or vibration has been reported.

3 TYPES OF PROPELLERS The various types of propellers are described briefly in this paragraph. The construction and operation of the main types of propellers in common use, are described in detail in paragraphs 4 and 5.

3.1 **Fixed-pitch Propellers.** Because of its lightness, cheapness and simplicity, a fixed-pitch propeller is often fitted to a single-engined aircraft. The pitch selected for any particular engine/airframe combination will always be a compromise, since the angle of attack will vary with changes in engine speed and aircraft attitude. Too coarse a pitch would prevent maximum engine power from being used during take-off and climb, and too fine a pitch would prevent economical cruising, and would lead to overspeeding of the engine in a dive.

3.2 **Variable-pitch Propellers.** With this type of propeller the blade angle may be varied in flight, so that engine power may be fully utilized. Variable-pitch propellers were originally produced with two blade-angle settings; a fine pitch to enable full engine speed to be used during take-off and climb, and a coarse pitch to enable an economical engine speed to be used for cruising. The introduction of an engine-driven centrifugal governor enabled the blade angle to be altered automatically (within a pre-determined range), in order to maintain any engine speed selected by the pilot, regardless of aircraft speed or attitude.

3.3 **Feathering Propellers.** If an engine failure occurs, the windmilling propeller may cause considerable drag, and adversely affect controllability of the aircraft. In order to reduce this drag, the blades of most constant speed propellers fitted to multi-engined aircraft are capable of being turned past the normal maximum coarse-pitch setting into line with the airflow. This is known as the 'feathered' position. Feathering the propeller not only reduces drag, but also minimizes engine rotation, thus preventing any additional damage to the engine.

3.4 **Reversible-pitch Propellers.** On some aircraft, the propeller blades may be turned past the normal fine-pitch setting, to a pitch which will produce thrust in the opposite direction (reverse thrust). On selection of reverse pitch by the pilot, the blades may be turned to a fixed reverse-pitch angle, but on some installations the pilot has control of blade angle, and can select any angle within a given range on each propeller individually. Reversible-pitch propellers provide braking during the landing run, and facilitate aircraft ground manoeuvring.

4 FIXED-PITCH PROPELLERS Fixed-pitch propellers normally have two blades, and are manufactured from either wood or aluminium alloy; they are generally only fitted to single-engined light aircraft.

4.1 **Wooden Propellers.** Wooden propellers are made up from a number of planks glued together. The wood used is usually either birch or mahogany, and is specially selected and seasoned for the purpose. After glueing and a further short seasoning period to equalise moisture content in the planks, the block is cut to shape and finished. An abrasion resistant coating of either canvas or cellulose is applied to the blades, and a metal sheath is normally screwed on to the leading edges and blade tips to protect the wood from being damaged by stones. The propeller is then given several coats of varnish or cellulose paint to protect it from atmospheric conditions.

4.1.1 If the engine shaft has an integral flange, the propeller is clamped between this flange and a separate steel faceplate. If the shaft is splined, the propeller is mounted on a steel hub, which is internally splined to fit the shaft, and has an integral rear flange and detachable front flange between which the propeller is mounted. In either case, a large clamping area is required so as to minimize damage to the wood fibres when the attachment bolts are tightened.

4.1.2 Hubs fitted to parallel splined shafts are mounted between a front and rear cone, the purpose of which is to ensure that the propeller is concentric with the shaft. The shaft is threaded to receive a large nut, which is tightened against the front face of the front cone. Hubs fitted to tapered shafts are similarly attached, but may not be mounted on cones.

4.2 **Metal Propellers.** Metal propellers are usually aluminium alloy forgings, and are anodised and painted for protection. They are usually bolted directly on to a shaft with an integral flange, but if they are fitted to a splined shaft they are mounted on a hub which is similar to that used for wooden propellers, but without a front flange.

5 **VARIABLE-PITCH PROPELLERS** Variable-pitch propellers consist of a number of separate blades mounted in a central hub, and a mechanism to change the blade angle according to aircraft requirements. The blades and hub are often aluminium alloy forgings, but the hub on a large propeller may be constructed from steel forgings because of the high centrifugal forces which it has to contain. The blades are mounted in the hub in ball or tapered roller bearings, and the pitch-change mechanism is attached to the hub and connected to each blade through rods, yokes or bevel gears. Operation and control of the pitch-change mechanism varies considerably, and three main types are discussed in this paragraph.

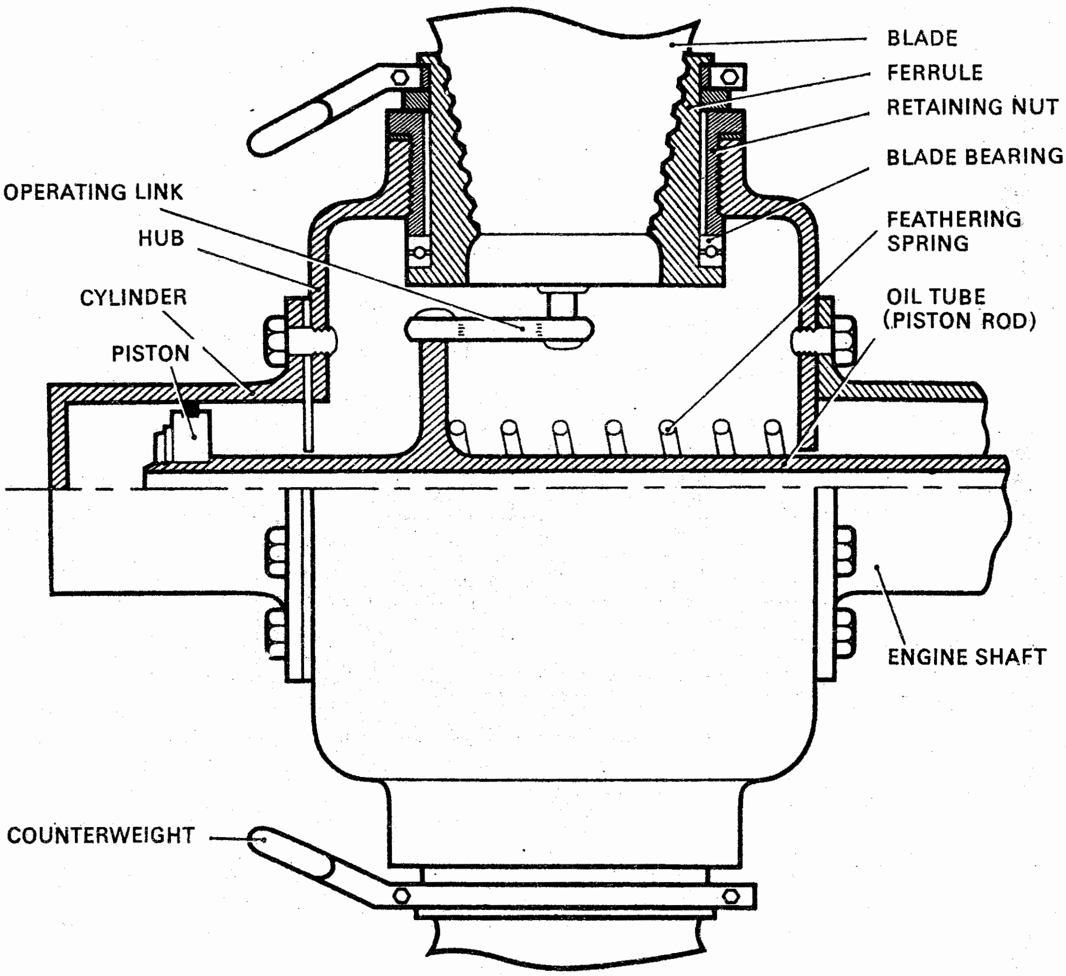

Figure 3 SINGLE-ACTING PROPELLER

5.1 **Single-acting Propeller.** A single-acting propeller is illustrated in Figure 3; it is a constant-speed, feathering type, and is typical of the propellers fitted to light and medium sized twin-engined aircraft. A cylinder is bolted to the front of the hub, and contains a piston and piston rod which move axially to alter blade angle. On some propellers, oil under pressure, fed through the hollow piston rod to the front of the piston, moves the piston to the rear to turn the blades to a finer pitch; on other propellers the reverse applies. When oil pressure is relieved, the counterweights and feathering spring move the piston forward to turn the blades to a coarser pitch. Counterweights produce a centrifugal twisting moment as described in paragraph 2.3 (a), but, because they are located at 90° to the chord line, they tend to move the blades to a coarser pitch. Counterweights must be located far enough from the blade axis, and must be heavy enough to overcome the natural twisting moment of the blade, but since weight and space are limiting factors, they are generally only used with blades of narrow chord.

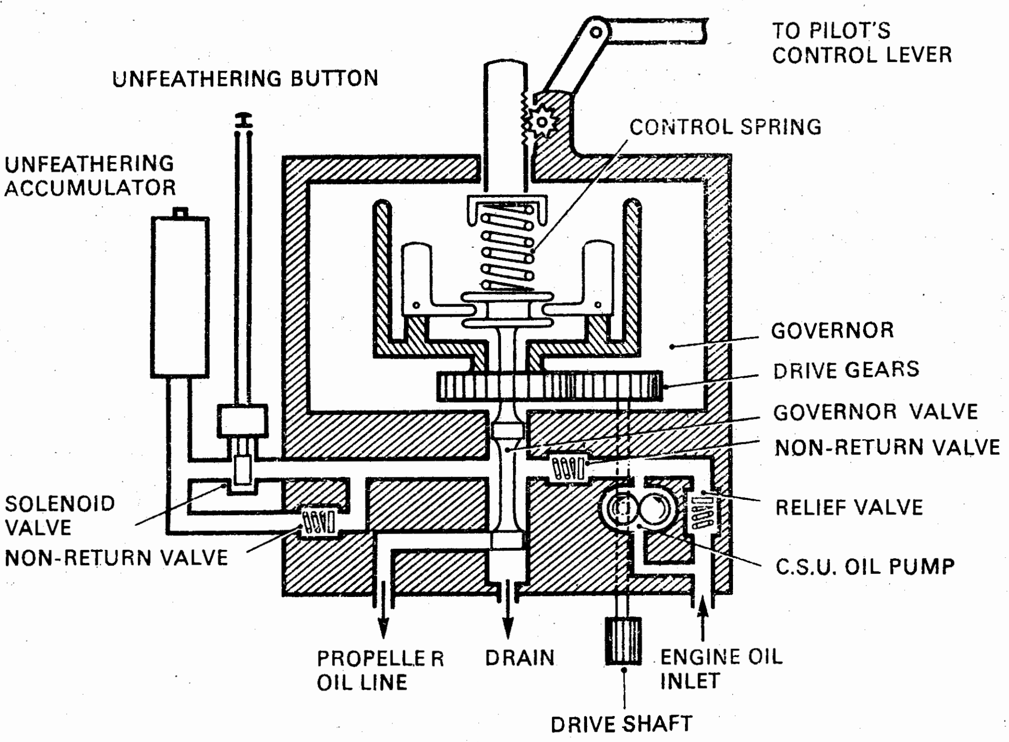

Figure 4 CONSTANT SPEED UNIT

5.1.1 **Propeller Control.** Blade angle is controlled by a constant-speed unit (Figure 4), which comprises a centrifugal governor, a governor valve, and an oil pump to boost engine oil pressure sufficiently for operation of the propeller control mechanism. The governor is driven from the engine shaft, and movement of the governor weights under centrifugal force is opposed by a control spring, the loading of which is set by means of the pilot's control lever. The position of the governor valve is determined, therefore, by engine speed and the force exerted by the spring; when these forces balance the oil line to the propeller is blanked off, and oil is trapped in the cylinder of the pitch change mechanism (see Figure 3).

(a) When the pilot's control lever is set to the maximum rev/min position, and the throttle is at a low power setting, the governor valve will be fully down, and oil from the pump will be directed through the hollow piston rod to turn the propeller blades to fully fine pitch. As the throttle is opened and rev/min are increased, centrifugal force on the governor weights will raise the valve, until a position is reached where maximum rev/min are obtained and the oil line to the propeller is blanked off. Any further increase in power will tend to increase rev/min and result in the governor valve being lifted; oil will drain from the propeller and produce a coarser blade pitch to maintain the specified maximum rev/min.

(b) During flight, rearward movement of the pilot's control lever will reduce control spring loading, and allow the governor weights to lift the valve; this will result in a coarser blade angle, and the increased load on the engine will reduce engine speed until the spring force is balanced by centrifugal force on the governor weights. Forward movement of the pilot's control lever will increase spring loading, and result in a finer propeller pitch and higher engine speed.

(c) If propeller load decreases in flight, or power is increased, the engine will begin to speed up, the governor weights will raise the valve, and propeller pitch will coarsen to maintain the set engine speed; conversely an increase in propeller load, or a decrease in engine power, will result in a finer propeller pitch, to maintain the set engine speed.

5.1.2 Feathering is accomplished by moving the pilot's control lever to the appropriate position, which is normally obtained by moving the lever through a gate in the quadrant. This action raises the governor valve fully, allowing oil to drain from the propeller, and the blades to turn to the fully coarse (feathered) position under the action of the counterweights and feathering spring.

5.1.3 In order to unfeather the propeller, a separate source of oil under pressure is required; on light aircraft this is usually provided by an accumulator which is charged during normal operation. To unfeather, the pilot's control lever is moved into the constant speed range, thus lowering the governor valve, and the unfeathering button is pressed, releasing oil from the accumulator and allowing it to flow to the propeller. This action commences unfeathering, and once the propeller starts to windmill the normal oil supply completes the operation.

5.1.4 When the engine is stopped on the ground, oil pressure in the cylinder is gradually relieved by leakage through the constant speed unit (CSU), and this would enable the propeller blades to turn to the feathered position under action of the feathering springs. This condition would result in unacceptable loads on the engine during starting, and a centrifugal latch is fitted to prevent forward movement of the propeller piston when the engine is stopped. Figure 5 shows the operation of a centrifugal latch; it is disengaged by centrifugal force at all speeds above ground idling, thus enabling the propeller to function normally during flight, but below this speed centrifugal force is overcome by return springs, and the piston can only move forward a short distance, equivalent to approximately 5° of blade angle. When the engine is started, oil pressure builds up to move the blades to fully fine pitch, and centrifugal force disengages the latch.

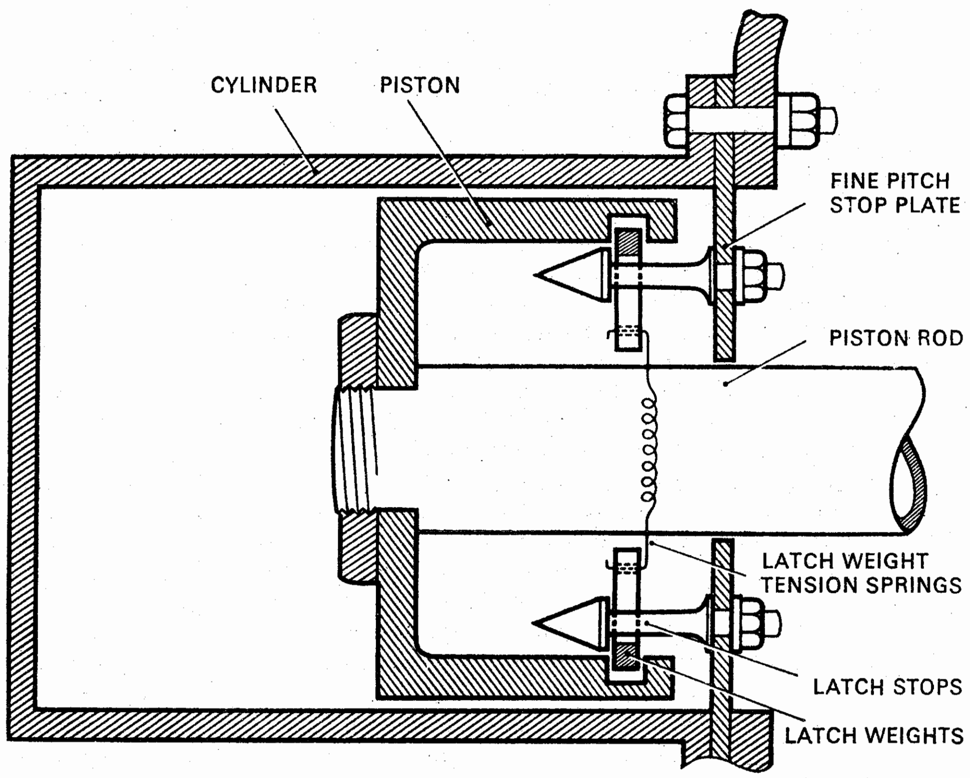

Figure 5 CENTRIFUGAL LATCH

5.1.5 Because of the predominance of single-acting propellers on light aircraft, only a simple propeller has been described. However, there is a wide variety of propeller/engine installations, and some of the safety features attributed to double-acting propellers will also be found on particular single-acting propellers.

5.2 **Double-acting Propeller.** This type of propeller is normally fitted to larger engines and, because of engine requirements, is more complicated than the propellers fitted to smaller engines. Construction is similar to that of the single-acting propeller, the hub supporting the blades, and the cylinder housing the operating piston. In this case, however, the cylinder is closed at both ends, and the piston is moved in both directions by oil pressure. In one type of mechanism (Figure 6), links from the annular piston pass through seals in the rear end of the cylinder, and are connected to a pin at the base of each blade. In another type of mechanism, the piston is connected by means of pins and rollers to a cam track and bevel gear, the bevel gear meshing with a bevel gear segment at the base of each blade; axial movement of the piston causes rotation of the bevel gear, and alteration of blade angle. Operating oil is conveyed to the propeller mechanism through concentric tubes in the bore of the engine reduction gear shaft.

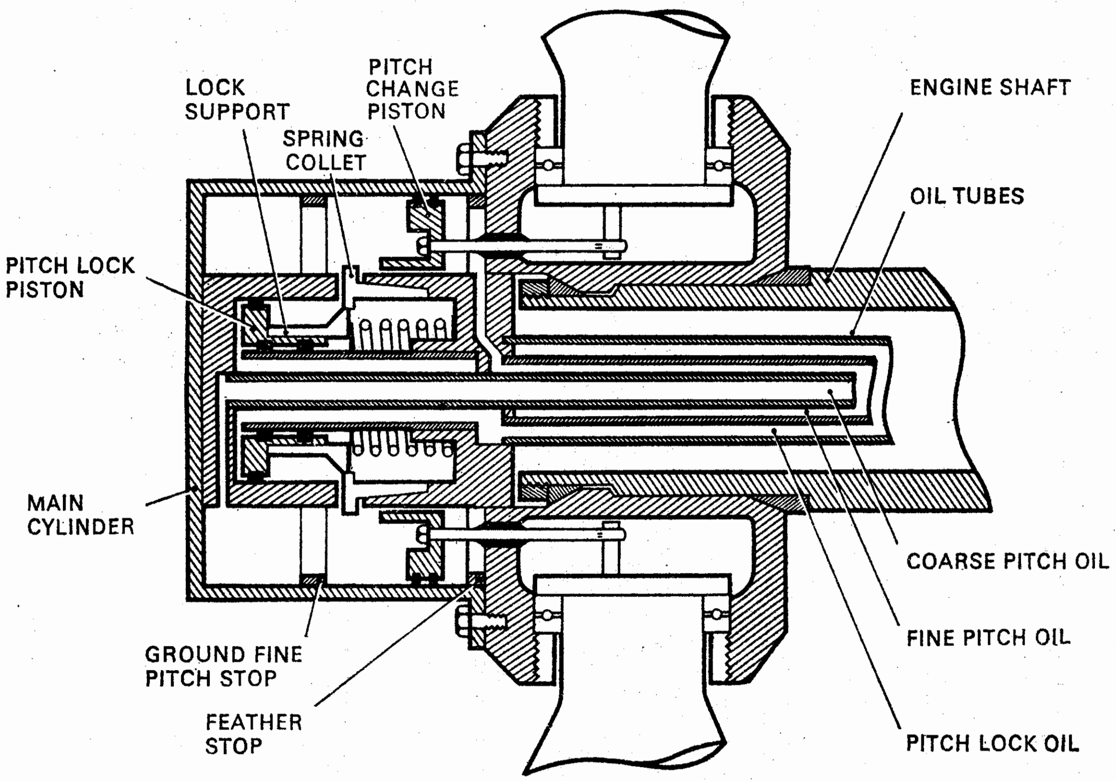

Figure 6 DOUBLE-ACTING PROPELLER

5.2.1 **Normal Operation.** In a turbo-propeller installation the power control lever is often connected to both the fuel control unit and the propeller control unit (PCU), so that fuel flow and engine speed are selected at the same time. The PCU is basically a CSU as illustrated in Figure 4, but the PCU includes a number of additional features. Constant speed operation is controlled in a similar manner to that on the single-acting propeller; the governor weights opposing control spring force to raise or lower the governor valve, and to supply oil to the appropriate side of the pitch change piston, whenever engine speed varies from the speed selected. Figure 7 illustrates the PCU.

(a) In the 'on speed' condition, centrifugal force on the flyweights balances the force of the control spring, and the governor valve traps oil in both sides of the pitch change cylinder.

(b) In the 'underspeed' condition, control spring force is greater than the centrifugal force on the flyweights, and the governor valve is lowered, supplying oil to the rear of the pitch change cylinder, and providing a drain for oil from the front of the cylinder. Blade angle decreases, and the engine speeds up until centrifugal force on the flyweights balances the force of the control spring, and the governor valve is returned to the 'on speed' condition.

(c) In the 'overspeed' condition, control spring force is less than the centrifugal force on the flyweights, and the governor valve is raised, directing oil to the front of the pitch change cylinder, and providing a drain for oil in the rear of the cylinder. Blade angle increases, and the engine speed decreases because of the added load, until the flyweights and control spring are once more in balance.

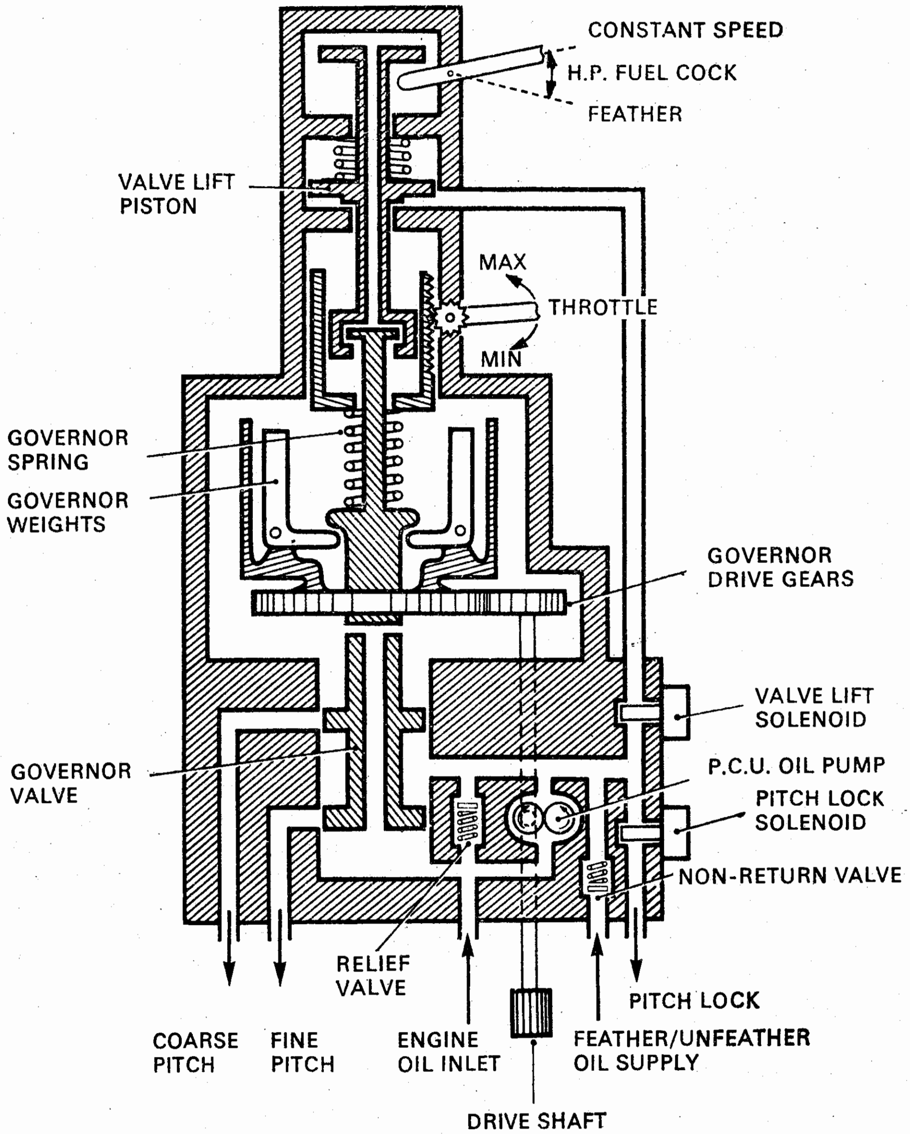

Figure 7 PROPELLER CONTROL UNIT

5.2.2 **Fine Pitch Stops.** During starting and ground running, a very fine propeller pitch may be required, to minimize propeller load, and to prevent engine overheating; however, during flight, this very fine pitch would lead to engine overspeeding, and excessive drag if the PCU were to fail. To cater for both these requirements, the pitch change piston on the type of propeller illustrated in Figure 6, is provided with two fine pitch stops, the flight fine pitch stop being withdrawn for starting and ground operations. The flight fine pitch stop is in the form of a spring collet, the prongs of which are designed to spring inwards. When the collet is operating as a stop, the pitch-lock piston is held in the forward position by a spring, forcing the spring collet open, and preventing the pitch change piston from moving forward further than the flight fine pitch position. When ground fine pitch is required, a solenoid in the PCU is energized (normally by operation of both a stop withdrawal lever and a throttle-operated switch) and oil pressure is ducted through the third oil line to the front of the pitch lock piston; as the piston moves rearwards, support for the collet is withdrawn and the prongs spring inwards, allowing the pitch change piston to move fully forward to the ground fine pitch position. The pitch lock solenoid is disarmed when the throttles are moved forward for take-off, and, when the propeller has coarsened into the constant speed range, the pitch lock piston moves forward under spring pressure and opens the spring collet to form the flight fine pitch stop.

NOTE: The term 'pitch lock' is used, in the above paragraph, to describe a means of holding the fine pitch stop in a prescribed position. Some manufacturers use the term to describe a device which locks the blades at whatever angle they happen to be, should failure of the pitch change mechanism occur.

(a) The entire power-unit and the aircraft must be safeguarded in the event of the failure of the pitch-lock unit to operate, and a safety system is incorporated in the PCU. If, during flight, the propeller blades move to a pitch finer than flight fine pitch, a switch fitted to one blade closes, and completes the circuit through an isolating switch to a solenoid in the PCU. This solenoid directs oil pressure to a valve-lift piston, which lifts the governor valve and directs oil to the front of the pitch change piston. This action coarsens the propeller blade angle, and breaks the circuit to the valve-lift solenoid. If the pitch-change piston does not latch over the spring collet as it moves rearwards, the sequence will be repeated as the blades fine-off past flight fine pitch again. An isolation switch prevents operation of this safety system when ground-fine pitch is purposely selected.

5.2.3 **Feathering.** Facilities for the manual feathering of the propeller are provided on all large piston and turbo-propeller engines. With some turbo-propeller installations, however, the drag from a windmilling propeller in fine pitch could be very dangerous, particularly with a twin-engined aircraft, and for these aircraft automatic feathering is also provided.

(a) Manual feathering of the propeller on a piston engine, is normally carried out by movement of the propeller control lever to the 'feather' position, and operation of the feathering pump. These actions raise the governor valve, and supply oil under pressure to the appropriate side of the pitch-change piston. On a turbo-propeller installation, manual feathering is carried out by an interconnection between the PCU and the high pressure fuel cock. When the fuel cock is moved to the 'feather' position, linkage to the PCU lifts the governor valve independently of the governor control, and oil is directed to the front of the pitch change piston to turn the blades fully coarse. Since the oil pump in the PCU is driven by the engine, the oil supply may be insufficient to feather the propeller completely, and operation of the electrically-driven feathering pump may be necessary.

(b) Automatic feathering is initiated by means of a torque switch. Whenever the power levers are positioned above the idling range, and the engine torque falls below a specified amount, the torque switch closes and completes a circuit to the feathering pump and the valve-lift solenoid in the PCU. The solenoid directs oil to the valve-lift piston, which raises the governor valve, and opens the oil ports from the feathering pump to the front of the pitch change piston, thus feathering the propeller.

5.2.4 **Unfeathering.** On turbo-propeller engines, when the high pressure fuel cock is open and the power levers closed, the governor valve is in a suitable position to direct oil from the feathering pump to the rear of the pitch change piston. Selection of the feathering pump switch (which is often incorporated in the fire control handle), supplies oil to the PCU and thence to the propeller, and activates the engine ignition system. When the propeller blades have turned from the feathered position, the airstream commences to windmill the propeller and rotate the engine, and normal oil pressure builds up to complete the unfeathering operation.

5.2.5 **Reversing.** In a reversing propeller, the propeller mechanism includes a removable ground fine pitch stop, which enables the propeller to fine-off to a negative pitch when certain actions have been taken and certain conditions are fulfilled. Various safeguards are incorporated to prevent selection during flight. The means of achieving negative pitch vary considerably, but operation of a typical hydraulically operated propeller is described in the following paragraphs.

(a) Electrical control is exercised by throttle-mounted switches, weight contact switches on the landing gear, and a master switch or lever to arm the circuit. With the throttle levers closed beyond normal idling to a datum position, 'reverse' selected, and the weight of the aircraft on its wheels, electrical power is supplied to a pitch-stop withdrawal solenoid, and oil pressure is directed to withdraw the fine-pitch stop and move the pitch-change piston forward to the reverse stop, where it is held by hydraulic pressure. Operation of the 'reverse' lever also changes the sense of operation of the throttle levers, which are pulled further back to increase power in reverse pitch.

(b) Indication of stop withdrawal, and movement of the blades to negative pitch, is provided by hub-mounted switches, which illuminate appropriate warning lamps on the flight deck.

(c) Re-selection of positive blade angle is achieved by moving the throttle into the normal idling range, and by moving the master lever out of the reverse position. Oil is ducted to the front of the pitch change piston, and the blades move to a positive angle; the stop returns to normal operation once the blades have moved past the ground fine pitch angle.

5.3 **'Beta' Control.** On some gas turbine engines, a form of control known as 'beta', or blade angle control, is used for ground operations, and may be applied to either single-acting or double-acting propellers. With this system, the throttles (usually known as power levers) operate in a gated quadrant. During flight these levers cannot be closed below the 'flight idle' gate, and the CSU operates normally to maintain any pre-selected propeller speed. In the ground idling and reversing range, the power levers control propeller pitch to vary power at both positive and negative blade angles, at constant propeller speed, and the governor mechanism is overridden. An overspeed sensor, and mechanical pitch stop, prevent operation in the ground (fine pitch) range during flight. In the beta range, the pitch stop is withdrawn, and movement of a power lever rotates a setting cam in the associated CSU, which raises or lowers the governor valve according to whether a coarser or finer pitch is required. A mechanical feed-back mechanism, operated by linkage from the propeller blades, resets the governor valve via a follow-up cam, and pitch change ceases when the angle scheduled by the power lever is achieved.

5.4 **Electrically Operated Propellers.** As with other types of variable-pitch propellers, a hub is mounted on the engine reduction gear shaft, the individual blades are fitted into the hub, and the pitch change mechanism is fitted to the front of the hub. In this type, however, the pitch change mechanism consists of a reversible electric motor, driving a bevel gear through a gear train with a very high reduction ratio. The bevel gear meshes with a bevel gear segment attached to the root of each blade, and, when rotated, turns the blades to alter propeller pitch. Electric power to the motor is provided through a brush and slip-ring arrangement at the rear of the hub. A motor brake is provided to prevent overrun, and normally consists of two friction discs, one fixed to the rotating motor shaft, and the other keyed to the stationary motor casing. The brake is applied (discs held together) by spring pressure, and released by means of a solenoid whenever a pitch change is initiated.

5.4.1 Some electrically operated propellers are controlled by an engine-driven CSU, and switches are also provided which enable propeller pitch to be controlled manually. The CSU is similar to those fitted to hydraulically operated propellers, but the governor valve supplies oil to the appropriate side of a piston contained in the CSU, which is connected to the central contact of a switch unit. Movement of this piston in either direction completes a circuit to the pitch change motor, and alters blade angle as required.

5.4.2 On some multi-engined aircraft an electrical control system is used. A single propeller pitch lever controls the speed of a master electric motor, which is used as a reference for engine speed, and which drives the stator of a contactor unit for each engine. Each engine drives an alternator, which supplies three-phase alternating current to the stator windings of the appropriate contactor, the frequency being proportional to engine speed. During operation, a magnetic field is built up round the stator with a phase rotation opposite to that of the stator. If the stator speed and alternator speed are the same, the magnetic field will, therefore, be stationary; any variation in alternator speed will result in rotation of the magnetic field, the direction of rotation depending on whether the alternator is rotating faster or slower than the stator. Rotation of the magnetic field influences a concentric rotor, which rotates with it, and closes a pair of contacts to complete the circuit to the appropriate windings in the propeller pitch change motor. Switches are normally provided to enable pitch changes and feathering to be carried out manually.

6 INSTALLATION AND MAINTENANCE

6.1 **Wooden Fixed-pitch Propellers.** Because of the nature of the material from which they are made, wooden propellers are relatively easily damaged by stones and other hard objects, and they may also be affected by climatic conditions. These propellers should frequently be inspected for breaks in the surface finish, scores, nicks, cracks, delamination, and security of the leading edge sheath. Minor defects in the surface finish may be repaired by touching-up with varnish or paint as appropriate, but any damage to the wood, other than very minor damage (see paragraph 6.1.2), must be assessed in accordance with the approved repair schemes, and the propeller repaired or returned to the manufacturer as appropriate.

6.1.1 **Periodic Maintenance.** The intervals at which the propeller must be removed for inspection are specified in the approved Maintenance Schedule. With the propeller removed from the aircraft, the blades and boss should be inspected for the sort of damage described in paragraph 6.1, paying particular attention to those areas which are not visible when the propeller is installed. In addition, the following inspections should be carried out:—

(a) Bolt holes should be examined for ovality, rough edges, and cracks radiating into the boss.

(b) Boss faces should be examined for damage where they have been in contact with the hub flanges, particularly at the circumference of the flanges.

(c) The centre bore should be examined for cracks and delamination of the plies.

(d) The mounting hub should be examined for corrosion, cracks, correct fit on the crankshaft, and for condition of the attachment bolts and nuts.

(e) Where mounting cones are fitted, these should be checked for corrosion, and for picking-up of the surface. Correct fit between the hub and cones may be checked using engineers' blue, an 80% contact normally being required.

6.1.2 **Repairs.** The limits of repairable damage are normally laid down in the appropriate aircraft manual, and are related to a maximum depth and area, expressed as a percentage of the thickness or chord of the blade at that point.

(a) Minor indentations and small longitudinal cracks may usually be repaired by plugging with a mixture of glue and sawdust, then sanding smooth.

(b) Deep cuts or damage must be removed, and an insertion repair carried out. Identical timber must be used, and particular attention must be paid to matching the grain direction.

(c) If slight tip or trailing edge damage is repaired by sanding to a new profile, both blades must be similarly shaped.

(d) If repairs to the metal sheath are permitted, extreme care is necessary to prevent bruising of the wood when shaping the new metal. The original screw and rivet holes must be used, and the manufacturer's recommended procedures carefully followed.

(e) In all cases where repairs have been carried out, the propeller must be balanced (paragraph 2.5), and re-protected in the original manner.

6.1.3 **Installation.** Before installing a propeller, the propeller shaft and threads should be checked for damage. The fit of the hub on the shaft should be checked using engineers' blue, and any high spots should be removed with a fine oil stone. Boss and hub flange faces should be checked for cleanliness, to ensure that maximum friction will be obtained.

(a) When assembling the hub to the shaft, it is usually recommended that an anti-seize compound should be applied to the threads, and engine oil to the shaft. Where cones are fitted, these should be clean and dry.

(b) The angular position of the propeller on the hub is not important, unless the engine is likely to be started by hand swinging. In this case it should be mounted in a convenient position in relation to aircraft height and engine compression. The attachment bolts should be tightened evenly, and in proper sequence, to the specified torque.

(c) After installation, the track of the propeller must be checked. This is normally measured on a trestle or platform vertically below the boss; when the propeller is rotated the blades should track within $\frac{1}{8}$ inch of each other, but a greater tolerance may be permitted on repaired propellers, provided that no vibration is evident during engine runs.

(d) After engine runs to check the reference rev/min, the propeller attachment bolts and the hub retaining nut should be checked for tightness, and re-locked. It is recommended that the bolts should also be checked after each of the first few flights.

NOTE: Shrinkage washers are sometimes fitted to the attachment bolts of wooden propellers, to take up any shrinkage which may occur after installation. These washers must be fitted strictly in accordance with the manufacturer's instructions.

6.2 **Metal Fixed-pitch Propellers.** Aluminium alloy propeller blades are less prone to surface damage than wooden propeller blades, but sharp indentations and scores will cause stress concentrations which may lead to failure, particularly if a number of damaged areas form a line across a blade. Such propellers should be inspected frequently for corrosion, dents, nicks, cuts, and other surface damage.

NOTE: Blade failures have been known to occur, through corrosion which has started underneath blade decals attached with a water-soluble adhesive. Particular attention should be paid to any instructions or directives which have been issued regarding inspection, removal or replacement of these items.

6.2.1 **Periodic Maintenance.** Metal propellers are not normally overhauled at definite periods, and are only removed for repair or reconditioning when the condition of the blades makes this necessary. When the propeller is removed, the mounting bolts should be examined for cracks, using a suitable non-destructive testing method, and the propeller mounting flange bolt holes should be examined for ovality and cracks. In addition, the faces of the propeller boss should be checked for fretting, corrosion, and cracks emanating from the bolt holes. Further information on the maintenance of propeller blades will be found in CAA Airworthiness Notice No. 55.

6.2.2 **Repairs.** Propellers which are bent or twisted, which have surface cracks in a chordwise direction, or which have sustained damage in the form of cuts, nicks, or gouges, beyond the limits of depth or area specified by the manufacturer, must be returned to an approved overhaul organisation for repair. Minor repairs may be carried out by removing metal from the damaged area, so that the final depression is within the specified repair limits for the particular blade area. Metal should be removed with a smooth file and emery cloth, and the repair should progressively be checked by the penetrant dye process, until all damage has been removed and a smooth shallow depression remains.

(a) After repairs have been satisfactorily carried out, the propeller should be carefully balanced. If repairs have been made to one blade only, it may be necessary to remove material from the other, heavier blade, at the position corresponding to that of the repair on the damaged blade. Care must be taken not to reduce blade chord or thickness below the minimum dimensions specified for the particular propeller. If only a very small amount of metal was removed during repair, balance may often be restored by applying additional paint to the lighter blade.

(b) After balancing, the propeller should be partly or completely reprotected, depending on the extent of the surface damage, using the primer and paint or varnish specified by the manufacturer.

6.2.3 **Installation.** Fixed-pitch metal propellers are normally installed on a flanged propeller shaft, and a spacer is often used to give clearance between the propeller and the engine cowling. Dowels are used to locate the propeller on the spacer or propeller shaft flange, and these should be a tight press fit in the holes. The dowels, spacer and flange should be inspected before assembly to ensure that they are undamaged, and the propeller and spacer should be assembled together before installation on the engine.

(a) If the engine is likely to be hand-swung, the propeller should be fitted to the engine in a convenient position. The attachment bolts should be tightened evenly, and in proper sequence, to the specified torque.

(b) It is not usually necessary to check the track of a metal propeller after initial installation, but it may be necessary if vibration is evident during operation.

(c) The engine should be ground run after installing the propeller, to check for vibration and determine the engine speed obtained at full throttle. This reference rev/min should be corrected for ambient conditions, and recorded in the engine log book.

(d) The propeller attachment bolts should be checked for tightness after the engine run.

6.3 **Variable-pitch Propellers.** In some instances, variable-pitch propellers may be fitted with steel blades, and particular care must be exercised during inspection, because of the adverse effects of surface damage on the fatigue life of these blades. Inspection and repair must be carried out strictly in accordance with the manufacturer's instructions. Maintenance of variable-pitch propellers with aluminium alloy blades is described below.

6.3.1 **Periodic Inspection.** The following inspections should be carried out at the periods specified in the approved Maintenance Schedule, or as recommended in CAA Airworthiness Notice No. 75.

(a) All visible parts of the propeller, its components, controls, pipe connections and wiring, should frequently be inspected for damage and security.

(b) The blades should be inspected for damage in the form of abrasions, cuts, nicks, or corrosion. Minor erosion or dents may usually be left until the propeller is removed, but cuts or gouges which may lead to cracks should be blended out immediately, and the area should be repainted.

(c) The spinner, hub and blade roots of hydraulically-operated propellers should be examined for traces of oil leaking from the pitch change mechanism. If the propeller is a 'dry hub' type, oil leaking into the hub may, through centrifugal force, flow through the blade bearings, remove the grease, and result in premature failure of the bearings. Some traces of oil may be found after initial installation, but, if the leakage persists, the propeller must be stripped to the extent necessary to cure the leak, and to clean and re-grease the bearings. This particular problem does not apply to propellers with 'wet' hubs, but any leakage should, nevertheless, be investigated.

(d) The CSU/PCU, and connecting pipes should be inspected for oil leaks. Leakage at the mounting face of the CSU/PCU may be remedied by tightening the nuts or replacing the gasket, but leakage from other parts of the unit will normally require a replacement of the complete unit.

(e) Whenever the propeller is removed, the slip rings and contact brushes should be examined for damage and wear. Brush wear over the operating period should be assessed, and the brushes should be replaced if the rate of wear indicates that they will not remain serviceable until the next overhaul.

6.3.2 **Damaged Blades.** Blades which are bent, twisted or cracked, or have severe surface damage, must be considered unserviceable, and the propeller must be returned to the manufacturer or an approved overhaul organisation. Minor surface damage may be blended out in the same way as for fixed-pitch metal propellers, and within the limitations imposed by the manufacturer.

(a) If vibration is experienced, the blades should be inspected for signs of cracks, dents, or bending. The track of each blade should be checked, and the blade angles should be measured at the specified station. It is usually possible to adjust the blade angle of an individual blade by fitting shims to, or by adjusting the length of, the operating rod from the pitch-change mechanism to the blade. If all these checks are satisfactory, it is unlikely that the propeller is the cause of the vibration.

6.3.3 **Installation of Propeller.** The method of installation will depend on the type of propeller, and all instructions detailed in the appropriate Maintenance Manual should be carefully followed; these will include any special checks to be carried out, and details concerning lubrication, torque loading and locking of retaining parts. The following procedures are applicable to most propellers.

(a) Remove all protective covers and plugs, and clean parts which have been treated with a protective coating. Lubricate specified parts with the recommended grease or oil before installation.

(b) Fit the electrical brush gear housing to the engine reduction gear casing, and check that it is square with the engine shaft, using a dial test indicator clamped to the shaft.

(c) Fit the sling to the propeller, lightly smear the front and rear cone seatings with engineers' blue, and temporarily fit the propeller to check the contact area of the cones. Tighten the hub retaining nut by hand, rotate the propeller at least one revolution, then remove the propeller and check the extent of blueing of the cones. If the contact area is less than 80%, high spots may be removed by light stoning, or, where permitted, by lapping on a suitable mandrel. Clean the cones and cone seatings.

(d) With hydraulically-operated propellers, fit and lock the oil tubes in the engine shaft.

(e) Refit the propeller, lightly lubricating the splines, cone bore and threads with the specified lubricants. Cone faces should not normally be lubricated, as this may result in looseness of the propeller when the oil film is lost. Lubricating the propeller bore, rather than the shaft, will prevent any lubricant from being displaced on to the cone face when the propeller is installed.

(f) Turn the blades to the feathered angle, and fit the pitch-change mechanism.

(g) Install the brush gear, and check for correct contact between the brushes and the slip rings.

(h) Fit the spinner, and turn the blades through their full pitch range, to check for fouling.

6.3.4 **Installation of CSU/PCU.** Installation of the CSU/PCU is normally straightforward. A new gasket should be fitted to the mounting flange, and the unit should be installed carefully, ensuring that the driven gear meshes with the driving gear or quill shaft, and that any dowels are correctly located. Mechanical linkage on a piston engine should be adjusted, so that the CSU control is on the maximum rev/min stop when there is a slight clearance between the pilot's control lever and the forward end of the gate in which it operates. The controls to the PCU of a turbine engine are interconnected with the high pressure fuel cock, and with one or more of the electrical contacts associated with the operation of the various propeller functions; they may also be electrically or mechanically connected to the controls on the flight deck. Mechanical linkage is normally adjusted by locking the pulleys and levers in set positions, using rigging pins or similar equipment as necessary, and adjusting the connecting rods or cables to suit. Details of the procedures for setting up the propeller controls on any particular aircraft must be obtained from the appropriate Maintenance Manual.

6.3.5 **Testing After Installation.** After installing a propeller, the engine must be ground run to check propeller operation. Aircraft propeller installations vary considerably, and no set testing procedure would be satisfactory for all aircraft. It is imperative, therefore, that any particular installation should be tested in accordance with the approved Maintenance Manual, which will normally include the following general requirements.

(a) The engine should normally be fully cowled, and the aircraft should be facing into wind before starting an engine run. It is sometimes recommended that the pitch change cylinder should be primed with oil before starting, by operation of the feathering pump.

(b) The safety precautions appropriate to engine ground running should be taken, the controls should be set as required, and the engine should be started.

(c) As soon as the engine is operating satisfactorily, and before using high power, the propeller should be exercised in the manner specified in the Maintenance Manual, to establish that the pitch change mechanism is operating.

(d) The checks specified in the Maintenance Manual to confirm satisfactory operation of the propeller system, including constant speed operation, feathering, operation of the propeller pitch change throughout its range, synchronisation with other propellers on the aircraft, and operation of associated warning and indicating systems, should be carried out.

(e) Engine running time should be kept to a minimum consistent with satisfactory completion of the checks, and a careful watch should be kept on engine temperatures to avoid overheating. With turbine engines, changes to operating conditions should be carried out slowly, to avoid rapid engine temperature changes, and to conserve engine life.

(f) When all checks have been successfully carried out, the engine should be stopped, and a thorough inspection of all propeller system components should be carried out, checking for security, chafing of pipes and cables, and signs of oil leaks.

NOTE: If vibration was experienced during the engine run, the hub retaining nut should be re-tightened after the engine shaft has cooled down.

6.4 **Additional Inspections.** In addition to the normal inspections carried out on a routine basis, certain occurrences will require special checks to be carried out, and these checks are briefly described in the following paragraphs.

6.4.1 **De-icing Equipment.** Damage to de-icing equipment fitted to the propeller should be dealt with as described in Leaflets **PL/1—3** or **PL/1—4,** as appropriate.

6.4.2 **Lightning Damage.** If a metal propeller is struck by lightning, burn damage to the blades is likely to occur. In removing this damage the normal repair limits apply, but after cleaning out all physical damage, a further specified thickness of metal must be removed, and the depression blended to a smooth contour. The damaged area should then be chemically etched, and inspected with a magnifying glass to ensure that there are no signs of material abnormalities. Any electrical circuits in the propeller should be checked for continuity and insulation resistance.

6.4.3 **Overspeeding.** Propellers may occasionally exceed their normal maximum rotational speed, and be subjected to centrifugal forces in excess of those for which they were designed. With variable-pitch propellers, overspeeding will normally only occur following failure of the control system, but with fixed-pitch propellers the maximum engine speed may easily be exceeded during manoeuvres if the engine speed indicator is not carefully monitored. The extent of the checks which must be carried out following overspeeding, will depend on the margin by which the normal maximum rev/min have been exceeded, and on any particular instructions contained in the approved Maintenance Manual. The figures quoted here are typical values.

(a) No special checks are normally required following overspeeding up to 115% of normal maximum rev/min, but it may be recommended that the track of the propeller is checked.

(b) If the propeller has been overspeeding between 115% and 130% of normal maximum rev/min, for a period in excess of any specified time limit, it should be removed for inspection. All blades should be carefully inspected for material failure, using a penetrant dye process. Blade bearings should be crack tested, and the rolling elements and raceways should be inspected for brinelling (i.e. indentation). The hub and counter-weights should be inspected for cracks and distortion, and particular attention should be paid to the blade mounting threads and spigots.

(c) If the overspeeding has been in excess of 130% of normal maximum rev/min, the propeller should be returned to the manufacturer for investigation.

6.4.4 **Special Instructions.** Manufacturers of propellers may issue, from time to time, instructions dealing with the detection and rectification of faults which are known to exist on particular types of propellers. These instructions are often issued in the form of Service Bulletins, and engineers should be acquainted with such advice, and should take action accordingly.

7 STORAGE

7.1 **Installed Propellers.** Propellers installed on an engine which may be out of use for a period of up to three months should be kept clean, and should be inspected regularly for corrosion. The internal parts of a variable-pitch propeller will be protected by exercising the propeller during weekly engine runs where these are possible, but, if the engine cannot be run, the propeller should be feathered and unfeathered using the feathering pump. If the engine is likely to be out of use for more than three months, the propeller mechanism should be flushed with inhibiting oil, and all external parts of the propeller should be treated with lanolin or an approved rust preventative. The propeller operating mechanism should be covered with waxed paper, and all visible parts should be regularly inspected for corrosion.

7.2 **Uninstalled Propellers.** Uninstalled propellers should be stored in conditions which are clean, dry, warm, and free from corrosive fumes. Two-bladed propellers are usually stored in racks to permit free circulation of air, but propellers with more than two blades may be stored vertically, on stands, to minimise the amount of floor space they occupy. Propellers should be retained in the manufacturer's packaging whenever possible, or wrapped in mouldable wrap and waxed paper. The external parts of metal propellers should be coated with lanolin or an approved alternative. The pitch change mechanism of a hydraulically operated propeller should be inhibited with an approved oil, and all loose parts, such as oil tubes and mounting cones, should be coated with lanolin and wrapped in waxed paper.

7.2.1 When a variable-pitch propeller is disassembled for storage, individual mechanical parts should be immersed in inhibiting oil, then allowed to drain, bearings should be coated with mineral jelly, and electrical connections should be smeared with petroleum jelly. All electrical equipment, such as motors and slip rings, should be thoroughly cleaned, the connections smeared with petroleum jelly, external surfaces should be treated with a rust preventative, and each part sealed in a moisture vapour proof bag. All parts of the propeller should then be wrapped in waxed paper and, if possible, packed in a suitable carton or crate.

7.2.2 When assembled propellers or pre-loaded blade assemblies are held in storage, the bearings must be exercised after six months and nine months. At the end of twelve months in storage the bearings must be removed and examined for brinelling and corrosion, and, if they are found to be satisfactory, they should be cleaned, greased, and reassembled on the blade. They will then be satisfactory for a further six months storage.

7.2.3 The maximum storage period varies between different types of propellers, but generally, if a propeller is retained in the manufacturer's packing, it will, subject to the checks outlined in paragraph 7.2.2, remain in a satisfactory condition for three years. If the propeller, or individual components, are not retained in the original packing, they will normally require re-inhibiting every twelve months, and overhauling after three years.

7.2.4 Rubber components are normally subject to a specific life, counted from the cure date or assembly date, and must be discarded at the overhaul nearest to their life expiry. Details concerning the life of a particular component should be obtained from the relevant Maintenance Manual. Loose rubber components should be stored in the dark in an unstressed condition, and retained in the manufacturer's packing until required for use.

7.3 All propellers or propeller components retained in storage should be suitably labelled to show their part number, modification standard, original date of storage, and any other details relevant to the actions taken subsequent to the original storage date.

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AIRCRAFT

PROPELLERS

FLUID DE-ICING SYSTEMS

1 INTRODUCTION This Leaflet gives general guidance on the installation and maintenance of fluid de-icing systems for aircraft propellers. It should be read in conjunction with the Maintenance Manuals for the aircraft and system components concerned.

NOTE: This Leaflet incorporates the relevant information originally published in Leaflet PL/3-1, Issue 1, 1st December, 1950.

2 GENERAL The system provides a film of de-icing fluid to the propeller blade surfaces during flight which mixes with the water or ice and reduces the freezing point of the mixture. Where ice has already formed on the blades, the fluid penetrates under the ice and loosens it sufficiently for it to be thrown off by centrifugal action.

2.1 Fluid is distributed to each propeller blade from a slinger ring which is mounted on the back of the propeller hub. The fluid is pumped into this ring through a delivery pipe from a supply tank.

2.1.1 Some propellers have rubber overshoes fitted to the blades to assist the distribution of the fluid. On this type of installation fluid is fed from the slinger ring to a small trough, which is part of the overshoe, and is then forced by centrifugal action along longitudinal grooves in the overshoes.

2.1.2 On propellers which are not fitted with overshoes, fluid is fed from the slinger ring through a pipe to the root of the blade and is then distributed by centrifugal action.

2.2 The fluid may be pumped to the slinger ring from the supply tank by an independent electrically driven pump but air pressure is sometimes used.

2.2.1 The electric pump may be controlled by a switch and, in some installations, the pump speed may be varied by means of a rheostat. Non-return valves are sometimes provided to prevent loss of fluid when the pump is not operating.

2.2.2 Where air pressure is used to supply fluid, a relief valve is usually fitted to the air supply line and a control valve provided to regulate the fluid flow.

3 INSTALLATION The information contained in the following paragraphs outlines the checks and procedures necessary on initial installation of the system.

NOTE: Pipe-lines and supply tanks should be installed in accordance with Leaflets **AL/3-13**, **AL/3-14** and **AL/3-15**. For guidance on the installation of electric cables and the testing of circuits, see Leaflets **EEL/3-1** and **EEL/4-1**.

3.1 **Slinger Ring**

3.1.1 The pipe and nozzle which deliver fluid to the slinger ring should be positioned so that there is sufficient clearance between the pipe and the side of the ring to prevent interference when the propeller is rotating. This clearance is important as the tolerance is small and an error may render the system inoperative.

3.1.2 The feed pipes between the slinger ring and the propeller blades should be positioned so that there is sufficient clearance to prevent damage being caused by vibration during service.

3.1.3 On propellers which are not fitted with overshoes, correct distribution of fluid over the propeller blades depends on the shape of the feed pipes and, therefore, care should be taken that the pipes are not damaged or distorted in any way, particularly when fitting or removing the propeller.

3.2 **Pumps.** In some instances a pump may have several delivery outlets and where the number of outlets exceeds the number required, those which cannot be used are routed back into the inlet pipes. Alternatively, on some gear type pumps, outlets which are not used may be blanked off provided that the appropriate gear wheel is removed.

4 TESTING The following tests refer to systems in which the propellers are not fitted with overshoes and where the systems are operated by electrically-driven pumps: the tests may, however, be adapted to other systems. When applying the tests the system should be filled with the fluid specified in the Maintenance Manual for the aircraft concerned.

4.1 **Flow Test.** Before commencing the initial flow test, the pump filter should be checked for cleanliness. A check should also be made to ensure that the tank vent system is unobstructed. An ammeter should be fitted in the electrical circuit of the system. The voltage of the power supply should also be checked to ensure that it is at the correct level.

4.1.1 The delivery pipe-line should be disconnected at a convenient point near the slinger ring and a calibrated container positioned to receive the fluid. The pump should be operated and the fluid delivery rate and ammeter reading noted. On multi-engined aircraft the test must be applied to all propellers simultaneously in order to determine the delivery rate to each slinger ring.

4.1.2 The delivery rate of the fluid should be within the limits specified by the manufacturer. Where a rheostat control is provided for varying the delivery rate, the flow should be checked at the various settings.

4.1.3 If the amperage required to operate the pump exceeds the rated value, or the delivery rate of the fluid is less than the prescribed minimum, the slinger ring, pipe-lines and tank vent system should be checked for obstruction or damage. If these checks are satisfactory, the pump may be defective and should be removed for checking.

4.2 **Functioning Test**

4.2.1 If there is any doubt as to whether the propeller de-icing system is functioning properly it should be checked during an engine ground run.

4.2.2 The propellers should be painted with commercial whitewash and allowed to dry. A suitable dye should be added to the fluid so that when the de-icing system is operated the dyed fluid will stain the whitewash and indicate the distribution over the blades. Uneven distribution may be caused by the slinger ring being fitted eccentrically, by the feed pipes from the ring being incorrectly located or by obstructions in supply pipelines.

5 CLEANING THE SYSTEM When the de-icing system is likely to be out of use for a long period it is advisable to remove all traces of de-icing fluid. This may be done by draining the supply tank and re-filling with a mixture of 95% methylated spirits and 5% distilled water; the system should then be operated until the tank is empty. During this operation the propeller should be turned so that the feed pipes leading from the slinger ring to the blades receive an equal amount of fluid.

5.1 **Inhibiting.** The fluid used in de-icing systems is stable and non-corrosive but leaves a gummy residue on drying out. Inhibiting the fluid pump and system is at the discretion of the aircraft operator, but if it is not inhibited it is advisable that a certain level of de-icing fluid (approx. 2 gallons) is maintained in the tank and the system operated at regular intervals.

5.1.1 If the pump and system associated with a propeller utilising overshoes is to be inhibited, the propeller blades should be covered before commencing the process, to prevent deterioration of the overshoes which could result from contact with the inhibiting fluid. Similar precautions must also be taken when draining the system of inhibiting fluid and preparing it for use.

6 PERIODIC INSPECTION The following information should be related to the Maintenance Schedule for the particular aircraft.

6.1 **General**

6.1.1 After each flight when the system has been used, the propeller blades should be cleaned with methylated spirits or warm soapy water, as recommended by the manufacturer. The supply tank should be replenished with the fluid specified in the Maintenance Manual.

6.1.2 Examine overshoes for defects, paying particular attention to the following:—

(i) Check edges and tips of overshoes for adhesion failures. It should be borne in mind that the shoe tips and edges may lift in flight and it may not be easy to detect this defect.

(ii) Check for blisters. These should be repaired in accordance with the manufacturer's instructions. Deformations caused by irregularities in the cement film should not be mistaken for blisters.

(iii) Check for freedom from cuts especially at the leading edge.

6.1.3 Overshoes may be cut back slightly to remove damage caused by stones or grit; the manufacturer's instructions on this procedure and also on any necessary checks concerning propeller balance, must be closely followed.

6.1.4 The bottom of the trough, the longitudinal grooves, pipes and valves, as applicable to the system, should be free from gummy deposits.

6.1.5 The trough should be free from damage. Troughs are easily deformed but may be manipulated back to the correct shape; care should be taken to ensure that the correct clearance is maintained between the trough and the feed pipe. When the trough is damaged to such an extent that the beading wire has broken, a new part should be fitted.

6.2 **Filters.** At the period specified in the approved Maintenance Schedule, the pump filter should be dismantled and cleaned in methylated spirits. After re-assembly the system should be flow-tested as outlined in paragraph 4.1.

6.3 **Pumps.** When a pump has been dismantled for inspection, the valves, pistons, etc., should be cleaned in methylated spirits, and the gears and bearings in paraffin. On re-assembly parts such as bearings, gears and gear housings should be lubricated with the specified lubricants and functional tests of a pump carried out in the manner prescribed in the relevant Maintenance Manual.

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AIRCRAFT

PROPELLERS

ELECTRICAL DE-ICING SYSTEMS

1 INTRODUCTION This Leaflet gives guidance on the inspection and maintenance of systems employed for de-icing certain types of propeller by an electrical heating method. Since these systems vary between different aircraft, the information given in this Leaflet is of a general nature and it is, therefore, important that it should be read in conjunction with the installation drawings, Maintenance Manuals, Overhaul Manuals and approved Maintenance Schedules for the aircraft and propeller concerned.

2 GENERAL In electrical systems, the basis for effective de-icing is formed by resistance wire heating elements bonded to the leading edges of the propeller blades; in the case of turbine engine propellers, wire woven or sprayed elements are also bonded to the front shell of the spinner. Depending on the type of aircraft, the power for heating the elements is either direct current or alternating current and is applied in a controlled sequence by a cyclic timer unit. In turbopropeller engine installations, the propeller heating circuit forms part of a power unit de-icing and anti-icing system, and the cyclic control is integrated with the engine air intake heating circuit.

2.1 **Construction.** The construction of the elements, or overshoes as they are sometimes called, varies between propeller types. In one commonly used propeller, the heating element wires are interwoven with glass threads which form a glass cloth base, this in turn, being cemented between sheets of rubber. A protective guard of wire gauze is cemented beneath the outer rubber covering. The overshoe is shaped to fit round the blade leading edge and is cemented to it. In some cases, the overshoe is cemented in a rebate machined in the leading edge, so that it lies flush with the blade surfaces.

2.2 **Power Supplies.** The power required for heating is conveyed to the elements via cables, slip rings and by brushes contained within a brush block housing. The slip rings are normally mounted at the rear of the propeller hub or on a starter ring gear, and the brush housing on the engine front casing, but in some systems the method of mounting may be the reverse way round. The cables are of sufficient length and are positioned so as to allow for movement of the blades throughout their designed pitch range.

2.3 **Heating Control.** Efficient operation of these systems necessitates a relatively high consumption of electrical power. This is, however, controlled by employing a cyclic de-icing technique whereby a short unheated period allows a thin film of ice to build up on the leading edges of the propeller blades. Before this film builds up sufficiently to interfere appreciably with the aerodynamic characteristics of the blades, the cyclic control applies heating power. The ice already deposited then acts as thermal insulation, and as the ice in contact with the blade surfaces melts, the main ice catch is carried away under the action of centrifugal and aerodynamic forces.

3 INSTALLATION AND MAINTENANCE Full details of the methods of installation and checks necessary for the inspection and maintenance of electrical de-icing systems for propellers, will be found in the relevant aircraft and propeller Maintenance Manuals, and approved Maintenance Schedules; reference must therefore be made to such documents at all times. The information given in the following paragraphs is intended only as a general guide to the procedures normally required.

3.1 Overshoes

3.1.1 Overshoes, and anti-erosion strips where fitted, should be examined for splits, wrinkling, tears, discolouration as a result of overheating, security of attachment to blades and general condition. To avoid corrosion, anti-erosion strips must be renewed as soon as there are signs of splitting or advanced erosion likely to cause failure before the next scheduled inspection. If a heater element is exposed as a result of damage in the overshoe, or if the rubber is found to be tacky, swollen or deteriorated (as a result of contact with oils or solvents) the overshoe should be removed and replaced by a serviceable one.

3.1.2 Cable assemblies should be examined for signs of cracking or fretting, security at the root ends of propeller blades, at sliprings and brush block housings. When blades have been turned through their operating pitch range, cables should also be checked for signs of strain.

3.1.3 In the case of an element having burned out, the overshoe must be removed. Before installing a serviceable overshoe, the metal of the relevant blade should be examined for signs of damage as a result of localised burning. Where element burn out has resulted in localised areas of damage to the blade, the repair should be carried out in accordance with the Maintenance and Overhaul Manuals for the propeller concerned before a serviceable overshoe is installed.

NOTE: Depending on the type of propeller, it may also be necessary for a blade to be crack tested prior to the installation of a serviceable overshoe.

3.1.4 When a heated spinner is removed, it should be examined for damage and security of the electrical contacts and heating elements, together with areas of local overheating and non-adhesion to ensure that the latter do not exceed the permissible limits specified in the Maintenance and Overhaul Manuals. On metal spinners, shallow and uniform dents are permissible provided the elements are secure in the region of any such indentations but may be blended out with the elements intact, provided every care is taken to avoid damage to the elements, and the rework is in accordance with specified procedures. After such rework the elements must be thoroughly examined for "lifting" and other damage, and checks should be made on the resistance values of the elements, and on the continuity and insulation resistance of complete overshoes. Fibreglass spinner shells should be examined for signs of delamination resulting from local overheating or damage.

3.2 Brushes and Slip Rings

3.2.1 Brushes should be checked for wear, damage, cleanliness and freedom of movement in their respective holders. Permissible wear limits, which are normally related to the length of brush extending beyond the face of the brush block housing, are given in the appropriate aircraft and propeller Maintenance Manuals together with the methods of measurement to be adopted. Special measuring gauges are provided for some brush gear assemblies and these should always be used. Brushes worn beyond limits, must be replaced by new ones together with new brush springs.

3.2.2 Before fitting a brush, the brush holder must be thoroughly cleaned with a dry cloth or small spiral hair brush; solvents must not be used.

3.2.3 Brushes must be free to slide in their respective holders, and particular attention must also be paid to their precise location with respect to each other. In some installations, a means of position identification is provided. For example, in one typical system, the brushes have a chamfered corner which must be nearest to the centre of the brush holder when the brushes are in the correct position.

NOTE: Brushes are fragile and care must be taken to avoid placing any side loads on them during installation.

3.2.4 When a new brush has been fitted, at least 80 per cent of the face must make contact with the slip ring. A typical method checking this is as follows:—

(i) Inspect and note the appearance of the brush surface.

(ii) Ensure that the brush is correctly positioned in its holder and that the holder is secure.

(iii) Turn the propeller by hand for several revolutions.

(iv) Remove the brush and examine the contact area which will be apparent from the changed appearance of the brush face.

3.2.5 Whenever a brush block, or pack assembly, has been fitted, the alignment of the brushes with the slip ring surfaces, and also the clearance between the main body of the brush block and slip rings, should be checked through a complete revolution of the propeller. If the clearances are not within the specified limits, the brush block should be repositioned on its mounting in the manner appropriate to the particular installation. In some installations, shims are provided for adjustment purposes; when a brush block or pack assembly is removed the shims must be retained with the assembly.

NOTE: The brush packs of propellers used with certain types of turbopropeller engines, are individually weight balanced on initial assembly. When installing or removing such packs, care must be taken not to interchange their component parts otherwise rebalancing will be necessary.

3.2.6 Following the installation of a new brush, functional testing of the complete de-icing system should be delayed until other engine ground running checks have been completed. This will allow brush bedding to take place before heating current is applied.

3.2.7 Slip rings should be checked for security of attachment, signs of scoring, discolouration as a result of burning and for deposits of oil, grease or dirt. The insulation filling fitted between the slip rings of certain types of propeller should also be inspected for separation from the slip rings, flaking and localised damage to the surface of the filling. If the defect is of a minor nature, a repair should be carried out in the manner prescribed in the relevant propeller Maintenance Manual.

NOTE: On completion of a repair to the insulation, an insulation resistance test must be carried out.

3.2.8 Dirty slip rings should be cleaned by wiping with a lint free cloth moistened with white spirit, or by spraying them with a specified cleaning fluid from an aerosol type container. The surfaces should be dried and cleaning operations completed using a clean, soft, lint free cloth.

3.3 **Electrical Checks and Tests.** The checks and tests necessary to ensure correct functioning of a complete propeller de-icing system consist of those mentioned in the following paragraphs. The information given is of a general nature only and should be read in conjunction with the relevant propeller Maintenance Manual and approved Maintenance Schedule.

3.3.1 **Continuity and Heater Resistance Checks.** Continuity checks and measurement of the resistance of individual heater elements must be carried out before installation of a propeller, at the prescribed inspection periods, and following any repairs to overshoes. The resistance values obtained must be within the limits specified for the type of propeller.

3.3.2 **Insulation Resistance Checks.** These checks are necessary to determine whether there is any breakdown of the insulation between heater elements, blades and, where appropriate, the propeller spinner. The insulation resistance between brush gear and earth must also be checked.

(i) During service, the insulation resistance of heater elements may vary as a result of moisture absorption caused by atmospheric conditions. Tests must therefore also be carried out at the prescribed inspection periods, to ensure that the resistances have not fallen below the specified minimum "in service" values (2 to 4 megohms are typical).

NOTE: When checking the insulation resistance of some types of propeller de-icing system, account must also be taken of the specification of cement used for bonding the elements to the blades since the cement has a direct bearing on the resistance values obtained. The limits relevant to the cement specifications are usually presented in the form of graphs, and are contained in the relevant propeller Maintenance Manual.

3.3.3 **Voltage Proof Check.** This check is required for some types of propeller following repairs to the heater element overshoes. The leads from all the heater elements are connected together and a high voltage (typical values are 1360 volts d.c. or 960 volts a.c.) applied between the leads and the blade. The voltage should be maintained for not less than one minute and a check made to ensure that there is no breakdown of insulation resistance.

NOTE: The voltage must be increased and decreased gradually.

3.3.4 **System Tests.** Functional testing of a complete de-icing system must be carried out at the check periods specified in the approved Maintenance Schedules, when a system malfunction occurs, when a new or overhauled propeller has been installed, after replacement of a component (e.g. a cyclic timer, heater element or brush pack) and also after repairs to an overshoe. A functional test consists principally of checking that heating current is applied to the blade elements and spinner elements, where applicable, at the periods governed by the operation of the cyclic time switch, and as indicated by an ammeter which forms part of the circuit in the majority of installations. Particular attention should be paid to any limitations on supply voltages to the propeller heating elements, and engine air intake elements where appropriate, engine speeds and duration of tests during ground running. If any protective devices or sections of circuit have been temporarily isolated for testing purposes, the circuit must be restored to normal operating conditions on completion of tests.

4 REPAIRS Damage to an overshoe in the form of cuts, nicks, tears, lifting edges, etc., may be rectified as a minor repair, provided the overshoe is electrically serviceable and the blade metal beneath the overshoe has not suffered damage. Cutting back or cropping a worn or damaged overshoe tip is not permissible. Damaged, worn or missing anti-erosion strips fitted along overshoe or blade leading edges, must be renewed as a minor repair. Any damage to blade leading edges beneath a strip, should be repaired before fitting a new strip. Where a metal guard is fitted along the leading edges of an overshoe and a blade, only local lifting at the edges of a guard should be re-bonded as a minor repair.

4.1 **Repair Methods.** The repair methods to be adopted and the nature of the work involved, depend largely on the extent of damage to the overshoes. Repair schemes, the materials required, and procedures to be adopted, are detailed in Maintenance Manuals and Overhaul Manuals for the relevant type of propeller; reference must therefore be made to these documents. In some cases, the necessary primers, cements, sealing paints, anti-erosion strips and general materials for carrying out minor repairs are available in kit form. The following summary serves as a guide to some important precautions and practical aspects common to repair methods.

4.1.1 It cannot be over-emphasised that chemical cleanliness of surfaoes is absolutely essential to obtain good adhesion. All cleaning should be carried out, particularly in the repair area, with a clean lint-free cloth moistened in the cleansing agent specified, e.g. methyl ethyl ketone or acetone. Swabbing, or the use of excessive quantities of cleansing agent, should be avoided, and adequate masking should be employed, where necessary, to protect adjacent serviceable parts or components.

NOTE: Cleansing agents are highly flammable and some may be toxic. Cleaning should therefore be carried out in a well ventilated area, free from excessive heat, sparks or open flames and prolonged exposure to the fumes should be avoided.

4.1.2 After surfaces have been cleaned and the specified primer and cement applied, they must not be contaminated by foreign matter or moisture of any kind. To prevent contamination by handling, gloves made from polyvinylchloride (p.v.c.) should be worn.

4.1.3 To ensure that moisture is not trapped under repairs, all damaged areas must be completely dried out before repairing; failure to observe this precaution may lead to the start of corrosion under the repairs.

4.1.4 After cleaning, sufficient time must elapse to ensure that the cleansing agent has evaporated before applying the bonding medium to the surfaces.

4.1.5 Where anti-erosion components are being initially fitted to leading edges of painted blades, the paint should be removed from the relevant area with specified paint remover. Similarly, sealing paint must be removed from overshoes before initially fitting anti-erosion components.

4.1.6 When an overshoe has split, worn or lifted at its edges or tip, it should be carefully peeled back at the damaged portion and the exposed area of the blade carefully inspected for signs of corrosion. Any light corrosion within the exposed area should be cleaned out and the reworked area of the blade blended into the adjacent surface in accordance with the blade repair procedures specified in the propeller Maintenance Manual. The exposed metal surface and, if necessary, the under surface of the overshoe, should be cleaned with a cleansing agent and after drying, the overshoe should be rebonded to the blade.

NOTE: If corrosion is excessive or extends beyond the area exposed by lifting of the overshoe, the latter should be removed and following reworking and cleaning of the blade surface, a primer should be applied and a new overshoe bonded to the blade.

4.1.7 The cement specified for the repair of overshoes and their complete bonding to a particular type of propeller, may vary between a ready-to-use type and a type which firstly requires the mixing of two constituent parts in definite proportions. Details of the cement specification and the mixing procedure where appropriate, are given in the relevant propeller Maintenance Manual and reference should therefore be made to this document. The following points should be particularly noted:—

(i) The drying time should be correct in relation to local temperature and humidity conditions.

(ii) The bonding efficiency of a cement should be tested before final application. A typical test is carried out by firstly preparing one surface of a duralumin test plate in a similar manner to the surface of a blade, and also the surface of a 1 inch wide strip of rubber cut from an old overshoe. Cement is then applied to both surfaces and allowed to dry for the specified period. The surfaces are then pressed into contact and the test plate firmly mounted on a bench so that the test strip is in the vertical position. A 10 pound weight is then attached to the upper end of the strip and the rate at which the strip separates from the plate is noted. The rate should not exceed 1 inch per minute over a distance of 6 inches.

(iii) Prepared cements have a certain "life" after mixing (e.g. 2 hours) and they must, therefore, always be used within the time specified.

4.1.8 Small slits or nicks should be repaired by applying cement to the edges and, after allowing it to become tacky, the edges should be pressed firmly together. A bandage, made up of thin rubber strip and a soft pliable pad, may be used to apply pressure to local areas.

4.1.9 Where damage cannot be repaired in the manner described in paragraph 4.1.8, or where small portions of rubber are missing from an overshoe, repairs should be carried out by using a filler paste which is made up by mixing rubber dust with an epoxy resin adhesive.

(i) After removing all loose and damaged rubber from the area and after thorough cleaning, the paste should be applied and worked into the area by means of a suitable spatula. The filler should be allowed sufficient time to cure until hard and its surface should then be blended into that of the overshoe by using a medium grade file. The repair should be finished off with a fine grade silicon carbide paper.

NOTE: Uncured epoxy resin adhesives should not be allowed to come into contact with the skin or eyes. All other recommended precautions associated with the handling of these adhesives should be observed.

4.1.10 Before fitting a new overshoe, the bonding area of the blade should be masked off and then all traces of old cement and primer removed from the area by working over with a stiff brush and the specified cleaning agent. The bonded area should be finally cleaned with lint free cloth soaked in cleaning agent, and allowed to dry. Any traces of a solvent film, or of the cleaning agent, must be removed before applying a new coat of primer and bonding cement.

NOTE: In cases where an overshoe is to be bonded to a blade without a leading edge rebate, a template of the overshoe should first be prepared. After cleaning the blade, the template should then be laid over the area to be occupied by the overshoe with its centre line coincident with that of the blade leading edge, and the border of the bonding area marked out with a soft crayon.

4.1.11 Prior to applying cement to the bonding surface of an overshoe, the surface should be brushed with a fine steel wire brush and cleaned with the specified cleaning agent. No significant quantity of rubber should be removed during brushing as a reduction of rubber thickness may lead to an electrical failure of the heating element. The bonding surface must be allowed to dry out thoroughly.

4.1.12 A coat of cement should be evenly applied by means of a clean brush, to the prepared bonding surfaces of an overshoe and blade and then allowed to dry for the period determined for the particular type of cement being used (see also paragraph 4.1.7).

NOTE: To prevent the edges of an overshoe from curling while applying the cement, masking tape should be placed around the edges of the outer surface of the overshoe. The tape should be removed before installing the overshoe.

4.1.13 An overshoe should be positioned at the correct radial distance, and with its centre line coincident with that of the blade leading edge. Polyvinylchloride (p.v.c.) sheeting should be interposed between the flanks of the overshoe and blade to prevent premature adhesion of the bonding surfaces. Working from the leading edge towards the flanks, a rubber roller should be used to press the overshoe into contact with the blade, progressively removing the p.v.c. sheeting and taking care to prevent the formation of air pockets between the overshoe and blades. Any puckering or wrinkling of the edges of an overshoe must be worked out smoothly and carefully. Excess adhesive, which may have been rolled out at the overshoe edges, should be removed with a cloth moistened in a solvent, e.g. toluol.

NOTE: Metal or wooden rollers should not be used for the purpose of pressing overshoes into contact with blades as damage could be caused to the wire heating elements.

4.1.14 Cement should be allowed sufficient time to cure (a typical period is 24 hours at a minimum temperature of 20°C). When fully cured, a check should be carried out in the manner prescribed in the relevant Maintenance Manual, to ensure that the required standard of adhesion has been achieved. Following the satisfactory bonding of an overshoe, an insulation resistance check should be carried out (see also paragraph 3.3.2 (i)), the outer surfaces of the overshoe should be degreased and a coat of sealing paint applied.

4.1.15 Reference should be made to Maintenance Manuals and other relevant documents concerning any requirements for rebalancing a propeller after a new overshoe has been fitted. Propellers for some types of aircraft have moment-balanced overshoes to obviate rebalance of the hub and blade assembly after a new overshoe has been fitted.

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AIRCRAFT

ELECTRICAL EQUIPMENT

BATTERIES—LEAD-ACID

1 INTRODUCTION This Leaflet gives general guidance on the installation and maintenance of aircraft general purpose lead-acid batteries.

1.1 The information given should be read in conjunction with the Maintenance Manuals and Overhaul Manuals issued by the battery manufacturers, relevant aircraft Maintenance Manuals and approved Maintenance Schedules. Reference should also be made to the following Leaflets and British Standards which contain information closely associated with the equipment covered by this Leaflet.

EEL/1-2 Carbon-Pile Voltage Regulators – D.C. Generator Systems

EEL/1-4 D.C. Generators

BS 89 Electrical Indicating Instruments

BS G205 Part 1 Secondary Batteries (Acid and Alkaline) General Requirements

BS 3031 Sulphuric Acid for use in Lead-Acid Batteries.

2 GENERAL CONSTRUCTION Lead-acid batteries vary in type principally in the thickness of their plates and the type of separators employed. In the conventional type, groups of positive plates, negative plates and separators, are assembled in such a way that the electrolyte solution of sulphuric acid and distilled water can flow freely around the plates. In some types of battery however, the plates and separators are compressed to form a solid block, the separator material being such that it absorbs electrolyte and leaves only a small amount free above the block.

2.1 The cell groups are located within containers made of a shock-resistant and acid-resistant material, e.g., polystyrene, and are linked by terminal connecting strips. Vents and plugs are fitted to each cell and are designed to allow gas to escape without leakage of electrolyte. In batteries utilising solid block type cells, the cells are grouped into single blocks (e.g. a 24-volt battery has two single blocks each comprising six individual cells) and are usually enclosed within a polyester bonded fibreglass outer container which also supports the main terminal receptacle.

3 CHEMICAL PRINCIPLE During charging the active material on the positive plates of a cell is converted to lead peroxide and the material on the negative plates to spongy or porous lead. Sulphuric acid is returned to the electrolyte during the charge, gradually strengthening it until the fully charged state is reached. In the charged condition and after a battery has been standing for a specified time (e.g. 8 hours) the open circuit voltage of a cell should be 2·10 to 2·20 volts.

3.1 When discharging, both the positive and the negative plates are partially converted to lead sulphate. The sulphuric acid is diluted as part of the process by the formation of water. If lead sulphate in a more permanent form is produced on the plates due to excessive discharge, or other misuse, this will act as a high-resistance component impairing the efficiency and recoverability of the battery.

4 MAINTENANCE The information given in the following paragraphs is intended to serve as a general guide to maintenance practices and precautions to be observed. Precise details concerning a specific type of battery are given in the relevant manuals and approved Maintenance Schedules, and reference must be made to such documents.

4.1 **Safety Precautions.** Lead-acid batteries must be prepared for service, charged, tested, and generally maintained, in a well ventilated workshop area entirely separate from that used for the servicing of nickel-cadmium batteries. This also applies to servicing and test equipment, tools and protective clothing, all of which should be identified as being for use in lead-acid battery servicing only.

4.1.1 Alkaline solutions must not be allowed to come into contact with batteries, otherwise severe damage to cells will result.

4.1.2 When handling batteries, or acid, a rubber apron and rubber gloves should be worn; in addition, when dealing with acid, goggles should be worn. After use, these articles should be rinsed free of acid and dried thoroughly. To avoid cracking, or perishing, they should be stored in a cool place, the aprons being hung with as few folds as possible. The gases given off by batteries are highly explosive. Naked lights therefore, should not be used at any time to examine a battery.

4.1.3 Containers made of a suitable material such as glass, glazed earthenware or ebonite or, alternatively, utensils having a lead lining, should always be used for handling acid or distilled water. When transferring fluids from containers a suitable funnel should be employed.

NOTE: Containers filled with distilled water should be stored separately from those containing acid. All containers should be suitably marked, indicating their contents.

4.1.4 When acid has been spilt on the floor of the workshop area or on benches, it should be removed by firstly, washing the affected surfaces with water, then neutralised by washing with sodium bicarbonate solution and lastly, washed again with water.

NOTE: Water and neutralising solution should be soaked up with sawdust, which should afterwards be removed and buried or burned.

4.1.5 If electrolyte comes into contact with the skin, the affected area should firstly be washed with cold water, then neutralised by washing with a sodium bicarbonate solution and lastly, washed with warm water. In the event of electrolyte being splashed into the eyes, they should firstly be washed with cold water, then bathed with 5 per cent solution of sodium bicarbonate, and then again washed with cold water. Immediate medical attention should be obtained in the event of skin burns or eye injury.

4.2 **Inspection Before Charging.** All batteries must be inspected before charging and before installation. The following checks are typical of those comprising a battery inspection schedule:—

(i) The outside of the battery case should be examined for signs of damage and evidence of locally overheated areas.

(ii) The cover, sealing gaskets, or mats, as appropriate to the type of battery, should be in good condition.

(iii) There should be no evidence of arcing having occurred between the battery and the aircraft structure. If signs of arcing are present, the aircraft battery compartment should be checked to determine whether any insulation provisions have failed, and the necessary remedial action taken. The battery should be cleaned as necessary.

(iv) The tops of cells should be inspected for signs of electrolyte leakage, and cleaned and dried where necessary.

(v) The battery receptacle should be checked for evidence of burns, cracks and bent or pitted terminals. Defective receptacles should be replaced, because they cause overheating and arcing, and may depress output voltage, which will result in premature battery failure.

(vi) All terminals and any exposed cell connecting links must be checked for security, evidence of over-heating and corrosion. The terminal nuts, where appropriate, should be tightened to the specified torque values. An acid-free petroleum jelly (e.g. white vaseline) or a silicone base grease, should be lightly smeared onto terminal contacts, connector pins, etc.

NOTE: A loose cell link can generate heat and cause arcing which may ignite battery gases.

(vii) Vent caps should be checked for security and to ensure that gas exit holes are clear.

4.2.1 Extreme care must be exercised when working around the top of a battery with the cover removed to avoid dropping tools onto the cell connecting links as severe arcing will result, with possible injury to personnel and damage to the battery. Rings, metal watch straps and identification bracelets should not be worn, thereby preventing contact with connecting links and terminals.

4.3 **Initial Filling.** A dry uncharged battery must be filled with an electrolyte consisting of battery grade sulphuric acid (see BS 3031) at the relative density recommended by the manufacturer of the particular type of battery, this data being given with the other instructions for filling and charging.

NOTE: The relative density of the acid should not be more than 1·300. It is recommended that the acid suppliers be required to lower the relative density to 1·300 (corrected to a temperature of 15°C (60°F)) prior to delivery.

4.3.1 Filling should be carried out methodically to avoid missing any cells. This can be ensured by removing the plug from No. 1 cell and filling as required, then removing the plug from No. 2 cell and fitting it to No. 1 cell, after which No. 2 cell should be filled and fitted with the plug from No. 3 cell. This procedure should be followed for each cell in numerical order, until the last cell is fitted with the plug from No. 1 cell. On batteries that fill slowly, e.g. those with a solid block plate arrangement which fill by absorption, the vent plugs should be left off until no more electrolyte is absorbed and the free electrolyte level remains constant.

4.3.2 Although the required electrolyte level will vary with the type and make of battery concerned, in all cases it must cover the top of the plates.

NOTE: When poured into the cells, the electrolyte must be at, or only very slightly above, ambient temperature and, if it is obtained by diluting concentrated acid, it must be allowed to cool before use. When diluting concentrated acid, the acid must always be added to the water (at a controlled rate) and never vice versa, since the latter procedure can be extremely dangerous.

4.3.3 After filling, the battery should be allowed to stand for 6 to 8 hours (depending on the manufacturer's instructions for the particular type of battery) so that the battery can cool down, after which the electrolyte level should be restored by adding more electrolyte of the same relative density; the battery is then ready for initial charge.

4.3.4 The relative density of the electrolyte is generally related to a temperature of 15°C (60°F). Readings taken at other temperatures should, therefore, be corrected to 15°C (60°F) as follows:—For the Celsius scale, 0·003 (3 points) should be added to the hydrometer reading for each 4°C by which the temperature of the electrolyte is above 15°C, or 0·003 (3 points) should be subtracted from the hydrometer reading for each 4°C by which the temperature of the electrolyte is below 15°C. Similarly, for the Fahrenheit scale, to correct to 60°F, 0·001 (1 point) should be added or subtracted for every 2·5°F above or below 60°F.

4.3.5 For batteries which are to be used in climates where the temperature frequently exceeds 32°C (90°F) manufacturers sometimes recommend the use of an electrolyte of reduced relative density. For example, a battery may be filled with electrolyte of density 1·260 in temperate conditions, but in tropical conditions the density of the electrolyte may be reduced to 1·230 resulting in a fully charged density of 1·240 to 1·255.

4.4 **Charging Conditions.** When charging several batteries, they should be of the same capacity rating, at the same state of discharge and the same recommended charging rate, and connected in series. The number of batteries which may be so connected depends on the voltage available in the charging circuit.

4.4.1 Each group of batteries should be connected to a separate circuit containing an ammeter, voltmeter, variable resistance and other relevant controls.

NOTE: Ammeters and voltmeters should be of the moving coil type, or digital presentation type, and checked for accuracy at the periods specified for the charging equipment. Accuracy should be within the values specified for the appropriate type of instrument (see BS 89).

4.4.2 All supply leads and connecting cables must be well insulated, of ample cross-sectional area and kept as short as possible. Free ends of cable wires should not be connected to batteries; use should be made of cable end lugs or connector plugs of the type specified for the battery. All connections should be firmly made to give good electrical contact before switching on the charging equipment. To prevent reverse charging, the polarity of the supply leads should be checked with the aid of a centre zero type voltmeter.

4.4.3 It is preferable that neither pole of the charging circuit should be earthed, but if one pole is earthed, it is recommended that the controlling resistance should be between the battery and the unearthed pole.

4.4.4 Batteries requiring different charging rates should not be charged in series, but if this is not possible the limiting current should be that of the battery requiring the lowest charging current.

4.4.5 Vent plugs should be completely unscrewed and lifted, but left in the vent holes before charging is commenced. They should remain in this position during the whole period of charge.

4.4.6 When ready to charge, the variable resistance in the charging circuit should be set in the position of maximum resistance (i.e. minimum current) the charging circuit should be switched on, and the current should be adjusted to the value specified for the particular type of battery.

4.4.7 Charging should, when practicable, be continuous until a fully charged condition is indicated. If charging is interrupted, and batteries are to be left unattended after switching off, both positive and negative supply leads should be disconnected from the batteries.

4.4.8 When cells commence gassing, the voltage and relative density should be measured periodically. In the fully-charged state both values should remain steady.

4.4.9 If a battery in a group should reach the fully-charged condition before the others, the charging circuit should be switched off and the charged battery disconnected. The charging current should then be re-adjusted to a value suitable for continuing the charge of the remaining batteries, and the charging circuit switched on again.

4.4.10 If there is any indication of electrolyte spillage, the affected parts should first be rinsed with water, then with a solution of water and washing soda, and finally sponged with clean water and thoroughly dried. A re-check should be made after 24 hours for any further signs of electrolyte spillage, or corrosion.

4.5 **Charging.** The charging of batteries may be related to the three conditions under which they are normally available. The three conditions are: (a) dry and uncharged and requiring filling and initial charge, (b) filled but uncharged and requiring initial charge, and (c) in service and requiring recharging.

NOTE: In tropical conditions it is often recommended that the batteries are charged at half the usual rate, with double the charging time.

4.5.1 **Batteries Received Dry and Uncharged.** After filling in accordance with specified procedures (see also paragraph 4.3) batteries should be charged, using direct current of correct polarity, at the "initial" charging rate recommended by the battery manufacturer; this will vary from 1 ampere to 5 amperes for a total charging time of about 24 hours.

(i) The charge should not be considered complete until the voltage and the relative density (if applicable) of each cell remain constant for the period specified for the type of battery. This period is usually between 3 and 5 hours.

(ii) The electrolyte temperature should be checked frequently during the charging period and must not exceed the temperature specified by the battery manufacturer. If the maximum temperature is exceeded the charge should be stopped until the electrolyte temperature has dropped by the specified amount (usually about 12°C (22°F)); or the charging current may be halved and the charging time doubled.

(iii) On completion of the charge, any gas in the electrolyte should be released by gently rocking the battery, the electrolyte level then being adjusted as specified by the battery manufacturer.

4.5.2 **Batteries Received with Electrolyte.** A battery of the type which forms a solid block with the plates and separators is normally despatched already filled with electrolyte.

(i) On receipt of the battery the vent plugs should be removed and the level of the electrolyte checked to ensure that it is approximately ¼ in above the perforated strip and, if necessary, adjusted to this level using sulphuric acid of relative density 1·270.

(ii) The battery should receive a charge current at a value appropriate to the ampere-hour rating of the battery, until the voltage is stable over five consecutive half-hourly readings. Should the temperature of the electrolyte reach 60°C (140°F), the charge should be interrupted until the temperature falls below 43°C (110°F).

(iii) During the charge the vent plugs should be kept in, but not screwed down. If the battery was properly filled it should not require any topping up during this time. If the electrolyte level disappears, acid of relative density 1·270 should be added; if the electrolyte level is high the excess should be withdrawn.

4.5.3 **Re-Charging a Battery in Service.** The electrolyte level should be checked and, if necessary, adjusted with distilled water, and the battery put on charge at the normal rate recommended. In a fully charged condition, all the cells should gas freely and the relative density of the electrolyte should be within the limits given when corrected for temperature. The main terminal voltage should, under normal temperature conditions, be between 30 and 32·4 volts when measured with the charging current flowing. The charge should be continued until the readings are constant for 3 hours.

NOTE: At all times during charging, a check should be kept on the battery temperature to ensure that the maximum permissible limit is not exceeded.

4.6 **Electrolyte Level and Adjustments.** The periods at which adjustments to the electrolyte should be carried out vary largely with the state of charge and duty cycle of the battery.

4.6.1 The level in the cells must be maintained by the addition of distilled water, as only the water from the electrolyte is lost through electrolysis or evaporation. After initial charge the relative density of the electrolyte should not normally require adjustments, but, in exceptional cases, it may be adjusted in accordance with the manufacturer's instructions.

4.6.2 In order to ensure the mixing of acid with the distilled water, topping-up should be done immediately before a battery is put on charge. Adjustments must be to the correct level to prevent overflow of the electrolyte which could occur as a result of gassing and expansion during the charge. If a battery is to be exposed to very low temperatures, its charge after topping-up, should be prolonged for at least one hour. This will ensure thorough mixing of the electrolyte and thereby avoid the possibility of the water freezing. An additional precaution against freezing is to maintain the battery in a fully-charged state.

4.6.3 For some types of battery, special fillers may be necessary to ensure correct electrolyte level but, in general, the level is specified as a measurement taken from the top of the separator guards or plates.

4.6.4 After adding distilled water, it should be borne in mind that relative density readings cannot be relied upon until the electrolyte and water have been mixed by the gassing of the cells whilst on charge.

4.6.5 A record of the quantity of water added to battery cells should be maintained, since frequent additions are grounds for rejection of cells.

4.6.6 If, one hour after charging, the electrolyte level falls below the specified value, the battery should be reconnected to the charging equipment and the electrolyte level adjusted with the battery on a low charge and slightly gassing.

4.7 **State of Charge.** On reaching the fully-charged condition, a lead-acid battery displays three distinct indications: (i) the terminal voltage ceases to rise and remains steady (e.g. 31 volts for a new battery) with charging current flowing, (ii) the specific gravity of the electrolyte ceases to rise and remains constant, and (iii) both sets of plates gas freely. In the conventional type of lead-acid battery all three indications must be in evidence before the battery can be regarded as being completely charged.

NOTE: The terminal voltage at the end of charge normally diminishes with the age of a battery. If it is equal to, or below, 28·5 volts a battery should not be put back into service.

4.7.1 In the case of batteries using cells of solid block construction, the state of charge is indicated by the open circuit voltage and gassing. Relative density readings cannot be made since there is insufficient free electrolyte. The method of carrying out an open-circuit voltage check is given in the following paragraphs, the current and voltage values being based on a typical 24-volt 18 ampere-hour (one-hour rate) battery.

(i) Connect the battery to a load that will take approximately 20 amperes, and after current has been flowing for 15 seconds, measure the on-load voltage.

(ii) Disconnect the load and take an off-load voltage reading immediately; the increase in reading from on-load to off-load should be approximately 1 volt if the battery is in good condition.

(iii) The state of charge is assessed from the off-load voltage. If the voltage is between 25·1 volts and 25·8 volts the battery may be regarded as fully charged. An off-load voltage of between 24·5 volts and 25·1 volts indicates a battery that is from half to quarter discharged. A half-discharged battery will indicate an off-load voltage of between 24·2 to 24·5 volts.

4.8 **Capacity Tests.** A capacity test should be carried out after initial charge, and thereafter at intervals of three months, or at any time the capacity of a battery is in doubt. Details of test methods are given in the relevant manuals.

4.8.1 The battery should be fully charged (see paragraph 4.4) and then connected to a suitable discharge control panel incorporating a variable-load resistance, an ammeter and an ampere-hour meter. A separate voltmeter is necessary to measure voltage at the battery terminals, or cell connecting strips.

NOTE: If the control panel is not of the automatic type, or if no ampere-hour meter is incorporated, accurate monitoring and control of current must be maintained throughout the tests.

4.8.2 The battery should then be discharged at a rate corresponding to the rating of the battery (as detailed in the appropriate manuals, e.g. an 18 A.H. battery rated at the 1 hour rate would be discharged at 18 amps) until the battery reaches its fully discharged condition. This condition is denoted by the main terminal voltage, or the relative density of the electrolyte, falling to the respective fully discharged values for the particular type of battery. The minimum acceptable capacity for use on aircraft is 80 per cent which, in the case of the example rating quoted, provides a duration of discharge equal to 48 minutes. The result, however, should be compared with previous readings to assess rate of deterioration.

4.9 **Insulation Resistance Test.** This test should be carried out at the periods specified in the approved Maintenance Schedule and at any time that electrolyte leakage is suspected.

4.9.1 The battery should be fully charged (see paragraph 4.5) and the case and cell tops wiped dry. It should then be fitted to a metal base plate by the fixing method normally used in the aircraft. A test should be made between one terminal of the battery and the base plate, using a 250-volt insulation tester, and the minimum insulation resistance obtained must be not less than one megohm. If a reading below this value is obtained, the battery should be checked for presence of moisture, leaking case, or vented electrolyte, and remedial action taken in accordance with the procedures specified in the relevant manual.

4.10 **Leakage Test.** If there is no apparent visible damage to a battery, it should be given a leak test using the tester designed for the particular type of battery. Vent caps should be removed, and with the tester held firmly over each vent in turn, a pressure of $14kN/m^2$ ($2\ lbf/in^2$) should be applied by means of the pump on the tester. There should be no detectable leakage after a period of not less than 15 seconds.

5 INSTALLATION Before installing a battery it should be ensured that it is of the correct type, fully charged and the electrolyte is at the correct level (see paragraphs 4.4 and 4.6). A capacity test and insulation resistance test must also have been carried out in the manner prescribed for the particular battery (see also paragraphs 4.8 and 4.9). In aircraft using batteries in parallel, it is important to ensure that all batteries are at the same state of charge. Reference should be made to the relevant aircraft Maintenance Manual for details of the battery system and associated installation instructions. Before coupling the battery connecting plug, a check should be made to ensure that the battery system is switched off and that all electrical services are isolated.

NOTE: Batteries are heavy units and require the use of approved and careful handling methods to prevent possible injury to personnel, and damage to the cases or components adjacent to the battery location.

5.1 The battery compartment should be clean, dry and free of any acid corrosion or damage. Apart from the mounting tray, which is usually made of an acid-resistant material, the structure adjacent to the battery compartment should be treated with an acid-resistant paint as a protection against the corrosive acid fumes from the battery.

5.2 When a battery is located in its compartment, it should be ensured that it is securely attached and that the appropriate clamps, or bolts are not over-tightened.

5.3 Terminal contacts or connector pins should be lightly coated with an acid-free petroleum jelly (e.g. white vaseline) or a silicone base grease.

5.4 The supply cables from the battery should be checked for signs of chafing or other damage; connecting terminals or plugs must be secured without any strain on the terminals, plugs or cables.

5.5 Battery installations are normally designed so that in flight, sufficient air is passed through the compartments to dilute the gases given off by the battery, to a safe level. Ventilation systems should therefore be checked to ensure there is no obstruction or, if integral venting is used, the system connections should be checked for security and freedom from leaks.

NOTE: In some ventilation systems, non-return valves are incorporated in the battery compartment vent lines. These valves should also be checked for security and correct location.

5.6 After installation, a check should be made that the electrical connections of the battery supply cables have been correctly made by switching on various electrical services for a specific time period and noting that readings of the aircraft voltmeter remain steady.

6 MAINTENANCE OF INSTALLED BATTERIES Batteries should be inspected at the periods specified in the approved Maintenance Schedule. The details given in the following paragraphs serve as a guide to the checks normally required.

6.1 The battery mounting should be checked for security and the outside of the battery base examined for signs of damage and evidence of local overheating. The latches of the cover should operate smoothly and firmly secure it in position.

6.2 Connector lugs or plug pins, should be checked for security and for signs of contamination, burns, cracks, bending or pitting.

6.3 Cables should be examined to ensure that their protective covering has not been damaged, and that they have not been affected by dampness or by general climatic conditions prevailing in the battery compartment.

6.4 The tops of all cells and vent caps should be inspected for signs of electrolyte leakage and cleaned where necessary.

NOTE: When removed, the cover of a battery and cell vent caps should not be placed on any part of the aircraft structure or equipment.

6.5 Depending on the type of battery installed, either the relative density, or open-circuit voltage, should be checked to ensure that the values obtained are within the permissible limits.

6.6 The electrolyte level should be checked and, if necessary, adjusted with distilled water (see also paragraph 4.6). The amount of water added to the cells should be recorded. A cell requiring more than the specified amount should be regarded as suspect and the battery should be replaced by a serviceable unit.

NOTE: Batteries should be removed from aircraft in order to carry out electrolyte level adjustments.

6.7 The battery ventilation system should be checked to ensure security of connections and freedom from obstruction. Acid drain traps, where fitted, should be checked for signs of acid overflow and, if necessary, removed for cleaning.

6.8 During checks on a generator voltage regulator system, it must be ensured that the voltage setting does not cause excessive charging current to be fed to the battery system. A voltage set higher than the specified value, coupled with high ambient temperature, is the most common cause of battery overheating, resulting in a 'thermal runaway' condition and damage to the battery. In some cases consideration may have to be given to aircraft operating in extremely hot climates and the system voltage may have to be reduced. In such cases, the battery may then have to be operated slightly below its maximum capacity.

NOTE: Other factors which may cause 'thermal runaway' are inadequate battery ventilation, high relative density of the electrolyte or a low end-of-charge reading.

6.9 At the periods specified in the approved Maintenance Schedule, the battery must be removed from the aircraft for capacity and insulation resistance tests (see paragaphs 4.8 and 4.9).

7 BATTERY RECORDS A technical or service record should be maintained for each battery in service and should provide a fairly comprehensive history of each battery, so that in the event of a malfunction it will assist in determining the problem. The example shown in Figure 1 is intended only as a guide.

LEAD-ACID BATTERY—SERVICE RECORD

NUFACTURER: .... AIRCRAFT TYPE: ....

E OF MANUFACTURE: .... AIRCRAFT REGISTRATION:.....................

T No. & RATING: .... DATE INSTALLED: ....

AL No.:..

ATE	REASON FOR SERVICE S—Scheduled F—Failure	ELECTROLYTE LEVEL & ADJUSTMENTS (c.c. added)	ELECTRICAL CHECKS		LEAK TEST	CHARGE			REMARKS
			CAPACITY	INSULATION RESISTANCE (ohms)		RATE	RELATIVE DENSITY	END-OF-CHARGE VOLTS	

Figure 1

8 STORAGE AND TRANSPORTATION Lead-acid batteries should be stored in a clean, dry, cool, well-ventilated area entirely separate from nickel-cadmium batteries. The area should also be free from corrosive liquids or gases. New batteries may be stored either dry and uncharged, or filled and charged. Batteries of solid block construction may also be stored in the condition in which they are despatched by the manufacturer i.e. filled and uncharged. In this condition only the positive plates are formed so that the batteries remain inert until they are prepared for use. Batteries removed from service must always be stored in the fully-charged condition (see also paragraph 8.1.1). The appropriate storage limiting periods must be in accordance with those specified in the relevant manuals. Typical periods are 5 years in a temperate climate for charged or uncharged batteries and from 2 to 3 years in a tropical climate for uncharged batteries, and 18 months for charged batteries. If the storage limiting periods have been exceeded, uncharged batteries should be charged, bench checked or returned to the manufacturer for examination and re-lifing.

8.1 Charged batteries should be periodically inspected and given a freshening charge every 2 to 4 weeks. The capacity of batteries should also be checked during the storage period at a frequency which is dictated mainly by their condition. It is recommended that capacity tests be carried out every 6 months for new batteries, and every 3 months for batteries returned from service.

8.1.1 Batteries which have been in use and are discharged, should not be allowed to remain, or be stored in this condition, because of the danger of sulphation of the plates. The lower main terminal voltage limit appropriate to the type of battery should be checked and recharging carried out as necessary; a typical lower limit is 21·6 volts.

8.2 If it is necessary to return a battery to the manufacturer, or to an approved overhaul Organisation, it should be prepared in accordance with the transportation requirements specified by the manufacturer for the appropriate battery condition i.e. charged or uncharged. An up-to-date service record should accompany the battery and "This Way Up" international signs affixed to the container.

NOTE: If transportation is to be by air, the container must comply with IATA regulations concerning the carriage of batteries.

Issue 3.

June, 1979.

AIRCRAFT

ELECTRICAL EQUIPMENT

VOLTAGE REGULATION

1 INTRODUCTION This Leaflet gives guidance on the operating principles, installation and maintenance of voltage regulators. As details can vary between types of regulator, and as a result of the electrical power supply requirements of a particular type of aircraft, the information is of a general nature only, and is based on some typical voltage regulators in current use. This Leaflet should, therefore, be read in conjunction with the Maintenance Manuals and other approved documents for the voltage regulators concerned, and for the type of aircraft in which they are installed. Reference should also be made to the following Leaflets which contain information closely associated with voltage regulators.

EEL/1-1 Batteries—Lead-Acid
EEL/1-3 Batteries—Nickel-Cadmium
EEL/1-4 D.C. Generators
EEL/1-5 Power Supply—A.C. Generators
EEL/1-6 Bonding and Circuit Testing
EEL/1-8* Power Supply Systems
EEL/1-9* Circuit Protection Devices
EEL/3-1 Cables—Installation and Maintenance

1.1 The adjustments specified in this Leaflet form part of voltage regulator maintenance and checking procedures, and it is emphasised that manufacturer's recommendations should always be carefully followed as a mal-adjustment may cause extensive damage not only to the regulators but also to the associated generators and batteries.

2 GENERAL Voltage regulators are used in aircraft primary power supply systems to maintain the system voltage within the limits necessary for the correct operation of the associated electrical services. In addition, they are, in some cases, used to control the sharing of load between generators operating in parallel.

2.1 Depending on the size of the aircraft and design of the generating system, regulators may be of the single unit type operating in conjunction with separate reverse current cut-out relays, voltage differential sensing relays and paralleling relays, or integrated with these components to form special control units or panels.

3 PRINCIPLES The basic requirement of maintaining a substantially constant voltage in an aircraft power supply system is achieved by the automatic control of the generator field strength, using various types of voltage regulator. The principles of operation of some of these types are contained in the following paragraphs.

*Leaflets **EEL/1-8** and **EEL/1-9** will be published in a later batch of Leaflets.

3.1 **Carbon-pile Voltage Regulator.** The operation of the carbon-pile type of voltage regulator is based on the fact that the contact electrical resistance between faces of carbon discs varies not only with actual area of contact, but also with the pressure by which disc faces are held together. If therefore, a 'pile' of carbon discs or washers is connected in series with the shunt field winding of a generator (Figure 1) the resistance of the field circuit can be varied by adjusting the pressure applied to the 'pile'.

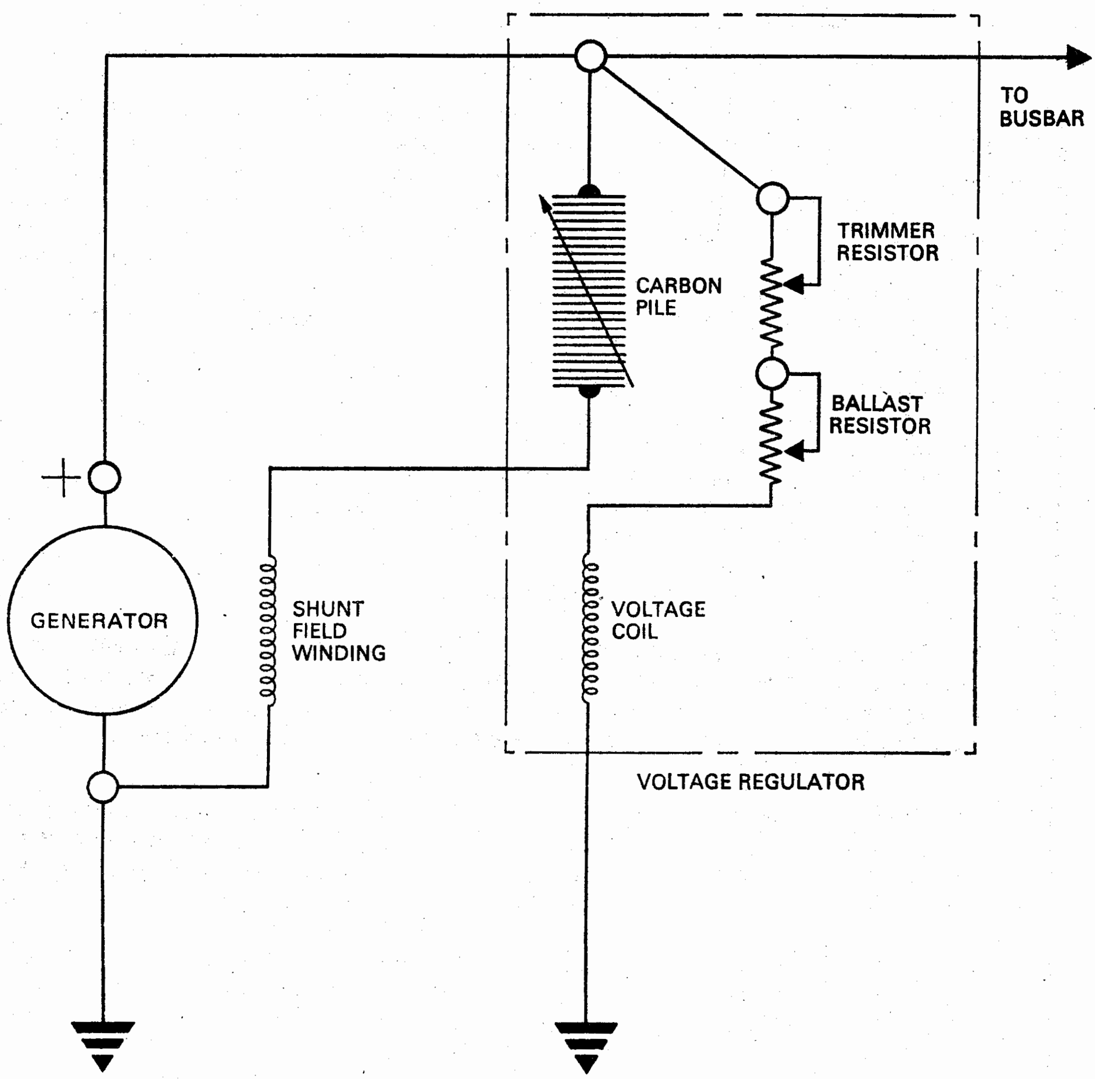

Figure 1 CARBON-PILE VOLTAGE REGULATOR PRINCIPLE

3.1.1 The necessary variation of pile compression is made through the medium of an electromagnet which opposes the compressive effect of a plate-type control spring (Figure 2). Under static conditions the compressive effect is at a maximum and carbon-pile resistance is at some minimum value. The electromagnet is energised by a voltage coil which is connected across the generator output terminals so that coil current and, consequently, electromagnetic force are substantially proportional to generator output voltage. As the rotational speed of the generator increases, the progressive increase in its voltage results in an increase of electromagnetic force until, at a pre-set voltage level, the electromagnetic force is balanced by the plate-type control spring. If the generator output voltage exceeds the pre-set level, the increase in electromagnetic force overcomes the force of the plate-type control spring and reduces the pile compression, thereby increasing the resistance of the generator shunt field circuit and thus checking the rise in output voltage.

3.1.2 **Construction.** The construction of a typical carbon-pile voltage regulator is shown in Figure 2. The pile unit is housed within a ceramic tube which, in turn, is enclosed in a solid casing or, more generally, a finned casing for dissipating the heat generated by the carbon pile. Electrical contact at each end of the pile is made by carbon inserts. The initial pressure on the pile is set by a compression screw acting through the pile on the armature and spring plate which is supported on a bi-metal washer. This washer compensates for temperature effects on voltage coil resistance and on any expansion characteristic of the regulator, thus maintaining constant pile compression. The electromagnet assembly comprises a cylindrical yoke in which is housed the voltage coil, a detachable end-plate and an adjustable soft-iron core (see also paragraph 3.1.3(b)). The cables from the voltage coil and carbon pile terminate at a connector block or plug on the end plate of the regulator.

3.1.3 **Regulator Adjustments.** Three separate adjustments are normally provided in carbon pile-voltage regulators: (a) voltage coil circuit resistance, (b) magnet core airgap and (c) carbon pile compression.

(a) **Voltage Coil Circuit Resistance.** Adjustment of voltage coil circuit resistance is accomplished by a ballast resistor, pre-set by the manufacturer, to give the correct ampere turns in the voltage coil at the nominal voltage to be controlled. In addition to the ballast resistor, a trimming resistor is also provided for raising or lowering the regulated voltage level within certain limits, after the regulator is installed in an aircraft.

(b) **Magnet Core Airgap.** The airgap between the magnet core and the armature is pre-set by adjusting the position of the magnet core within the end-plate of the electromagnet housing (Figure 2). The adjustment provides for optimum regulation at the nominal controlled voltage.

NOTE: In some older types of regulator a screw passes through the magnet core, limiting excessive armature movement and preventing the armature from adhering to the face of the core. In later designs this screw is not fitted.

(c) **Carbon Pile Compression.** Initial compression of the carbon pile is adjusted by the compression screw (Figure 2) to give the correct setting of the plate-type control spring, so that, over the working range of the pile, the spring and magnetic forces exactly counterbalance at any position of the armature. The setting of the screw may be regarded as the characteristic setting of the regulator, and determines the degree of regulation and the stability factor.

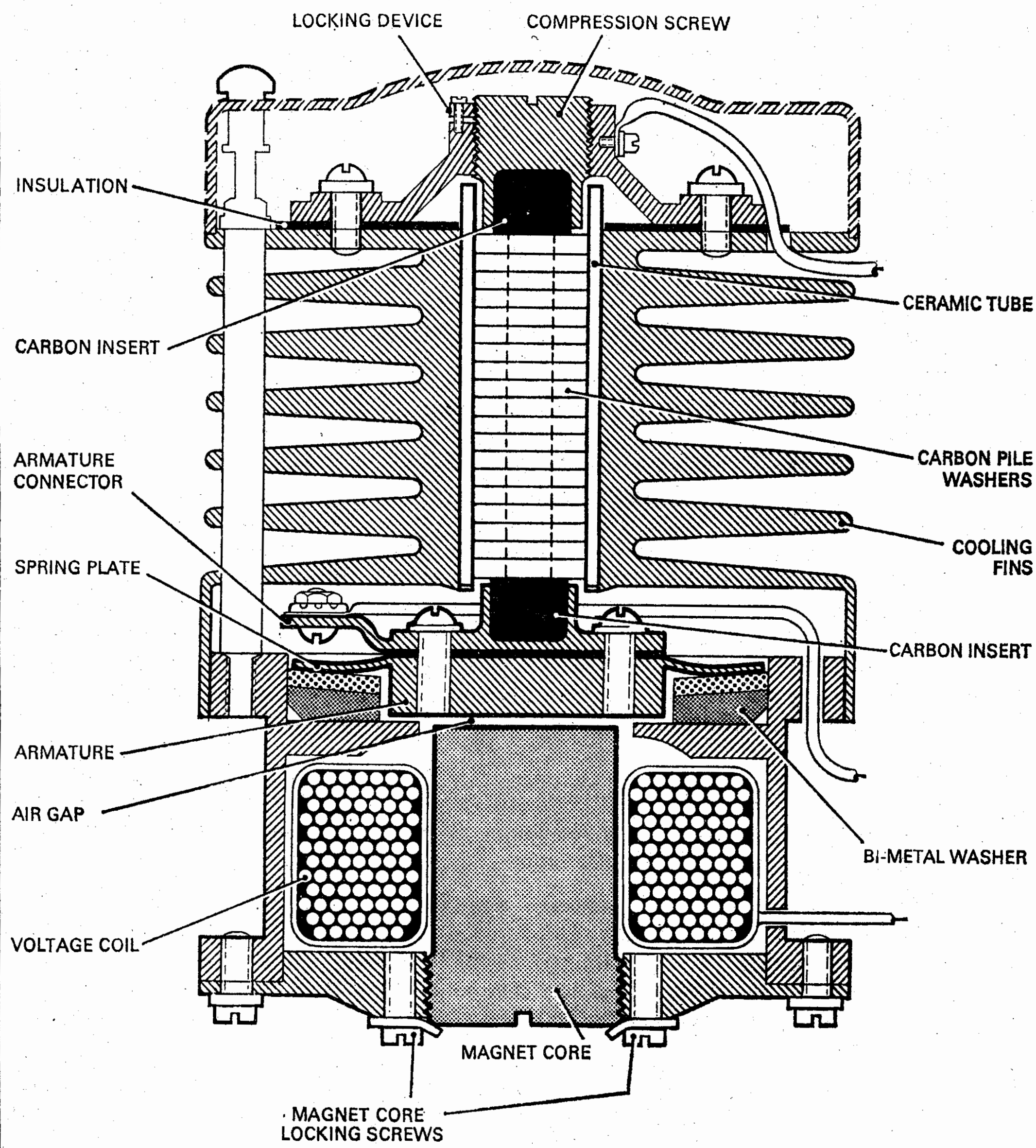

Figure 2 CARBON-PILE VOLTAGE REGULATOR CONSTRUCTION

3.2 **Vibrator-type Voltage Regulator.** This type of voltage regulator usually consists of a voltage regulator, a current limiter, and a reverse current cut-out relay housed in the one metal container.

3.2.1 **Principle of Operation.** The output from the generator armature, entering through terminal G (Figure 3) passes through the heavy coil of the current limiter and the current coil (series winding) of the reverse current cut-out relay, then to earth.

No current can flow to the battery or the load busbars until the points of the cut-out relay close. As the generator output voltage rises, the magnetic strength of the voltage coil (shunt winding) of the cut-out relay increases enough to close the contacts and put the generator 'on line'. Load current flowing through the cut-out relay current coil now aids the voltage coil in maintaining the contacts closed. The field coils of the generator are excited from the output of the armature, and the earth circuit of the field is completed through the contacts of both the voltage regulator and current limiter. When the voltage rises to its regulated value, the magnetic pull produced by both coils of the voltage regulator opens the regulator contacts. With the regulator contacts open, the earth circuit of the field now includes the resistor, and the field current drops, as will the output voltage. When the contacts open, the accelerator winding circuit is opened and its field collapses completely, rapidly decreasing the flux, so the spring can close the contacts more rapidly than if this winding were not used.

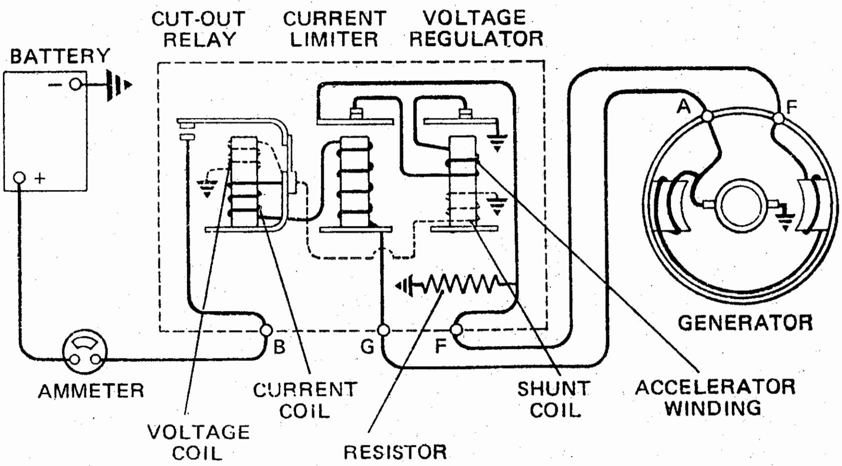

Figure 3 THREE-UNIT VIBRATOR-TYPE VOLTAGE REGULATOR

(a) Some regulators employ a second resistor in the regulator housing, in parallel with the generator field. When the field circuit is open-circuited and the field current begins to fall, the inductance of the coil will produce a voltage surge which would tend to cause arcing at the contact points; the purpose of the resistor, therefore, is to suppress the arcing. In normal operation, the contacts open and close between 50 and 200 times per second to maintain the voltage at a constant value.

(b) In some generators one end of the field is connected to the earthed brush, and a positive potential is on the field in the regulator to control the voltage (Figure 4). Before the voltage reaches the regulated level, current flows through the field from the armature of the cut-out relay, through both the voltage regulator and current-limiter contacts and through the earth in the generator. When the voltage rises to the pre-set value, the regulator contacts open, and resistor R_1 is inserted in the field circuit and reduces the generator output voltage. When the field circuit is opened and the current drops, the induced voltage surge would tend to cause arcing at the contacts, but since resistor R_2 is in parallel with the field coils, it will shunt off some of the current and minimise the arcing.

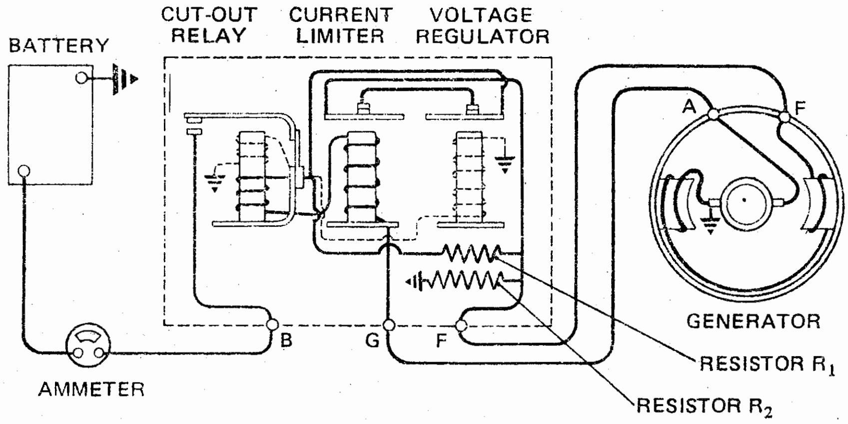

Figure 4 THREE-UNIT VIBRATOR-TYPE VOLTAGE REGULATOR CONNECTED BETWEEN THE POSITIVE SIDE OF THE GENERATOR ARMATURE AND THE FIELD

(c) Some types of vibrator-type voltage regulator have two sets of movable contacts and one fixed contact (Figure 5). When the engine is running at a relatively slow speed and the field current demands are high, the regulator vibrates between the centre and lower contacts. As the voltage rises to the regulated setting, the contacts open and a resistor is inserted into the field circuit. When the engine speed is high and field current demand is low, the magnetic pull of the voltage regulator is strong enough to cause the contacts to vibrate between the centre and top contacts. When the contacts are open, the resistor is in the field circuit, but when the voltage is high enough to close the top contacts, the field windings are shorted out and no field current flows.

3.2.2 **Current Limiting.** At any time the current drawn by the load reaches the pre-set value, the magnetic field produced by the heavy coil of the current limiter will open the limiter contacts and insert a resistor into the generator field circuit. The increased field resistance will, therefore, lower the output voltage and decrease the current. When the current drops, the contacts close and the voltage again increases. As long as the demands for current exceed the pre-set value, the current-limiter contacts will vibrate.

3.2.3 **Reverse Current Cut-out Relay.** When the generator voltage rises above that of the battery, the magnetic field of the voltage coil in the reverse current cut-out relay will close the contacts and place the generator on line. Load current then flows through the current coil and produces a magnetic field, which aids that produced by the voltage coil and holds the contacts tightly closed. When engine speed decreases and the generator output drops below that of the battery, current will flow from the battery into the generator armature. Current flowing through the current coil of the cut-out relay produces a magnetic field which opposes the field of the voltage coil, and a spring will now open the contacts, taking the generator off line.

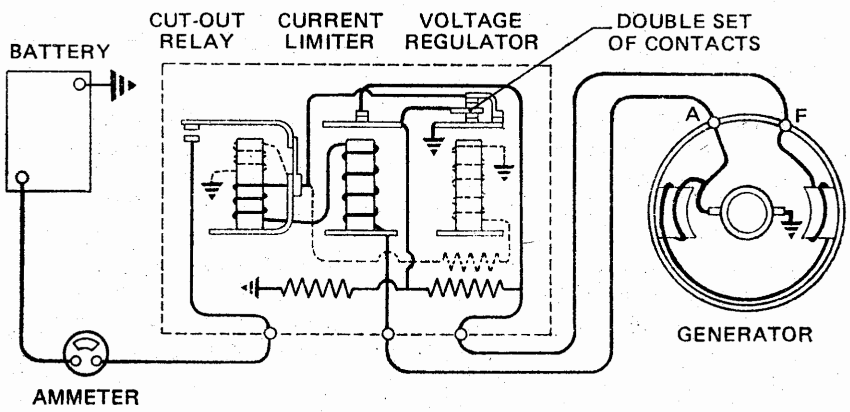

Figure 5 THREE-UNIT VIBRATOR-TYPE VOLTAGE REGULATOR WITH A DOUBLE SET OF CONTACTS

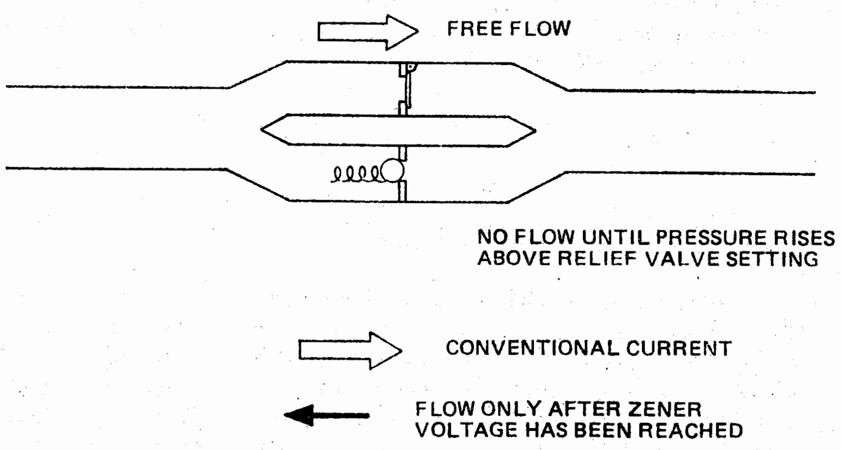

Figure 6 PRINCIPLE OF A ZENER DIODE

3.3 **Solid-state Voltage Regulators.** These generally fall into two categories: transistorised voltage regulators, which use a transistor to actually control the flow of field current but an electromagnetic coil is used to sense the voltage, and transistor voltage regulators, which are fully solid-state and sense the voltage by a zener diode.

3.3.1 Transistor Voltage Regulators

(a) **Zener Diode.** The principle of operation of a zener diode is that it will allow a free flow of electrons in one direction, but will block the flow in the reverse direction until the voltage has risen to its breakdown, or zener, voltage. This breakdown action does not damage the properties of a zener diode in any way (Figure 6).

(b) **Principle of Operation.** A complete basic circuit of a typical transistor voltage regulator is shown in Figure 7. The output of the generator is connected across the voltage divider network of resistors R_1, R_2 and R_3. The zener diode D_1 senses the volts drop across R_1 and a portion of R_2. When the voltage across D_1 is low, there is no current flow through the base of driver transistor T_1; with no base current there will be no emitter-collector current to produce a volts drop across R_5. Base current can flow through the output transistor T_2 and will conduct, giving a current flow to the generator field. With the field receiving its full field excitation current, the output voltage will rise, and at the regulation level the voltage across the zener diode will cause it to breakdown. With this breakdown, base current will now flow in T_1, which causes an emitter-collector current to flow through R_5. The voltage build-up across R_5 brings the base of T_2 to the same potential as its emitter and shuts it off, so no field current can flow through T_2, causing the generator terminal voltage to fall. Diode D_2 provides a constant voltage drop, so the emitter of T_2 will be sufficiently below the level of the line voltage, permitting the current through R_5 to bring the base voltage of T_2 up to that of its emitter so that T_2 is shut off. Diode D_3 protects the transistors against voltage surges when field current is suddenly cut off. The rapid collapse of the field would induce a voltage high enough to damage the transistors but is prevented from doing so by D_3 conducting the voltage to earth. Diode D_4 is a transient suppression diode that protects the transistors from any externally-generated voltage surges, while capacitors C_1 and C_2 smooth out pulsations and cause the regulator to operate smoothly.

3.4 Magnetic Amplifier Voltage Regulator

3.4.1 **General.** This voltage regulator is essentially a two-stage magnetic amplifier which derives its a.c. power from the generator output and supplies rectified power to the generator exciter field. The reactive load division circuitry provides balanced kVAR loading during parallel operation. In case of either a three-phase symmetrical line-to-line or line-to-earth fault, the regulator can usually supply sufficient excitation to enable the generator to supply current to operate protective devices. During an unbalanced fault condition, negative sequence sensing circuitry limits the highest phase voltage to specified limits. The regulator performs all of its functions with the a.c. generator and integral exciter as its only power supply.

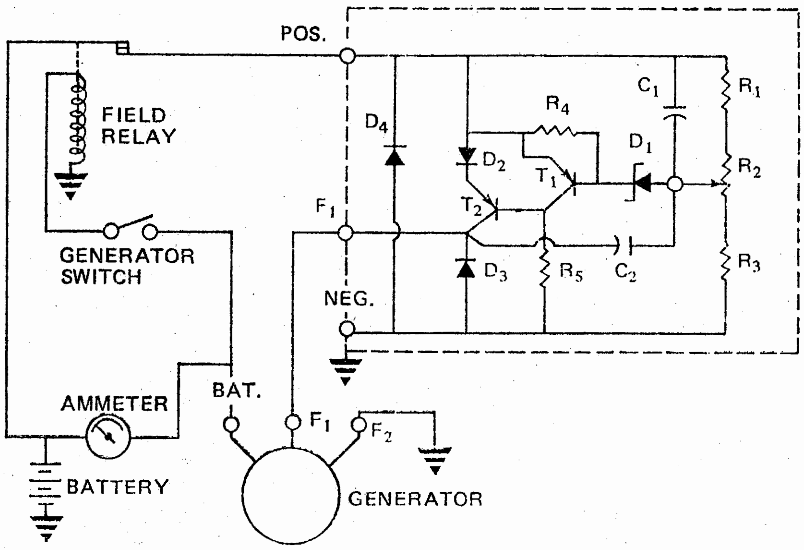

Figure 7 TRANSISTOR VOLTAGE REGULATOR

3.4.2 **Operation.** Figure 8 is a block diagram of the regulator/generator circuitry. The regulator can be considered as four basic parts: the voltage error detector and reactive load division section, the pre-amplifier, the d.c. bias supply and negative sequence sensing unit, and the power amplifier. When full load is applied to the generator, line voltage will start to decrease and an error signal is introduced to the pre-amplifier. An amplified error signal is then fed into the signal winding of the power amplifier, resulting in additional core saturation, thus allowing more current to flow through the load winding and to the exciter field. The increased exciter field current results in increasing generator output voltage towards the desired level.

3.4.3 **Voltage Error Detector**

(a) The voltage error detector monitors or 'senses' the average three-phase output of the generator and provides an error signal proportional to the variation of that voltage above or below a nominal pre-set or reference value.

(b) **Reactive Load Division.** During parallel operations a current transformer and reactor package provide a corrective signal to the error detector to maintain proper reactive load division between generators. In parallel operation all generator output voltages are common regardless of differences in excitation applied to the various generators. However, since those generators with more excitation are producing more kVAR than those with less excitation, reactive current will flow from those with more excitation to those with less. One of the functions of the regulator is to sense the difference in reactive load division, by means of the direction and magnitude of reactive current flow, and to balance the system by increasing the excitation on each generator as required. In single generator operation, output voltage varies with the excitation applied.

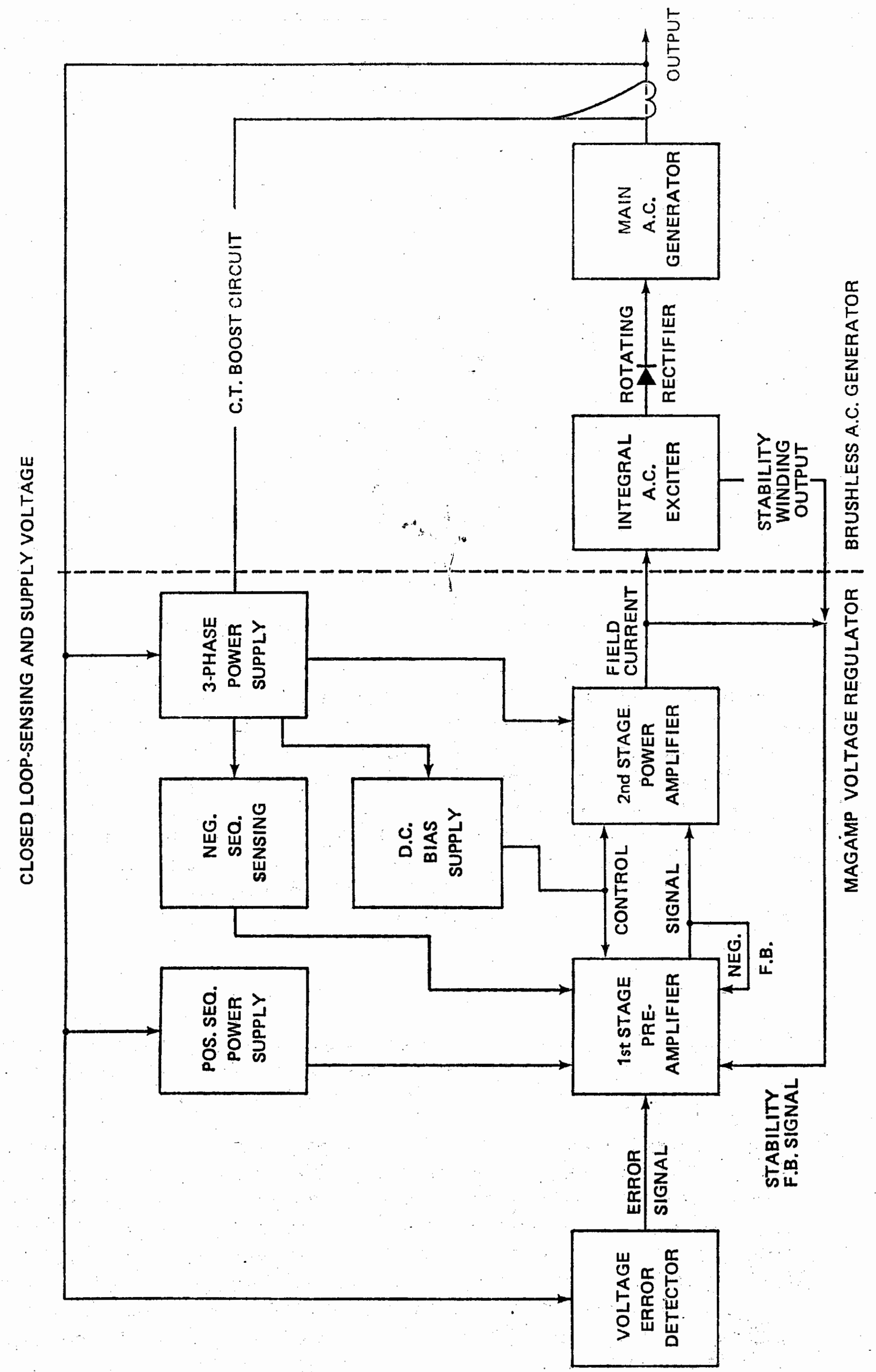

Figure 8 VOLTAGE REGULATOR/GENERATOR CIRCUIT IN BLOCK DIAGRAM FORM

(c) **Negative Sequence Sensing Unit**

(i) Under balanced three-phase voltage conditions, only a positive sequence vector rotation is present, i.e. vector rotation is ABC, assuming generator output rotation to be ABC. However, during an unbalanced three-phase condition, both positive sequence (ABC) and negative sequence (CBA) vector rotation will exist (Figure 9).

(ii) The negative sequence sensing filter (Figure 10) is designed to allow only the CBA rotation to be sensed. Thus, unbalanced three-phase voltages can be detected.

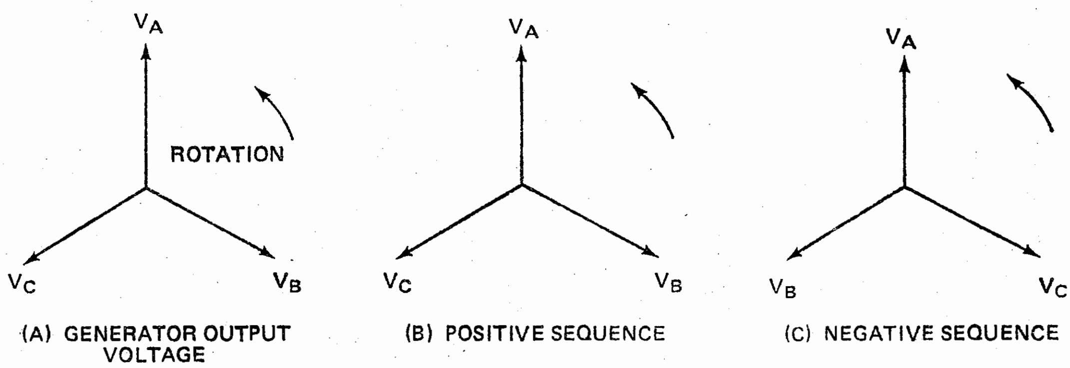

Figure 9 POSITIVE AND NEGATIVE SEQUENCE VOLTAGE VECTOR DIAGRAMS

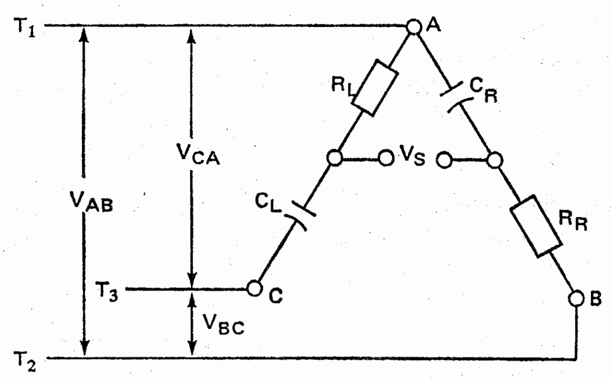

Figure 10 SCHEMATIC DIAGRAM OF NEGATIVE SEQUENCE SENSING FILTER

(d) **Positive Sequence Power Supply**

(i) A positive sequence sensing filter is used to obtain a power supply for the pre-amplifier load winding as it will not deviate greatly under unbalanced line conditions. The positive sequence voltage magnitude changes little in comparison with the change between line voltages under a wide range of unbalanced fault conditions.

(ii) The positive sequence sensing filter (Figure 11) is identical with the negative sequence sensing filter (Figure 10) except that the input connections have been reversed. This, in essence, takes the ABC rotation of the generator output and reverses it to CBA, thus the positive sequence voltage of the generator has been reversed to negative sequence voltage by reversing the leads, and fed into the filter to obtain an output signal.

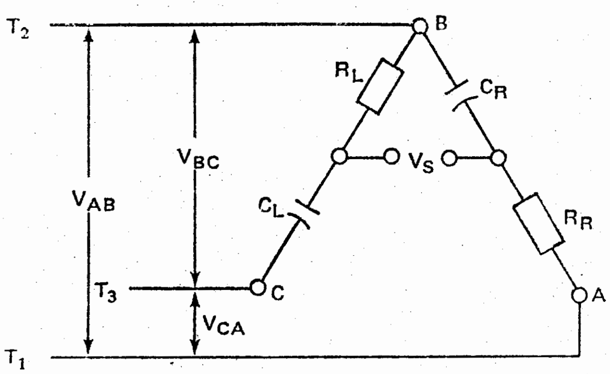

Figure 11 SCHEMATIC DIAGRAM OF POSITIVE SEQUENCE SENSING FILTER

3.4.4 **D.C. Bias Supply.** The d.c. bias supply obtains power from a three-phase transformer, which is connected to the generator terminals and fed into a three-phase, full-wave silicon rectifier bridge. The d.c. bias supply provides power to the bias windings of the pre-amplifier and the power amplifier.

3.4.5 **Pre-amplifier**

(a) **Load and Bias Windings.** Basically the pre-amplifier consists of a push-pull, parallel, self-saturating, load-winding circuit and four matching sets of control windings, all wound on four common cores. Each control winding functions as described in (b) to (e):—

(b) **Error Winding.** The error, stability, and negative feedback control windings are wound uni-directionally, whereas the load and bias windings are wound push-pull or opposing. Therefore, a current flow in the uni-directional windings will tend to add to the net flux, and hence increase the load current, in one half of the load circuit while decreasing the net flux and the current flow in the other half. The opposing voltage, dropped across resistors, will differ and a resultant voltage will appear across the amplifier output. The polarity and proportional magnitude of the output voltage will vary with that of the input or control signal, thus high gain voltage amplification is obtained. A d.c. input signal of a few milliamperes at very low voltage applied to the error winding, controls a substantial output signal voltage.

(c) **Negative Feedback Winding**

(i) Like any high gain amplifier, the magnetic pre-amplifier is subject to drift or slight change in output with respect to fixed input, due to temperature and other variables. In order to minimise such drift and to provide a convenient gain control, a negative feedback circuit is provided.

(ii) As indicated by Figure 8, a portion of the pre-amplifier output is taken from the load circuit and fed into the negative feedback windings. These windings create a control flux opposing that created by the error signal winding. The effects of this action should be noted:

—In the case of amplifier drift, the output tends to vary with no change in the error signal. In this case a portion of the output is fed back in opposition to the direction of change and automatic correction takes place.

—Since a portion of the output signal is fed back in opposition to the error signal, a large error signal is required to obtain the same output. Since a variable resistor controls the amount of feedback, it therefore controls the required input for a given output and hence the gain of the amplifier. This resistor may be used to control the overall gain of the regulator to provide the required degree of generator output voltage control.

(d) **Stability Winding.** The purpose of a stability circuit is to oppose sudden changes in error signal and thereby to minimise or damp out generator voltage overshoot and prevent system oscillation. As Figure 8 indicates, it obtains its signal from the exciter field and from the pre-amplifier output. Usually a special stabilising or damping winding is provided in the exciter field of a.c. brushless generators. By transformer action, this winding picks up a rate-of-change signal from the current supplied to the exciter field. Whereas a steady state of slowly changing exciter field current will have little effect on the winding, a sudden increase or decrease will immediately create a signal in the stabilising winding, which, when applied to the stability winding of the pre-amplifier, will oppose the direction of the change and hence tend to damp it out.

(e) **Negative Sequence Winding**

(i) The negative sequence winding is wound in such a fashion that a signal from the negative sequence unit will produce a flux in the pre-amplifier in such a direction as to reduce the voltage regulator output. In this way, the highest phase voltage can be limited to a safe value during unbalanced faults.

(ii) A negative sequence voltage is produced only during an unbalanced line-to-line or unbalanced line-to-earth fault. Although a negative sequence voltage is produced during an unbalanced fault, a diode is usually put in series with the negative sequence winding to prevent the winding from being energised unless approximately a one-third balance of one phase, in comparison with the average phase voltage, exists.

3.4.6 Power Amplifier

(a) The power amplifier comprises a three-phase, full-wave bridge magnetic amplifier, supplied from the combination of a three-phase power transformer and three current transformers, the latter being a part of a current transformer package (paragraph 3.4.7). The power amplifier supplies current to the exciter field of the generator. Silicon rectifiers are used in the self-saturated circuits of the amplifier, to maintain minimum size and weight, and to reduce reverse currents to a very low level; because of the high-gain, square loop core materials are used in the amplifier. Utilisation of current transformers as an integral part of the regulator electrical design causes the power output capabilities of the regulator to increase in accordance with the load on the a.c. generator, and hence the excitation demands of its rotating exciter. When the a.c. generator is subjected to a three-phase fault, all power for the exciter field is supplied via the current transformers and the power amplifier in the regulator. This method of supplying field power improves voltage recovery time after load switching, or removal of fault.

(b) **Load Winding.** Power obtained from the transformer package and the boost current transformers is fed directly through the six load windings and to the exciter field.

(c) **Bias Winding.** Power is obtained from the same d.c. bias supply that feeds the pre-amplifier bias winding. The load circuit would be self-saturating in the absence of other control and maximum current would flow at all times. To prevent this and to provide a range of control, d.c. bias is applied through the bias winding such that the induced flux opposes the load flux and the output is reduced by approximately one-half. Adjustment is normally provided for initial setting up.

(d) **Signal Winding.** The output signal from the pre-amplifier varies from zero for nominal generator output voltage to positive for below nominal, and to negative for above nominal. For a below-nominal generator voltage, the signal applied to the signal winding causes an increase in flux in the six cores, thus approaching saturation and increasing the field current to the generator exciter. For an above-nominal signal, the signal is negative; the core flux and the excitation current are reduced.

3.4.7 Current Transformer Boost Current

(a) The three current transformers mounted on the generator feeders are connected in series with the low potential ends of the power transformer secondary windings. One of the regulator requirements, generally, is that it shall furnish excitation to the generator during a three-phase system fault or line-to-earth fault. During such a fault, generator voltage drops to near zero, but a very high current flow occurs through the generator feeders and, by means of the current transformer boost circuit, power is taken from the current in the generator feeders and fed into the power amplifier power supply. In the absence of bias and signal voltage, the power amplifier load windings tend to self-saturate the cores and full load current flows to the exciter field, proportional to the fault current.

(b) The current transformer boost circuit also performs two other functions. During normal operation a small but significant amount of voltage is added to the power supply and, since the amount added is proportional to the load current, this aids the power amplifier and hence the regulator in compensating for load instabilities.

The current transformers are also sensitive to the phase relation of the generator output current to voltage; the function is much the same as that of the reactive load division circuit and tends to increase or reduce the excitation as required to provide reactive load equalisation in parallel operation.

3.4.8 **Temperature Compensation.** As the power amplifier is single-ended, whereas the pre-amplifier is push-pull or self-balancing, some temperature compensation is required. This is usually provided by positive temperature coefficient resistors (TCR) built into the saturable reactor cases and connected in series with the d.c. bias winding. This temperature compensation takes care of core shift and control winding resistance changes due to temperature variation.

3.4.9 **Commutating Rectifier.** The output of a magnetic amplifier normally contains a sawtooth a.c. ripple component in addition to the d.c. component. Since the output current is uni-directional by virtue of the silicon rectifiers, and since the exciter shunt field is inductive, the field winding will tend to store energy. If there were no way to discharge this energy the apparent resistance would increase, increasing the voltage and decreasing the current to the field to the point where failure of one or more of the silicon rectifiers may occur due to high inverse voltage. To prevent this, another silicon rectifier is usually connected across the output, opposed in direction to the d.c. amplifier output. This rectifier, called the commutating rectifier, provides a convenient path for discharge of stored energy in the field winding and permits the exciter field load to appear resistive rather than inductive to the magnetic amplifier.

3.4.10 **Closed Loop Operation of the Voltage Regulator**

(a) The process of actual regulation of a.c. generator voltage may be more easily understood by means of idealised curves as shown in Figure 12. The operating characteristic curves for the detector, pre-amplifier, power amplifier and exciter-generator combination are shown in their relationship to one another.

(b) During initial adjustment of the complete regulator, the coupled sections are so aligned that, when generator output voltage equals its rated or nominal value, the error detector signals $I_S = 0$, the pre-amplifier output $E_O = 0$, and the power amplifier output to the exciter field is approximately one half its maximum value.

(c) When the system is disturbed in some manner to cause a momentary increase in a.c. generator voltage to some new value, which is higher than rated value, the detector sends a negative I_S signal to the pre-amplifier. The pre-amplifier produces a negative E_O output to the power amplifier, which in turn drives the power amplifier to a new lower value of field current I_F. The lower field current permits the generator to drop to a new value lower than the previous value. As shown, the condition rapidly repeats itself around the loop until an equilibrium condition is reached.

(d) It should be noted that there is theoretically only one condition of generator speed, loading, etc., at which the system can operate with zero per cent voltage regulation; that is, the generator output remains exactly at rated value, and the detector and pre-amplifier output signals remain zero. At all other conditions a steady state error must exist; that is, the output voltage will remain slightly above or below its rated value and a corrective signal passes through the regulator. The maximum error which can occur under specified conditions, compared with rated output, is the per cent regulation. The amount of continuous fluctuation which occurs in the output voltage as a result of hunting of the regulation circuits, compared with rated output, is termed the per cent modulation.

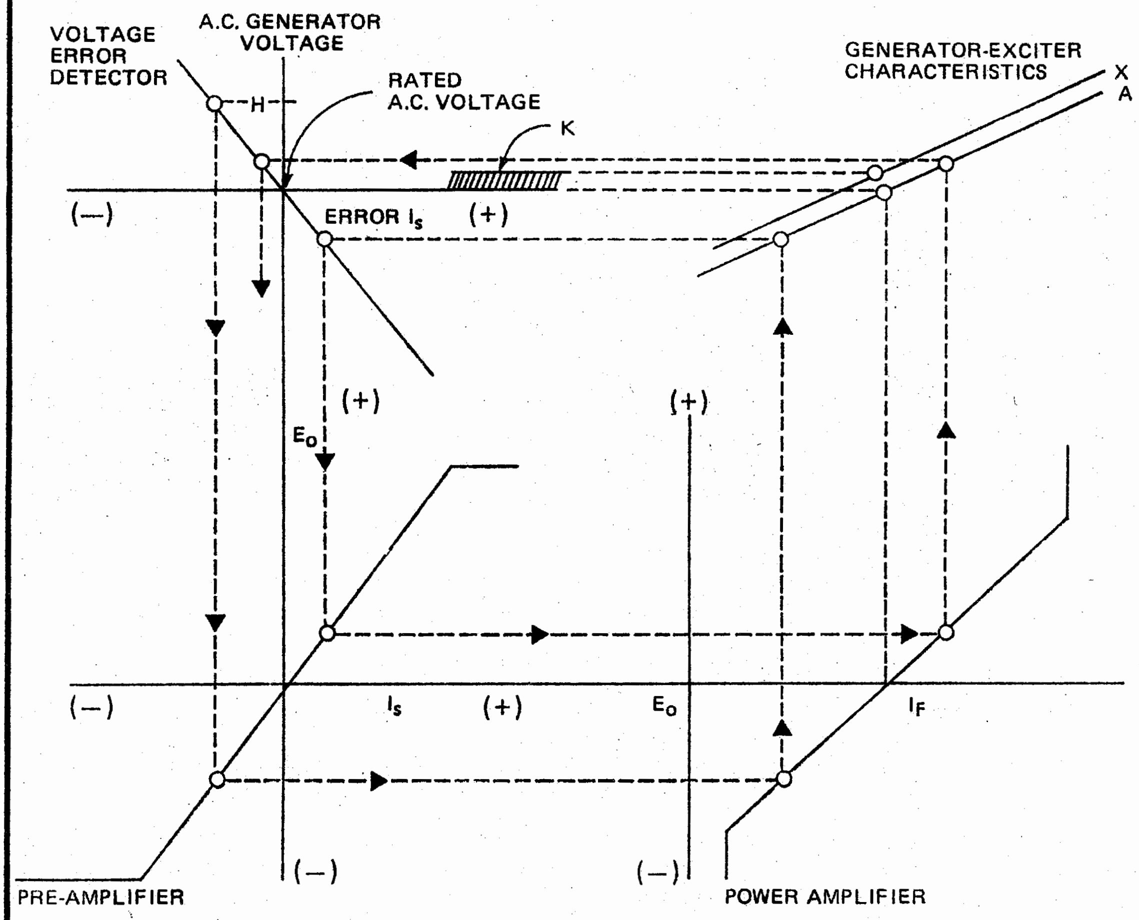

Figure 12 GENERATOR/REGULATOR CLOSED LOOP OPERATION

4 MAINTENANCE PRACTICES

4.1 **General.** The maintenance practices for voltage regulators will depend upon their type and on the type of aircraft installation; reference must, therefore, be made to the relevant aircraft Maintenance Manual for the specific instructions. The information given in the following paragraphs serves only as a general guide.

4.2 **Removal/Installation**

4.2.1 **Removal.** Carry out electrical safety procedures as detailed in the relevant aircraft Maintenance Manual. Disconnect electrical connections, identifying if necessary. Refit all terminal covers and fit blanks as required. Carefully remove the voltage regulator from its mounting, taking care not to cause damage to the regulator or any items of equipment or fittings in the area.

4.3 **Pre-installation Checks.** Regulators should be inspected for damage or deterioration which may have occurred in storage or transit. New or overhauled regulators are normally kept in their special packaging containers until required and these should be carefully examined for signs of damage before removing the regulator. It must be verified that the shelf life, where specified, has not been exceeded.

4.3.1 **Regulator Installation.** In general, regulators should be mounted in accordance with the relevant Maintenance Manual. In the case of carbon-pile voltage regulators, these should normally be mounted with the axis of the carbon pile horizontal, and located so that there is minimum vibration and no restriction to the free circulation of air over the casing and through the cooling fins. All connections must be secure and made in accordance with the relevant Maintenance Manual and aircraft installation wiring diagrams.

4.4 **Adjustment/Tests**

4.4.1 **General.** The checks to be carried out after installation and during specified inspection periods are detailed in the relevant aircraft Maintenance Manuals and Maintenance Schedules, and reference must be made to such documents for the procedures to be adopted. In general, the checks involve the measurement and adjustment of voltage output with associated generator systems operating singly and/or in parallel, at selected speeds, and under no-load and selected load conditions. The details given in the following paragraphs are based on the checks specified for typical generating systems and are intended to serve only as a general guide to checking procedures.

NOTES: (1) Voltage measurements must be made by a first-grade voltmeter connected in the aircraft system at the measuring points specified in the Maintenance Manual.

(2) Throughout the checking procedures all engine speed limitations and generator ratings must be strictly observed.

4.4.2 **Voltage Output Checks.** Each generator should be run and the system checked and adjusted strictly in accordance with the relevant aircraft Maintenance Manual instructions. On installations that include carbon-pile voltage regulators, there is usually a period of warm-up to allow the drying out of any moisture absorbed by the carbon pile.

(a) Each generator output voltage should be checked to ensure that it is within the limits specified in the relevant aircraft Maintenance Manual. Where necessary, the trimmer resistance of the appropriate voltage regulator should be adjusted to bring the voltage within the limits. In installations with carbon-pile voltage regulators, the magnet cores or pile compression screws must not be touched.

(b) When the output voltages have been set, a check should be made to ensure that they remain stable and within limits when a generator is switched on and off, and also when run under specified load and speed conditions.

4.4.3 **Paralleling Checks.** In multi-generator system installations, it is also necessary to carry out paralleling checks and adjustments to ensure not only that generator output and busbar voltages remain within limits, but also that electrical loads are shared equally between generators. These checks and adjustments should be carried out strictly in accordance with the relevant aircraft Maintenance Manual, and the following procedures are intended only as a general guide.

(a) Generators should be run at the speed corresponding to normal cruising and switched on in pairs and in combinations appropriate to the installation. A specified maximum electrical load should then be switched on and the readings on the ammeters, or kW/kVAR meters for an a.c. system, of the relevant generator systems noted. The readings should be steady and should indicate that each generator is carrying its share of the load within the tolerance quoted in the aircraft Maintenance Manual.

(b) If such a load distribution is not obtained, it should be determined from the readings of the ammeters, or the kW/kVAR meters for a.c. systems, which generator has the greater error in the division of load current and further off-load checks made on the relevant voltage regulating circuit. If necessary, the voltage settings should be re-adjusted to bring them to within the tolerances quoted in the relevant aircraft Maintenance Manual.

(c) The load should again be switched on and the load-sharing check repeated.

NOTES: (1) Before carrying out any adjustments necessary to correct an unbalance in load sharing, the possibility of high-resistance faults having occurred in a generator supply circuit should be investigated and rectified.

(2) During adjustments, the specified electrical load, once selected, must not be altered.

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AIRCRAFT

ELECTRICAL EQUIPMENT

BATTERIES—NICKEL-CADMIUM

1 INTRODUCTION This Leaflet gives general guidance on the maintenance and installation of nickel-cadmium batteries (in particular of the semi-open type), which provide a standby source of d.c. power in aircraft. It should be read in conjunction with the Maintenance Manuals and Overhaul Manuals issued by the battery manufacturers, relevant aircraft Maintenance Manuals and approved Maintenance Schedules.

1.1 The information provided by this Leaflet is set out as follows:—

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet EEL/1—5, Issue 1, dated 15th June 1962.

2 GENERAL DESCRIPTION Nickel-cadmium batteries may be divided into three ranges of basic design, as described in the following paragraphs.

2.1 **Sealed Batteries.** This range of batteries consists of those having the cells completely sealed. In general the batteries are of small capacity, and may be used for emergency lighting purposes.

2.2 **Semi-sealed Batteries.** The cells in this range of batteries are usually mounted in steel containers and are fitted with safety valves. The batteries may be charged fairly rapidly but are very sensitive to overcharge, thus, for aircraft usage, they are usually fitted with a thermal protective device. Under normal conditions the battery requires practically no maintenance beyond periodic cleaning and capacity checks.

2.3 **Semi-open Batteries.** These batteries are generally used as the main aircraft batteries. The cells are similar in appearance to those of the semi-sealed type, but are deliberately allowed to 'gas' to avoid excessive heating should the battery be on overcharge. The cell cases are usually manufactured from nylon. Because of gassing, the electrolyte has to be 'topped-up' at periods which vary according to the duty cycle of the battery and the conditions under which it is operated. 'Topping-up' periods are specified in the approved Maintenance Schedule for the aircraft concerned (see also paragraph 4.3).

3 CONSTRUCTION The plates comprise a sintered base on a nickel-plated steel support. The active materials are nickel hydroxide on the positive plates, and cadmium hydroxide on the negative plates, and these are impregnated into the sintered base by chemical precipitation. This type of plate construction allows the maximum amount of active material to be employed in the electrochemical action.

3.1 After impregnation with the active materials, the plates are stamped out to the requisite size. The plates are then sorted into stacks according to the type of cell into which they are to be mounted. Usually there is one additional negative plate for a given number of positive plates. The plates are then welded to connecting pieces carrying the cell terminals, after which a separator is wound between the plates and the insulation is checked under pressure. The plate group is then inserted in the container, the lid secured and pressure-tested for leaks. The separators are usually of the triple-layer type, one layer being made from cellophane film, the other two being woven nylon cloth. Cellophane is used because it has low electrical resistivity and is a good barrier material which contributes to the electrical and mechanical separation of the positive and negative plates, and keeps finely divided metal powder particles from shorting out the plates while still permitting current flow. It also acts as a gas barrier, preventing oxygen given off at the positive plate during overcharge from passing to the negative plate where it would combine with active cadmium, reduce cell voltage, and produce heat as a result of chemical reaction. The cellophane is prone to damage at high operating temperatures, and failure will result in an adverse change in the operating characteristics of a battery (see also paragraph 4.5.8 (a)).

3.2 The electrolyte is a solution of potassium hydroxide and distilled water, having a relative density of 1·24 to 1·30. It is impregnated into cells under vacuum, after which the cells are given three formation cycles, re-charged, and then allowed to stand for a minimum period of 21 days. The discharge characteristics at the end of this period enable the cells to be matched.

3.3 In a typical battery each component cell is insulated from the others by its moulded plastic case. All the cells are interconnected via links secured to the terminals of the cells, and are contained as a rigid assembly in the battery case. A vent cap assembly is provided on the top of each cell and, in general, is constructed of plastic, and is fitted with an elastomer sleeve valve. The vent cap can be removed for adjustment of the electrolyte level, and acts as a valve to release gas pressure generated during charging. Except when releasing gas, the vent automatically seals the cell to prevent electrolyte spillage and entry of foreign matter into the cell.

3.3.1 Two venting outlets, a pair of carry-strap shackles, and a two-pin plug for quick-release connection of the aircraft battery system cables, are embodied in the battery case. A removable cover completes the case, and incorporates a pair of slotted lugs which engage with attachment bolts at the battery stowage location.

3.4 **Chemical Principle.** During charging an exchange of ions takes place; oxygen is removed from the negative plates and is added to the positive plates, bringing them to a higher state of oxidation. These changes continue in both sets of plates for as long as the charging current is applied or until both materials are converted; i.e. all the oxygen is driven out of the negative plates and only metallic cadmium remains, and the positive plates become nickel hydroxide.

3.4.1 The electrolyte acts only as an ionized conductor and is forced out of the plates during charging. It does not react with either set of plates in any way, and its relative density remains almost unchanged. Towards the end of the charging process and during overcharging, gassing occurs as a result of electrolysis which reduces only the water content of the electrolyte. Gassing is dependent on the temperature of the electrolyte and the charging voltage (see also paragraph 4.5.5).

3.4.2 During discharge, the chemical action is reversed; the positive plates gradually losing oxygen while the negative plates simultaneously regain lost oxygen. The plates absorb electrolyte to such an extent that it is not visible at the top of the cells.

4 MAINTENANCE Nickel-cadmium batteries must be prepared for service, charged, tested and otherwise generally maintained, in a well ventilated workshop area which is entirely separate from that used for the servicing of lead-acid batteries. This also applies to servicing and test equipment, tools and protective clothing, all of which should carry some form of identification. Anything associated with lead-acid batteries (acid fumes included) that comes into contact with a nickel-cadmium battery or its electrolyte can cause severe damage to this type of battery.

4.1 Precise details of inspection and maintenance procedures, and the sequence in which they should be carried out, are given in the relevant battery maintenance and overhaul manuals, and other approved supplementary servicing instructions; reference should, therefore, always be made to such documents. The information given in the following paragraphs is intended to serve as a general guide to the procedures to be carried out appropriate to battery service life and condition, and also to the precautions to be observed.

4.2 **Inspection.** The following checks are typical of those comprising a battery inspection schedule:—

(a) The battery should be identified to establish any known history. If the battery is a new one a servicing record card should be raised (see paragraph 7).

(b) The outside of the battery case should be examined for evidence of damage, and of locally overheated areas.

(c) The battery cover should be removed and its rubber lining inspected for condition. Cover latches should operate smoothly and provide proper security of the cover. Extreme care must be exercised when working around the top of a battery with its cover removed. Tools should not be dropped onto the cell connecting links, as severe arcing will result with possible injury to personnel and damage to the battery. Such personal items as rings, metal watch straps and identification bracelets should be removed, to avoid contact with connecting links and terminals.

(d) There should be no evidence of arcing having occurred between the battery and the aircraft structure. The section near the bottom of the case and the slotted lugs of the cover tie-down strap are areas which are most likely to be affected. If signs of arcing are present, the aircraft battery compartment should be inspected and the battery should be completely dismantled and overhauled.

(e) The battery should be inspected for signs of electrolyte leakage and should be cleaned where necessary (see paragraph 4.4).

(f) The battery receptacle should be checked for evidence of burns, cracks and bent or pitted terminals. Defective receptacles, which can overheat, cause arcing and depress output voltage, should be replaced.

(g) All cell links should be checked for security and evidence of overheating, and their terminal nuts should be tightened to the specified torque values. Any cell link showing damage to its plating should be replaced.

(h) Vent caps should be checked for security and also to ensure that gas exit holes are free from dirt or potassium carbonate crystals. Clogging of vents causes excessive pressures to build up, resulting in cell rupture or distortion of parts. Cell valves, when fitted, should also be checked for security and freedom from dirt or crystal formation. Dirty vent caps or valves should be removed and cleaned (see paragraph 4.4.3).

NOTE: Potassium carbonate is a white crystal formed by the reaction of potassium hydroxide with carbon dioxide in the air; it is non-corrosive, non-toxic, and non-irritating.

(j) Temperature sensing devices, when installed, should be checked for secure attachment with leads and connectors showing no signs of chafing or other damage. Electrical checks and/or calibration of these devices should be carried out at the periods specified in the approved Maintenance Schedule.

4.3 **Electrolyte Level and Adjustments.** The level of the electrolyte should, depending on manufacturer's recommendations, only be adjusted when a battery is at the end of charge, while still charging, or after a specified standing time. If electrolyte level adjustments were to be made in the discharged or partially discharged condition, then during a charge electrolyte would be expelled from the cells, resulting in corrosive effects on cell links, current leakage paths between cells and battery case, and a reduction of electrolyte density. The manufacturer's instructions regarding checks on electrolyte level and adjustments should be carefully followed and the maintenance kit equipment designed for a particular type of battery should be used.

NOTE: Adjustments should not be made when batteries are installed in aircraft.

4.3.1 Only the purest water available, preferably pure de-mineralised or distilled water, should be used for adjusting electrolyte levels, and a record of the quantity added to all cells should be maintained, because it is largely on this evidence that periods between servicing are determined (see also paragraph 7). The 'consumable' volume of electrolyte is normally specified in manufacturer's manuals, but in the absence of such information, a useful guide line is that batteries should not be left for periods which would require the addition of water to any cell by an amount in excess of 1 cc per ampere-hour capacity.

4.3.2 In the event that the electrolyte becomes contaminated, particularly with oil, foaming of the electrolyte will occur. In such cases, a neutralizing fluid, which is available from the relevant battery manufacturer, should be added to the electrolyte, strictly in accordance with the manufacturer's instructions.

4.3.3 Additional potassium hydroxide should not normally be required, but if electrolyte in solution is necessary for topping-up it must be ensured that it is in the proportions specified in the relevant manual.

NOTE: Contamination of the electrolyte with tap water, acids, or other non-compatible substances, will result in poor performance or complete failure of a battery.

4.3.4 Potassium hydroxide should be kept in special containers, and because of its caustic nature, should be handled with extreme care to avoid contamination of the person or clothing. Rubber gloves, a rubber apron and protective goggles should always be worn. If contamination does occur, the affected parts should be immediately rinsed with running water. If available, vinegar, lemon juice or a mild boric acid solution may also be used for treatment of the skin. Immediate medical attention is required if the eyes have been contaminated. As a first-aid precaution, they should be bathed with water or a weak boric acid solution, applied with an eye bath.

4.4 **Battery Cleaning.** Dirt, potassium carbonate crystals, or other contaminating products, can all contribute towards electrical leakage paths (see also paragraph 4.6) and be a prime cause of unbalanced cells. Cleanliness of batteries is therefore essential.

4.4.1 Deposits should be removed from the tops of cells by using a cloth soaked in de-mineralised or distilled water and a stiff fibre bristle brush. Wire brushes or solvents should not be used. If any contaminating product is caked under and around cell connecting links, the links should be removed, if necessary, to facilitate cleaning. Care should always be taken to ensure that debris is not forced down between cells, and in some cases it may be better to scrape deposits loose and then blow them with low-pressure compressed air. The air itself should be clean and dry, and goggles should be worn to protect the eyes.

4.4.2 Some manufacturers specify periodic flushing of cell tops and battery case with de-mineralised or distilled water while brushing away deposits. This method is not recommended, and batteries in a dirty condition, or showing low resistance, should be dismantled and completely serviced.

4.4.3 When it is necessary to clean vent caps and valves, they should be removed from the cells, using the correct extractor tool, and should be washed in warm water to dissolve any potassium carbonate crystals which may have accumulated within the outlet orifices. They should then be rinsed in de-mineralised or distilled water, dried and re-fitted. Valves should also be tested for correct functioning in accordance with manufacturer's instructions before re-fitting.

NOTE: Cells should not remain open for longer than is necessary.

4.5 **Charging of Batteries.** New nickel-cadmium batteries are normally delivered complete with the correct amount of electrolyte, and in the fully discharged condition. Following a visual check for condition, they must, therefore, be charged in accordance with the manufacturer's instructions before being put into service. Once in service, batteries must then be charged at the periods stated in the approved aircraft Maintenance Schedule. The following information on charging methods and associated aspects is of a general nature only. Precise details are given in relevant manufacturer's manuals and reference must, therefore, always be made to such documents.

4.5.1 **Constant-Current Charging.** This method is the one which should normally be adopted for the workshop charging of batteries, the charging equipment being adjusted and monitored throughout the charging period to supply current at either a single rate, or at several different rates in a stepped sequence. Although more time-consuming than the constant potential method which is often adopted in aircraft battery systems, constant current charging is more effective in maintaining cell balance and capacity. The hour rate of charge current required must be in accordance with that specified by the relevant battery manufacturer.

NOTE: The 'hour rate' of a battery refers to the rate of charge and discharge expressed in multiples of 'C' amperes, where 'C' is the 1-hour rate. For example, if a battery has a capacity of 23 ampere-hours, then 'C' would be 23 amperes and for a 10-hour rate the charge or discharge current rate would be $\frac{C}{10}$ amperes, i.e. 2·3 amperes.

4.5.2 **Vent Caps.** Before charging, the battery cover should be removed, and with the aid of the special wrench provided in the battery maintenance kit, the vent cap of each cell should also be removed.

4.5.3 **Connection to Charging Equipment.** Charging equipment should not be switched on until after a battery has been connected and the charging circuit has been checked for correct polarity connections.

4.5.4 **Electrolyte Level.** The electrolyte level should be checked and adjusted, as necessary, in accordance with the manufacturer's recommendations (see also paragraph 4.3).

4.5.5 **Gassing.** Gassing of cells occurs within the region of final charge, as a result of the electrolysis of water into hydrogen and oxygen gases. When gases escape from a cell, the quantity of fluid electrolyte is reduced; vigorous prolonged gassing should therefore be avoided. A "dry" cell is more likely to suffer separator damage, and any cell running hotter than its neighbours should be investigated.

(a) The gassing/temperature phenomena provide a useful indication of impending failure of cells; e.g. a cell that gasses sooner and more actively than its neighbours is going to lose more electrolyte, and as a result will run hotter and tend to dry out. Minor differences in gassing are hard to detect, but large differences should be noted and investigated.

4.5.6 **State of Charge.** The state of charge cannot be determined by measurement of the electrolyte relative density or battery voltage. Unlike the lead-acid battery, the relative density of the nickel-cadmium battery electrolyte does not change. Except for 'dead' batteries, voltage measurements at either open circuit or on-load conditions do not vary appreciably with state of charge. The only way to determine the state of charge is to carry out a measured discharge test (see paragraph 4.7).

4.5.7 **Charging of Individual Cells.** Individual cells must be in an upright position and adequately supported at the sides parallel to the plates during charging. A special frame may be built to fit a cell, or boards or plates may be placed on each side and held together with a clamp. After charging and removal from its support, the sides of a cell should be inspected to ensure there are no bumps or bulges which would indicate an internal failure.

NOTE: Cells should always be fully discharged before removal from a battery and before re-assembly.

4.5.8 **Thermal Runaway.** In some small aircraft the battery may be charged by constant potential supplied directly from the d.c. bus-bar. Under correct conditions of temperature and voltage, the internal voltage of the cells rises gradually as the electrochemical action takes place, and it opposes the charging voltage until this is decreased to a trickle sufficient to balance continuous losses from the cells. The energy supplied to a fully charged battery results in water loss by electrolysis and in heat generation. For a battery in good condition, a point of stability will be reached where heat as a result of trickle current will just balance radiated and conducted heat losses. At low temperatures, a battery will appear to have a limited capacity, and will require more voltage to accept a given amount of charge. As the battery becomes warm, however, its responses return to normal. Operation at high temperatures also limits the capacity, but in such conditions, a battery is subjected to the danger of a 'thermal runaway' condition.

(a) At higher than normal temperatures, the heat loss of the battery through radiation and conduction is lower than the heat generating rate and this results in a higher battery temperature. This, in turn, reduces the internal resistance of the battery, so that higher than normal charge current is admitted resulting in an increase in chemical activity, additional heat and a further increase in charging current. This recurring cycle of temperature rise, resistance and voltage drop, and charge current rise, progressively increases the charging rate until sufficient heat is generated to completely destroy a battery.

(b) Other factors which can cause overheating of a battery are as follows:—

(i) Voltage regulator of aircraft generating system incorrectly adjusted.

(ii) Frequent or lengthy engine starts at very high discharge rates.

(iii) Loose link connections between cells.

(iv) Low electrolyte level (see also paragraph 4.3).

(v) Leakage currents between a cell and battery container and the airframe structure. Periodic measurement of leakage current and removal of any electrolyte that may have accumulated around and between cells should be carried out to prevent high leakage and short circuits from developing (see also paragraph 4.6).

(vi) Use of unregulated, or poorly regulated, ground support equipment to charge a battery, particularly a battery which has become hot as a result of excessive engine cranking or an aborted engine start.

(vii) High initial charging currents imposed on a hot battery.

(viii) Unbalanced cells. Cell unbalance (see paragraph 4.9) refers to an apparent loss of capacity and to variations in cell voltage at the end of charging cycles. These variations can develop over a period of time, particularly when subjected to operating conditions like those occurring in aircraft utilising charging circuits of the constant potential type. Other factors which may also contribute to cell unbalance are cell position in the battery, e.g. centre cells run warmer than outer cells, and the self-discharge of individual cells.

(c) In some types of aircraft, the batteries specified for use incorporate a thermostat type detector which illuminates a warning light at a pre-set temperature condition. In addition, a thermistor type sensing network may also be incorporated. The network operates in conjunction with a special solid-state, pulse-charging unit, and its function is to monitor the charging current and to de-energize the charging circuit when the battery temperature exceeds a safe operating limit. Detection devices should be checked at the periods stated in the approved aircraft Maintenance Schedule and in accordance with the relevant manufacturer's instructions.

4.6 **Electrical Leakage Check.** Electrical leakage refers to current flowing in a path other than that desired, and in connection with batteries, this means current between the terminals or connectors of cells and any exposed metal on the battery case. The only pertinent measure of leakage of importance to a cell is the rate of discharge caused by the leakage, and this is only significant when its value approaches that specified for the particular type of battery. In one type for example, a leakage of up to 0·020 amps is quoted as the permissible value. Typical methods of determining electrical leakage are described in the following paragraphs.

4.6.1 The positive lead from the terminal of a multi-range testmeter should be connected to the positive terminal of the battery and, after selecting the appropriate scale range (usually the one amp. range) the negative terminal lead from the testmeter should be touched on any exposed metal of the battery case. If a pointer deflection is obtained it will denote a leakage and the testmeter scale setting should be adjusted, if necessary, to obtain an accurate reading which should be within the limits specified.

The foregoing check should be repeated between the battery negative terminal and battery case, when again any readings obtained should be within limits. If either of the readings obtained exceed the specified limits the battery should be thoroughly cleaned (see paragraph 4.4) and the checks again repeated.

4.6.2 If, after thorough cleaning, the leakage current is in excess of the limits it is probable that one of the cells is leaking electrolyte and is therefore defective. This cell may be found by measuring the voltage between each cell connecting link and the battery case. The lowest voltage will be indicated at the connecting links on each side of the defective cell which should be replaced (see also paragraph 4.12).

4.7 **Capacity Test.** The capacity or state-of-charge of a fully-charged battery is checked by discharging it at a specified rate (preferably automatically controlled) after it has been standing for a certain time period, and noting the time taken for it to reach a specified on-load voltage. For example, a 23 ampere-hour battery is left to stand for 15 to 24 hours and is then discharged at 23 amperes, i.e. the 1-hour rate, to 20 volts. A battery should give at least 80% of the capacity specified on its nameplate, or the minimum authorised design capacity, whichever is the greater.

NOTE: Some batteries of U.S. origin have initial capacity ratings which are significantly higher than those specified on their nameplates. When the nameplate ratings are no longer obtainable such batteries are rejected.

4.7.1 True capacity must always be recorded, meaning that a full discharge is required, and not one which is terminated when the minimum acceptable level has been reached. Because it is essential to monitor a number of cell voltages very closely, the service of two persons is desirable towards the end of discharge for measurement and recording. At this stage, voltages fall very quickly, and it is highly desirable that measurements be made with a digital voltmeter.

NOTE: No cell should be allowed to go into reverse polarity before the measured discharge is complete, and the terminal voltage should not go below 1 volt per cell, since excessive gassing may result.

4.8 **Capacity Recycling Procedures.** The purpose of recycling is to restore a battery to its full capability and to prevent premature damage and failure. The discharge rates and voltage values appropriate to the recycling procedures vary between types of battery, and reference should always be made to the relevant manual. The figures quoted in the following paragraphs are typical, and serve only as a guide to the limits normally specified.

4.8.1 The battery should be discharged at a current equal to or less than the one-hour rate, and as each cell drops below 0·5 volts (measured by a digital voltmeter) it should be shorted out by means of a shorting strip. The cells should remain in this condition for a minimum period of 16 hours, preferably 24 hours.

NOTE: A battery should not be discharged at an excessively high rate and cells then short-circuited, since this produces severe arcing and excessive heat generation.

4.8.2 The shorting strips should then be removed, and the battery charged for 24 hours at the specified recycling charging rate. After approximately five minutes of charge, individual cell voltages should be measured and if any cell voltage is greater than 1·50 volts, distilled water should be added. The amount of water required depends on the rated ampere-hour capacity; a typical maximum value is approximately 1 cc per rated ampere-hour.

4.8.3 After approximately 10 minutes of charge, individual cell voltages should again be measured. Any cell measuring below 1·20 volts or above 1·55 volts should be rejected and replaced.

4.8.4 After 20 hours of charging, individual cell voltages should be measured and recorded, and, if necessary, distilled water should be added to the normal level appropriate to the type of battery.

4.8.5 At the end of the 24 hours charge period, cell voltages should again be measured and compared with those obtained after 20 hours. If the 24 hour voltage reading is below the 20 hour reading by more than 0·04 volts, the cell concerned should be rejected and replaced.

4.9 **Cell Balancing.** If a battery fails to give 80% capacity on test, and if premature ageing of some cells is suspected, a cell balancing test should be carried out. The procedure for carrying out the test appropriate to a particular type of battery is prescribed in the relevant manual, and reference should always be made to such document. The following details, based on the test specified for a typical 23 ampere-hour battery, are given only as a general guide.

4.9.1 Note the time, and discharge the battery at 23 amperes until the terminal on-load voltage falls to 20 volts, then stop the discharge. During the discharge, the voltage of each cell should be frequently checked with a digital voltmeter. A zero reading early in the discharge indicates a short circuit cell; a reverse reading indicates a weak cell. In either case the discharge should be stopped, even if the overall battery voltage has not yet fallen to 20 volts. The weak or faulty cell should be shorted out, preferably through a 1 ohm resistor.

4.9.2 Note the time and recommence the discharge at the lower rate of 2·3 amperes. Frequently check the voltage of the cells and short out each cell (with individual shorting strips) as it falls below 1 volt. Record the lapsed time of discharge for the cell to fall below 1 volt, thereby obtaining an indication of the relative efficiency of the cells.

(a) Some manufacturers specify 0·5 volts as the point at which shorting of the cells should be carried out. This is satisfactory providing that sufficient time is available to permit shorting of all cells before any are subjected to reverse voltage resulting from the charging effect of stronger cells.

4.9.3 The discharge should be stopped when all the cells are shorted out. The battery should be left in this condition, and also with the main terminals shorted together, for as long as possible, but never less than 16 hours.

4.9.4 The battery should then be charged and the cell-balancing procedure repeated. The discharge times recorded for each cell to fall below 1 volt should show an improvement over those previously recorded.

4.9.5 Weak and internally short-circuited cells should be replaced in accordance with the instructions detailed in the relevant battery Maintenance Manual (see also paragraph 4.12).

4.10 **Voltage Recovery Check.** This check, which should be made at a given time after shorting strips have been removed from the cells or main battery terminals, provides a ready means of detecting high resistance short-circuits and damaged connections within a battery. A typical procedure for this check is given in the following paragraphs.

4.10.1 Shorting strips of one ohm resistance should be connected between cells, and the battery should be allowed to stand for 16 to 17 hours. At the end of this period, the voltage of individual cells should be measured to ensure that they do not exceed the minimum value specified for the battery (a typical minimum value is 0·20 volts).

4.10.2 The shorting strips should then be removed, and after a further standing period of 24 hours, individual cell voltages should again be measured to check their recovery to within normal operating values. A typical minimum value specified as a basis for rejection of a cell is 1·08 volts.

4.11 **Insulation Resistance Test.** A test for insulation resistance may be specified by some manufacturers as the means of checking for electrical leakage. Reference should, therefore, be made to the appropriate maintenance manual for the procedure to be adopted, for permissible values, and for any remedial action to be taken.

4.12 **Cell Removal and Replacement.** Cells should be removed from a battery whenever they are suspected of leakage of electrolyte, internal short-circuits, when they fail to balance (see also paragraph 4.9) or if the insulation resistance is found to be below the value specified for the particular battery. The method of removing and replacing cells may vary between types of battery, and the instructions issued by the relevant manufacturers must, therefore, always be carefully followed. The information given in the following paragraphs, although based on a specific type of battery, is intended to serve only as a guide to the practical aspects generally involved.

4.12.1 The battery should be discharged and the cell links disconnected and removed both from the faulty cell and from the adjoining cells. The cell position should be noted for subsequent entry in the battery record card.

4.12.2 The vent cap should be loosened using the special key provided with the battery maintenance kit.

4.12.3 A cell extractor tool should then be fitted to the cell on the terminals normally used for connecting the cell links. The battery is then held firmly and the cell withdrawn vertically upwards without using undue force. When one cell is removed and all other cell links are disconnected, it is relatively simple to withdraw the remaining cells without the aid of the extractor.

NOTE: After removing a cell, its vent cap should be re-tightened.

4.12.4 Cells and the inside of the battery case should be thoroughly cleaned and dried (see paragraph 4.4).

4.12.5 After carrying out all necessary checks, serviceable cells should be replaced in the battery case in their correct positions, and a cell-to-cell voltage check should be carried out to ensure that polarities are not reversed. It must be ensured that any new cells are of the same manufacture, part number, and are of matched capacity rating.

NOTE: A steady force should be used on terminals to press cells into place. Tight cells should not be hammered into place. For easiest assembly, the cell at the middle of a row should be inserted last.

4.12.6 The surfaces of cell terminals and connecting links should be clean, and, after ensuring the correct positioning of links, terminal nuts should be tightened to the specified torque value, and in a sequence commencing from the battery positive terminal. Care should always be taken to ensure that nuts actually tighten the connector assemblies, and are not binding as a result of thread damage or bottoming.

NOTE: Once a tightening sequence has been started it should be completed, thereby ensuring that a nut has not been overlooked. One loose connection can permanently damage a battery and may cause an explosion.

4.12.7 On completion of cell replacement procedures, the battery should be re-charged, tested for insulation resistance, and, if any new cells have been fitted, a capacity test should also be carried out.

4.13 **Rejected Batteries or Cells.** Any batteries or cells which are rejected should be conspicuously and permanently marked on their cases to indicate that they are to be used only for general ground use.

5 INSTALLATION It should be ensured that the battery is of the correct ampere-hour rating, fully charged, and that the electrolyte is at the corrrect level. Depending on the service history of the battery, appropriate tests, e.g. capacity test, capacity recycling and cell balancing, must also have been carried out in the manner prescribed for the particular battery. Reference should be made to the relevant aircraft Maintenance Manual for details of the battery system and associated installation instructions. Before coupling the system connecting plug, a check should be made to ensure that the battery system switch is OFF, and that all electrical services are isolated.

NOTE: Batteries are heavy units, and they require the use of approved handling methods to prevent possible injury to personnel and damage to the cases or components adjacent to the battery location. Vent pipes should not be used for lifting purposes.

5.1 The battery compartment should be thoroughly clean and dry, and the battery should be securely attached in its mounting. Clamp nuts should not be over-tightened since distortion of the battery cover may result, which could affect the venting arrangements.

NOTE: If a battery compartment has been previously used for lead-acid batteries, it should be washed out with an acid neutralising agent, dried thoroughly, and painted with an alkaline-resistant paint.

5.2 The supply cables from the battery, and, where appropriate, thermostat and battery charging system cables, should be checked for signs of chafing or other damage. Cable connecting plugs should be securely made, without any strain on the plugs or cables.

5.3 Battery installations are normally designed so that in flight, sufficient air is passed through the compartment to dilute the hydrogen gas given off by a battery, to a safe level. Ventilation systems should therefore be checked to ensure there is no obstruction or, if integral venting is used, the connections should be checked for security and leaks.

NOTE: In some ventilation systems, non-return valves are incorporated in the battery compartment vent lines. These valves should also be checked for security and correct location.

5.4 After installation, a check should be made that the electrical connections of the battery supply cables have been correctly secured by switching on some electrical services for a specific time period and noting that readings of the aircraft voltmeter remain steady. A typical load and time is 30 amperes for 30 seconds. For battery systems having a separate 'in-situ' charging unit, the unit should be switched on and its electrical settings checked to ensure proper charging of the battery.

6 MAINTENANCE OF INSTALLED BATTERIES Batteries should be inspected at the periods specified in the approved aircraft Maintenance Schedule. The details given in the following paragraphs serve as a general guide to the checks normally required.

6.1 The battery mounting should be checked for security, and the outside of the battery case should be examined for signs of damage and for evidence of locally overheated areas. The latches of the cover should operate smoothly and should firmly secure the cover in position.

6.2 Connecting plugs of the battery receptacle, thermostat and battery charger units, where fitted, should be checked for signs of contamination, burns, cracks, and bent or pitted terminal fittings.

6.3 The tops of all cells and vent caps should be inspected for signs of electrolyte leakages and should be cleaned where necessary.

6.4 The electrolyte level should be checked, and if any adjustments are necessary, these should be made after removing the battery from the aircraft and checking that it is in the fully charged condition. The amount of water added to the cells should be noted on the battery record card. A cell requiring more than the specified amount should be regarded as suspect, and the battery should be replaced by a serviceable unit. In aircraft having an independent charging unit, the unit should be switched on and the battery charged in accordance with the procedure specified in the relevant aircraft Maintenance Manual.

NOTE: When removed, the battery cover and cell vent caps should not be placed on any part of the aircraft structure or equipment.

6.5 The battery ventilation system should be checked to ensure security of connection, and freedom from obstruction.

7 BATTERY RECORDS A technical or service record should be maintained on each battery in service. Discretion may be exercised as to the layout of such a record and the extent of the details it should contain. It should, however, provide a fairly comprehensive history of the specific battery, so that in the event of a malfunction it will assist in establishing the fault. The example shown in Figure 1 is intended only as a guide.

8 STORAGE AND TRANSPORTATION Nickel-cadmium batteries should be stored in a clean, dry, well-ventilated area and should be completely segregated from lead-acid batteries. The area should also be free from corrosive liquids or gases. It is recommended that they should be stored in the condition in which they are normally received from the manufacturer, i.e. filled with electrolyte, discharged and with shorting strips fitted across receptacle pins. Cell connecting strips and terminals should be given a coating of acid-free petroleum jelly (e.g. white vaseline).

8.1 The temperatures at which batteries may be stored are quoted in the relevant manuals, and reference should therefore be made to these. In general, a temperature of 20°C is recommended for long-term storage.

8.2 If batteries are to be stored in a charged condition, they must be trickle charged periodically in order to balance the inherent self-discharge characteristic. Since this discharge is temperature sensitive, the trickle charge rate is therefore dependent on the storage temperature conditions.

8.3 If it is necessary to return a battery to the manufacturer or to an approved overhaul organisation, it should be discharged, but not drained of electrolyte. It should be packed in its original container, together with its service record (see paragraph 7) and 'This Way Up' international signs affixed to the outside.

NOTE: If transportation is to be by air, the container must comply with IATA regulations concerning the carriage of batteries containing alkaline electrolyte.

NICKEL-CADMIUM BATTERY SERVICE RECORD

BATTERY AND AIRCRAFT DATA

Manufacturer ....

Part No....................................

Serial No..................................

Rating: Volts............... Ah...........

Mod. State.................................

Aircraft Type...............................

Registration ....

Battery Function (e.g. Standby, A.P.U. Starting)

....

Date Installed..............................

Hours Flown.................................

SERVICING DATA

Date Removed...............................

Date Serviced ....

Workshop Ambient Temp..............

Reason for Removal.......................

Servicing Instructions Used..............

Date Released ....

Operation	Results/Comments	Initials	
		Mech.	Insp.
Details of operations performed and measurements required—			

CELL DATA

Position in Battery	Serial No.	Water Added (c.c.)	Voltage	Temperature	Final Voltage	Capacity (Ah)
1 2						
19 20						

MAIN TERMINAL VOLTAGE...............................

I hereby certify that the inspection/overhaul/repair/replacement/modification specified above has been carried out in accordance with the requirements of Chapter A4—3 of British Civil Airworthiness Requirements.

Signed...

Firm...

CAA Approval Ref.
or Licence No. ....

Date ....

Figure 1

Issue 2

December, 1983

AIRCRAFT

ELECTRICAL EQUIPMENT

POWER SUPPLY—D.C. GENERATORS

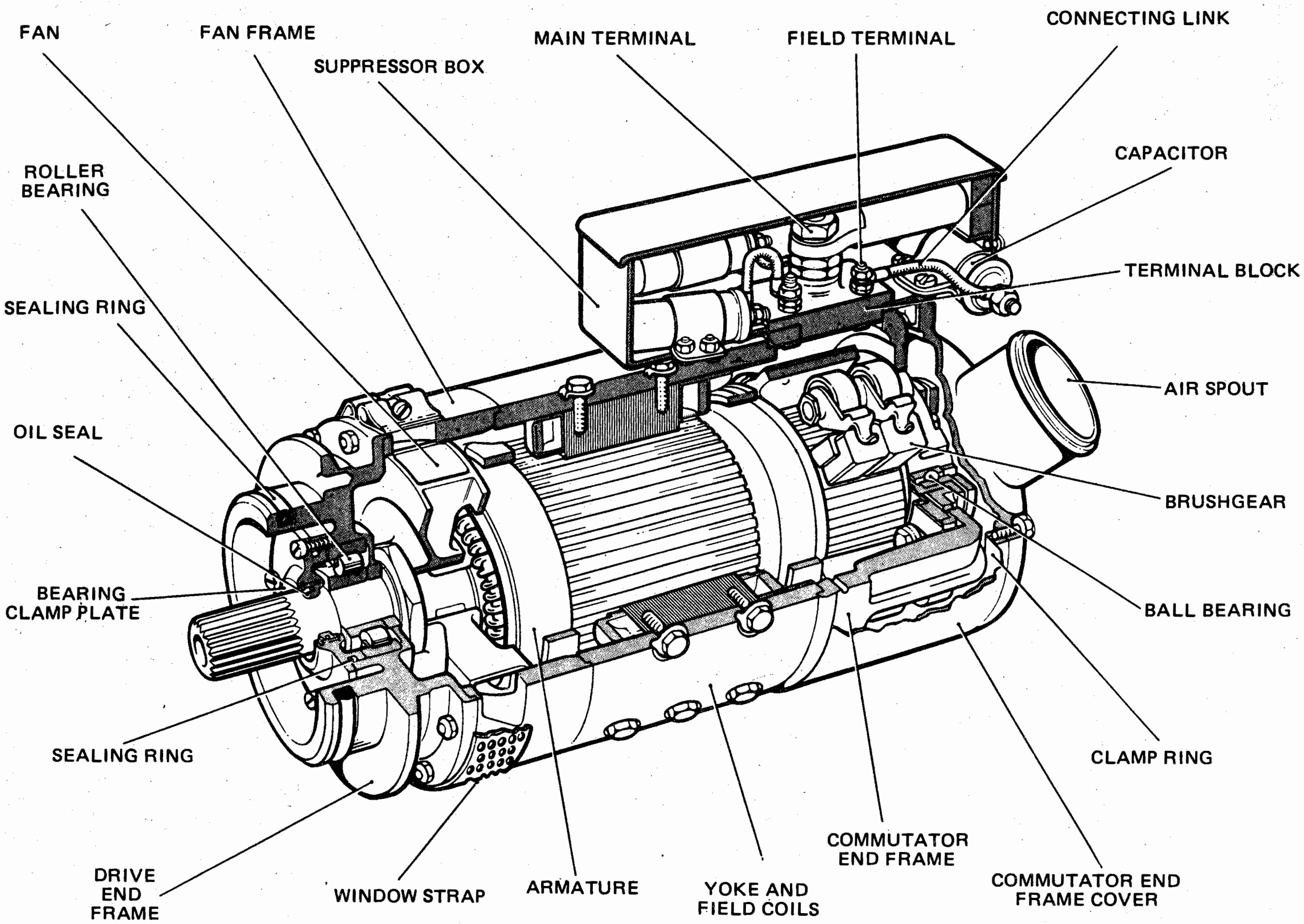
1 INTRODUCTION This Leaflet gives general guidance on the installation and maintenance of engine-driven generators used to provide direct-current power supplies for the various electrical consumer services installed in some aircraft. It should be read in conjunction with the relevant aircraft Maintenance Manual and the approved Maintenance Schedule; such documents providing full details of construction, servicing, repairs and test procedures relevant to specific types of generators. Reference should also be made to the following Leaflets which contain information closely associated with the equipment covered by this Leaflet.

EEL/1-1 Batteries—Lead-Acid
EEL/1-2 Voltage Regulation
EEL/1-3 Batteries—Nickel-Cadmium
EEL/1-6 Bonding and Circuit Testing
EEL/3-1 Cables—Installation and Maintenance

1.1 There are a number of variations in the design and construction of generators and to provide full information would be beyond the scope of this Leaflet. The constructional and operating details given in the relevant paragraphs are based on some typical machines and are therefore intended to serve only as a general guide to the methods adopted.

2 CONSTRUCTION AND OPERATION Figure 1 illustrates a typical generator of the self-excited shunt-wound type. It consists of two major assemblies: a fixed stator, or yoke assembly, and a rotating armature assembly. The yoke assembly houses the magnetic field poles and associated coil windings. The armature assembly comprises a solid or hollow steel shaft upon which is mounted a stack of laminations, slotted to accommodate insulated copper wire or strip armature windings, and the commutator. The complete assembly is statically and dynamically balanced. One end of the shaft is serrated, splined or keyed, either internally or externally, for coupling to the relevant drive shaft of an engine. In some types of light aircraft, the generator employed is driven by a belt fitted around pulleys at one end of the armature shaft and the engine crankshaft. The armature shaft is supported in bearing assemblies housed in frames secured at the commutator end and drive shaft end of the yoke.

NOTE: A typical input speed range for generators installed on turbo-prop aircraft is 4500-8500 rev/min. A typical generator rating for a medium-sized turbo-prop aircraft requiring a d.c. power supply at 28 volts nominal would be:
Continuous: 30 volts 300 amps; cooling air 152 mm (6 in) water gauge.
Continuous: 30 volts 375 amps; cooling air 254 mm (10 in) water gauge.
15 Minutes Emergency Overload: 30 volts 400 amps; cooling air 254 mm (10 in) water gauge.


FAN
FAN FRAME
SUPPRESSOR BOX
MAIN TERMINAL
FIELD TERMINAL
CONNECTING LINK
CAPACITOR
TERMINAL BLOCK
AIR SPOUT
BRUSHGEAR
BALL BEARING
CLAMP RING
COMMUTATOR END FRAME COVER
COMMUTATOR END FRAME
YOKE AND FIELD COILS
ARMATURE
WINDOW STRAP
DRIVE END FRAME
SEALING RING
BEARING CLAMP PLATE
OIL SEAL
SEALING RING
ROLLER BEARING

2.1 The commutator end frame is a substantial cast component which, in addition to supporting the armature shaft, provides an attachment for the brushgear and main output terminal assembly. Depending on the type of generator, the brushgear assembly may consist of either two brushes, or four brushes mounted in boxes in diametrically opposite pairs on a support ring. Four double brush-box assemblies are also employed in some types. A brush spring post is fitted adjacent to each brush-box, and the brush springs are fitted to sleeves assembled to the spring posts. The sleeves are adjustable to permit setting of brush pressure. The brushgear support ring is also adjustable to provide for the setting of the brushes to the optimum position. Apertures are provided in the commutator end frame to allow access to the brushgear for inspection purposes. Under normal operating conditions the apertures are covered by a window strap. Interference to radio reception signals is suppressed by capacitors which are housed in a section of the terminal box and connected between the output terminals and frame. In some generators the capacitors may also be connected between the field terminals and frame.

2.2 The drive end frame is secured by nuts fitted on studs fixed in the end of the yoke, and has an integral flange for securing the generator to the associated engine mounting. Depending on the type of generator and engine mounting, the flange may be drilled for fixing over mounting studs, or machined for fixing by a special 'manacle' ring.

2.3 To obtain the maximum rated output under continuous running conditions, generators must be satisfactorily cooled, and the method most commonly employed for this purpose utilises the ram effect due to propeller slipstream or the normal airstream set up in flight. An air duct facing into the airstream is joined to a spout which is secured to the commutator end cover. The air passes over the commutator and windings at a predetermined pressure and rate of flow, and escapes through apertures in the window strap and an outlet union positioned at the drive end of the generator. In order to assist cooling under minimum air conditions and when operating at ground level, some generators may also incorporate an impeller type fan secured to the armature shaft at the drive end. In some types of generator, a thermally-operated switch unit is located in the yoke assembly. This is set to operate at a pre-determined temperature and is connected to an overheat warning light circuit.

2.4 When the armature is rotated within the yoke assembly, the armature windings cut the weak magnetic field set up by the residual magnetism of the pole shoe assemblies, and small voltages are induced in the windings. The armature windings are connected in parallel with the shunt field windings and are terminated at the commutator in such a manner that the voltage generated across the brushes is always of the same polarity. The small generated voltages therefore cause a flow of direct current through the field windings to increase the flux density. The increased field density, in turn, builds up the value of the voltages induced in the armature windings and also the voltage picked off by the brushes. The build-up of generated voltage progresses until a value predetermined by the setting of the associated voltage regulator connected in the shunt field circuit is reached. The voltage regulator automatically adjusts the resistance of the shunt field circuit in proportion to changes in generated voltage, thereby controlling the excitation current to maintain a constant voltage output essential for the efficient operation of associated consumer services.

3 INSTALLATION The arrangements for the installation of generators depend primarily upon the type of engine and, in some cases, also upon the particular type of aircraft. Reference should therefore always be made to the relevant Maintenance Manuals in which the specific installation instructions are given. The information given in the following paragraphs serves as a general guide to the methods to be adopted and to the checks to be carried out prior to installation.

3.1 Before installing any generator a check should be made to ensure that its type, part number and direction of rotation are correct for the particular installation. These details are given on a name plate attached to the generator yoke or casing. The rotation is specified as the direction of armature rotation when viewed from the driving end.

3.2 Housings and terminals should be checked for cleanliness and freedom from corrosion, distortion, cracks or other damage. The movement of armatures should also be checked for freedom by manually rotating the appropriate assembly at the driving end.

3.3 On generators employing drive shafts, a light coating of grease or engine oil should be applied to the splines after first removing any protective compound from the shaft. Reference should always be made to the relevant generator and aircraft Maintenance Manuals for details of the type of lubricant to be used.

3.4 In belt-driven generator installations, drive pulleys and belts should be checked for security and condition. After installation, belts should also be checked to ensure that they have the correct tension. Low tension will permit belt slippage, with a resulting rapid belt wear and low or erratic generator output, while excessive tension will cause rapid wear on the belt and on the generator bearing. The tension may be checked either by measuring the torque required to slip the belt at the generator pulley, or by measuring the amount of belt deflection caused by a predetermined load. Reference should always be made to the Maintenance Manuals for details of the measuring procedure and permissible limits.

3.5 The appropriate generator mountings at engine drive units should be inspected for cleanliness and damage, paying particular attention to mounting studs and drive shafts. If gaskets are employed between mounting faces these should be checked for serviceability and renewed as necessary.

3.6 When locating generators of the splined drive type they should be turned slightly in each direction about the drive axis to facilitate proper engagement of the splines. After a generator has been correctly orientated on its mounting it should be secured by the appropriate method (e.g. self-locking nuts and studs, bolts, or 'manacle' ring), paying particular attention to any torque values specified for tightening.

NOTE: Generators which are to be mounted horizontally should be adequately supported during installation and not be allowed to hang on their drive shafts or mounting studs.

3.7 Generator cables should be checked to ensure that they are free from damage to terminations, fraying and chafing of insulation covering. The alignment of cable ends should also be checked to ensure that cables are not subjected to strain particularly at points of entry to terminal boxes. The identification of terminations should be checked and connections made in accordance with relevant generator and aircraft installation wiring diagrams.

3.8 Before connecting cooling ducts they should be inspected for cleanliness, signs of damage and for correct orientation. Gaskets, where applicable, should also be inspected for condition and renewed as necessary. Where cooling ducts or scoops are fitted to movable cowlings, the alignment of cooling duct to generator cooling air entry should be checked.

3.9 After installation, a check should be made that all associated electrical circuits are in a safe condition for operation, and a generator function test carried out to the requirements specified in the relevant aircraft Maintenance Manual.

4 INSPECTION AND MAINTENANCE The information in the following paragraphs is a guide to the general practices adopted for the inspection and maintenance of generators at specified inspection periods, and whenever their serviceability is suspect. Precise details of all necessary checks and tests are given in the relevant Maintenance Schedules and Maintenance Manuals, and reference should always be made to such documents.

4.1 **Security and Visual Defects.** Checks should be made for the following:

(a) Security of mounting and signs of damage.

(b) Security of all electrical connections, signs of cracks in terminal boxes and damage to terminal post threads.

(c) Signs of damage or corrosion at cable terminations, fraying and chafing of insulation and outer coverings; cables should be renewed as necessary.

(d) Security of cooling ducts and cleanliness of air outlet screens around generator.

(e) Evidence of oil having entered generator casings. This may be checked by shining a light into air outlet screens and brush inspection apertures. If oil is present it is possible that oil seals have failed and the generator should be removed for examination.

(f) Condition and correct tension of drive belts (see also paragraph 3.4).

4.2 **Commutators.** Commutators should be inspected for signs of excessive arcing, scoring, proud mica and carbon deposit. Carbon dust should be removed with a supply of clean, dry compressed air from a low pressure source.

4.2.1 In some generators, brushes are employed which have been specially developed to eliminate brush wear at high altitudes. The brushes in one particular category form a dark film on the surfaces of commutators. This film may give the impression that the surfaces are dirty but it is, in fact, a protective semi-lubricating surface which, so far as is practicable, should not be disturbed.

NOTE: The cleaning of commutators should be carried out in accordance with the relevant Maintenance or Overhaul Manual. Under no circumstances should an abrasive material be used.

4.3 **Brushgear.** Covers should be removed from inspection apertures or housing and the brushgear checked for condition and settings. Each brush should be examined for condition and wear.

4.3.1 The length of each brush should be measured on the longest side and sufficient allowance made to ensure a satisfactory performance until the next inspection period.

4.3.2 Brushes should be free but not slack in their boxes. If brushes are tight as a result of carbon deposits having formed in the boxes, the brushes should be removed and the boxes cleared of deposits by means of a soft cloth moistened in the recommended cleaning fluid. Before refitting the brushes, low-pressure, dry compressed air should be directed around the boxes and brushgear housing to remove any remaining carbon deposits.

4.3.3 If brushes are found to be contaminated by oil or grease they should be renewed. If this is not done, lubricant will be exuded when the brushes become warm during subsequent operation of the generator, thus affecting the combined efficiency of brushes and commutator.

NOTE: Serviceable brushes should be subjected to the minimum amount of handling, and be labelled to identify their positions when removed from their boxes.

4.3.4 The pressure exerted by brush springs should be checked to ensure that it is within specified permissible limits. The check is carried out by using a suitably calibrated spring balance in the manner prescribed in the relevant Maintenance Manual.

NOTE: The pressures are the same for each of the brushes employed in a generator.

4.3.5 An essential prerequisite to good commutation of d.c. generators is the correct positioning of brushes around the commutator. For this reason, the rocker containing the brush boxes is adjustable within a limited number of degrees of arc. Adjustments are pre-set and, during inspection, a check should be made to ensure that the rocker is secure in the position determined for the specific type of generator. The position is normally indicated by the alignment of datum marks painted or engraved on the rocker and commutator end frame. For details of the method of obtaining the requisite positions of brushgear, reference should always be made to the relevant generator Overhaul Manual.

4.3.6 When new brushes are fitted, they should be bedded down in accordance with the procedures specified in Overhaul Manuals to suit the contour of a commutator, thus obtaining the necessary surface finish over a maximum arc of contact. In general, the procedure is carried out in two stages; preliminary bedding and final bedding run.

(a) At the preliminary stage, the brushes are approximately shaped to the required contours by an interposed thin abrasive strip affixed around the commutator. After checking that brush spring pressures are within the limits specified, the armature should be turned by hand in the normal direction of rotation until the approximate contours are obtained. The brushes should then be withdrawn from their boxes and the abrasive strip removed. After removing traces of carbon deposits with clean, dry compressed air, the brushes should be refitted to make direct contact with the commutator in preparation for final bedding.

(b) For final bedding of brushes, a generator is usually run as a motor, ensuring correct direction of rotation, until every brush is evenly bedded over its entire contact area. It is then driven at a specified rev/min and loaded progressively from zero to full load current at the rated voltage, avoiding severe sparking. With properly bedded brushes the commutation should be such that only light pin point sparking is evident at full rated load.

NOTE: In the initial stages of a bedding run, care should be taken to avoid the application of heavy currents which might cause damage to armatures or brushes because of the high current density through the small areas of contact surface available. Prolonged running on light load should also be avoided since this practice causes glazing of brush and commutator surfaces to the detriment of subsequent operation.

4.4 **Electrical Tests.** All generators should be subjected to certain functional tests prior to their installation, at periods specified in Maintenance Schedules, and at any time their operation is suspect. The nature of the tests and permissible limitations varies with each type of generator and aircraft installation; reference should, therefore, always be made to the relevant Maintenance and Overhaul Manuals.

5 STORAGE AND TRANSIT Generators should be stored, preferably in their original packing, in conditions which are clean, dry, of even temperature, well ventilated and free from corrosive fumes. Limiting periods of storage are quoted in manufacturer's Maintenance and Overhaul Manuals and, provided recommended storage and packing conditions are met, generators will not require attention throughout these periods. At the end of the storage periods, or whenever there is evidence of deterioration of the packing, generators should be inspected and tested in accordance with the instructions contained in the relevant Overhaul Manuals. Protection covers are provided for attachment to drive end frames and air inlet spouts and these should be fitted to generators prior to packing and transit.

EEL/1-5

Issue 1.

December, 1978.

AIRCRAFT

ELECTRICAL EQUIPMENT

POWER SUPPLY—A.C. GENERATORS

1 INTRODUCTION This Leaflet briefly outlines the construction and operating fundamentals of alternating current generators, and also gives guidance on their installation and maintenance. As relevant details can vary between different types of generators, and on the electrical power supply requirements of a particular type of aircraft, the information is of a general nature only, and is based on typical generators in common use. The Leaflet should, therefore, be read in conjunction with the Maintenance Manuals and other approved documents for the particular generators concerned, and for the type of aircraft in which they are installed.

1.1 Reference should also be made to the following Leaflets which contain information associated with electrical power generation.

EEL/1-1 Batteries—Lead-acid

EEL/1-2 Carbon-Pile Voltage Regulators—D.C. Generator Systems

EEL/1-3 Batteries—Nickel-Cadmium

EEL/1-6 Bonding and Circuit Testing

EEL/1-8* Power Production Systems

EEL/1-9* Circuit Protection Devices

EEL/3-1 Cables—Installation and Maintenance

NOTE: The previous Leaflet **EEL/1-5** was entitled "Batteries (Nickel-Cadmium, Sintered-Plate)"; all relevant information is now incorporated in Leaflet **EEL/1-3.**

2 GENERATOR TYPES Alternating current generators are generally of two types; those designed for operation over a wide variable speed and variable frequency range (frequency-wild generators), and those designed for constant speed and constant frequency operation (constant-speed generators).

2.1 **Frequency-wild Generators.** These fall into two categories; those used on small aircraft to provide a direct current voltage output, and those used to provide an alternating current voltage output to supply systems that do not require a fixed frequency supply. Figure 1 illustrates a generator the output of which is rectified to provide direct current. Generators of this type are utilised in a variety of small aircraft requiring direct current as the primary power source. The principal components of the generator are the rotor, the stator, and a rectifier assembly. The rotor comprises two extruded steel pole pieces pressed on to a shaft against each end of a field coil. Each pole piece has six 'fingers', so shaped that when the pole pieces are in position, the 'fingers' mesh with, but do not touch, each other. Two slip rings are pressed onto one end of the rotor

*Leaflets **EEL/1-8** and **EEL/1-9** will be published in May, 1979.

shaft and are electrically connected to the rotor field coil. The rotor is rotated by a driving belt and pulley driven by the engine, or by coupling the generator directly to the engine gearbox drive shaft. The stator comprises three star-connected coils wound around a laminated core; one end of each coil is connected to the rectifier assembly while the other ends are joined together to form the 'star' or neutral point. The rectifier assembly is located opposite to the drive-end of the generator, and consists of six silicon diodes connected to form a full-wave bridge rectifier circuit. Three of the diodes (negative) are mounted on the end frame, while the other three (positive diodes) are mounted on a 'heat sink' plate on the inside of the end frame. Spring-loaded brushes are located inside the end frame and make contact with the rotor slip rings to complete the field or excitation coil circuit.

2.1.1 These small generators do not usually incorporate permanent magnets and are not self excited. They therefore require a supply of direct current from an independent source for the initial excitation of the rotor field windings. In the type illustrated in Figure 1, this is provided from the busbar of the electrical system of the aircraft when the battery, or an external power supply, is connected to that busbar. The current passing through the field coil circuit causes the 'fingers' of the rotor pole pieces to become alternately north and south electro-magnetic poles. As it rotates, the magnetic field set up in the rotor poles induces a three-phase alternating voltage in the stator windings at a frequency dependent on rotor speed. The output is supplied to the rectifier assembly, and the direct current thus obtained is then supplied to the electrical system busbar, thereby maintaining excitation of the field coil. The rectified output is also fed to a voltage regulator which is pre-set to regulate the generator voltage, within the limits specified for the generator and aircraft electrical system.

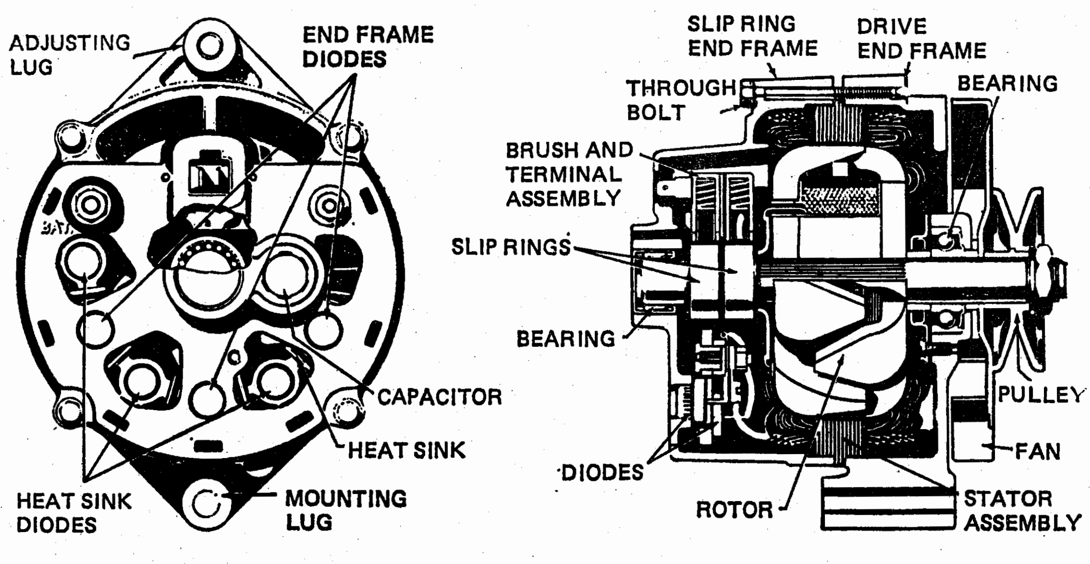


Figure 1 TYPICAL SMALL BRUSHLESS D.C. GENERATOR

2.1.2 Figure 2 illustrates a typical three-phase, frequency-wild generator, which is used in some aircraft for the supply of alternating current to electrical systems that do not require a fixed frequency supply, such as resistive load circuits for de-icing and anti-icing systems. This generator has a power output of 15 kVA at 208 volts, and its frequency and driven speed ranges are 335 to 535 Hz and 6700 to 10 700 rpm, respectively. The generator consists of two major assemblies; a rotor assembly and a fixed stator assembly. The rotor assembly has six poles, each of which is wound with a field coil; the coils terminate at two slip rings secured at one end of the rotor shaft. Three spring-loaded brushes are equi-spaced on each slip ring, and are contained within a brushgear housing. The brushes are electrically connected to direct current input terminals housed in an excitation terminal box mounted on the outside of the brushgear housing. The terminal box also houses capacitors connected between the terminals and earth, to suppress interference which may affect, for example, the reception of radio signals. The rotor shaft is splined at the drive end, and supported in a roller bearing fitted in the main housing. An oil seal is provided to prevent the entry of oil from the driving source into the main housing. The stator windings are star-connected, and an end frame clamps the whole assembly in the main housing, which has an integral flange for mounting the generator at the corresponding drive shaft outlet of the engine accessory gearbox. The ends of the stator windings are brought out to a three-way output terminal box mounted on the end frame. The generator is cooled by ram air passing into the main housing via an inlet spout; the air escapes from the main housing through ventilation slots at the drive end, from where it is usually ducted overboard.

(a) Direct current for the initial excitation of the rotor field windings is provided from the main busbar via a 'start' switch in the circuit to the excitation terminals and brushgear. As the generator rotates, a three-phase alternating voltage is induced in the stator windings which is supplied to the busbar distribution. The output voltage is controlled by feeding it to a voltage regulator, and to a three-phase bridge rectifier, which together with other protection circuits, are contained within a separate control unit. At a pre-determined output voltage, the generator is able to run as a self-excited machine, and could operate independently of the direct current supply from the main busbar.

2.2 **Constant-speed Generators.** These generators are utilized in those types of aircraft requiring (i) a much wider application of alternating current, (ii) a considerable amount of electrical power, and (iii) generator system load-sharing capability. Generators designed for such applications are currently of the brushless type, and are driven by an engine through the medium of a special constant-speed drive unit. In most applications, the generators may be removed and installed separately and with the drive unit 'in-situ', but for certain types of aircraft, the generators are integrated with the drive unit so that removal and installation as a complete assembly is necessary. Examples of both types are illustrated in Figures 3 and 4, respectively. The constant-speed drive is basically a differential gear transmission system which converts variable input speed of an engine to a constant output speed appropriate to the generator rating. The output speed of the generator is controlled by a hydromechanical governor system. The construction of generators varies, but, in general, they consist of three principal components; a pilot exciter, a main exciter and rotating rectifier, and a main generator. All three components are contained within a casing made up of an end bell section and a stator housing section. A mounting flange, which is an integral part of the stator housing section, provides for attachment of the generator to the constant-speed drive unit by means of either studs and retaining nuts, or a quick attach/detach type of coupling.

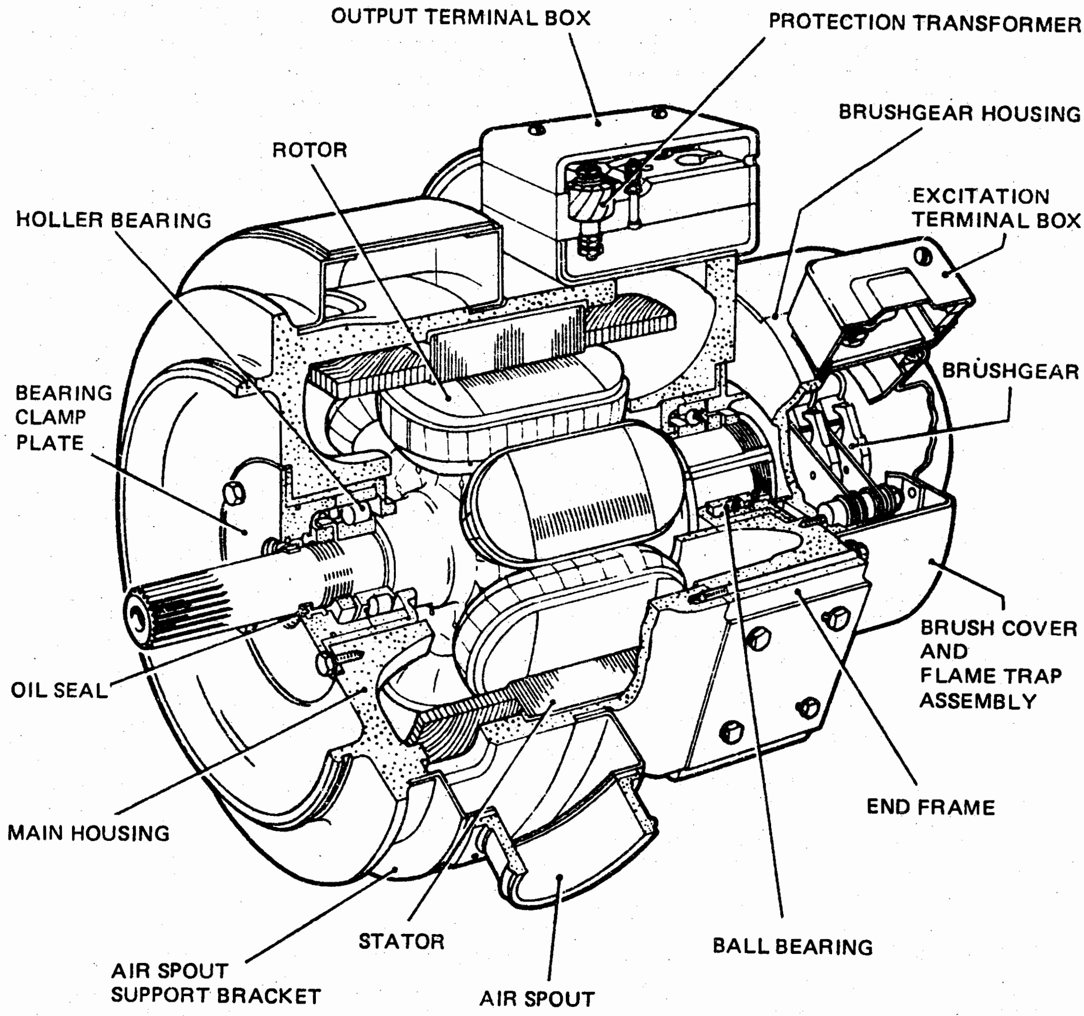


Figure 2 TYPICAL LARGER FREQUENCY-WILD GENERATOR

2.2.1 The purpose of the pilot exciter is to provide the magnetic field necessary for initial excitation of the main exciter. It comprises a stator, and a permanent magnet rotor which is mounted on the same shaft as the main exciter and main generator rotor. The a.c. output from the pilot exciter is fed to the main exciter field via a control and protection unit.

2.2.2 The rotating rectifier assembly supplies excitation current to the main generator rotor field coils from the main exciter rotor, and eliminates the need for brushes and slip rings. It usually consists of six silicon diodes connected as a three-phase, full-wave bridge rectifier circuit, sometimes contained within a tubular insulator located in the hollow shaft on which both the exciter rotor and main generator rotor are mounted, but can be mounted in any convenient position on the rotor, provided the radius from the centre line is not excessive.

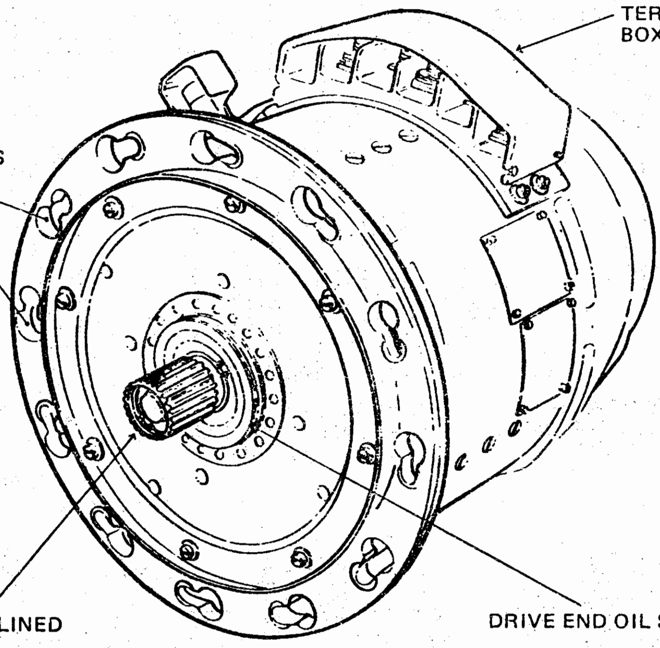


Figure 3 TYPICAL CONSTANT-SPEED GENERATOR

2.2.3 The main generator consists of a three-phase, star-wound stator, a rotor and associated field windings, which are connected to the rotating rectifier assembly. The leads from the three stator phases are connected to a terminal block, which permits connection of the generator to the aircraft power distribution system.

2.2.4 When a generator starts operating, an initial flow of current is provided to the field of the main exciter via the control and protection unit, and a three-phase voltage is produced in the exciter rotor. This voltage is then supplied to the rotating rectifier assembly, the direct current output of which is, in turn, fed to the field coils of the main generator rotor as the required excitation current. A rotating magnetic field is thus produced which induces a three-phase voltage output of 200 volts, at a frequency of 400 Hz, in the main stator windings. The output voltage is sensed at the busbar by the voltage regulator, which controls the amount of excitation current required by the main generator section to maintain the desired a.c. output.

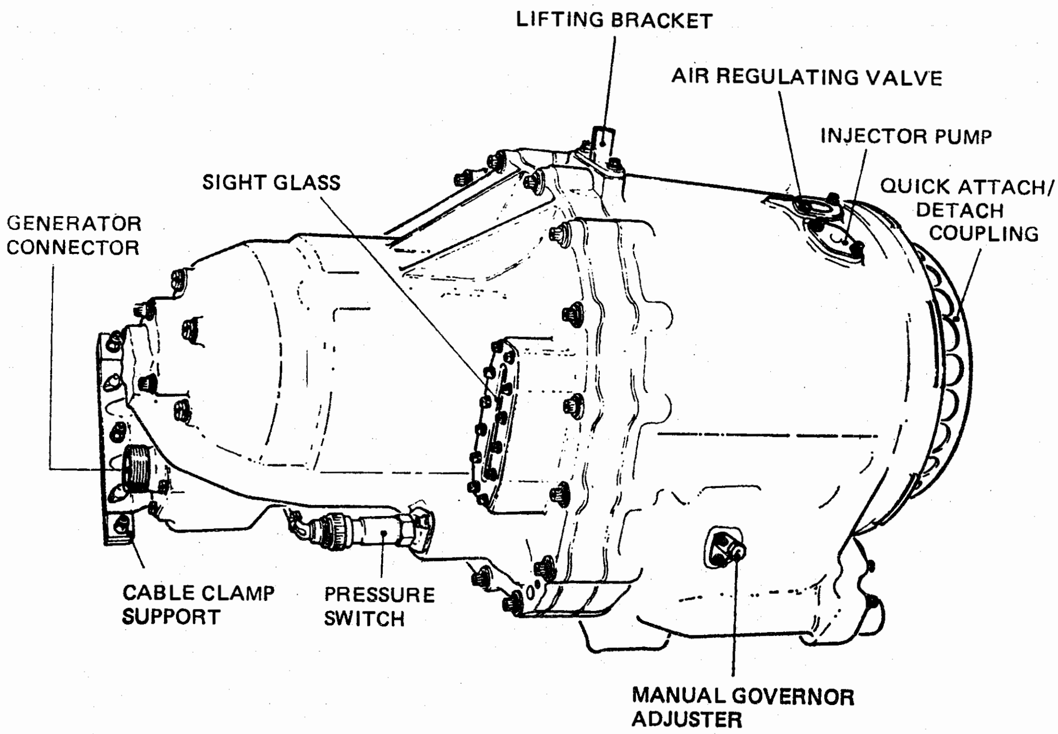


Figure 4 TYPICAL INTEGRATED DRIVE GENERATOR

2.2.5 Generator cooling is normally provided by ram air which enters through the end bell section of the casing, and passes through the windings, the rotor shaft, and the rectifier assembly. The air is exhausted through a perforated screen around the periphery of the casing, at a point adjacent to the main generator stator, then usually ducted overboard. In the case of integrated drive generators, cooling of the windings and rectifier assembly is provided by oil which is also used for the speed governing hydraulic system. The oil is supplied from a reservoir which is integral with the casing of the integrated drive generator, and is circulated by a charge pump driven by the output shaft of the hydraulic transmission system. The oil is passed through an oil cooler mounted on the engine, and, depending on the installation, the cooling medium for the oil may either be air tapped from a low-pressure stage of the compressor or fuel from the fuel system of the aircraft.

3 MAINTENANCE PRACTICES

3.1 **General.** Maintenance practices to be adopted for generators will depend upon their type and on the type of aircraft in which they are installed. Reference must, therefore, be made to the relevant aircraft Maintenance Manuals for the specific details. The information on adjustment of belt tension for belt-driven generators is given in Leaflet **EEL/1-4.** The information given in the following paragraphs is to serve only as a general guide.

3.2 **Removal**

3.2.1 As a generator may be too heavy to lift with safety or without injury, approved handling methods must be used. Care should be taken to avoid damaging other equipment located in and around the area, such as fire detection elements which are highly susceptible to damage. The remaining checks and precautions can be summarised as follows:—

(a) Carry out electrical safety procedures as indicated in the Maintenance Manual.

(b) Where necessary, electrical connections should be identified when disconnected. Refit terminal covers and fit blanks if required.

(c) In the case of integrated drive generators, drain the cooling oil from the unit (see paragraph 3.5.4). Disconnect cooling system oil lines and blank off to avoid contamination.

(d) For other than integrated drive generators, disconnect the cooling ducts and blank off.

(e) Install a component hoist, if it is required, and adjust so that the weight of the generator is just being supported and correctly balanced by the hoist, then release the generator attachment fasteners.

(f) Carefully remove the generator from its housing/mounting, taking care not to damage the drive coupling and adjacent items of equipment or engine structure.

(g) Following the removal of the generator, check drive belts or drive coupling splines for wear against the wear limits in the aircraft maintenance manual.

NOTE: Damage can result if the generator is allowed to hang on splined drive couplings.

3.3 **Pre-installation Checks**

3.3.1 Before installing any generator a check should be made to ensure that it is the correct unit for the particular installation.

3.3.2 Housings, terminals and electrical connections should be checked for cleanliness and freedom from corrosion, distortion, cracks or other damage.

3.3.3 The rotational movement of generator rotors should be checked for freedom by manually rotating them at the driving end.

3.3.4 Rotor shaft splines should be checked for signs of damage and wear. A similar check should also be made on the mating splines of the drive shafts of an accessory gearbox or constant-speed drive unit as appropriate. A light coating of lubricant of the type specified in the relevant Maintenance Manual should be applied to rotor shaft splines before installing a generator.

3.3.5 On installations in which belt-driven generators are employed, the security and condition of drive pulleys and belts should be checked.

3.3.6 The mountings appropriate to the type of generator should be checked to ensure that they are clean and free from damage. Where specified, a coating of anti-corrosion compound should also be applied to mounting surfaces.

3.3.7 Where appropriate, new gaskets should be fitted between mounting faces, and new O-rings should also be fitted on generator drive shafts.

3.3.8 Generator cables should be checked for signs of damage to terminations, for fraying, and for chafing of insulation covering. The coincidence of cable ends should also be checked to ensure that cables will not be subjected to strain particularly at points of entry to terminal boxes or other forms of connector.

3.4 **Installation Procedures**

3.4.1 When locating generators of the splined drive shaft type, they should be turned slightly in each direction about the drive axis to facilitate proper engagement of the splines.

3.4.2 After a generator has been correctly orientated on its mounting, it should be secured, paying particular attention to any torque values specified for tightening retaining nuts or quick attach/detach couplings as appropriate to the installation. Before finally tightening the retaining nuts of generators having buttonhole-shaped slots in their mounting flanges (see Figure 3) the generators should be rotated on the mounting studs until the latter are concentric with the slotted sections.

3.4.3 Generators which are to be mounted horizontally should be adequately supported during installation and not be allowed to hang on their drive shafts or on mounting studs. In some aircraft in which constant-speed generators may be removed and installed separately from their drive units, or which are of the integrated drive type, a special hoisting rig is provided and this must be used in the manner specified in the relevant aircraft Maintenance Manual.

3.4.4 Integrated drive generator units are usually provided with an electrically-operated disconnect mechanism which permits isolation of the generator from the engine in the event of malfunction of either the transmission system, the constant-speed drive or the generator. The mechanism is controlled by a switch in the flight compartment, and a solenoid which, on being energised, disengages the constant-speed input drive clutch from the input gear thus preventing rotation of the transmission. The constant-speed drive can normally only be re-engaged by manually operating a reset handle located at the bottom of the integrated drive unit.

NOTE: This should only be done with the engine at rest or damage may result.

3.5 **Cooling Systems.** Whenever servicing is carried out on an integrated drive generator the following information should be carefully observed.

(a) An integrated drive generator which has recently been running may contain hot oil under pressure.

(b) Do not overfill. Overfilling can cause overheating and oil sludging, resulting in transmission damage.

(c) The minimum number of components should be in the line when flushing is carried out. This is to prevent the debris that usually accumulates in the oil cooler from contaminating them: never flush with new components connected into the system.

(d) Specific maintenance procedures for each type of generator and aircraft installation will be found in the relevant Maintenance Manual, to which full attention should be given. The following procedures are therefore to serve only as a general guide.

3.5.1 Before connecting cooling ducts to an air-cooled generator, the ducts should be inspected for cleanliness, signs of damage and for correct orientation. Where a cooling-air duct or scoop is fitted to a removable cowling panel, the duct or scoop should be checked for correct alignment with the air inlet connection of the generator.

3.5.2 As stated in paragraph 2.2.5, the oil supplied to integrated drive generators passes through an oil cooler mounted on the engine. Before installation of a replacement integrated drive generator it is necessary to ensure that the cooler inlet and outlet pipelines are free from any contamination. Flushing should be carried out to ensure that debris from a previous failure will not contaminate the replacement (see paragraph 3.5.3). On completion, the pipelines should be correctly orientated and their connections to the generator unit tightened to the specified torque values, and wire locked. This also applies to vent pipes and drains. On completion of the installation procedure, the oil system must be filled and primed (see paragraph 3.5.5).

3.5.3 **Flushing.** This should be carried out with the minimum number of components in the lines to prevent the debris, that usually accumulates in the oil cooler, from contaminating them. A system should never be flushed with new or replacement components connected into the lines. A preferred method would, therefore, be to remove the system for flushing in the workshop. The general procedure for flushing the aircraft system, when required, should be carried out in accordance with the following steps:—

(a) Fill and prime the system as listed in paragraph 3.5.5 but do not carry out the topping-up section of the procedure.

(b) Drain the system as listed in paragraph 3.5.4.

(c) Fill and prime the system as listed in paragraph 3.5.5.

3.5.4 **Draining**

(a) Place a suitable container beneath the magnetic drain plug.

(b) Vent the integrated drive generator by pressing in the case pressure vent valve, after first allowing the oil to cool.

(c) Clean the area around the magnetic drain plug.

(d) Remove the magnetic drain plug.

(e) Inspect the magnetic drain plug for contamination.

(f) Fit the drain hose in place of the magnetic drain plug; oil will flow through the drain hose. When the oil content has drained into the container, remove the drain hose.
NOTE: This oil should never be used to refill the system.

(g) Ensure that serviceable sealing rings are fitted to the magnetic drain plug, then refit. Place a warning placard on the integrated drive generator stating that it is drained of oil.

3.5.5 **Fill and Prime**

(a) Vent the integrated drive generator case.

(b) Connect the delivery hose of the replenishing gun to the re-oiling coupling.

(c) Carefully fill with oil until the oil reaches the top of the oil level mark on the sight glass.

(d) Close the case pressure vent valve.

(e) Disconnect the re-oiling delivery hose and assemble the quick-release cap to the re-oiling coupling.

(f) Pull the disconnect reset handle to ensure that the integrated drive generator is engaged.

(g) Carry out an engine dry motoring cycle, to ensure that the system is fully primed.

(h) Vent the case and allow the specified time for the oil levels to equalise. Check that the oil level is within the oil level mark on the sight glass. If the oil level is correct, close the case pressure vent valve by pulling it out to its fullest extent.

(j) If the level is not correct, repeat steps (a) to (g) for low level or carry out the drain procedure for high level.

3.6 **Adjustment/Test**

3.6.1 All generators must be subjected to certain functional tests following their installation, at periods specified in Maintenance Schedules, and at any time their operation is suspect. The nature of the tests, permissible limitations and adjustments that may be made varies with each type of generator and aircraft installation; reference must, therefore, always be made to the relevant aircraft Maintenance Manual.

EEL/1-6

Issue 2

September, 1988

AIRCRAFT

ELECTRICAL EQUIPMENT

BONDING AND CIRCUIT TESTING

1 INTRODUCTION

1.1 The purpose of this Leaflet is to provide guidance and advice on the inspection and testing of bonding and electrical circuits after installation and at the periods specified in the Approved Maintenance Schedule for the aircraft concerned.

1.2 Subject headings are as follows:—

1.3 Related CAIP Leaflets:—

AL/3-7 Control Systems
AL/3-9 Fire Detection Equipment
BL/6-1 Soft Soldering
EL/3-9 Piston Engines — Magnetos
EL/5-2 Piston Engine Ignition Cables and Harnesses
EEL/1-1 Batteries — Lead-Acid
EEL/1-3 Batteries — Nickel-Cadmium
EEL/1-7 Fire Detection and Extinguishing Systems — Electrical Tests on Systems
EEL/3-1 Cables — Installation and Maintenance

2 GENERAL

2.1 As each test normally requires specified equipment, care should be taken that it is correctly used (e.g. good electrical contact should always be made). The methods of testing and inspection will vary with different types of aircraft and the equipment fitted, therefore reference must be made to the appropriate Maintenance Manuals for detailed information.

2.2 To ensure the reliability of test equipment, it should be carefully serviced and certified at the periods recommended by the manufacturer. The performance of equipment should also be checked before and after use.

2.3 After completion of all tests, the installations should be inspected to ensure that all connections have been re-made and secured, and that test equipment, tools, etc., have been removed. This should be carried out immediately prior to the fitting and securing of panels, covers, etc., as appropriate. As far as the installation permits, the circuits should then be proved, by making ground functioning checks of the services concerned. A dated record of all relevant figures obtained during the checks should be retained. Any disconnections or disturbance of circuits associated with flying or engine controls, will require duplicate inspection and functioning tests as outlined in Leaflet **AL/3-7**.

3 BONDING

3.1 Bonding is the electrical interconnection of metallic aircraft parts (normally at earth potential) for the safe distribution of electrical charges and currents.

3.2 **Function of Bonding.** Bonding provides a means of protection against charges as a result of the build-up of precipitation, static, and electrostatic induction as a result of lightning strikes so that the safety of the aircraft or its occupants is not endangered. The means provided are such as to (a) minimise damage to the aircraft structure or components, (b) prevent the passage of such electrical currents as would cause dangerous malfunctioning of the aircraft or its equipment, and (c) prevent the occurrence of high potential differences within the aircraft. Bonding also reduces the possibility of electric shock from the electrical supply system, reduces interference with the functioning of essential services (e.g. radio communications and navigational aids) and provides a low resistance electrical return path for electric current in earth-return systems.

3.3 **Primary and Secondary Conductors**

3.3.1 Primary conductors are those required to carry lightning strikes, whilst secondary conductors are provided for other forms of bonding. The current British Civil Airworthiness Requirements (BCAR) for bonding paths are as follows:—

(a) BCAR Section D **D4-6** and Section K **K4-6**;

(i) 'The cross sectional area of Primary Conductors made from copper shall be not less than 0·0045 sq in, i.e. 0·25 in by 26 swg, except that, where a single conductor is likely to carry the whole discharge from an isolated section, the cross sectional area shall be not less than 0·009 sq in, i.e. 0·5 in by 26 swg. Aluminium Primary Conductors shall have a cross sectional area giving an equivalent surge carrying capacity.'

(ii) The cross sectional area of secondary conductors made from copper must not be less than 0·001 sq in which corresponds to 44 strands of 39 swg for braided conductors. Where a single wire is used its size must be not less than 18 swg.

(b) BCAR 23 **ACB 23.867** and JAR-25 **ACJ 25X899 (4.2)**;

(i) 'Where additional conductors are required to provide or supplement the inherent primary bonding paths provided by the structure or equipment, then the cross sectional area of such primary conductors made from copper should not be less than 3 mm² except that, where a single conductor is likely to carry the whole discharge from an isolated section, the cross sectional area would be not less than 6 mm². Aluminium primary conductors should have a cross sectional area giving an equivalent surge carrying capacity.'

(ii) Where additional conductors are required to provide or supplement the inherent secondary bonding paths provided by the structure or equipment, the cross sectional area of such secondary conductors made from copper should be not less than 1 mm². Where a single wire is used its size should be not less than 1·2 mm dia.

3.4 Bonding of Aircraft of Metallic and Non-Metallic Construction

3.4.1 The skin of an all-metal aircraft is considered adequate to ensure protection against lightning discharge provided that the method of construction is such that it produces satisfactory electrical contact at the joints.

NOTE: An electrical contact with a resistance less than 0·05 ohm is considered satisfactory.

3.4.2 With regard to aircraft of non-metallic or composite construction, a cage, consisting of metallic conductors having a surge carrying capacity at least equal to that required for primary conductors and to which metal parts are bonded, forms part of the configuration of the structure and must conform to the requirements of BCAR.

3.4.3 The earth system, which in the case of aircraft of metallic construction is normally the aircraft structure and for aircraft of non-metallic construction is the complete bonding system, must be automatically connected to the ground on landing. This is normally achieved through the nose or tail wheel tyre, which is impregnated with an electrically conducting compound, to provide a low resistance path.

NOTE: On some aircraft, a static discharge wick or similar device trailed from a landing gear assembly is used to provide ground contact on landing.

3.4.4 The reduction or removal of electrostatic charges which build up on such surfaces as glass fibre reinforced plastic, can be achieved by the application of a paint, e.g. PR 934, which produces a conductive surface.

3.5 Bonding Connections

3.5.1 When a bonding connection is to be made or renewed, it is essential that the conductor has the specified current-carrying capacity, since the bond may have been designed to carry relatively high electrical loads, e.g. under circuit fault conditions.

3.5.2 The manufacturers of solid bonding strip and braided bonding cord usually quote the cross-sectional area on the relevant data sheet. However, in the case of renewal or repair, if the original conductor cannot be matched exactly, a replacement manufactured of the same type of material, but of greater cross-sectional area, should be selected.

3.5.3 Braided copper or aluminium cords fitted at each end with connecting tags or lugs (usually referred to as 'bonding jumpers'), should be used for bonding connections between moving parts or parts subjected to vibration, and these are suitable both as primary and secondary conductors.

3.5.4 The tags or lugs on bonding jumpers are generally fitted by the 'crimping method', see Leaflet **EEL/3-1** and only the correct form of crimp and crimping tools should be used for the particular connection. During assembly of the connections to aluminium cords, anti-oxidant (crimping) compound consisting of 50% by weight of zinc oxide in white petroleum jelly, and complying with DTD 5503, should be applied to the connections.

3.5.5 Where applicable, the soldering of tags or lugs fitted to braided copper cord should be in accordance with Leaflet **BL/6-1**, using a resin flux. Special care is necessary because overheating and cooling of conductors will cause brittleness, whilst a loss of flexibility up to 25·4 mm (1 inch) from the lug may occur as a result of the capillary action of the molten solder.

NOTE: Primary flexible conductors are often made of 600 strands of copper wire, 0·0048 inch in diameter, and formed in a flat braid approximately 0·625 inch wide.

3.5.6 All bonding connections should be properly locked to prevent intermittent contact which may be caused by vibration.

NOTE: Intermittent contact is worse than no contact at all.

3.5.7 Bonding connections should not interfere mechanically or electrically with any associated or adjacent equipment, and bonding jumpers should not be excessively tight or slack.

3.5.8 The run of all primary conductors should be as straight as possible; sharp bends must be avoided.

3.5.9 The number and location of bonding connections to the various components is important and this should be checked and verified by reference to the relevant drawing, e.g. where an engine is not in direct electrical contact with its mounting it should be bonded with at least two primary conductors, one on each side of the engine.

3.5.10 In most instances the following joints are considered self-bonding, provided that all insulating materials (e.g. anodic finish, paint, storage compounds, etc.), are removed from the contact faces before assembly, but if any doubt exists regarding the correctness of the bonds, a bonding test should be carried out:—

(a) Metal-to-metal joints held together by threaded devices, riveted joints, structural wires under appreciable tension and bolted or clamped fittings.

(b) Most cowling fasteners, locking and latching mechanisms.

(c) Metal-to-metal hinges for doors and panels and metal-to-metal bearings (including ball bearings).

(i) In the case of bearings for control surface hinges it should be ascertained which bearings are classified as self bonding, e.g. metal-to-metal, nylon with conducting grease.

(ii) Where applicable, bonding jumpers for control surfaces should be as flexible and as short as possible, of as low impedance as is practicable and should not be tinned. The possibility of a jumper jamming the controls must be avoided.

3.6 **Flexible Bonding Connections**

3.6.1 Flexible hose connections used for joining rigid pipes should be bonded by fitting clips around the pipes approximately 13 mm (½ inch) away from the hose, and bridging with a corrugated bonding strip or jumper; the practice of tucking the ends of bonding strips between the hose and the pipe is not recommended. To obtain good electrical contact the area under each clip should be cleaned and, after the clip has been fitted, protection should be restored.

3.6.2 Not only must the flexible hose connection be bridged, but each pipe run should be bonded to earth at each end, particularly within a radius of 2·42 metres (8 feet) of any unscreened radio equipment or aerial lead, where earthing bonds should not be more than 1·5 metres (5 feet apart), or less distance apart, if called for by the manufacturer.

3.6.3 If bridging strips or bonding cords are fractured a new conductor should be fitted. The soldering of broken ends is prohibited.

3.6.4 High-pressure flexible pipe assemblies are usually self-bonding, but a bonding test should be made between the assembly end-couplings to prove the integrity of the bonding.

NOTE: The provisions of paragraph (3.6.2) above also apply to any long electrically-conducting parts (including metallic conduits and metal braiding) which are not insulated from earth.

3.6.5 When any bonding or earth connection is made to the structure or equipment, the specified standard of protection against corrosion should be provided.

3.6.6 After a non-conducting protective coating has been removed from the connecting area, the preferred sealing and anti-oxidant treatment as specified on the relevant drawing and specification should be carried out.

NOTE: Non-conducting protective treatments include all generally used priming and finishing paints, varnishes and temporary protectives, chromic, anodic and phosphate coatings. Metallic coatings, such as cadmium and tin, are satisfactory conductors and should not be removed. If a polysulphide compound is used for sealing the earth or bonding point, it must be ensured that the anti-oxidant to be subsequently applied will not have a detrimental effect on the sealing; e.g. DTD 5503 should not be used.

3.6.7 When the connection has been made any excess compound should be wiped off, using a rag damped in methyl ethyl ketone (MEK), and the connection and adjacent area re-protected by the specified method, this depending on the materials concerned and the position of the connection.

3.6.8 When a 'corrosion washer' forms part of the connecting assembly, it should be correctly fitted and be of the correct material for the type of connection concerned.

NOTE: A corrosion washer is plated, or manufactured of a material having a potential such that when placed between materials of widely differing potentials it reduces the risk of corrosion caused by electrolytic action.

3.7 Earth Terminals

3.7.1 When earth-return terminal assemblies are fitted or replaced, the correct method of fitting to the structure, the corrosion protection required and the exact location on the structure should be carefully checked. The procedure for fitting and the number of terminations to be attached will vary with the design of the terminal assembly and the type of structure, therefore reference should be made to the relevant drawings and instructions to ensure both electrical and structural integrity.

3.7.2 All earth terminal assemblies should be checked for resistance between the lug attachment point(s) and the surrounding structure and this must not exceed the figure specified for the aircraft concerned (e.g. 0·025 ohm). When earth terminal assemblies are also used to carry electrical supplies, a millivolt drop test, as outlined in paragraph 4.3 must be carried out.

3.7.3 If the resistance in either case is unsatisfactory, the terminal assembly should be removed, the contacting faces cleaned with a fine abrasive (e.g. aluminium wool), and reassembled using, where applicable, new corrosion washers. The connecting area should be sealed and treated with anti-oxidant compound as specified in the relevant drawing and specification.

NOTE: Leads connected to earth terminal assemblies should be of insulated cable with terminal tags fitted by the crimping method. It is important that the cable is of the specified gauge for the service concerned and is kept as short as possible.

3.8 **Resistance Values.** The CAA's Requirements with regard to the maximum resistance values for the various conditions of bonding are summarised in Table 1.

TABLE 1

Bonding Classification	*Test Condition*	*Maximum Resistance*
Primary	Between extremities of the fixed portions of aircraft of non-metallic or composite construction.	Estimated and declared by manufacturer.
	Between extremities of the fixed portions of metallic aircraft.	0·05 ohm
	Between bonded components and portions of main earth system to which they are connected.	
Secondary	Between metallic parts normally in contact with flammable fluids and main earth system, and also between the parts themselves.	1 ohm (See Note 1)
	Between all isolated conducting parts which may be subject to appreciable electrostatic charging and the main earth system. (See Note 2.)	0·5 megohm or 100 000 ohms per sq ft of surface area whichever is the less
	Between equipment supplied from an unearthed system, of any voltage, and the main earth system.	1 ohm (See Note 1)
	Between equipment containing circuits carrying 50 volts (rms or dc) or more, and the main earth system.	

NOTES: (1) The value of 1 ohm is chosen to allow for the inclusion of the resistance of any cable that may be employed for this bonding case, but no one contact resistance should exceed 0·05 ohm.

(2) The parts concerned are those situated inside and outside an aircraft and having an area greater than 3 sq in and a linear dimension greater than 3 inch.

3.9 **Bonding Carrying the Main Electrical Supply**

3.9.1 The cross-sectional area of the main earth system, or any connection to it, must be such that without over-heating or causing excessive voltage drop, it will carry any electrical currents which may pass through it normally or under fault conditions.

3.9.2 If, under fault conditions, it should form part of a short-circuit, not provided against by a protective device, it should be capable of carrying the full short-circuit current which can pass, without risk of fire or damage to the bonding system.

NOTE: For example, paragraph 3.9.2 may apply to bonding which under fault conditions becomes part of a starter or other heavy current circuit. Particular attention should be given to non-metallic aircraft fitted with a double-pole wiring system to which single-pole equipment has subsequently been added.

3.10 Bond Testing

3.10.1 Special test equipment, comprising a meter and two cables each of specific length, is required for checking the resistance of bonding. A meter widely used, consists of an ohmmeter operating on the current ratio principle, and a single 1·2 volt nickel-alkaline cell housed in a wooden carrying case. The associated cables are 60 feet and 6 feet in length, and are fitted with a single-spike probe and a double-spike probe respectively. Plug and socket connectors provide for quick-action connection of the cables to the instrument.

3.10.2 Prior to carrying out a bonding test, a check should be made on the state of the nickel-alkaline cell of the tester by observing;

(a) that a full-scale deflection of the meter is obtained when the two spikes of the 6-foot cable probe are shorted by a suitable conductor; and

(b) that the meter reads zero when the two spikes of the 6-foot probe are shorted by the single spike of the 60-foot probe.

3.10.3 The 60-foot lead of the test equipment should be connected to the main earth (also known as the bond datum point) at the terminal points which are usually shown diagrammatically in the relevant Aircraft Maintenance Manual. Since the length of a standard bonding tester lead is 60 feet, the measurement between the extremities of the larger types of aircraft may have to be done by selecting one or more main earth points successively, in which event the resistance value between the main earth points chosen should be checked before proceeding to check the remote point.

NOTE: When connecting the 60-feet lead to an earthing point, any protective treatment (e.g. strippable lacquer) should be removed at the point of contact.

3.10.4 The 6-foot test lead should be used to check the resistance between selected points; these are usually specified in the bonding test schedule or the Maintenance Manual for the aircraft concerned. When the two spikes of the test lead probe are brought into contact with the aircraft part, the test-meter will indicate, in ohms, the resistance of the bond.

3.10.5 As an alternative to the above, the four terminal method of resistance measurement may be adopted with the appropriate miliohmmeter (see Figure 1). With this type of instrument, a test current (approximately 2 amps) is supplied by the internal batteries and passed through the resistance via cables C1 and C2. The voltage drop across the resistance is measured (P1 and P2) and compared with the current flowing. The resultant value is then displayed (normally digitally) on the meter. The test leads may be in the form of duplex spikes (see Figure 2) or when used in association with crocodile type test leads, single spikes. In order to check that the instrument is functioning correctly, the two hand spikes should be placed on a low resistance conductor with the potential spikes (P1 and P2) closely together (see Figure 3). The result of this test should be a zero reading on the meter.

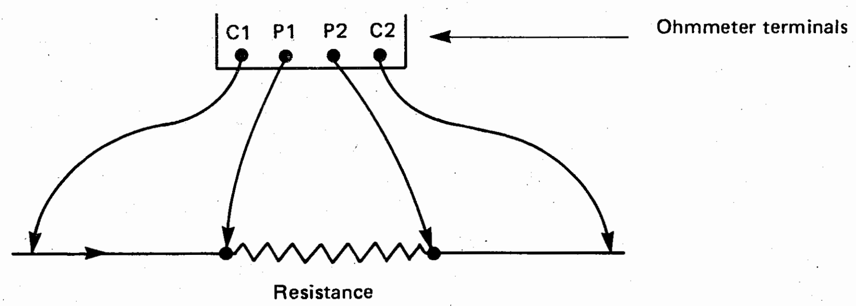


Figure 1 FOUR TERMINAL RESISTANCE MEASUREMENT

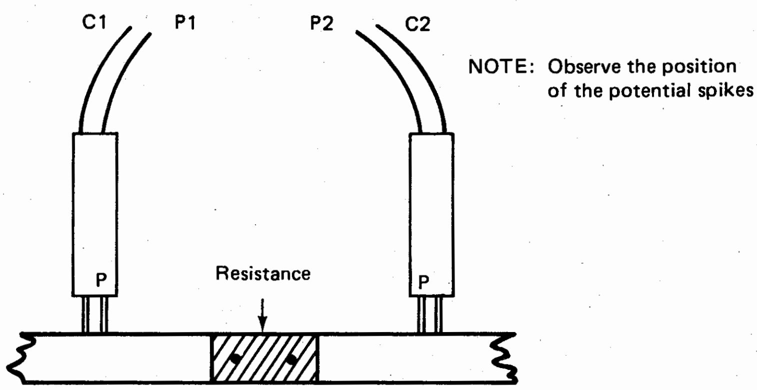


Figure 2 DUPLEX HAND SPIKES

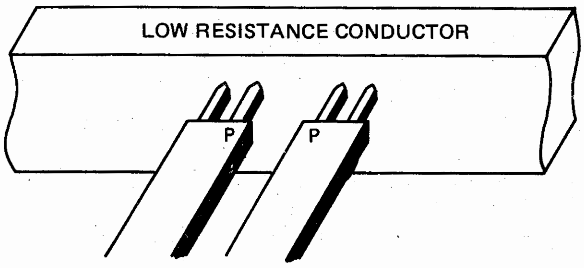


Figure 3 TEST POSITION OF HAND SPIKES

3.10.6 To ensure good electrical contact at the probe spikes, it may be necessary to penetrate or remove a small area of a non-conducting protective coating. Therefore, after test, any damage to the protective coating must be restored.

3.10.7 If the resistance at a bond connection is excessive, rectification action will depend on the type of connection. The following action should be taken for the more common types of connections:—

(a) In the case of bonding jumpers, the connecting tag or lug should be removed and the contacting faces thoroughly cleaned, using a slight abrasive if necessary. The bare metal thus exposed should be only just large enough to accept the palm of the tag or lug. The connecting area should be sealed and treated with anti-oxidant as specified in the relevant drawing and specification.

NOTE: When an abrasive has been used it is important to ensure that all traces of it are removed.

(b) Where equipment is bonded through a holding bolt, the bolt should be removed and the area under the bolt-head, or nut, thoroughly cleaned and protected as recommended in paragraph 3.10.7 (a). The correct washer (both with regard to size and material) should be fitted before the bolt is replaced and tightened.

(c) Where the required bond value cannot be obtained at a structural joint the advice of the manufacturer should be sought.

NOTE: Corrosion tends to form at a bonding or earth connection and is often the cause of excessive resistance.

3.10.8 The resistance between the main earth system and a metal plate on which the earthing device (e.g. tyre) is resting should be measured and should not exceed 10 megohms when measured with a 250-volt or 500-volt resistance tester, as specified in the test schedule.

NOTE: After carrying out tests, all areas where the protective coating has been removed should be re-protected using the appropriate scheme.

3.11 Bonding Tester Servicing

3.11.1 A tester requires little in the way of servicing, apart from periodic attention to the alkaline cell, which should be removed at prescribed intervals for routine servicing. When replacing the cell, it is most important that the polarity of connection is correct. The ohmmeter is normally sealed in its case and no attempt should be made to open it; if a fault should develop, then the complete instrument should be withdrawn from use and overhauled.

3.11.2 The leads are an integral part of the tester, and being carefully matched to the meter unit must not be modified or altered in any way. All contact surfaces of plug pins and probes must be kept scrupulously clean, and the points of the probe spikes should be reasonably sharp to give effective penetration of protective finishes, etc., on metal surfaces.

3.11.3 The accuracy of the tester should be checked periodically by using it to measure the resistance of standard test resistors. Normally, three such resistors are supplied for testing purposes and the readings obtained should be within 10% of the standard ohmic values.

4 INSPECTION AND TESTING OF CIRCUITS

4.1 Inspection of Wiring System

4.1.1 Before carrying out tests, or when inspection is specified in the Approved Maintenance Schedule, all aircraft circuits, together with plugs, sockets, terminal blocks and equipment terminals, should be examined, as appropriate, for signs of damage, deterioration, chafing, poor workmanship and security of attachments and connections. It is not intended, for the purpose of this examination, that electrical apparatus should be removed from its mountings or that cables should be unduly disturbed, but if modifications or repairs, for example, have been carried out in the vicinity, looms should be closely inspected for ingress of metallic swarf between cables. Whenever a structure is opened over wiring which is not normally visible through available inspection panels, circuits so exposed should be thoroughly inspected.

4.1.2 The primary purpose of the inspection is to determine the physical state of the wiring system, especially at bends, points of support, duct entries, etc., or where high temperature or contamination could cause local deterioration. Where cables are grouped together, the state of the outer cables is generally indicative of the condition of the remainder.

4.1.3 Cables completely enclosed in ducts obviously cannot be examined along their length, but should be checked for continuity and insulation, especially if oil or water ingress is suspected. Where there is evidence of damage to the ducts, the cables should be exposed to ascertain their condition.

4.1.4 Terminations must be secure and good electrical contact obtained without strain on the threads of terminal pillars or studs. Torque loadings, where appropriate, should be within the limits specified.

4.2 **Continuity Testing**

4.2.1 A concealed break in a cable core or at a connection may be found by using a continuity tester which normally consists of a low voltage battery (2·5 volts is satisfactory) and a test lamp or low reading voltmeter.

NOTE: In some testers incorporating a test lamp, semiconductors are included in the test lamp circuit and, to prevent damage, the currents should be limited to 120 milliamps.

4.2.2 Before testing, the main electrical supply should be switched off or disconnected. A check should be made that all fuses are intact and that the circuit to be tested is not disconnected at any intermediate point. All switches and circuit breakers, as appropriate, should be closed to completed the circuit.

4.2.3 When carrying out a low voltage continuity check, it is essential to work progressively through the circuit, commencing from the relevant fuse or circuit breaker and terminating at the equipment. Large circuits will probably have several parallel paths and these should be progressed systematically, breaking down as little as possible at plug and socket or terminal block connections. In testing of this nature, it is valueless to check several low resistance paths in parallel.

4.3 **Millivolt Drop Test.** Excessive resistance in high-current carrying circuits can be caused by loose terminal connections, poorly swaged lead ends, etc. Faults of this kind are indicated by low terminal voltage at the connections to the service load and by heating at a conductor joint. If such faults are suspected, a millivolt drop test as described below is recommended, but it is also acceptable to check along progressive sections of the system with an accurately calibrated voltmeter:—

(a) For continuously-rated circuits, the test should, whenever possible, be made with the normal operating current flowing, the power being derived from an external source. For short-rated circuits, a suitable resistance or other dummy load should be used in lieu of the normal load and the current should be scaled down to avoid overheating.

NOTE: The test voltage may be reduced for safety reasons.

(b) The millivolt-meter should be connected to each side of the suspected joint and a note made of the volt drop indicated. The indicated reading should be compared with the figures quoted in the relevant publication (an approximate guide is 5 mV/10 amps flowing).

4.4 **Insulation Resistance Testing**

4.4.1 In the following paragraphs general test procedures are outlined; however, as a result of the wide variation in electrical installation and equipment which exists with different aircraft, the routing charts and Approved Test Schedule for the aircraft concerned must be consulted. All ancillary equipment should be tested separately in accordance with the appropriate manufacturers' publications.

4.4.2 After installation and where specified in the Approved Maintenance Schedule or Test Schedule, aircraft circuits should be tested by means of a 250-volt insulation tester which should have its output controlled so that the testing voltage cannot exceed 300 volts. In all systems having nominal voltages over 30 volts, cables forming circuits essential to the safety of the aircraft should be tested individually. Other circuits may be connected in groups for test. However, the numbers of circuits which may be grouped for test is governed by the test results; where the insulation resistance so measured is found to be less than the appropriate minimum value stated in paragraph 4.5.4, the number of circuits grouped together should be reduced.

NOTE: Information on the testing of magneto earthing circuits is given in Leaflet **EL/3-9**.

4.4.3 Immediately after an insulation test, functioning checks should be made on all the services subjected to the test. If the insulation test or subsequent functioning tests should reveal a fault, the fault should be rectified and the insulation and functioning tests should be repeated in that sequence on the affected circuits.

4.4.4 **Preparations Prior to Test.** Before beginning an insulation test on a system, the following preparations should be made, details of which will depend on the installation concerned:—

(a) The aircraft battery and any external supply should be disconnected.

(b) Where applicable, circuit breakers should be closed.

(c) The power selector switch should be switched to the position appropriate to that required for normal in-flight operation.

(d) All switches in the circuit concerned should be 'ON', dimmer-switches should be set at the minimum resistance position and micro-switches operated to the 'ON' position.

(e) All items of ancillary equipment which are supplied by the system concerned should be disconnected. This includes all rotary equipment (e.g. generators, motors, actuator units, etc.), radio equipment, capacitors, semiconductors, voltage regulator coils, electrical instruments, fire extinguishers, etc.

(f) In cases where the insulation resistance with the items connected is not less than 2 megohms, the disconnection may be made by the earth lead, leaving the item connected to the circuit.

NOTE: Bonded earth connections to the airframe structure should, if possible, remain undisturbed for the purpose of these tests.

(g) Components such as cut-outs and relays which are normally open should have their terminals bridged to ensure continuity of the circuit, and disconnected leads from suppressors should also be bridged for similar reasons. Where a suppressor cannot be bridged, and plug and socket connections are used, the capacitors should be discharged before the circuit is re-connected, otherwise arcing and burning of the pins may occur. Items in series which are disconnected should also be bridged so that part of the circuit is not omitted.

4.5 Testing the System

4.5.1 Double-pole systems on some older types of aircraft can be tested by connecting the leads of the insulation tester to each of the battery leads and measuring the resistance between them and, afterwards, checking the resistance between each battery lead and earth; fuses should be left in position for this test. On some large aircraft with double-pole systems, cables may be grouped as for single-pole systems, the earthing checks being made between bunched positive and earth and bunched negative and earth.

4.5.2 To test single-pole systems, one lead of the tester should be connected to earth and the other to the cable or bunch of cables to be tested. When cables are bunched together, it is advisable to limit the number to the smallest convenient figure. If the insulation resistance is less than the appropriate value quoted in paragraph 4.5.4, the number of circuits should be reduced. Testing should continue until, by process of elimination, any defective cables have been identified.

4.5.3 **Test Results.** The results of insulation tests are of little significance unless they are related to test results obtained on other occasions. The insulation resistance values are likely to vary with changes in the temperature and humidity of the local atmosphere, e.g. if the aircraft has been in damp conditions for some time before the test, low readings can be expected. Results of tests and the temperature and humidity conditions at the time of the test should be recorded, so that any pronounced drop in resistance found on subsequent tests can be checked and rectified as necessary.

4.5.4 Section J of British Civil Airworthiness Requirements does not specify minimum values of insulation resistance, but gives guidance on values that may be expected during maintenance testing. These values can be, and frequently are, exceeded considerably on new installations. The values given are as follows:—

(a) Wiring (including accessories for jointing and terminating):—

In engine nacelles, undercarriage wheel wells and other situations exposed to weather or extremes of temperature .. 2 megohms

Galley and other non-essential services, lighting, signalling and indication services .. .. 5 megohms

Other services .. .. 10 megohms

NOTE: The above values relate to single circuits or small groups of circuits.

(b) Wiring accessories alone (e.g. terminal blocks, connectors, plugs and sockets, etc.):—

Between terminals .. ..100 megohms

Between terminals bunched together and earth $\frac{200}{\text{number of terminals}}$ megohms

(c) Rotating machinery whichever is the greater of $\frac{\text{rated voltage}}{150}$ or 0·5 megohms

(d) All other equipment (including indicating instruments) .. .. 5 megohms

4.6 Functioning Tests

4.6.1 Before conducting any tests, all precautions for aircraft and personnel safety should be taken. Whenever possible, functioning tests should be carried out using an external supply coupled to the ground supply connector. Tests must ensure proper functioning of individual and integrated sections of circuits, and should be in accordance with schedules established by reference to details in the relevant Maintenance Manual, Wiring Diagram Manual or, where appropriate, instructions relating to the incorporation of a modification or any substantial rewiring.

NOTE: Where applicable, when one or more engines are running, the power supply can be obtained from the associated generators, due reference being made to the functioning of any isolating relays.

4.6.2 For certain circuits (e.g. standby lighting), functioning tests can only be carried out using the aircraft battery system, but this battery should be used as little as possible.

4.6.3 After the normal functioning test of an individual circuit has been completed and the circuit switched off, the fuse should be removed or the circuit breaker tripped and the circuit again switched on to check the isolation of the circuit concerned.

4.6.4 When the operation of a circuit (e.g. generator equaliser circuit) depends on the inherent resistance value of the circuit, the resistance should be measured with a low reading ohm-meter (such as that used in a bonding tester) to determine that the resistance is within the specified limits.

EEL/1-7

Issue 2

September, 1988

ELECTRICAL EQUIPMENT

FIRE DETECTION AND EXTINGUISHING SYSTEMS

ELECTRICAL TESTS ON SYSTEMS

1 INTRODUCTION

1.1 The purpose of this Leaflet is to provide guidance and advice on the electrical tests applicable to the circuits and components of fire, overheat and smoke detection systems and also of fire extinguishing systems. It should be read in conjunction with the Maintenance Manuals for both the equipment and the aircraft in which it is installed, Wiring Diagram Manuals, approved drawings, test schedules and Approved Maintenance Schedules.

1.2 Subject headings are as follows:—

1.3 Related CAIP Leaflets:—

AL/3-8	Fire — General Precautions
AL/3-9	Fire Detection Equipment
AL/3-10	Fire Extinguishing Equipment
EEL/1-6	Bonding and Circuit Testing

1.4 The conditions under which detection and extinguishing systems should be fitted to aircraft are prescribed in British Civil Airworthiness Requirements.

2 DETECTION SYSTEMS

2.1 Detection systems are designed to give indications of fire, smoke or hydraulic mist at various locations in an aircraft by the illumination of warning lamps and, in the event of fire, by audible warning devices. Engine and auxiliary power unit (APU) compartments, where there is likelihood of fire, are protected by fire detection and extinguishing systems, while other areas, such as equipment bays, cargo and baggage compartments, are fitted with smoke detection systems but not necessarily extinguishing systems. On some turbine powered aircraft, detection systems are also used to indicate potentially dangerous overheat situations in critical parts of the structure, e.g. landing gear wheel bays and structure adjacent to hot air ducting supplying air for cabin pressurisation and de-icing systems. Test facilities, for completely testing the continuity and operation of the circuit, are generally provided in detection systems. Alternatively, some circuits may be fitted with warning lamps which incorporate a press-to-test facility.

2.2 **Types of Detectors**

2.2.1 For fire warning and overheat warning purposes, the detectors in use are of, 'unit', 'continuous' or, 'sensor/responder' type. Detectors may be used separately, or together in a combined fire warning and engine overheat system. For detecting the presence of smoke and hydraulic mist, special detectors are used particularly in compartments which are not accessible in flight.

2.2.2 **Unit Type Detectors.** These detectors are normally situated at points most likely to be affected by fire, e.g. an engine breather outlet or hot air ducting. The type most commonly employed is a switch, the contacts of which are actuated by the differential expansion of dissimilar metals.

2.2.3 **Continuous Type Detectors.** These detectors are designed to provide maximum coverage in the particular fire zone and are employed principally for engine and APU installations and, in some instances, are also installed in landing gear wheel bays. A system in most common use, consists of a number of lengths of sensing elements containing a special temperature-sensing material, and a control unit. The elements are joined together to form a continuous loop round the installation, and depending on the type of control unit, variations in either the resistance or the capacitance of the elements with changes in temperature, are detected and used for controlling visual and/or audible warning devices.

2.2.4 **Sensor/Responder Type Detectors.** Sensor/Responder type detectors operate on gas law principles when exposed to temperatures outside of the calibrated range. The detector, which has dual sensing functions, comprises a responder and a pneumatic sensor (see figure 1).

(a) **Responder** — The responder comprises an electrical interface, responder diaphragm, and two switches; the Alarm Switch (normally open), and the Integrity Switch (normally closed), both of which 'respond' to gas pressure changes.

(b) **Pneumatic Sensor** — The pneumatic sensor is a hermetically sealed corrosion resistant steel tube filled with an inert 'averaging' gas (normally Helium), and, a central core element made of a metal hydride which is enclosed in an inert metallic material with absorption and discharge properties.

(c) **Operation** — In the case of a general overheat (approx 177° C), the averaging gas will expand, and, via the responder diaphragm, close the Alarm Switch. However, under the circumstances of a direct fire, any impinging flame on the detector causes the core element to gas (normally Hydrogen). This gassing will increase line pressure within the detector and close the alarm switch. Both of the above functions are reversible. That is to say, as the sensor cools, the averaging gas pressure is lowered, and where appropriate, the gas from the core material returns to the core element.

(d) **Integrity Monitoring** — The Integrity Switch is kept closed by gas pressure. Should a leak develop, the contacts will open and signal a lack of detector integrity. A test selector switch is also normally incorporated to monitor the integrity of the contacts and associated circuitry.

2.2.5 **Smoke Detectors.** These units vary in construction and the application of any one version depends largely on the type of aircraft and its particular operating configuration, i.e. passenger with separate baggage and cargo compartments, or all-cargo, all require electrical power for their operation, and normally operate on photo-electric, visual or ionisation principles.

(a) **Photo-electric** — Air from the appropriate compartment is arranged to flow through a detecting chamber containing a projector lamp. In the event that smoke is present, it causes a change in the amount of light transmitted from the lamp. In some commonly used detectors the changing light transmission is detected by a photo-electric cell, the output of which varies to energise a warning light system. In addition to the detecting cell, certain detectors also employ a balancing cell against which the detecting cell output is continually compared. Both cells are connected in a bridge circuit coupled to the warning light system.

(b) **Visual** — For those types known as visual smoke indicators, any smoke present within the detecting chamber is illuminated by the projector lamp and is visible through an observation window. When clear air is present in the chamber the observation window appears dark and, in order to check that the lamp is illuminated, a small tell-tale window is provided adjacent to the observation window and directly in front of the lamp.

(c) **Ionisation** — This type of detector analyses the chemical properties of the air being monitored and reacts to combustion gases whether visible or not. When the air/combustion gases enter the detector, they modify the balance between the two ionisation chambers. Ionisation of the monitored air, is effected by a small particle of radioactive material which bombards the oxygen and nitrogen molecules in the ionisation chamber. This action permits a small current flow except where there is smoke which reduces current flow. A field effect transistor then evaluates this change and transmits a warning.

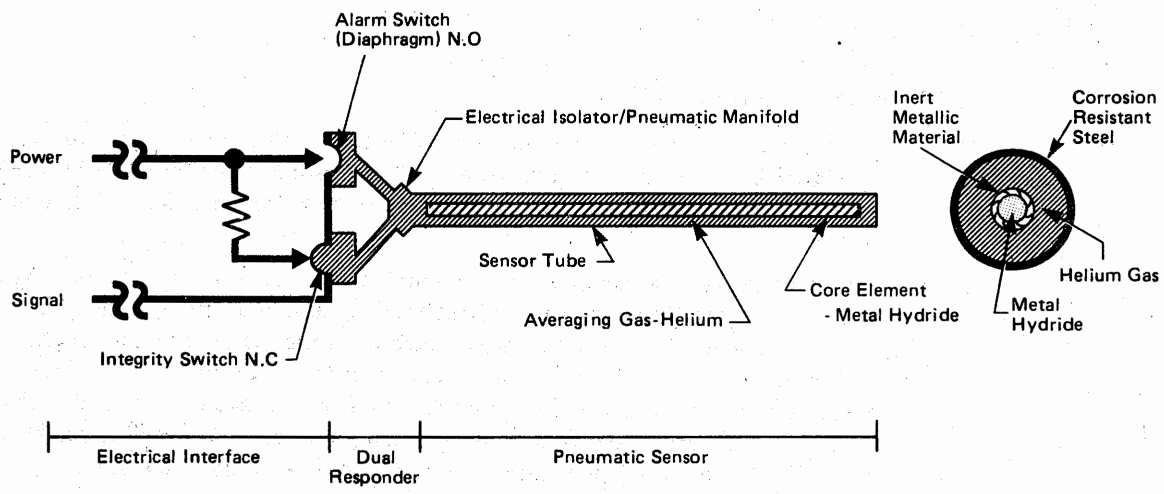


Figure 1 SENSOR/RESPONDER TYPE DETECTOR (SCHEMATIC)

2.3 Tests

2.3.1 **General.** The procedures for performing electrical tests on fire detection systems and components, and the amount of test equipment required, vary between installations and reference should be made to the relevant Maintenance Manual, Wiring Diagram Manual and test schedule for appropriate details. The details given in the following paragraphs are intended to serve only as a general guide to the tests which are normally concerned with the checking of insulation resistance, circuit resistance and overall system functioning.

2.3.2 Test Precautions

(a) Fire detection equipment is located in areas where maintenance operations are comparatively frequent, e.g. engine nacelles and wheel bays, and it is, therefore, susceptible to damage from actions unconcerned with the testing of the fire detection system. When work is being carried out in these areas extreme care is therefore necessary to prevent damage or contamination of the system, since a spurious fire warning or failure to detect an actual fire could result.

(b) Before using high voltage equipment for testing circuits in any area where explosive vapours or gases from fuel, cleaning or sealing compounds, cements and similar materials may be present, it must be ensured that the area concerned is completely cleared of such vapours by forced air circulation.

(c) It should be ensured that personnel working on, or in the vicinity of, an aircraft during the testing of fire detection systems, are fully aware of such tests and do not misinterpret the indications of associated warning lights and operation of a fire warning bell. Warning placards should also be placed in the Flight Crew compartment, and the associated work areas.

2.3.3 Insulation Resistance Tests

(a) **Unit Type Detectors.** The method of testing differential expansion type detectors is straightforward, consisting only of resistance measurement between each terminal and the outer casing, by means of a 250 volts insulation resistance tester.

(b) **Continuous Type Detector.** Before carrying out tests on continuous type detector systems, the appropriate circuit breakers should be tripped, and the ends of the complete loop must be disconnected from the system junction boxes or bulkhead fittings. If possible, this should be done by disconnecting cables at terminals rather than disconnecting the element connectors, thus avoiding disturbance of torque loaded unions and sealing washers. The tester should be of the 250 volt type, and open-ended test leads should be used to avoid damaging the centre electrodes of elements and the sockets of interconnectors.

(i) Resistance should be measured between the centre electrode and element sheath and the reading obtained should not be less than that specified (a typical value is 1 megohm). If this minimum resistance is not achieved, systematic checks should be made at intermediate elements and interconnectors to isolate the cause; this could be metallic chips, dirt or moisture in the connections or a fractured element into which water has penetrated.

(ii) The resistance between the centre electrode and sheath of single elements disconnected at both ends, and between the socket and body of each individual connector should also be measured to ensure that it is not less than the specified value (a typical minimum value is 20 megohms).

NOTE: An insulation resistance test should not be performed on any single element whose temperature at the time of test exceeds that of prevailing ambient conditions, and under no circumstances should be prolonged.

(iii) On satisfactory completion of the foregoing tests, sensing elements and cables should be re-connected, circuit breakers reset and a functioning test of the complete detection system carried out. (See paragraph 2.3.5(b).)

2.3.4 **Circuit Resistance Tests.** The resistance of the centre electrode of the complete sensing element loop should be measured by means of a safety ohmmeter or universal type test meter connected at the system junction boxes or bulkhead fittings. A similar check should be carried out on individual sensing elements prior to installation. The readings obtained in both cases should be within the ranges specified in the relevant aircraft Maintenance Manual. On completion of resistance tests a functioning test of the complete detection system should be carried out. (See paragraph 2.3.5(b).)

2.3.5 **Functioning Tests.** Functioning tests must be carried out at the check periods specified in Approved Maintenance Schedules, when a system malfunction has occurred or a major component (e.g. a control unit or a sensing element) has been replaced. The method of testing depends mainly on the fire detection system equipment specified for the particular type of aircraft. Reference should therefore be made to relevant manuals and test schedules for precise details of testing, specific test equipment required and also for any precautions to be observed. There are, however, aspects of testing which are of a standard nature and these are given in the following paragraphs for general guidance.

(a) **Unit Type Detectors.** Differential expansion switch type detectors and their associated circuits, may be checked for functioning by heating the switch with a shroud type of heater element clamped round the outer casing of the switch. Under no circumstances should a naked flame be used. The detectors will re-set automatically when the source of heat is removed. In some types of aircraft employing a large number of detectors, test switches are provided to check the continuity of the wiring between the detector and associated warning lights. Whenever it becomes necessary to change a detector, it is important that the replacement has the correct temperature setting, since warning temperatures vary between locations.

(b) **Continuous Type Detectors.** The operation of continuous type detection systems is checked by the use of 'in-situ' test circuits arranged to simulate fire conditions. Each circuit is controlled by an independent switch normally located on the fire-warning and extinguishing control panel.

(i) With all relevant circuit breakers closed and electrical power switched on, a check should be made that fire warning lights illuminate and the alarm bell rings as each test circuit switch is placed in the 'TEST' position. At the same time, checks should be made to ensure that the alarm bell ceases to ring when the isolation or cut-out switch is operated.

(ii) In some types of aircraft, one test switch only is provided and is common to all detection systems. In such cases, it must, therefore, be checked that when the switch is closed (a position normally placarded 'FIRE'), all fire-warning lights illuminate simultaneously with ringing of the alarm bell. Independent checks on each system should be done by opening and closing the relevant circuit breakers.

(iii) At the periods specified in the Approved Maintenance Schedule, it is also necessary to disconnect the aircraft wiring from the control units of continuous type detector systems and to substitute a test circuit in order to check that the resistance levels at which the units will operate and reset their associated warning circuits, are within the limits permissible for the type of unit and system. The test equipment required and the test procedures may vary slightly between systems, and detailed information should always be obtained from relevant manuals. In general, a test circuit consists of an accurately calibrated potentiometer connected to the control unit in lieu of the sensing element loop, a test lamp connected to represent the system warning lamp, and a test switch. With power applied to the circuit, the potentiometer resistance should be adjusted and measured at the points at which the test lamp is illuminated and extinguished, i.e. simulating the operating and resetting resistances respectively of a complete sensing element loop. If the resistance values obtained are outside the permissible limits or the test lamp fails to respond in the manner described, a control unit must be withdrawn from service. On satisfactory completion of the tests, the aircraft wiring should be reconnected to the control unit, checking that the coincidence and identification of the terminal end is in accordance with the relevant wiring diagram. A functioning test of the complete detection system should also be carried out.

(iv) In addition to the fire warning lights and test circuits, certain detector systems also use a short-circuit warning light system which can discriminate between a sensing element loop resistance drop caused by short-circuits or by rise in temperature. This system must, therefore, also be tested and a common single-pole, double-throw switch is provided for the testing of each warning circuit. When the switch is placed at the 'DISCRIMINATOR' position, the detector system control unit responds to a rapid drop in sensing element loop resistance, and it should be checked that the appropriate warning lights illuminate, thereby indicating the simulated short-circuit condition. Illumination of the warning lights should also be checked by disconnecting each sensing element loop at a convenient point and shorting the centre electrode to ground.

NOTE: At no time during these tests should both the fire warning and short-circuit indicating lights be on simultaneously.

(c) **Sensor/Responder Type Detectors.** The testing of Sensor/Responder type fire/overheat detection systems is normally limited to checking the Sensor and, the integrity of the associated circuits.

(i) **Sensor Test** — Testing the Sensor section of the detector requires specialised equipment which, for the purpose of activating the alarm circuit, simulates a fire/overheat condition. This is accomplished with a resistive type heater which encases and heats up a small section of the sensor element, a test procedure which must be carried out in accordance with the manufacturers instructions.

(ii) **Responder Test** — For most modern aircraft, the integrity of responder circuitry, is checked by the self test facility, whereby each detection sensor loop is constantly monitored by an electronic logic circuit board or control card. Further test facility is provided for in the flight crew compartment in the form of a fire/overheat test panel. This panel allows the flight crew to check the fire/overheat sensor systems on the engines, auxiliary power unit (APU), and smoke detection systems.

(d) **Smoke Detectors.** The method of testing smoke detectors varies because of the differences between types of unit and the procedures detailed in relevant manuals and test schedules must, therefore, be strictly observed. The checks described in the following paragraphs, although based on the requirements for some currently used detector units, are intended to serve only as a general guide.

(i) Test switches are provided in detector units and when operated it should be checked that the appropriate smoke indicator lights, and fire indicator lights where fitted, are illuminated thereby simulating a smoke condition.

(ii) Where appropriate to the type of detector, the established signalling voltage should be checked against the value which is inscribed on the unit. In addition to this, a second value is also inscribed to denote the percentage observation density of smoke to give a one volt increase in calibrated voltage. A voltmeter test socket is provided for the purpose and the readings obtained determine the smoke sensitivity of the unit. For example, the inscription '8·6/15' indicates the calibrated voltage and percentage obscuration density respectively, and if a reading of 8 volts is obtained during a check, then the sensitivity is equal to 15 (8·6 — 8) = 15 x 0·6 = 9% obscuration. If, therefore, this detector is subsequently subjected to smoke of a density which obscures its light beam by 9%, the associated warning system will be operated. A typical sensitivity limit for a new detector is between 8% and 14% while for used detectors a limit between 8% and 30% smoke obscuration is acceptable.

(iii) The **photo-electric** cells of twin-cell detector units must be checked to ensure that the current output balances at the required operating levels and a 'zero' switch, shutter adjusting screw and sensitive relay pointer are normally provided for this purpose. The 'zero' switch cuts out a resistor in the projection lamp circuit so that the voltage is raised for testing purposes to make the lumen output of the lamp comparable to that produced with engines running. When the switch is raised and held 'on' it should be checked that the sensitive relay pointer indicates zero. If necessary, the pointer should be set to zero by means of the shutter adjusting screw. If, during this check, excessive adjustment is required, i.e. more than two turns of the screw per micro-amp, a defective balancing cell or detecting cell is indicated and the smoke detector unit should be changed.

(iv) Functional testing of **visual** smoke indicators is straightforward and, in general, is confined to checking that with electrical power applied to the unit, serviceability of the projector lamp is indicated by illumination of the tell-tale window. At periods specified in the Approved Maintenance Schedule a leak test and a smoke test should be carried out, in the manner appropriate to the type of indicator, to check that air flow through the detecting chamber is not obstructed.

(v) The test procedures for **ionisation** type smoke detectors, are normally confined to self test, or circuit integrity checks carried out by on-board computers. However, for those smoke detectors located in cargo compartments or ventilation ducts, test procedures may require removal of the detector or in-situ tests. For those smoke detectors installed in toilet compartments, testing will normally include verification of the visual and aural warnings.

3 EXTINGUISHING SYSTEMS

3.1 These systems are provided for power plants, APUs, and in some types of aircraft, for landing gear wheel bays, baggage compartments and combustion heater installations. A system generally consists of a number of metal containers or bottles, containing an extinguishant e.g. methylbromide, bromotrifluoromethane or bromochlorodifluoromethane (B.C.F.) which is pressurised with an inert gas and sealed by means of a discharge or operating head. When operated, either by selector switches in the cockpit or crash switches, an electrically fired cartridge ruptures a metal diaphragm within the discharge head and the extinguishant is released to flow through spray pipes, spray rings or discharge nozzles into the appropriate fire zone. Electrical power is 28 volts d.c. and is supplied from an essential services busbar.

3.2 Two extinguishing methods are used for power plants. In the first method, which is employed in the majority of older types of aircraft, an individual system is provided for each power plant. The second method, known generally as the 'two-shot system', is the one most widely used and comprises connections between the individual power plant systems, so permitting two separate discharges of extinguishant into any one power plant.

3.3 In several types of aircraft, indication that a fire extinguishing circuit has been operated, is provided either by, warning lights or, indicating fuses connected in the circuit. The fuses contain a small charge and are enclosed within a domed cover which is normally transparent. When current flows in the relevant extinguishing circuit the charge is fired, and this causes a red powder to be spattered on the inside of the domed cover, thus furnishing a clear and lasting indication of the operation of an extinguisher.

3.4 In some installations special switches are incorporated to automatically operate the extinguishers in the event of a crash. These switches also connect cabin emergency lights to the aircraft battery power supply. Two types of crash switch are in common use: the inertia control type and the frangible type. An inertia controlled switch generally consists of a heavy piston supported on its own spring and so arranged that at the required degree of deceleration (a typical value is 3g), it compresses the spring and causes a bow spring to snap over thereby bridging contacts connected in the extinguishing system circuit. To allow resetting of the switch after operation or rough handling during transit, a reset plunger is incorporated.

3.5 Frangible switches consist of two electrical contacts mounted in a hermetically sealed glass envelope. The contacts are prevented from closing by a spring, but in the event of the glass envelope being shattered, the contacts will close and complete the circuit to the extinguishing system. The switches are located in positions such as the wing tips, the underside of engine nacelles, at various points on the underside of the fuselage, etc., so that in the event of a crash, at least one of the switches will be shattered.

3.6 Tests

3.6.1 The testing of fire extinguishing control circuits must be carried out at the check periods specified in Approved Maintenance Schedules, or when a system malfunction has occurred or a major component has been replaced. As in the case of fire detection systems, the procedures for testing the circuits can vary, particularly in installations which are interconnected with other circuits. For example, in one type of aircraft, the operation of a control switch in addition to arming the relevant engine fire extinguishers, automatically closes the fuel shut-off valve, trips the generator field circuit and shuts off the supply of fluid from the engine-driven hydraulic pump. Therefore, in carrying out the test procedures appropriate to the extinguisher discharge circuits, it must also be established that the other circuits function correctly. Test procedures are detailed in the manuals and test schedules for the relevant aircraft type, reference should therefore be made to these documents and also to the associated wiring diagrams. The testing of extinguisher discharge circuits, however, follows the same broad pattern, their purpose being to check the continuity between control switches and cartridge unit connections. The details given in the following paragraphs are based on some typical systems and are intended to serve only as a general guide.

3.6.2 **Discharge Circuit Functioning Tests.** Before commencing the tests, the system circuit breakers should be tripped and the cables disconnected from the cartridge units at the extinguisher discharge heads.

(a) A 28 volt indicator test lamps should be connected to the cable plugs and, where appropriate, lamps should also be connected to the holders of indicating fuses after having first removed the fuses.

(b) Circuit breakers should then be reset and with electrical power applied, the lamps should not light.

(c) Each system control switch or fire control handle, as appropriate, should be operated in turn noting that the relevant lamps are illuminated to simulate 'firing' of the extinguishers.

(d) The operation of systems incorporating crash switches should also be similarly checked to ensure continuity between the switches, extinguisher cartridge units and cabin emergency lights. Before switching on the electrical power, it is necessary to bridge the terminals of certain types of inertia controlled switches and for all frangible type switches, by means of shorting links. With electrical power applied it should be noted that the test lamps at the extinguisher cable plugs and the emergency lights are illuminated.

(e) In some types of inertia controlled switches, a plunger is provided at the top of the casing, and may be turned to either a 'SET' position, its normal functional position, or a 'TRIP' position. In order to test the switch circuit for continuity, the plunger must be turned to the 'TRIP' position and then pressed down firmly. This releases the inertia unit, thereby simulating a rapid deceleration condition, and with electrical power applied it should be noted that all relevant lamps are illuminated. A switch should be reset by turning the plunger to the 'SET' position, depressing a lever at the side of the switch casing to its full extent, and whilst the lever is held, depressing the plunger. The side lever should then be released before releasing the plunger. When the switch is set the side lever must be level with the top of its guard.

3.6.3 **Cartridge Unit Tests.** The tests on cartridge units are normally concerned with the checking of insulation resistance and the continuity and resistance of the fuse element within the cartridge. Before commencing the tests, the date of manufacture stamped on the unit body should be checked to ensure the cartridge life has not exceeded that specified in the appropriate Maintenance Manual. The units should be removed from extinguisher discharge heads for testing and as an additional safeguard they should be mounted on a fixture in such a way that the charge end is shielded, but unrestricted, in case of accidental firing.

NOTES: (1) Cartridge units contain gunpowder and should therefore be handled with extreme care at all times. They should be kept dry and if a unit is not to be refitted immediately following the tests it should be stored in a polythene bag.

(2) Where a power supply cable is connected to a cartridge unit through a Breeze type plug and socket, it must be disconnected or mated only after slackening off its outlet gland nut. If this is not done, or if the necessary internal movement is otherwise prevented, e.g. by corrosion, the two wires of the cable become severely twisted together inside the socket and may be broken or short-circuited.

3.6.4 **Insulation Resistance.** The resistance should be measured to ensure that it is not less than the value specified for the cartridge unit (a typical minimum value is 20 megohms). The check should be carried out, firstly, by shorting together the appropriate pair of connector pins, and then connecting a 250 volt insulation resistance tester between the shorted pins and cartridge unit body.

3.6.5 **Continuity and Resistance.** The continuity and resistance of a fuse element should be checked by connecting a safety ohmmeter across both pins of the connector. The reading obtained should be between the limits specified for the cartridge unit (the limits for a typical unit are between 5 and 6 ohms and between 7 and 11 ohms).

NOTE: Care must be taken to ensure that the correct type of safety ohmmeter is used for the tests and that its current output does not exceed the level required to detonate the charge.

3.6.6 **Tests on Indicating Fuses.** The testing of indicating fuses is normally concerned with checking their continuity and resistance, and should be carried out at the regular intervals specified in the Approved Maintenance Schedule; every three months is generally recommended. Before commencing such tests, a fuse should be removed from its holder and a check made on the date recorded on the side of its body, to ensure that the specified life of the fuse (normally three years) has not been exceeded. A fuse should be properly located within its holder for testing and the resistance should be measured by means of a safety ohmmeter connected to the fuse holder. The reading obtained should be between the limits specified in the relevant manual (the limits for typical fuses are between 10 and 16 ohms and between 31 and 39 ohms).

NOTE: As in the case of extinguisher cartridge units, fuses contain an explosive charge and, although not having as great an effect, they should always be handled with extreme care. It is also necessary to ensure that the correct type of safety ohmmeter is used for the test, and that its current output does not exceed the level required to detonate the fuse. The maximum test current for a typical fuse is 13 mA.

3.6.7 **Final Inspection.** At the conclusion of the functioning tests on the discharge circuits of extinguishers and associated circuits, the electrical power source should be disconnected and a careful inspection of complete systems should be carried out to verify that:—

(a) All test lamps have been removed.

(b) Plugs, sockets and cables disconnected for test purposes have been reconnected to their respective items of equipment and locked as necessary, in accordance with the approved wiring diagram. In order to prevent cross connection of the cartridge units, particular attention should be paid to the cables connecting the discharge heads of extinguishers mounted in adjacent positions. The cables are normally of different lengths.

(c) Damage has not been caused to cartridge unit cables fitted with Breeze type sockets as a result of removal and replacement. (See NOTE (2) paragraph 3.6.3.)

(d) Switches have been reset and locked where applicable.

(e) System components disturbed for the tests have been returned to their previous condition and locked as necessary.

(f) All relevant fuses and circuit breakers have, as appropriate, been replaced and reset.

(g) Shorting links have been removed from frangible type crash switches and that inertia controlled switches are in their 'SET' positions.

EEL/1-9

Issue 1.

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AIRCRAFT

ELECTRICAL EQUIPMENT

CIRCUIT PROTECTION DEVICES

1 INTRODUCTION This Leaflet gives information of a general nature on the types of circuit protection devices used in typical aircraft installations. There are wide variations in the application of these devices, and no attempt is made in this Leaflet to describe any particular aircraft installation. It is important, therefore, that this Leaflet should be read in conjunction with the relevant aircraft constructors' and equipment manufacturers' manuals.

1.1 The following Leaflets contain information associated with the subject covered by this Leaflet and reference should be made to these as appropriate:

EEL/1-2 Voltage Regulation

EEL/1-4 D.C. Generators

EEL/1-5 Power Supply—A.C. Generators

EEL/1-6 Bonding and Circuit Testing

EEL/1-8* Power Supply Systems

EEL/3-1 Cables—Installation and Maintenance

1.2 For those not familiar with the basic principles of circuit protection devices, brief details of construction and operating principles are given in the introductory paragraphs associated with each group of devices.

2 GENERAL Fault conditions such as a short circuit or an overload will cause excessive current to flow in that circuit which, if left unchecked, would produce sufficient heat to cause considerable damage to the cables. Damage would not necessarily be confined to a single circuit as the heat generated by the first failure could also burn the covering and insulation of adjacent cables causing further short circuits. It is essential, therefore, that a means of protection is integrated into electrical circuits. Devices normally used for this purpose are fuses, current limiters, limiting resistors and circuit breakers. Other fault conditions such as reverse current flow, over and under voltage and frequency, and phase imbalance are protected against by the incorporation of other devices and circuit arrangements within the generator control units of the main power supply system.

3 SHORT CIRCUIT AND OVERLOAD

3.1 **Fuses.** A fuse is made up of a fusible element or link manufactured from such materials as tin, lead, alloys of tin and bismuth, silver, or copper, and having a pre-determined low melting point. Construction and current ratings are varied in order to provide a suitable selection of protection for specific electrical installations and individual circuit requirements.

* **Leaflet EEL/1-8 will be published in a later batch of Leaflets.**

3.1.1 **Light Duty Fuses.** Light duty fuses normally have the fusible element encased in a protective glass or ceramic tube, which also localises any flash which may occur when the element is ruptured. Metal end caps are fitted to enable the element to be connected to the circuit. The fuse is normally held in its holder by means of a screw or bayonet cap which may have a small hole drilled through the centre to allow the insertion of a fuse tester probe. The assembly is secured to the fuse panel by a clamp nut and circuit connections are made via terminals located on the fuse holder.

3.1.2 **Heavy Duty Fuses.** Heavy duty fuses, used normally for such circuits as main electrical distribution, consist of a ceramic tube in which a number of identical fusible elements are connected in parallel to end contacts. The tube is filled with a packing medium of granular quartz, magnesite (magnesium oxide), kieselguhr or chalk (calcium carbonate) to damp down the explosive effect of the resulting arc when rupturing takes place. The pack tube is sealed at each end with metal end caps, formed into mounting lugs, and fireclay cement. When an excessive current is flowing each element will be heated close to its melting point until one element fails, and being connected in parallel, will transfer its share of the load to the remaining elements causing further failures in quick succession.

3.2 **Current Limiters.** Current limiters are used mainly for the protection of heavy duty power distribution circuits and consist of a high melting point single strip of tinned copper shaped at each end to form mounting lugs. The central portion of the strip is, in some cases, "waisted" to form the fusible area, and is encased in a ceramic housing which also has a window, of glass or mica, set in one side to allow for a visual inspection of the device. The time/current characteristic of the device will allow a considerable overload current in the circuit before rupturing occurs.

3.3 **Limiting Resistors.** Limiting resistors provide another form of circuit protection for circuits which normally have high initial starting current, e.g. engine starter motor, invertor circuits and circuits containing high capacitive loads. In order, therefore, to keep the initial current surges within a reasonable limit the starting section of the appropriate circuit incorporates a limiting resistor which is shorted out when the current has fallen to a safe level. Figure 1 shows a limiting resistor in a typical turbine engine starter circuit utilising a time switch for the control of the limiting resistor.

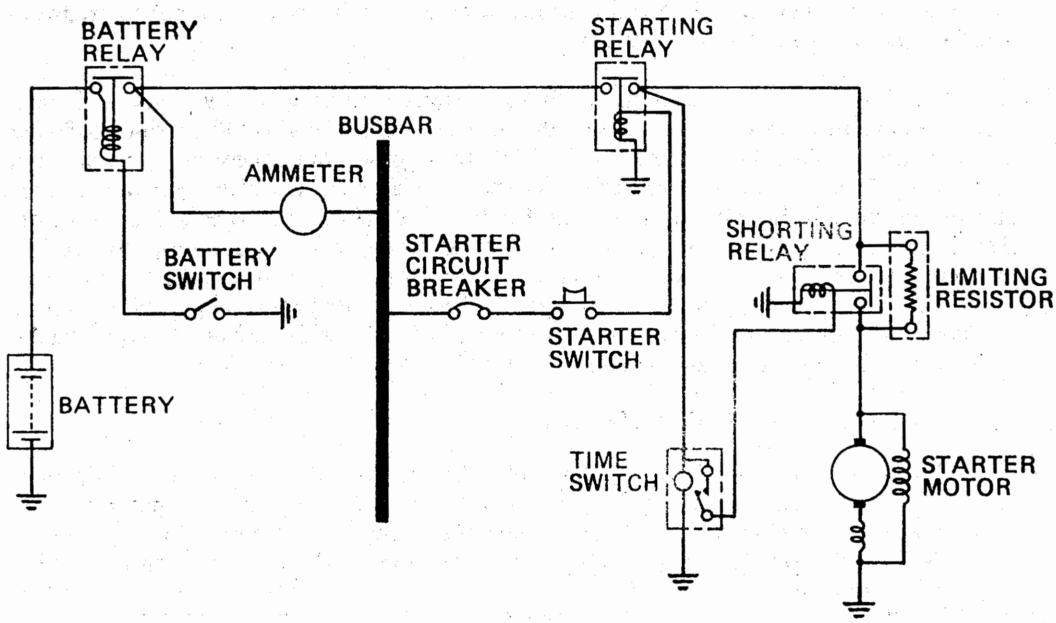


Figure 1 APPLICATION OF A LIMITING RESISTOR

3.3.1 The limiting resistor is connected in parallel to the contacts of a shorting relay which is controlled by the operation of a time switch. When the starter push switch is operated, current will flow from the busbar to energise the main starting relay and close its contacts, which in turn causes the time switch to operate, and supplies current through to the starter motor via the limiting resistor so reducing the peak current and the initial torque of the starter motor. After a pre-determined period of time, which allows for a build up of the speed at which the engine shaft is being rotated, the torque load of the starter motor reduces and the time switch causes a set of contacts to close to energise the shorting relay. With the relay energised the current from the busbar passes direct to the starter motor. When engine ignition takes place and the engine reaches 'self sustaining speed', the power supply to the starter motor circuit is then switched off.

3.4 **Circuit Breakers.** The range of circuit breakers designed for use in aircraft is extensive, and a full description of each specific type is outside the scope of this Leaflet; therefore, the following information is only of a general nature and limited to typical examples of the principal classes: Manually operated thermal trip, electromagnetically operated thermal trip, and reverse current trip circuit breakers. For precise details of any particular type fitted to an aircraft, reference should be made to the Maintenance Manual or Wiring Diagram Manual for the relevant aircraft or to the manufacturers' Technical Publication.

3.4.1 **Manually Operated Circuit Breakers.** Manually operated circuit breakers are of the trip free type to ensure that the circuit breaker cannot be maintained closed, or held against a fault current when any part of a circuit is carrying overload current. The circuit breaker is tripped by the operation of a thermal overload device if an overload current should flow in all, or any part of, the circuit. Compensation is normally provided to reduce variation in tripping time with change in ambient temperature. The contacts remain open after tripping on overload, and the operating button or lever is automatically returned to the fully open position.

(a) Manual operation of a circuit breaker is usually by means of a single push-pull button, or lever, by pushing the button to close the contacts and pulling the button to open. The portion of the button visible when the breaker is closed is normally black, while a white band on the button is exposed when the breaker is open. The current rating is marked in white in the centre of the end of the button. The mechanism is so constructed that it provides a positive snap action make and break of the contacts, so reducing the risk of the contacts becoming burnt. Circuit breakers are normally constructed in such a manner that the calibration cannot be interfered with without dismantling the device or breaking a seal.

(b) Three pole circuit breakers are so constructed that the three sets of contacts open and close together when operated manually and open on overload current in one or more lines. The difference in time between the making or breaking of the three sets of contacts should not normally exceed 5·0 ms.

(c) Any form of thermal trip mechanism requires a certain period of time to operate under overload conditions, the length of the 'waiting time' depending on the severity of the overload, hence a circuit that is protected by a simple thermal trip unit may possibly suffer damage if a really severe overload should occur. Protection against sudden severe overloads is given in other types of manually operated circuit breakers by a magnetic trip which operates almost instantaneously when the current through the main contact assembly exceeds the normal (continuous maximum) rated current by several times. Normal protection against sustained, but less severe, overloads of more than the rated current is given by the usual thermal trip mechanism. The theoretical circuit and principle of latching control in this form of circuit breaker is illustrated in Figure 2.

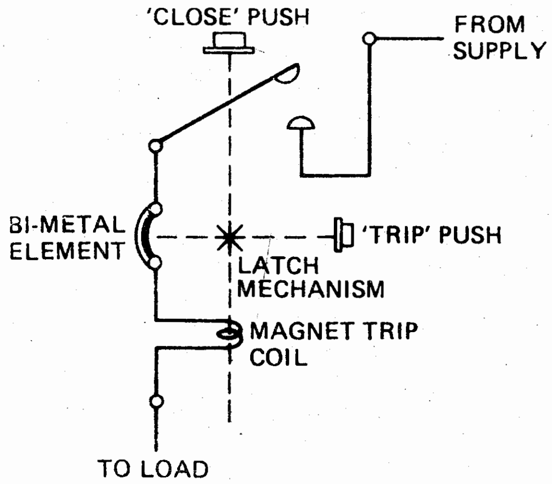


Figure 2 PRINCIPLE OF A THERMAL/MAGNETIC CIRCUIT BREAKER

(d) The magnetic trip element is simply an electromagnet and an attracted armature which, when attracted to the pole faces of the electromagnet, operates the contact assembly trip latch. The magnet coil is connected in series with the thermal element and the main contacts, and the spring loading of the armature is such that the armature cannot be attracted until the current through the coil (and also through the contacts) exceeds the danger level already quoted.

3.4.2 **Electrically-Operated Circuit Breakers.** The theoretical circuit of a typical circuit breaker used to link a d.c. generator to the busbar of an installation is shown in Figure 3. This type of circuit breaker consists of a stationary electromagnet, a pivoted soft iron armature which is attracted to the pole faces of the electromagnet when the winding is adequately energised, a pivoted contact bridge carrier which is latched to the pivoted armature, a contact bridge which incorporates a bimetal plate and is permanently secured to the carrier, and two groups of fixed contacts which are bridged by the contact bridge when the armature, if latched to the contact carrier, is held against the pole faces of the electromagnet. The circuit breaker is normally biased to the open condition by the action of an accelerating spring (attached to the thermal element) and two throw-off springs (located in recesses in the pole pieces). With the thermal element at ambient temperature, the latch of the carrier is engaged with a roller on the armature, hence when the circuit breaker is open with the magnet system de-energised both auxiliary switches are closed. The sequence of operation for closing action by remote control, tripping by overload, and resetting after tripping on overload are given in the following paragraphs.

(a) **Closing Action.** On applying a positive supply to terminal 7, with terminal 4 already connected to the supply return, current flows through the low resistance 'closing' coils only and immediately attracts the hinged armature to the pole faces, compressing the two throw-off springs. Since armature and contact-bridge carrier are effectively linked by the latching device, the armature takes the carrier with it and thus extends the accelerating spring. Just before the armature reaches the limit of its travel, contact is made between the two sets of stationary contacts by the contact bridge, completing the main circuit to the controlled unit. Further movement of the armature towards the pole faces increases the loading on the main contacts, and the ultimate stage in armature travel causes both auxiliary switches to open. At the same time the indicator lamp contacts, which are operated by a plunger attached to the contact bridge carrier, open to interrupt the indicating circuit to signify that the main contacts of the circuit breaker are, in fact, effectively closed.

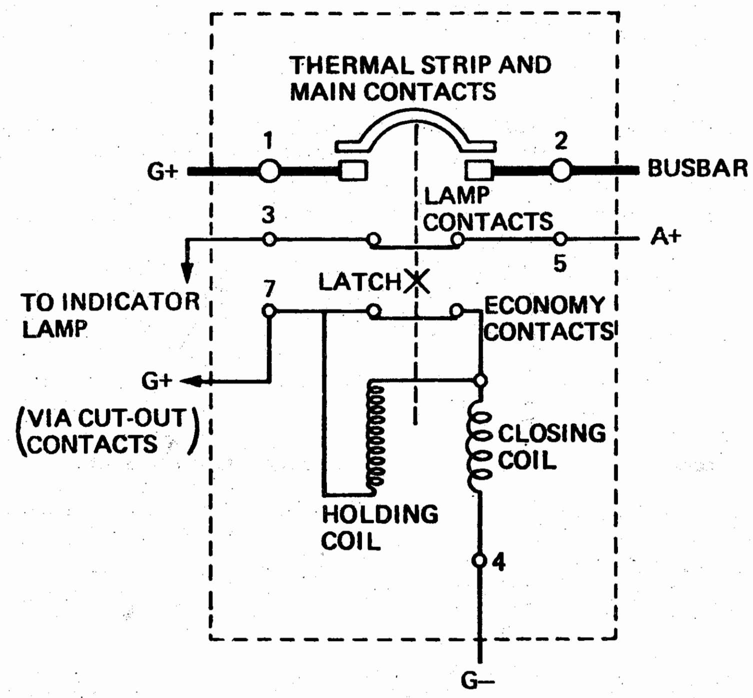


Figure 3 INTERNAL CIRCUIT OF A TYPICAL HEAVY DUTY CIRCUIT BREAKER

(b) **Trip Action.** With maximum continuous-rated current flowing through the main stationary contacts of the circuit breaker, the heating effect of the current in the bimetal plate is insufficient to cause distortion of the bimetal plate and the circuit breaker remains closed. Increases in current beyond this value, if sustained, will increase the heating of the bimetal plate and, because of the differing coefficients of expansion of the two metals, cause distortion; as a result the trip bolt is forced down against the latch, and the latch is disengaged from the roller on the armature. With the mechanical connection between the armature and contact bridge carrier being broken the carrier is pulled away from the armature by the accelerating spring, breaking the main contacts and interrupting the main circuit. The indicator lamp contacts, which are operated by a plunger on the contact bridge carrier, close to give indication that the circuit breaker has tripped. Only the contact bridge carrier, acting under the applied force of the accelerating spring, is released from the magnet pole faces; the armature remains in its energised state since the economy contacts (which are operated by a plunger on the armature) remain open, and current through the magnet winding remains at the normal level.

(c) **Resetting Action.** After tripping action has occurred, the main contact assembly is in the open position but the armature remains attracted to the pole faces of the magnet core. In this condition the bimetal thermal element no longer carries current and begins to cool down; the distortion of the element is reduced as cooling proceeds and eventually resumes its original position. On interrupting the supply to terminal 7 (by means of the reset push switch which is normally closed), the magnet winding is de-energised, and the throw-off springs push the armature away from the pole faces until the armature roller re-engages with the latch on the carrier. On restoring the supply to terminal 7 (by releasing the reset push) the closing section of the winding is again energised through the now closed economy contacts to close the circuit breaker in the normal manner.

3.4.3 **Short-Rated and Continuous-Rated Circuit Breakers.** Typical circuit diagrams for short-rated and continuous-rated circuit breakers are shown in Figure 4. The operating mechanism comprises a two-core electromagnet and thermal trip system substantially similar to that of the circuit breaker described in paragraph 3.4.2, but in this type the magnet winding consists of a single low-resistance coil wound on each of two cores, the two coils being connected in series; in the continuously-rated version an economy resistor is placed in series with the winding (as the contact assembly closes) to reduce coil current and prevent undue temperature rise in the magnet assembly.

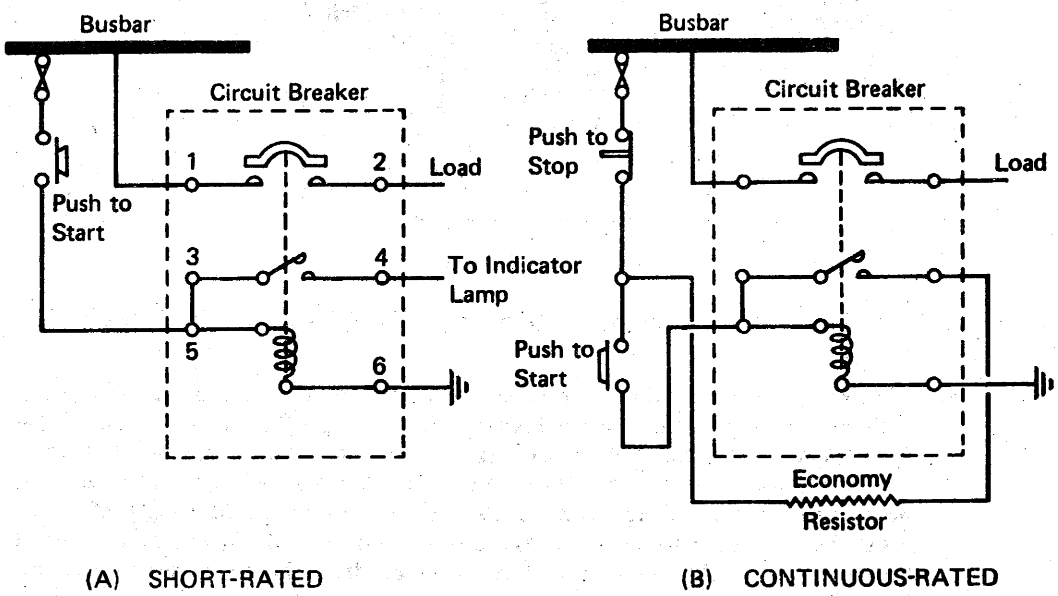


Figure 4 TYPICAL CIRCUIT DIAGRAMS FOR SHORT-RATED AND CONTINUOUS-RATED CIRCUIT BREAKERS

(a) **Example B.** In this type of electrically-operated thermal trip circuit breaker the remote control of closure and tripping of the contacts assembly is provided by an electromagnet system similar in form to that of a cylindrical type of heavy duty relay. The contact assembly is operated by the axial movement of a cylindrical plunger which is drawn, against spring control, into the interior of a solenoid when the solenoid is energised. The solenoid winding is in two sections, one of which is normally short circuited by auxiliary armature operated contacts; these contacts open, thereby placing the two sections of the solenoid winding in series, as the armature moves into the operated position, provides an adequate 'hold-on' magnetic field with a relatively small current in the winding circuit. Protection against sustained overload is given by a bimetal thermal trip system, and provision is made for manual (local) tripping by a push-button on the circuit breaker casing. The breaker is reset, after having been tripped thermally or manually, by de-energising the magnet winding; on releasing the armature from the operated position the latching system reverts to normal, and the circuit breaker resets itself for further operations.

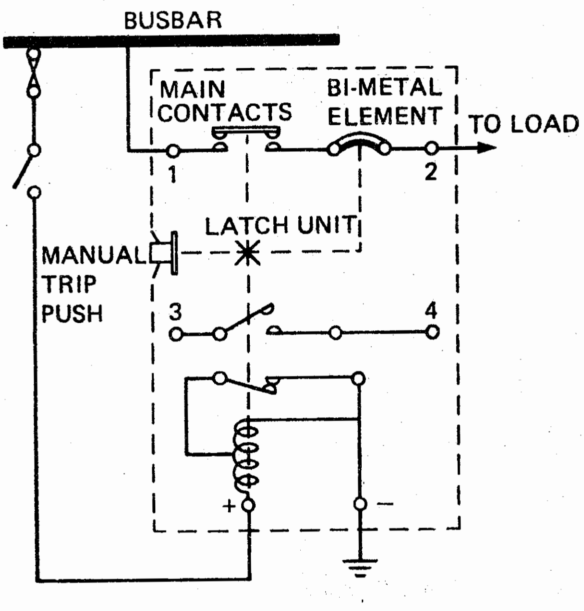


Figure 5 EXAMPLE B

(b) **Example C.** A further example in this range of circuit breakers for remote control (electromagnetic) closure and tripping, thermal tripping for circuit protection against sustained overload, and manual (local) tripping for emergency use which differs from others previously described in that the main contacts assembly, which is closed by an electromagnet system, is subsequently retained in the closed condition by a mechanical latching system; the operating coil of the circuit breaker is in use only during the actual closing operation, and is automatically disconnected from its supply as the main contacts are latched on. The internal circuit and latching connections are illustrated in Figure 6. The latch mechanism is subsequently freed, allowing the spring loaded main contact assembly to open, by the movement of a trip which, in turn, is operated either by pressing on a manual trip button (on the circuit breaker casing), energising a second magnet system (the remote trip system) or by distortion of the bimetal element of a thermal trip system (in series with the main contacts) as a result of an overload condition in the protected circuit. After tripping by any one of the three methods, the circuit breaker is reset by completing the remote control operating circuit.

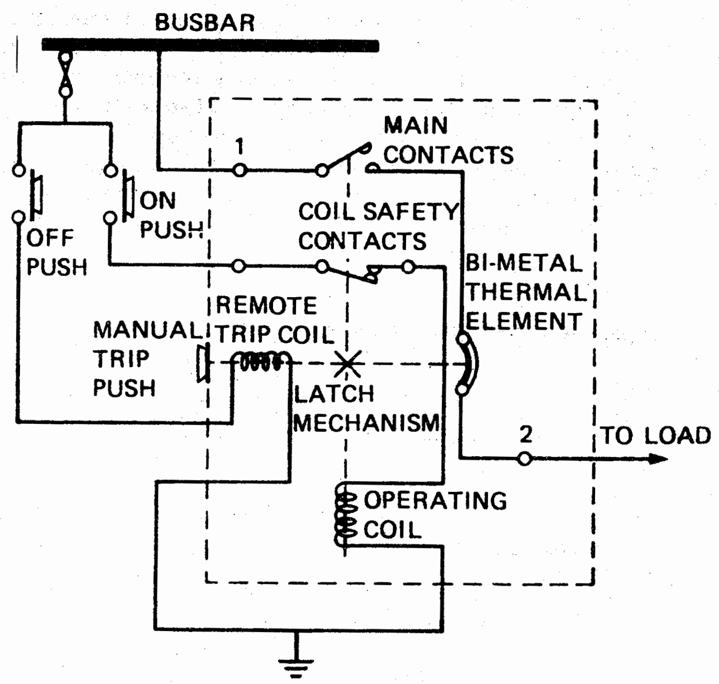


Figure 6 EXAMPLE C

4 REVERSE CURRENT FLOW

4.1 Reverse Current Trip Circuit Breaker

4.1.1 General

(a) A further category of circuit breaker designed for the control and protection of circuits in which the current flow is normally in one direction only, which trip automatically if the current in the controlled circuit should undergo a reversal of direction is illustrated in Figure 7. Circuit breakers of this specialised form are normally incorporated in certain aircraft d.c. power supply systems, where their primary function is the isolation of any generator which, for any reason, takes current from the main busbar for unduly protracted periods. This type of circuit breaker is not affected by the momentary reversals of current in the generator output circuit which take place when the generator, with falling output, cuts out under its normal automatic control system. Such a circuit breaker is normally closed and takes no active part in the general functioning of the power supply system, opening only if the normal generator controls fail to cut out a negative output generator.

(b) The circuit breaker embodies a spring loaded contact assembly which is closed manually by a setting handle and is then held in this condition by a latch assembly. The controlled generator is then connected to the busbar through a series connection consisting of the main contacts and a single turn coil. The main contacts open to disconnect the generator from the busbar when the latch assembly is released; this action is performed by the displacement of a trip lever, which in turn is operated either manually (by pressing the trip button), by remote control through the attracted armature electromagnet system, or automatically when a reverse current condition, of sufficient magnitude and duration, develops in the single turn coil. After tripping by any of these methods, the circuit breaker must be reset by operating the setting handle.

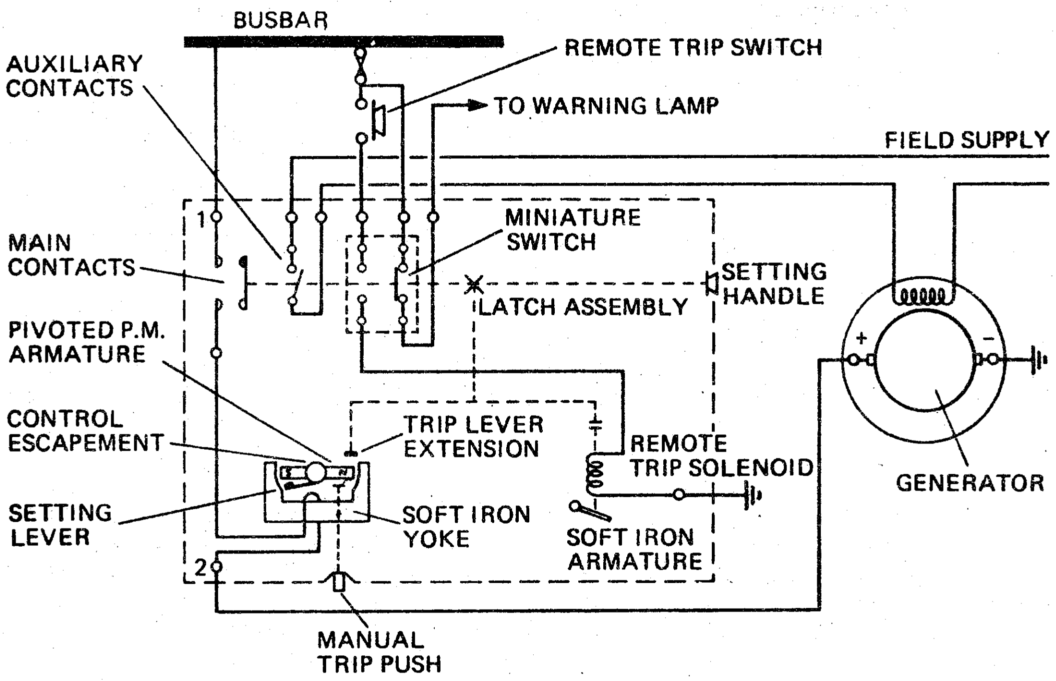


Figure 7 REVERSE CURRENT CIRCUIT BREAKER OPERATION

4.1.2 Reverse Current Trip System

(a) The single turn coil shown in Figure 7 is located over a soft iron yoke provided with pole faces between which is pivoted a permanent magnet armature. With current passing through the single turn coil a magnetic field is established between the pole faces of the soft iron yoke; polarity of this field (and hence the direction in which it tends to displace the pivoted permanent magnet armature) is dependent on the direction of current through the coil.

(b) The polarity of the yoke field, with current passing through the single turn coil in the normal direction, is such that the armature takes up a position in which one of its arms is poised above an extension of the trip lever, while the other end lies immediately below, and just clear of, a setting lever. The same position is maintained by the armature when there is no current through the single turn coil.

(c) With a reversal of current in the coil the polarity of the yoke field is also reversed, and a force tending to deflect the ends of the pivoted armature towards the trip lever extension and the setting lever is established. The setting lever, which is contacted almost immediately by the armature on the initial movement of the latter in the reverse current direction, controls an escapement mechanism; this mechanism in turn controls the rate at which all further rotary movement of the armature (after the setting lever has been contacted) is made, and the design is such that the rate of armature movement is approximately proportional to the force applied to the setting lever by the permanent magnet armature.

(d) The force exerted on the setting lever by the end of the armature under reverse current conditions is determined by the intensity of the yoke field and thus varies with the magnitude of reverse current in the single turn coil.

(i) Sustained reverse current, if slightly above the designed minimum value, results in a small but constant force being applied to the setting lever, and the escapement allows the armature to turn quite slowly until, after an appreciable delay, it displaces the trip lever to unlock the latching assembly and so permit the spring-loaded contact assembly to open.

(ii) Large reverse current, if sustained, will result in the circuit breaker tripping after a shorter delay, while an extremely severe reverse current will cause almost instantaneous tripping.

(iii) If the reverse current is not sustained and falls to less than the designed minimum trip value before the permanent magnet armature, restrained in its movement by the escapement, has been able to operate the trip lever, the armature is returned to its original position and no trip action takes place.

4.1.3 **Remote Tripping**

(a) Remote tripping of the circuit breaker is effected by means of a tripping solenoid which, when energised, attracts a hinged soft iron armature to displace the trip lever and so release the mechanical latch assembly. The supply to the tripping solenoid is controlled by a push-switch, and the remote trip operating circuit is interrupted, when the circuit breaker is open, by the normally open contacts of the miniature switch shown in Figure 7. The normally closed contacts of this switch, which open as the main contacts close, control a warning light or indicator.

(b) The contact assembly also incorporates a set of auxiliary contacts which open and close with the main contacts; these auxiliary contacts complete the circuit to the field winding of the generator when the circuit breaker is closed. A mechanical indicator, visible through an inspection window in the breaker casing, provides a visual check on the breaker state, i.e. set or tripped. The manual trip push is formed at the end of a spring-loaded plunger which, when pressed, swings the permanent magnet armature on its pivot until it displaces the trip lever and trips the circuit breaker.

4.2 Reverse Current Cut-out Relays

4.2.1 **General.** The generator of an aircraft electrical power supply system has to be protected from the battery voltage when the engine is shut down or when a failure of its output occurs. This is normally achieved by the action of a reverse current cut-out relay, fitted either as a separate unit or as an integral part of the voltage regulator. The circuit arrangement for such a relay as an integral part of a voltage regulator, typical of many light aircraft systems, is illustrated in Figure 8.

4.2.2 **Sequence of Operation**

(a) When the generator output voltage rises above that of the battery, the magnetic field of the voltage coil will cause the armature to move against spring tension and close the contacts of the reverse current cut-out relay placing the generator output on the busbar. Load current will now flow through the current coil and produce a magnetic field, which aids that already produced by the voltage coil, and maintains the contacts of the relay tightly closed.

(b) As the generator is being shut down or if a failure of its output occurs, the generator voltage decays to a level which is below that of the battery, resulting in a current being drawn from the battery through the busbar, circuit breaker, and the current coil of the relay. The current flow is now in the reverse direction to the previous current flow, causing an opposite magnetic field to that being produced by the voltage coil. When these two fields cancel each other out, spring tension will open the contacts, automatically disconnecting the generator from the busbar.

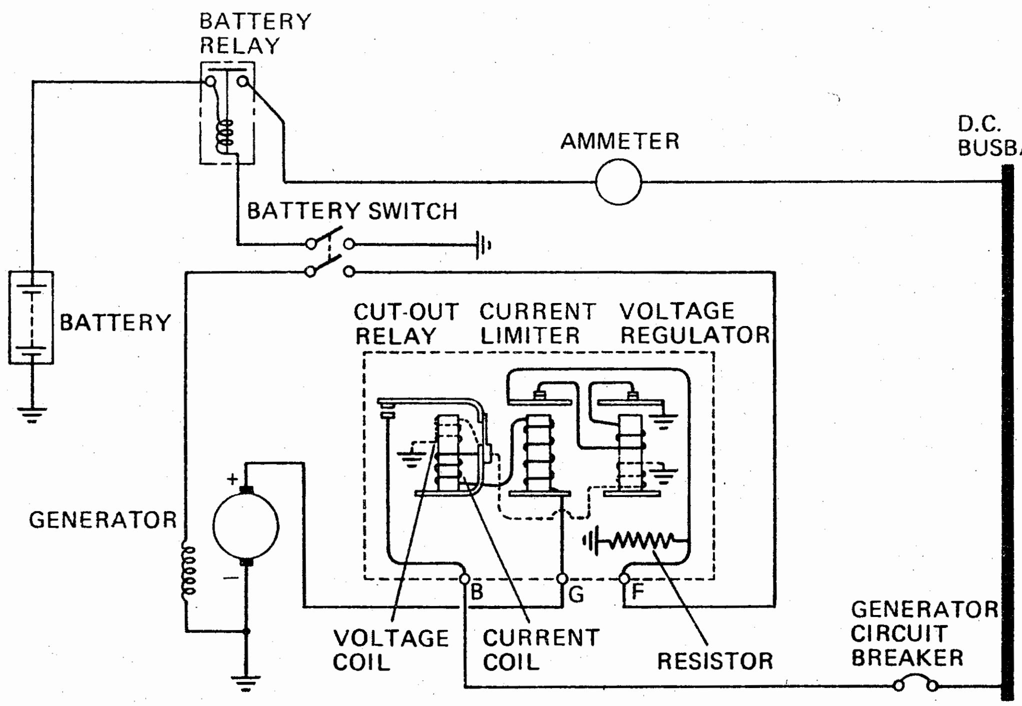


Figure 8 REVERSE CURRENT CUT-OUT RELAY OPERATION

5 OVERVOLTAGE

5.1 **General.** Overvoltage is a condition which could arise in a power supply system in the event of a fault in the generator field excitation circuit, such as internal grounding of the field windings, or an open circuit in the voltage regulator sensing lines. It is, therefore, necessary to protect consumer equipment against voltages higher than those at which they are normally designed to operate. The methods used vary between aircraft; therefore, reference should be made to the relevant Maintenance Manual for the aircraft concerned. Figure 9 illustrates an example of a typical overvoltage protection circuit for a light aircraft.

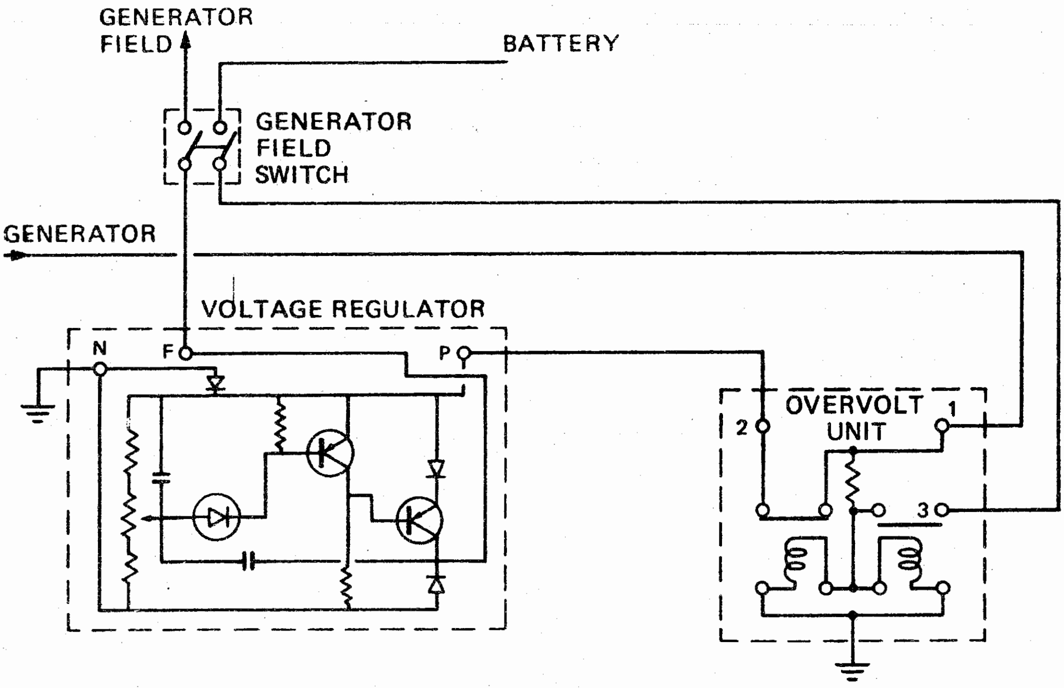


Figure 9 OVERVOLTAGE PROTECTION (D.C.)

5.1.1 The overvolt unit comprises two relay coils, one having a pair of normally closed contacts and the other, a pair of normally open contacts. The generator field supply passes via the normally closed contacts to the voltage regulator. Should the generator output voltage rise to a pre-determined value both relay coils become energised via the resistor; opening the generator field circuit causing the generator output to fall to zero, while a permanently connected battery supply will hold on the overvolt relays via the now closed set of contacts.

5.1.2 To reset the system, the generator field switch should first be selected to the OFF position which will reset the generator field circuit so that the generator may be brought on line by returning the field switch to the ON position. If the cause of the overvoltage condition still exists the generator will automatically be tripped off again and no further attempt at resetting should be made until the cause has been established and rectified.

5.2 **A.C. Supply Systems.** A typical method of overvoltage protection, as used in an a.c. power supply system utilising magnetic amplifiers for the control and protection, is illustrated in Figure 10. The circuit is formed by the combination of a single-phase magnetic amplifier and a rectifier bridge, the output of which is applied to the operating coil of a protection relay. The a.c. windings of the magnetic amplifier are normally supplied from a supply and reference transformer, while a voltage sensing network is used in conjunction with the control winding.

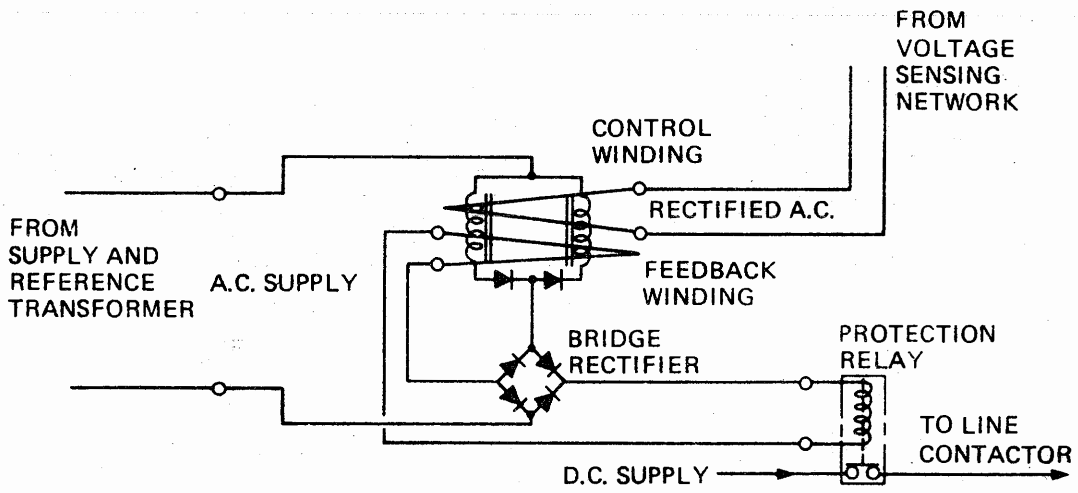


Figure 10 OVERVOLTAGE PROTECTION (A.C.)

5.2.1 At the nominal supply voltage the circuit is adjusted so that the protection relay is de-energised; with an increase of supply voltage, the magnetic amplifier saturates and energises the protection relay which interrupts the d.c. supply to the hold-in circuit of a line contactor which disconnects the generator from the busbar. At the same time, the main control unit interrupts the supply to the generator field, causing its output to collapse to zero.

6 UNDERVOLTAGE

6.1 **General.** Undervoltage occurs in the normal course of operation when a generator is being shut down, and reverse current flow from the battery to the generator is a normal indication of this condition.

6.2 **D.C. Supply Systems.** In a single d.c. generator power supply system, additional undervoltage protection is not essential since the reverse current is sensed and checked by the reverse current cut-out relay.

6.3 In a multi-generator system additional protection is required and usually takes the form of a polarised relay designed to be energised by a voltage rising to a pre-determined level and to be de-energised as the voltage falls approximately 2 volts below that level. A typical circuit, as used on a twin-engined light aircraft, is illustrated in Figure 11.

6.3.1 The undervolt relay is energised by the generator supply through the generator field switch, and a warning light is connected in series with the normally closed contacts of the unit. When the engine and generator is at rest, or the generator isolated or faulty, the undervolt unit will be de-energised and the warning light illuminated.

6.4 **A.C. Supply Systems.** In an a.c. power system an undervoltage condition results in a lagging current, or reactive power, which is the equivalent of reverse current. The protective function is, therefore, usually performed by the reactive load sharing circuit of an a.c. power supply system. Further information may be found in Leaflet **EEL/1-8**.

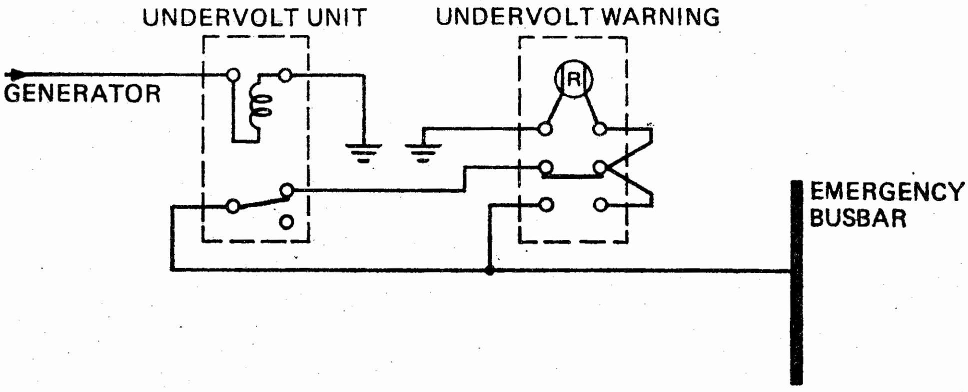


Figure 11 UNDERVOLTAGE PROTECTION (D.C.)

7 UNDER/OVER FREQUENCY Protection against these faults is required only in a.c. power supply systems and protection is usually effected by the real load sharing circuit of the system. Further information may be found in Leaflet **EEL/1-8**.

8 MAINTENANCE PRACTICES The method of installing the principal protection devices of aircraft electrical circuits, and the carrying out of the relevant maintenance procedures, will vary between types of aircraft. For precise details of any particular aircraft, reference should be made to the Maintenance Manual and Wiring Diagram Manual for the aircraft concerned. Certain aspects are, however, of a general nature and the information given in the following paragraphs is intended only as a general guide.

8.1 **General Precautions**

8.1.1 On aircraft which have three-phase a.c. primary power supply, the voltage potential between phases is 200 volts RMS and can be lethal. Therefore, before carrying out any maintenance on the aircraft's electrical power supply and distribution system, it should be ensured that the system is de-energised and that no external supplies are connected to the aircraft.

8.1.2 To eliminate the possibility of damage to equipment or the structure of the aircraft by the shorting of live terminals to earth, and before removing any circuit protection device, it should be ensured that all electrical power is off, by disconnecting ground power supplies and the aircraft batteries. Notices should be prominently displayed adjacent to the ground power plugs and aircraft battery connections stating that electrical power supplies are not to be connected.

8.1.3 Sufficient time must always be allowed for the thermal element to cool adequately before attempting to reset a circuit breaker which has tripped on overload. If the breaker trips again shortly after resetting, it must be assumed that a fault condition exists, so further attempts at resetting should not be made until the fault has been investigated and cleared.

8.2 **Checking of Components.** Whenever the serviceability of a protection device is suspect, or at specific inspection periods, components should be subjected to the following checks:—

(a) Check component for proper installation, security of attachment, physical damage, and for any evidence of overheating.

(b) Check that electrical connections are secure and free from contamination.

(c) Check all wiring for physical damage such as chafing, fraying or cut insulation.

8.3 **Removal/Installation.** Procedures for the less complex protection devices, such as fuse-holders and circuit breakers, will usually be provided within the relevant aircraft Wiring Diagram Manual. Procedures for the more complex units, such as reverse current cut-out relays and reverse current circuit breakers, will be in the relevant aircraft Maintenance Manual. The information given in the following paragraphs is intended only as a general guide to the safety precautions that should be observed.

8.3.1 Following removal of circuit protection devices, and where replacements are not readily available, to ensure that the aircraft remains electrically safe, all exposed terminations on cables should be covered with insulating boots or tubing. In addition, all plugs and sockets should be protected with plastic, or equivalent, dust caps to prevent damage to pins and the possible ingress of moisture or foreign matter. Electrical power supplies may then be re-connected to the aircraft power distribution system to permit operation of other services.

8.4 **Power Supplies for Testing.** Power supplies for the testing and ground operation of aircraft electrical systems should be those obtainable from either ground supply sources or the auxiliary power supply of the aircraft. Use of the aircraft battery power supply should be severely restricted. Before applying external power to an aircraft distribution system, it should be ascertained that all associated switches located in the crew compartment, on the ground power control panel and on the cabin ground service panel, as applicable, are selected to the off, normal or open position as required.

8.4.1 Damage to the equipment of the aircraft can occur if the electrical power supply circuits have been subjected to an abnormally high or abnormally low voltage, extreme frequency variations or to the application of incorrect phase rotation.

8.4.2 Prior to carrying out any functional tests or adjustment procedures, it should be ensured that all applicable fuses have been refitted and circuit breakers reset. Relevant warning notices should be removed.

EEL/1-10

Issue 1.

June, 1981.

AIRCRAFT
ELECTRICAL EQUIPMENT
LIGHTING SYSTEMS

1 INTRODUCTION This Leaflet gives information of a general nature on the different types of lighting which can make up typical aircraft lighting systems. No attempt is made in this Leaflet to describe any particular aircraft installation; it is important, therefore, that this Leaflet should be read in conjunction with the relevant manufacturers' and aircraft manuals.

1.1 The following Leaflets contain information associated with the subject covered by this Leaflet, and reference should be made to these as appropriate:

EEL/1-6 Bonding and Circuit Testing
EEL/1-9 Circuit Protection Devices
EEL/3-1 Cables—Installation and Maintenance
AL/11-6 Ice Detection Systems

2 GENERAL Lighting plays an important role in the safe operation of an aircraft and in the control of many of its systems. In the main, lighting falls into two groups—external lighting and internal lighting. The main functions of such lighting are:

(a) **External Lighting**

(i) The marking of some of the aircraft's extremities by means of navigation lights.
(ii) The attracting of attention by means of flashing lights.
(iii) Forward and lateral illumination for aircraft landing and taxying.
(iv) Illumination of parts of the aircraft, to enable visual checks for ice formation.
(v) Illumination to facilitate evacuation of passengers and crew following an emergency landing.

(b) **Internal Lighting**

(i) Illumination of flight deck instrumentation and control consoles.
(ii) Illumination of passenger compartment and passenger information signs.
(iii) Indication and warning of system condition and operational status.
(iv) Emergency lighting.

2.1 In general, white incandescent and fluorescent lamps, electro-luminescent (electrically activated phosphor) and self-illuminating signs are used to provide aircraft lighting. Coloured lighting used for warning lights, indicator lights on instrument panels, navigation and anti-collision lights is normally achieved by the use of coloured lenses. Emergency lights are used to illuminate both internal and external emergency egress paths.

2.2 Primary power supplies required for the individual lights and lighting systems described in this Leaflet will vary according to the size and complexity of the aircraft and may be either a.c. or d.c. Reference should, therefore, be made to the relevant aircraft Maintenance Manual for precise details. Individual circuit protection is normally provided by panel mounted circuit breakers whilst lighting controls are conveniently located throughout the aircraft.

2.3 Requirements for the minimum intensities, dihedral angles, effective flash frequency and colours which are applicable to the external lights provided in order to comply with the Rules of the Air and Air Traffic Control Regulations are contained in JAR-25 and BCAR Chapter **D6-7** for large aeroplanes, **G6-7** for rotorcraft and **K6-7** for light aeroplanes.

3 EXTERNAL LIGHTING

3.1 **Navigation Lights.** The requirements and characteristics for navigation lights have been agreed internationally, and for UK registered aircraft are set out in the statutory Rules of the Air and Air Traffic Control Regulations and the Air Navigation Order. Briefly, the requirement is that every aircraft in flight or moving on the ground during the hours of darkness shall display:

(a) A green light at or near the starboard wing tip, visible in the horizontal plane from a point directly ahead through an arc of 110° to starboard (dihedral angle R of Figure 1).

(b) A red light at or near the port wing tip, with an arc of visibility to port similar to that in (a) (dihedral angle L of Figure 1).

(c) White light visible from the rear of the aircraft in the horizontal plane through an arc of 140°. The conventional location of this light is on the tail of the aircraft, but in some cases, notably such aircraft as the wide bodied types, a white light meeting the specification is mounted on the trailing edge section of each wing tip (dihedral angle A of Figure 1).

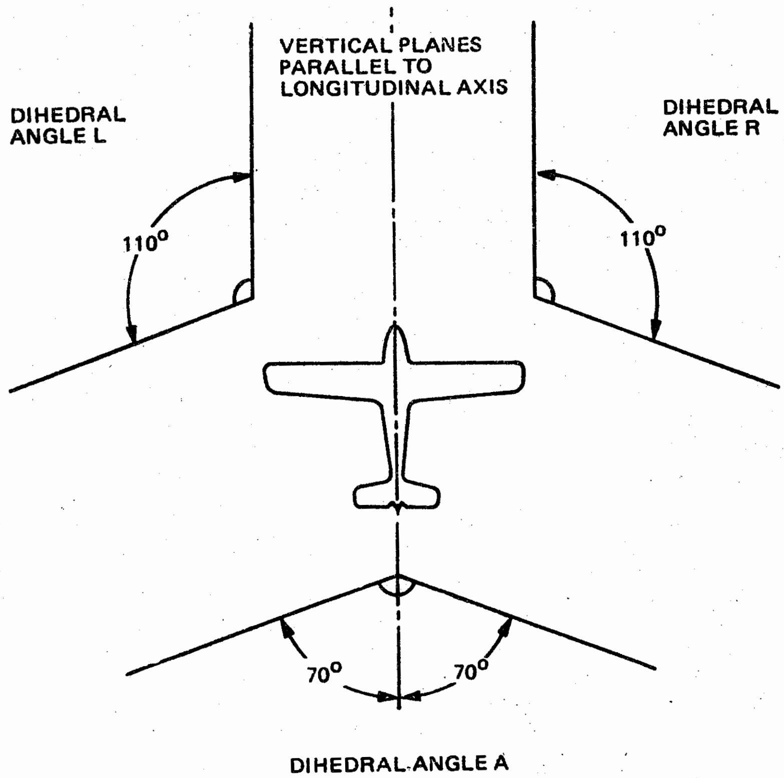


Figure 1 EXTERNAL LIGHTING ANGLES

3.1.1 Construction of the light fittings varies in order to meet the installation requirements for different types of aircraft. In general, however, they consist of a filament type lamp, an appropriate fitting and a transparent coloured screen or cap. To obtain a sharp cut-off of light at the required angle of visibility, the screen and the filament of the lamp are shaped and arranged accordingly.

3.1.2 Originally, navigation lights were required to emit a steady light, but in order to improve the attention attracting function, subsequent legislation required the lights to flash in a controlled sequence. However, following the introduction of flashing anti-collision beacons the requirement for flashing navigation lights was discontinued, and the steady lighting requirement was re-introduced. It is, therefore, possible for some aircraft, which are below a certain weight criterion and registered before current regulations became effective, to be still equipped with flashing navigation lights.

3.2 Anti-Collision Lights

3.2.1 Anti-collision lights complement the navigation lights and by emitting a flashing light attract attention and thus enable the presence of an aircraft to be more readily identified. The lights may be of the type which emits a rotating beam of light or of the strobe type, from which short-duration flashes of high intensity light are emitted. In some current types of aircraft both types are used in combination, the strobe lighting forming supplementary lighting.

3.2.2 **Rotating Beam Lights.** These lights, or beacons as they are often called, consist of a filament lamp unit and a motor. In some cases the motor drives a reflector (see (a)) and in others the actual lamp unit (see (b)). The drive transmission system is usually of the gear and pinion type and has a specific reduction ratio. All components are contained within a mounting enclosed by a red glass cover. The motor speed and gear drive ratios of beacons are such that the reflector or lamp unit, as the case may be, is operated to establish a beam of light which rotates at constant frequency. Typical speeds are 40-45 rev/min giving a flash frequency of 80-90 Hz/min (but see paragraph 2.3). There are variations of design, but the two types described in (a) and (b) usefully illustrate how the rotating reflector and rotating lamp techniques are applied.

(a) The beacon illustrated in Figure 2 employs a V-shaped reflector which is rotated at approximately 45 rev/min by a motor, over and about the axis of a sealed beam lamp. One half of the reflector is flat and emits a narrow high-intensity beam of light near the horizontal, while the other half is curved to increase the up and down spread of its emitted beam to 30° above and below the horizontal, thereby effectively reducing the light intensity.

(b) The beacon illustrated in Figure 3 is one employing two filament lamps, mounted in tandem, each of which is pivoted on its own axis. One half of each lamp forms a reflector by being silvered, and the drive from the motor is so arranged that the lamps oscillate through 180° and, as can be seen from the inset diagram, the light beams are 180° apart at any instant.

3.2.3 **Strobe Lighting.** This type of lighting system is based on the principle of a capacitor-discharge flash tube. The light unit takes the form of a quartz or glass tube filled with xenon gas which is connected to a power supply unit made up essentially of a capacitor, and which converts an input power of either 28 V d.c. or 115 V a.c. into a high d.c. output, usually around 450 V. The capacitor is charged to that voltage and periodically discharged between two electrodes in the xenon-filled tube, the energy producing an effective high-intensity flash of light having a characteristic blue-white colour.

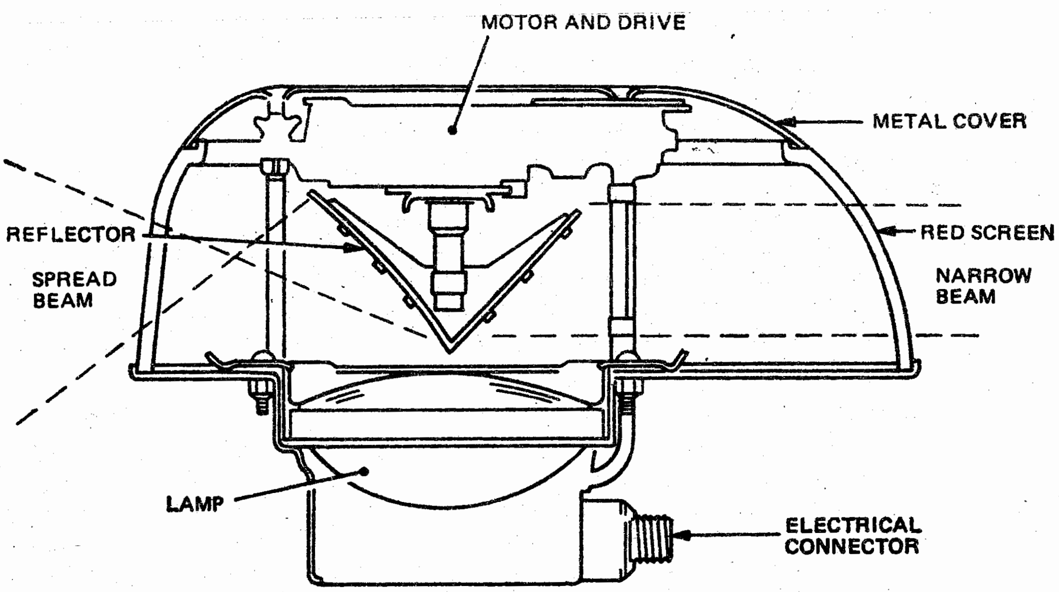


Figure 2 ROTATING REFLECTOR BEACON

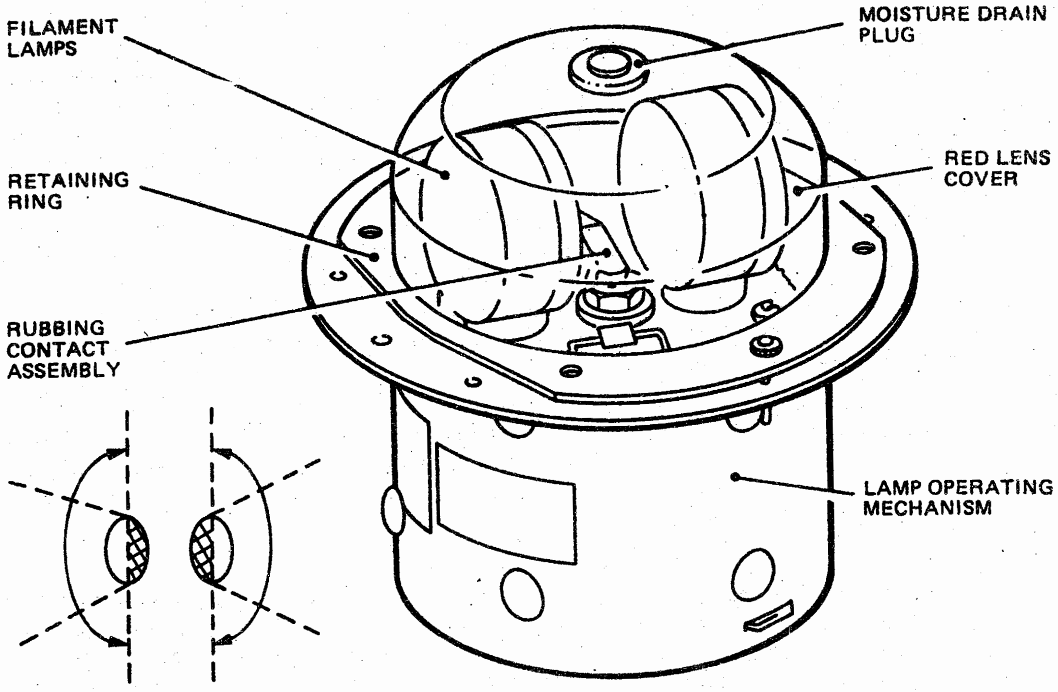


Figure 3 ROTATING LAMP BEACON

3.2.4 **Supplemental Lighting.** Depending on the size of the aircraft, strobe lighting may be installed in the wing tips to supplement the conventional red beacons, or may be used in combination as a complete strobe type anti-collision high-intensity lighting system controlled in a flashing sequence by controllers and flasher timing unit.

3.3 **Landing and Taxying Lamps.** Landing and taxying lamps, as the names indicate, provide the necessary illumination for the landing of an aircraft and for taxying it to and from runways and terminal areas at night and in poor visibility conditions.

3.3.1 **Landing Lamps.** Landing lamps are used to illuminate that area of the runway immediately ahead of the aircraft. These lamps are generally of the sealed beam type and are, in some aircraft, mounted in wing leading edges, front fuselage sections, or on the nose landing gear, so as to direct beams of light at pre-determined and fixed angles. In other aircraft the lamps are mounted under the wings and may be extended to pre-selected angles and then retracted. Actuator operated lamps are normally operated through a slipping clutch mechanism or shear links to ensure retraction, should they not be retracted or fail to retract, before a high air speed is achieved. The requirements for landing lamps fitted to rotorcraft differ, in respect to angles of coverage, and reference should, therefore, be made to BCAR Chapter **G6-1.**

3.3.2 **Taxying Lamps.** Taxying lamps are also generally of the sealed beam type, located, in most cases, on the nose landing gear. The power rating of such units is normally lower than that of the landing lamps, 250 W being typical, and the supply required is either d.c. or a.c. In some designs the function of a taxying lamp is combined with that of a landing lamp, the lamp unit then consisting of two filaments, one of 600 W and the other of 400 W. Typically both filaments may provide the illumination for landing, and for taxying only the 400 W filament would be used.

3.3.3 In addition to taxying lamps, some of the larger types of aircraft are equipped with lamps which are so mounted as to direct beams of light to the sides of the runway, and are known as runway turn-off lights. The primary function of these lights is to illuminate the points along the runway at which the aircraft can turn to leave the runway.

3.4 **Ice Inspection Lamps**

3.4.1 Ice inspection lamps, or wing-scan lamps as they are sometimes called, are fitted to transport aircraft to allow for the visual inspection of the wing leading edges and air intakes of turbine engines, for the formation of ice. Further information on ice inspection lamps is given in Leaflet **AL/11-6.** The lamps are generally of the sealed beam type with power ratings ranging from 60 to 250 W depending on the light intensity required for the particular aircraft type.

3.5 **Service Lighting**

3.5.1 Service lighting is fitted to some aircraft to provide general illumination for routine inspection and servicing in such areas as wheel wells, air conditioning compartments, tail cone, APU compartments, electrical/electronic equipment centres and fuelling panels. The lights are generally of the explosion-proof dome or bulkhead type with conveniently located control switches.

3.6 **Exterior Emergency Lighting**

3.6.1 Exterior emergency lighting is normally provided by white incandescent lights at each overwing emergency exit to illuminate the area where an evacuee is likely to make the first step outside the passenger cabin, along a portion of the overwing escape route to an area where first contact with the ground would be made.

3.6.2 At each non-overwing emergency exit not having an escape assist means, similar illumination is provided which is capable of lighting the ground surface where an evacuee is likely to make first contact with the ground outside the passenger compartment.

3.6.3 Where an emergency exit has an escape assist means, illumination is provided to ensure that it is visible from the relevant emergency exit and to illuminate the area of the ground with which an evacuee would first make contact. In some such installations the light units may form part of the escape assist means and are, therefore, automatically activated when the assist means is erected.

4 INTERNAL LIGHTING

4.1 An important requirement of internal lighting is that there should be adequate illumination of the aircraft interior for all conditions of flight. To achieve this, most passenger transport aircraft have flight deck and passenger compartment lighting divided into three groups:—

(a) **Main.** Main lighting is usually equally distributed and connected to the various busbars, so ensuring that single power failures do not result in the loss of all main lighting.

(b) **Standby.** In the event of a total electrical power failure, illumination, at a considerably lower level, would be provided by standby lighting normally powered from the aircraft batteries.

(c) **Emergency.** Emergency lighting is normally provided for the illumination of emergency exit paths and exits throughout the aircraft. Such lighting is, in some aircraft, arranged and connected in groups to the aircraft batteries, capable of being automatically transferred to emergency battery packs when the main battery voltage level has fallen to a pre-determined value. On other aircraft these are of the self-contained battery operated type.

4.2 The internal lighting can also be further divided into four categories—flight deck or operational lighting, passenger compartment lighting, service lighting (which includes galleys, toilet and cargo/baggage compartments) and emergency lighting to assist egress and survival independently of passenger compartment lighting.

4.3 Flight Deck Lighting

4.3.1 General

(a) To ensure adequate illumination of all instruments, switches, controls, etc., and of the panels to which these items are fitted, the following types of lighting are used:

(i) Integral lighting, in which the light source is contained within the instrument.

(ii) Pillar and bridge lighting, in which a number of lights are positioned on an instrument panel to illuminate small adjacent areas, and to provide the dial lighting of individual instruments.

(iii) Trans-illuminated panels, which are used to allow engraved marks on various controls, notices and instructions to be read under night conditions.

(iv) Flood-lighting, whereby lamps are positioned around the flight deck so as to illuminate an entire instrument panel or general area.

(v) Electro-luminescent lighting for control-position indicators and passenger information signs.

(b) The choice of colour for the lighting of aircraft flight decks has been the subject of many tests and studies, and as far as the contribution to the safe and efficient operation of aircraft at night is concerned the choice has been between red and white. Red lighting was introduced during the second world war, was subsequently carried over to civil aviation, and for some time was universally adopted as the principal lighting scheme, supplemented by a certain amount of white lighting. However, from continued tests and studies of the comparative merits of red and white lighting, it was generally concluded that at the brightness levels adopted, the advantages of white light were very significant.

(c) White light is superior to red for several reasons which can be listed as follows:

(i) The amount of electrical power required is reduced since red filters, which absorb about 80% of the light, are eliminated.

(ii) Heat dissipation problems are reduced.

(iii) White lighting permits colour coding of displays, use of red warning flags and other similar indications.

(iv) Contrasts between instrument displays and readability are improved.

(v) Eye fatigue is reduced.

(vi) Better illumination is provided in thunderstorm conditions.

(d) There are a few disadvantages, of course, but they are so outweighed by the advantages that white lighting has become standard for instrument and panel lighting and is used in many aircraft currently in service.

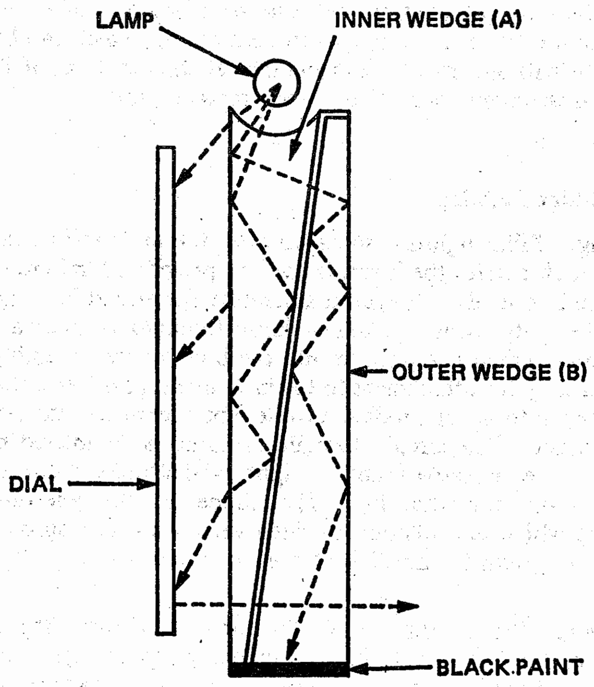


Figure 4 WEDGE-TYPE LIGHTING

4.3.2 Integral Lighting

(a) A common form of integral lighting for instruments is that known as 'wedge' or 'front' lighting; a form deriving its name from the shape of the two wedge shaped portions of glass which together make up the instrument cover. This type of lighting relies for its operation upon the physical law that the angle at which light leaves a reflecting surface equals the angle at which it strikes that surface. The two wedges, which have polished surfaces, are mounted opposite to each other with a narrow air space separating them, as illustrated in Figure 4. Light is introduced into inner wedge (A) from lamps set into recesses in its wide end. A certain amount of light passes directly through the wedge and on to the face of the dial while the remainder is reflected back into the wedge from the polished surfaces. The angle at which the light rays strike the wedge surfaces governs the amount of light reflected back; the lower the angle, the more the light is reflected back.

(b) The double wedge mechanically changes the angle at which the light rays strike one of the reflecting surfaces of each wedge, so distributing the light evenly across the dial and also limiting the amount of light given off by the dial face. Since the source of light is a radial one, the initial angle of some light rays with respect to the polished surfaces of inner wedge (A) is less than that of others. The initially low angle light rays progress further down the wedge before they leave and spread light across the entire dial. Light escaping into outer wedge (B) is confronted with constantly decreasing angles, and this has the effect of trapping light within the wedge and directing it to its wide end. Absorption of light reflected into the wide end of outer wedge (B) is ensured by painting its outer part black.

(c) A further form of integral lighting has 'festoons' of micro-miniature lamps mounted in clusters around the inside of the instrument casing, which can have a significant lamp mortality without unduly reducing the satisfactory level of illumination and the need for instrument removal for lamp replacement.

4.3.3 Pillar and Bridge Lighting

(a) **Pillar Lighting.** Pillar lighting, so called after the method of construction of the attachment which carries the lamp, is used to provide illumination for individual instruments and controls. A typical assembly, illustrated in Figure 5(a), consists of a miniature centre contact filament lamp (commonly known as a pea lamp) inside a housing, which is a push fit into the body of the assembly. The body is threaded externally for attachment to the instrument panel and has a hole running through its length to accommodate a cable which connects the positive supply to the centre contact. The circuit through the lamp is completed by a ground tag connected to the negative cable. Light is distributed through a filter and an aperture in the lamp housing. The shape of the aperture distributes a sector of light which extends downwards over an arc of approximately 90° to a depth slightly less than 50 mm (2 in) from the mounting point.

(b) **Bridge Lighting.** Bridge lighting, as illustrated in Figure 5(b), is a multi-lamp development of the individual pillar lamp described in (a). Two or four lamp housings are fitted to a bridge structure designed to fit over a variety of standardised instrument cases. The bridge fitting is made up of two light alloy pressings fixed together by rivets and spacers, and carrying the requisite number of centre contact assemblies above which the lamp housings are mounted.

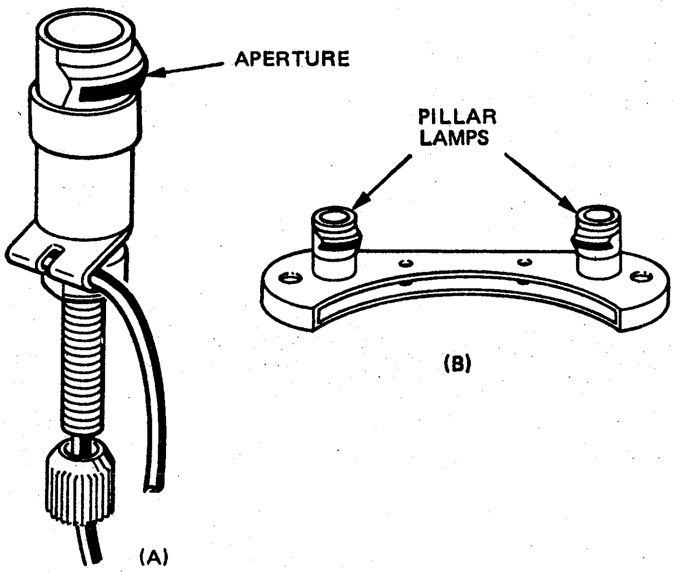


Figure 5 PILLAR AND BRIDGE LIGHTING

4.3.4 **Trans-illuminated Panels**

(a) Trans-illuminated panels are designed to suit the relevant metal panel on which instruments or controls are mounted and are formed from clear sheet acrylic plastics, faced on the upper and lower surfaces by a thin sheet of translucent white plastics and faced again by a sheet of black or grey plastics. The layers are then bonded together to form the panel (see Figure 6). Where necessary, numerals and inscriptions are then engraved through the outer layer to the white layer. Where components are required to be illuminated, facets are cut and angled in the surface surrounding the component. The light, transmitted by the panel clear core, originates at lamps suitably positioned in the panel. Direct emission of light is prevented by caps fitted to the lamp holders. The overall effect is to provide a clear white engraving legible during the day and illuminated by light conducted through the panel during darkness.

(b) Illumination for standard trans-illuminated panels is provided by lampholders mounted on the metal panel back plate, with the trans-illuminated panel being held in position by rubber skirted lamp caps which screw into the lamp holders.

(c) Printed circuit trans-illuminated panels use a double-faced copper laminate applied to the rear of the layered plastics panel, the lamp holders being a part of the plastics panel. Power supplies to the circuit board are introduced by a captive connector fixing screw which locates in a connector mounted on the metal panel back plate. The trans-illuminated panels are held in position by the captive connector fixing screw and captive fixing screws.

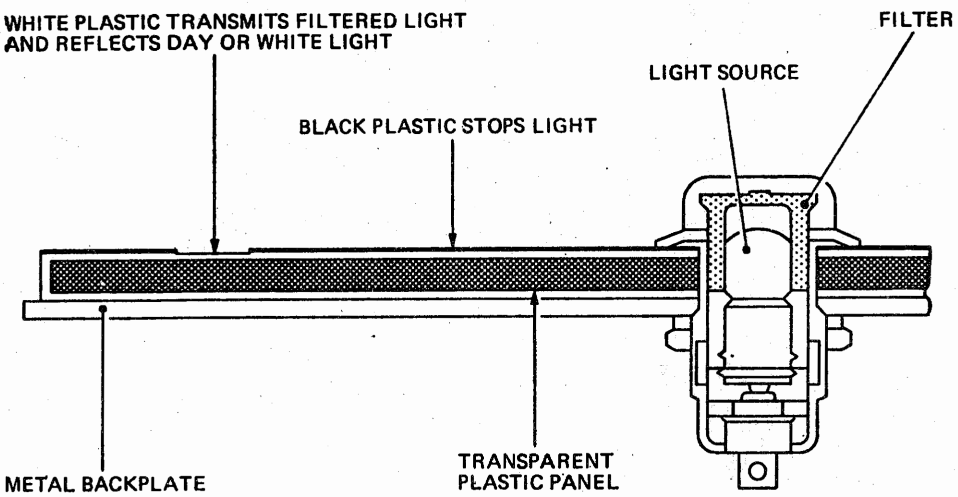


Figure 6 TRANS-ILLUMINATED PANEL

4.3.5 **Flood-lighting.** Flood-lighting is normally used for the general illumination of instruments, control panels, pedestals, side consoles and areas of the flight deck flooring. The lights usually take the form of incandescent lamp or fluorescent tube units, and, depending on the size and type of aircraft, both forms may be used in combination.

4.3.6 **Electro-Luminescent Lighting**

(a) Electro-luminescent lighting is employed in a number of aircraft for the illumination of passenger information signs and may also be used for the illumination of instrument dials and selective position marking of control valves and switches.

(b) An electro-luminescent light consists of a thin laminate structure in which a layer of phosphor is sandwiched between two electrodes, one of which is transparent. The lighting requires an a.c. power supply for its operation, and when this is applied to the electrodes the phosphor particles become luminescent, that is to say, visible light is emitted through the transparent electrode. The luminescent intensity is proportional to the voltage and frequency of the a.c. supply.

(c) The area of the phosphor layer which becomes luminescent when the power supply is applied is that actually sandwiched between the electrodes; consequently, if the back, non-transparent electrode is so shaped as to form a letter or figure, the pattern of the emitted light through the transparent electrode will be an image of that back electrode.

4.4 Central Warning System

4.4.1 A central warning system is an automatic signalling system which provides an 'attention getting' display in response to fault signals from specified systems. Urgency of crew action is normally indicated by the colour of the display, and/or audio tone, indicators for "Alert" signals (those demanding instant action) generally being coloured red, and "Caution" signals (those requiring less urgent action) being coloured amber.

4.4.2 Origination of a fault signal will cause flashing of the relevant alert or caution lamps mounted on the main instrument panels, illumination of the relevant inscription of the display unit and, in certain cases, lighting of warning lamps incorporated in, or adjacent to, control levers. Complete identification of the indicated fault will generally necessitate reference to warning indicators and instruments associated with the system at fault, as more than one fault condition can usually cause illumination of any one display unit inscription. Response to alert warnings should, however, normally be instinctive and should generally result in cessation of operation of the fault source.

4.4.3 Display signals other than major failure warning lamps, can usually be cancelled by operating a cancel switch. Integral self-test equipment is normally provided for in-flight testing of the system and may also provide an altitude inhibit control system which extinguishes and inhibits certain centralised warning captions during automatic landings, approach, and go-round procedures.

4.4.4 In addition some central warning systems are also equipped with advisory lights, normally coloured blue, that advise when a system which is operated intermittently has been activated.

4.5 Passenger Compartment Lighting

4.5.1 The extent to which lighting is used in a passenger compartment is dependent to some extent upon the size, but largely on the decor used for that aircraft, and can vary from a small number of roof mounted incandescent lamp fittings to a large number of fluorescent fittings located in the ceiling and hat racks so as to combine concealed, pleasing, and functional lighting effects.

4.5.2 Each fluorescent tube fitting requires a ballast unit to provide the momentary high voltage which enables the tube to strike and become fully illuminating. In all commercial passenger transport aircraft the lights are controlled from panels at the cabin attendants' stations.

4.5.3 In addition to the passenger compartment general lighting, lights are also provided at passenger service units and for the illumination of essential passenger information signs, such as "Fasten Seat Belts/No Smoking" and "Return to Cabin". The lights for these signs may be of the incandescent type or, as in a number of aircraft types, of the electro-luminescent type described in paragraph 4.3.6. Lights for signs conveying essential passenger information are usually controlled from the flight deck.

4.6 Cargo and Baggage Compartment Lighting

4.6.1 Dome lights are evenly distributed throughout the cargo and baggage compartments to provide the basic illumination for the handling of cargo and baggage. Lights located adjacent to the doors also provide the lighting for the entry areas.

4.6.2 Each dome light is usually provided with a protective guard both to prevent damage to the unit during cargo handling and to minimise the risk of fire by preventing the cargo or baggage from coming into direct contact with a hot lens unit.

4.7 **Internal Emergency Lighting**

4.7.1 It is essential that adequate illumination of the flight deck, and the various sections of the passenger compartment containing exits, escape hatches, chutes, etc., which must be deployed under emergency conditions, is maintained following failure or disconnection of the normal lighting systems. The lighting intensity is normally acceptable at a lower level than that provided by the standard lighting systems, since the lighting is strictly for the purpose of evacuation of the aircraft. Such lighting is normally of the white incandescent type receiving electrical power supplies as described in paragraph 4.1(c), while self-illuminating lights, as described in paragraph 4.8, are often used for emergency exit signs and hatch release handles.

4.7.2 In some aircraft the lighting is connected directly to an emergency battery (generally of the nickel-cadmium type, but sometimes of the silver-zinc type) which, under normal operating conditions of the aircraft, is maintained in a fully-charged state by a trickle charge from the aircraft main busbar system. Primary control of the emergency lights is in some aircraft by means of a control switch located on the flight deck, but in others a secondary control by means of acceleration sensitive ('g') switches is also employed for their automatic operation.

4.8 **Self-illuminating Signs.** Self-illuminating signs are entirely self-powered and require no period of daylight exposure to operate. Their brightness is such that they are instantly seen in dark areas by persons that are not dark-adapted, and present no direct radiation hazard.

4.8.1 Self-powered lights consist of a small sealed glass envelope internally coated with a layer of phosphor and containing tritium gas. Tritium is an isotope of hydrogen and emits beta-particles (electrons) of low energy which, on striking the layer of phosphor powder, cause it to emit visible light, the colour of the emitted light being controlled by the selection of the phosphor coating. Placing the light element behind a suitable silk-screened diffusing panel provides a ready means of conveying instructions or notices in darkened areas.

5 MAINTENANCE PRACTICES

5.1 **General.** Most light units and components can be maintained without the use of special tools. However, when special equipment or procedures are required to remove or install a light or component, detailed instructions will be found in the relevant aircraft Maintenance Manual. When defective filaments, lights or components are replaced, identical parts should always be used unless substitutes have been authorised. Identification details of the recommended filament and the acceptable substitutes are usually found in the relevant aircraft Maintenance Manuals. Particular attention should be paid to these manuals when maintenance is carried out on retractable landing or taxying lamps, so ensuring that the correct angular settings have been maintained. A spare filament storage area is often located within the flight deck for in-flight use. Operational check procedures for the lighting systems will be detailed in the relevant aircraft Maintenance Manual, to which reference should be made, and the information given in the following paragraphs thus serves only as a general guide.

5.2 **Checking of Lighting Components**

5.2.1 At the specified inspection periods, or whenever the serviceability of a light or lighting system is suspect, the checks (a) to (d) should be carried out:

(a) Check the component for proper installation, security of mounting, physical damage, and any evidence of overheating.

(b) Check that terminal connections are secure and free from foreign matter, moisture and corrosion.

(c) Check bonding connections for proper electrical contact and security, in accordance with Leaflet **EEL/1-6**.

(d) Check wiring for physical damage such as chafing, fraying, damaged insulation, or contamination by harmful fluids such as hydraulic fluids, etc.

5.3 **Removal and Installation of Lighting Components.** Should it be necessary to remove a component of a lighting system, either as a result of a check or for the purpose of bench testing, and should special tools or equipment be required, full details will normally be found in the relevant aircraft Maintenance Manual. In the absence of such information it is recommended that the procedure of 5.3.1 and 5.3.2 be adopted.

5.3.1 **Removal**

(a) Trip the applicable circuit breaker, or remove the appropriate fuse, to ensure electrical safety.

(b) Gain access to the component.

(c) Disengage from or remove the attachment parts.

NOTE: Attachment parts are sometimes removed after disconnecting electrical connections or wiring terminals.

(d) Disconnect electrical connections or wiring terminals from the component.

(e) Install dust covers on plugs and receptacles, and install identification tags and insulating boots on wiring terminals.

(f) Remove the component.

5.3.2 **Installation**

(a) Ensure that the appropriate fuse or circuit breaker is still electrically safe.

(b) Connect electrical connections or wiring terminals to component.

NOTE: Connection of electrical connections or wiring terminals is sometimes accomplished after installation of the component.

(c) Position the component on its mounting and install attachment parts.

(d) Install or secure parts that have been removed to gain access to the component.

(e) Carry out check (by operating the appropriate switch, after re-setting of the circuit breaker or replacement of the fuse) for correct electrical operation of the circuit.

5.4 **Filament Replacement.** Replacement filaments should be restricted to those recommended by the aircraft manufacturer, so as to ensure the satisfactory operation of the light and to prevent damage to the circuit and circuit components.

5.4.1 **Fluorescent Lighting.** Fluorescent lighting has three general removal/replacement methods which cover the main types of light units in use. The first method is used when a fluorescent tube is retained at each end by a butt-on type tube holder which has a movable centre tab. The second method is used when the tube is retained by a spring-loaded tube holder at one end and a stationary tube holder at the other end. The third method is used when the tube is rotated or turned in the tube holder for removal and installation. With all methods, precautions are necessary to avoid damage to the tube, tube holder, and the associated ballast unit by subsequently overheating.

(a) Butt-on type tube holders have a movable centre tube which retains the tube base pins against spring contacts. When the top of the centre tab is pressed outwards, the pins can be removed from the tube holders (see Figure 7). The tube should not be rotated as this may cause damage to the pins, tube holders, and, subsequently, the ballast unit. To replace the tube, firstly check that the spring contacts are in position and then press the pins at each end of the tube into the tube holders until they are secure in the contact detents.

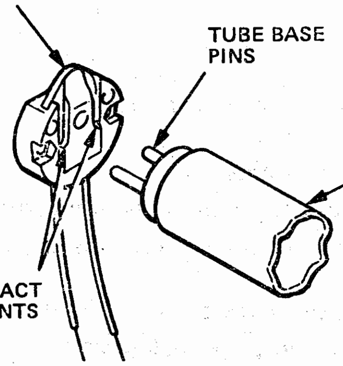


Figure 7 BUTT-ON TYPE TUBE HOLDER

(b) To withdraw the tube from a spring-loaded tube holder opposing a stationary tube holder, apply gentle pressure with the tube towards the spring-loaded tube holder until the tube base pins on the opposite end of the tube are released from the stationary tube holder, and can be withdrawn. The tube should not be rotated during this operation, or damage may result in the same way as for the butt-on type of tube holder. To replace the tube, position the base pins in the spring-loaded tube holder (ensuring that it is not rotated) and gently apply pressure toward the spring-loaded tube holder with the tube until the pins on the opposite end of the tube can be inserted into the stationary tube holder (see Figure 8).

(c) To withdraw the tube from a rotation-type tube holder, carefully rotate the tube (in either direction) until the tube base pins release from the contact detents in both tube holders, and remove the tube. To replace the tube, place the tube base pins in the tube holders and carefully rotate the tube (in either direction) until the pins engage with the contact detents.

(d) When a fluorescent light ballast unit has been replaced following a failure, it is recommended that the contacts in the tube holders be checked and that the tube or tubes be replaced, so as to avoid the possibility of faulty contacts or faulty tubes causing a further failure of the ballast unit as a result of overheating.

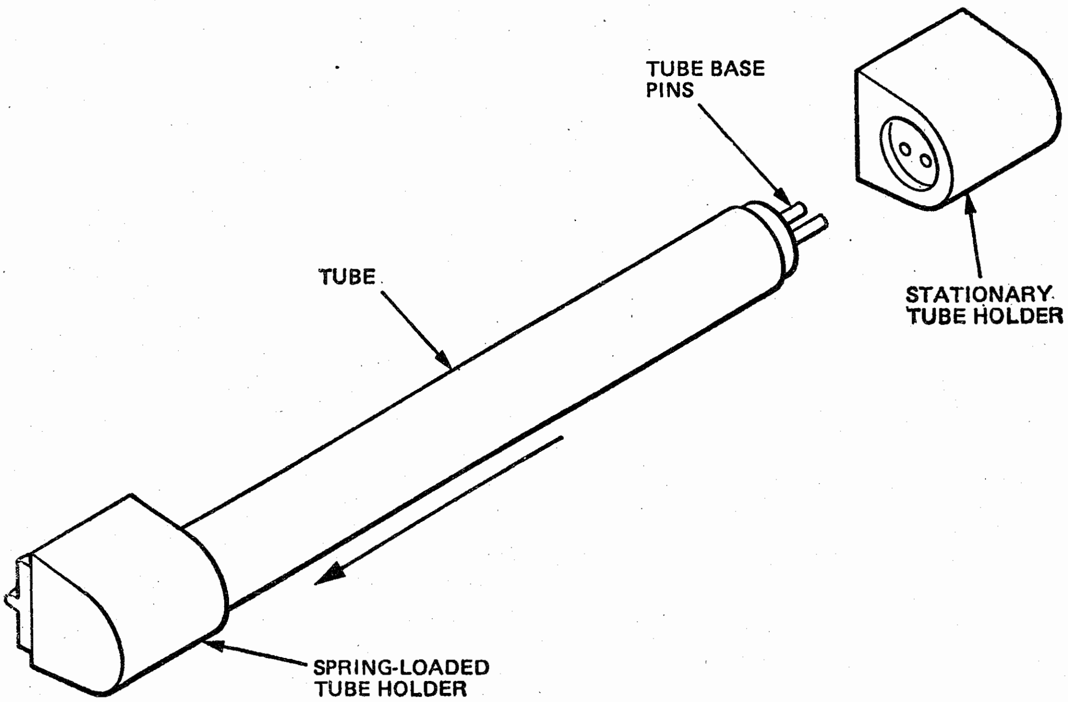


Figure 8 SPRING-LOADED TUBE HOLDER

5.5 **Strobe Lighting.** Strobe high intensity lighting can be dangerous to servicing personnel, as the energy storage capacitors are charged to voltages which can be lethal. Accordingly, a minimum of two minutes should be allowed for the capacitors to discharge after the circuit has been de-energised. In addition, it should be borne in mind that damage to the eyes may result from looking directly into high intensity light.

5.6 **Plastics Fittings and Fixtures.** Plastics fittings and fixtures are used extensively in aircraft lighting systems and also in the interior trim, therefore, extreme care should be taken when handling such parts. Where possible, the use of tools should be kept to a minimum, and only gentle hand pressures should be applied when removing plastics-based trim panels, light lenses and lens covers.

5.7 **Self-illuminating Signs.** The only possible hazard attendant upon the use of such signs is that due to inhalation or absorption into the body of gas released in the event of breakage of the glass envelope. Tritium gas is mildly radioactive, therefore, the signs should be handled carefully to avoid breakage. Should breakage occur, the aircraft should be evacuated and all doors left open to allow maximum ventilation. Disposal of broken signs are subject to the Radioactive Substances Act 1960 and the Radioactive Substances (Luminous Articles) Exemption Order 1962 and should, therefore, be returned to the manufacturer for disposal. All self-illuminating signs should be checked for luminosity level on initial fitting and at periods specified in the relevant maintenance schedule. Such signs usually have a scrap life of 5 years and should then be returned to the manufacturer for disposal.

EEL/2-1

Issue 1.

December, 1979.

AIRCRAFT

ELECTRICAL EQUIPMENT

CHARGING ROOMS FOR AIRCRAFT BATTERIES

1 INTRODUCTION This Leaflet gives guidance on the setting-up and operation of rooms equipped for the purpose of charging aircraft batteries.

1.1 Mandatory provisions for the setting-up and operation of battery charging rooms are contained within the Factories Act.

1.2 The following Leaflets contain information associated with the subject covered by this Leaflet, and reference should be made to these, as appropriate.

BL/1-7 Storage Conditions for Aeronautical Supplies

EEL/1-1 Batteries—Lead-acid

EEL/1-3 Batteries—Nickel-cadmium

2 BUILDING AND EQUIPMENT

2.1 **General**

2.1.1 In no circumstance should the same facility be used for both nickel-cadmium and lead-acid battery charging; and the ventilation arrangements shall be such that no cross contamination can occur.

2.1.2 Buildings and rooms used for the purpose of charging batteries should be well lit and cool, and should have a ventilation system which is capable of exhausting all the gases and fumes which may be present during the servicing and charging operations. The floor surface should be of a material which is impervious to acid and alkali, has non-slip qualities and is quick drying and able to be washed down easily. Examples of such materials are dustless concrete, bituminous compound or tiling. Adequate and suitable drainage should be provided for washing down purposes. Because of the fire risk, it is strongly recommended that doors should be fitted so that they open outwards, thus facilitating easy evacuation from the building in the event of fire. To permit free and easy movement of batteries, steps and thresholds should, where possible, be eliminated. If, however, different levels are unavoidable they should be linked by inclines.

2.2 **Water Supply.** At least one tap in each room where battery charging is carried out should be connected to a mains fresh water supply. Sinks and draining boards and a hot water supply should also be provided.

2.3 **Lighting.** The level of lighting within the charging rooms should be sufficient to enable the level of the electrolyte in individual cells of batteries to be easily determined without additional lighting. To prevent accidental ignition of gases all electrical fittings should be of a sparkproof design.

2.4 **Ventilation.** Hydrogen is given off at all stages of lead-acid battery servicing; the highest concentration being at the end of the charging cycle. Hydrogen is also produced when nickel-cadmium batteries reach the fully charged state; i.e. at the 'overcharge' point and for a 24 hour period thereafter. Heavy corrosive fumes are also emitted when mixing of electrolytes takes place. Therefore, a ventilation system is required which is capable of extracting all gases and fumes, whether heavier or lighter than air.

2.5 **Temperatures**

2.5.1 **Electrolyte Temperature.** The maximum permissible electrolyte temperature during charging is normally 50°C (122°F), but some batteries of special design, however, have lower limits; for such batteries the temperature limitations will be specified in the manufacturer's publication for that battery.

2.5.2 **Environmental Temperature.** Environmental temperatures exceeding 27°C (81°F) for lead-acid batteries and 21°C (70°F) for nickel-cadmium batteries impose time penalties in reaching the fully charged state and may also be deleterious to the batteries. The temperature of battery charging rooms should, therefore, be maintained at a temperature consistent with specified limitations, and with a free air flow around each battery or cell.

3 CHARGING BOARDS AND BENCHES

3.1 Detailed differences exist between the various types of charging board, but in general each board consists of a pair of terminals, to which the rectified a.c. supply is connected (or in the case of a board which has a built-in rectifier unit, to which the mains supply is connected), together with a number of pairs of output terminals, to which the batteries are connected for charging.

3.2 All the output circuits are internally connected in parallel, and are, therefore, independent of each other, with the level of charge being controlled separately for each output circuit. Each pair of output terminals is normally designed to have one group of batteries or cells connected in series.

NOTE: Parallel connection of batteries to one pair of output terminals is not permitted.

3.3 Charging boards should be mounted directly above the rear of the benches so that the necessity for long connecting cables is avoided.

3.4 Battery connecting cables should be well insulated and should be of a sufficient capacity to carry the charging current required. The free ends of connecting cables should be fitted with suitable connectors, which should be firmly secured to the battery and charging board before commencing charging operations. Connections to the charging boards should not be made or broken when power is switched on. On completion of the charging cycle, power should be switched off and the charging cables should be disconnected, first from the battery and then from the charging board.

3.5 Benches

3.5.1 Benches and associated equipment should be sited so that the need for personnel to lean over batteries is kept to a minimum. It is recommended that the height of battery charging benches be approximately 0·5 m (20 in) from the floor. At this height, lifting strain is minimised, and a more effective visual inspection of the batteries can be made.

3.5.2 The surfaces of battery charging benches should be acid and alkali resistive, and should facilitate cleaning. It is generally considered that batteries should not be allowed to stand directly on wood or concrete, but should rest on suitable grids.

4 POWER SUPPLIES

4.1 Transformer/rectifiers which normally provide rectified a.c. for charging board supplies should be sited in a fume free, dry and cool position, preferably in a separate room, located as near as possible to the charging boards. Charging boards which require 240 volts mains supply, should be supplied from a ring main system.

5 STORAGE

5.1 **Batteries.** In order to preserve an orderly flow of work through a battery charging room, storage facilities should be provided such that incoming unserviceable batteries may be separated from those ready for issue, preferably in clearly placarded areas. The storage facilities should be further grouped for those batteries requiring initial charge and those awaiting routine servicing. Batteries which are serviceable and awaiting issue are best stored in an area which is not subjected to excessive vibration. It is essential that whilst in store, lead-acid batteries be segregated at all times from nickel-cadmium batteries; preferably in separate store rooms. For further information on the long term storage of batteries, reference should be made to Leaflets **BL/1-7, EEL/1-1** and **EEL/1-3.**

5.2 Electrolytes

5.2.1 The handling and storage of electrolyte materials should always be in accordance with the manufacturer's instructions. It is, however, essential that when undertaking the mixing or breaking down of these chemicals, separate areas are provided. Glass, earthenware or lead-lined wood containers are suitable for the storage of lead-acid battery electrolyte (sulphuric acid), whilst plain iron, glass or earthenware containers are suitable for the storage of nickel-cadmium battery electrolyte (potassium hydroxide). Galvanised containers or containers with soldered seams must not be used. Each container should be clearly marked as to its contents and should be stored accordingly. Waste or surplus materials should be disposed of in accordance with locally approved instructions. If, however, doubt exists, all electrolytes should be neutralised prior to disposal (paragraph 5.4). All mixing vessels, mixing rods and other similar items should be clearly marked with "acid only" or "alkaline only", and their use should be restricted accordingly.

5.2.2 Stocks of electrolyte materials which are retained in a battery charging room should be restricted to the quantities required for immediate use. The storing of electrolytes mixed ready for use should be avoided as far as possible.

(a) Sulphuric acid containers should be kept tightly sealed when not in use, to prevent contamination. Only the container which is required for immediate use should be retained in the charging room.

(b) Potassium hydroxide is supplied in solid form contained in steel drums. Once a drum has been opened the contents are liable to carbon dioxide contamination. The entire contents should, therefore, always be mixed as soon as a drum has been opened. Any unused mixture should be stored in a stoppered glass container.

5.3 De-mineralised and distilled water are generally supplied in carboys, and should be stored separately from the electrolytes, so as to avoid contamination. Carboys should be firmly stoppered when not in use, and should be clearly marked as to the contents. Only the water container used for 'topping up' should be kept in the charging room, and the stopper should be refitted immediately after use.

5.4 The neutralising agents for the two types of electrolytes are given below, together with the action that should be taken in the event of contamination and/or spillage.

5.4.1 **Sulphuric Acid.** The neutralising agents are:—

(a) Saturated solution of bicarbonate of soda.

(b) Ammonia powder.

(c) Borax powder.

The acid should be soaked up with sawdust which should then be removed and buried. The affected area should be treated with one of the above, followed by washing down with copious amounts of fresh water.

5.4.2 **Potassium Hydroxide.** The neutralising agents are:—

(a) Boric acid solution.

(b) Boric acid crystals or powder.

The alkali should be soaked up with sawdust, which should then be removed and buried. The affected area should be treated with one of the above, followed by washing down with copious amounts of fresh water.

5.4.3 Containers of sawdust and neutralising agents should be clearly marked with their contents and use, and sited in readily accessible positions.

6 PROTECTION

6.1 To prevent the risk of burns, such personal items as rings, metal watches, watch-straps and identification bracelets should be removed, to avoid contact with connecting links and terminals. Personal protection against the harmful effects of acid and alkali contamination should be in accordance with the provisions of the Factories Act.

6.2 In general, smoking should only be permitted in rooms which do not have a direct access to battery charging rooms or chemical mixing areas. Naked lights, non-safety matches and automatic lighters should not be taken into battery charging rooms.

6.3 Fire extinguishers of the CO_2 type and buckets of sand should be placed at strategic points inside the building for use in the event of any chemical fires.

7 DOCUMENTATION

7.1 Records of battery servicing should be maintained to the standard recommended by Leaflets **EEL/1-1** for lead-acid batteries and **EEL/1-3** for nickel-cadmium batteries.

8 SERVICING AND TEST EQUIPMENT

8.1 Servicing of aircraft batteries should be carried out in accordance with the instructions contained in the manufacturers' Maintenance Manual.

8.2 In addition to the general engineering hand tools which may be required for aircraft battery servicing, the following specialised items will also be required:—

(a) Hydrometers.

(b) Thermometers.

(c) Battery kits (as supplied by battery manufacturers).

(d) Capacity test sets.

(e) Leakage tester (lead-acid batteries).

(f) Filler pumps (for transferring of liquids from one container to another).

(g) Calibrated test equipment:

(i) Insulation resistance tester.

(ii) Universal test meter.

(iii) Digital voltmeter.

8.2.1 To prevent cross-contamination between the two types of aircraft batteries, two sets of equipment should be held, each being contained in separate cupboards and clearly marked "acid only" or "alkaline only" as appropriate to the application. Wherever possible, tools and equipment comprising the sets should be those constructed of an insulating material. Each item should be identified as to its application, and in the case of hydrometers and thermometers, this is usually best done on the instrument case.

EEL/3-1

Issue 3.

June, 1981.

AIRCRAFT

ELECTRICAL EQUIPMENT

CABLES—INSTALLATION AND MAINTENANCE

1 INTRODUCTION This Leaflet gives guidance on the installation of the various types of electrical cables used for the wiring of general services in aircraft, and their attachment to various forms of terminations, but does not include information on the types of cables designed for specific functions, e.g. high voltage ignition supplies or radio-frequency services. The CAA requirements for electrical installations in aircraft are prescribed in Section J of British Civil Airworthiness Requirements, the relevant parts of which should be read in conjunction with this Leaflet.

1.1 To maintain general environmental suitability, only the types of cables specified by the aircraft or equipment manufacturer, or approved equivalents, should be used. This will ensure that the cables will be suitable for the voltages which will be applied to them under the conditions of operation and test, and that the current ratings will be such that when the cables are installed and carrying the most onerous loads in the most adverse ambient temperatures probable, the temperatures attained by the conductor will not cause damage to the cables.

NOTE: British Standard G212 gives general requirements for aircraft electrical cables.

1.2 The following Leaflets contain information associated with the subject covered by this Leaflet, and reference should be made to them as appropriate:

BL/6-1 Soft Soldering
BL/6-2 Brazing
EEL/1-6 Bonding and Circuit Testing
AL/3-7 Control Systems

1.3 To obviate the need for the revision of this Leaflet when new issues of the specifications referred to are published, the prefix or suffix indicating the issue number of the specification has been omitted.

2 CABLE IDENTIFICATION Aircraft electrical cables are normally marked with an identification code as shown in the following examples:

(a) **Period 1963 to Mid 1970s:**

Nyvin 22 - B B

- B — Year of Manufacture Code Letter
- B — Manufacturer's Code Letter
- 22 — Cable Size
- Nyvin — Cable Type Name

(b) **Period Mid 1970s to 31st December 1978:**

Minyvin G XX X 22

- 22 — Cable Size
- X — Year of Manufacture Code Letter
- XX — Manufacturer's Code Letter
- G — Country of Origin
- Minyvin — Cable Type Name

(c) With effect from 1st January 1979 the country of origin code for Great Britain was changed from G to GBx, although the rest of the code remained unchanged.

2.1 There is a further requirement that an adequate means of identification be provided for cables, connectors, terminals, plugs and sockets, etc., when installed in the aircraft, and methods of so doing for cables are described in paragraph 9.

3 DETERIORATION Aircraft cables are designed to provide the best possible combination of resistance to deterioration caused by extremes of temperature, mechanical damage and contamination by fluids, and in general, are suitable for installation without additional mechanical protection. Working conditions and environment, however, may necessitate the provision of extra protection in those places where the cables are exposed to the possibilities of local damage or conditions which could cause deterioration, and protection is described in paragraph 7.3.

4 RECEIPT AND STORAGE OF CABLES Prior to delivery, cable ends are sealed, so far as is practicable, to prevent ingress of moisture, and the cables are generally supplied on drums suitably labelled and protected to prevent damage during transit or storage. Smaller sizes of cable may sometimes be supplied in wrapped coils. Visual examination of cables on receipt, by nature of the packing, is often restricted to the outer turns. Such an examination is of little value in checking for faults in the cable, therefore, if the condition of the packing, as received, gives rise to doubt regarding the soundness of the cable, it should be returned to the manufacturer.

4.1 Cables should be stored in a clean, well-ventilated store. They should not be stored near chemicals, solvents or oils and, if necessary, protection should be provided against accidental damage. Loose coils, whether wrapped or not, must not be stored so that a heavy weight is imposed on them, since this may cause unacceptable distortion of the insulation or damage to the protective coverings. The ends of cables in store should be sealed against the ingress of moisture by the use of waterproof tape or a suitable sealing compound.

5 HANDLING OF CABLES It is important that cables should be handled carefully at all stages of storage and installation.

5.1 When taking long lengths of cable from a drum or reel, the cable should not be allowed to come in contact with rough or dirty surfaces. Preferably the drum or reel should be mounted so that it can rotate freely, but heavy drums may need some means of control over rotation.

5.2 Care should be taken to remove the twist out of each turn of cables drawn from loose coils, otherwise severe kinking, with consequent damage to the cable, may occur.

6 MADE-UP CABLING Cable looms and cable runs made-up on the bench should be inspected before installation in the aircraft to check the following:

(a) That all cables, fittings, etc., are of the correct type, have been obtained from an approved source, have been satisfactorily tested before making up and have not deteriorated in storage or been damaged in handling.

(b) That all connectors and cable looms conform to the relevant aircraft Maintenance Manual, Wiring Diagram Manual or Modification Drawing in respect of terminations, length, angle of outlets and orientation of contact assemblies, identification, and protection of connections.

(c) That all crimped joints (see paragraph 7.5.7) and soldered joints (see paragraph 7.5.8) have been made in accordance with the relevant aircraft Maintenance Manual, Wiring Diagram Manual or Modification Drawing, are clean and sound, and that insulating materials have not been damaged in any way.

(d) That cable loom binding and strapping is secure.

(e) When required by the relevant aircraft Maintenance Manual, Wiring Diagram Manual or Modification Drawing continuity, resistance and insulation tests should be carried out in accordance with those instructions. For further details and guidance see Leaflet **EEL/1-6.**

7 INSTALLATION OF CABLING IN AIRCRAFT In addition to the checks outlined in paragraph 6, the cabling should be installed in accordance with the requirements of the relevant aircraft Maintenance Manual, Wiring Diagram Manual or Modification Drawing. Guidance on the factors requiring special attention during the installation is given in the following paragraphs.

7.1 **Contamination.** To prevent moisture from running along the cables and seeping into the associated equipment, the cables should be so routed as to run downwards away from the equipment. Where this is not possible, the cable should incorporate a descending loop immediately before the connection to the equipment. Where conduits, tubes or ducts are used, they should be installed in such a way that any moisture accumulating in them will be able to drain safely away. Cables which are routed through such fittings should be capable of withstanding any such moisture as may be encountered.

7.2 **Interference.** Interfering magnetic fields may be set up by electrical equipment, electrical currents in the cabling, or the aircraft structure, and also by magnetic materials. Cables are required, therefore, to be installed so as to reduce electrical interference to a minimum and to avoid interaction between the different electrical services.

NOTE: Requirements for the avoidance of compass and radio interference are given in Chapter **J4-1** of British Civil Airworthiness Requirements.

7.3 **Protection of Cabling.** The cables are required to be protected from abrasion, mechanical strain and excessive heat and against the deleterious effects of fuel, oil and other aircraft fluids, water in either liquid or vapour form and the weather. Cables should be spaced from the skin of the aircraft so as to reduce the effect of the high skin temperatures likely to be reached in the tropics. The cables should not be run near the hot parts of an engine or other hot components unless a cooled-air space or heat barrier is interposed.

NOTE: Where it is not possible to install apparatus in a position protected from the weather, the requirements of Section J of British Civil Airworthiness Requirements must be taken into consideration.

7.3.1 Cables must not be supported or allowed to bear on sharp edges such as screw heads or ends, or on the edges of panels, metal fittings, bulkheads or lightening holes.

7.3.2 Where cables are routed through metal fittings or bulkheads, etc., the edges of the holes through which they pass must be radiused and smoothed and fitted with an insulated bush or sleeve. Cables which are drawn through holes or tubes must be an easy fit requiring only a moderate, steady pull, care being taken to keep the cables parallel to one another and to avoid the formation of kinks (which may cause fracture of the conductor).

7.3.3 Conduits, ducts and trunking used for carrying cables should have smooth internal surfaces. Rigid ducts and conduits should be adequately flared at the outlet or bushed with insulating material.

7.3.4 Cables being fitted through pressure bungs should be fitted into the correct size holes for the size of cable, to ensure efficient sealing. Only the recommended cable threading tool should be used for this purpose to avoid damaging the bung membrane. Bungs without membranes should have filler plugs fitted in unwired holes.

7.4 **Support of Cabling.** The cabling must be adequately supported throughout its length, and a sufficient number of cable clamps must be provided for each run of cable to ensure that the unsupported lengths will not vibrate unduly, leading to fracture of the conductors or failure of the insulation or covering. Bends in cable groups or bundles should not be less than eight times the outside diameter of the cable group or bundle. However, at terminal blocks, where the cable is suitably supported at each end of the bend, a minimum radius of three times the outside diameter of the cable, or cable bundle, is normally acceptable.

7.4.1 Cables must be so fitted and clamped that no tension will be applied in any circumstances of flight, adjustment or maintenance, and so that loops or slackness will not occur in any position where the cables might be caught and strained by normal movement of persons or controls in the aircraft, or during normal flying, maintenance or adjustment.

7.4.2 Where it is necessary for cables to flex in normal use, e.g. connections to retractable landing gear, the amount and disposition of slack must be strictly controlled so that the cable is not stressed in the extended position, and that the slack will not be fouled, chafed, kinked or caught on any projection during movement in either direction.

7.4.3 Cables should normally be supported independently of, and with maximum practicable separation from, all fluid and gas carrying pipelines. To prevent contamination or saturation of the cables in the event of leakage, cables should be routed above rather than below liquid carrying pipelines. Cables should not be attached to, or allowed to rub against, pipelines containing flammable fluids or gases.

7.5 **Cable Terminations.** There are several methods by which cables are terminated, but the one most commonly used is the solderless or crimped termination. The soldered method is also used, but is generally confined to the joining of internal circuit connections of consumer equipment and in some cases, to the connection of single core cables and plug and socket contacts. The means of terminating cables and effecting junctions between cables and equipment must be in accordance with the requirements of the relevant aircraft Maintenance Manual, Wiring Diagram Manual or Modification Drawing. Therefore, the information given in the following paragraphs is of a general nature and is intended only as a guide.

7.5.1 **General Requirements.** The conductors should be firmly secured to the connections on the equipment, using the appropriate method for the particular installation. The surfaces of electrical contacts should be clean, and the mating parts should be in contact over the full area. The protective sleeves fitted over connections should be undamaged and positioned correctly. Holding screws and nuts should be properly locked where provision is made for this to be done; particular care should be taken where varnish is the locking medium as it must not be allowed to spread onto, or over, the electrical contact surfaces. Torque loading of holding screws or nuts should be to the recommended values and should be marked in accordance with the maintenance instructions. The connections should not place either the cable or the equipment in a state of tension. Twisting and kinking in the vicinity of the connection should be avoided, as this may lead to a fracture if the cable is subjected to vibration.

7.5.2 To facilitate installation, maintenance and repair, cable runs and looms are broken down at specified locations by junctions, such as connectors or terminal blocks. Before assembly to these junctions, cables should be cut to the required length, with the cut being clean and square, and the wire conductor not deformed. If necessary the conductors of large diameter cables should be re-shaped after cutting. Good cuts can only be made if the blades of cutting tools are sharp and free from nicks. A dull cutting edge will deform and extrude the conductor strands.

7.5.3 Before cables can be assembled to connectors, terminals, crimps, etc., the insulation must be cut back and stripped from the connecting ends to expose the wire conductors. Care should be taken when stripping cable that the conductor strands are not cut or nicked. If the lay of the wire conductor strands is disturbed, it should be re-imposed by a light twisting action. Excessive twisting should be avoided as this will increase the diameter of the cable and may result in a defective joint.

7.5.4 On small diameter cables, only the recommended stripping tools should be used for removing the insulation. On no account should a knife or side cutting pliers be used because of the high risk of damage to the conductor strands. For size 8 or larger diameter cables a knife may be used to make lengthwise cuts partially through the outer covering and insulation; these should then be bent back and cut off with side cutters or scissors. The stripped cable should be examined for signs of damage, severed strands and cleanliness, before it is connected up.

7.5.5 The following general precautions are recommended when stripping any type of cable:

(a) When using any type of cable stripper, hold the stripper so that the cutting blade is square to the cable.

(b) Follow the manufacturer's instructions when adjusting automatic stripping tools, to avoid damaging the conductor strands by cutting or nicking; this is especially important for aluminium cables and the smaller sizes of copper cables. Cut-off and re-strip (if length is sufficient), or reject and renew any cable which has been so damaged.

(c) Ensure that the outer covering and the insulation are clean cut, with no frayed or ragged edges.

(d) When using hand-operated strippers to remove lengths of insulation longer than 19 mm (0·75 in), the stripping should be accomplished in two or more operations.

(e) Re-twist conductor strands by hand, or with pliers, if necessary, to restore the natural lay and tightness of the conductor strands.

7.5.6 **Aluminium Cables.** The use of aluminium cables in aircraft has been brought about chiefly by the weight advantage of this metal over copper. However, in order to obtain satisfactory electrical connections, certain special installation techniques are necessary.

(a) Aluminium cables should be stripped very carefully, since individual conductor strands will break very easily after being nicked.

(b) Bending of aluminium cables will cause "work hardening" of the conductor strands, resulting in failure or breakage of strands much sooner than in cables with copper conductors.

(c) Aluminium, when exposed to the atmosphere, forms an oxide film which acts as an insulator. This film can, if left untreated, cause corrosion at connecting joints, and as it also increases in thickness as heat is generated by current flow, it will further increase the electrical resistance of that joint (see paragraph 7.5.7 (d)).

7.5.7 **Crimped Connections.** A crimped connection is one in which a cable conductor is secured by compression to a termination so that the metals of both are held together in close contact. A typical crimp termination has two principal sections, crimping barrel and tongue (see Figure 1), together with, in some types, a pre-insulated copper sleeve which mates with the crimping barrel at one end and is formed, during the crimping process, so as to grip the cable insulation at the other in order to give a measure of support. The barrel is designed to fit closely around the cable conductor so that after pressure has been applied a large number of points of contact are made. The pressure is applied with a hand or hydraulically operated tool fitted with a die or dies, shaped to give a particular cross-sectional form to the completed joint.

(a) The precise form of the crimp is determined by such factors as the size and construction of the conductor, the materials, and the dimensions of the termination. It is, therefore, most important that only the correct type of die and crimping tool should be used, and that the necessary calibration checks have been made to the tool.

NOTES: (1) British Standard G178 gives information regarding the production and testing of crimped joints for general purpose electrical cables. Reference should also be made to the appropriate manufacturer's technical literature on this subject.

(2) British Standard G180 gives information on the permanent splicing of aircraft electrical cables.

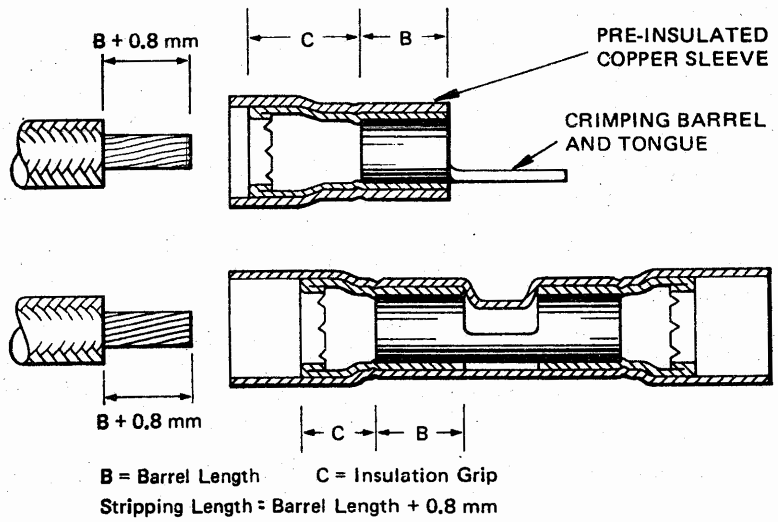


Figure 1 TYPICAL CRIMP TERMINATIONS

(b) Hand crimping tools (see Figure 2) normally have a self-locking ratchet which prevents opening of the tool until the crimping action is complete. Some tools are equipped with a nest of various size dies to allow for a range of different sizes and types of terminations, while others are suitable for one size and type only. In addition, many of the tools and/or dies are colour coded to correspond with the colour marking used on some terminations. It is essential that the recommendations and instructions of the relevant aircraft or equipment manufacturer should be strictly complied with when undertaking work of this nature.

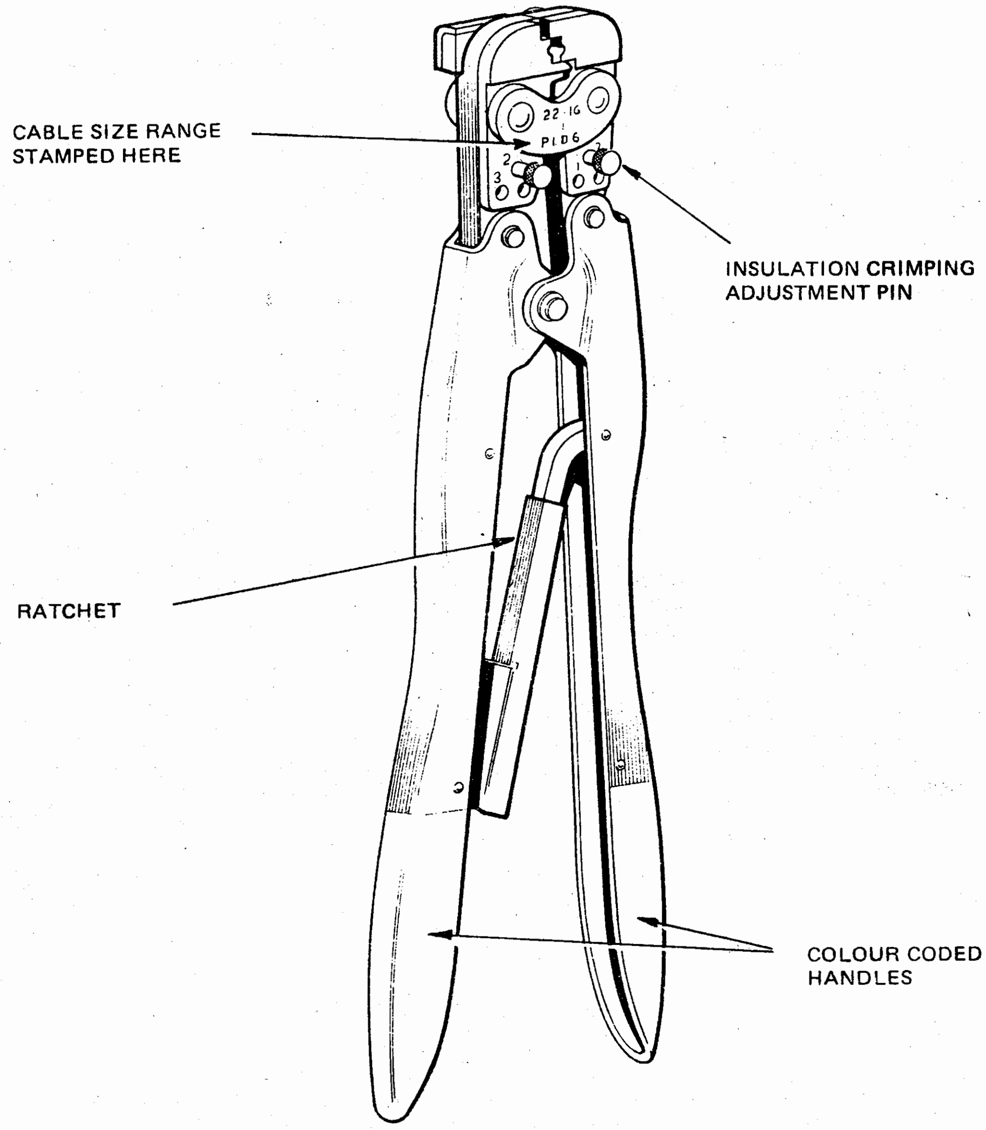


Figure 2 EXAMPLE OF A HAND OPERATED CRIMP TOOL

(c) There is a vast range of terminations available, many of which are colour coded, and suitable for use only with specific types of aircraft cable. It is, therefore, vital that the appropriate manufacturer's instructions regarding the use of cables and terminations are followed.

(d) Only aluminium or bimetal (AlCu) terminations should be used to terminate aluminium cables and the cable should be stripped immediately prior to making the joint. The barrel of some aluminium terminations may contain a quantity of inhibiting compound, others not so filled require that inhibiting compound be applied before crimping takes place. Some specifications also require additional sealing after crimping. The compound will also minimise later oxidation of the completed connection by excluding moisture and air.

(e) The following general precautions are recommended when making crimped cable joints:

(i) When initially inserting the appropriate termination tongue-first into the barrel crimping jaws of the crimping tool, ensure that the termination barrel butts flush against the tool stop (see Figure 3).

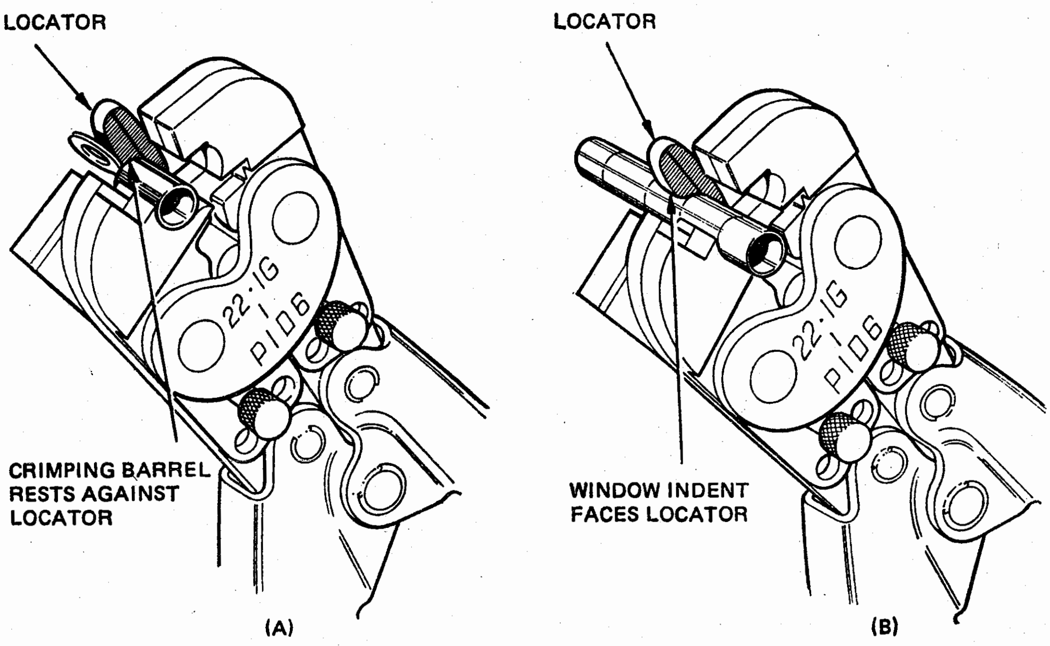


Figure 3 CORRECT LOCATION

(ii) When positioning the prepared cable end into the terminal barrel of an uninsulated termination, ensure that the cable dielectric butts flush against the end of the barrel, or for a pre-insulated termination to the top of the insulation support.

(iii) Ensure that the tool handles of a hand operated tool are squeezed fully together, or in the case of power operated tools, the pressure relief valve has operated, to ensure that the crimp has been completed and allow release of the jaws.

7.5.8 **Soldered Connections.** In general, aircraft installations are such that it should not be necessary to make soldered joints within the aircraft. If, however, soldering is required, it should be carried out strictly in accordance with the procedures in the relevant aircraft Maintenance Manual or Wiring Diagram Manual. Soft soldering and silver soldering are the two methods used for aircraft electrical cabling systems.

(a) **Soft Soldering.** Where electrical connections are made by the soft soldering method special care is necessary because over-heating and slow cooling of conductors or terminal fittings will cause brittleness. The connections to socket inserts, plug pins, etc., should be free from excess solder which may cause short-circuits, impair the operation of spring contacts, or obstruct the mating of plugs and sockets. Further information on soft soldering will be found in Leaflet **BL/6-1.**

(b) **Silver Soldering.** Low temperature brazing, also known as silver soldering, is a brazing process which uses filler alloys based mainly on silver and copper, with a melting range of 505 to 850°C. Silver soldering is typically employed on certain EGT/JPT/TGT compensating lead terminations.

7.5.9 **Looped Connections.** In the case of some small instruments on older types of aircraft, the wire conductors may be looped around the terminal screw, but it should be ensured that the wire conductors are securely held between a plain washer and the metal base or insert. To reduce the likelihood of breakage under vibration, such connections should not normally be soldered, unless a double-back loop is formed and reinforcement is provided at the end of the soldered portion, and care is taken to ensure that wicking does not occur.

7.5.10 **Screened Cables**

(a) There are several methods of connecting the metal braided screens of cables, each depending on the circuit application and type of cable being used. Therefore, for precise details, reference to the relevant aircraft Maintenance Manual, Wiring Diagram Manual or Modification Drawing should be made. In general, however, the connections will normally be made utilising either soldered sleeves or crimping, and in one of the following forms:—

(i) "High"—fitted with no ground wire.

(ii) At the end with a ground wire.

(iii) At the end with link wires to other screens and ground wire.

(iv) Mid-span with a ground wire.

(v) Mid-span with link wires to other screens and ground wire.

(b) When preparing screened cables for the required screen termination, care should be taken to ensure that removal of any outer protective covering does not cause damage, in the form of cuts and nicks, to the metal braiding. If the connection is such that the metal braiding has to be cut off it should be done squarely and cleanly, ensuring that the braiding is not frayed at the cut edge. Where the braiding is to form the tail of the connection, it should be picked out of its mesh and the individual wires should be carefully twisted together. When cutting and preparing the metal braiding, care should also be taken to avoid damaging the insulation of the conductor.

8 PLUG AND SOCKET CONNECTORS To prevent damage and the entry of dirt, the protective caps which are provided with connectors should be fitted at all times other than when the connectors are being worked on. During work protection may then be in the form of a linen or plastic bag, totally enclosing the connector and secured to the cables. This temporary protection should only be removed just prior to connection being made in the aircraft. When a connector is disconnected, and it is intended that it be left open for a period of time, then both plug and socket should be protected to prevent damage and the entry of dirt.

8.1 **Miniature Connectors.** Extreme care should be taken when handling and connecting miniature and sub-miniature connectors. Both plugs and sockets should be checked for any signs of dirt, bent pins or physical damage to the shells before attempting to connect. If connectors will not mate, check for the reason, and rectify or renew. On no account should force be used to effect mating.

8.2 **Lubrication.** Some ranges of plugs and sockets require the engaging threads to be lubricated with a suitable lubricant to ensure that they can readily be disconnected. Lubrication should be carried out in accordance with the recommendations in the relevant aircraft Maintenance Manual, Wiring Diagram Manual or Modification Drawing.

8.3 **Assembly and Maintenance of Electrical Plugs and Sockets.** There are many different types of plug and socket connectors, each having its own maintenance requirements, therefore, reference should always be made to the relevant manufacturer's Maintenance Instructions and aircraft Maintenance Manual or Wiring Diagram Manual for precise details of cable preparation, special tool requirements (including insertion and extraction tools) and crimping information. The following paragraphs are, therefore, only intended as a guide on general maintenance practices and the safety precautions which should be observed.

8.3.1 **General Maintenance and Repair**

(a) The appropriate contacts and inserts for all the contact holes should be selected.

(b) All unused holes in the cable sealing grommet should be fitted with an approved filler plug.

(c) For connectors with cable clamps which are not provided with resilient bushings, it may be necessary to increase the diameter of the cables to enable a firm clamp to be obtained without distorting the cables. This may be achieved by one or more of the following methods, but whichever method is used, care should be taken to ensure that cables are not forced against any metal parts of the clamp; that the clamp is not over-tightened so as to crush or deform the cables; or that any cables connected to an outer ring of contacts are not forced to the clamp centre causing the holes in any sealing grommet to become deformed and consequently straining the contact joints.

(i) A plain insulation sleeve may be fitted over the cable bundle.

(ii) A plain insulation sleeve may be fitted over each individual cable.

(iii) The cable bundle may be wrapped around with a number of turns of a suitable tape.

(iv) A small roll of a suitable tape may be placed in the centre of the cable bundle.

(d) Where cable clamps are fitted with resilient bushings, care should be taken to ensure that the bushings used are of such size that the cables are firmly held in place but do not crush or deform the cable insulation when the clamp is tightened. To provide the proper fit for bushings, the following procedure should be applied. The smallest size or sizes of bushings to be omitted or the next smallest size or sizes shall be added, whichever is required.

(e) Some connectors have a "ground" connection point, provided with a "grounding" screw and washer, which should always be removed if a ground wire is not being connected.

(f) When connectors are installed as a provision for the installation of equipment at a later date, they should be protected by dust caps. Unused connectors supported only by the cables should be protected with an insulating sleeve pulled over the connector and cables so that it extends sufficiently to enable the end to be folded back and secured. This should then be clamped to the aircraft structure.

8.3.2 **General Maintenance and Repair Procedures.** The following procedures should be followed for the maintenance and repair of aircraft electrical plugs and sockets:

NOTE: No attempt should be made to straighten bent contacts since the resulting work-hardening may result in failure of the contacts.

(a) **Preparation**

(i) The cable clamp securing screws should be loosened and any packing should be discarded.

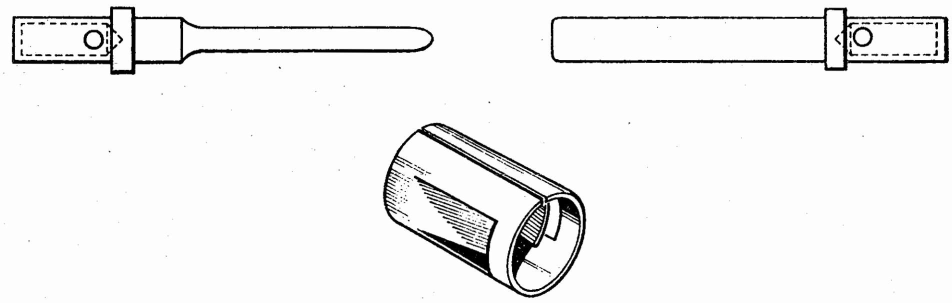
(ii) The threaded backshell should be unscrewed and eased back over the cables.

(b) **Removal of Wired Contacts.** There are two basic types of contact retention used in plug and socket connectors in aircraft, one with the contacts being released for removal from the rear of the contact insert and the other from the front. Each system requires the use of different types of insertion/extraction tools, therefore, it is essential that the correct procedures and tools are used for a particular type of plug or socket.

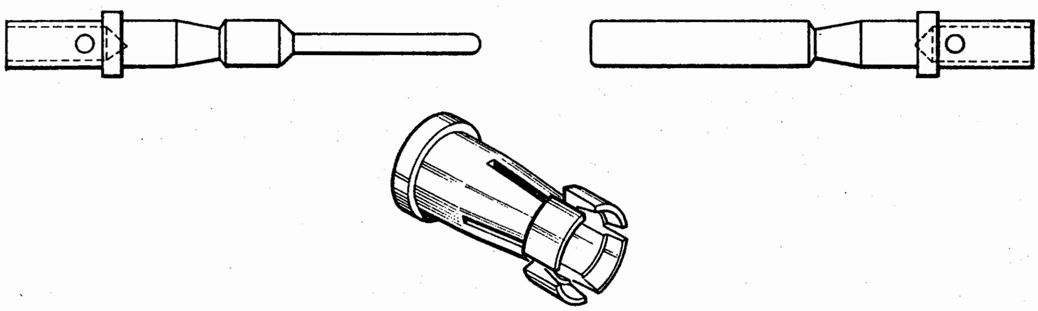
(i) **Rear Release.** The appropriate extraction tool should be positioned over the cable connected to the contact to be removed. To ensure that the contact retention system has been released (see Figure 4A), the extraction tool should be slid slowly into the contact insert hole in the plug or socket until a positive resistance to further movement is felt. With the cable held against the extraction tool, the contact should be removed by pulling the cable and tool from the plug or socket insert.

(ii) **Front Release.** The appropriate extraction tool should be positioned over the contact to be removed and, with the central plunger of the tool held back, pushed into the plug or socket to release the contact retention system (see Figure 4B). Depressing the central plunger of the extraction tool will eject the contact rearwards, out of the plug or socket. Extreme care should be taken when using this type of tool as their tips are easily damaged, which unless identified and replaced with a serviceable one, can cause damage to inserts and contacts.

NOTE: In repair operations only one contact at a time should be removed and repaired, so as to avoid the possibility of misconnection.



(A) REAR RELEASE



(B) FRONT RELEASE

Figure 4 COMPARISON OF RELEASE SYSTEMS

(c) **Removal of Unwired Contacts.** The sealing plug should be removed and the appropriate unwired contact extractor should be slid slowly, and straight, into the contact insert hole. Stopping of the extractor will indicate that it has bottomed on the contact shoulder. The contact should then be removed by slowly pulling the extractor and contact from the plug or socket.

(d) **Preparation of Cable and Crimping the Joint.** Stripping of coverings and insulation of cables should be done as recommended in paragraph 7. It should be noted, however, that if wire strands are damaged during this operation, the cable end should be cut off and the stripping procedure repeated.

(i) The appropriate contact for the plug or socket should be selected and the prepared cable should be inserted into the contact barrel ensuring that the wire conductors are visible through the inspection hole positioned at the base of the crimp barrel of the contact.

(ii) Where more than the required length of wire is exposed between the insulation and the contact, the wire end should be trimmed by cutting off the surplus without deforming the wire end. If the wire becomes deformed, the complete end must be cut off and the preparation should be repeated.

(iii) The contact should be inserted into the appropriate crimping tool and the prepared cable should be positioned and then the handles of the recommended calibrated crimping tool should be closed in a continuous movement. Most hand operated tools are provided with a ratchet assembly which will not release the jaws until a full stroke has been completed.

(iv) A check of the contact for any distortion because of a faulty tool or die should be made. If distortion has occurred the tool should be replaced with a serviceable one, the bent contact cut off and a new joint made.

(e) Inspection for a correctly formed crimp joint should be carried out in the following manner :

(i) It should be ensured that the conductor is visible though the inspection hole of the crimp connection barrel.

(ii) The crimp pattern should be clean, with the crimp indentations evenly spaced.

(iii) The crimp identification pattern must not break over the cable entry end of the connection barrel or the shoulder of the contact.

(iv) There must not be any cracks visible at the edge of the inspection hole or at the cable entry end of the connection barrel.

(f) Insertion of wired contacts into the plug or socket should be carried out in the following manner:

(i) The connected cable should be placed into the recommended insertion tool with the tool tip butting against the contact shoulder. The contact should be pushed slowly and straight into the rear of the contact insert. Firm stoppage of the contact indicates that it has seated in the insert. The cable should then be released from the tool and the tool removed by pulling it backwards.

(ii) If contacts are to be inserted into holes near the edge of the insert, the open side of the tool should always face the edge of the insert; this avoids excessive strain on the insert.

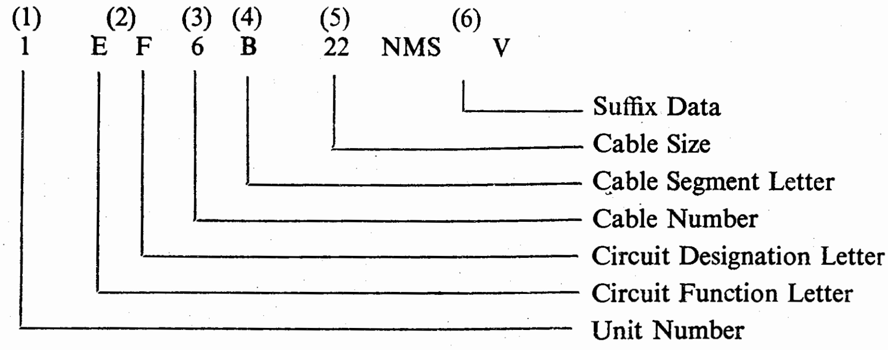
(iii) The proper size contacts and sealing plugs should be fitted into any vacant contact insert holes and the plug or socket should be reassembled by screwing on the backshell. Re-fitting of the cable clamp assembly is described in paragraph 8.3.1 (c) and (d).

8.3.3 **Inspection and Testing.** The test probes used for inspection and testing should be of such size that the contacts are not damaged or spread. On socket contacts the test probes should be of the same size or less than the mating plug contact. This is most important as the use of oversize test probes can result in open circuits and intermittent connections when the plug and socket are mated.

9 IDENTIFICATION OF INSTALLED CABLES Aircraft cables are normally marked with a combination of letters and numbers to provide the necessary information to identify the cable, the circuit to which it belongs, the cable size, and any additional information necessary to relate it to a circuit diagram or routeing chart. Such a code is usually either of the aircraft manufacturer's own specification or one devised by the Air Transport Association of America under Specification 100 (ATA 100) which has been accepted as a standard.

9.1 The ATA 100 Specification basic coding consists of a six position combination of letters and numbers, which are printed on the outer covering of the cable. The identification code is normally printed at specified intervals along the length of the cable. Where printing is not practical the code is printed on non-metallic sleeves and positioned along the cable length.

9.1.1 **Basic Cable Coding System**



Position 1—Unit number, used where components have identical circuits.

Position 2—Circuit function letter and circuit designation letter which indicate circuit function and the associated system.

Position 3—Cable number, allocated to differentiate between cables which do not have a common terminal in the same circuit. Generally, contacts of switches, relays, etc., are not classified as common terminals. Beginning with the number one, a different number is given to each cable.

Position 4—Cable segment letter, which identifies the segment of cable between two terminals or connections, and differentiates between segments of the circuit when the same cable number is used throughout. Segments are lettered in alphabetical sequence, excluding the letter I and O. A different letter is used for each of the cable segments having a common terminal or connection.

Position 5—Cable size.

Position 6—Suffix data, used to indicate the type of cable and to identify its connection function. For example, in the example code NMS V indicates nyvinmetsheath ungrounded cable in a single-phase system.

NOTE: Full details of the cable coding system will be found in the Maintenance Manual or Wiring Diagram Manual for the relevant aircraft.

9.1.2 To assist the fitting and positioning of insulating or indentification sleeves to cables, full use of the recommended lubricants should be made. To prevent over extension of small diameter sleeves it is recommended that thimble jigs or needle tools are used. Three-prong fitting pliers can damage overlays on sleeves and should only be used on the larger diameter sizes and then only extended to approximately 300% of the sleeve internal diameter. When positioning sleeves on cables care should be taken to ensure they slide and not roll.

10 INSPECTION AND TESTING OF CIRCUITS

10.1 Before carrying out tests, or when inspection is specified in the approved Maintenance Schedule, all aircraft circuits, together with plugs, sockets, terminal blocks and equipment terminals, should be examined, as appropriate, for signs of damage, deterioration, chafing, poor workmanship and security of attachments and connections. Information and guidance on the inspection and testing of electrical circuits are given in Leaflet **EEL/1-6**.

10.1.1 The methods of testing and inspection will vary with different types of aircraft and the equipment fitted, therefore, reference must be made to the relevant Maintenance Manuals for detailed information.

10.2 **Test Equipment.** Each test requires specified equipment and care should be taken that it is correctly used. To ensure the reliability of test equipment, it should be carefully serviced and certified at the periods recommended by the manufacturer. The performance of equipment should also be checked before and after use.

10.2.1 After completion of all tests, the installation should be inspected to ensure that all connections have been re-made and secured, and that test equipment, tools, etc., have been removed. This should be carried out immediately prior to the fitting and securing of panels, etc. The circuits should then be proved, as far as the installation permits, by making ground functioning checks of the services concerned.

10.3 Any disconnection or disturbance of circuits associated with flying or engine controls will require duplicate inspection and functioning test as outlined in Leaflet **AL/3-7.**

MMC/1-1

Issue 1.

16*th May,* 1975.

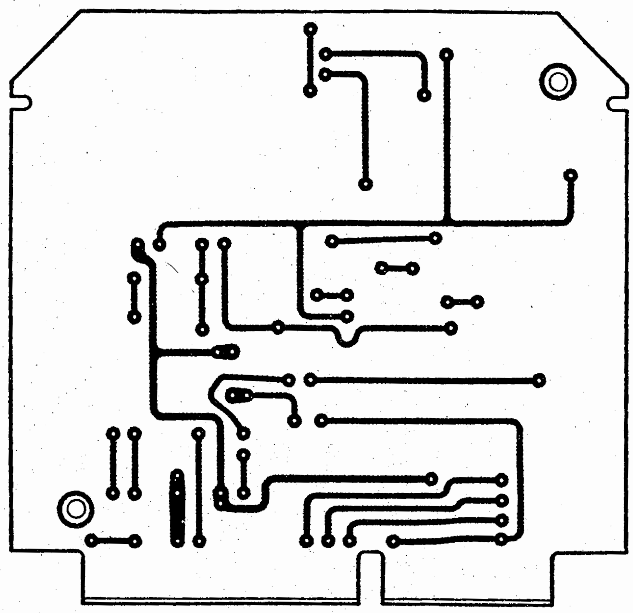
AIRCRAFT

MICROMINIATURE CIRCUITS

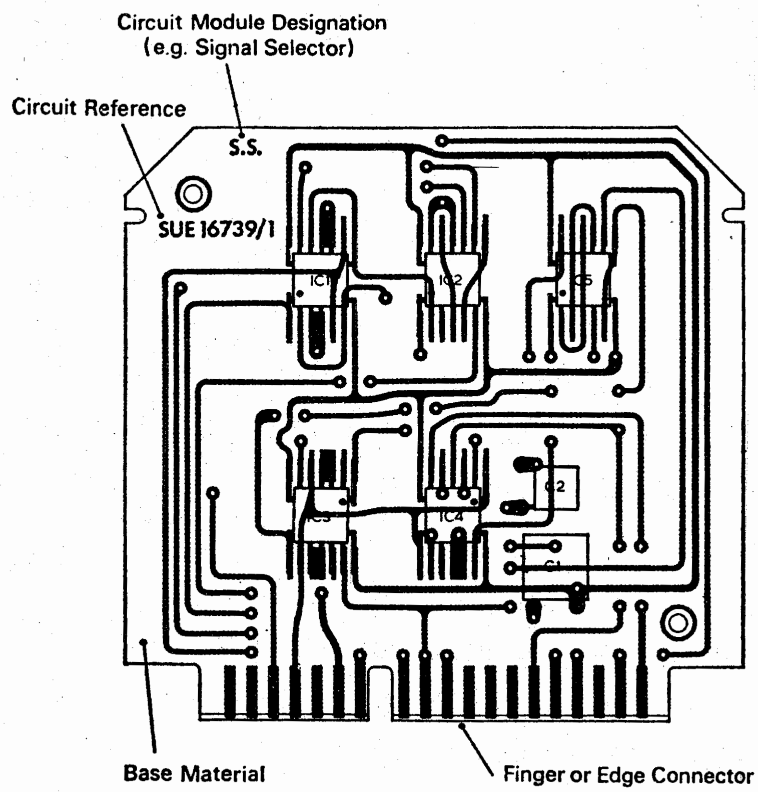
PRINTED WIRING BOARDS

1 INTRODUCTION The assembly of the various circuits which form part of the units employed in aircraft electronic systems, necessitates the interconnection of many components by means of electrical conductors. Before the introduction of printed wiring, these conductors were formed by wires which were connected to the components either by soldering, or by screw and crimped terminal methods. In the development of circuit technology, the significant trends towards micro-miniaturisation, rationalisation of component layout and mounting, weight saving, and the simplification of installation and maintenance, became essential factors; and, as a result, the technique of printing the required circuits was adopted. In this technique, a metallic foil is first bonded to a base board made from an insulating material, and a pattern is then printed and etched on the foil to form a series of current conducting paths, the pattern replacing the old method of wiring. In some cases, an additive process (see paragraph 7.2) may be adopted whereby copper is deposited only in those areas where conducting paths are required. Connecting points and mounting pads, for the soldering of components appropriate to the circuit, are also formed on the board, so that, as a single assembly, the board satisfies the structural and electrical requirements of the unit of which it forms a part. If the circuit is a simple one, the wiring may be formed on one side of a board, but, where a more complex circuit is required, wiring is continued on to the reverse side, which also serves as the mounting for components. In addition, complex circuits may be incorporated in multi-layer assemblies. A typical example of the printed wiring technique, as it is applied to a double-sided board, is shown in Figure 1. In this example, connections to and from the circuit are made by finger or edge contacts, which plug into a correspondingly shaped socket. Other methods of connection include flat cables and plugs, flexible printed wiring, and board-mounted connectors.

1.1 The design of printed wiring boards and the production of complete assemblies are of a specialised nature, and both may vary according to individual circuit requirements and specifications. The information given in this Leaflet is, therefore, intended purely as a general guide to typical production methods and inspection procedures, and is set out as follows:—



FRONT


Circuit Module Designation
(e.g. Signal Selector)
Circuit Reference
S.S.
SUE 16739/1
IC1
IC2
IC5
IC3
IC4
C2
C1
Base Material
Finger or Edge Connector

REAR

1.2 Other relevant information is contained in Leaflets **BL/1-12** and **BL/6-1**, and in the following specifications:—

BS 2572	Phenolic Laminated Sheet.	
BS 2782	Methods of Testing Plastics.	
BS 4025	General Requirements and Methods of Test for Printed Circuits.	
BS 4584	Metal-clad Base Materials for Printed Circuits.	
BS 4597	General Requirements and Methods of Test for Multi-layer Printed Wiring Boards using Plated-through Holes.	
DEF STAN 59-47	Protective Coatings for Printed Wiring Boards.	
DEF STAN 59-48	Part 1	Test Requirements for Single and Double-sided Printed Wiring Boards.
	Part 2	Test Requirements for Multi-layer Printed Wiring.

NOTE: With the introduction of the BS 9000 series of specifications, it is probable that certain of the specifications noted above will be affected, and that the relevant information will be withdrawn or combined under a new number.

2 BASE MATERIAL The base material, or laminate as it is sometimes called, is the insulating material to which the conducting material is bonded. The base material also serves as a mounting for the components which comprise the circuit. The base material is commonly made up either of layers of phenolic resin impregnated paper, or of epoxy resin impregnated fibre glass cloth which has been bonded to form a rigid sheet, which can be readily sawn, cut, punched or drilled. The thickness of the base material depends on the strength and stiffness requirements of the finished board, which, in turn, are dictated by the weight of the components to be carried, and by the size of the printed conductor area.

2.1 The resin of the base material is brought to a state of partial cure (known as 'B' – stage or 'prepreg' material) in which it is dry and not tacky, but on heating it again flows and regains its adhesive properties. The base material is normally stored at a low temperature in the 'B' – stage state until it is required for the next stage in the manufacture of a circuit board, which is the bonding to it of the conducting material.

3 CONDUCTOR MATERIAL The most commonly used conducting material is copper foil, the minimum purity value of which is 99·5%. The normal weights per unit area of the foil are as follows:—

(a) 1 oz/ft^2 (0·0014 in. thick approx.)

(b) 2 oz/ft^2 (0·0028 in. thick approx.)

(c) 3 oz/ft^2 (0·0045 in. thick approx.)

4 BONDING OF CONDUCTOR MATERIAL For the manufacture of a typical circuit board, the base material and copper foil are cut into sheets, and are then inspected and assembled inside a clean room (see Leaflet **BL/1-12**) in alternate layers with stainless steel separator plates (known as cauls) interposed between the layers, as shown in Figure 2. The steel plates, which are accurate in thickness to within 0·001 inch, are very hard, and have a delicately grained surface which is imparted to the finished boards. The layered sheets (the assembly) are then passed out of the clean room to be bonded in a hot press. During the pressing operation, the heat melts the resin in the base material, so that it flows and fully wets out the material and the copper foil. The pressure applied is adjusted so as to exclude all air and vapour from any residual volatiles. As polymerization of the resin mix proceeds, each layer of base material reaches the fully cured state ('C' – stage) with the copper foil firmly bonded to it. After cooling has taken place, the individual copper-clad boards are trimmed to the required size, inspected, and packed in sealed polythene bags.

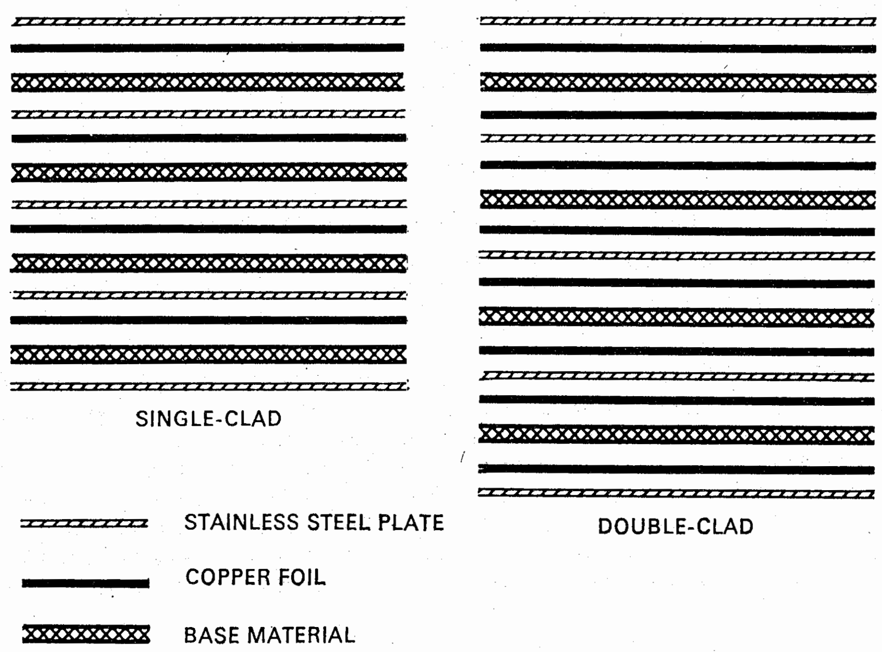


Figure 2 BONDING OF CONDUCTOR MATERIAL

4.1 **Inspections and Tests.** After manufacture, all boards should be inspected, and tests should be carried out on selected samples, in accordance with the relevant specifications. The details given in the following paragraphs are intended only as a guide to the inspections and tests which are generally required

4.1.1 **Appearance.** The copper surface should be free from resin and from undesirable defects, such as blisters, wrinkles, pinholes, bumps, deep scratches, and pits. Any discolouration or contamination of the surface should be removed by an aqueous solution of hydrogen chloride, or by a suitable organic solvent.

4.1.2 **Thickness.** The thickness of a board should be checked, to ensure that it does not depart at any point from the specified nominal thickness. A typical thickness range is from 0·031 to 0·125 in. and the preferred tolerances over this range are from ±0·0035 to ±0·008 in. for paper base material, and from ±0·006 to ±0·012 in. for glass cloth base material.

4.1.3 **Bow and Twist.** Bow should be measured parallel to the edges of the board. The board should be laid, concave side uppermost, on a flat horizontal surface, and a straight edge should be offered to the upper surface, in the direction of maximum curvature. The maximum clearance between the board and the straight edge should be taken as the measure of bow. Twist, which should be measured with the predominantly concave side of the board downwards on a flat horizontal surface, is taken as the separation of any one of the corners of the board on the concave side with the three other corners held lightly in contact with the surface. The permissible limits of bow and twist are governed by such factors as board thickness, weight of copper foil, and type of assembly, e.g. single-clad or double-clad.

4.1.4 **Peel Strength.** Peel strength is the minimum load required to pull a strip of foil (either 1 inch or ⅛ inch wide) from the base material. The foil should be detached from one end of the specimen, and pulled in a direction perpendicular to the plane of the board, so as to peel off a specified length of foil at a steady rate (e.g. a 1 inch length at 2 inches per minute). The load should be measured by any suitable load measuring device, e.g. a spring balance, and should be within the limits specified. Typical values of peel strength are, not less than 12 ozf per ⅛ in. width for phenolic paper base, and not less than 24 ozf per ⅛ in. width for epoxy glass.

4.1.5 **Heat Resistance by Solder.** For this test, a one inch square specimen of the board should be floated, with the copper face downwards, on to the surface of clean molten solder. The temperature of the solder should be measured by a thermocouple and potentiometric apparatus, and should be within the limits specified for the test; a typical value is 250°C ±2°C. The specimen should be left in contact with the solder for 10 seconds. The copper should not show any signs of blistering, or of delamination, at the end of this time. For double-clad boards, a fresh specimen should be used for testing each side.

4.1.6 **Pull-off Strength.** For this test, a specimen of the board, of any convenient size, is printed (see paragraph 7) with a test pattern consisting of up to ten lands. A hole is drilled through the centre of each land, and, after tinning of the lands, a short length of hard-drawn brass wire is passed through each hole, and is soldered at right angles to the lands. A load is applied to the free end of each wire in turn, in a direction perpendicular to the surface of the board, by a tensile testing machine, and the load is increased until the land is pulled from the base material. The minimum pull-off force required should not be less than the value specified; a typical value for phenolic paper base materials is 7 lbf and a typical value for epoxy glass base materials is 15 lbf.

4.1.7 **Electrical Tests.** On each batch of boards, it is also necessary to investigate certain electrical properties, and, for this purpose, specimens should be printed with specific circuit patterns. The following tests are those generally carried out:—

(a) **Surface Resistance.** This test is designed to ascertain the insulation resistance (in megohms) between adjacent printed conductors when a test voltage of either 85 volts d.c. ±10% or 500 volts d.c. ±10% is applied to the conductors for one minute.

(b) **Loss Tangent.** The loss tangent (sometimes called the dissipation factor or power factor) of a material, is a measure of its insulating characteristics in an alternating electric field. The lower the loss tangent, the smaller is the power wasted in the form of heat.

(c) **Foil Resistance.** The resistance of a strip cut from a board should be measured with a suitable electrical bridge. Care should be taken to ensure that the bridge current used is not so high as to cause any appreciable heating of the strip.

NOTE: Details of electrical test methods and values are given in the relevant British Standards and DEF Specifications.

5 MACHINING OF BOARDS All boards require machining, e.g. guillotining, sawing, punching, and drilling during the various stages of production.

5.1 **Guillotining.** This is one of the quickest and most economical methods of cutting sheets of copper-clad laminates into strips and panels, and it is frequently employed in conjunction with subsequent punching operations. Correctly performed guillotining results in a clean, burr-free edge, with no wastage of stock.

5.1.1 There is no advantage in heating epoxy/glass laminates. However, with phenolic/paper laminates, the best guillotined edge can be obtained by pre-heating them within the temperature range recommended for the particular grade of material. This temperature range may vary between 40°C to 130°C, although lower temperatures can be used for trimming, where only the edge on one side of the cut is important. Heating by radiation, infra-red or convection, is suitable, and so far as is possible a sheet of laminate should be heated on both sides thereby preventing the tendency for the sheet to curl. Overheating of the material must be avoided, as this results in blistering, which in effect hardens the board and makes subsequent drilling or punching operations more difficult.

5.1.2 Machines, not specifically designed for guillotining laminates, may be used, but difficulties in producing a clean edge may arise. Blades set specifically for sheet metal cutting have a 'scissor' action, and cutting laminated sheet with such blades produces irregular and chipped edges, which may start cracks running into the material at an angle from the edges. Raising the pre-heating temperature of the sheet can alleviate the problem in some instances, but it is better to reposition the blades, so that the cutting edges are at an approach angle of ½° to 1½° for cutting speeds of 600 ft/min to 1,000 ft/min respectively, across the surface of the laminate.

5.1.3 Laminates are abrasive and, therefore, the sharpness of cutting edges must be monitored. Clearance between the blades should be kept to a minimum, bearing in mind that during use thermal expansion of the blades will occur.

5.1.4 Adjustable stops are essential if dimensional and angular accuracy is to be maintained, and under these controlled production conditions, strip width can be kept within ±0·010 inch over a length of 4 feet. The constant use of one section of the blades, e.g. when cutting strips into panels, will result in uneven wear; to prevent this accurate adjustments should be made to the blades so that their entire length is brought into use.

5.1.5 As copper surfaces are easily scratched, the careful handling of laminates and the removal of swarf during guillotining is essential.

5.2 **Sawing.** Cutting with a circular saw is superior to guillotining as it gives a cleaner edge, especially so as the thickness of the laminate increases. Wood-cutting machinery is satisfactory for laminates, but certain features are essential in order to maintain efficiency and accuracy over long production runs. Table size should be compatible with the largest sheet likely to be cut, otherwise excessive overhang of the sheet will result in chipped edges and slower work. A moving table is ideal; a sheet can be clamped to it, and a straight edge can readily be obtained by working against a fence.

5.2.1 The saw blade gap should be such that a clearance of not more than 0·062 in. is obtained on each side of the blade; the height of the blade, relative to the table, should be adjustable. A blade set too high will give a rather ragged edge, while too low a setting may result in some lifting at the top edge of the work. Paper based sheets may be cut with high speed steel blades, but these blades may require frequent sharpening as some deterioration of the finish of the sawn edges may become evident after one or two hours of operation. The blades may be hollow ground and from 8 in. to 12 in. in diameter, with 0·187 in. tooth pitch. Teeth may be sharpened square, or with a 20° angle right and left, for staggered points. For regular use, tungsten carbide-tipped blades are preferable for cutting paper based sheet. Such blades may be from 8 in. to 12 in. in diameter with a 0·375 in. tooth pitch.

5.2.2 Both steel and tungsten carbide-tipped blades can be used at cutting speeds of up to 10,000 ft/min, with a corresponding feed of about 30 ft/min for 0·060 in. thick material. Too fast a feed will result in chipping and flaking of the material; if the feed is too slow, overheating of the blade and of the material may result. Any burring of the cut edge of the copper should be removed with either a hand, or mechanical, scraper.

5.2.3 The life of tungsten carbide-tipped blades is considerably reduced when cutting copper-clad epoxy/glass laminates. A 12 in. diameter steel disc with the edge resin-coated and embedded with diamond grit will be more durable. The disc can be used dry, but when so used an extraction system for the removal of glass dust should be installed. A cutting speed of approximately 10,000 ft/min is suitable, but the feed rate should be less than when using a toothed blade.

5.3 **Drilling.** The type of resin, base material and the degree of cure, are the main factors affecting the drilling characteristics of a laminate. All laminates are abrasive, particularly those with glass fibre base material, and drilling techniques should be adapted to suit. The drill can be quickly blunted, which causes overheating and degradation of the work; it is, therefore, most important that cutting edges are kept sharp, and friction is reduced to a minimum. Other aspects to be taken into account are the type of drilling machine, type of drill, drilling speed, length of run, and accuracy and finish of holes.

5.3.1 Machines are normally specially designed for printed circuit board drilling, and they incorporate multi-spindles, the location and feed of which are controlled automatically. Control may be effected by numerical information recorded on punched cards or tapes, or by means of a template and stylus.

5.3.2 Sharp-pointed, slow-spiral, high-speed steel drills should be used for drilling boards with a phenolic/paper base, while epoxy/glass base boards should be drilled with solid tungsten carbide drills.

5.3.3 Drilling speed may be kept as high as possible, but is limited by feed rate. A high speed/feed ratio results in excessive friction and overheating, to the detriment of both the drill and the work; after cooling down, holes shrink and are no longer round. The diameters of holes specified for printed circuit boards are generally in the range 0·030 in. to 0·050 in. and, when an automatically-controlled machine is used, the best results are obtained at speeds in the range 15,000 to 25,000 rev/min. With manually-operated machines optimum results will be obtained at slower speeds. Boards drilled singly will allow for cooler and faster running than those drilled in packs, which is similar to drilling a thick section, and, therefore, requires slower speed and frequent drill withdrawal to clear the swarf.

5.4 **Punching.** Where large quantities of laminates are required, and cost of tools is acceptable, punched parts can be produced by conventional pierce and blank methods; such methods are most commonly adopted for copper-clad phenolic/paper base laminates. The quality of the work and the ease with which it can be carried out depend mainly on whether the job has been planned within the mechanical limitations of the material, and on whether due consideration has been given to its characteristics. Reference should be made to the data sheets relevant to the particular material grades, but the observations given in the following paragraphs generally apply.

5.4.1 Better results are usually obtained when the phenolic/paper base laminates are heated, particularly for complex shapes. The blanking operation is more critical than piercing, and the best grades of punching materials will produce simple shapes, at thicknesses up to 0·060 in. approximately, without heating. When the material is heated through the range 60°C to 120°C, according to grade, thicknesses up to 0·125 in. can be blanked. With the better grades of materials, heating is not required for piercing unless the standard required is very critical.

5.4.2 Copper-clad epoxy/glass laminates have very good punching properties at room temperature, although tool wear is high because of the abrasive nature of the material. For work that is to be plated through the holes however, the smoother finish obtained from drilling is recommended.

5.4.3 The heating methods adopted for guillotining epoxy/glass laminate may also be employed for punching. To avoid excessive chilling of a laminate, the punching tool should also be heated to approximately two-thirds of the temperature of the laminate. Strip may be passed through an electric tunnel heater attached to the tool, thereby serving a dual function of heating the stock and the punching tool. Optimum clearances vary according to working temperatures, but the following features, if incorporated in press tool design, can assist trouble-free operation:—

(a) Laminates shrink on to a punch when holes are pierced. The punch should, therefore, be oversize irrespective of hole diameter required. Typical oversize values are 0·003 in. for cold piercing and 0·006 in. for hot piercing on stock of 0·062 in. thickness.

(b) Punch and die clearance should be a minimum (0·001 in. overall) if straight sided holes are required. If tapered holes are acceptable, up to 0·0045 in. overall tolerance will give less wear and drag on the punch and will reduce the tendency towards surface lifting of the stock on withdrawal.

(c) Clearance for blanking should be kept to a minimum and should certainly not be more than 0·002 in. overall. Blanking dies should be undersize to a degree depending on the thickness of the material, and on whether it is being worked in a cold or heated condition. Typical values for 0·06 in. material are 0·003 in. (cold) and 0·0015 in. (heated).

5.4.4 Holes may also be pierced in boards on semi-automatic turret presses using a drilled template. The template holes are colour-coded to aid in the selection of the designated punch size. When a stylus point is depressed into a hole the press is tripped to operate and to pierce the board.

6 CIRCUIT ARTWORK The quality of a printed wiring board is, in the first instance, dependent on the production of master artwork which must show precisely the circuit conductor pattern required, where components are to be located, circuit module designations and other essential references. Artwork production requires the use of dimensionally stable base materials, and the application of skilled drafting techniques, because, unlike conventional electrical drawings, which are used as a guide to the build-up of an assembly of wiring and connections, a printed wiring board is an actual reproduction of the original artwork produced for it.

6.1 Artwork is normally prepared under controlled temperature and humidity conditions (typical figures are 20°C ±2°C and 50% ±5% R.H.) and, under these conditions or variations therefrom, the materials for artwork layout are required to exhibit minimal changes in dimensions; thus, dimensional stability is of great importance. Materials which are satisfactory in this respect, and which are in common use, are:—

(a) Polyester film.

(b) Optical glass plate.

(c) Foil card, made up of a sheet of aluminium with a white paper surface on each side.

(d) Aluminium sheet coated with several coats of white enamel.

6.2 Optical glass plate is the most stable of materials for artwork production, but, as it is difficult to work on direct, other methods of laying out circuit patterns are desirable. Two methods which are generally recommended are:—

(a) Initial preparation of the artwork on polyester film, followed by photographic transfer to the glass under controlled environmental conditions.

(b) Preparation of the artwork direct onto the glass by means of a numerically-controlled drafting machine.

6.3 The required circuit patterns may be drawn in ink, or, as is more usual, by the application of self-adhesive black material specially produced in tape form to represent conductors, and in other shapes to represent terminal points, edge connector contacts, drilling points, connector pads, etc. The material is produced in a wide range of sizes to suit both the scale selected for the drawing and the reduction ratio required for the subsequent photographic and printing processes.

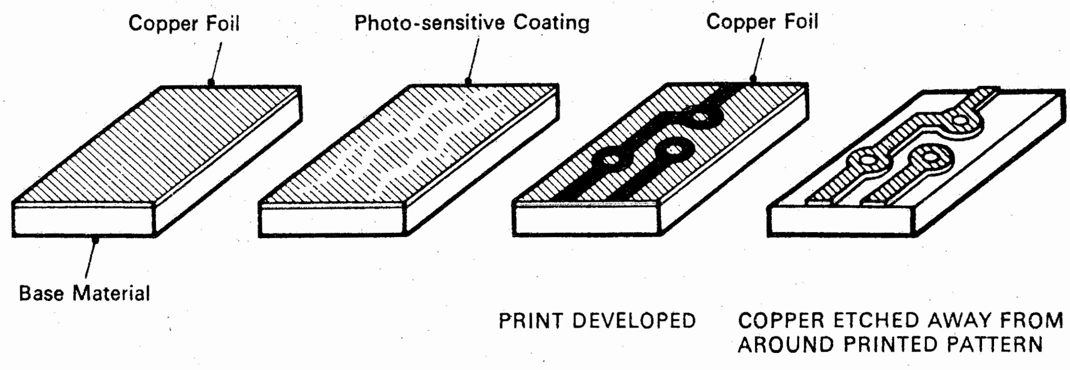
6.4 The layout and drafting of master artwork vary according to both the skill of the draftsman concerned and the environmental conditions existing at the photographic stage. In order to normalise the photographic film, environmental conditions at the photographic stage should be the same as those under which the artwork was produced. Other factors which may cause inaccurate reproduction include, damage to artwork during handling and storage, shrinkage of tapes causing breaks in connections, tape overlaps causing distortion of sharp edges, and lack of temperature stabilisation of artwork before the photographic stage.

6.4.1 Human error in drafting can be reduced, and, in certain cases, eliminated, by the use of numerically-controlled drafting machines. These are accurate X and Y co-ordinate plotting machines which are capable of automatically plotting a point, or line, on a surface whether it be on a film or glass base. To eliminate problems which arise with drawing tape deterioration or movement during the course of time, a copy of the original master artwork should be made immediately on highly stable material. All subsequent modifications to the artwork can then be carried out on the new master, and copies can be made from it. Artwork should be allowed to stabilise under the specified controlled environmental conditions before being photographed, and variations in these conditions between photographic and board production stages should be kept to a minimum. This is particularly important with multi-layer circuit assemblies, and when artwork has to be moved from one place to another.

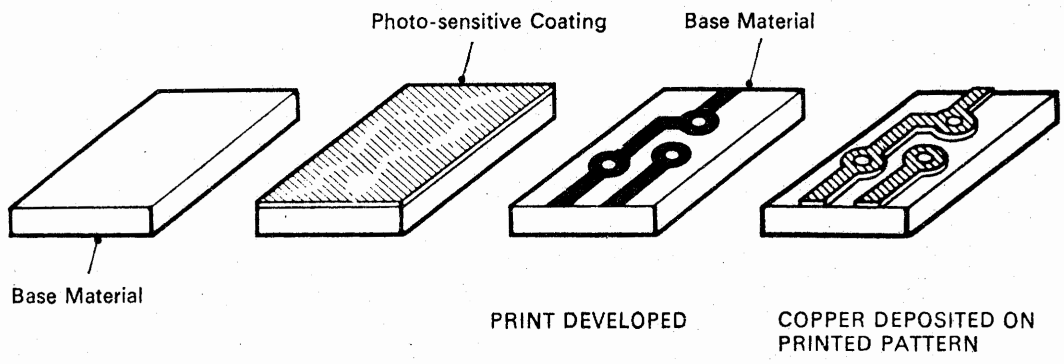
6.5 For circuits which are to be printed on both sides of a board, accurate registering during the photographic stage is essential, and, where numerically-controlled drafting machines are available, they should be used. An alternative technique for accurate registration of double-sided boards, consists of drafting both circuit patterns on a single piece of artwork material with tapes of different colours. Red tape is used for one pattern, and blue tape for the other; while black tape is used for those conducting paths which are common to both patterns and which must appear on both sides of the boards. During the photographic process, colour filters are used, in turn, to eliminate the red and the blue tape images, so that two negatives are produced, each of which shows a separate side of the board in perfect register.

7 PRINTING OF CIRCUITS The printing of circuits is carried out using either an etching process or an additive process. Both of these processes, which are shown in Figure 3, are briefly described in the following paragraphs.

7.1 **Etching Process.** In this process the copper foil is first cleaned, either chemically or mechanically, and is then coated with a photo-sensitive solution known as a 'resist'. A wide range of these solutions is available, but mostly they are allied to the dichromated glues, which have the property of becoming soluble when exposed to strong light. A photographic positive of the circuit artwork is then placed over the sensitised board and time-exposed in a special printing machine. After exposure, the resist is washed away to leave unprotected areas of copper around the circuit pattern, and the board is dried by a clean, oil- and water-free air blast. The complete board is then inspected to ensure that no resist has been removed from any part of the conductor pattern itself, and that no resist particles are present in areas which are to be etched away. The board is then placed in a bath which contains an etching solution, such as ferric chloride or ammonium persulphate, which etches away all the unprotected copper. In order to minimize 'undercutting' by the etching solution, the solution is either agitated over the immersed board, or directed over its surface by spray jets. The etching time is dependent on such factors as bath temperature, specific gravity and pH value of the etching solution; checks on the pH value are of particular importance when ferric chloride is used. When the etching process has been satisfactorily completed, the board is thoroughly washed in water in order to remove all traces of etching solution, and is then dried and given a final inspection.



(a) ETCHING PROCESS



(b) ADDITIVE PROCESS

Figure 3 PRINTING PROCESSES

7.1.1 As printed circuit boards with the same circuit pattern are often required in large numbers, the simple 'print and etch' process which is described in paragraph 7.1 is generally superseded by a screen printing process. This process involves the preparation, by photographic means, of a gelatine stencil which is applied to a silk screen. The circuit pattern is then printed through the screen with rapid drying resist inks. It is a common practice to print the circuit on the board as a negative, i.e. leaving the copper foil bare over the areas where it is to remain on the finished board. A metal which will be resistant to the etching solution is then applied to the copper. This may be done either by immersing the board in solder, or by plating on a suitably resistant metal. The ink is then removed from the remaining areas of the board, and the exposed copper is etched away.

7.2 **Additive Process.** In this process, copper is deposited only in the areas where conductors are required. To achieve this the base material is pre-coated with a suitable adhesive, the circuit holes are pre-fabricated, and the board is sensitised with a photo-resist solution. A negative of the circuit pattern is then screen printed onto the board so that the exposed areas define the conductor network. These exposed areas are chemically activated, and the board is then immersed in an electroless copper plating solution. After a period of time consistent with the deposition of the required thickness of copper, the board is removed from the bath. The major advantages of the additive process are; no chemical etching takes place, thereby eliminating wastage of copper and problems associated with undercutting; the thickness of the deposited copper can be reduced and made more uniform, the conductor widths and spacings are less restricted, and the hole diameters can be reduced, thereby increasing the board area available for routeing of conductors.

7.3 **Inspection.** After printing, circuit patterns should be inspected and particular attention should be paid to the following:—

(a) **Dimensional Accuracy and Condition of the Edges of Conductors.** Ragged edges, tapering of end contacts and burning of conducting areas under edges of the resist material, may all be caused by over-etching, which would lead to rejection of the board. Minor imperfections may be accepted, provided that the reduction in the total width of the conductor does not exceed the values specified for the pattern.

NOTE: The inspection of conductor patterns can be aided by the use of a light box, or of an optical system.

(b) **Condition of the Pattern Surfaces.** These should be clean, and free from hairline cracks, blistering, large pinholes, dents and scratches. Minor superficial dents may be accepted provided that they are parallel to the track of a conductor, and so long as they do not affect the bond of the conductor.

(c) **Particles of Copper in Unwanted Areas.** These particles, which are produced as a result of under-etching, should always be removed.

(d) **Insulation Areas.** These should be free from flaking, crazing, resin starvation and similar imperfections.

(e) **Lack of Resin Bond in Etched Areas.** This is indicated by changes in colour (fogging) of the base material.

8 SOLDERING METHODS There are two main methods of soldering employed in connection with printed circuit boards; (a) hand soldering and (b) mass soldering.

8.1 **Hand Soldering.** This method is used for soldering joints separately, e.g. in limited batch production, and when a component or a wire is replaced after a test or a repair has been carried out. This method involves the use either of electrically heated hand irons, or of resistance type hand tools when the use of these is permitted (see also Leaflet **BL/6-1**).

8.2 **Mass Soldering.** In this method, all joints of a finally assembled board are soldered simultaneously, by bringing the board into contact with an oxide-free surface of molten solder, which is contained in a special type of bath. Mass soldering may be carried out in any one of five different ways: some details of each are given in the following paragraphs.

8.2.1 **Flat or Static Dipping.** In flat or static dipping (see Figure 4(a)) one edge of the board is first lowered on to the solder, and the other edge is then lowered slowly to allow flux and solvent vapour to escape. An angled path is also adopted when withdrawing the board; this assists the solder to drain, and thus prevents 'icicling' (see paragraph 11.2.1). This technique can also be automated, for production line purposes, by conveying the boards across the surface of the solder as shown in Figure 4(b).

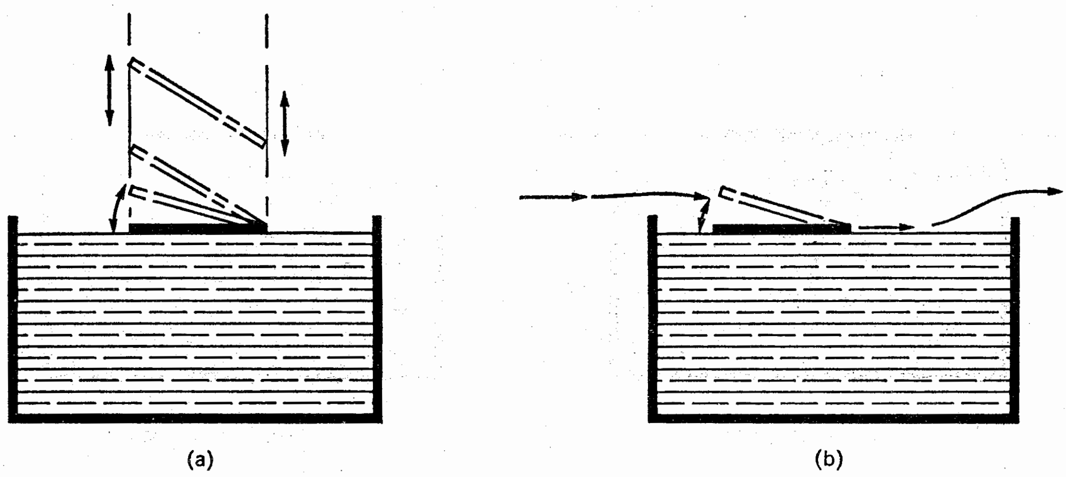
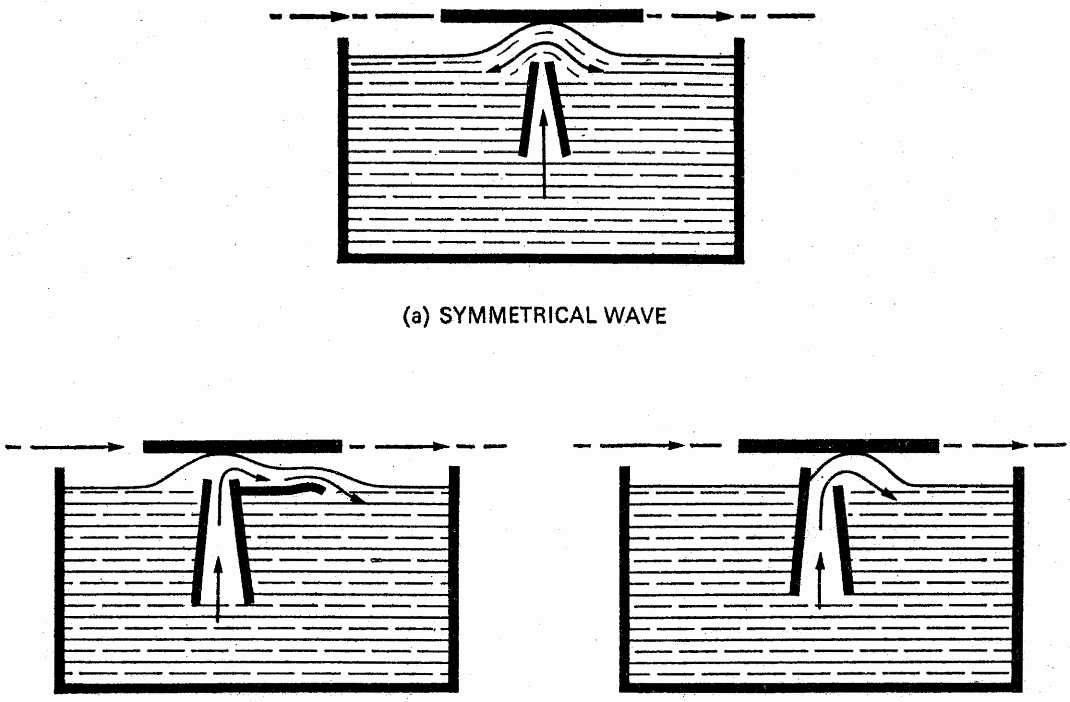


Figure 4 FLAT OR STATIC DIPPING

8.2.2 **'Wave' Soldering.** In wave soldering (see Figure 5), the surface of the solder is maintained free of dross by pumping the solder from the bottom of the solder bath through a narrow slot, so that a symmetrical 'standing wave' of solder is produced across the width of the bath. The height of the wave is governed by the impeller pump speed, which is usually variable (typical wave heights vary between $\frac{1}{8}$ in. and $\frac{3}{4}$ in.). In order to assist in drainage of the solder from the board, the wave forms may be varied as shown in diagrams (b) and (c) of Figure 5.

(a) The wave soldering technique is part of an automated soldering process whereby a circuit board after being fluxed, either manually or automatically, is passed against the crest of the solder wave by a conveyor (see Figure 6). Each solder joint area is in contact with the solder for only a few seconds to prevent distortion and damage to the board and its assembled components. The width of the solder wave determines the maximum width of the circuit board which can be treated, but there is no limit to the length of the board since it is traversed by the conveyor.



(a) SYMMETRICAL WAVE

(b) DOUBLE WAVE

(c) UNI-DIRECTIONAL WAVE

Figure 5 WAVE SOLDERING

(b) A typical machine employing this technique is shown in Figure 6. The assembled circuit board is clipped, with the side to be treated downwards, into the carrier, which is then placed on the conveyor for traversing at the required speed selected on the control console. The console also contains controls for pump speed, solder wave height, solder temperature, fluxing and pre-heating of the board. The board is first conveyed over the fluxer unit, the joints to be soldered passing against the crest of a flux wave produced by a pump. After being fluxed, the board passes over radiant heaters, which pre-heat the board and condition the flux. The conditioned board is then conveyed over the wave soldering unit for soldering of all joints. The combined molten solder flow and traversing of the board provide a 'washing' action around the joints of the board, thereby assisting in solder penetration, and the removal of excess flux, or unwanted metallic coatings, which could have weakening effects on joints.

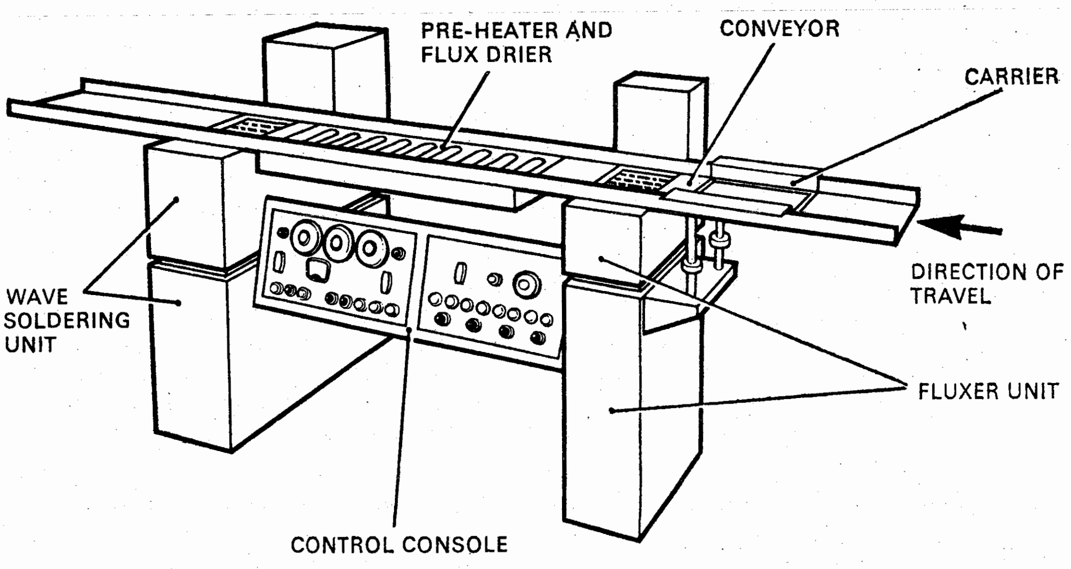


Figure 6 WAVE SOLDERING MACHINE

8.2.3 **Weir and Cascade Soldering.** These systems (see Figure 7) are of the moving solder type, the solder flowing down a trough by gravity, and then being returned to the main bath by a pump. In weir-soldering (diagram (a)) a circuit board is lowered on to the solder; while in cascade soldering (diagram (b)) a board is conveyed across the crests of solder waves in a direction opposite to the solder flow.

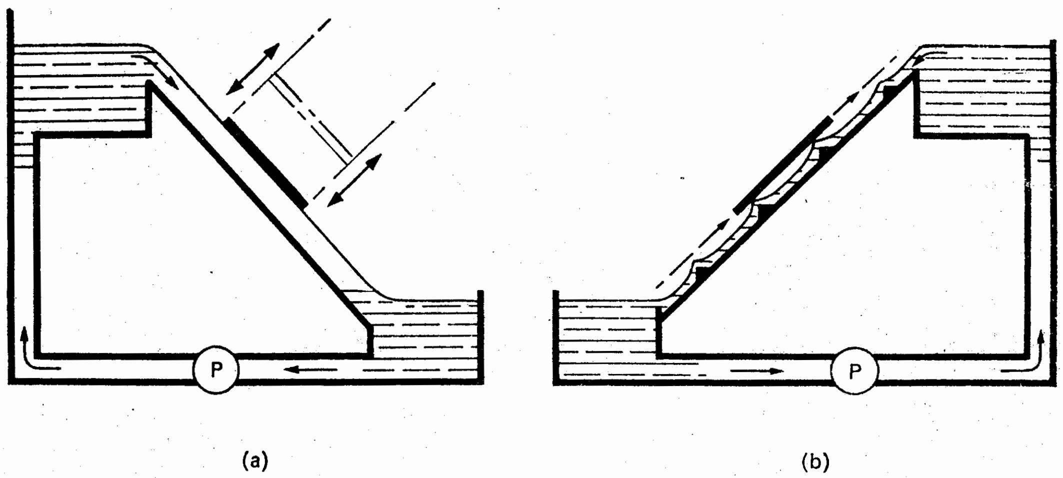


Figure 7 WEIR AND CASCADE SOLDERING

8.2.4 **Reflow Soldering.** This automated soldering process (also known as 'heat cushion' soldering) is applied particularly to circuit boards on which microcircuits and associated devices are to be assembled. These efficient but costly components require a special soldering technique, so that their full potential as surface-mounted devices can be realised. The reflow technique (see (a)) is generally recognised as the best method, since the soldered joints are easier to inspect and to remake when a faulty component has to be replaced. In addition, soldering times and the risk of overheating sensitive components are reduced, and distortion of leads is prevented.

(a) A reflow soldering machine, which may be either bench-mounted or free standing, consists primarily of an electrically-heated electrode, which is lowered, by a pneumatic ram, to make contact with the joint to be soldered. A control panel is provided for lowering the ram, for pre-selecting the load to be applied, and also for pre-selecting the heating power to the electrode. A pre-set timing device is also provided, both for cutting off the heating power, and for supplying a blast of air for subsequent cooling of the soldered joints.

(i) The sequence of reflow soldering is shown in Figure 8. The leads of the circuit or component, and the relevant lands on the circuit board which have been pre-tinned by such methods as wave soldering or dip soldering, are first brought into contact with each other and accurately aligned. The sequence is then initiated by lowering the electrode on to the lead to be soldered. Shortly before the electrode makes contact with the lead, the pre-set heating power is automatically switched on. The electrode is then pressed on to the lead under a load which gradually increases until the pre-selected value is reached. The solder melts, and in reflowing, it forms a 'cushion' through which the lead is pressed against its corresponding land of the circuit board. As soon as the cushion is formed, the timing device cuts off the heating supply. After a 0·75 second delay, an air blast is delivered to cool the soldered joint; this accelerates the completion of the soldering process, and also improves the quality of the joint. At the end of the cooling period, the load is relieved, and the electrode is automatically raised ready for the next operation.

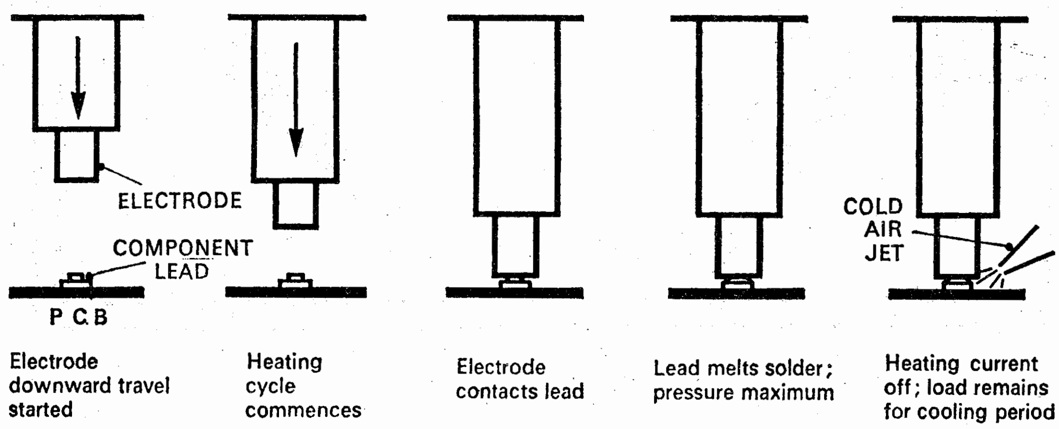


Figure 8 REFLOW OR 'HEAT CUSHION' SOLDERING

9 SOLDER SPECIFICATION For the mass-soldering of printed wiring boards, solder complying with BS 219 Grade K (60/40 tin/lead) is the one most commonly used, since it has a free-flow characteristic which permits good joint formation in the short period during which boards are in contact with the solder.

9.1 Solder is normally supplied in the following forms:—

(a) Bars, for use in machines which are provided with an automatic system of feeding solder during machine operation.

(b) Wire, for use in machines which have an electronically controlled wire feeder system.

(c) Sticks, for the filling and replenishing of machines which are not fitted with an automatic feed system; and for use in static dip solder baths.

(d) Pellets, for the initial charge of some machines and for the topping up of small baths, where rapid melting is required with minimum loss of temperature.

(e) Flux-cored wire.

9.2 The soldering temperature is chosen for each individual combination of board and types of material being processed, but it should normally be within the range 220°C to 260°C. Given components of good solderability, complete wetting and filling of the joints should be achieved within a few seconds. Higher temperatures and longer times may cause trouble because of distortion of boards and deterioration of the components mounted on the other face.

10 FLUXES AND THEIR APPLICATION To assist in the wetting of surfaces by molten solder, a flux must be used both to prevent oxidation during joint formation, and to dissolve the thin oxide films which may already be present on the surfaces which are to be joined, and on the solder itself. Fluxes are, therefore, substances that yield an acid when they are heated to the soldering temperature. Once the oxide films have been dissolved by the acid, the flux must be readily displaced by the molten solder as it wets and spreads over the surfaces.

10.1 **Types.** The flux to be used is most often dependent on the type of materials being soldered, but in the majority of applications a rosin-based flux is required. The types most commonly used are activated by organic agents in an organic solvent to provide some slightly increased rate of dissolution of metal oxides with a minimum risk of subsequent corrosion. In some cases, special additives may also be included to provide a self-supporting foam for transferring the correct amount of flux to a board, and also to prevent spattering, thereby ensuring an even flux coating.

NOTE: Foam fluxes are not compatible with protective coatings and these should, therefore, be removed before commencing a soldering operation.

10.2 **Application.** Fluxes may be applied to printed wiring boards by any of the following methods:—

(a) Dipping on to the surface of a bath of flux.

(b) Brushing.

(c) Spraying.

(d) Rolling on, by contact with a plastic foam roller.

(e) Wave fluxing, i.e. by passage over a standing wave of flux.

(f) Foam fluxing, i.e. by passage over a standing wave of foamed flux produced by aeration from a submerged porous element.

10.3 **Heating of Fluxes.** When mass soldering, by either the wave, weir or cascade methods, it is necessary for some of the volatile solvent from the flux layer to be removed, in order to prevent the formation of gases which would result in non-wetted areas of a board (see also paragraph 11.1.1). Solvent is removed, between the fluxing and soldering stages, by passing the boards over controlled infra-red heaters or hot air blowers.

10.4 **Removal of Flux Residue.** The residue from certain types of activated flux dries into a hard, non-hygroscopic, non-conductive and non-corrosive deposit, which is fully soluble in denatured ethyl alcohol or in isopropyl alcohol. This deposit may also be removed by aromatic solvents, e.g. xylol and toluol, or by chlorinated hydrocarbon solvents, e.g. trichlorethane and freon. If such solvents are used, ultrasonic cleaning, spray or jet washing, or brush cleaning methods may be adopted for complete removal of residue, bearing in mind any detrimental effects the cleaning methods may have on specific board components. Foam fluxes leave a thin residue, which is readily removed by warm water.

11 SOLDERABILITY AND SOLDERING TECHNIQUE DEFECTS On completion of a soldering operation, it is necessary to check that the soldered connections have the highest possible level of quality. When tin-lead alloys containing 60-65% tin are used, all soldered connections should be bright, and should have smooth concave fillets joining the circuit board and component termination. Usually these checks entail inspection of the whole, or a selected portion of the work, using a magnifier of about ×10 power. For these operations to be effective, personnel engaged on inspection should have a full understanding of what constitutes a satisfactory soldered joint, and should readily be able to recognise solderability defects and defects which arise from the soldering process itself.

11.1 **Solderability Defects.** Solderability is assessed as the extent of wetting by the solder, and, in this connection, there are normally three classes of defect which must be recognised. Guidance on these is given in the following paragraphs.

11.1.1 **Non-Wetting or Partial Wetting.** This defect arises from incomplete coverage (wetting) of the surface by the film of solder. In the non-wetted areas the colour of the original base metal is exposed, although this may not be clear if a metallic coating of similar colour to solder had been electro-deposited on the base metal prior to soldering. Thus, a partially wetted solder film on palladium may be difficult to distinguish from one which has de-wetted.

(a) Flux residues tend to remain adhered to non-wetted areas, but to drain away from a continuous wetted film of solder. Non-wetting is usually the result of an inadequate time-temperature cycle, or of insufficient flux activity, for the particular surface being soldered. Non-wetting may also arise in small areas for other 'mechanical' reasons, such as splashed solder resist, or soldering near large components which act as heat sinks.

(b) A very small amount of non-wetting may reveal itself merely as pinholes or porosity in the solder film, and if examined under a microscope only exposed base metal will be visible at the base of these pores. If such porosity is not concentrated in one area, and constitutes less than about 5% of the total area soldered, it may be considered that this is the limit of acceptability.

11.1.2 **De-wetting.** De-wetting of a solder film presents an appearance similar to that of water on a greasy surface. De-wetting occurs when a surface is initially wetted and the solder adheres to the surface, but after a time the solder coating retracts because of radial increase in contact angle, causing the solder to collect into discrete globules and ridges. The remainder of the base metal surface, however, remains a solder colour, but has a very small thickness of solder retained on it and poor solderability.

(a) De-wetting arises from contamination of the base metal surface, e.g. by embedded cleaning abrasive, and normally causes a breakdown of fillets between terminations and board connectors. Although the breakdown of the fillet may not be considered as harmful, it, in fact, results in poor formation of soldered joints. If the area being soldered is restricted by a layer of solder resist (e.g. surrounding a land) excessive solder applied to the land may mask de-wetting, and simply embed the component termination, thus giving the appearance of a good soldered joint. The poor wetting may, however, result in interface penetration by atmospheric gases, leading to a high electrical resistance in the soldered connection.

NOTE: In extreme cases of surface contamination, non-wetting and de-wetting occur simultaneously. In such cases it is most unlikely that any time-temperature combination will be effective in producing a good joint.

11.2 **Soldering Technique Defects.** Guidance on some of the more common defects which may result from the soldering technique and method adopted, is given in the following paragraphs.

11.2.1 **Icicling.** Icicles of solder arise mostly in wave soldering operations in which the printed wiring board approaches and leaves the solder bath in the horizontal plane. The icicles form as a result of the 'peel back' of the solder film from the board as it leaves the solder, the solder solidifying before it can flow back into the bath. The situation may be alleviated by the use of an angled exit from the solder, but such factors as the temperature, speed of movement and flux composition are also involved in curing this trouble. Impurities in the solder may also give rise to an excessive amount of icicling.

11.2.2 **Bridging.** A bridge of solder between adjacent termination wires or conductors on printed wiring boards may arise from the same cause as icicles. Other causes may be, incorrect spacing of conductors, or the formation of oxide film on the surface of the solder. The type of flux employed may also have an influence.

11.2.3 **Porosity.** Pores in a soldered joint may arise from solidification of the solder around an escaping bubble of air or flux vapour. This hole or cavity may be small, and it may not reduce the volume of the solder fillet by any significant extent, in which case, it may be considered as a minor defect, but larger holes or cavities may be a reason for rejection of the work. It should be remembered that, when liquid solder solidifies, there is approximately 3% contraction in its volume. This contraction will produce a small surface indentation, which is distinctly different from a cavity which has been produced by the entrapment of air or flux vapour. Normal shrinkage may not be considered as a cause for rejection.

(a) In the case of boards with plated-through holes (see paragraph 13.2) bad cases of blistering of the solder fillets on a land, or of cavities or incomplete fillets, may arise if the quality of the plating of a hole is poor. Incomplete plating of the surface of the hole first allows the escape of gases or water vapour from the laminate itself, and also allows liquid flux to adhere to the hole. This subsequently gives rise to vapour as the solder above the flux solidifies, forming blisters in the solder. The application of excessive flux, or the inadequate predrying of the flux in order to remove solvents, may also cause porosity in the fillets of joints.

11.2.4 **Dull, Rough or Gritty Solder.** Soldered joints made with tin-lead alloys, and especially those in the region of the eutectic composition, will normally present a brilliant and smooth appearance. If the surface of the solder is dull, and the normal smooth contour of the joint is correct, it is an indication that some vibration or movement had occurred as the solder solidified. If the surface of the solder is also irregular and rough, this may indicate that the soldering temperature was too low, thus producing a 'cold' joint.

(a) A matt or dull finish on the solder can arise when impurities are present in a solder. The presence of copper will produce a dull surface when its concentration is not in excess of approximately 0·3 to 0·4%. Above 0·5% (in 60/40 solder) the silicon, lead and copper eutectic composition is exceeded, and primary crystals of copper and tin intermetallic compound will be present, giving a gritty or sandy appearance to the solder. The presence of other elements, such as gold, silver, iron and nickel, in excess of their solubility can also produce similar effects.

11.3 **Solder Contamination.** Molten solder readily dissolves many metals with which it comes in contact, so that after a period of use the solder is not as pure as when it was originally charged into the appropriate soldering machine. Solder should be checked for contamination at a frequency consistent with usage, and should be changed when necessary. The metals most likely to produce solder impurity are as follows:—

(a) **Copper.** Copper is unavoidably picked up by solder, from the conductor patterns of boards and from component lead wires. The amount of copper which is soluble in the solder bath depends on the tin content and on the temperature of the solder. Some solder alloys have a higher tolerance for copper than others, and at the normal working temperature can hold 0·5% of copper in solution before the gritty intermetallic compound appears in the melt. Normally, however, a limit of 0·3% of contamination should not, and need not, be exceeded.

(b) **Zinc and Cadmium.** Contamination with zinc can arise from an excessive number of brass tags or other brass components on the underside of circuit boards. A few brass pins per board do no harm, but, if brass surfaces are large, pre-tinning after nickel plating of surfaces will prevent zinc from being picked up. Cadmium contamination is mainly caused by cadmium-plated components coming into contact with the molten solder. The maximum permissible limits of zinc and cadmium contamination are 0·002% and 0·003% respectively.

(c) **Iron.** The iron content should not exceed 0·003%. Iron may be picked up from tinned steel components, such as tags or board chassis, or from the inside of the solder bath if this has become tinned through the use of an unsuitable cover flux, or through severe overheating.

(d) **Silver and Gold.** Silver and gold from plated components, or from plated wiring, can also contaminate molten solder, and, in small solder baths particularly, contamination can be serious.

11.3.1 **Dross and Oxides.** All molten solder in contact with the atmosphere immediately forms a thin layer of oxide, and the rate at which it forms and grows depends on the extent to which the dross-forming impurities, zinc and cadmium, may be present in the solder, and also on whether or not the solder is being overheated. A constantly moving solder surface also causes more rapid oxidation and dross formation than a static surface, and the rate at which it forms depends on the solder wave form; high or cascading waves will produce more dross than low, smooth waves.

(a) There are no additives which can be directly mixed with solder for effective prevention, or reduction, of oxidation in a wave soldering machine, or in static baths; low impurity levels are the only effective way to reduce drossing. Certain anti-oxidant oils, or cover fluxes, are available which, when applied to the solder surface, help to reduce to a minimum the area which is exposed to the atmosphere. These oils are normally used in conjunction with those wave soldering machines which incorporate a special unit for either injecting oil through the solder and onto the surface of the wave, or applying a thin film of oil directly on to the top of the wave. In both cases the oil drains down the sides of the wave, and spreads out, so protecting the solder in the bath. For static solder baths, and for wave soldering machines which do not incorporate an oil injection unit, it is usual to apply a small quantity of cover flux to the surface of the solder.

12 SOLDER RESISTS These are organic coatings which are designed for use on both rigid and flexible printed circuits, to mask off those areas where soldering is not required. Some important advantages of the use of solder resists are as follows:—

(a) Elimination of bridging and icicling between closely spaced conductors and mountings.

(b) Protection is afforded against corrosion and contamination during storage, handling and subsequent life of the circuit.

(c) Flexibility of circuit patterns is maintained since a resist flexes with the conducting material.

(d) The surface resistance values of the circuit patterns are improved.

(e) Minimizing of solder contamination from large surfaces of copper and other plating materials, thereby maintaining a high level of solder purity and an extension of bath life.

(f) Heat distortion is minimized, since a resist acts as a heat barrier.

12.1 **Application.** Solder resists are applied by a silk screening process, in a manner similar to that used for circuit printing (see paragraph 7.1.1). The mesh size of the screen should be such as to permit adequate application of resist, so that after curing it will afford maximum resistance to the heat of soldering and to the solvency of fluxes. For some types of resist, their characteristics can be varied to suit particular applications, e.g. to achieve a better cure when curing facilities are limited in capability. A better cure may be achieved by adding to the resist the appropriate amount of catalyst specified by the manufacturer for the particular case.

12.2 **Curing.** The curing of resists is carried out by passing the circuits through ovens which incorporate both a conveyor system and exhaust blowers which will remove the fumes given off by the resists. The method of heating the ovens depends on the particular design, but generally it is either by infra-red radiant heaters or by normal convection heating. Infra-red radiant heating will normally cure the resist in 1 to 2 minutes, with the copper surface temperature raised between 132°C and 160°C. The curing time under convection heating is approximately 1 hour, with the copper surface temperature raised between 132°C and 143°C. In both cases, curing is followed by forced cooling, with air at room temperature for a period of 1½ to 2 minutes.

12.2.1 The effectiveness of the cure may be checked by applying a drop of toluene to the resist, and, after a period of 1 minute, removing the toluene, and checking that the resist is intact. Alternatively, cure effectiveness may be checked by applying a flux to the resist, and, after dipping the board in a solder bath for 8–10 seconds, observing that there is no solder adhering to the surface of the resist.

12.3 **Insulation Resistance.** After curing, the insulation resistance of the resist should be measured, since the resist becomes an integral part of the printed circuit. The resistance values vary with the actual circuit pattern, the type of base material, the type of resist, and on the cure.

12.4 **Storage.** Resists should be stored in closed containers in a cool, dry, place, and in accordance with any other conditions, appropriate to the storage limiting period, imposed by the manufacturers. Resists have a tendency to thicken during storage, but their normal flow characteristic can be restored by stirring.

13 PLATING OF PRINTED WIRING CIRCUITS Plating finishes for printed wiring circuits are used as aids to the performance of circuits under specific conditions of use, and are not intended to be decorative. The choice of finish is, therefore, governed strictly by the functional and environmental conditions in which the circuit will be used. In many cases, different parts of a circuit may be subjected to different conditions of use, and provided there is clear demarcation between these parts, they can be plated with the appropriate finishes. A typical example of this differential plating method, is a circuit that is tin/lead plated for solderability over the component area, and nickel/gold plated for durability on edge-connector finger contacts.

13.1 **Plating Materials and Thicknesses.** The materials and thicknesses which are specified for a circuit, depend on a number of factors, of which the following are of importance: (a) the environmental conditions; (b) durability (in the case of edge-connector finger contacts); (c) contact resistance; (d) solderability; (e) metallic migration; (f) alloying, and (g) cost. To be considered, also, is the fact that with boards printed by the etching process (see paragraph 7.1), conductors increase in width as well as in thickness. In some metals (e.g. solder) these effects can be more pronounced than in others. The applications of the materials most commonly used for plating are given in the following paragraphs.

13.1.1 **Copper.** Copper plating is normally restricted to circuits with plated-through holes, since this is the means by which durability is given to the holes. The surface plating thickness of the circuit tracks is governed by the plating thickness required for the walls of the holes. Typical specified values are between the limits 0·001 in. and 0·004 in. Because of its poor resistance to climatic changes, copper plating is usually followed by a protective plating process.

13.1.2 **Solder.** This is the standard finish over copper for circuits requiring environmental protection coupled with good solderability. Plating thickness limits between 0·0003 in. and 0·002 in. are common. A disadvantage of solder plating, is that greater difficulty is experienced with growth in width of conductors during plating, than with any other finish.

13.1.3 **Nickel.** Nickel is usually applied as an undercoat for either rhodium or gold, not only to provide a hard base for edge-connector finger contacts and switching contact surfaces, but also to reduce the thickness of rhodium or gold needed to ensure minimum porosity. The plating thickness limits are generally between 0·000025 in. and 0·0004 in.

13.1.4 **Rhodium.** This is the hardest noble metal in common use as a plating material, and, because of its extremely good resistance to wear and corrosion, it is applied principally to switching contact surfaces. Two different plating processes may be adopted: (a) plating directly onto copper; the thickness of the rhodium deposit being generally between 0·00005 in. and 0·0002 in., (b) plating over a nickel undercoat 0·00025 in. thick, with the rhodium deposit thickness limited to 0·000015 in. The latter process is widely adopted, since it avoids the higher internal stress which is inevitable with thicker rhodium deposits.

13.1.5 **Silver.** Silver is particularly suitable for power switching where low contact resistance is important. Thicknesses of up to 0·0005 in. are frequently used to provide good solderability with reasonable corrosion resistance. Under some combinations of humidity and direct current potential, difficulty can be caused by the migration of silver between unconnected conductors.

13.1.6 **Gold.** Gold gives a durable, low-resistance, corrosion-resistant finish with a long service life, and it is commonly used for edge-connector finger contacts, even where other parts of the circuit are plated with a different finish. Its solderability is good, but there is a danger of formation of a brittle gold/tin alloy, which can cause 'dry joints' under extreme conditions of service. This embrittlement can be minimized by restricting the plating thickness to below 0·0001 in., but for non-porous surfaces, a thickness of about 0·0002 in. is usually regarded as the minimum.

13.1.7 **Palladium.** Of the noble metals recommended for plating, palladium exhibits the most useful combination of properties. It is the least costly, the deposit is comparatively free from internal stress, and it is completely impermeable at thicknesses of 0·0002 in. and above. It is applied principally to contacts and switching surfaces, the plating thickness limits being generally between 0·00005 in. and 0·00025 in.

13.2 **Through-hole Plating.** Through-hole plating is a process which is widely employed to provide a conducting surface in the holes of single-sided and double-sided boards, and also to provide a land or pad for the connection of components. This process is generally used with epoxy/glass laminates, since they can be plated more easily than those of the phenolic/paper type. When holes have been punched or drilled in the appropriate positions, the board is pre-treated, and a thin layer of copper (approximately 0·000020 in.) is deposited on its surfaces by an electroless copper plating process. The desired thickness of copper through the holes, and on the other surfaces of the board, is then built up by normal electrolytic deposition of copper pyrophosphate. Following this deposition, a photo-sensitive resist is applied, and the circuit pattern is exposed and etched. A typical sequence of the steps involved in the process is illustrated in Figure 9.

13.2.1 Boards should be inspected to ensure that the positions and sizes of the holes conform to the circuit design requirements. The plating of hole walls should also be visually inspected against a strong light, for signs of inclusions that may affect the insertion of component leads or their solderability. There should be no apparent failure of the plating, but pinholes are permissible provided that the total of their maximum dimensions, relative to hole diameter, does not exceed the specified limit. A typical value is 25% of the hole diameter.

14 ORGANIC PROTECTIVE COATINGS After printed wiring boards have been manufactured, organic coatings are applied to their surfaces, to protect them from oxidation and contamination. The coatings vary, depending on whether temporary protection is required, e.g. for maintaining clean copper surfaces during normal handling prior to soldering, or, whether permanent protection is to be applied after soldering for protecting the circuit and components from subsequent environmental contaminants. For temporary protection the coating is usually of a rosin-based type which does not require removal before soldering, since it also serves as a flux. Permanent protective coatings are usually epoxide- or polyurethane-based resin having exceptionally low oxygen absorption, high humidity resistance, and resistance to cracking and discoloration. The coatings for both types of protection may be applied with a brush, a spray, a roller, or by a dipping operation. The procedures to be adopted for each of these operations may vary with the type and proprietary brand of coating. Details of coating procedures are contained in the relevant data sheets, or technical bulletins, which are issued by the coating manufacturers; reference should, therefore, be made to such documents before coating operations are carried out.

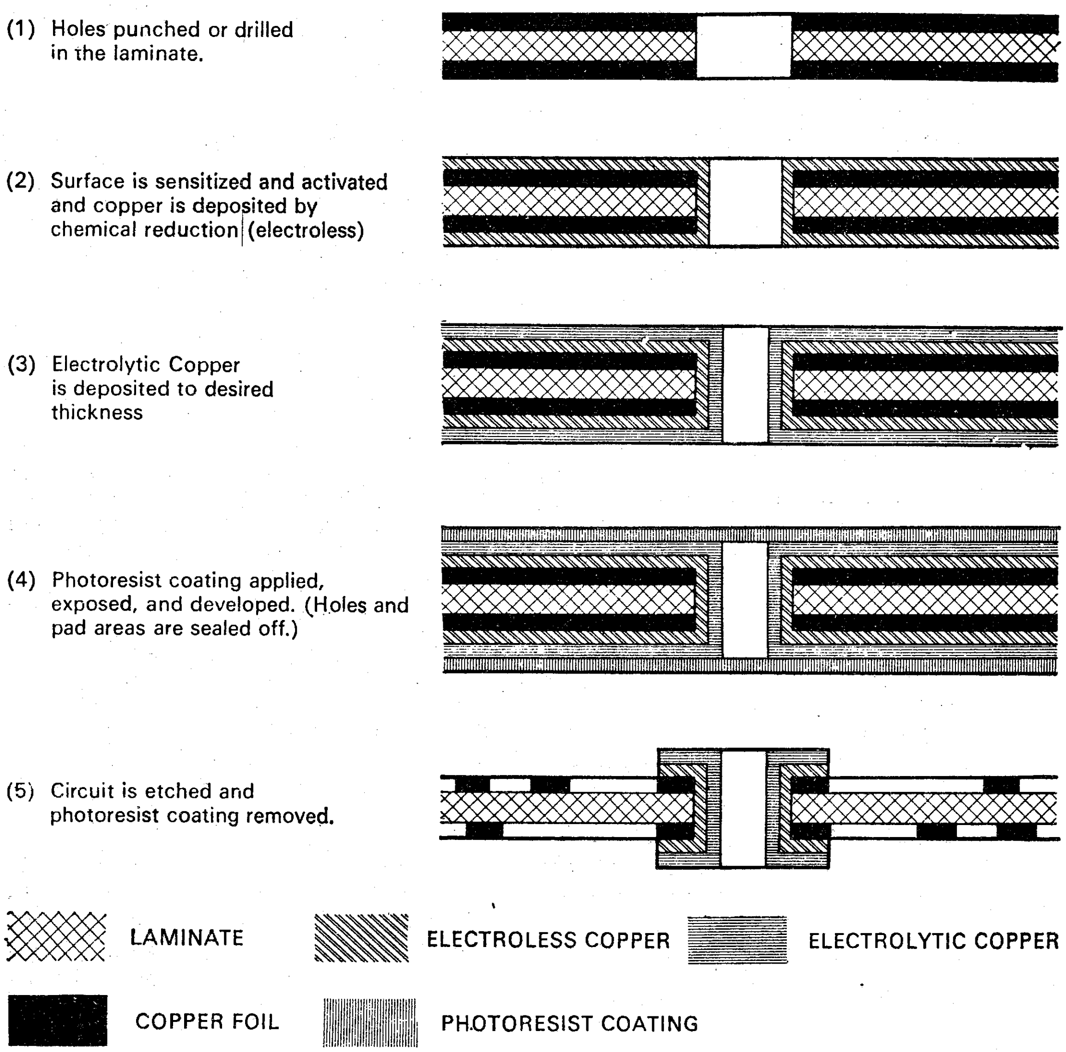


Figure 9 THROUGH-HOLE PLATING

15 MULTI-LAYER CIRCUITS In order to save weight and space, and to provide for the interconnection of integrated circuits (which are a feature of a large majority of electronic equipment) the relevant circuits are assembled as a multi-layer moulded package, consisting of three or more single and/or double-sided printed boards and insulating layers of 'prepreg' material (see paragraph 2.1). The fundamentals of a typical moulding and curing operation are outlined in the following paragraphs.

15.1 **Registration Jig.** The individual boards and 'prepreg' material are first cleaned, to exclude all extraneous particles, and are then assembled in their appropriate sequence on the polished surface of a steel plate, which forms the bottom of a registration jig. The function of the jig is to permit accurate register of the positions of individual circuits, and for this purpose locating pins pass through holes around the periphery of the circuit boards and 'prepreg' material. The number and positioning of locating holes depend on the size and complexity of the circuit. When the complete assembly has been mounted onto the locating pins, a second steel plate of the registration jig is fixed in position, with its polished surface adjacent to the multi-layer assembly.

15.2 **Moulding and Curing.** The moulding and curing cycle of the multi-layer assembly is carried out by loading the registration jig into a hydraulically operated laminating press equipped with flat and parallel platens. The platens are designed to be heated (either by steam or electricity) up to a temperature of 175°C, and the hydraulic pressure on the area of the multi-layer assembly is selected and controlled within the range 10–500 lbf/in². Uniform distribution of heat and pressure is facilitated by placing several sheets of dry paper padding between the registration jig and the platens. If the press platens are electrically heated, the press is loaded hot at 170°–175°C; but, in the case of steam heating, which gives a faster temperature rise, the press may be loaded either hot or cold. A temperature gradient occurs across the surface of most hot press platens, the edges being up to 5°C cooler than the centre, depending on the platen size. To minimize the effect of this temperature variation on the curing of the multi-layer assembly, the dimensions of the platens are normally designed to be greater than those of the multi-layer assembly, so that the cooler areas of the platen surfaces are not in contact with the assembly.

15.2.1 The hydraulic pressure is controlled initially, at a specific value between 10 and 30 lbf/in² on the area of the multi-layer assembly. When the temperature within the assembly rises to 110°–120°C, the resin in the 'prepreg' layers begins to flow; this usually occurs after 3 to 7 minutes. The resin gels after a further 1 to 3 minutes, and, immediately before this occurs, the hydraulic pressure is increased to a specific value between 250 and 300 lbf/in². This pressure is maintained throughout the remainder of the cycle. The full laminating pressure is largely dependent on the width of the circuit conductors to be moulded, and while a high pressure is desirable, to ensure that the multi-layer assembly is completely void-free, if it is too high, narrow conductors in the circuit pattern are liable to become distorted. A pressure within the range 200–300 lbf/in² is generally recommended for conductors which are less than 0·020 in. wide. During pressing the temperature within the assembly continues to rise to a maximum of 160°–170°C, and this temperature is maintained for 35–40 minutes, to ensure that the resin in the 'prepreg' layers is fully cured (generally referred to as the 'C'-stage). The platens are then cooled (while under pressure) and the multi-layer assembly is removed from the press when the temperature within the assembly has fallen to below 50°C.

15.2.2 The exact point at which the resin gels, depends on the rate of temperature rise within the multi-layer assembly, which, in turn, depends on the rate of temperature rise in the press platens, and on the thickness and the nature of the padding between the registration jig and platens. Another factor is that although the 'prepreg' material is manufactured to have specific flow properties, there may be slight but significant variations in these properties between batches of material. This is particularly true where the material has been stored for several months prior to use, and, for this reason, the resin flow of a sample of each batch of material should be measured, not only on receipt, but also before use.

15.2.3 The stage at which full laminating pressure should be applied may be determined by either of two methods. In the first and simplest method, the resin which is exuded from the edges of the multi-layer assembly is probed as it progresses to a gelled state. The second method, which is the one preferred, requires control by temperature measurement. A thermocouple element is inserted into the middle layers of the assembly, in the trim or test area around the edges. The thermocouple is connected to an accurate temperature indicator, and, from the readings obtained, a temperature/time curve is plotted, from which an accurate forecast can be made of the point at which full laminating pressure should be applied. A curing cycle curve based on the moulding and curing of some typical circuit laminates and 'prepreg' materials is shown in Figure 10.

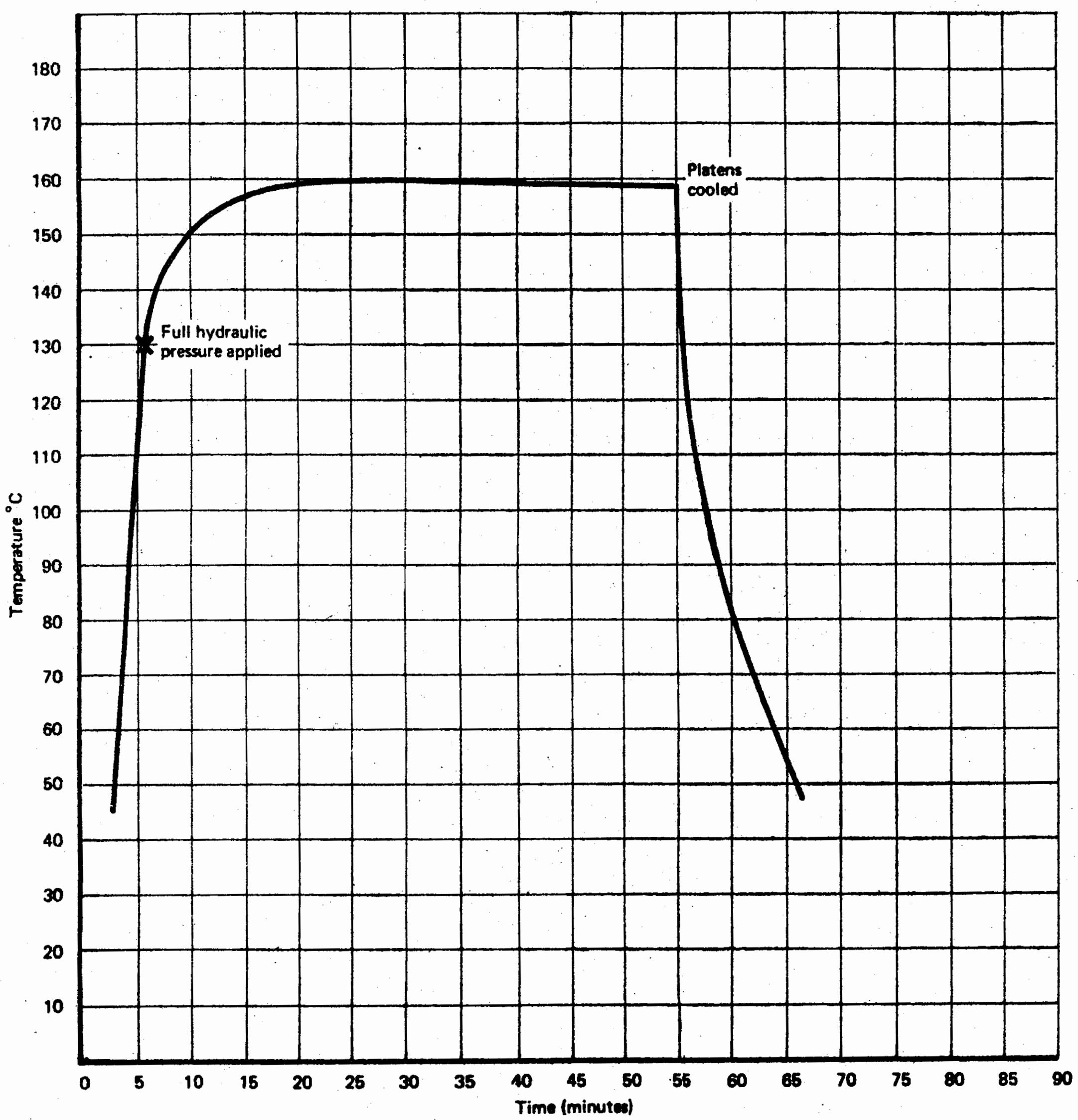


Figure 10 CURING CYCLE

15.3 **Thickness of Layers.** A multi-layer assembly can be made up from a number of different thicknesses of laminates, but a more economical design results when all layers are of the same thickness. The number and thicknesses of layers are limited by the following:—

(a) The required overall thickness

(b) The minimum thickness of the boards in the assembly.

(c) The thickness that has to be allowed for 'prepreg' ('B'-stage) material.

(d) The smallest hole-diameter required.

Laminate manufacturers normally quote an overall laminate thickness and the increases in percentage thickness with increasing core thickness. These criteria are an important consideration when the final thickness of the multi-layer assembly is a critical factor; for example, edge-connectors, wrapped pins, etc., may necessitate a final thickness tolerance as small as ± 0·007 in.

15.3.1 The interconnection between layers is achieved by the connection of the through-hole plating to the thin rim of copper which is exposed where the hole passes through each copper layer. In some cases, interconnection is made by means of solid copper pillars which, unlike plated-through holes are not necessarily extended through the entire board; they can be routed around conductors of intermediate layers and brought to the surface at any convenient point.

15.3.2 The number and thickness of 'prepreg' material layers used is an important factor in the moulding and curing operation. Too few layers could result in an unreliable bond; but too many could limit the number of layers which could be designed into a given thickness, or result in an unacceptable overall thickness for a particular circuit configuration. Excessive 'prepreg' material can also cause inconsistent resin flow during the curing operation.

15.3.3 The overall thickness of a multi-layer assembly can be adjusted by adding or subtracting layers of 'prepreg' material, so long as the specified thickness limitations are not exceeded. Design requirements may require a spacing between copper foils that is thicker than the maximum allowable thickness of 'prepreg' material. In such cases, an unclad laminate can be used as an insulator between the facing foils. The thickness of this insulator should not exceed 0·020 in.

15.4 **Inspection of Circuits.** On completion of the moulding and curing cycle, multi-layer circuit assemblies should be inspected for the following:—

(a) Blistering, which can be caused by insufficient pressure, or by excessive moisture absorption.

(b) Air voids at the interfaces of individual circuits. Any voids which are found in the layers, particularly in areas immediately adjacent to copper conductors, are likely to have been caused either by excessive pressure, or by full laminating pressure which has been applied too late.

(c) Variations in thickness, which may be the result of non-uniform circuit configuration, or of the press platens not being parallel.

(d) Resin-starved areas, which have been caused by excessive resin flow or pressure.

(e) Resin bead around the edges of the multi-layer assembly; the absence of such a bead is an indication that the application of full laminating pressure had been delayed.

(f) Blotching of surfaces; this may be caused by low resin content of the 'prepreg' material, or by excessive laminating pressure.

(g) Register of circuit layers; in assemblies which use epoxy glass laminates, visual checks may be made, but the accuracy of this means of measurement is poor. In critical circuit applications, and for greater accuracy generally, the circuits should be inspected by X-ray techniques.

(h) Circuit continuity; if open circuits are found during continuity tests, this is usually the result of excessive laminating pressure having been applied before the resin in the 'prepreg' material layers had gelled.

16 FLEXIBLE PRINTED WIRING CIRCUITS Unlike rigid printed wiring boards, flexible circuits serve only as a means of interconnecting units, particularly those which require to be moved relative to each other, and those which may be mounted in different planes. Flexible circuits also permit easier assembly and higher density packaging of units. Flexible circuits are of laminated form, consisting of a flexible base insulation material (e.g. polyester, epoxy glass cloth and polyimide) copper foil, and an insulating coverlay of the same material as the base. Any one of three basic methods may be used in their production; die stamping, fusion bonding, and etched foil.

16.1 **Die Stamping.** In the die stamping method, the copper foil is coated with a heat-sensitive adhesive, and is brought into contact with the base material. A heated metal cutting die is used to cut the copper foil into the required conductor pattern, the stroke of the die being controlled to prevent damage to the base material. Heat from the die activates the adhesive, which then bonds the copper conductor pattern to the base material. The coverlay, which is adhesive coated and pre-punched, is laid over the exposed copper, and is thermally bonded to it. Finally, the circuit is blanked into its finished shape, and is completely encapsulated, except for exposed contacts and termination pads.

16.2 **Fusion Bonding.** In the fusion bonding method the base material is brought almost to its melting point, so that it fuses on to the copper foil. The conductor pattern is then etched in a similar manner to rigid printed wiring boards (see paragraph 7.1). A coverlay is then applied and the whole circuit is placed in a heated platen press. When the platen temperature approaches the melting point of the base material, pressure is applied, in order to effect a bond between the three layers of the circuit. When the assembly is cooled and removed from the press, the required pads and terminations, necessary for the soldering of connections, are provided by removing, by abrasion, the coverlay and the oxide coating on the copper. The circuit is then blanked into its final shape.

16.3 **Etched Foil.** In the etched foil method, the circuit pattern is produced in the same way as for rigid printed wiring boards (see paragraph 7.1), and the three layers are thermally bonded to each other by means of adhesive coatings. Holes are either drilled or pierced in the coverlay, prior to the bonding operation, in order to expose the connection and termination points on the circuit pattern.

MMC/1-2

Issue 1.

14*th November*, 1975.

AIRCRAFT

MICROMINIATURE CIRCUITS

PRINTED WIRING BOARD REPAIRS

1 INTRODUCTION When in service, a printed wiring board assembly may fail for either a mechanical or electrical reason, and once the reason has been established, an accurate assessment should be made not only of the actual repair task to be accomplished, but also of peripheral supporting tasks. The importance of such assessment and of decisions subsequently taken cannot be over emphasized, since the aim of any repair scheme should be to restore a board assembly to its original design and manufacturing specifications.

NOTE: Information on printed wiring techniques, manufacturing methods and inspection procedures, is given in Leaflet MMC/1-1.

1.1 Although there is a basic similarity between certain repair procedures for printed wiring boards and for the more conventional electrical equipment, e.g. the soldering of connections, it does not necessarily follow that there can always be a common application of requisite tools, equipment and skill. There are a number of factors to be taken into account, e.g. the type of board, its construction, circuit track configuration, the degree of miniaturisation, nature and handling of components, soldering temperatures and frequency of application. All such factors highlight the need for adopting a specialized approach to repair tasks, the selection and training of personnel being of particular importance (see also paragraph 7).

1.2 Detailed procedures are laid down in the relevant manufacturer's repair and design specifications, or in specifications which are otherwise approved, and reference should, therefore, always be made to the appropriate documents before undertaking a repair. Attention should also be paid to any limits which may have been imposed on the amount of repair work permissible on any one board.

1.3 The information given in this Leaflet, although based on methods which have proved to be practical and acceptable in service when carried out by properly trained personnel, is intended to serve only as a general guide to the establishment of certain minimum standards of repair.

1.4 The Leaflet is set out as follows:—

2 DAMAGE TO BOARDS The details given in the following paragraphs are intended as a general guide to damage leading to possible failures of printed wiring boards.

2.1 **Cracks.** Cracks in the base laminate can produce mechanical distortion and breakage in conductor tracks, and no repair should be attempted. A cracked board should always be replaced by a serviceable unit.

2.2 **Warping.** A warped board may sometimes be repaired by clamping it flat in a special jig and then subjecting it to high temperature cycling in an oven for a specified time period account being taken of temperature effects on the board and its components. It is, however, recommended that a warped board be replaced by a serviceable unit because, apart from the need for specialized equipment beyond the scope of a normal workshop, it is not uncommon for warping to re-occur.

NOTE: A warp should not be taken out of a board by manually bending it against the warp, as this can cause cracking or breaking of the board and conductor tracks.

2.3 **Blistering.** This is a fault which may occur in the base laminate of a board, particularly a multilayer type of board. It may affect the electrical characteristics of a circuit and the strength of a board, in which case the board should be removed and returned to the manufacturers, since the fault can only be rectified by the application of specialized repair techniques. If tests indicate that circuit electrical characteristics are not affected by blistering, no further action is necessary.

2.4 **Damaged Tracks.** The damage may be any of the following which reduce the cross-sectional area of the track below the tolerance of the original specification: (a) complete break (b) scratches (c) nicks (d) pinholes. A fault which may also occur is lifting or separation of a section of track from the base laminate, leading to fracture under subsequent in-service vibration. Repairs are possible (see paragraphs 3.2 to 3.4) the choice of method depending largely on the size of gap to be bridged, size of damaged area to be covered, and on whether the board is of the single-sided, double-sided or multilayer type. If a damaged track forms part of a coil or a high frequency section of a circuit, a repair is not recommended, since it may produce adverse effects on the electrical characteristics of the circuit.

2.5 **Damaged Lands.** Damage to lands may be either scratches, nicks or lifting from the base laminate, and it is possible for repairs to be carried out (see paragraph 3.5).

NOTE: The term 'land' is used throughout this Leaflet to define the portion of conductive pattern which provides connection or attachment of components. In some repair specifications the alternative term 'pad' may also be used.

2.6 **Edge-contact Damage.** Edge-contacts may be damaged either by scratches, nicks or lifting from the base laminate; in such cases a board should be replaced. If, in service, a board cannot be replaced, a repair should only be sanctioned on the understanding that replacement will be effected at the earliest opportunity.

2.7 **Defective Plated-through Holes.** Holes may become defective as a result of damage to plating, particularly when removing or replacing components. Re-plating of holes is not possible, but repairs may be carried out by by-passing the defective holes (see paragraph 3.6).

2.8 **Defective Eyelets.** Replacement of a defective eyelet, e.g. one having a deformed barrel, should only be carried out when a new eyelet of the same type, and special insertion tool, are available. If an eyelet shows evidence of poor connection at conductor tracks, but is otherwise satisfactory, it may be re-soldered (see paragraph 3.7).

2.9 **Damaged Encapsulant Coatings.** A damaged coating may allow an ingress of moisture causing a subsequent breakdown of the electrical characteristics of the board or failure of a component. It is, therefore, very important to replace a damaged coating as soon as possible after the board has been thoroughly dried out. The replacement method to be adopted depends on the type of board, its application, and type of encapsulant material; reference should, therefore, always be made to the relevant specifications and instructions.

NOTE: In referring to encapsulant coatings, the alternative term 'conformal' may be used in some repair specifications.

3 TYPICAL REPAIR METHODS All repair procedures should comply with those laid down in relevant specifications, or with procedures which are otherwise approved. When repairs are carried out by properly trained personnel repaired boards should continue to meet their performance specifications and have a high standard of reliability. The details given in the following paragraphs relate to typical repair methods which have proved to be practical in operation and acceptable in service. In some cases, alternative methods of repair are possible for the same defect, and these are noted, where appropriate.

NOTE: Information on other procedures associated with repair methods, i.e. encapsulant coating removal, soldering and de-soldering, is given in paragraphs 6, 7 and 8 respectively.

3.1 **General Precautions.** The following general precautions must be observed when carrying out repairs. Additional precautions appropriate to a specific repair process are given in the relevant paragraphs.

(a) A board requiring either removal and replacement of a component, or any form of repair should, where practical, be removed from its associated equipment.

(b) Repairs should only be carried out when the cause of a failure is known, since otherwise the failure may be indicative of latent weaknesses elsewhere in a board.

(c) Handling of boards should be kept to a minimum to avoid changes in electrical characteristics. Boards should be handled by their edges, except at those points where connector contacts are provided.

(d) Contacts formed on the edges of boards should be protected from damage throughout repair operations. This may be done by placing a suitably-cut length of U-shaped PVC extrusion over them. Tubes of the type used for the storage of dual-in-line packages may also provide protection when suitably prepared. Adhesive tapes should not be used, as parts of the adhesive may be left on the contacts and form undesirable dirt traps.

(e) Boards should be firmly held in a suitable jig or holding fixture to prevent shock or damage.

(f) Assembled boards should not be handled by the components, as this may cause breaking of leads and pulling away of conductor tracks.

(g) When a repair method is to be applied to conductor tracks or to the outer layers of a multilayer board, care must be taken to ensure that the method chosen does not include any operation liable to cause damage to plated-through holes, or internal conductors.

(h) When a repair or component installation procedure requires that holes be drilled through printed tracks and base laminate, drilling should be done from the track side. Care should be taken to ensure that the track is not lifted, and that no damage is caused to components or tracks on the other side of the board.

NOTE: Unless programmed drilling machines, or machines of similar capability are available, no attempt should be made to drill a multilayer board.

(j) The repair of defective plated-through holes in multilayer boards should not be carried out other than in accordance with an approved repair scheme.

(k) In cases where bonding of wire by means of a rubber compound is specified, e.g. in broken track repair schemes, the suitability of certain silicon rubber compounds should be verified, particularly where bonding is to be done in the vicinity of precious metal contacts or leads.

(l) Certain semiconductor components are particularly susceptible to thermal shock, and, in some cases, to transient static voltage also. The relevant manufacturer's instructions should be followed without exception. Where any doubt exists, or where instructions are not available, heat sinks and precautions against transient static voltages should be applied. (See also paragraphs 4.4.1 (c) and 7.3.5).

(m) A lead pencil, or other conductive material which can leave a conductive residue, should not be used to trace circuitry, or be allowed to touch any part of a board or component.

(n) Care should always be taken to ensure that a board and its components will not be adversely affected by the use of any of the solvents specified for cleaning purposes and for the removal of particular types of encapsulant coating (see also paragraph 6.1). Chlorinated solvents, for example, should not be used on silicone covered or bonded components, or where there is a risk of component identification markings being removed. In addition, strict attention must be paid to the toxic effects of various solvents, and, therefore, to any special ventilation requirements in the places where repairs are carried out. Solvents commonly used are listed in Appendix 2 to this leaflet for guidance only; reference should always be made to specific approved procedures and instructions.

(o) Conductor widths and spacings should not be reduced below any tolerances associated with the method specified for the repair of damaged or defective conductor tracks.

(p) Boards awaiting repair, or replacement in equipment after repair, should be placed in vertically partitioned racks, so that they are stored supported on their edges and not stacked.

(q) Application of soldering tools to joints should be limited to the time necessary to achieve a successful melt of the solder (see also paragraph 7.3.1). If the correct bit profile is chosen, together with fine gauge solder, a successful joint will normally be achieved in 3 seconds. Excessive heating, or mechanical stress exerted during the application of heat, are common causes of land and conductor track de-bonding.

(r) If it is necessary to apply a sideways force to a component termination, to assist in component removal, it should be done with the minimum of stress applied to the board's conductor track or land. In the event that there is too great a risk of damage being done to a conductor track or land, the component should be removed by cutting its leads and removing the leads separately.

(s) On completion of a repair, flux residue or other debris should be removed using a suitable solvent and brush, and the repair should be visually inspected to ensure that it has been carried out neatly and efficiently, and that no further damage has been caused in effecting the repair. Encapsulant coatings removed prior to the repair procedure, should be made good by applying coatings conforming to the original, or to an approved alternative material specification. The inspection, and the re-coating process, where appropriate, should be followed by tests to establish that electrical characteristics have not been impaired in an unacceptable manner, and also that the board performs its overall function in accordance with the original design requirements.

3.2 **Broken Tracks.** There are several methods which may be adopted for the repair of broken tracks and details of these are given in the following paragraphs. The choice of any one is dependent on such factors as the size of gap to be bridged, width of tracks, position of components relative to tracks, relative positions of tracks on opposing sides of the board, the effects that bridging may have on the vibration characteristics of the board, and whether edge sealing of holes is necessary following drilling. Reference should, therefore, always be made to the design specifications and the approved repair schemes.

NOTE: The reasons why breaks have occurred should always be established in order that remedial action relevant to board design or handling procedures, can subsequently be taken.

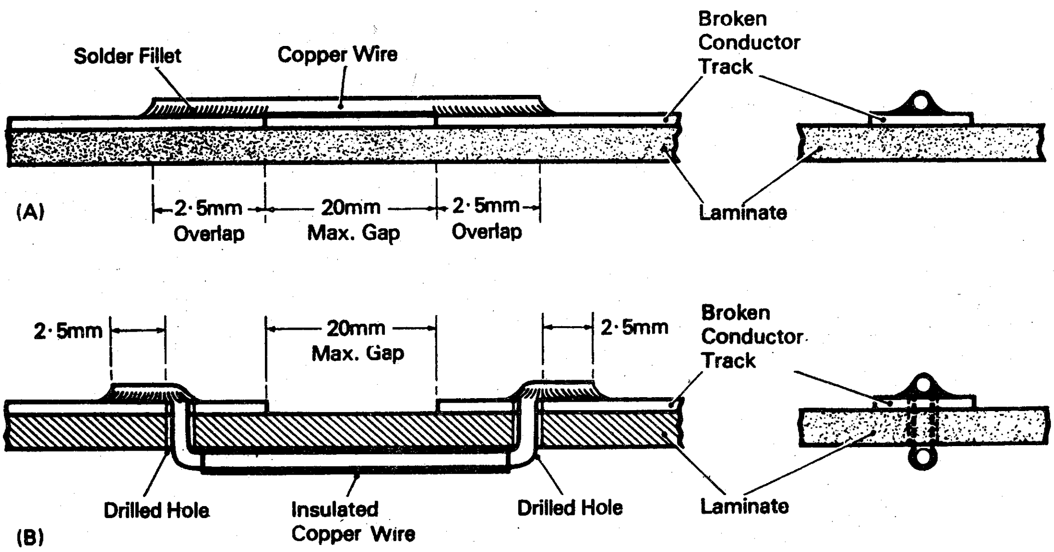


Figure 1 BROKEN TRACK REPAIRS—WIRE METHOD

3.2.1 **Method A.** This method should be used where the gap distance to be bridged is less than 20 mm (0·75 in) the repair being effected by soldering a piece of bare tinned-copper wire to the track either side of the gap as shown in Figure 1 (A).

(a) The track at both sides of the gap should first be cleaned, for at least 6·5 mm (0·25 in), with a rubber eraser and then with a suitable solvent cleaner. The cleaned areas should then be tinned, and a piece of tinned-copper wire, cut long enough to overlap the gap by a nominal 2·5 mm (0·1 in), should be soldered to the track. Care should be taken to ensure that the wire is in contact with the track along its centreline and for the whole length of the overlap, and also that it spans the gap evenly.

NOTE: The size of wire selected depends on the width of the track to be repaired, and as dimensions can vary between types of board, reference should always be made to the approved repair schemes.

(b) Figure 1 (B) shows an alternative method for use when it is necessary for the wire to be run for the major part of its length on the board surface opposite to that of the broken track. In this case, the wire is passed through holes which should be drilled through the track and base laminate, and the ends of leads clinched and soldered to the sections of track each side of the break. The wire should be insulated or sleeved and bonded to the board by means of a suitable epoxy type adhesive or a rubber compound (see also paragraph 3.1 (k)).

NOTE: Drilling of holes should always be done from the track side of the board taking care that no damage is caused to components or tracks on the opposite side.

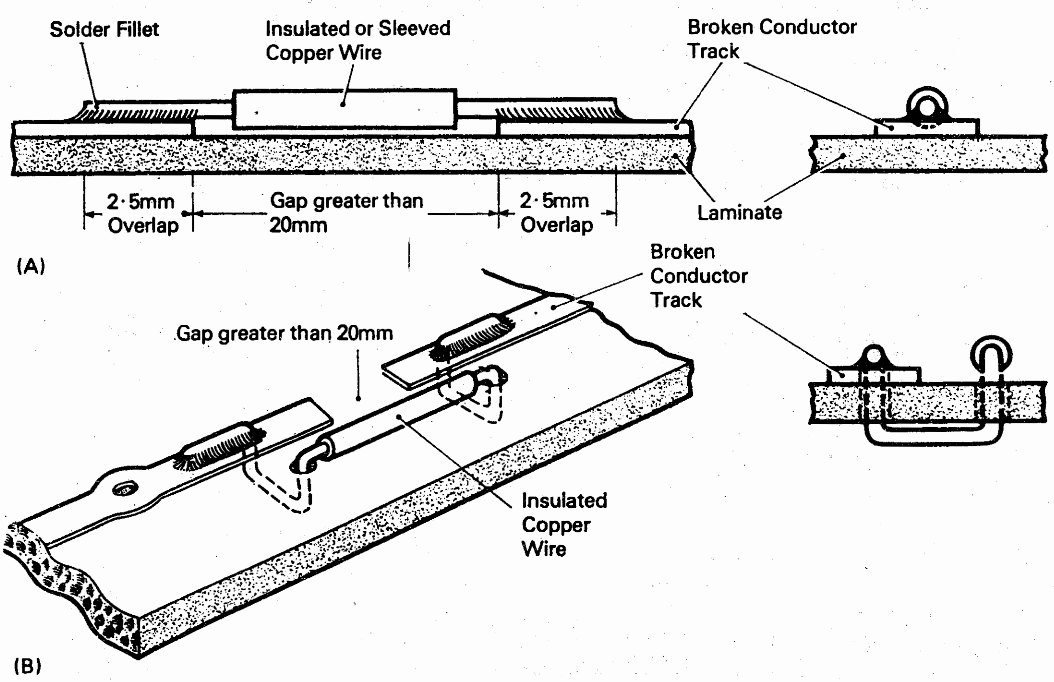


Figure 2 BROKEN TRACK REPAIRS (Gaps greater than 20 mm)

3.2.2 **Method B.** When the gap distance resulting from a break or missing section of track is greater than 20 mm (0·75 in), the wire method described in paragraph 3.2.1 (a) can be used except that the wire should be of the insulated type, or alternatively, bare wire with an appropriate length of sleeving (see Figure 2 (A)). If there is any possibility of the wire lifting, or vibrating to cause lifting of the track to which it is attached, the wire should be bonded to the board at convenient points by means of a suitable epoxy type adhesive or a rubber compound (see also paragraph 3.1 (k)).

(a) Insulated or sleeved wire may also be run on the opposite side of a broken track in a manner similar to that described in paragraph 3.2.1 (b) or on the same side as the track and parallel to it (see Figure 2 (B)). In the latter case, it is necessary

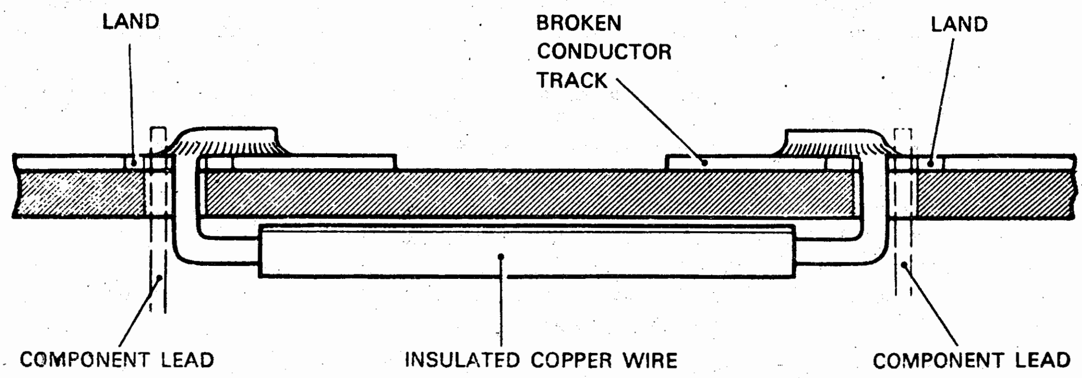


Figure 3 REPAIR OF BREAK BETWEEN LANDS to drill two additional holes in the base laminate. This method may also be used for the repair of a break on the component side of a double-sided board, or to by-pass a component in instances where its removal could cause further damage.

3.2.3 **Method C.** If a break has occurred between lands it may be repaired by soldering the ends of an insulated wire into the lands (see Figure 3). Before adopting this method however, it should be ensured that the wire ends and component leads can share the same land holes. The wire should be run on the side opposite to the track and, before soldering, the ends should be clinched to the track. If there is any possibility of the insulated portion of the wire lifting, or vibrating to cause lifting of

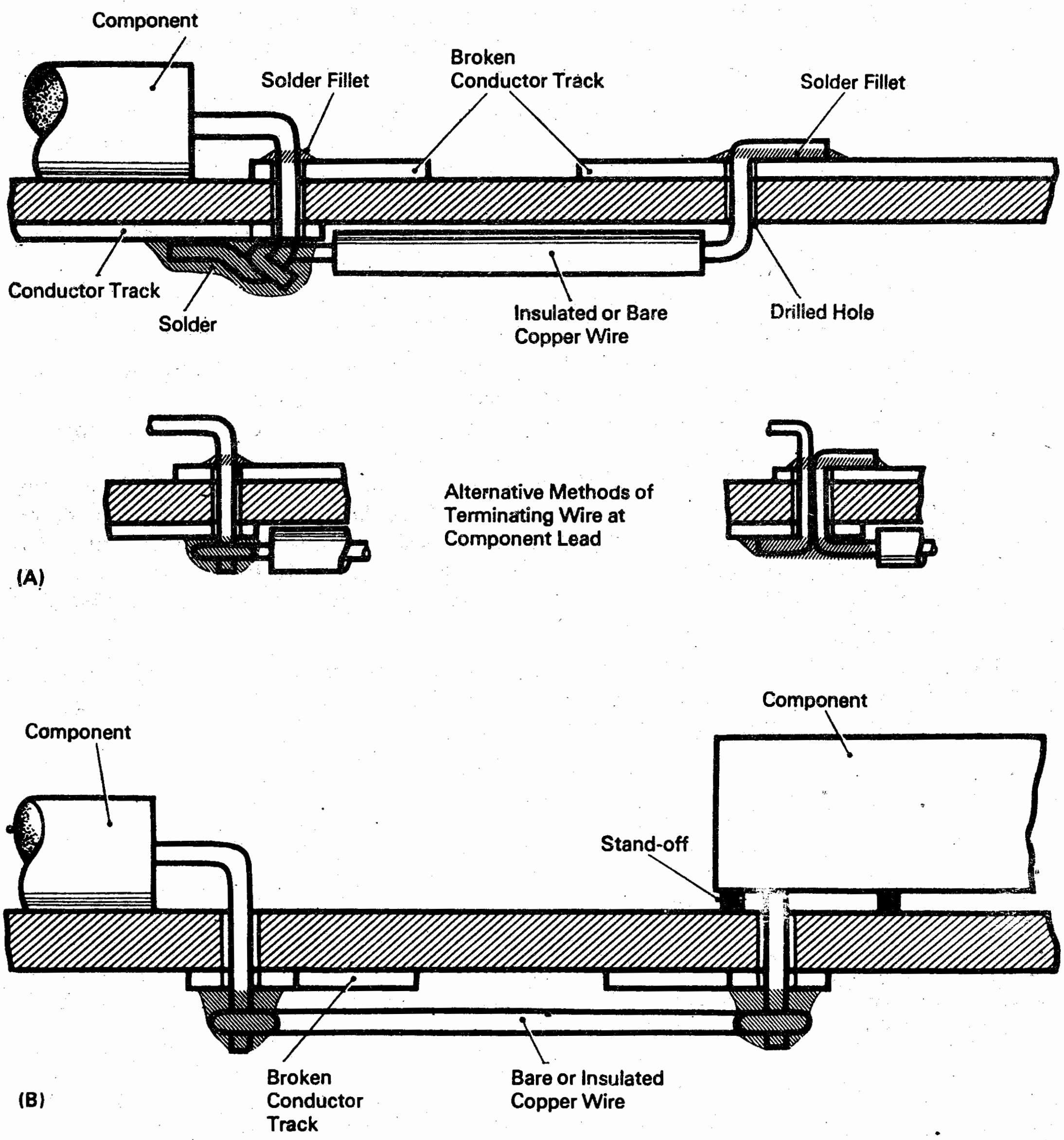


Figure 4 TRACK REPAIRS BETWEEN COMPONENTS the track to which it is attached, the wire should be bonded to the board at convenient points by means of a suitable epoxy type adhesive or a rubber compound (see also paragraph 3.1 (k)).

3.2.4 **Method D.** This method may be adopted for the repair of a broken track between components, particularly in cases where the ends of component leads can serve as connecting points for the repair wire, and also where it is not possible for the repair wire and component leads to share the same land holes (see Figure 4). The wire should be insulated or sleeved if the exposed length is greater than 5 mm (0·2 in).

(a) In the example shown at Figure 4 (A) connection is required between tracks on opposing sides of the board, so that it is necessary to drill a hole through the base laminate to accommodate one end of the wire. Depending on relative positions of tracks and components, the hole may be drilled so that the wire comes up either alongside the track or through it.

(b) The end of the wire is then clinched to the track and soldered. The other end of the wire is looped around and soldered to the component lead, which, depending on the length available, should either be clinched to its appropriate track, or extend from the hole as a short stub.

(c) Where it is possible for the repair wire and component lead to share the same hole, the end of the wire should be clinched to the track and soldered.

(d) The example shown at Figure 4 (B), is one in which the repair wire is connected and soldered to the leads of two components sharing a common track.

3.2.5 **Method E.** By this method (see Figure 5) a repair can be effected by soldering a strip of pre-tinned copper foil to the conductor track, but it should not be used for bridging gap distances greater than 10 mm (0·4 in). It should also be limited to track widths greater than 0·5 mm (0·02 in) to overcome difficulties in handling very narrow strips of foil. The foil should be approximately three-quarters of the track width to permit a well-formed fillet of solder along the overlapping ends, and should be of the same thickness as that of the board foil. Because the strip of copper foil on its own lacks mechanical strength it should be bonded to the board by applying a suitable epoxy adhesive or rubber compound to the area of the gap (see also paragraph 3.1 (k)).

3.3 **Scratched Tracks.** Tracks which are scratched, nicked, or have pinholes in them should be repaired, preferably, by the copper foil strip method referred to in paragraph 3.2.5, with the exception that bonding is not necessary.

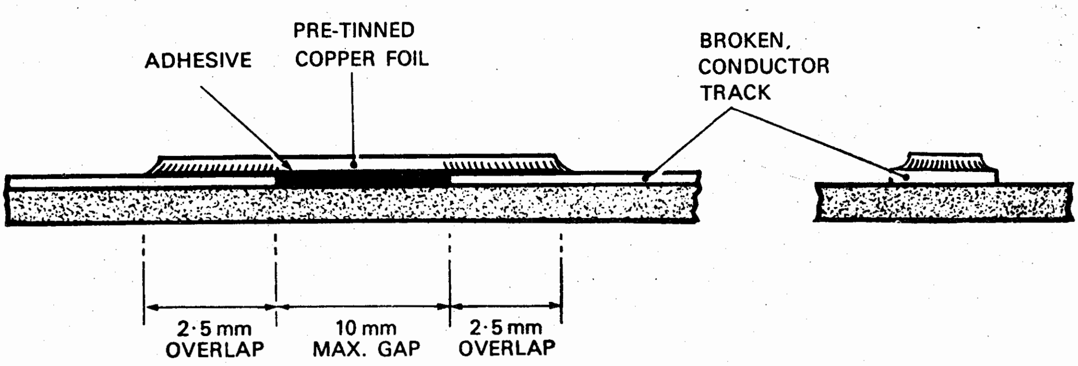


Figure 5 BROKEN TRACK REPAIR—COPPER FOIL METHOD

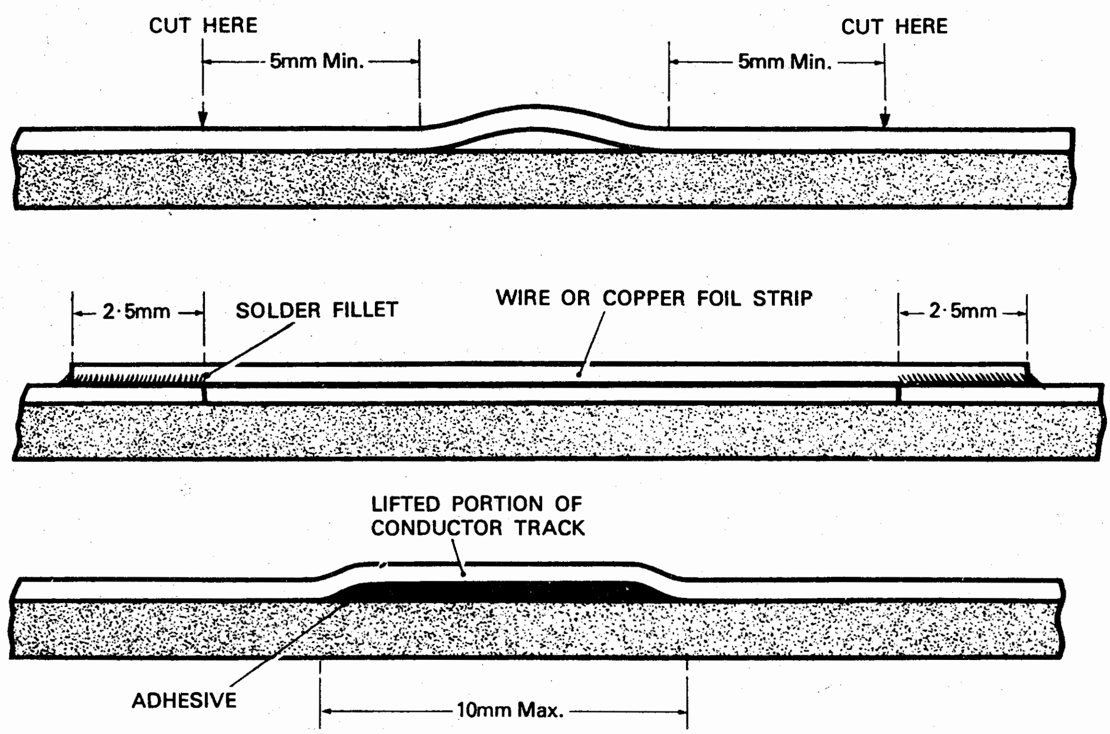


Figure 6 REPAIR OF A LIFTED TRACK

3.4 **Lifted Tracks.** Where a section of track has lifted or separated from the surface of a board (including the outer surfaces of a multilayer board) then, depending on the length of section concerned, and also whether the track is unbroken, it can be repaired either with a length of wire, or by restoring the adhesive bond (see Figure 6).

3.4.1 The wire method is normally used when the length of a lifted section exceeds 10 mm (0·4 in) and the repair procedure is similar to that described in paragraph 3.2.1.

3.4.2 For the adhesive bond method, the encapsulant coating should first be removed from the lifted section (see paragraph 6) and, with a scalpel, the section should be cut at least 5 mm (0·2 in) from each side of the point of lifting and then removed. Care should be taken not to cut the surface of the board. The board surface thus exposed should be cleaned with a solvent to remove all traces of adhesive and fragments of encapsulant coating. The ends of the track sections to be joined should also be cleaned for at least 6·4 mm (0·25 in) by means of a rubber eraser and solvent. After tinning the cleaned areas, a length of the appropriate diameter wire, or a length of copper foil strip, should be soldered to the track ends with a nominal overlap of 2·5 mm (0·1 in).

(a) If the length of a lifted section of track is less than 10 mm (0·4 in) and the track is undamaged, a repair should be effected by restoring the adhesive bond between the lifted section and the board. Following the removal of encapsulant coating, the underside of the lifted section and the exposed area of board should be cleaned with solvent applied by means of a small camel hair brush. Epoxy adhesive, prepared in accordance with the manufacturer's instructions, should then be forced under the entire length of the lifted section by means of a small plastic spatula. Alternatively, a suitably-cut piece of solid-film adhesive may be placed in position.

(b) After application of adhesive, the lifted section should be pressed firmly into contact with the board, excess adhesive removed, and the bonded joint then cured in accordance with the appropriate adhesive specification. Particular attention should be paid to curing temperature requirements, since some components and boards may not withstand the temperature limits that suit adhesives.

(c) If a lifted track has become stretched or otherwise damaged, the most effective repair technique is to cut out the relevant section of track, and to bridge the resulting gap, using either of the methods described in paragraphs 3.4.1 and 3.4.2.

3.5 **Damaged and Lifted Lands.** When tearing, cutting, scoring or lifting of lands has occurred, repairs may be carried out. This also applies to boards with plated-through holes provided that lifting has not damaged the hole plating. Some typical procedures are described in the following paragraphs.

Figure 7 REPAIR OF DAMAGED LAND—OVERLAID LAND

3.5.1 **Damaged Lands.** If a land has been damaged and its adhesion to the board is satisfactory, it may be overlaid with a second land, as shown in Figure 7. The replacement land should be cut so that it overlaps the board conductor track for at least 2·5 mm (0·1 in). Solder should first be extracted from the damaged land, which should then be cleaned with a rubber eraser and solvent cleaner. The adjoining section of conductor track should also be cleaned for a length of approximately 13 to 15 mm (0·5 to 0·6 in). The upper surfaces of the damaged land and cleaned section of track, and the under surface of the replacement land, should be tinned, and, after positioning the land over the damaged area, it should be soldered in position. In order to maintain alignment of the holes during soldering, a non-solderable guide pin should be inserted through them.

NOTE: When soldering a lead or pin of a component into the holes, care must be taken to ensure that the position of the replacement land is not disturbed.

(a) Figure 8 illustrates three different repair methods which involve cutting and removal of a damaged land from the board, and substitution of either a short length of bare tinned-copper wire or a replacement land. Lands should be cut from their tracks at points not greater than 5 mm (0·2 in) from the centres of the land holes. When cutting out lands, care should be taken not to score or cut the surface of the board.

(i) In the wire method shown in Figure 8 (A), the wire is looped around, and soldered to, the component lead, and is also soldered along the centre of the track with at least 10 mm (0·4 in) overlap. Additional support for the wire may be obtained by applying an adhesive fillet in the area of overlap. As in the case of a wire repair to a broken track, the size of wire selected depends on the width of track.

NOTE: This repair should be restricted to cases where the mechanical support achieved is adequate for the particular component, and where a board will not be subject to vibration.

(ii) In the method using a replacement land shown in Figure 8(B), the land should have sufficient conductor track attached to it to enable an overlap of at least 2·5 mm (0·1 in) to be soldered to the existing track. The existing track and the under surface of the replacement land should be cleaned and tinned; tinning of the replacement land should be limited to the overlapping portion only. With the aid of a non-solderable guide pin, the replacement land should then be positioned over the existing hole and soldered to the track. All traces of flux and dirt should be removed from between the under surface of the replacement land and the board, and the land should be lifted sufficiently to permit the smearing of a small quantity of adhesive on the land and board. The land should then be pressed firmly into contact with the board, excess adhesive should be removed and the bonded joint should be cured in accordance with the appropriate adhesive specification.

(iii) In some cases the method shown in Figure 8(C), may be adopted. After removal of the damaged land, a solderable pin should be inserted through the board hole and the component lead looped round and soldered to one end. A piece of bare tinned-copper wire is then soldered to the other end of the pin and to the conductor track in a manner similar to that described in sub-paragraph (i).

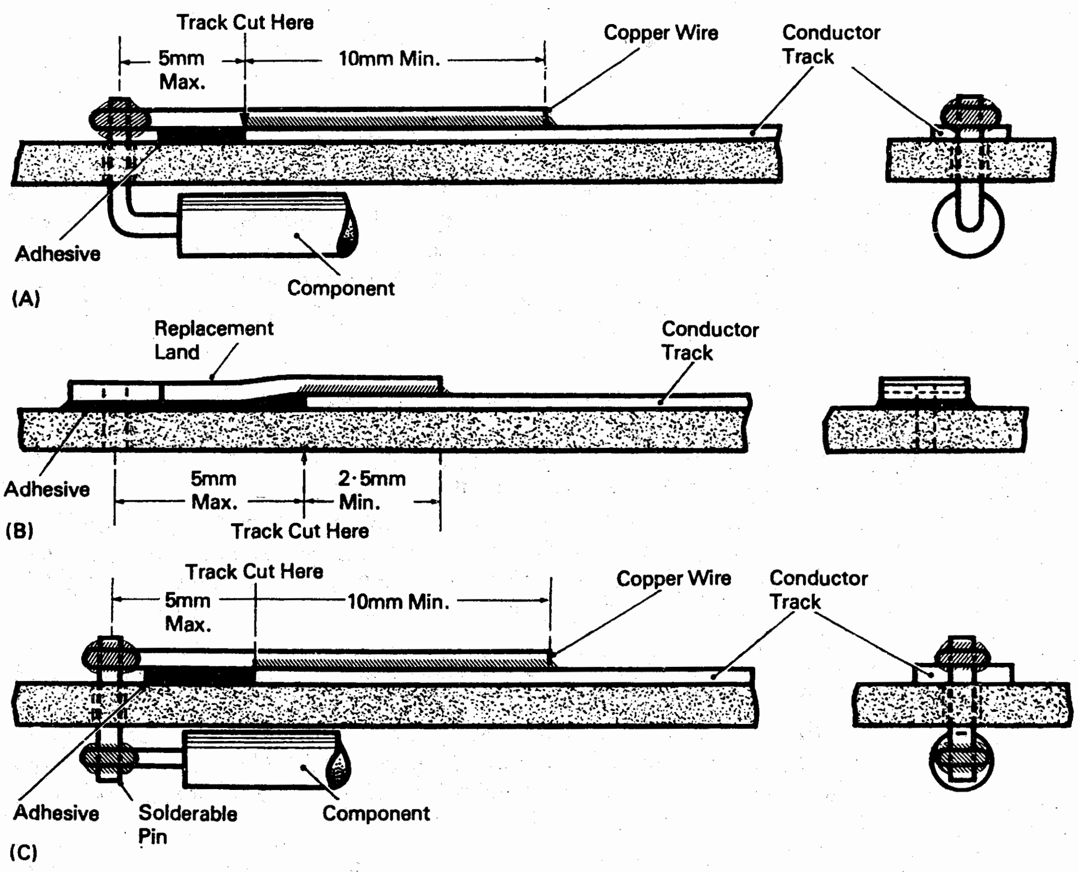


Figure 8 REPAIR OF DAMAGED LANDS

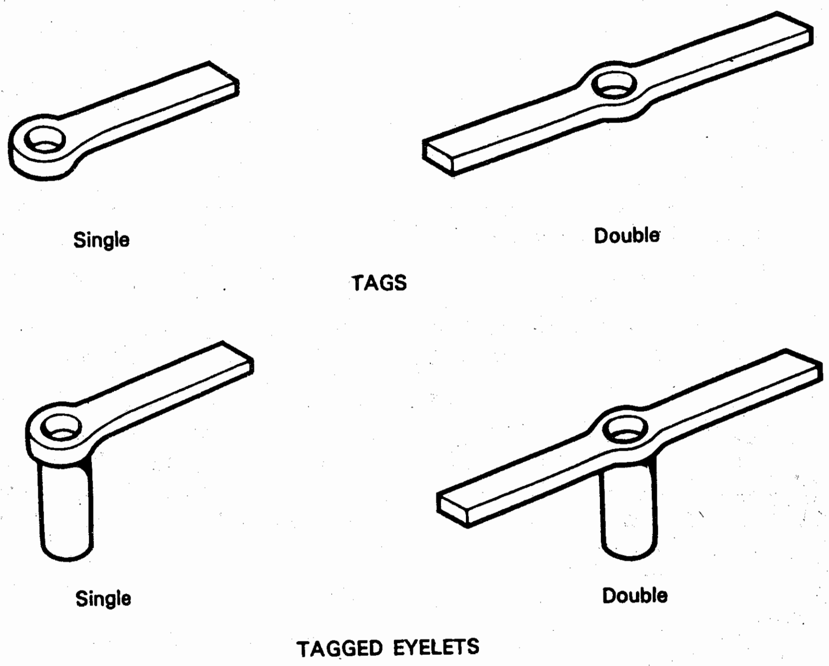


Figure 9 TAGS AND TAGGED EYELETS

(b) Soldered tags and tagged eyelets are commercially available in various forms and sizes, and these can also be used for the repair of damaged lands in the same way as an overlaid land or replacement land (see paragraphs 3.5.1 and 3.5.1 (a) (ii)). Some typical forms are shown in Figure 9. Holes should be drilled out to take eyelets which should then be installed using a commercially available machine or locally-made funnelling tool.

3.5.2 **Lifted Lands.** The procedures to be adopted for the repair of lifted lands depend on whether only partial lifting around a land hole, or complete lifting together with a section of track, has occurred. Before carrying out repairs, solder should be removed from lands and component leads should be disconnected.

(a) If a land has partially lifted, it should be carefully raised further from the board with a scalpel, and the undersurface and board surface should be cleaned free of flux and dirt. After the surfaces have thoroughly dried out, adhesive should be applied, and the joint should be bonded and cured.

NOTE: If a land becomes damaged when raising it from the board, or if lifting is still evident after curing, the land should be removed, and either a replacement land or a soldered tag should be fitted (see paragraphs 3.5.1 (a) (ii) and 3.5.1 (b)).

(b) Lands which have lifted together with a section of conductor track may be repaired by restoring the adhesive bond, or, preferably, by removing the land and track section and soldering on a replacement in the manner described in paragraph 3.5.1 (a) (ii).

(c) If a land has lifted under a mechanical connection, e.g. under the head of an eyelet, then provided that the connection is making adequate electrical contact, adhesive may be applied to the lifted portion and to the area immediately adjacent to it.

(d) In some cases, a land may serve a mechanical function only, i.e. to provide a solderable anchorage point for a component. If such a land is damaged or lifted, it should be removed and, after cleaning the area, an eyelet should be inserted in the hole and swaged to the board.

3.6 **Defective Plated-through Holes.** With the exception of holes in multilayer boards (see paragraph 3.1 (j)) repairs may be carried out, but the methods to be adopted vary, dependent on whether a hole is used solely as an interconnection between conductor tracks, i.e. without a component lead passing through it, or as a lead connecting point.

3.6.1 Three examples of repairs appropriate to defective interconnecting holes, are shown in Figure 10. In each case the hole is 'by-passed' by a short length of wire passing through extra holes drilled in the board laminate, and soldered to each

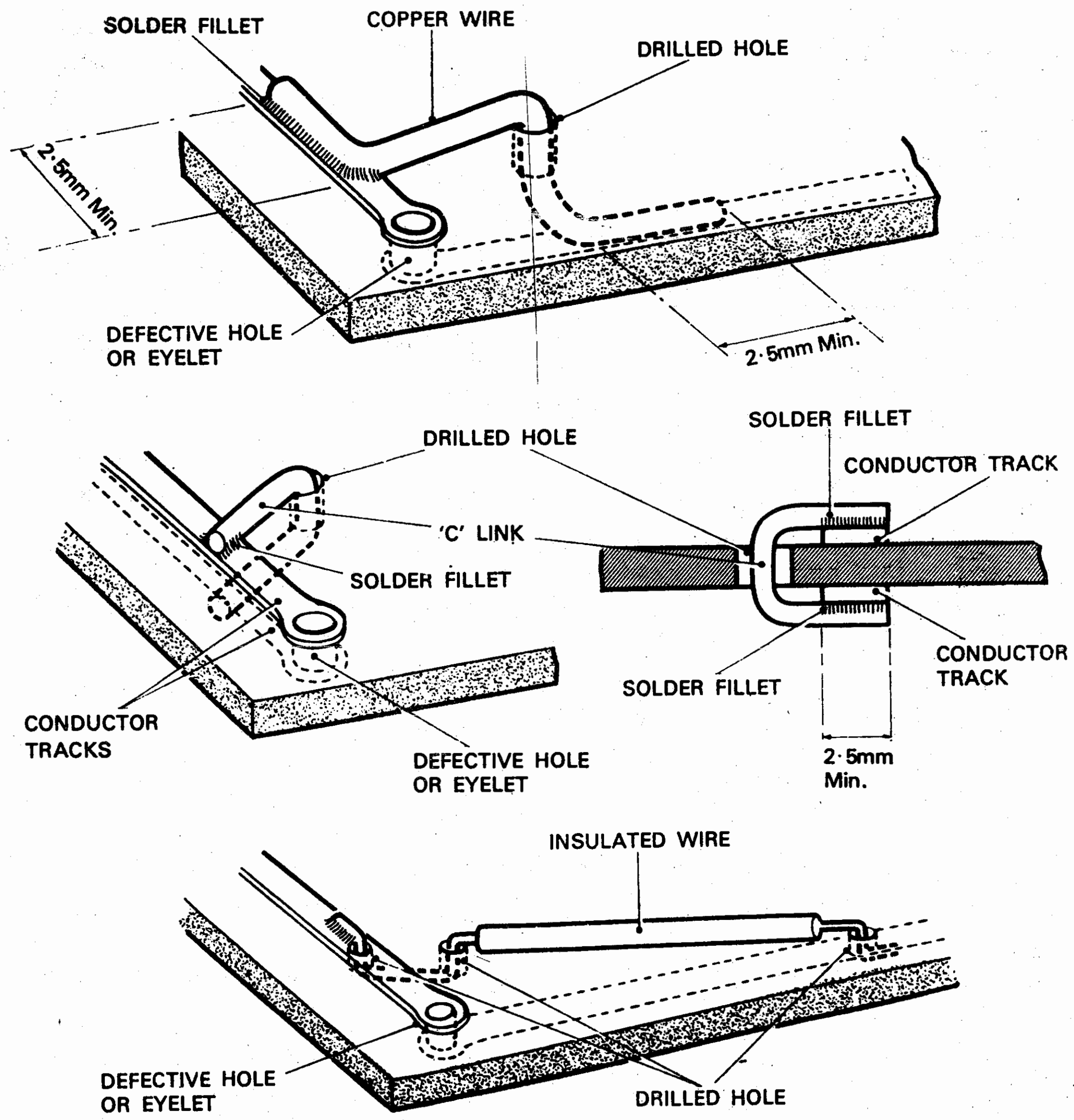


Figure 10 REPAIR OF DEFECTIVE PLATED-THROUGH HOLES AND EYELETS conductor track. In choosing a method, particular attention must be paid to the siting and drilling of holes in relation to the configuration and widths of conductor tracks, and to the position of components. The wire may be bare or insulated depending on the length required.

3.6.2 When a hole serving as a lead connecting point is damaged, and the hole size permits, a repair may be carried out by passing a wire link through it and soldering the ends of the link to the conductor tracks as illustrated in Figure 11. Any encapsulant coating should first be removed from the lands and from at least 2·5 mm (0·1 in) of connected conductor tracks (see paragraph 6). The component lead should then be removed by de-soldering with an extraction iron, ensuring that all excess solder is removed; this being of particular importance where gold plating is present. Following cleaning of the lands they should be re-tinned and the wire link clinched and soldered in place.

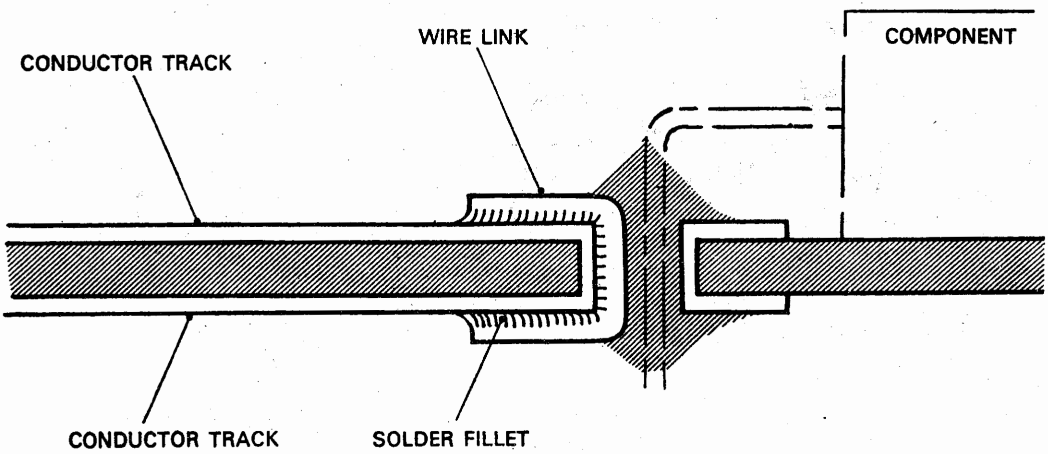


Figure 11 WIRE LINK REPAIR OF DEFECTIVE PLATED-THROUGH HOLE

3.7 **Defective Eyelets.** Eyelets showing evidence of damage, e.g. barrel deformation, may be drilled out using a drill of the same diameter as the hole in the board. Care should be taken to feed the drill slowly so as not to rotate the eyelet in the hole. The flanges should be de-soldered from the conductor tracks, and, after removal, a new eyelet of the same type should be inserted with an eyelet insertion tool, and soldered in place. Alternatively, and if track configurations and component spacing permit, damaged eyelets may be by-passed using either of the repair methods described in paragraph 3.6.1.

3.7.1 Eyelets which show evidence of poor electrical connection between flanges and conductor tracks, but are otherwise satisfactory, may be re-soldered.

4 COMPONENTS The components mounted and soldered to a printed wiring board vary not only functionally, but also in the method of lead termination. Some typical configurations are illustrated in Figure 12.

4.1 Resistors and capacitors are usually cylindrical, rectangular or disc shaped with round terminal wires protruding axially or radially from the body through rubber, plastic or glass seals. The wires are invariably of tin/lead plated copper. In the case of small semi-conductor diodes, which are similar in form to axial lead resistors, the wires are of nickel/iron alloy with a plating of nickel/gold to improve solderability.

4.2 Transistors provide a considerable variety in their mounting patterns. The wire terminations, or pins as in the case of power transistors, are brought out through the

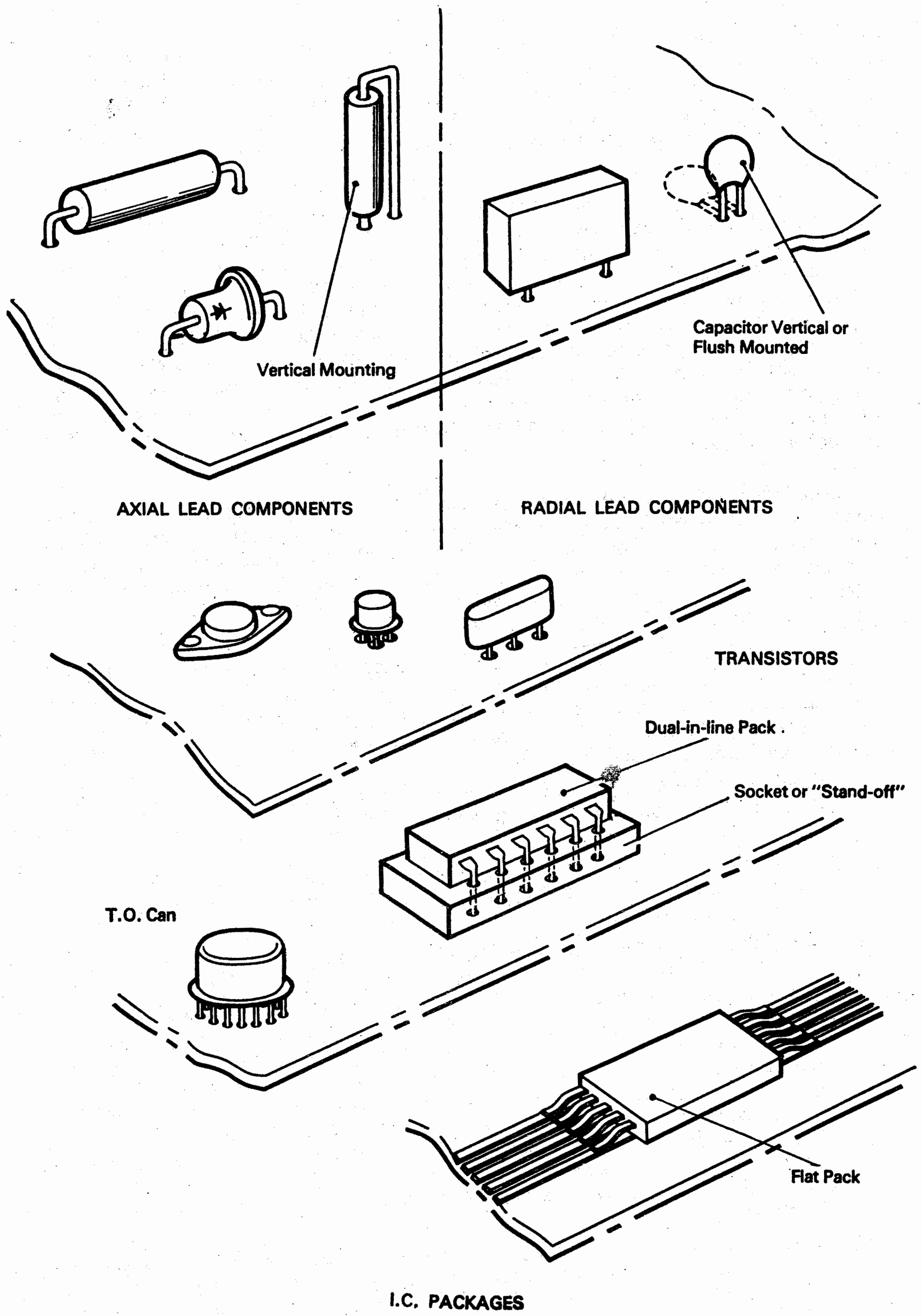


Figure 12 COMPONENT MOUNTING CONFIGURATIONS bases and are plated with either gold or tin/lead to improve solderability. When mounted on a board it is usual for transistors to be spaced a short distance away from the surface of the board by means of a socket (also referred to as a 'stand-off') designed to suit the particular transistor base and board hole spacing configurations. Power transistors are connected to a board via an integral heat sink, or by a separate heat sink specifically profiled for board use.

4.3 Integrated and other forms of microcircuit packages (I.C. packages) are complex components having, in some cases, as many as forty terminations and are often assembled in high density. The mounting patterns for these packages fall into three basic categories: (a) small circular cans (T.O. cans) with a number of wire terminations brought out through the base for connection to board holes, either directly or via a socket or 'stand-off' (b) low profile rectangular packages (known as 'flat packs') with two rows of flat terminations designed for lap solder mounting on conductor tracks, and (c) rectangular packages (known as 'dual-in-line' packages) with two rows of angled tag type terminations designed for through-hole mounting, either directly or by means of a socket. In some cases, dual-in-line packages may also be mounted in a similar manner to 'flat packs'.

4.4 **Installation and Removal.** The procedures for the installation and removal of components vary, depending on such factors as type of component, circuit configuration, and circuit application. Reference should, therefore, always be made to the appropriate manufacturer's repair specifications, modification or overhaul instructions. The details given in the following paragraphs are intended only as a guide to important common aspects of installation and removal.

4.4.1 **General.** When installing or removing components, boards should be firmly held in a suitable jig or holding fixture, and extreme care should be taken to avoid damaging conductor tracks, base laminates, or other components. Damage can be caused by rough handling of boards, improper tool usage, or application of excessive heat during soldering and de-soldering.

(a) Handling of components and assemblies should be kept to a minimum, and should be carried out by means of devices that will not damage leads or component cases.

(b) Unless instructions are given to the contrary, the de-soldering of component leads should be carried out by means of specifically designed tools (see paragraph 4.4.4 and paragraph 8).

(c) I.C. packages require careful handling during installation and removal, and the insertion and extraction tools specifically designed for such purposes should always be used (see paragraph 4.4.4). Certain types of I.C. packages and also certain semiconductor devices (e.g. MOS (metal-oxide-semiconductor) flat packs and FET (field effect transistors)) are particularly sensitive to the generation of static electricity in their unassembled state so that more specialised handling techniques are required. These special techniques include the use of special storage containers, workshop tables with earth-connected tops, lead-shorting clips, earth-connected tweezers, solder pots and lead-forming die presses (see also paragraph 5.6.10). Procedural details are always given in the instructions associated with the relevant packages and devices, and these should, therefore, always be strictly observed.

(d) Components should be installed in such a way that their identification markings, i.e. part numbers, serial numbers, electrical ratings, colour codings and symbols, are visible. If markings are inadvertently removed from a component, or its required location unavoidably obscures the markings, the component should, where practical, be re-marked to agree with the original markings.

(e) Unserviceable components mounted on heat sinks should be removed as a complete unit. In cases where the removal of a heat sink may cause damage to the board, the unserviceable component should be removed separately.

(f) If it is necessary to remove an unserviceable component which is close to other components, these components should first be removed to prevent them being damaged.

(g) Components which, by virtue of their construction, may entrap liquids or moisture, should not be mounted on circuit boards prior to either flow soldering or cleaning operations. This also applies to components which are sensitive to thermal or mechanical shock stresses.

(h) After installing components with pin-type connections, the pins should not be bent against the mounting land, as this makes it impossible to remove the component without damaging the board.

(j) When components, such as electrolytic capacitors, diodes and transistors, are to be mounted on a board, particular attention must be paid to their orientation to ensure correct polarity.

4.4.2 **Component Clearances.** Unless otherwise stated, components should be mounted so that there is adequate clearance between them and the board to permit both the escape of gases generated during soldering and the dissipation of heat generated by components, also to facilitate board cleaning and removal of flux residue. The method of obtaining the required clearance depends on the type of component, and, as will be seen in Figure 13, typical arrangements vary from specifically designed 'stand-offs' to simple spacer strips of nylon or other material. Depending on the requirements of a specification or a repair instruction, spacer strips may either be bonded to the circuit board or temporarily inserted until after a soldering operation has been completed. Strips should neither extend beyond the edges of components nor be too close to the leads of components.

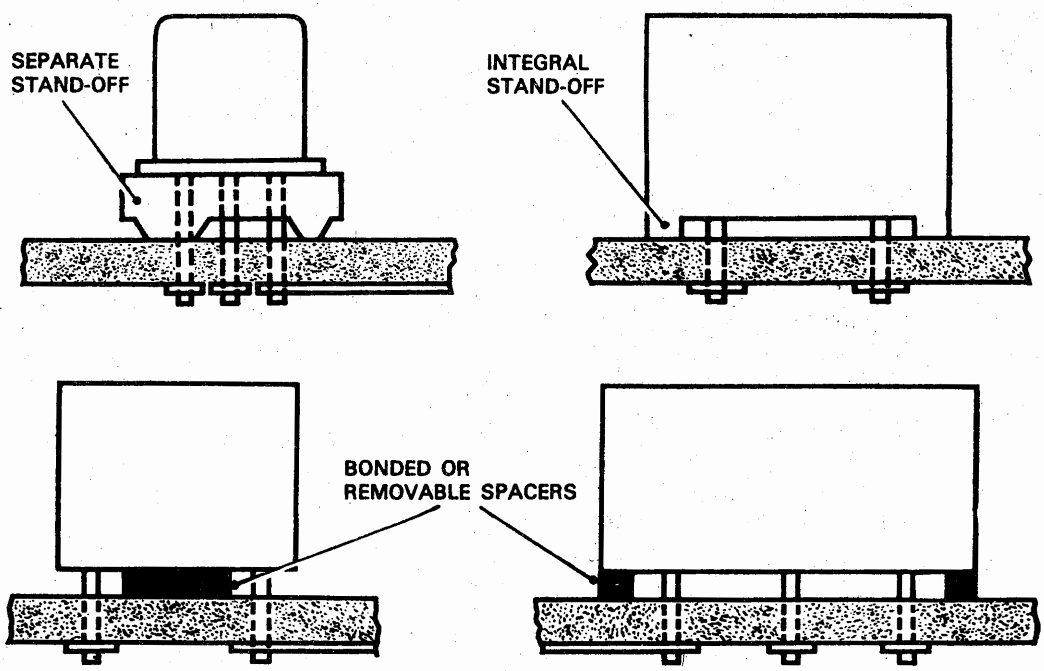


Figure 13 COMPONENT CLEARANCES

4.4.3 **Axial-lead Components.** Components with metal or conductive cases, should be covered with appropriate lengths of transparent insulating sleeving to prevent contact with circuit tracks or other metal parts. This also applies to certain types of diodes and capacitors encased in glass envelopes.

NOTE: Insulation tape should not be used instead of sleeving.

(a) The sleeving should be heated and shrunk on to the component so that it extends beyond the ends of the component body by about 1·5 mm to 3 mm (0·0625 in to 0·125 in).

NOTE: Sleeved components should not be mounted over soldered connections.

(b) Where it is necessary to mount an additional axial lead component on a board, e.g. a resistor or capacitor, it should first be ensured that sufficient space exists on the component side for positioning both the component and the extra jumper leads. Encapsulant coating should be removed from the relevant area of the board (see paragraph 6) and four holes should be drilled in the board to accommodate terminal pins and the jumper leads. The hole sizes and hole configuration should be in accordance with the appropriate installation drawing. An example of a typical mounting is shown in Figure 14.

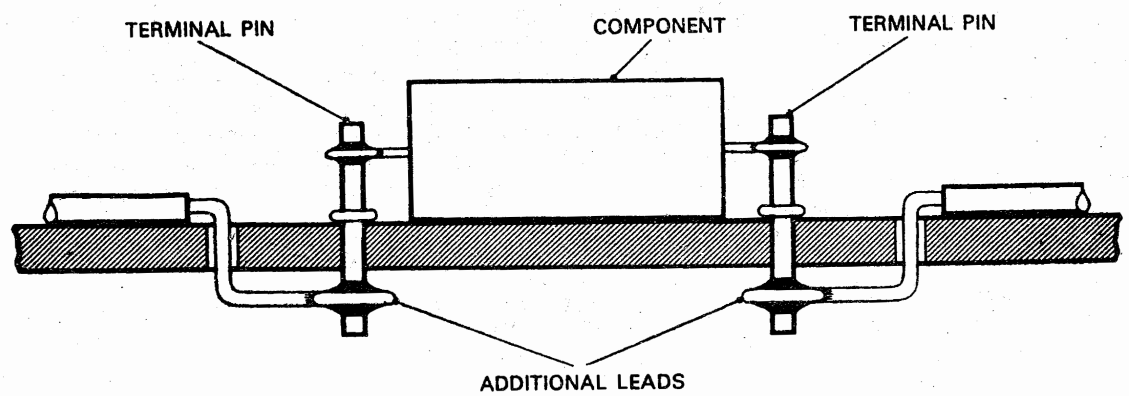


Figure 14 FITTING OF AN ADDITIONAL COMPONENT

(c) If terminal pins are to pass only through the base material of a board, they should be inserted from the component side. If, on the other hand, they must pass through a conductor track, insertion must be from the track side of the board. The methods and procedures for securing pins specified by the manufacturer should always be followed.

(d) If it is necessary to remove a defective axial lead component and replace it with a serviceable one, either of the two methods shown in Figure 15 may be used, the choice being largely dependent on the degree of component accessibility and the amount of soldering required at the board holes.

(i) In the method in Figure 15(A) the leads of the defective component should be cut, and the stubs de-soldered and removed with a solder extraction tool. The holes should be checked to ensure that they are clear of solder, and at the same time lands should be inspected for any signs of lifting. The leads of the serviceable component should then be bent (see paragraph 5.6) and soldered in the board holes.

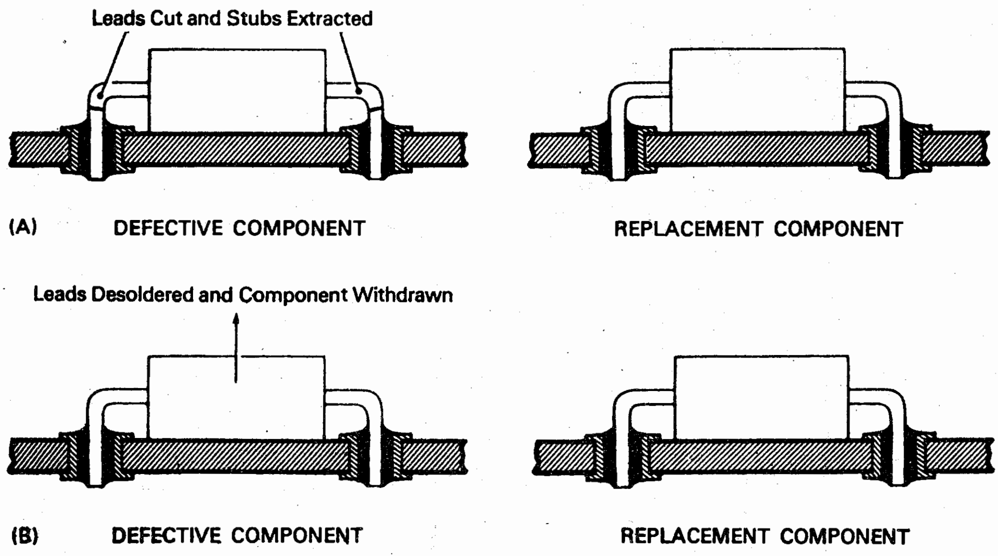


Figure 15 REPLACEMENT OF A DEFECTIVE AXIAL LEAD COMPONENT

(ii) In the method in Figure 15(B) the component is withdrawn from the board after de-soldering the leads. The checks to be carried out and the methods of fitting the serviceable component are the same as those for method (A).

4.4.4 **I.C. Packages.** These packages require careful handling during installation and removal, and reference should always be made to relevant instructions to ascertain any special precautions to be observed (see also paragraph 4.4.1 (c)). Extraction and insertion tools are commercially available and should be employed; two examples of such tools are shown in Figure 16. General procedures associated with installation and removal are given in the following paragraphs.

(a) **Dual-in-line Packs.** If it is necessary to remove a defective pack and replace it with a serviceable one, either of two methods can be used. In each case, encapsulant coating should first be removed from the repair area (see paragraph 6) and the area thoroughly cleaned.

(i) In the first method removal of a defective pack is effected by cutting through all the terminal tags with tip cutting pliers. Each tag stub should then be de-soldered and removed from its hole in the board with a solder extraction tool. After checking that the holes are clear of solder and undamaged, the replacement pack should be correctly orientated and its preformed tags inserted into the holes. The pack should then be pressed firmly down to the waisted portions of the tags and soldered into position.

(ii) In the second method the removal of a defective pack is effected with a heater block (see paragraphs 8.4 and 8.4.2) which permits simultaneous de-soldering of all the terminal tags. Solder should then be extracted from the holes and the replacement pack fitted in the manner already described.

(b) **Flat Packs.** After removal of encapsulant coating and cleaning of the repair area, all the leads along each side of the pack should be individually de-soldered, using a soldering iron with suitably shaped bit, or by one of the methods described in paragraphs 8.2, 8.3, and 8.4. Residual solder should be extracted from the

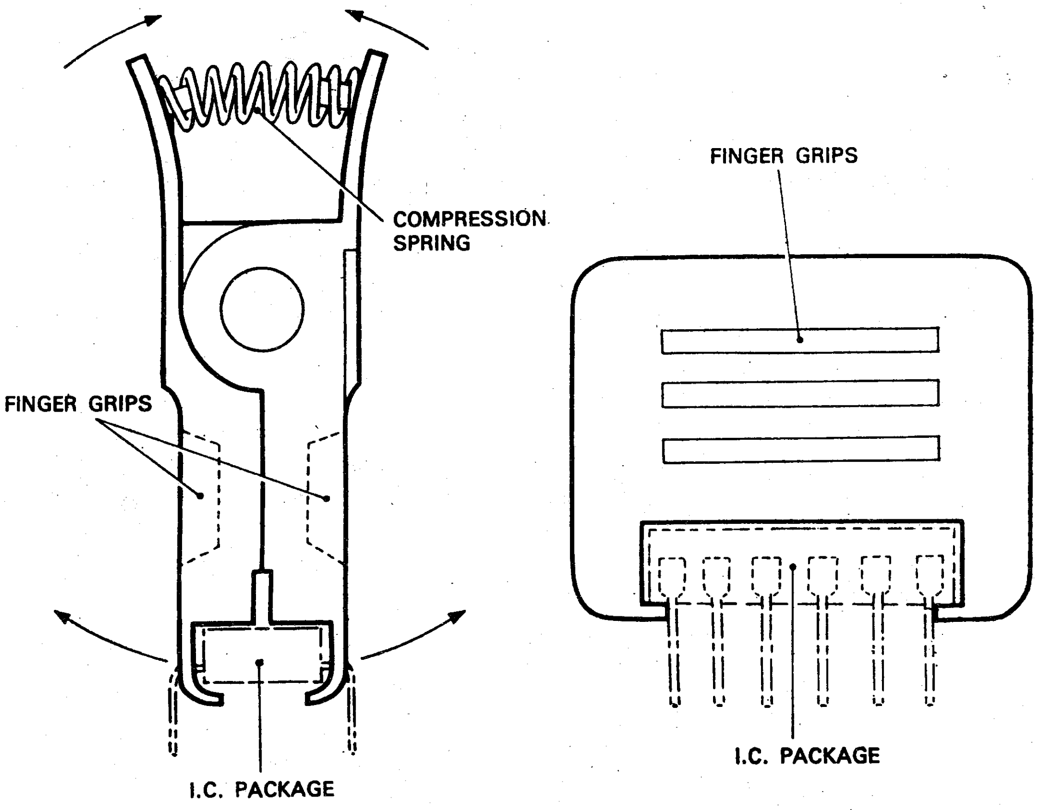


Figure 16 INSERTION AND EXTRACTION TOOLS

associated conductor tracks, which should then be re-tinned. Care should be taken to ensure that solder does not flow over the edges of the conductor tracks on to the board laminates, or cause 'bridging' of the tracks.

(i) The leads of the replacement pack should be cut to a length of 5 mm (0·2 in) and after bending (see paragraph 5.6) and checking for correct orientation, the pack should be positioned so that its leads overlap the portions of the associated conductor tracks equally. The pack should be held firmly in position and the leads attached individually by holding each lead in turn with fine tweezers and soldering it to the track, using an iron fitted with a suitably-shaped bit.

NOTE: Attachment of the leads should be done in the sequence specified in the manufacturer's instructions.

5 LEADS AND CONNECTIONS Leads of such components as transistors, diodes and trimmer capacitors, should be covered with insulation sleeving if displacement of the components from their normal position could cause short-circuiting of the leads.

5.1 Jumper leads should be of the insulated solid type, straight and short as possible, and routed point-to-point alongside component bodies. The leads should be arranged in a neat and orderly fashion, taking care that they are bent slightly to provide stress relief, and set at a safe distance from those components which operate at comparatively high temperatures.

5.1.1 Jumper leads should not be wedged under or between components. Depending on spacing and package density of a board leads may be passed underneath a resistor lead, or similar lead normally positioned off the surface of the board.

5.1.2 The removal of insulation covering should be done with an insulation stripper specifically designed to prevent damage to a conductor. Details of two recommended types of stripper are given in paragraph 7.4.

5.2 If clinching of component leads which pass through plated-through holes or eyelets is specified, the leads should extend through the board by an amount not less than the land radius or more than the land diameter. The leads should then be bent back in the direction of, and parallel to, the conductor tracks as shown in Figure 17. In order to facilitate straightening of the leads during a subsequent component removal operation, the leads should be angled at approximately 15 degrees.

5.3 Unless otherwise specifically authorised, leads should not be spliced.

5.4 The leads of tantulum capacitors usually contain welded joints; they should not, therefore, be subjected to twisting, bending, or undue stressing at the portion of the lead between the welded joint and capacitor body.

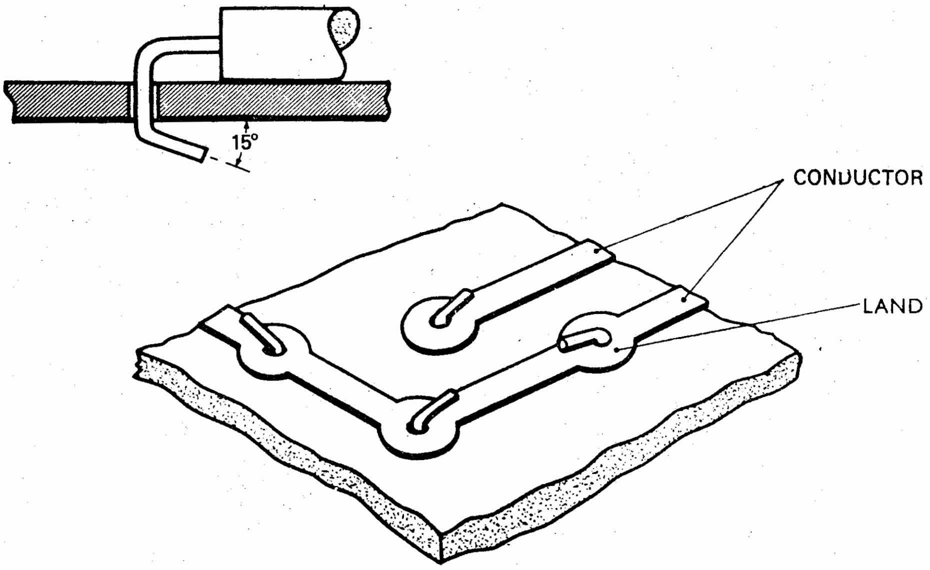


Figure 17 CLINCHING OF COMPONENT LEADS

5.5 Leads which are to be solder-connected to terminals should be firmly clinched to the terminals before soldering to ensure that the mechanical strength of the connection depends on the clinching and not on the solder. Unless otherwise specified, the ends of leads should be wrapped around terminals from between one-half to three-quarters of a turn. Some examples of recommended connections are shown in Figure 18. After wrapping and clinching, any extension of leads should be clipped close to the terminals.

5.5.1 If insulated leads are to be connected, the insulation should be cut-back by such an amount that after connection there is a small clearance between the end of the insulation and the terminal. A typical maximum value for this clearance is equal to the outside diameter of the insulation.

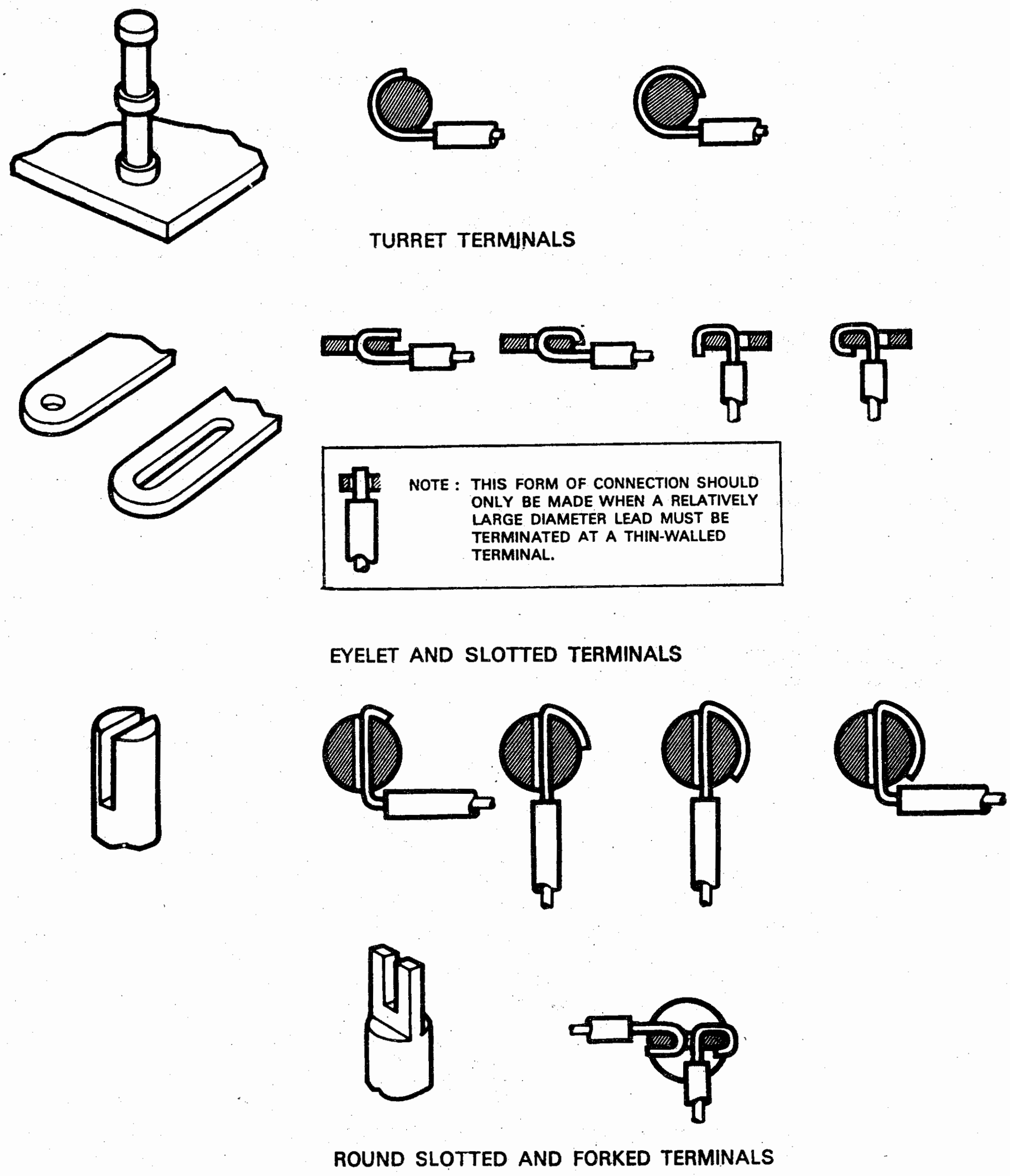


Figure 18 EXAMPLES OF TERMINAL/LEAD CONNECTIONS

(a) Where it is necessary to connect several leads to one terminal point, the terminal should be of the turret type with a location for each lead. The ends of the leads should be stacked in sequence from the base of the terminal to the top. They should not be wrapped over one another. If leads are of varying diameter they should be stacked with the largest diameter leads at locations nearest the base of terminals.

5.5.2 When connecting axial lead components to turret terminals, stand-off pins, off-set eyelets or plated-through holes, the leads should also be bent slightly in a horizontal plane to relieve stresses.

5.6 Bending of component and individual conductor leads during installation should be carried out with the utmost care to ensure that specified limits are not exceeded and that no damage is done to the seals of components or leads. Procedures and limits are specified in relevant manufacturer's manuals and specifications; reference should, therefore, always be made to such documents. The following paragraphs are a guide to the points to be generally observed.

NOTE: The dimensions quoted are examples, and as such, do not necessarily apply to all repair and component replacement practices.

5.6.1 The shaping and bending of leads should be done, prior to soldering, with the aid of a smooth metal rod or round-nose wire-forming pliers. Long flat-nose pliers

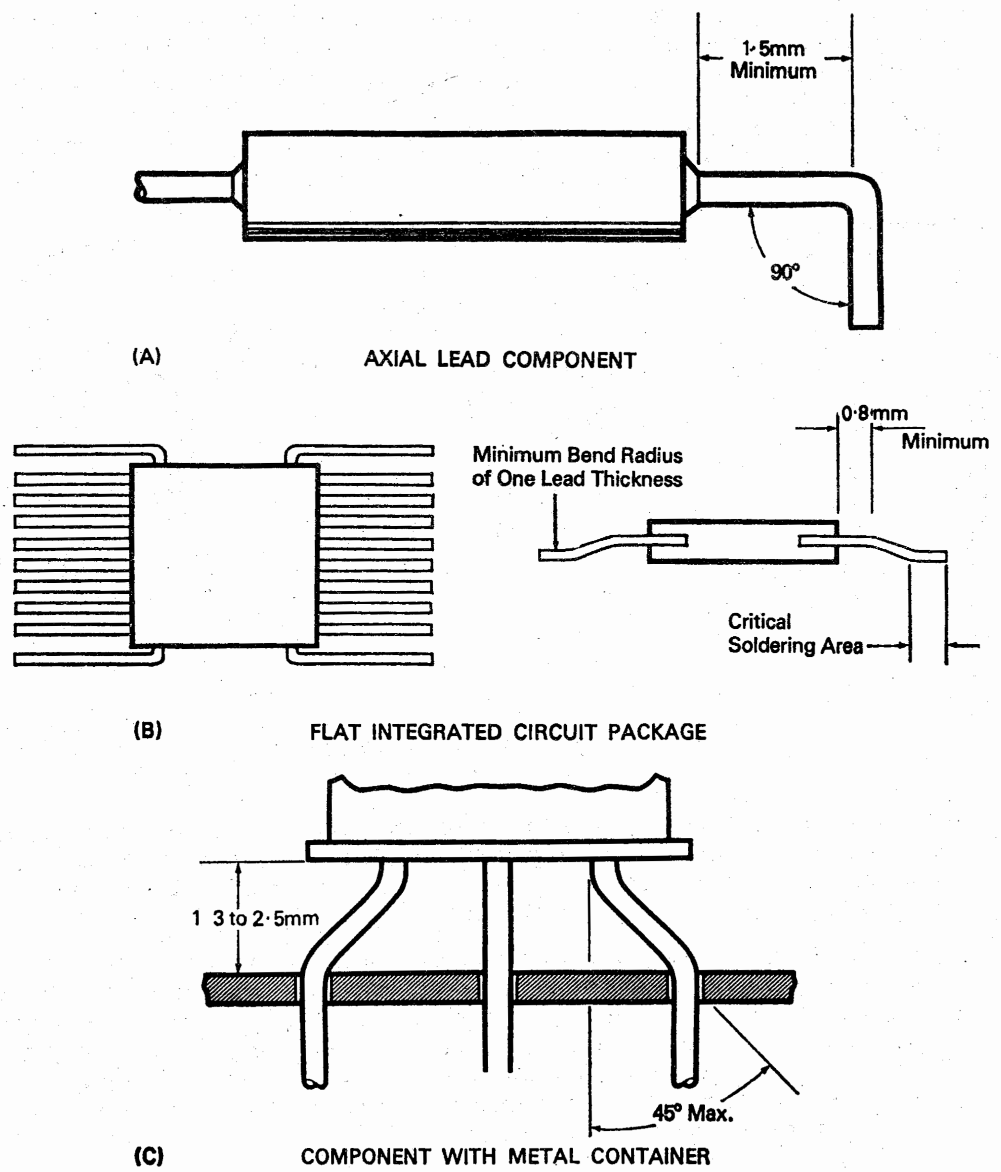


Figure 19 BENDING OF LEADS

are acceptable provided the jaws are smooth and the sharp edges of the jaws are covered with durable plastic tubing or tape.

NOTE: Tools designed solely for the forming and bending of leads, and for accurately gauging the distances between board holes are commercially available and, where possible, their use is recommended.

5.6.2 Solid conductor leads should not be bent with a sharp radius; a minimum of one lead diameter is typical. During the bending process, a component lead should be held at a point between the end of the component and the point of bend. The minimum distance between these two points (see Figure 19 (A)) should correspond to that specified, a typical value for all components except flat packs, being 1·5 mm (0·06 in).

5.6.3 The leads of flat packs should have a minimum bend radius of one lead thickness, and the distance between the end of the pack and point of bend (see Figure 19 (B)) should be a minimum of 0·8 mm (0·03 in). Solder seals, glass bead seals and other protrusions are considered to be included in the component body when measuring this distance. When being formed leads should be supported at a point adjacent to the body in order to avoid stress being applied at the seals.

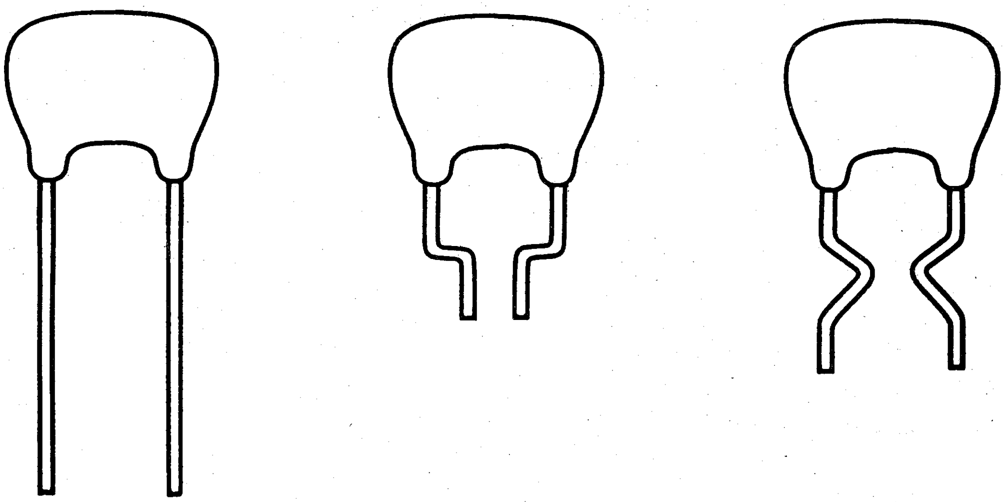


Figure 20 RADIAL LEAD CAPACITORS

5.6.4 In bending and forming leads care should be taken to ensure that they match the spacing of the holes in which they are subsequently to be soldered. Radial lead capacitors are normally designed to cover a range of standard hole spacings, and the leads may either be straight or pre-formed as shown in Figure 20.

5.6.5 If clipping of the leads of a component is required after bending, care must be taken to ensure that the junction between the leads and component body is not stressed and that no shock is transmitted to the junction. A lead should be held securely between the point of clipping and component body during the clipping operation. Clipping tools should be of the side-cutting type with either flush or semi-flush jaws. When in use, the cutting edge faces should be towards the component body and perpendicular to the axis of the leads.

5.6.6 Leads extending from the bottom of components with cylindrical metal containers, referred to as T.O. type cans, may be formed as shown in Figure 19 (C).

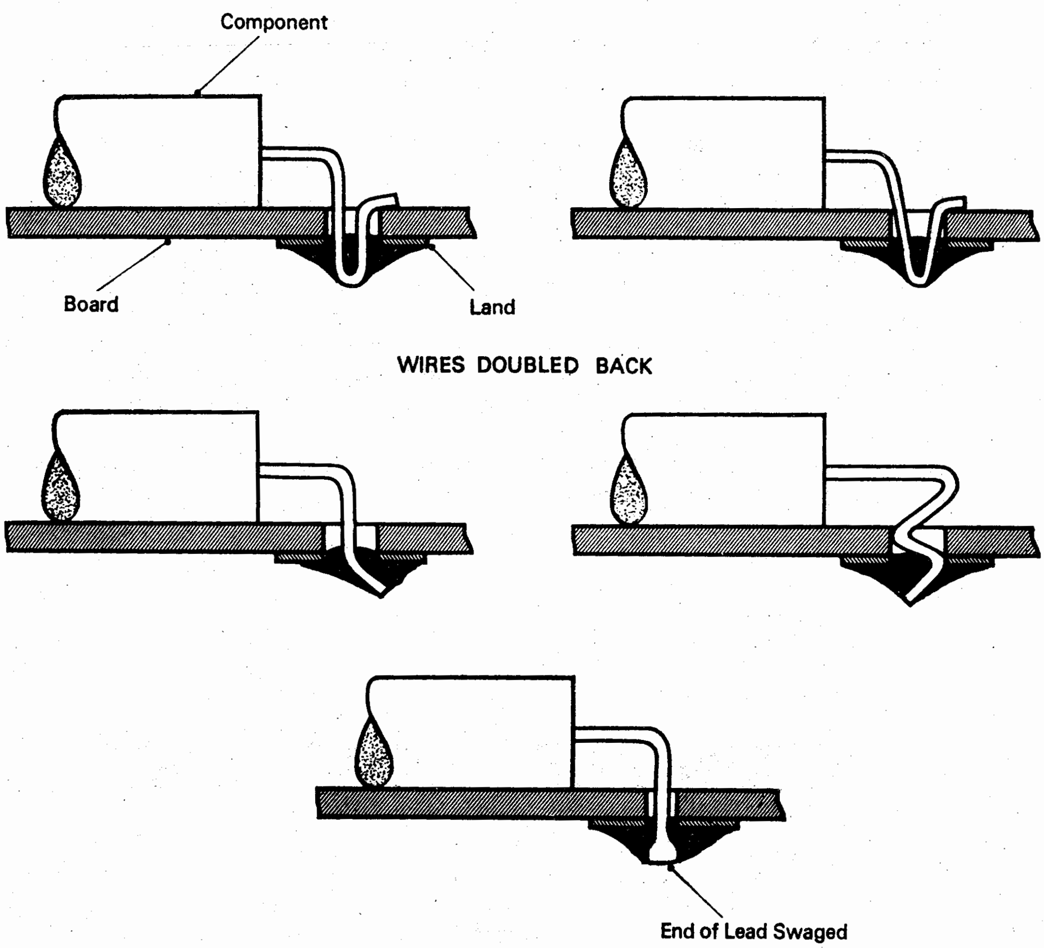


Figure 21 FORMING OF SMALL DIAMETER LEADS

5.6.7 For components with very small diameter leads, difficulty may be experienced in centering them in the board holes. This may be overcome by forming the leads in the manner illustrated in Figure 21.

5.6.8 Before mounting components on boards, the leads should be checked to ensure that any misalignment with the body junction is within specified limits. Provided that the specified limits are not exceeded, straightening of the leads is permitted.

5.6.9 Bending, cutting, straightening or insertion of leads into board holes, should be carried out in a manner which will not cause damage to the leads or the components, or cause changes in electrical ratings. If any of the damage referred to in the following paragraphs has occurred components should be rejected.

(a) Nicks or cuts in excess of 10% of lead diameter in the area between the component body junction and the point at which the lead will be soldered.

(b) Flaking or voids in the plating larger than one-tenth of lead diameter, and of a total area in excess of 10% of lead surface.

(c) Bends which at 2X or 10X magnification show cracks in the base metal. If there is any doubt regarding the presence of cracks, examination of a lead should be made at 30X magnification.

(d) Damaged insulation of connector contacts and of component cases.

(e) Evidence of leakage from components containing liquid dielectric.

5.6.10 If components are not to be mounted on their respective boards immediately after bending their leads, they should be stored in such a way that no damage or disturbance of the lead configuration can occur. It is recommended that the leads of radial lead components, dual-in-line packs, or other I.C. packages with similar lead configurations, be pierced into small sections of thick foam rubber or plastic, and the components then enclosed in dust proof packs. Where semiconductor devices require the use of lead-shorting clips, e.g. MOS (metal-oxide-semiconductor) and FET (field effect transistors) the clips should remain in position and the devices should be stored in their special foil-lined packs. The clips should only be removed after the devices and associated circuitry have been totally assembled on the board.

5.6.11 Bending of leads extending from glass seals should be carried out with the utmost care to avoid cracking or chipping of the seals.

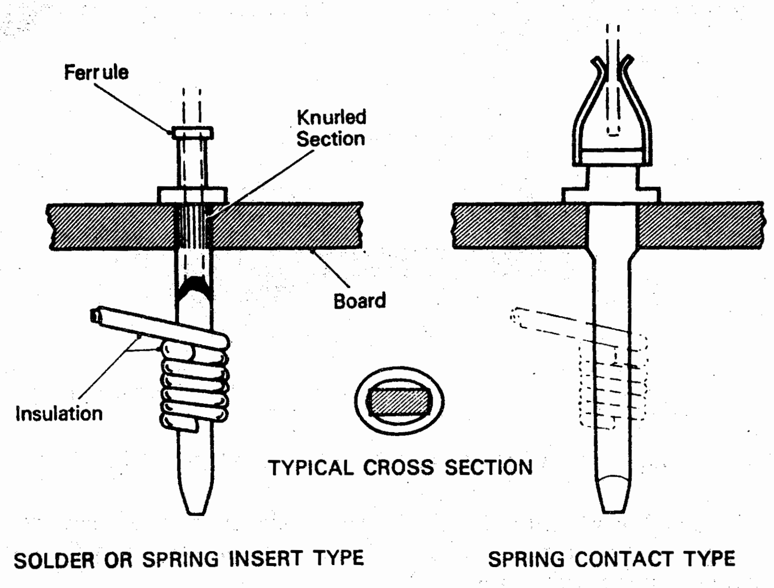


Figure 22 WIRE-WRAP CONNECTIONS

5.7 **Wire-wrap Connections.** These connections are of the solderless type requiring the use of specially designed pins which are pressed through the circuit board (see Figure 22). The pins may be either rectangular, square or V-shaped in cross-section, and provide a spring contact type of connection, or alternatively, a ferrule type of connection to which a lead may be soldered or make contact via a spring insert. In some applications, pins permitting a wire-wrap connection on both sides of a board may also be used. Typical materials used in the manufacture of pins are brass, beryllium copper, copper-nickel alloys, phosphor-bronze and nickel-silver alloys.

5.7.1 The wire, which should be tin- or silver-plated solid annealed copper (e.g. to BS 4109) is wrapped tightly around the pins with a wrapping tool, which ensures a good metal-to-metal contact by deforming the inside of the wire at the edges of the pins. The minimum number of turns required depends on the wire size, e.g. 5 turns minimum for wire size 0·56 to 0·71 mm (0·021 to 0·028 in) and 4 turns minimum for wire size 0·81 to 0·91 mm (0·032 to 0·034 in). Reference should always be made to the instructions specified for a wire wrapping operation. To improve the vibration resistance of a wire-wrapped connection, it is recommended that insulation should be left on the wire for at least one turn as shown in Figure 22.

5.7.2 On completion of a wire-wrapping operation, checks should be made to ensure that each turn of wire is in close contact, that turns have not overlapped, and that plating has not been removed from the wire. If any gaps are present between turns, it should be ensured that they are within specified limits; no attempt should be made to close them.

6 REMOVAL OF ENCAPSULANT COATINGS Prior to the de-soldering and re-soldering of connections, the encapsulant, which is used as an insulating coating, must be removed. In most instances, it is only necessary to remove the encapsulant from a small area in order to effect the required repair. Some typical methods are described in the following paragraphs, and the choice of any one of them is governed principally by the type and condition of the encapsulant and the nature of the printed wiring board and components mounted on it.

NOTE: The thermal parting, abrasion and hot air methods require certain expertise in their application, and it is recommended that they should only be carried out by personnel skilled in the appropriate techniques.

6.1 **Solvent Method.** In choosing the solvent method, any possible adverse effects that a specified solvent might have on a board and its components, should be very carefully considered (see also paragraph 3.1 (n) and Appendix 2). If removal from only a small area is required, the area should be swabbed a number of times with a cotton-tipped applicator dipped in fresh solvent until the area is free from encapsulant. The time required for a given encapsulant to dissolve varies with the type of encapsulant and the solvent used. Rubbing the coated surface carefully with a glass-fibre bristle brush or the end of the solvent applicator will help dislodge the coating. For some encapsulants, particularly those of the polyurethane type, effective removal can be achieved by a solvent applicator having a wedge-shaped tip. After removing the required amount of encapsulant, exposed solder connections should be cleaned.

6.1.1 If it is necessary to remove the entire encapsulant coating from a printed wiring board, the board can be immersed and brushed in a series of tanks containing the appropriate solvent, commencing with a high contamination tank and progressing to a final fresh solvent tank.

6.2 **Thermal Parting Method.** This method utilises a controlled, low-temperature heat source and should be employed for the localised removal of thick coatings of encapsulant from flat surfaces, as well as the softening of bonds between components and boards. Charring or burning of either the encapsulant or circuit board, can be prevented by using temperature-controlled tools designed specifically for thermal parting. The tools can be fitted with a variety of tips shaped to gain proper access to the areas from which encapsulant removal is required.

NOTE: Soldering irons should not be used for encapsulant removal, as their high operating temperatures will cause charring of the encapsulant, as well as possible de-lamination of the board material.

6.2.1 The procedure given in the following paragraphs is based on the use of a special parting tool.

(a) The appropriately shaped tip should be selected and the nominal temperatures set on the parting tool.

(b) The tip should be applied to the encapsulant coating under a light pressure, and the tip temperature regulated to a point where it effectively breaks down the coating without charring or burning. Depending on the type of material, the encapsulant will either soften or granulate, e.g. a polyurethane based material will soften, while an epoxy material will granulate.

(c) Gradually reduce the thickness of the coating without contacting the surface of the board, and remove as much coating as possible from around component leads to allow easy removal of the leads. A stream of dry air at low pressure, or a bristle brush, should be used during the parting process to remove waste material.

(d) If a faulty component is to be removed from a board, the connecting leads of the component should first be cut, thereby permitting its removal separate from the removal of the soldered joints on the board. Once sufficient encapsulant coating has been removed, the component body should be heated with the parting tool so as to weaken the bonded joint between the component body and board, and thereby permit lifting of the component from the board. The remaining encapsulant should then be removed by further thermal parting or by an abrasion method, and the remaining leads and solder joints should be removed by the appropriate solder extraction method (see paragraph 8).

6.3 **Abrasion Method.** The removal of encapsulant coatings by this method requires the use of glass-fibre bristle brushes, or rotary abrasive tools such as end mills, rotary files, or bristle brushes, driven by a miniature type electric motor. The brushes and rotary tools mentioned, as well as others containing abrasive materials, should be carefully selected to suit the various types of coating and configurations of the areas from which a coating is to be removed. The motor should have fingertip control and should be of the high-speed, low-torque type to prevent excessive frictional heating, and to facilitate removal of coatings, particularly those of the soft and pliable type. When in use, great care should always be taken to prevent abrading tools coming into contact with the bare materials of boards and circuit tracks.

6.3.1 The abrasion method is primarily suited to the removal of coating from the circuit side of a board where easier access for rotating abrasive devices is permitted. It can also be applied to the component side of a board provided that there is adequate clearance between components. The method should not be used for removing coatings from components, or for breaking the bond between components and boards. In such cases the thermal parting method (see paragraph 6.2) should be employed.

6.3.2 Rubberized abrasives of the correct grade are ideally suited to removing thin hard coatings from flat surfaces, but not for soft coatings, as these cause the abrasive to 'load' with coating material, and so become ineffective.

6.3.3 Rotary bristle brushes are better suited for use on contoured or irregular shaped surfaces, such as soldered connections, as the bristles easily conform to the contours and surface irregularities. They can be applied to both hard and soft coatings.

6.3.4 Tools should be applied to coatings with varying degrees of pressure to check the rates of coating removal. After getting the feel of these rates the coating can then be removed by applying the degree of pressure best suited to the conditions. Tools should be moved about in a circular motion to minimise localised heating and to avoid inadvertent damage to underlying materials by abrading through the coating too quickly. In some cases it may be necessary to change the tools during coating removal, e.g. removing the bulk of coating with a coarse abrasive tool, and then changing to a finer abrasive tool for final 'clean up' of the area.

6.3.5 Waste coating material should be removed periodically by brushing or by a source of low pressure air, thereby permitting visual inspection of the work surface to ensure that the abrading tool is not causing abrasion of the board's base material or conductor tracks. When all coating has been removed, the area should be cleaned with an appropriate solvent to remove any remaining contaminant particles.

6.4 **Hot Air Jet Method.** In this method there is no direct physical contact between the heating tool and board surfaces, the softening of encapsulant coating being accomplished by a jet of hot air passing through a hollow bit similar to that of a suction type solder-extractor iron. In some commercially available irons the hot air jet may also be selected as a mode of operation for encapsulant coating removal.

6.4.1 The air flow rate and temperature should be selected to achieve softening and breakdown of the specific type of encapsulant coating, without setting up local heating levels which could be of detriment to the board, components (particularly those with glass seals) or insulation of leads and components. When the coating becomes soft it should be removed by means of a small non-metallic spatula (e.g. teflon or nylon). The spatula should be free from sharp edges.

6.5 **Peeling Method.** This method is normally restricted to the removal of certain silicone based encapsulant coatings which require pre-soaking of the coating in a solvent (e.g. freon) and, as this also breaks its bond, the coating can be split by means of a scalpel and then peeled off.

7 SOLDERING In the repair of printed wiring boards, the hand soldering of joints plays a major role, and although it is based on simple and well-established rules, the continuing development of printed wiring boards and associated components, and of soldering equipment, has made it necessary for operatives to develop more specialized skills, both in the actual tasks to be performed and in post-repair inspection. It is most advantageous for operatives to participate in a recommended course on repair and specialised soldering techniques, terminating in selected practical tests, by means of which their capabilities can be demonstrated and finally certified. Re-certification of the operative should be carried out at regularly prescribed intervals, and whenever the results of inspections indicate a downgrading of soldering capability.

7.1 **Types of Soldered Joints.** There are basically five types of joints to be considered in soldering: (a) through-hole unplated, for component lead and jumper lead terminations, (b) through-hole plated, for lead terminations and connection of dual-in-line packs, (c) lap or co-planar, for the connection of flat packs, (d) terminal, for component lead and jumper lead terminations and (e) lead to track connections, as in certain repair methods (examples are shown in Figure 23).

7.2 **Materials.** Solder should be of the wire type, cored with an activated resin flux to a standard complying with BS 441 Grade K 60/40 tin/lead. It is recommended that the solder size be from 22 to 26 swg since this can help significantly to reduce the time required to make good soldered joints. In some cases, wire type solder and flux may be used separately, and should comply respectively with BS 219 and DTD Specification 599. Where small static dip solder baths or pots are used, it is recommended that they should be initially charged and topped up with solder which is commercially available in pellet form.

NOTE: To prevent tin/lead separation, bath or pot solder should be stirred before use and at frequent intervals during a soldering operation. It should also be checked for contamination at a frequency consistent with usage, and changed when necessary. Further information on solders and fluxes is contained in Leaflets **BL/6-1** and **MMC/1-1**.

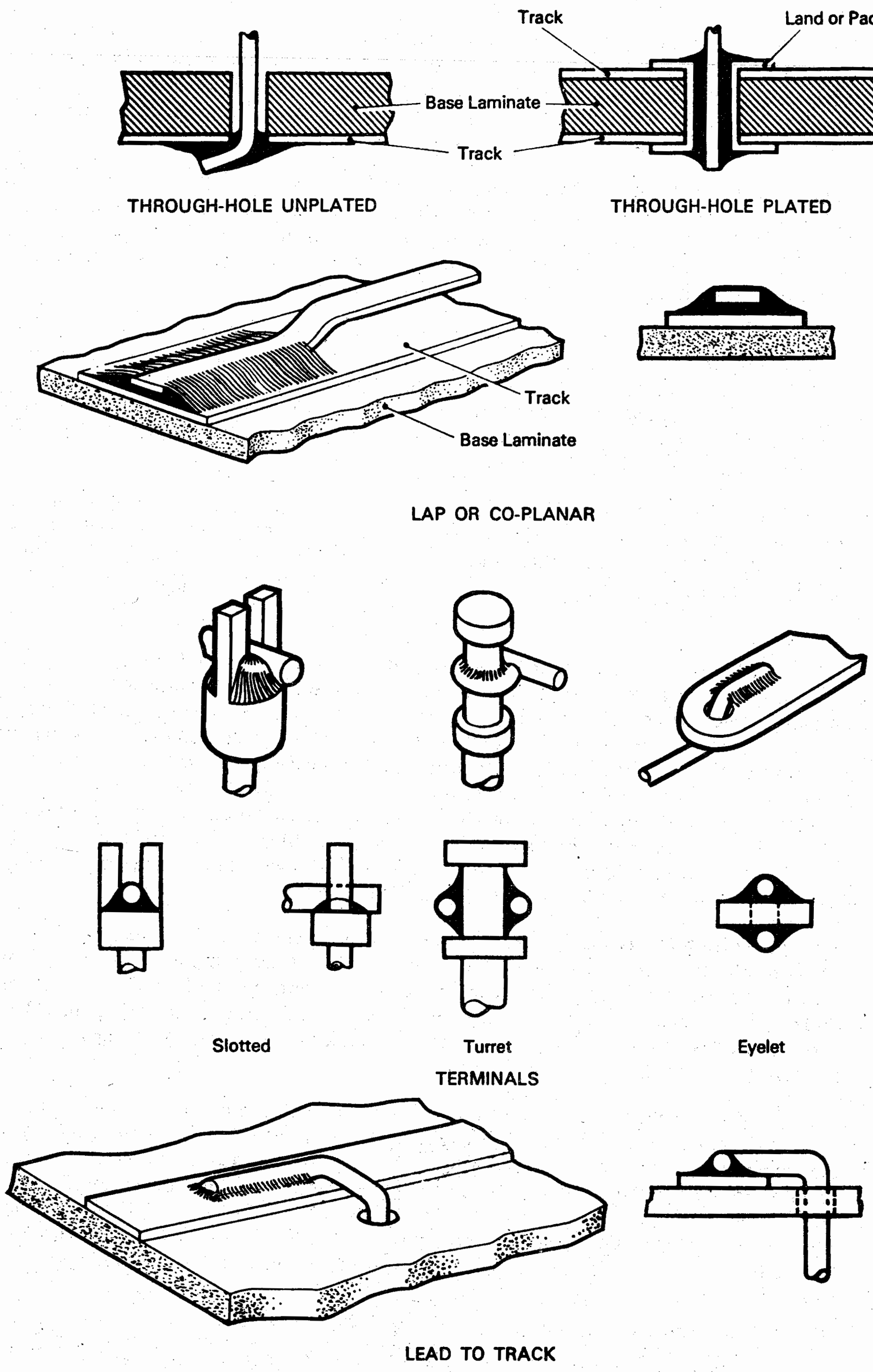


Figure 23 TYPICAL SOLDERED JOINTS

7.3 **Soldering Equipment**

7.3.1 **Soldering Irons.** Soldering irons should be of the light-weight electrically-heated type and should be carefully selected on the bases of such essential requirements as—(i) capability for soldering very small joints, (ii) good temperature/voltage stability, (iii) high rate of thermal recovery after each application to a joint, (iv) prevention of overheating during idling periods, and (v) power consumption related to actual job requirements. The wide variety of irons that are commercially available are of the temperature controlled type; the control being effected by one of the following—(vi) preset power output of the heater element, (vii) thermostatic switching, (viii) electromagnetic switching as in Curie effect irons, and (ix) transistorised power control of pre-selected temperatures. Some irons are designed for direct operation from the normal mains voltage supply, while others are designed for operation at either 6 volts, 12 volts or 24 volts, obtained from mains-connected voltage conversion units.

(a) **Temperature.** Solderability temperature is normally 230°C (446°F) but it is necessary that the bit temperature of an iron be above this value to allow for the thermal load of a joint, and also to avoid a lengthy 'dwell' time. The majority of irons have a bit temperature in the range 260°C to 320°C (500°F to 608°F) under idling conditions. The bit temperature should be periodically checked during soldering operations, such checks being facilitated by means of a bench-mounted pyrometer. A typical pyrometer consists of a thermo-couple against which the soldering iron bit is brought into contact, and a galvanometer calibrated in degrees Celsius.

(b) **Bits.** These are of the detachable type designed in a variety of shapes and sizes thereby permitting a selection best suited to the size and type of joint to be soldered. Bits are manufactured from high-grade copper, and may be unplated, or plated with an iron coating. The shanks are normally chromium-plated as a protection against corrosion, to prevent feed-back of solder, and also to facilitate their removal and replacement. Unplated bits permit satisfactory soldering to be carried out, but they require frequent 'dressing' on account of wear, and this results in considerable variations in heat retention capability. Iron-plated bits, on the other hand, wear less rapidly, and it is therefore recommended that these always be used.

7.3.2 **Soldering Iron Stands.** In between soldering operations, irons should be supported on bench stands designed specifically to permit the irons to idle in free air.

7.3.3 **Cleaning Sponge.** A synthetic or natural fine-textured sponge saturated in water (preferably distilled) should be provided to remove dirt particles and oxide scale from soldering iron bits. In some types of soldering iron stands commercially available, a sponge and water receptacle is incorporated.

7.3.4 **Solder Pots.** For certain soldering operations, e.g. tinning the ends of jumper leads, tags and leads of certain small components, the use of bench-mounted solder pots is generally recommended. A typical pot consists of an electrically-heated crucible and a tube which is tapered so that the end of a lead inserted into it, is guided down and dipped into the molten solder. In some cases a thermostat control and a thermometer are incorporated.

7.3.5 **Heat Sinks.** In some printed wiring board assemblies, components may be employed which are sensitive to the effects of temperature and require the use of a heat sink tool to conduct heat away from the components during soldering and de-soldering (see paragraph 7.6 (e)). In the absence of specially designed heat sink tools

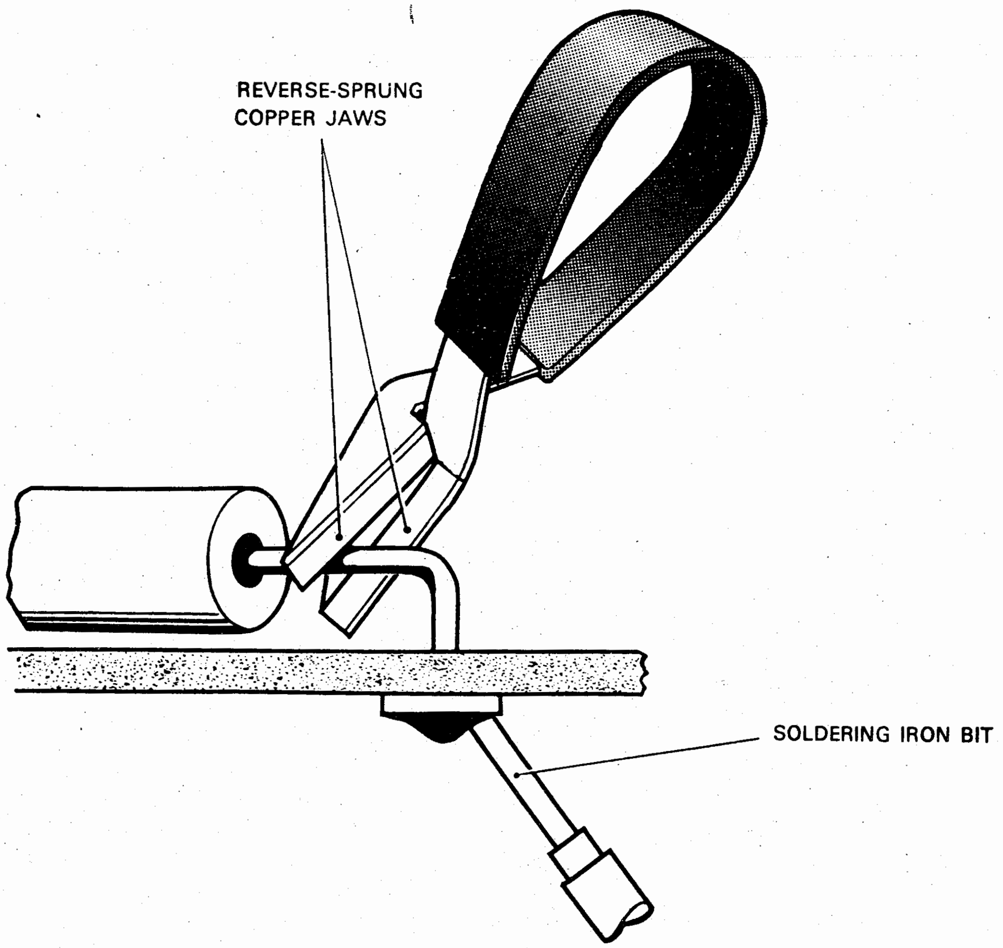


Figure 24 HEAT SINK

of the type shown in Figure 24, small, flat nose, smooth jawed pliers, or miniature type alligator clips with flattened ends and small copper strips soldered to them, may also be used.

7.3.6 **Anti-wicking Tool.** Wicking is a term used in connection with the soldering of leads, and it refers to the seepage of solder along the conductor. Wicking should not be allowed to extend beneath the insulation covering of a lead and it is, therefore, recommended that an anti-wicking tool (see Figure 25) be used. The jaws of the tool are of the reverse-sprung type, and the shape of the tips permits gripping of the lead insulation and the exposed part of the lead, so that during soldering the tips serve as a heat sink.

7.4 **Lead Insulation Strippers.** These should be of either a mechanical cutting or a thermal type.

(a) Mechanical strippers should be of such a design that the cutting blades may be set for the removal of a specific size of insulation without cutting, or nicking of the metal conductor.

(b) Thermal type strippers employ small jaws which are electrically heated, and when closed round the insulation they soften it sufficiently to permit its withdrawal from the conductor. The power ratings of heating elements vary depending on the type of insulation to be removed. Typical ratings of two strippers commercially available are 14 watts for PVC, polythene and similar low-temperature insulation materials and 48 watts for PTFE insulation only. The power supply required is either 12 volts or 24 volts.

NOTE: Extreme care should be exercised when carrying out thermal stripping of insulation, as the fumes given off are highly toxic, particularly from PTFE insulation.

7.5 **Preparation for Soldering**

7.5.1 **Cleanliness.** Cleanliness is the keynote of all soldering operations and the following points should be observed:—

(a) Work areas should be maintained in a clean and orderly condition. Any dirt, oil, grease, solder splashes, wire clippings, or other foreign matter, should be promptly removed from the immediate soldering area.

(b) All hand tools, supporting jigs, heat sinks and anti-wicking tools should be cleaned frequently, using an appropriate solvent such as aliphatic naptha or isopropyl alcohol.

(c) Components, leads and terminals, should be kept in dust-proof packages until ready for use (see also paragraph 5.6.10).

(d) Hand creams, oils, lotions and similar skin conditioners should not be used by operatives.

(e) Prior to starting soldering operations, hands should be washed and dried with a clean lint-free cloth.

(f) The surface of all types of joints to be soldered should be clean, bright and free from grease, dirt, oxides, or any other foreign substance which may interfere with the action of the flux and prevent proper solder flow. Where the solderability of a component lead is unknown, or doubt exists, a 'tinning' test should be carried out on the wire off-cut after preparing the component for assembly on the board.

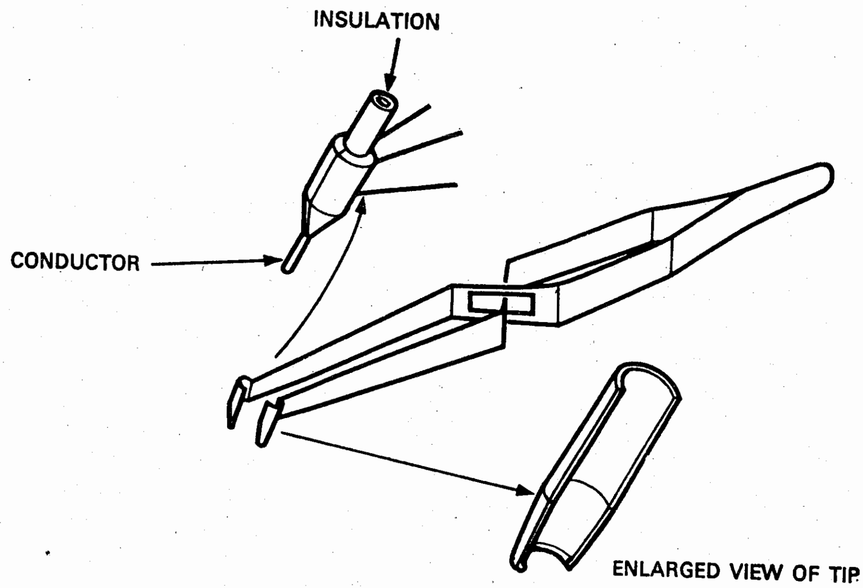


Figure 25 ANTI-WICKING TOOL

7.5.2 **Soldering Iron Maintenance.** Soldering irons should always be maintained in a clean and serviceable condition, particular attention being paid to the condition of the bit, its security of attachment and tinning.

(a) **Cleaning and Tinning.** Before using a soldering iron, it must be ensured that the bit is free of oxides and dross, and that its working surface is bright and tinned to avoid the transfer of impurities to soldered joints.

(i) **Unplated Bits.** When a bit reaches the lowest temperature required to melt the solder, it should be tinned by applying flux and solder to its working surface until a thin film of solder adheres to it. A recommended method of applying the solder for tinning is to wrap a suitable length of it round the bit in order to protect the working surface from oxidation as the bit reaches solder melting temperature. The bit should then be wiped on a damp, fine-textured sponge to remove excess solder and any oxide film that may have formed. As a result of the effects of molten solder, unplated bits become worn and pitted fairly quickly, and frequent dressing is therefore necessary (see also paragraph 7.3.1 (b)). This should be carried out when the bit is cold, by filing the working surface to a smooth finish. After dressing, the bit should be cleaned and re-tinned in the manner already described.

(ii) **Plated Bits.** Plated bits should be tinned in a manner similar to that of unplated bits. If the working surface has an additional protective coating, such as pure tin, nickel, silver, or gold in some cases, the surface should be flooded with molten solder during the initial heating, or these coatings will burn off. A plated bit may idle for a long time without damage, provided that it remains tinned. However, the durability of the tinning depends on the bit temperature. A bit that idles for several minutes between soldering operations will not require frequent tinning if the bit temperature is maintained within the normal idling temperature range i.e. 260°C to 320°C (500°F to 608°F). If the oxides that form on a bit cannot be removed by wiping it on a damp sponge, the bit should be allowed to go cold and all the scale removed by abrasion, by means of a fine grade emery cloth, an abrasive coated stick of polyurethane foam, or a glass-fibre bristle brush. After cleaning, the working surface, which should have a grey metallic appearance, should be re-tinned.

NOTE: A file should not be used since it will remove most, if not all of the plating on the iron, thereby shortening the life of the bit.

7.6 **Soldering Procedure.** The following points should be observed when carrying out the soldering procedure:—

(a) Component terminals and leads, as well as the ends of individual jumper leads, should, unless otherwise specified, be cleaned and tinned prior to making the final soldered joint. Additional tinning is not normally required on those components having pre-tinned leads.

(b) The soldering iron bit should be cleaned by wiping it on a damp sponge, and fresh solder should be applied between each jointing operation.

(c) The soldering iron bit should be applied to the appropriate joint area until the tinning solder reflows to make the joint. The bit should be positioned so as to obtain maximum heat transfer from the bit to the contact area, but at the same time avoiding excessive heat application and consequent damage to surrounding areas.

(d) After a joint has been made by the initial reflow, the soldering iron bit should be held in position and additional solder should be applied to the heated members of the joint (not the soldering iron bit) until it has melted sufficiently to provide a uniform film, or fillet, around the joint members.

(e) If it is necessary to use heat sinks they should not be placed too close to a joint, otherwise they may seriously reduce the rate of heating at the joint itself. Care should also be taken to ensure that they are not inadvertently placed beyond the component to be protected, as this will result in the heat from the joint merely draining through the component. Heat sinks should be removed soon after a soldering operation is completed, or they will act as a heat reservoir which will, itself, heat the component to be protected.

(i) Some components are very often provided with a heat sink device which is intended to remove heat generated while the components are in operation. Such heat sinks do not necessarily give any protection against overheating while soldering operations are being carried out, because, in many cases, the heat from the connection being soldered must pass through the heat-sensitive region before reaching the heat sink.

(f) Joints should be permitted to cool without any relative movement between joint members taking place.

(g) The mechanical strength of a soldered joint should not be checked by twisting, pulling, or pushing a component or lead, as this can result in poor or broken connections (see paragraph 7.7).

(h) Flux residue should be removed from soldered joints and surrounding areas, immediately after a soldering operation, by using the method specified in the appropriate repair instructions. Residue should not be burned off with a soldering iron, since both the bit and the soldered joint will become so contaminated that the solder will merely form a globule over a high resistance joint of dirt and corrosive oxide. Furthermore, there exists the possibility that continued heat application may damage the adhesion of conductor tracks to the base laminate of the board.

7.7 **Inspection of Soldered Joints.** On completion of a soldering operation, joints should be visually inspected, paying particular attention to the aspects given in the following paragraphs. Where necessary, and in particular on high density packaged boards, an optical magnifier of 10X power should be used.

NOTE: Reference should also be made to Leaflet MMC/1-1 which contains additional information on solderability and soldering technique defects.

7.7.1 All soldered joints should present a neat, bright and shiny appearance with well-formed solder films or fillets feathering out to a thin edge, indicating proper 'following and wetting' action by the solder.

7.7.2 The quantity of solder used in making the joint should not be excessive. In general, if the contour of conductors and joint configuration cannot be determined, then there is excessive solder. Other indications of excessive solder are globular formations, and bridging of joints or conductor tracks.

7.7.3 The ends of leads passing through plated or unplated holes, should not extend from their mounting lands by distances greater than those specified in the relevant repair instructions.

7.7.4 There should be no evidence of flux residue at points of contact, or of pitting and holes in the solder. Joints with such defects should be inspected carefully to ensure that no movement of a conductor occurs when the joint is probed with a tool that will not adversely affect the joint. The joint should also be observed under magnification to determine whether or not pitting and holes are only surface imperfections. If movement of a conductor occurs, and pitting and holes extend below the surface, the joint is unacceptable.

7.7.5 There should be no evidence of 'cold' joints, as indicated by a dull, chalky or crystallized flaky surface of the solder. Such a joint is a high resistance, or an insecure joint, caused by insufficient heating, or by movement of a conductor, during soldering. It can also be caused by 'packing', or 'piling' solder on top of a joint which has been improperly prepared or cleaned.

7.7.6 Joints should be free of solder 'icicling', i.e. sharp points of solder, which may cause arcing or corona effects.

7.7.7 Insulated leads should be checked to ensure that their insulation is at the specified distance from the appropriate termination, and that there are no signs of cracking, charring, or decomposition of insulation.

8 DE-SOLDERING METHODS

8.1 **Wicking Method.** This method utilizes a lengh of flux-impregnated braid formed to resemble a lamp wick, which is applied to a solder joint between the solder and the heated bit of the soldering iron (see Figure 26). The combination of heat, molten solder and air spaces in the wick creates a capillary action, which causes the solder to be drawn into the wick. In the absence of commercially available braided wicks, lengths of stranded wire may be used. The wire should be stripped of insulation and dipped in flux prior to de-soldering.

NOTE: The wicking method is rather limited in its application, and in any event, care should be exercised because the long soldering iron 'dwell' time required at a joint could cause overheating of the board and weakening of conductor track adhesion.

8.1.1 The method should be used to remove solder from surface joints only, since the capillary action of the wick can only overcome the surface tension of the molten solder. This is also true for double-sided circuit boards without reinforced holes. Wicking should not be used on through-hole plated joints because the capillary action of this type of joint is, in most cases, stronger than that of the wick and prevents complete removal of solder from the hole.

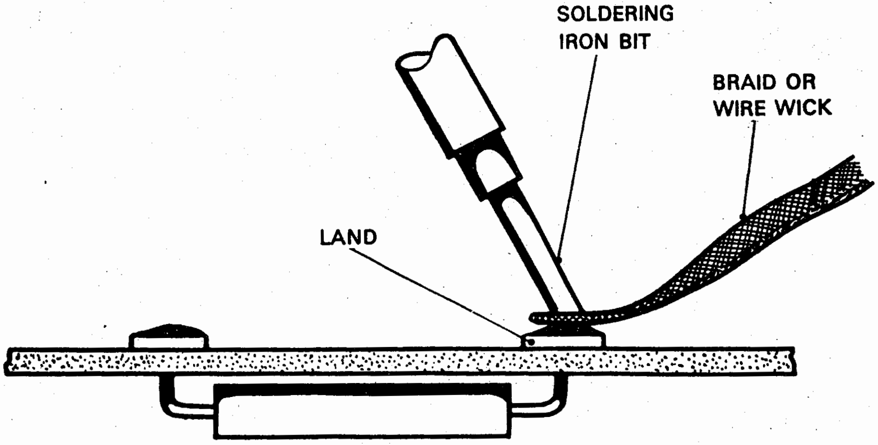


Figure 26 WICKING METHOD

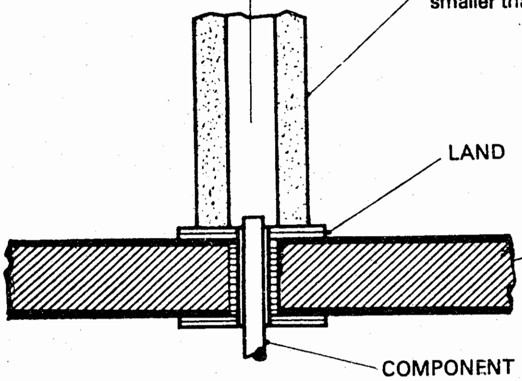


Figure 27 SOLDER SUCTION METHOD

8.1.2 When the ends of braid or wire become saturated with solder, they should be cut off, thereby ensuring proper withdrawal of solder on each application.

8.2 **Solder Suction Method.** In this method de-soldering is carried out by drawing molten solder from a joint through a hollow bit. The hollow bit may form part of a separate suction de-soldering tool which is used in conjunction with a conventional soldering iron, or it may form part of a specially designed suction iron. The principle of the method is shown in Figure 27. In a separate de-soldering tool, the suction is generated by depressing a spring-loaded piston inside the tool body, and then releasing it when the solder at the joint has melted. The solder is drawn into a chamber from which it can be immediately ejected by depressing the piston again. In the simpler types of iron, the suction is generated by a squeeze bulb of stiff rubber connected to the hollow bit via a small collecting chamber. Before the bit is applied to the joint, the bulb is depressed and as soon as the solder melts the bulb is released to draw up the solder into the collecting chamber. The solder remains molten and can be ejected by depressing the bulb again. The use of this type of iron should generally be limited to de-soldering of surface joints only.

8.2.1 Extractor irons designed for operation from a suction pump are also commercially available, and can be more effective than the squeeze bulb type, particularly for the de-soldering of through-hole plated joints. The irons are provided with various sizes of tubular bits to suit joint configurations. The selection of the proper size of bit is based on the minimum inside diameter required to fit over a lead or connector pin, at the same time, permitting molten solder to pass through the bit. The maximum outside diameter of a selected bit should not cover a mounting land completely, should not touch the board laminate itself, and should not extend over the flanges of eyelets. For terminal de-soldering, the outside diameter of the bit should be selected to permit entry into the desired area.

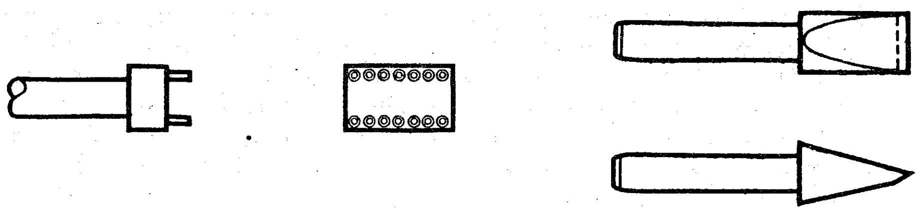
NOTE: Instructions issued by the specific extractor iron manufacturer should always be followed, and the effects the use of the iron may have on board circuit components should also be ascertained. For example, irons with instant-start suction pump motors can generate transient voltages, and it is essential that such voltages are not transmitted via leakage paths into the board circuit; the effects being particularly harmful where MOS (metal-oxide-semiconductor) devices are employed.

(a) The heated bit is applied to the soldered joint, and when melting of the solder is noted, the vacuum should be turned on to withdraw solder into the collector chamber of the iron. When removing a lead from a through-hole type joint, the residual tinning of the lead and hole wall causes re-sweating and the formation of new joints. To overcome this problem, the lead should be gently oscillated with the soldering iron bit while the vacuum is being applied, thereby permitting cool air to flow into the hole and around the lead and wall of the hole.

NOTE: De-soldering iron bits should be kept as clean as possible to avoid contamination of joint surfaces when removing solder.

8.3 **Hot Air Jet Method.** This method uses a controlled flow of hot air, and permits melting of a solder joint without physical contact. The heated air may be supplied through the hollow bit of a specially designed tool, or, in some commercially available solder extractor irons, it may also be selected as a mode of operation. The hot air jet may be applied to very delicate joints, and, in particular, to the de-soldering of lap joints between flat pack integrated circuit leads and conductor tracks. The air flow rate and temperature should be selected to achieve de-soldering without setting-up local heating levels which could be of detriment to the board material, components and their leads, and conductor tracks.

8.3.1 De-soldering should commence on one side of a pack; the hot air jet being progressed from lead to lead along the side. As soon as the solder melts at each joint, the leads should be lifted away from their tracks with the aid of non-metallic tweezers or a small non-metallic spatula. This operation should be repeated on the other side of the pack. When all the leads are free, the pack should be lifted from the board again with the aid of tweezers, or extraction tool (see Figure 16). In cases where a pack is bonded to the board, the bonding material should first be softened by means of the hot air jet (see paragraph 6.4). The conductor tracks should be cleared of residual solder by means of a solder extractor iron.



(A) DUAL-IN-LINE PACKAGE DESOLDERING (B) FLAT PACK DESOLDERING

Figure 28 HEATER BLOCKS

8.4 **Heater Block Method.** The heater block method is intended for the simultaneous de-soldering of a number of connections, e.g. the connections of dual-in-line circuit packages. The de-soldering bits take the form of a small copper block which is normally arranged in the manner shown in Figure 28 (A). The pins are of tubular steel and are precision brazed in the block at a spacing which corresponds both to the relevant hole spacing of the board and to the pin configuration of the package. The block should be applied to connections on the circuit side of a board and, with the aid of tweezers, or extraction tool, the package should be gently pulled from the plated-through holes as soon as the solder melts. Residual solder should be removed from the holes by a solder extractor iron before remounting the original package, or mounting its replacement, as appropriate.

8.4.1 For the removal of flat pack integrated circuit packages, a typical de-soldering bit is shaped as shown in Figure 28 (B). In use, the bevelled portion of the bit is held against all the soldered joints at each side of the package, in turn, and as the solder melts, the package is gently pulled away from the board. The de-soldering bit should not come into contact with any adjoining conductor tracks or the base laminate.

8.4.2 Extreme care should be exercised when using heater blocks of all types. They act as heat reservoirs and when applied to a board considerable heat can be transmitted into the base material. In addition tracks connected to circuit packages may, in some cases, be of varied thickness and width, so that blocks can apply different heating levels. Blocks should be kept as clean as possible to avoid contamination of joint surfaces when de-soldering.

APPENDIX 1

TOOLS AND MATERIALS

1 The following tools and materials are required for carrying out repairs and modifications to printed wiring boards.

2 TOOLS

Jig or suitable fixture for supporting boards during repair.

Temperature-controlled soldering iron and interchangeable bits.

Soldering iron stand.

Sponge for cleaning soldering iron bits. This may be a separate item or integral with certain types of soldering iron stand.

Static dip solder bath or pot.

Bench-mounted pyrometer for checking soldering iron bit temperatures.

Solder extractor iron of either the squeeze bulb type or controlled vacuum type.

Cutters with side cutting jaws, with cutting jaws angled at 45°, and with shear cutting jaws

Snipe-nosed and flat-nosed pliers.

Scalpel.

Stainless steel and non-metallic tweezers with pointed and radiused tips.

Dental probe.

Solid carbide drills in a range of diameters to suit conductor track widths, and repair wire sizes.

Rubber eraser, or glass fibre stick, for cleaning conductor tracks after removal of encapsulant coatings.

Small disposable plastic spatulas.

Small stiff-bristle brush.

Small camel hair paint brush.

Heat sinks. In the absence of specially designed tools, small flat nose, smooth jaw pliers or miniature type alligator clips with flattened ends and small copper strips soldered to them may be used.

Anti-wicking tool.

Lead insulation stripper of either the mechanical cutting or thermal type.

Heater blocks for de-soldering of dual-in-line and flat packs.

Polyurethane foam stick with abrasive coating.

Tools for insertion, extraction and general handling of dual-in-line and flat packs.

Optical magnifier. For short term examination of a small area, a watchmakers' eyeglass, or pocket magnifier are satisfactory. For detailed examination and inspection of complete assemblies for long periods, a bench-mounted magnifying viewer is recommended.

3 MATERIALS

Tinned copper wire to BS 4109. The sizes of wire required depend on the width of conductor track to be repaired, and should, therefore be selected in accordance with relevant manufacturer's repair instructions or standards.

Copper foil to BS 2870.

PTFE insulated wire to BSG 210.

PTFE insulating sleeving.

Rosin cored solder of 22-26 SWG and to BS 441 Grade K 60/40 tin/lead.

Terminal pins, turret lugs and eyelets in sizes appropriate to the relevant repair instructions or standards.

Epoxy resin adhesive and hardener appropriate to the relevant repair instructions or standards.

Polyurethane lacquer, hardeners and thinners appropriate to the relevant repair instructions or standards.

APPENDIX 2

CLEANING SOLVENTS

Isopropyl Alcohol Methylated Spirits	Flammable and should be used with caution. Avoid breathing vapours; use in well-ventilated area.
1.1.1 Trichloroethane Chloroethane Trichlorotrifluoroethane	Non-flammable, low-toxicity, chlorinated.
Trichlorotrifluoroethane with isopropanol	Low-toxicity, chlorinated. Under evaporation conditions and towards end of evaporation cycle, a flammable vapour rich in alcohol is produced.

NOTE: Toxic solvent containers should be clearly labelled.

Issue 2.

June, 1981.

AIRCRAFT

MICROMINIATURE CIRCUITS

LIST OF ABBREVIATIONS

1 INTRODUCTION This Leaflet has been introduced in view of the many technical papers and specifications relevant to Printed Circuits, Solid-State and Microminiature Circuit Technology, that have a large number of abbreviated terms, commonly used as a form of shorthand communication. As the meanings of such abbreviations are not always explained in an accompanying text, a number of abbreviations, therefore, have been collected and are set out in this Leaflet.

1.1 As is often the case with abbreviations, many of those given in this Leaflet have different meanings in other disciplines. It is, therefore, recommended that they should not be applied outside the scope of this Leaflet.

ACI	Asynchronous Communications Interface
ACIA	Asynchronous Communications Interface Adapter
a-d	Analogue to Digital
ADC	Analogue—Digital Converter
AFI	Automatic Fault Isolation
AIM	Avalanche Induced Migration
AL-gate MOS	Aluminium-gate Metal-oxide-semiconductor
ALM	Analogue Memory System
ALPS	Advance Logic Processing System
ALRS	Arithmetic-logic Register Stack
ALT	Axial Lead Tubular (ceramic capacitors)
ALU	Arithmetic logic Unit
APD	Average Propagation Display
APG	Automatic Programme Generation
APTE	Automatic Programmable Test Equipment
As	Arsenic
ASCR	Asymmetrical Silicon Controlled Rectifier
ASR	Automated Send/Receive
ATE	Automated Test Equipment
ATG	Automatic Test Generation
ATOL	Automatic Test-orientated Language
ATPG	Automatic Test Pattern Generation
BarITT	Barrier Injection Transit Time
BBD	Bucket Brigade Device
BCD	Binary-coded Decimal
BCSL	Base Current Switch Logic
BeAMOS	Beam Addressed Metal Oxide Semiconductor
BFET	Bipolar Field Effect Transistor
BFL	Buffered Field-effect-transistor Logic
BIGFET	Bipolar Insulated Gate-field Effect Transistor
BIMOS	Bipolar Metal Oxide Semiconductor
bit	Binary Digit
BITS	Backplane Integrated Test System
BML	Bipolar Memory Linear
BOP	Bipolar Operational Power
BORAM	Block Orientated Random-access Memory
BOSS	Binary Option Selection Switch
BPI	Bits Per Inch
BSR	Bit Shift Register
'B' Stage Material	Semi-cured material (Printed Circuit Board Laminates) also called 'Prepreg'
BU	Buffer Unit
BWO	Backward Wave Oscillator
CAD	Computer-aided Design
CAM	Content-Addressable Memory
CAPS	Computer-aided Programming Software (Automatic Testing and Fault-diagnosis)
CASH Circuit	Charge Amplified Sample and Hold Circuit
CATT	Controlled Avalanche Transit Time
CCCL	Complementary Constant Current Logic
CCD	Charge-coupled Device
CCL	Collector-coupled Logic also Constant Current Logic
CCO	Current-controller Oscillator
CCR	Condition Code Register
CCSL	Compatible Current-sinking Logic
CDA	Current-differencing Amplifier
CDI	Collector Diffusion Isolation (Diffused)
Cerdip	Ceramic Dual-in-line Package
CERMET	Ceramic Metallic
CHL	Current-hogging Logic
CMI	Compound Monolithic Integration
CML	Current Mode Logic (differential amplifier)

CMOS (C-MOS)	Complementary Metal-oxide-semiconductor
CMOS/DAC	Complementary Metal-oxide-semiconductor/Digital-Analogue Circuit
CMRR	Common-mode Rejection Ratio
CO	Controlled Oscillator
COM	Computer Output in Microfilm
COS	Complementary Oxide-silicon
COS/MOS	Complementary Oxide-silicon/Metal-oxide-silicon
CPU	Central Processing Unit
CR	Control Register
CRC	Cyclic Redundancy Check
CROM	Control and Read-only Memory
CRT	Cathode Ray Tube
CSL	Current-sinking Logic
'C' Stage Material	Fully-cured Material (Printed Circuit Board Laminates)
CTD	Charge-transfer Device
CTF	Contrast Transfer Function
CTL	Common Transistor Logic also Complementary Transistor Logic
CTR	Current Transfer Ratio
CVM	Correlating Voltmeter
CVT	Constant Voltage Transformer
CWV	Crest Working Voltage

DA	Device Adapter
d-a	Digital to Analogue
DAC	Digital-to-Analogue Converter
DAD	Data Acquisition Display
DAR	Data Access Register
DAS	Data Acquisition Sub-system
DC	Discrete Component
DCC	Discrete Component Circuit
DCD	Differential Correlating Detector
DCFL	Direct-coupled Field-effect-transistor Logic
DCL	Direct Coupled Logic
DCM	Digital Capacitance Meter
DCTL	Direct-coupled Transistor Logic
DDA	Digital Differential Analyser
DDR	Data Direction Register
DDS	Digital Display System
DEB	Data Exchange Bus
DED	Double Error Detection
DEDS	Data Entry and Display Sub-system
DF	Dissipation Factor (capacitors)
DFGA	Distributed Floating-gate Amplifier
D/G	Driver/Gate
DI	Dielectric Isolation also De-ionized Water
DIC	Digital Integrated Circuit also Dust-in-line Ceramic
DIL	Dual-in-line
DILLCD	Dust-in-line Liquid Crystal Display
DIM	Digital Impedance Meter
DIOS	Distributed Input/Output System
DIP	Dual-in-line Package also Dust-in-line Plastic
DL	Data Logging
DLD	Delay Line Decoder
DLDVM	Data Logging Digital Voltmeter
DMA	Direct Memory Access
DMC	Direct Memory Channel
DMM	Digital Multi Meter
DMOS	Double-diffused Metal-oxide-semiconductor
DMOST	Double-diffused Metal-oxide-semiconductor Technology
DMU	Data Management Unit (Computer)
DMUX	De-multiplexer
DOLS	Direct Off-line Switching
DP	Data Processing
DPM	Digital Power Meter
DPP	Delay Power Product
DPS	Data Processing Sub-system
DPVS	Digital Programmed Voltage Source
DR	Data Register
DSB	Double-sided board
DSC	Digital-to-synchro Converter
DSG	Digital Signal Generator
DSM	Dynamic Scattering Mode
DTL	Diode-transistor Logic
DTL/TTL	Diode-transistor Logic/Transistor-transistor Logic
DTL/TTL/CMOS	Diode-transistor Logic/Transistor-transistor Logic/Complementary Metal-oxide-semiconductor
DTL/TTL/MOS	Diode-transistor Logic/Transistor-transistor Logic/Metal-oxide-semiconductor
DTLZC	Diode-transistor Logic Zener Circuit
DUF	Diffusion Under Epitaxial Film
DUT	Device Under Test (Automatic Testing)
DUV	Data Under Voice
DVM	Digital Voltmeter

EAROM	Electrically Alterable Read-only Memory
EBCDIC	Extended Binary-coded Decimal Interchange Code
E beam	Electron Beam
EBES	Electron Beam Exposure System
EBS	Electron-bombarded Semiconductor
ECD	Electro Chromic Display
ECL	Emitter-coupled Logic
ECM	Electronic countermeasure
ECTL	Emitter-coupled Transistor Logic
ED Copper	Electro-deposited Copper (Printed Circuit Boards)
EE-PROM	Electrically Erasable Programmable Read-only Memory
EFL	Emitter-follower Logic
EIDA	Electronic Intelligence Data Acquisition
El-Pc	Electroluminescent-photoconductive
emi	Electro Magnetic Interference
EMP	Electro Magnetic Pulse
EMR	Electro-mechanical Relay
epi	Epitaxial
EPROM	Erasable Programmable Read-only Memory
EPS	Encapsulated Power Supply
EPUT	Events Per Unit Time
ESD	Energy Storage Device (Electro-chemical)
ESS	Electronic Switching System

Famos	Floating-gate Avalanche-injection Metal-oxide-semiconductor
FBG	Feed Back Gate
fdm	Frequency Division Multiplex
FDNR	Frequency Dependent Negative Resistance

FDV	Fault Detection Verification
FED	Field Effect Device
FET	Field Effect Transistor
FF	Flip-Flop
FFT	Fast Fourier Transform
FIFO	First-in First-out
FILU	Flag and Interface Logic Unit
FODTS	Fibre-optic Data Transmission System
FP	Flat Pack
FPLA	Field Programme Logic Array
F-PROM	Field Programmable Read-only Memory
FSK	Frequency-shift Keying
FTU	Function Test Units
FVC	Frequency-to-voltage Converter
GaAsFET	Gallium Arsenic Field Effect Transistor
GDN	Ground
GDT	Gas Discharge Tube
Ge	Germanium
GFET	Gate-field Effect Transistor
GFL	Guided Fault Location
GPIB	General Purpose Interface Bar
GPP	Ground Power Plane
GTOSCR	Gate and Turn off Silicon Controlled Rectifier
HCMOS	High-density Complementary Metal-oxide-semiconductor
HDDT	High Density Digital Tape
HIC	Hybrid Integrated Circuit
HIIC	High Isolation Integrated Circuit
HLTTL	High Level Transistor-transistor Logic
HMOS	High-performance Metal-oxide-semiconductor
HNIL (HiNil)	High Noise Immunity Logic
HOS	Higher Order Software
HSLI	High Speed Logic Interface
HTFD	Hybrid Thick Film Device
HTL	High Threshold Logic
HV	High voltage
HVPS	High Voltage Power Supply
IC	Integrated Circuit
ICE	In-circuit Emulator
IDDS	Incandescent Digital Display System
IEC	Infused Emitter coupling
IFU	Inter-face Unit
IG-FET	Insulated Gate-field Effect Transistor
IHS	Integrated Heat Sink
IIL (I^2L)	Integrated Injection Logic
ILP	Integral Lead Package
IMPATT	Impact Avalanche Transit Time
INCITE	Instructional Notation for Computer-controlled Inspection and Test Equipment
I/O	Input/Output
IOC	Input Output Controller
IOI	Input Output Interface
IOP	Input Output Processor
IPA	Integrated Photodetection Assembly
IR	Infra-red
I-RLED	Infra-red Light Emitting Diode
J-FET	Junction-Field Effect Transistor
JI	Junction Isolation
KMNR	Kodak Micronegative Resist (Semiconductor resist in ICs)

Laput	Light-activated Programmable Uni-junction Transistor
LARAM	Line Addresses Random-access Memory
LASCR	Light-activated Silicon Controlled Rectifier
LCD	Liquid Crystal Display
LCS	Large Core Store
LCT	Logic Circuit Test
LDO	Low Distortion Oscillator
LED	Light-emitting Diode
LED/IC	Light-emitting Diode/Integrated Circuit
LIC	Linear Integrated Circuit
LID	Leadless Inverted Device
LIFO	Last-in First-out
LL	Logic Level
LLL	Low-Level Logic
LOCMOS	Local Oxidation Complementary Metal-oxide-semiconductor
LOCMOS/CMOS	Local Oxidation Complementary Metal-oxide-semiconductor/ Complementary Metal-oxide-semiconductor
LOCOS	Local Oxidation-of-silicon
LOSOS	Local Oxidation Silicon-on-sapphire
LPSTTL	Low-power Schottky Transistor-transistor Logic
LRS	Linear Reversive Sequence
LS(TTL)	Low-power Schottky (Transistor-transistor-logic)
LSA	Limited Space-charge Accumulation also Logical Signal Assessor
LSB	Least Significant Bit
LSD	Least Significant Digit
LSI	Large Scale Integration
LSIA	Large Scale Integration Array
LSIATE	Large Scale Integration Automatic Test Equipment
LSI/MOS	Large Scale Integration/Metal-oxide-silicon
LSI/RAM	Large Scale Integration/Random-access Memory
LSI/ROM	Large Scale Integration/Read-only Memory
LSISi-gate MOS	Large Scale Integration Silicon-gate Metal-oxide-semiconductor
LSU	Line Switching Unit also Logic Switching Unit
LVDT	Linear Variable Displacement Transducer also Linear Variable Differential Transformer
MAR	Memory Address Register
MBP	Microwave Bonded Package
MC	Memory Cycle
MCA	Multichip Array
MCC	Multichip Carrier
MC MOS	Multichip Metal-oxide-semiconductor
MCU	Microprocessor Control Unit
mcw	Modulated Continuous Wave
MDS	Microprogramme Development System also Microcomputer Development System or Microprocessor Development System
MEAL	Micro-extended Assembly Language

MECL	Multiple Emitter-coupled Logic also Motorola Emitter-coupled Logic
MEDU	Monitor Equalisation Display Unit
MES FET	Metalised Semiconductor Field-effect-transistor
MIC	Monolithic Integrated Circuit also Microwave Integrated Circuit
MICROM	Micro Instruction Control Read-only Memory
MIR	Memory Information Register
MIS	Metal Insulator Silicon
MLA	Microprocessor Language Assembler
MLE	Microprocessor Language Editor
MM	Micromodule
MMA	Microelectronic Modular Assembly
MMIC	Millimeter-wave Integrated Circuit
MNOS	Metal-nitride-oxide Semiconductor
MOA	Micropower Operational Amplifier
modem	Modulator/Demodulator
MOS	Metal-oxide-silicon
MOSFET	Metal-oxide-silicon Field Effect Transistor
MOS/FIFO	Metal-oxide-silicon/First-in First-out
MOSIC	Metal-oxide-silicon Integrated Circuit
MOS/LSI	Metal-oxide-silicon/Large Scale Integration
MOS/RAM	Metal-oxide-silicon/Random-access Memory
MOST	Metal-oxide-silicon Transistor also Metal-oxide Semiconductor Technique
MOS/TTL	Metal-oxide-silicon/Transistor-transistor Logic
mP	Microprocessor Unit
MPC	Metallised Polycarbonate Capacitor
MPU	Microprocessor Unit
MReq	Memory Request
MRV	Maximum Reverse Voltage
MSB	Most Significant Bit (a/d and d/a Converters)
MSD	Most Significant Digit
MSI	Medium Scale Integration
MST	Monolithic System Technology
MTF	Modulation Transfer Function
MTL	Merged Transistor Logic
MTONS	Metal Thick Oxide-nitride-silicon
MTOS	Metal Thick Oxide-silicon
MU	Microprocessing Unit
MUX	Multiplexer
NDRO	Non-destructive Read-out
NE-PC	Neon-photo Conductive
N-FET	N-type-conduction Field Effect Transistor
N-MOS	N-channel Metal-oxide-silicon
N-MOSLSI	N-channel Metal-oxide-silicon Large Scale Integration
NRZ	None Return to Zero
NRZI	Non-return to Zero Inverted
OBO	On-board Oscillator
OCR	Optical Character Recognition
ODD	Optical Data Digitiser
OEM	Original Equipment Manufacturer
OpAmp	Operational Amplifier
OTA	Operational Transconductance Amplifier
PACE	Processing and Control Element
PAM	Pulse Amplitude Modulation

PAR	Programme-aid Routine
PC	Programme Counter (Microprocessor)
pc	Printed Circuit
P^2C-MOS	Double Polysilicon Complementary Metal-oxide-semiconductor
PCB	Printed Circuit Board
PCCD	Profiled Charge Coupled Device
PCM	Pulse Code Modulation
PDO	Phosphorous-doped Oxide
PDP	Power Delay Product
P-FET	P-type-conduction Field Effect Transistor
PFR	Power Fail Restart
Phot-SCR	Photo-sensitive Silicon Controlled Rectifier
PIA	Programmable Interference Analyser also Programmable Interface Adapter
PIU	Peripheral Interface Unit
P-JFET	P-type-junction Field Effect Transistor
PLA	Programmable Logic Array also Programmed Logic Array
PLL	Phase-locked Loop
Pmma	Polymethylmethacrylate (semiconductor resist in ICs)
P-MOS	P-type Metal-oxide-silicon
P-MOS/FET	P-type Metal-oxide-silicon/Field Effect Transistor
PP	Power Plane
PPM	Pulse Position Modulation
PPP	Potential Power Plane
PPS	Programmable Power Switch
PRACL	Page-replacement Algorithm and Control Logic
PRAM	Programmable Analogue Module
PRBSG	Pseudo-random Binary Sequence Generator
PROM	Programmable Read-only Memory
PRR	Pulse Repetition Rate
PSD	Phase-sensitive Detector
PSK	Phase Shift Key
PSL	Polycrystalline Silicon Layer
PSO	Phase-shift Oscillator
PSU	Power Supply Unit
PTD	Propagation Time Delay
PTH	Plated-through Hole
PTM	Pulse Time Modulation
PTV	Peak Transient Voltage
PUT	Programmable Unijunction Transistor
PW	Printed Wiring
PWB	Printed Wiring Board
RALU	Register and Arithmetic Logic Unit
RAM	Random-access Memory
RAMEn	Random-access Memory Enable
RAS	Random-access Store
RBI	Ripple Blanking Input
RBO	Ripple Blanking Output
RCTL	Resistance-coupled Transistor Logic
RF Cycle	Refresh Cycle
rfi	Radio-frequency Interference
RIM	Read-in Mode
RLC	Radial Lead Capacitor
RMM	Read-mostly (memory) mode
RMOS	Refractory Metal-oxide-semiconductor
ROM	Read-only Memory
ROS	Read-only Store
R Req	Refresh Request
RTD	Resistance-temperature Device
RTL	Resistor Transistor Logic
R/W	Read/Write

SAD	Serial Analogue Delay
SAILS	Soft-ware Adaptable Integrated Logic System
SAW	Surface Acoustic Wave
SBS	Silicon Bilateral Switch
SCDX	Solid State Control Differential Transmitter
SCO	Servo Control Oscillator
SCR	Silicon-controlled Rectifier
SDC	Synchro-to-digital Converter
SDFL	Schottky-diode Field-effect-transistor Logic
SDLC	Synchronous Data-link Control
SEC	Single Error Corrector
SEM	Scanning Electron Microscope
SFL	Substrate Fed Logic
S/H	Sample and Hold (function in electronic control systems)
Si	Silicon
SIC	Silicon integrated circuit
SID	Silicon Imaging Device
Si-gate MOS	Silicon-gate Metal-oxide-semiconductor
SIL	Single-in-line
SIP	Single-in-line Package
SIT	Silicon-intensifier Target
SLF	Straight Line Frequency
SLMS	Selective Level Measuring Set
SLVC	Super Linear Variable Capacitor
SMI	Static Memory Interface
SMO	Stabilised Master Oscillator
SMP	Switched Mode Power
SMPS	Switched Mode Power Supply
SMPSU	Switched Mode Power Supply Unit
SMRR	Senior Mode Rejection Ratio
S/N Ratio	Signal-to-noise Ratio
SOA	Safe Operating Area
SOS	Silicon-on-sapphire
SPAN	Stored Programme Alpha-numeric
SPC	Stored Programme Controlled
SPS	Switching Power Supply
SR	Status Register (Micro Processors)
SRD	Shift Register Decoder
SRT	Shift Register Transistor
SSB	Single-sided Board
SSCT	Solid-state Control Transformer
SSD	Static Sensitive Device
SSI	Small Scale Integration also Super Scale Integration
SSR	Solid State Relay
STT	Special to Type
STTL	Schottky Transistor-transistor Logic
SUS	Silicon Unilateral Switch

T/C/D	Timing/Control/Decoder
TDM	Time Division Multiplexed
TDRM	Time Displaced Ratio Meter
TED	Transferred Electron Device
TEM	Transverse Electromagnetic Mode
TFA	Transfer Function Analyser
TFHC	Thin Film Hybrid Circuit
TFT	Thin Film Transistor
THB	Through-hole Board
THP	Through-hole Plating
THPPCB	Through-hole Plated Printed Circuit Board
TIMOS	Total Implant Metal-oxide-semiconductor
TRAPATT	Trapped-plasma Avalanche Transit Time
TRL	Transistor-resistor Logic
TSDC	Two-speed Digital Converter
TSS	Tangential Signal Sensitivity
TTL	Transistor-transistor Logic
TTL/DTL	Transistor-transistor Logic/Diode-transistor Logic
TTL/DTL/CMOS	Transistor-transistor Logic/Diode-transistor Logic/Complementary Metal-oxide-semiconductor
TTL/ECL	Transistor-transistor Logic/Emitter-coupled Logic
TTY	Teletypewriter
TWT	Travelling-wave Tube

UART	Universal Asynchronous Receiver/Transmitter
UFET	Unipolar Field Effect Transistor
UJT	Unijunction Transistor
ULA	Uncommitted Logic Array
URCLK	Universal Receiver Clock
US/AR/T	Universal Synchronous/Asynchronous Receiver/Transmitter
USRT	Universal Synchronous Receiver/Transmitter
UTCLK	Universal Transmitter Clock
UUT	Unit Under Test

VCGO	Voltage Controlled Gunn Oscillator
VCO	Voltage Controlled Oscillator
VCR	Voltage Controlled Resistor
VDR	Voltage Dependent Resistor
VDU	Visual Display Unit
V-FC(V/FC)	Voltage to frequency Converter
V-FET	Vertical Fixed Effect Transistor
VHSIC	Very High-speed Integrated Circuit
VLED	Visible Light Emitting Diode
VLSI	Very Large-scale Integration
VMOS	Vertical (Structured) Metal-oxide-semiconductor
VOM	Volt-ohm-milliammeter
VSWR	Voltage Standing Wave Ratio
VTL	Variable-threshold Logic

WCS	Writable Control Store
WP	Workspace Pointer (Microprocessors)

XMOS	High-speed Metal-oxide-semiconductor

MMC/1-4

Issue 1.

January, 1981.

AIRCRAFT

MICROMINIATURE CIRCUITS

ANTISTATIC PROTECTION

1 INTRODUCTION Certain semi-conductor devices are susceptible to damage from electrostatic charges, and are at risk in any environment where they may come into contact with such charges. The prime risk during maintenance activities is the static charge held on personnel and tools, whilst in storage the risk is from the charge held on personnel and non-conductive packaging materials.

1.1 The metal oxide semi-conductor (MOS) and complementary MOS(CMOS) family of devices is most prone to damage from static electricity. Bi-polar devices which are also susceptible to this type of damage include, but are not limited to, Operational Amplifiers, Emitter-coupled Logic (ECL) devices, and Transistor-transistor Logic (TTL) devices. In addition, there is evidence to show that thick and thin film resistors, multi-metal-layer hybrid substrates, discrete transistors and diodes, Field Effect Transistors (FET) and Schottky TTL devices also suffer damage from electrostatic discharges.

1.2 The information given in this Leaflet, although based on practices which, when carried out by properly trained personnel, are proving to be effective, is intended to serve only as a general guide to the establishment of certain minimum standards of conduct during handling, packaging, storing and testing of these devices.

1.3 Reference should also be made to the following Leaflets which contain information associated with the devices covered by this Leaflet:

MMC/1–1 Printed Wiring Boards

MMC/1–2 Printed Wiring Board Repairs

MMC/1–3 List of Abbreviations

2 MOS DEVICE CONSTRUCTION

2.1 In an electronic circuit, a MOS device functions as a voltage-controlled resistor in which the MOS equivalent resistance between the drain and source is varied by a voltage applied to the gate electrode (see Figure 1). Physically, the gate electrode is a thin layer of metal deposited on a very thin layer of silicon dioxide (SiO_2 (glass)), typically 1000 to 1400 Angstroms thick. This layer of glass effectively insulates the gate electrode from the substrate, in essence, forming a capacitor, the plates of which are the gate electrode and substrate with the dielectric being the layer of glass between the gate electrode and substrate.

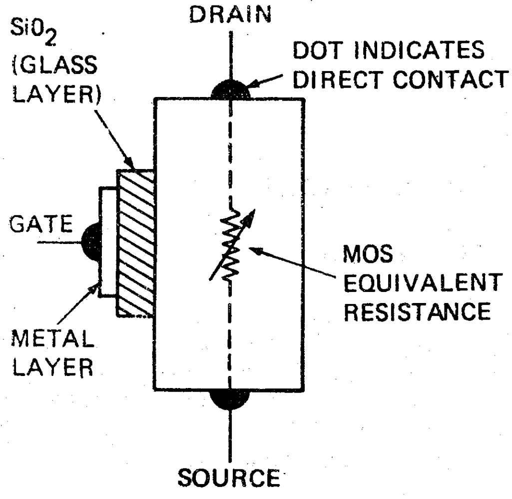


Figure 1 TYPICAL MOS DEVICE SHOWING THE INSULATED GATE

2.2 The dielectric strength of glass is approximately 10^1 V/cm, which means that a voltage in the range of 100 to 140 V can cause a rupturing of the glass, which would result in catastrophic damage to the device, usually as the result of a short circuit of the gate (electrode) to the source, drain or substrate. To avoid damage from overvoltage, manufacturers of MOS/CMOS devices usually incorporate protective circuitry on the gate electrode input pins (usually some type of resistor-diode network) so designed as to provide an alternative path for transient voltage such as electrostatic discharges. It is not the voltage discharge to ground but the potential difference between the pins on the device which causes the damage. With the elimination of such potential difference the damaging effects of an electrostatic discharge can be prevented.

2.2.1 For an unprotected MOS device the resistance at the input pins is approximately 10^{14} ohms. Using this figure it can be calculated that a current of approximately 10^{-12} ampere (10pA) can generate a 100 V potential which can rupture the layer of glass and destroy the device. Since all protective devices require the addition of some P-region the resistance can normally be reduced to approximately 10^{10} ohms. Although the effectiveness of the protective circuitry varies, most provide protection from human body electrostatic discharges only up to several hundred volts. Thus, such circuits can provide only limited protection against electrostatic discharges, which, in uncontrolled areas, can be measured in thousands of volts.

2.2.2 Figure 2 gives a schematic representation of a typical protected MOS device, as indicated by the presence of a built-in zener diode. The source, gate and drain electrodes are the equivalent of the emitter, base and collector electrodes of the typical bi-polar transistor (the substrate lead of the device is normally connected to the source lead). In most cases, the zener diode which protects the MOS device conducts at approximately 50 V. However, selection of a value for the substrate resistance can present a problem to the manufacturer as this resistance value must be great enough to limit current flow to prevent destruction of the zener diode, but must not be so high that the sum of the voltage drop across the zener-resistance combination exceeds the breakthrough voltage of the glass layer.

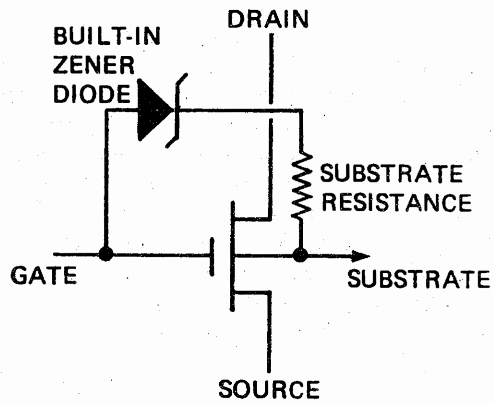


Figure 2 A TYPICAL PROTECTED MOS DEVICE

3 CAUSE OF STATIC ELECTRICITY

3.1 **Positive and Negative Charges.** Whether or not an item becomes subject to 'positive' or 'negative' electrostatic charges stems from the atomic or molecular structure of the materials involved in its construction. Materials which will readily give up electrons become charged positively, whereas others which have an affinity for electrons become charged negatively. Whenever two items are brought into contact and then separated, there is likely to be electron transfer and thus electrostatic charging, and this can result both from rubbing or non-frictional contact/separation. The net charges on the two materials will be equal but the conductivity (or resistivity) of the materials will greatly affect the potential electrostatic charges involved.

3.1.1 The charges tend to dissipate quickly over the entire surface of conductive materials, which not only lowers the electrostatic potential but increases the possibility of further dissipation to other materials which are in contact directly or via an air space.

3.1.2 On non-conductive materials the electrostatic charge can remain in localised areas at high potentials, creating electrical fields between themselves and other materials at different potentials and ground. Materials entering these fields can be charged by induction, which takes place when electrons of the material entering the field are attracted to those areas closest to any one of positive potential, leaving behind positive charged areas and creating negative charged areas. This transfer of electrons and consequent electrostatic charging by contact/separation is known as the 'triboelectric' effect.

3.2 **Prime Electrostatic Generators.** Materials common to electronic maintenance, repair and testing, which can be factors in the generation of electrostatic charges, include the human body, all work surfaces, floors (especially if waxed), furniture, personal clothing (including clean room garments), tools and all non-conductive packaging materials. Some type of motion is required for the generation of electrostatic charges and some non-conductive materials are extremely good generators of such charges. Nylon shirts or smocks, for example, can easily become charged to 20 000 V or higher. However, the human body is, in all likelihood, the most frequent source of damage to sensitive electronic components as a result of electrostatic discharge.

3.2.1 The electrostatic potential of the human body is a function of many variables, such as body capacitance, clothing material and style, body activity, relative humidity of the air, footwear, etc. A widely accepted electrical model for the human body is a capacitor (C_{HB}) and a series resistor (R_{HB}). There must, obviously, be a wide range of published values for both parameters, as many variables can affect them, e.g. body size, muscle tone, skin ruptures (spots, cuts, etc.), skin moistness, contact area, footwear, position in relation to the work piece, etc. However, the consensus of opinion would appear to support 200 pF as a reasonable approximation for C_{HB} and 1000 ohms for R_{HB} (including contact resistance). Table 1 gives representative data under typical industrial conditions.

TABLE 1 TYPICAL MEASURED STATIC CHARGES FOR THE HUMAN BODY

SITUATION	Relative Humidity of Air	
	Low 10-20%	High 65-90%
	Volts	Volts
Walking across a carpet	35 000	1 500
Walking over vinyl floor covering	12 000	250
Worker at bench	6 000	100
Vinyl envelopes containing work instructions	7 000	600
Polythene bag picked up from bench	20 000	1 200
Work chair padded with urethane foam	18 000	1 500

3.2.2 Clothing, floor coverings and furniture are not the only generators of static electricity. So, too, are many of the usual materials which are, unfortunately, still used for the packaging and transportation of electrostatic-sensitive semi-conductors and, in many instances, complete printed circuit board assemblies. Tools which have normally been used in electronic engineering and which have been thought to be safe, are often not. One particularly dangerous tool to use on an electrostatic-sensitive device is the plastics de-soldering tool; the sudden rapid movement of the plastics piston in the piston sleeve of the tool can generate a very high electrostatic potential. Another potentially dangerous tool is the electrical soldering iron which, unless it is 'grounded' at the tip, can also be a dangerous electrostatic carrier.

4 GENERAL HANDLING PROCEDURES FOR ALL SEMI-CONDUCTORS

4.1 It is not possible to lay down a degree of electrostatic protection which would cover all types of semi-conductor. However, there is a strong consensus of opinion that a significant reduction of dangers related to electrostatic charges can be achieved by making personnel aware of possible electrostatic generators and improved general handling techniques, such as:—

(a) Not removing or replacing line replaceable units with electrical power applied.

(b) Not unnecessarily touching the connectors, leads or edge connectors, etc., of printed circuit boards containing such devices.

(c) By using conductive packaging, shorting plugs, bands or wire when provided or prescribed in the relevant aircraft or equipment Maintenance Manual.

(d) By paying particular attention to stores procedures to ensure that protective packaging is not removed during any goods-inwards inspection.

5 ELECTROSTATIC-FREE WORK STATION

5.1 **General.** If, by the nature and volume of work, it is considered necessary to set up an electrostatic-free work station, guidance may be obtained from the following paragraphs which set out the various options which are open.

5.2 **Humidity.** A factor which needs to be considered when working with electrostatic-sensitive devices is the humidity of the working environment. The air in a very low-humidity environment is dry and has a very high resistance, such air will not discharge the static electricity as quickly as a moist air. Therefore, the working environment for an electrostatic-free work station should ideally, have a relative humidity of between 30 and 50%.

5.3 **Working Environment.** There are two basic methods of achieving a safe working environment in which to handle electrostatic-sensitive devices. One is dependent upon the provision of a conductive work surface, which, together with the operator and tools in use, is bonded electrically to a common ground. The other makes use of the conductive properties of an ionised atmosphere to dissipate static electrical charges.

5.3.1 **Conductive Work Surface Technique**

(a) The work surface of a bench is covered with a sheet of conductive material, e.g. plastics, or mat which is secured to the bench to prevent it from moving. The floor area in front of the bench is also covered with conductive material and electrically bonded to the work surface by means of a bonding strap. To be effective the bonding strap should have a resistance of approximately 2000 to 4000 ohms per linear foot, and should be as short as possible. A further bonding strap is used to link a wrist strap, worn by the operator, to the work surface, and this should have a resistance of 200 k ohms to 1 M ohms. To complete the system the work surface is connected to a suitable ground point. In addition the work seat may be covered with a conductive seat cover.

NOTE: Under no circumstances should the work surface of a static-free work station be connected to the electrical power supply ground circuit of the building.

(b) The main disadvantage of the conductive work surface is its conductivity. As each element of the system is bonded to a common ground to which the operator is connected via a wrist strap, immediately the operator is in direct contact with the work surface, which normally has a surface resistivity of approximately 3000 ohms, the wrist strap resistance is rendered ineffective.

5.3.2 **Conductive Atmosphere Technique**

(a) **Electrical Ionisation**

(i) An ozone laden atmosphere can be produced by several electrical methods. The safest and most acceptable method relies upon a capacitive connection between its ozone emitting needles and the conductor. The system for producing ozone consists of a rod made up of three separate elements. The outer element is a tube, made of an insulating material, which has sta less steel needles embedded at right angles at intervals along its length; the unt ends of these needles protrude through to the second element, which is another tube of the same material coated with rings of a silver compound which in contact with the needles. The third element which forms the centre of th rod is standard HT conductor cable (motor car ignition type) which is connected to an 8000 V secondary winding of a mains operated transformer The complete rod is housed in a metal shroud which both protects and supports it. The effective range of this type of electrostatic eliminator is normally 13 cm (5 in) but can be increased to 61 cm (24 in) by providing an air boost, at a pressure of 14 kN/m^2 (2 lbf/in^2).

(ii) The conductive atmosphere technique depends upon ozone which in concentrations exceeding 1·0 parts per million (ppm) causes discomfort. It has been demonstrated that the ozone concentration 50 mm (2 in) from the nozzle of the eliminator is less than the 0·05 ppm which the Institute of Aviation Medicine states is a maximum for long term exposure. Electrically, the eliminator is completely safe despite the high voltage involved, and the emitter rod can be freely handled during operation.

NOTE: Extended periods of working in such an atmosphere may, nevertheless, cause extreme drowsiness.

(b) In special circumstances when the setting up of an electrostatic-free work station is impractical, an air ioniser could be used. A blower projects a stream of air containing both positive and negative ions onto the work surface and onto the operator's hands temporarily neutralising the static charges in the region. These blowers may also be used in conjunction with a conductive work surface when high levels of electrostatic charging are being experienced.

5.4 **General Operating Procedures**

5.4.1 **Conductive-Surface Work Station**

(a) Following the initial setting up the station should be checked for an effective ground and periodically monitored thereafter. In order to establish that wrist straps have not developed any faults, periodic checks should be made on their resistive value.

(b) Under no circumstances should the operator, or anybody else, touch electrostatic-sensitive devices, or assemblies containing such devices, without first having placed a wrist strap in direct contact with his wrist.

(c) When a conductive surface station is equipped with an air-ioniser blower, the normal operating procedure is to allow the blower to operate for approximately two to three minutes before performing any work. The operator should also move his hands into the ionised airstream for a few seconds, to allow for charge dissipation, before handling electrostatic-sensitive devices.

5.4.2 **Conductive Atmosphere Work Station.** Before commencing work it should be ensured that the ionising bars are working properly. This can be done by checking for the smell of ozone, thus establishing the presence of a cloud of ionised air. Satisfactory operation of the eliminator should also be determined by the vibration felt when it is held loosely in the hand, while the flow of boost air can be felt by passing a hand close to the emitter nozzle.

5.4.3 The effectiveness of an electrostatic-free work station can be further checked by the use of an electrostatic-detecting meter. Such meters are normally capable of detecting the presence, and indicating the polarity and level of static electricity, and can be read on various scales, ranging from 30 to 50 000 V at distances of 6·5 to 30 cm (2·5 to 12 in).

6 GROUND CONNECTIONS

6.1 For grounding purposes a copper mat or plate should be sunk into the earth to a depth which will ensure that it will be constantly damp. A typical grounding arrangement is shown in Figure 3. Ideally, electrostatic-free work stations should be connected to the grounding mat with a connecting strip of the shortest possible length, so reducing the possibility of radio frequency pick-up.

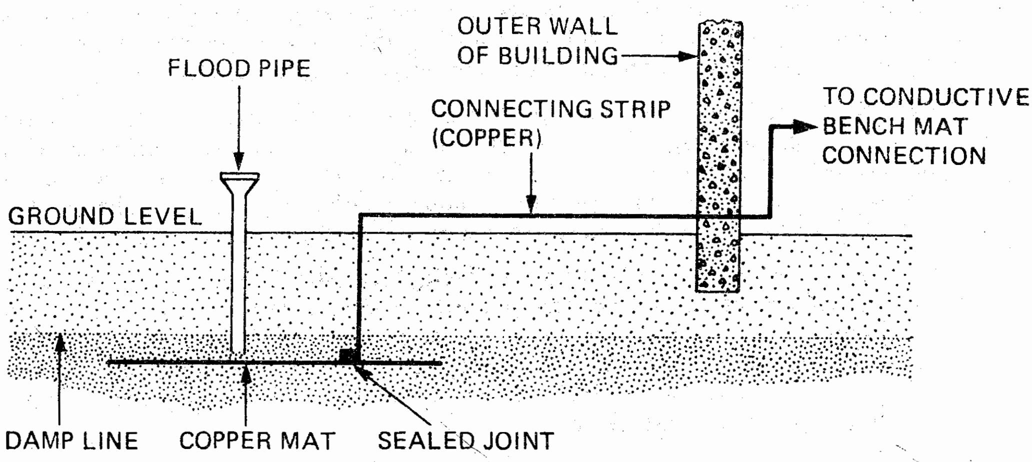


Figure 3 TYPICAL GROUNDING ARRANGEMENT

6.1.1 Care should be taken to use a material for the connecting strip which will not create a potential of more than 0·25 V with the material to which it is joined. If the connections are made by welding or soldering, they should be thoroughly cleaned to remove all traces of flux residue, and should then be completely covered with a sealing compound or other insulating covering.

6.1.2 In well drained locations, it is recommended that a pipe should be sunk over the ground mat to permit occasional flooding of the mat.

6.1.3 Where an outside wall position is not possible, a ground mat should be sited under the floor of the building or, alternatively, the work stations may be connected to grounding spikes.

7 ADDITIONAL PRECAUTIONS

7.1 **General.** Providing an electrostatic-free work station will not, on its own, ensure that no electrostatic-sensitive devices will be damaged or destroyed. Complete protection may only be achieved when certain standard operating and handling procedures are also adhered to. Only then will the complete effectiveness of the work station be realised.

7.1.1 Persons engaged in maintenance or repair work should be electrostatic conscious and should consider the avoidance of damage by electrostatic charges as a normal responsibility. They should also be aware of the necessity for the elimination of electrostatic generation such as plastics envelopes, non-conductive tapes and other commonly used items made from plastics, nylon and rubber.

7.1.2 The effectiveness of an electrostatic-free work station should be regularly checked with a static-detecting meter (see paragraph 5.4.3).

7.1.3 Work which involves the handling of exposed electrostatic-sensitive devices should not normally be undertaken outside the confines of an electrostatic-free work station. Such devices and any modules containing them should always be handled by their cases, and the unnecessary touching of connecting leads, pins or edge connectors, even if grounded, should be avoided. Modules, printed circuit boards or components should never be removed or replaced with electrical power supplies switched on. Devices which are supplied with pin shorting links or wires should only have such links or wires removed after the devices have been fitted into the circuit.

7.1.4 Soldering irons should always be used with a grounded bit, except for those which are normally used in conjunction with an isolation transformer, as grounding of this type of soldering iron may be hazardous to personnel. Any accumulated electrostatic charge on other hand tools should be discharged prior to the tool being used. No attempt should be made to test electrostatic-sensitive devices with a multimeter.

7.1.5 For both serviceable and unserviceable electrostatic-sensitive devices, modules and printed circuit boards the same precautions should be observed. It is, therefore, advisable to retain any conductive or anti-electrostatic packaging material removed from serviceable equipment for re-packaging of the unserviceable items, ensuring that the package is suitably labelled to show that the contents are unserviceable but contain electrostatic-sensitive devices.

8 TESTING

8.1 **General.** All testing of equipment containing electrostatic-sensitive devices should be strictly in accordance with the relevant manufacturer's instructions. The following paragraphs only draw attention to the more general precautions which should be observed during testing of electrostatic-sensitive devices and/or printed circuit boards or modules.

(a) In general, such items should not be inserted or removed from their installed positions unless all electrical power is switched off, as transient voltages may cause permanent damage.

(b) When bench testing, input test signals should not normally be injected into such items without electrical power being applied. All unused input connections should also, normally, be connected to a power source or to ground.

(c) Much of the test equipment used for the testing of such items will also contain electrostatic-sensitive devices. While calibration of this type of test equipment will not normally require the operator to wear a wrist strap, if a repair or replacement has to be made involving an exposed device or module, then a wrist strap should be worn, and the electrostatic damage-prevention measures of this Leaflet should be implemented.

9 STORAGE

9.1 **General.** The creation of a safe storage environment does not depend on the provision of the same kind of facilities which have been outlined. The packaging of equipment precludes the use of a conductive atmosphere technique; therefore, adequate protection is dependent upon the provisioning of a conductive surface. Whilst it is advisable to store electrostatic-sensitive equipment in grounded metal racks and cupboards this alone will not necessarily completely protect such equipment.

9.1.1 It is known that plastics and polymer based packaging materials will retain static charges which produce voltage gradients across the surfaces; accordingly, electrostatic-sensitive equipment must never be stored alongside non-electrostatic-sensitive equipment.

9.1.2 Electrostatic-sensitive equipment should be packed in a conductive material, such as will ensure that the whole of the package is maintained at the same potential, and should then be stored in grounded metal racks or cupboards.

9.2 **General Precautions**

9.2.1 All packages containing goods inward should be checked for the presence of electrostatic-sensitive devices by reference to external markings and reference numbers. Any package not so marked should, if it contains electrostatic-sensitive devices, be labelled accordingly, and should be handled and stored in accordance with the recommendations of this Leaflet.

9.2.2 The conductive packaging of such equipment should never be removed outside the confines of an electrostatic-free work station.

RL/2-1

Issue 2.

15*th November*, 1974.

AIRCRAFT

RADIO

ADF LOOP AERIALS

1 INTRODUCTION This Leaflet gives general guidance on the calibration and testing of loop aerials for Automatic Direction Finding (ADF) equipment. Although most aerials in current use are of the fixed loop type, certain aspects of testing appropriate to rotating loop aerials are retained as a guide to the continued serviceability of some existing installations. The Leaflet should be read in conjunction with the relevant aircraft and equipment Maintenance Manuals which contain details of the procedures to be adopted for specific installations. Reference should also be made to the following Leaflets and chapters of British Civil Airworthiness Requirements, which contain information closely associated with the equipment and practices covered by this Leaflet.

AL/10-5	Direct-Reading Magnetic Compasses
EEL/1-6	Bonding and Circuit Testing
RL/2-2	Radio—Aerials
RL/2-3	Screened Rooms for Radio Maintenance
Chapter **R4-5**	Bonding and Lightning Discharge Protection
Chapter **R4-6**	Tests for ADF Systems
App. No. 3	

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet **RL/2-1,** Issue 1 dated 15th March 1955, Leaflet **RL/5-2,** Issue 1 dated 15th June 1960, and Leaflet **RL/5-3,** Issue 1 dated 15th June 1962.

2 LOOP ERRORS When ADF loop aerials are installed in aircraft, errors are introduced which vary with the type of aircraft and the location of the loop. Two types of error may be introduced; (i) Quadrantal and (ii) Loop Alignment. In rotating loop installations a Field Alignment error may also be introduced. The direction and amount of such errors throughout the working range of the equipment must be known to enable corrections to be applied.

NOTE: Information on the correction of loop alignment errors is not included in this Leaflet as such procedures are fully described in the Maintenance Manuals and Overhaul Manuals for the equipment concerned.

2.1 **Quadrantal Error.** When installed, loop aerials are subject to bearing indication errors arising from radio frequency currents circulating in the metal structure of the aircraft. The loop is subjected to induction and re-radiated fields from these currents in addition to the radiation field of the distant transmitter. These errors are classified as quadrantal errors because maximum deviation occurs roughly at the centre of each of the quadrants formed by the horizontal axes of the aircraft (see Figure 1).

2.1.1 After the initial installation of ADF equipment, it is necessary to determine the amount and direction of the errors and also whether or not they remain constant over the full frequency range of the receiver. Any appreciable change of error between one frequency and another indicates that the installation is unreliable.

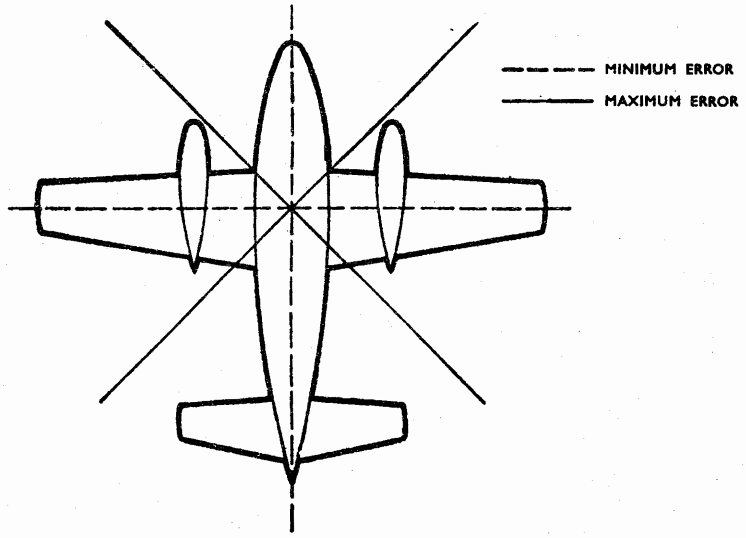


Figure 1 QUADRANTAL ERROR

2.1.2 Allowances for quadrantal errors are made by taking bearings from a transmitter of which the actual bearing is known and making appropriate corrections to the direction finding equipment in the aircraft; the procedure is known as "swinging for quadrantal correction" or, more briefly, "loop swinging".

2.2 **Loop Alignment (Installation) Error.** As it is not always possible to sight the loop for accurate alignment, the CAA recommends that, where applicable, the loop should be jigged at 90° to the loop base whilst the base itself is aligned to within ±0·25° of the longitudinal axis using the lubber lines, fore and aft fixing holes or other means of alignment provided by the aircraft manufacturer.

2.2.1 Systems should be checked by switching to LOOP, under conditions of no signal, and verifying that the remote indicators read ZERO when the plane of the loop is at 90° to the longitudinal axis of the aircraft.

2.2.2 Remaining loop alignment errors will be indicated when the loop is swung and these should be corrected at the same time as the quadrantal errors (see paragraph 3.3.1).

2.3 **Field Alignment Error.** A further error may be revealed on the quadrantal error curve for a rotating loop, should the loop be offset from the aircraft centre-line. In this case it will not be operating at the centre of the re-radiated radio field pattern and a correction should be embodied concurrently with the quadrantal error corrections (see also paragraph 4).

3 LOOP SWINGING The swinging method to be adopted will depend on the position of the loop. A loop mounted on the top of the fuselage can be calibrated on the ground, calibration being facilitated if the aircraft has a nose landing gear and is, therefore, approximately in its flight attitude. A loop mounted on the underside of a fuselage may be appreciably affected by the proximity of the ground, or parts of the aircraft such as the landing gear. If such interference is detected during ground swinging, the loop should be calibrated in the air. In all cases loop installations should be checked by an air test after normal quadrantal errors have been corrected.

NOTE: The highest possible degree of accuracy is essential when calibrating on the ground, or in the air, since observational errors in reading either the ADF bearing or the reference bearing, will cause the calibration curve to differ from the theoretical pure quadrantal curve.

3.1 **Night Effect.** To allow for variations of the ionosphere, no swings should be made at night. In temperate climates "night effect" commences about 2 hours before sunset and continues until 2 hours after sunrise, but in tropical countries the period may be reduced to 1 hour in each case.

3.2 **Ground Calibration.** Before swinging a loop on the ground a site must be selected that is flat and clear of obstructions. The site should be as far as possible from ferro-concrete and steel-mesh runways, hangars, railways and overhead or underground electrical power supplies; it should be remembered that the erection of new buildings may adversely affect the suitability of the site.

3.2.1 Bases specially prepared for magnetic compass swinging should not be assumed to be suitable unless check bearings are taken, e.g. by means of a portable direction finder, although allowances can be made for permanent errors on such sites. Bearings should be taken from a number of transmitters selected to give as wide a check as possible throughout the ADF frequency bands over a 360° range. Radio bearings of the selected transmitters should remain reasonably constant over the whole area which will be covered by the aircraft during the calibration procedure.

3.2.2 A loop can be swung with reference to either True or Magnetic North. The main advantage of referring to True North is that a base can be permanently marked out so that distant station bearings can be ascertained without reference to changes in magnetic variation. If the swing is referred to Magnetic North, the loop should be calibrated by means of a datum compass, such as the medium landing compass, which should be aligned with the aircraft's longitudinal axis and positioned at a specified distance from the aircraft (typical distances can vary between 50 and 150 feet). In order that the longitudinal axis may be accurately determined, aircraft datum points and directions from which they are to be sighted, must be carefully selected.

NOTE: Periodic calibration checks can be referred to the aircraft remote indicating compass system or, if no other method is available, to the aircraft direct-reading magnetic compass. A check should be made that the particular aircraft compass system used has recently been corrected; the correction procedure for direct-reading compasses is given in Leaflet **AL/10-5.**

3.2.3 Before commencing to swing a loop, a check should be made to ensure that the aircraft contains its full complement of airborne equipment; this is of particular importance if the loop has to be checked against the aircraft compass system. Doors and panels in the vicinity of the loop and the sense aerial, should be closed and secured. Ground equipment such as towing vehicles, towing arms, etc., should not be positioned near the aircraft. Internal power supplies should be used whenever possible. It should also be remembered that the ADF installation may suffer from interference if there are faults in the aircraft bonding or electrical systems, or if additions of aircraft equipment have been made in close proximity to the loop.

3.3 **Swinging By Reference To Magnetic North.** The results obtained by this method of swinging should be recorded on a suitable chart. A specimen chart showing typically essential information and an example calculation is given in paragraph 3.3.1. The swing should be repeated in each frequency band of the ADF receiver.

3.3.1 The aircraft should be turned through a specified number of magnetic headings to enable ADF bearings relative to the selected transmitter bearing (160° in the example considered) to be obtained. For initial swings and for check swings, heading intervals of 15° and 45° respectively, are usually satisfactory. The readings obtained should be entered in column 4 of the correction chart. When aircraft headings are derived from the compass system, the readings in column 4 should be corrected for deviation by taking the algebraic sum of the values entered in columns 2 and 3.

ADF LOOP CALIBRATION

Ref.: ....

Calibrated At: .... Aircraft Type: ....

Radio Station: .... Registration: ....

Frequency: .... ADF Type: ....

Distance: .... Loop Position: ....

Time Calibrated: .... Date: ....

Heading No.	1. Magnetic Bearing of Station from Site: 160					
	2	3	4	5	6	7
	Compass Heading	Compass Deviation	Magnetic Heading (2±3)	Bearing Indicated by ADF	Relative Bearing of Station (4+5) or (4+5−360)	Correction Required (1−6)
1	314	1°E	315	200	155 (i.e. 515–360)	+5

At the same time, the ADF bearing indicated by either the loop or goniometer scale, or other relevant bearing indicator, should be noted and entered in column 5. The relative bearing of the station (column 6) should then be obtained by adding together the magnetic heading and ADF bearing; in the example shown 360° has been subtracted from the total. The difference between the relative and magnetic bearings of the station then gives the amount of quadrantal error correction required and this is entered in column 7.

3.3.2 When completed, entries obtained in columns 5 and 7 should be plotted as shown in Figure 2. This depicts an almost perfect curve which is symmetrically balanced about the base line, and is of regular shape. A well sited loop should give similar results on all bands. For record purposes, the graph should also form part of the calibration chart.

NOTE: Departures from the shape of the curve shown in Figure 2, whether repeated on all frequency bands or not, necessitate elimination of the cause, or, if this cannot readily be done, re-siting of the loop. The most frequent cause of an incorrectly shaped curve is interference from aerials or other equipment in the vicinity of the loop.

3.3.3 Figure 3 shows the results of a swing where vertical shift has occurred from loop alignment error, and where horizontal shift is apparent as a result of field alignment error (see paragraph 2.3). The measurements should be re-checked to ensure that the loop is on the true centre line of the aircraft. In the example shown, repositioning the loop should have the effect of moving the curve 10° to the left, when an adjustment to the bearing indicator of 4° relative to the loop will revert the curve to that of Figure 2.

NOTE: Reference should always be made to the relevant equipment Maintenance Manuals for the methods of correcting loop and field alignment errors. Information of a general nature is given in paragraph 4 of this Leaflet.

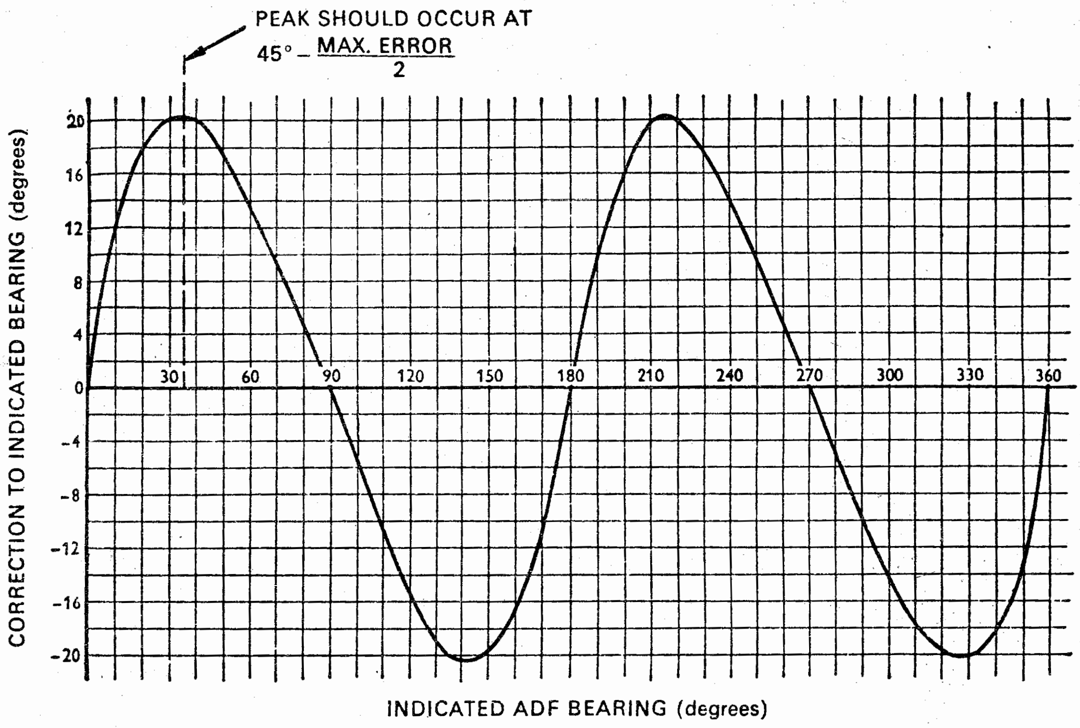


Figure 2 QUADRANTAL ERROR CURVE

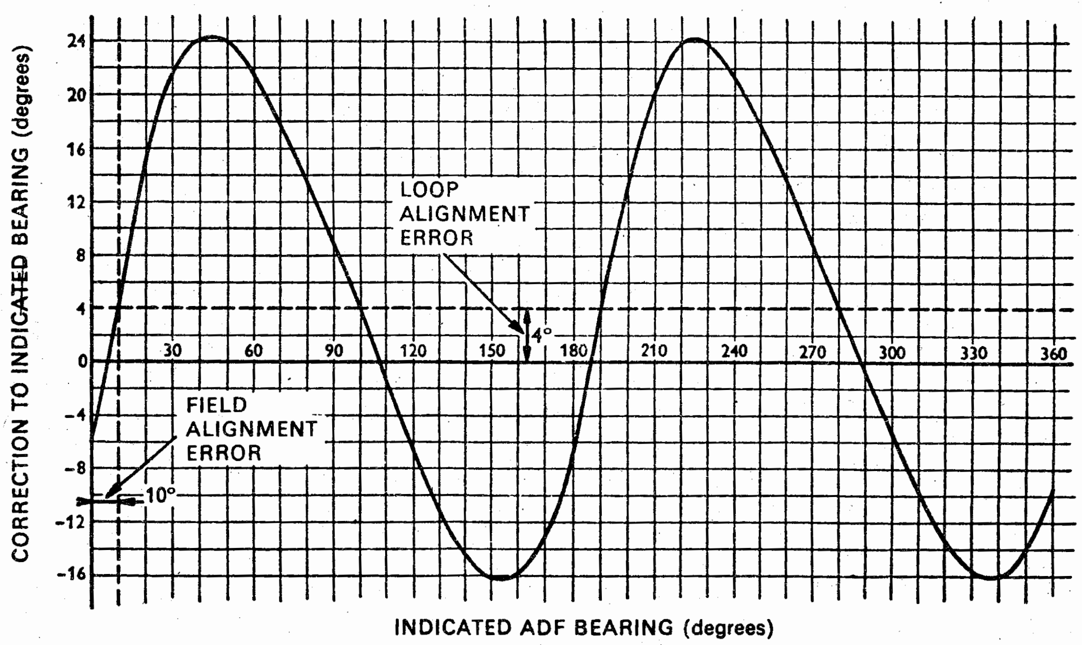


Figure 3 QUADRANTAL ERROR CURVE WITH VERTICAL AND HORIZONTAL SHIFT

3.4 **Air Calibration.** The method of air calibration should be selected according to prevailing circumstances and geographical location. Two methods are given in this Leaflet; Position Line Swinging and Single Point Swinging.

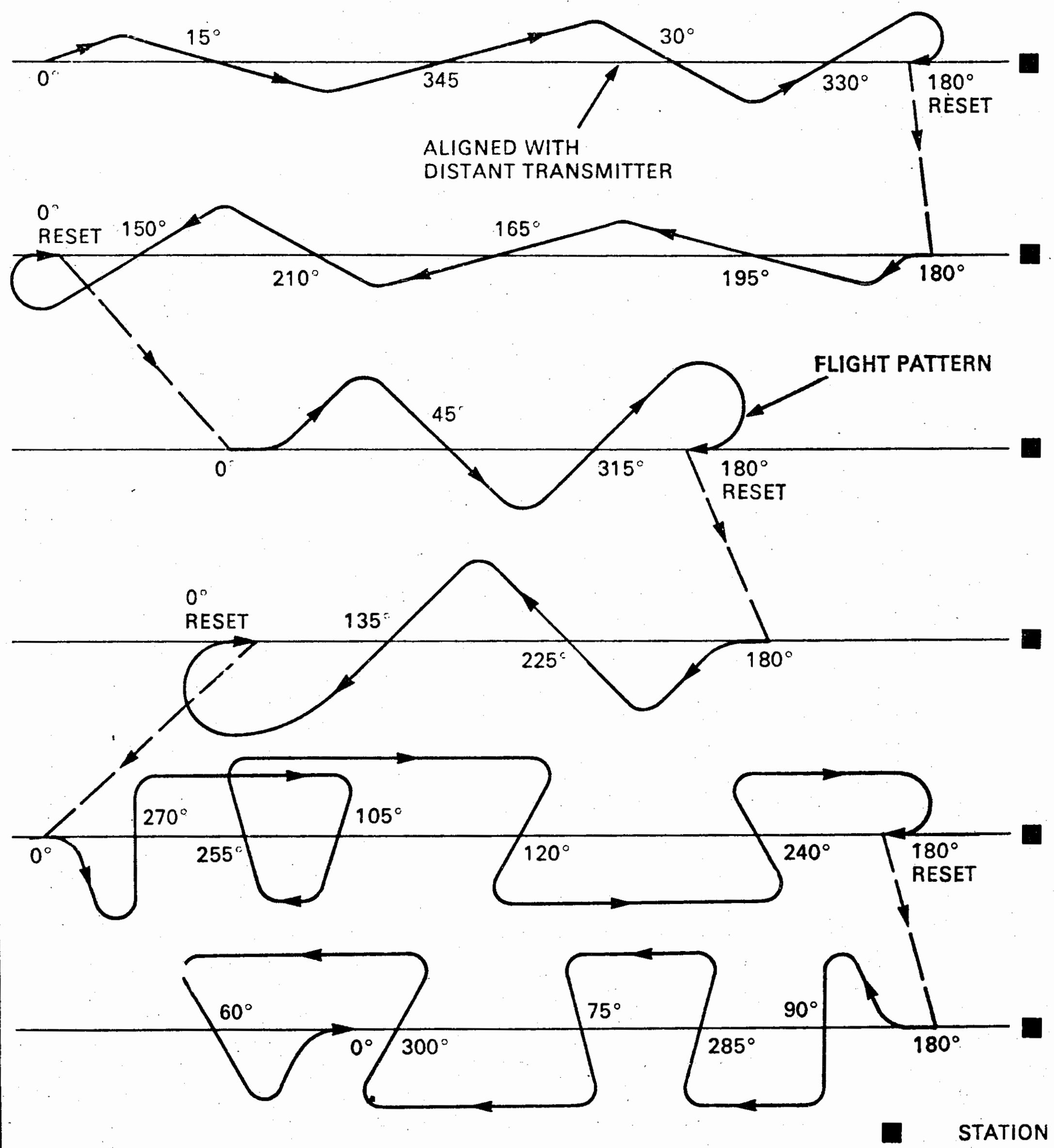


Figure 4 PATTERN OF FLIGHT FOR POSITION LINE SWINGING

3.4.1 **Position Line Swinging.** This method entails flying to a set pattern over such a series of landmarks as will produce a ground reference line aligned with a distant transmitter.

(i) The calibration flight should be made in smooth air conditions, when the wind velocity is negligible, in order to eliminate drift errors. All turns should be gradual and identical.

(ii) The ground reference line should be checked for any distortion of the transmitter radiation pattern. This may be done by flying across the line and observing the bearing indicator for irregularities in indication. If irregularities occur, the flight should be made at another altitude, or another reference line should be selected.

(iii) A pattern of flying similar to that shown in Figure 4 should then be followed, the indicator readings being recorded at each point of intersection with the ground reference line. The aircraft should approach each intersection in level flight and not on the point of a turn.

3.4.2 **Single Point Swinging.** For this method a clearly defined point should be selected which is inland and greater than 40 miles from the transmitter; the true bearing of the point from the transmitter should then be determined from plotting charts. The swing is made by flying a "clover leaf" pattern over the point at an altitude which permits accurate observation; the actual altitude will, of course, depend on the visibility and weather conditions prevailing at the time.

(i) A preliminary check should be made on the aural ADF signal to verify that the minima (null points) are sharp, well defined and in anti-phase.

(ii) The flight pattern should be flown accurately using the remote indicating compass system. The point should be approached on each leg from about 5 miles away with the automatic pilot engaged; after flying about 5 miles past the point the automatic pilot should be disengaged to enable a more rapid turn to be made.

(iii) The flight pattern over the point should consist of twelve even keel runs terminating in 30° turns to port, followed by a 40° turn to port for a second series of twelve runs, and a further 40° turn for a third and final series.

EXAMPLE: If the swing is related to True North, and the selected transmitter is due North of the chosen point, the true headings of the aircraft are as follows:

0	010	020
150	160	170
300	310	320
090	100	110
240	250	260
030	040	050
180	190	200
330	340	350
120	130	140
270	280	290
060	070	080
210	220	230

3.5 **Periodic Calibration Checks.** Periodic checks of the calibration are necessary to ensure that the original pattern of the errors has not changed. Such checks should be made on the following occasions:—

(i) When specified in the approved Maintenance Schedule.

(ii) After the addition, or removal, of aerials, radio equipment, or aircraft equipment in the vicinity of the loop.

(iii) After a lightning strike; in this case a loop calibration check should only be attempted after appropriate measures have been taken to reduce the aircraft's compass system errors to within the permitted tolerances. This is to ensure that the aircraft has been cleared of the effects of the strike.

4 QUADRANTAL ERROR CORRECTION The methods of correcting quadrantal errors vary between types of aerial, and reference to the relevant manufacturer's manuals should always be made for details of the procedure to be adopted. The information given in the following paragraphs is of a general nature, and is intended only as a guide to correction methods.

4.1 For aerials of the rotating loop type, corrections for both quadrantal and field alignment errors are given on a correction chart mounted adjacent to the loop, and the corrections are made by the mechanical adjustment of scales against fixed datums provided on the aerials.

4.1.1 If several aircraft of the same type are concerned, it is possible to replace loops in individual aircraft with loops in which the corrections for quadrantal error have already been incorporated. Since aircraft of the same type with similar ADF installations have very much the same quadrantal errors, a standard correction chart can be prepared for the aircraft on the basis of individual trial calibrations. If this procedure is adopted, a final check should be made for alignment of the loop with the longitudinal axis of the aircraft and for sense reversal. Bearing checks should be made by tuning to suitable transmitters, at the same time referring to previous loop calibration records to check that there are no discrepancies; should there be any, a swing should be made as outlined in paragraph 3.

4.2 Some types of ferrite-cored loops have certain values of quadrantal error correction built-in, by making the fore-and-aft loop more sensitive than the athwartships loop. The preparation of correction charts is, therefore, unnecessary. The correction values required are established on a prototype installation, and are inserted electrically by means of a corrector unit connected in the loop aerial cable.

4.3 In order to supplement a built-in quadrantal error correction, a loop equalizer unit is provided for mounting directly on the loop aerial connector. The unit also compensates for capacitance and inductance changes which occur when loop cables shorter than the standard length of 30 feet are used. Units are designed to suit the cable length and quadrantal errors of individual loop installations; the values being indicated by a suffix to the part number.

5 TESTING OF ADF LOOPS AND RECEIVERS ADF loops and receivers should be tested at the periods specified in the approved Maintenance Schedule. The following tests are normally required and may be carried out either by the Square Loop Method or by the Transmission Line Method, depending on whether an aerial is of the rotating type or the fixed type.

(i) Loop sensitivity; measured in microvolts per metre to give a standard audio output. For the purpose of this test the loop is normally placed in the position of maximum pick-up, and subsequent measurements are then taken a few degrees either side of the null point.

(ii) Compass sensitivity; measured in microvolts per metre.

(iii) Compass accuracy; measured in degrees.

(iv) Speed of loop rotation; measured in degree per second.

(v) Hunting; measured in degrees.

NOTE: The usual measurements for the particular equipment under test are quoted in the relevant manual.

5.1 **Square Loop Method.** This method is the one adopted for testing rotating circular, or flattened, air-cored loops in small screened rooms (or "cages") of the type described in Leaflet **RL/2-3.** In no circumstances should it be used for testing of fixed ferrite-cored loops (see paragraph 5.2).

5.1.1 **Connections to a Square Loop.** The loop under test is closely coupled to a square loop fed from a signal generator. For the purposes of this Leaflet, it is assumed that a self-supporting copper wire or strip is shaped into the form of a square loop the sides of which are 30 cm long, with lower horizontal limbs of from 12 to 14 cm long, fed from the signal generator through 75 ohm co-axial cable, in series with a 925 ohm non-inductive resistor (see Figure 5).

(i) This size of loop is convenient for the types of circular loops and flattened loops generally used in aircraft, but as can be seen from the formula given in paragraph 5.1.1 (iv), the dimensions, and consequently the attenuation figures, can be altered within reasonable limits.

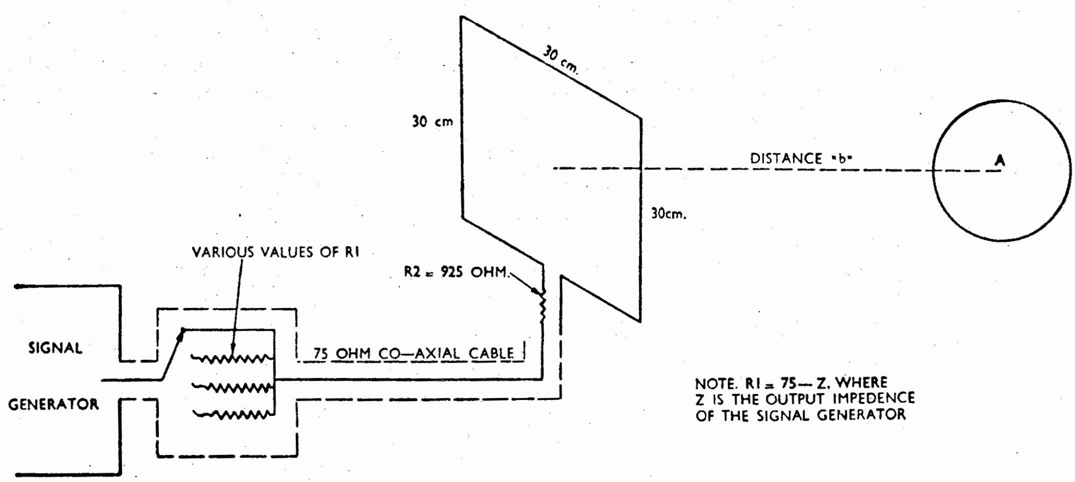


Figure 5 CONNECTIONS TO SQUARE LOOP

(ii) Some signal generators may have output impedances lower than 75 ohms, and these should be connected, as shown in Figure 5, to a 75 ohm co-axial cable, via a non-inductive resistor of a value to provide correct matching. The output impedance of some signal generators also varies at certain settings of output volts, and it may, therefore, be necessary to switch out the extra resistor, or insert one of a new value, depending on the output attenuator setting.

(iii) The current in the loop is determined by the voltage from the signal generator and the total series resistance of the loop circuit (1,000 ohms). No account is taken of the reactance of the loop, which is negligible at the test frequencies used.

(iv) The equivalent field strength produced by the loop at a point "A" on the axis (see Figure 5) is as follows:—

$$\frac{24Ia^2 \times 10^3}{(a^2 + b^2)\sqrt{(2a^2 + b^2)}} = \text{millivolts/metre (mV/m)}$$

where: I = loop current in milliamps,

a = length in centimetres of the side of the loop,

b = distance in centimetres of point "A" from the centre of the square loop.

EXAMPLE: With one volt from the signal generator, the loop current is 1 milliamp (mA) and the equivalent field at point "A", one metre away, is 5·15 mV/m., or +74·3 decibels to 1 microvolt. Attenuation of the applied voltage causes a corresponding attenuation of equivalent field strength, and a signal generator output of +NdB relative to 1 microvolt corresponds to a field strength of N − 45·7 decibels relative to 1 microvolt/metre.

(v) The example given above indicates that to provide a certain voltage at the loop to be tested, the signal generator voltage must be increased by 45·7 (46 to nearest whole number) decibels on this voltage, at which a number of disadvantages accrue, e.g., an abnormally high output from the signal generator is required. This results in a strong induction field from the loop, with consequent distortion of the field by reflection from the adjacent reflecting surfaces of the cage and associated wiring. As indicated in Table 1, distance "b" is required to be one metre, and as both loops have to be positioned so as to avoid the reflection mentioned above, this may result in undue utilisation of space within the cage. It is always advisable to check the complete test layout in a large open space outside the cage, free from obstructions, and these results should be confirmed at the selected position inside the cage. The positions and numbers of instruments, equipment and personnel in the cage at the time of initial testing should be noted, and this layout should be adhered to in all subsequent tests.

NOTE: If one side of the square loop is too near the side of the cage and/or the test equipment, an unbalance would result in the zero heading and the compass speed of rotation.

(vi) Table 1 provides for a number of distances between loop centres, within practical limits, resulting in even number decibel attenuations. A voltage multiplication factor is given, and may be used either where the operator so desires, or where no decibel setting is given on signal generator attenuator controls.

TABLE 1

Distance "b" between Loop Centres (cm)	Signal Generator Setting above Required Voltage (dB)	Voltage Multiplication Factor
100	45·7 (46)	—
80	40	100
74	—	80
67	—	60
58	—	40
53	30	30
42	—	20
33	20	10

NOTE: It is possible to further reduce the distance between loop centres.

5.1.2 **Setting up the Loop for Test.** The loop to be tested is placed at the selected distance from the square loop, with the lower sector of the loop being tested level with the lower horizontal limbs of the square loop. With induction systems, the loop does not "home" on the source of the signal but at 90° to it.

(i) The loop base should be aligned so that its fore and aft axis is parallel with a line drawn horizontally through the vertical limbs of the square loop. In subsequent setting-up with a sense aerial voltage, the loop indicator will initially read either zero or 180°; if the indicator reads 180°, the connections to the square loop should be reversed to obtain a zero reading.

NOTE: It should be borne in mind that it may be necessary to mount the loop base on a calibrated turntable in order to check the accuracy of synchro-system transmission.

5.1.3 **Sense Aerial Requirements.** A sense aerial signal of the correct magnitude and of a phase relative to the loop signal is required. Optimum conditions obtain when the depth of modulation of the locally modulated carrier approaches zero when the loop is receiving no signal. It follows that if the signal generator voltage supplying the square loop is, in addition, to be utilised directly for a sense aerial voltage, it must be severely attenuated. After attenuation, the voltage can be fed directly to the sense aerial input, as at the frequencies used, the required phase shift of 90° between vertical and loop voltage remains unaffected.

(i) **Setting-up for Testing.** The voltage induced in an aerial can be stated as:—

Microvolts/metre × Effective height of aerial in metres = Microvolts induced in the aerial.

An aerial of effective height of 0·25 metres, in a field of 1,000 microvolts per metre, will have induced in it a voltage of 250 microvolts. It is, therefore, necessary to know the effective height of the sense aerial associated with the loop, and this information can be found in the relevant manufacturer's manual. The following setting-up procedure is based on the assumption that the sense aerial effective height is 0·25 metres and that it has an effective capacitance of 50 picofarads (pf).

(a) The ADF receiver should be tuned to 500 kHz or other suitable mid-band frequency, and the function switch should be set to "OMNI". The signal generator should be fed through a 50 pf capacitor to the receiver aerial input, and the signal generator should be set to give 250 microvolts, modulated 30 per cent, at 400 Hz.

NOTE: The modulation percentage and frequency may differ for different equipments, but if so it is usually stated.

(b) The receiver gain controls should be adjusted to give rated audio output in milliwatts. The gain controls should then be left undisturbed whilst the signal generator is disconnected, reconnected to the square loop, adjusted to provide a field of 1,000 microvolts, at the ADF loop, and then connected to the equipment as shown in Figure 6.

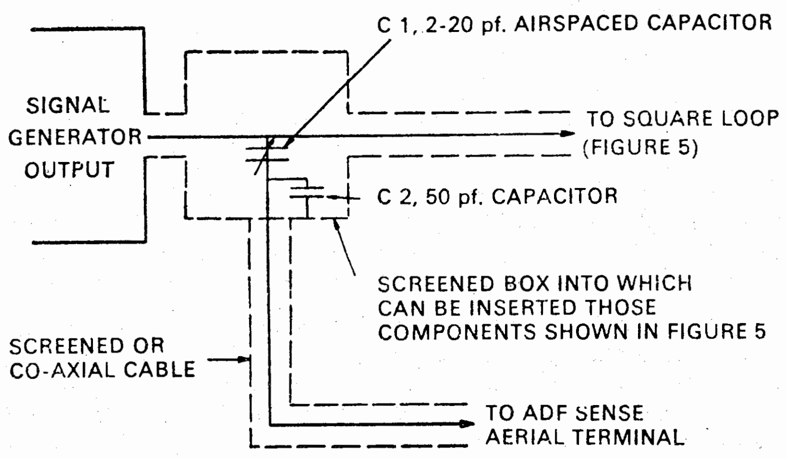


Figure 6 CONNECTIONS TO SENSE AERIAL

(c) The variable capacitor should be adjusted until rated audio output is again registered, taking care that the receiver gain control remains undisturbed. The variable capacitor can now be set in its position permanently, or its value carefully measured, and replaced by a fixed capacitor.

(ii) **Alternative Method of Testing.** If a vertical rod is placed in the field of the square loop as shown in the plan view of Figure 7, it will have a voltage induced in it, the amount being determined by its length and its distance from the square loop.

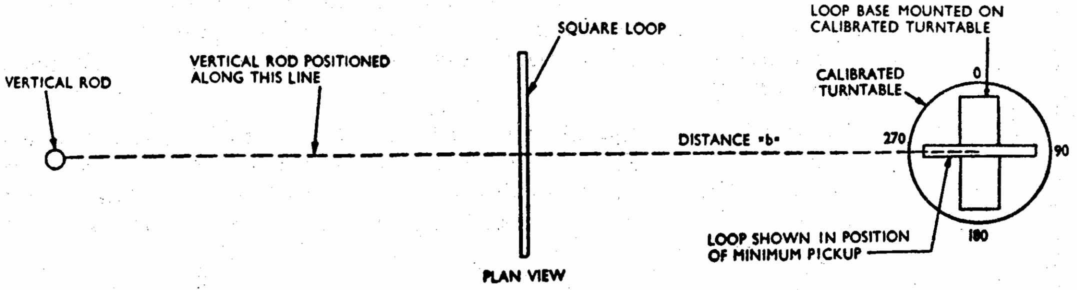


Figure 7 ALTERNATIVE METHOD OF PROVIDING SENSE AERIAL FEED

(a) For testing one particular ADF equipment, the rod length can be made to equal the effective height quoted for the sense aerial; the following formula may be used:—

$$L = \frac{E_h}{0{\cdot}635}$$

Where: L = Length of rod
E_h = Effective height of aerial

(b) For an effective height of 0·25 m, the length of the rod is approximately 40 cm, and this rod should, theoretically, be spaced the same distance away as the loop to be tested. However, as all the rod may not be cut by the square loop field, it should be moved slowly towards the square loop after the adjustments described in paragraph 5.1.3(i) have been made. When rated audio output is registered, the rod can be fixed and left in this position.

(c) Care should be taken to ensure that the rod and its screened feeder cable or co-axial cable equal the capacitance quoted (50 pf in the example given in paragraph 5.1.3(i) (a)) but, if not, a small "padder" capacitor should be added.

(d) Provided the capacitance is correct for the equipment under test, the rod need not equal the effective height for the particular equipment, and a smaller rod (say 30 cm) can be used, and positions determined for any equipment which requires to be tested. The smaller the rod, the nearer it must be positioned to the square loop. Similar results can be obtained by fixing the rod permanently and close up to the square loop, and by feeding the sense aerial through a 2–20 pf airspaced capacitor.

5.2 **Transmission Line Method.** This method is the one approved for testing fixed ferrite-cored loop aerials since it gives improved bearing accuracy and enables more accurate determination of the field strength voltage at the loop.

5.2.1 **Screened Room (Cage) Requirements.** The transmission line must be installed in a screened room of the general construction described in Leaflet **RL/2-3.** The rooms may vary in size, and for convenience they are divided into three groups (see Table 2), to each of which a particular attenuation formula is applicable. The limitations on distances d and d_2 of Figure 8 are also given.

TABLE 2
CAGE INTERNAL DIMENSIONS AND DISTANCE LIMITATIONS

Group	Cage Size	Height (in)	Length (in)	Width (in)	d_2 (not less than) (in)	d (in)
1	Larger than	144	152	108	50	24–50 }
2	Larger than	90	90	72	12	18–24 } but less than ½ of d_1
3	Less than 2 above				9	12–24 }

(i) Dimensions d and d_2 may need slight alteration when determining an attenuation constant, in order to arrive at a whole number. While a whole number constant will make subsequent testing easier, it is not suggested that continuous alterations are made in order to effect this.

(ii) Manufacturers of ADF equipment may give details in their manuals of a transmission line installation quoting cage size and all dimensions necessary to give a whole number attenuation constant. This Leaflet is concerned with the general methods to be adopted where these particular dimensions are not available or cannot be followed.

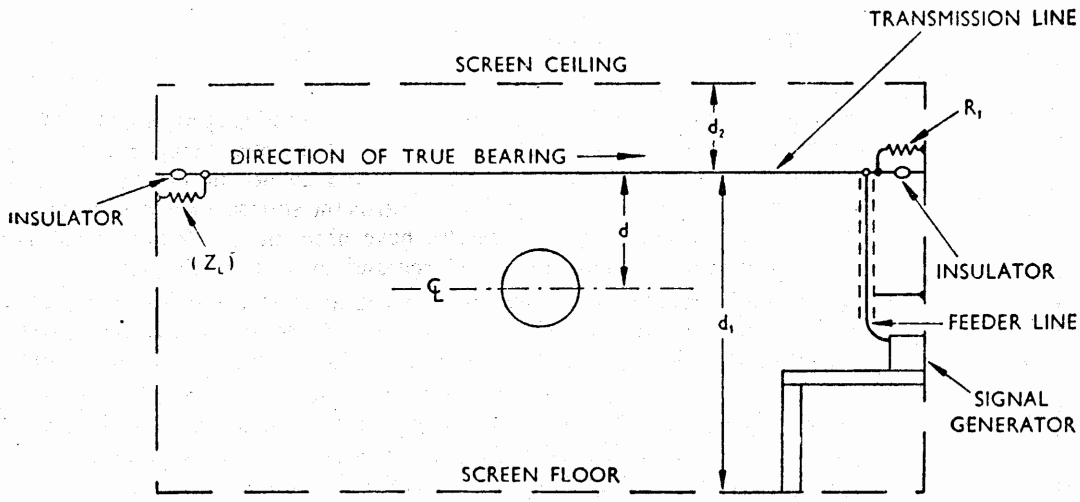


Figure 8 TRANSMISSION LINE SYSTEM GENERAL CONSTRUCTION

5.2.2 **Constructional Details**

(i) **Transmission Line.** The transmission line should be erected centrally along the length of the screened room (see Figure 8). Single-strand copper or tinned-copper wire of 22 s.w.g., or greater, is suitable, and should be secured to the inner wall of the cage by insulators and should be tensioned. The ends of the line (excluding insulators) should reach to within 4 inches of the cage walls.

(ii) **Feeder Line.** A feeder line, sometimes called a "concentric line", should be used to connect the signal generator to the transmission line.

(a) For cages of the sizes defined in Group 1 of Table 2, it is recommended that a copper tube of 1 inch diameter should be mounted vertically under one end of the tranmission line, with a feeder line of 18 s.w.g. copper wire suspended concentrically inside it.

(b) The output terminal of the signal generator should be so arranged that only a very short connector is required to the base of the tube.

(c) Both the signal generator and the concentric tube should be bonded to the cage wall.

(d) For smaller cages it will be found more convenient to use 70 ohm co-axial cable as a feeder line, maintaining an unbroken length from the signal generator to the transmission line. The cable should be kept as short as possible, fixed vertically below the end of the line, and should be bonded to the cage wall.

(iii) **Loop Mounting.** A rigid wooden stand should be mounted on the floor of the cage directly under the centre point of the transmission line.

(a) The top of the stand should consist of a non-metallic turntable, calibrated in degrees, and should be carefully aligned by two plumb bobs suspended from the transmission line and a straight-edge positioned through the 0°–180° points of the turntable. If a 360° cursor is fitted to the turntable it should be numbered in an anti-clockwise direction. If preferred, a normal reading cursor can be fitted to the top of the stand with 0° and 180° marks fixed to the turntable.

(b) The turntable forms the platform for the loop and should be accurately jigged to receive it. The fixed pointer on the loop base should be aligned with 0° of the turntable on that side of the stand nearest the feed line.

(c) For greater flexibility, the turntable can be constructed to move vertically thus ensuring that distance d remains constant for various loop centres, or, preferably, a number of platforms can be constructed to accommodate different loops. The use of nuts and bolts and other metal work should be avoided as far as practicable.

(d) For smaller cages it may be more convenient to mount the loop and turntable on a solidly constructed hinged wooden flap projecting from the workbench.

5.2.3 **Determination of Screened Room Constants.** The following paragraphs indicate the method of determining the screened room constants. These constants may be altered when alterations are made to the layout of the equipment in the screened room, and will need re-calibrating when a signal generator of different output impedance is used. It is important, therefore, that the screened room should not become encumbered with extra equipment, or the layout modified. The output impedance of the signal generator to be used should be displayed adjacent to the feeder connection.

(i) **Termination of Transmission Line (Z_L).** Two valve voltmeters (VV1 and VV2 of Figure 9) should be connected as shown, and the frequency at which the line resonates at ½ wave length should be determined.

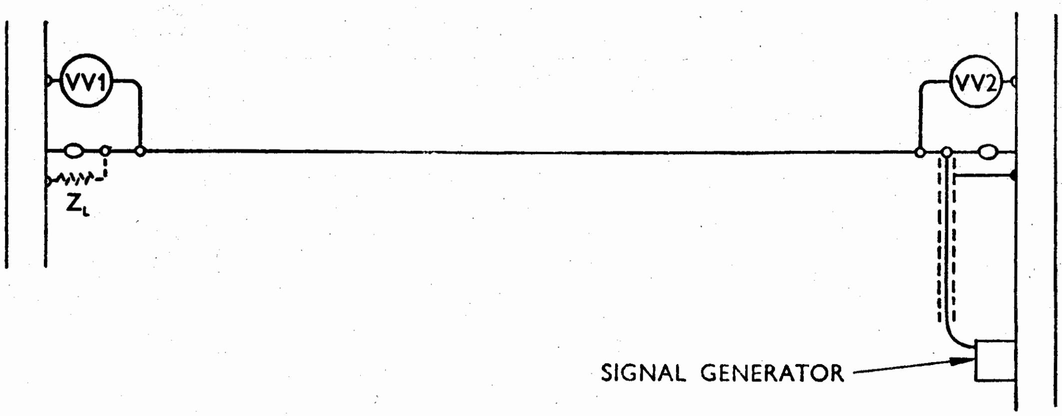


Figure 9 TRANSMISSION LINE CONNECTIONS

(a) With the signal generator connected, tune through the ADF frequency band and upwards until the voltage at the far end of the line reaches a maximum, and voltmeter VV2 shows a dip.

(b) A resistor approximating to the value of Z_L (between 300 and 500 ohms) should be connected as shown by the dotted lines in Figure 9; a 400 ohm non-inductive resistor is suitable.

(c) Both valve voltmeters should be set to zero. With the signal generator also set to zero, the output of the signal generator should then be raised to one or two volts, or to maximum. The voltage readings at both ends will be the same if the termination is correct.

(d) Alterations to the value of the temporary resistor Z_L, may be necessary to effect this condition and it should be noted that if the voltage at the end of the line is higher than that at the feeder, the termination is too high. The final value should be measured and recorded, and a non-inductive resistor placed permanently in the system.

(ii) **Termination of Feeder Line (R_1).** It is now necessary to correctly terminate the feeder line in order to ensure that standing waves are not present in the feeder.

(a) Where a short length of 70 ohm co-axial cable of known characteristic impedance is used, the use of the terminating resistor (R_1) can be dispensed with. Connect the feeder line to the transmission line, and proceed as indicated in paragraph 5.2.3(ii) (e).

(b) Where the cable is of considerable length, or where the impedance value is unknown, it will be necessary to find the frequency at which the feeder acts as a ¼ wave line as follows:—

Disconnect the feeder line from the transmission line, and connect valve voltmeters, VV1 and VV2, as shown in Figure 10.

Proceed as indicated in paragraphs 5.2.3(i) (a) and (i) (c) to find the resonant frequency.

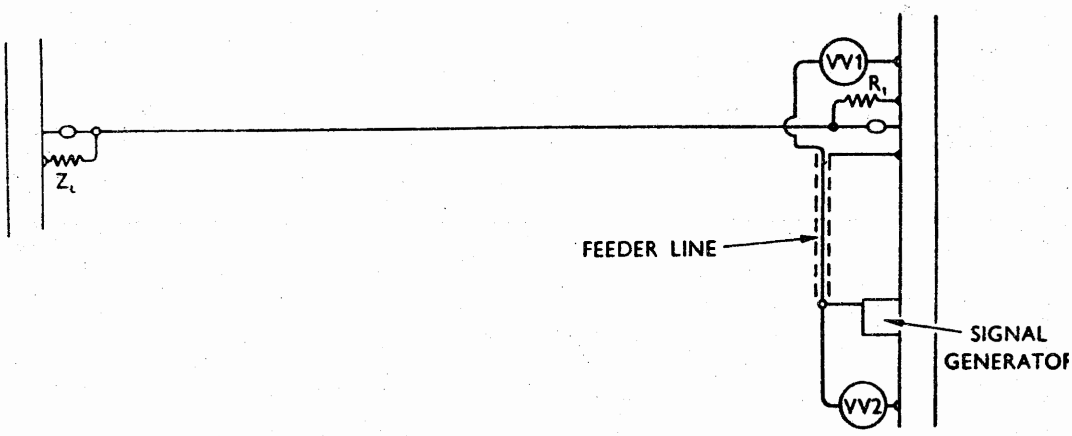


Figure 10 FEEDER LINE CONNECTIONS

(c) Where the feeder line has been constructed as in paragraph 5.2.2(ii), it will be helpful to start with an approximate value of impedance (Z_g). This can be found by application of the formula:—

$$Z_g = 138 \log_{10} \frac{d_2}{d_1}$$

where:

d_2 = inside diameter of tube

d_1 = outside diameter of wire

(d) Using non-inductive resistors, it is necessary to find an accurate value of Z_g which results in equal readings of voltmeters VV1 and VV2. Then:

$$R_1 = \frac{Z_L Z_g}{Z_L - Z_g} \text{ohms}$$

Where a considerable length of 70 ohm cable is used, $Z_g = 70$. Finally the feeder should be reconnected to the line and a permanent value of R_1 inserted.

(e) With VV1 connected across Z_L, and with VV2 connected across the signal generator terminals, the frequency over the entire ADF band should be varied. If the terminations are correct the readings of both voltmeters should remain sensibly equal.

5.2.4 **Calculation of Attenuation Constant.** The attenuation constant $K = \frac{E_L}{E/M}$,

where:

E_L = line voltage (in microvolts) from the signal generator.

E/M = field strength at a known distance in microvolts/metre and calculated from $E_{FS} + E_{FL} - E_C$ ($-E_{FLC}$ $-E_{CFL}$)

The terms E_{FS}, E_{FL} and E_C relate to cage Sizes 1 and 2, and terms E_{FLC} and E_{CFL} to a cage Size 3 (see Table 2) and are calculated from the formulae given in the following paragraphs.

(i) **Cage Size 1**

$$E_{FS} = \frac{2{\cdot}36 \times 10^3}{d} \times \frac{E_L}{Z_L}$$

$$E_{FL} = \frac{2{\cdot}36 \times 10^3}{2d_1 - d} \times \frac{E_L}{Z_L}$$

$$E_L = \frac{2{\cdot}36 \times 10^3}{2d_2 + d} \times \frac{E_L}{Z_L}$$

where: d, d_1 and d_2 are the dimensions (in inches) shown in Figure 8, and Z_L is the characteristic impedance of the line.

The length of the transmission line can be considered as infinite and is not taken into account.

NOTE: The output voltage indicated by the attenuator setting of a signal generator is usually the open circuit voltage, and may need compensating for the effect of loading. Thus, the term E_L given in the formulae for the three sizes of cage, is properly

$$E_L = E_{ind} \times \frac{Z_G}{Z_G + Z_o}$$

where:

E_{ind} = voltage indicated by signal generator (assuming E_L to be 1 millivolt and $Z_G = Z_o$, then E_{ind} is required to be 2 millivolts)

Z_G = characteristic impedance of feeder line.

Z_o = output impedance of signal generator.

(ii) **Cage Size 2**

$$E_{FS} = \frac{2{\cdot}36 \times 10^3}{d} \times \frac{E_L}{Z_L} \cos\theta$$

$$E_{FL} = \frac{2{\cdot}36 \times 10^3}{2d_1 - d} \times \frac{E_L}{Z_L} \cos\theta_1$$

$$E_C = \frac{2{\cdot}36 \times 10^3}{2d_2 + d} \times \frac{E_L}{Z_L} \cos\theta_2$$

where:

$$\theta = \tan^{-1}\frac{2d}{L}$$

$$\theta_1 = \tan^{-1}\frac{2(2d_1 - d)}{L}$$

$$\theta_2 = \tan^{-1}\frac{2(2d_2 + d)}{L}$$

The additional phase angle terms cos θ, cos θ_1 and cos θ_2 are added to take into account the length, in inches, of line L.

(iii) **Cage Size 3.** The forgoing formulae take into account direct voltage reflections from the line to the loop, and also reflections from the floor and ceiling of the appropriate cage. For Size 3 cages however, two further secondary reflections must be included; thus:

$$E_{FLC} = \frac{2{\cdot}36 \times 10^3}{2d_1 + 2d_2 + d} \times \frac{E_L}{Z_L} \cos\theta_3$$

$$E_{CFL} = \frac{2{\cdot}36 \times 10^3}{2d_1 + 2d_2 - d} \times \frac{E_L}{Z_L} \cos\theta_4$$

where:

$$\theta_3 = \tan^{-1}\frac{2(2d_1 + 2d_2 + d)}{L}$$

$$\theta_4 = \tan^{-1}\frac{2(2d_1 + 2d_2 - d)}{L}$$

5.2.5 **Simulated Sense Aerial.** Each item of equipment under test requires an individual sense aerial voltage related to the field strength obtaining at the loop, and dependent on the quoted effective height of the aerial. The quoted aerial capacitance must also be simulated.

(i) Figure 11(a) shows the connection of C_1 and C_{ae} to achieve this. Since several simulated aerials may be required, C_{ae} can be connected permanently to the cage wall, whilst the outer end of C_1 can be fitted with a "crocodile" clip to attach it to the transmission line when required.

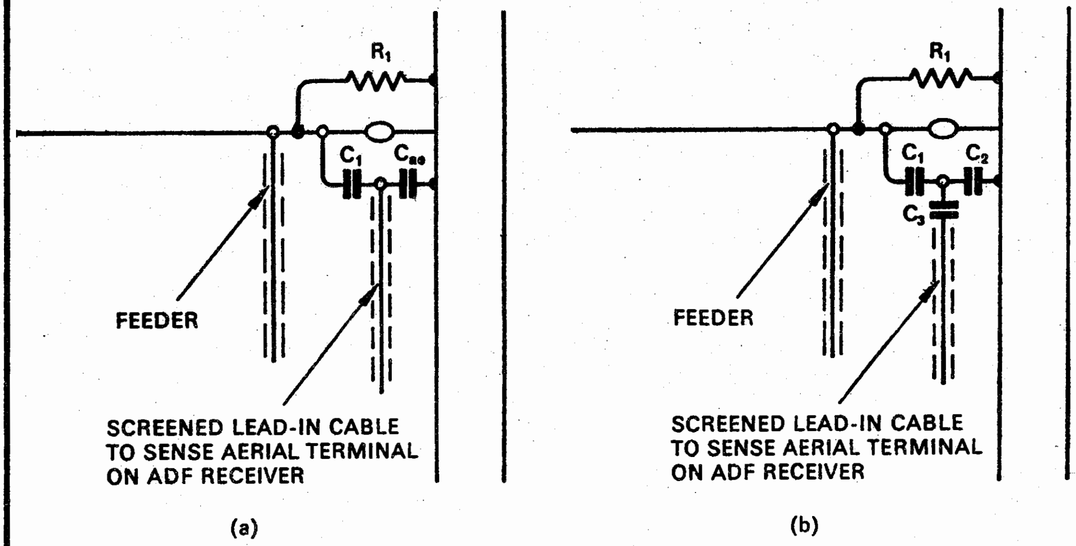


Figure 11 SENSE AERIAL CONNECTIONS

(ii) The values of C_1 and C_{ae} (in picofarads) can be determined by the ratio:—

$$\frac{K}{E_{hs}} = \frac{C_1 + C_{ae}}{C_1}$$

where:

K = the attenuation constant previously determined,

E_{hs} = the effective height of the sense aerial, in metres,

C_{ae} = aerial capacitance;

$$\text{therefore } C_1 = \frac{E_{hs} \times C_{ae}}{K - E_{hs}}$$

(iii) It frequently happens that with certain values of K, E_{hs} and C_{ae}, the value of C_1 becomes too low to achieve in practice. Reference should then be made to Figure 11(b). Choose a low value for C_1 such as not to affect the matching of the line; a value of 10 pf is suitable. Proceed to determine C_2 and C_3 as follows:

$$C_2 = \frac{C_1 (K - E_{hs})}{E_{hs}}$$

$$C_3 = \frac{C_{ae} (C_1 + C_2)}{C_1 + C_2 - C_{ae}}$$

5.2.6 **Loop Signal Simulator.** A loop signal simulator may be used as a substitute for a screened room and calibrated transmission line. It derives simulated loop aerial and sense aerial signals from a standard signal generator. The simulator consists of a metal box containing a transmission line with terminating resistors, a capacitance potentiometer for simulated sense aerial signals, and a rotatable miniature loop aerial. The values of the components used are chosen so as to give an effective attenuation constant of 10. The two coils of the miniature loop aerial are both the same size, so that it is unnecessary to allow for built-in quadrantal error correction. A table of corrections for instrument errors is normally attached to the top of the simulator, adjacent to the loop aerial bearing scale.

(i) When using the simulator, all power supplies should be filtered so as to avoid the introduction of unwanted signals and noise. In areas where severe electrical noise is experienced, it may also be necessary to operate the simulator and the equipment under test, in a screened room.

RL/2-2

Issue 2.

15*th November*, 1974.

AIRCRAFT

RADIO

AERIALS

1 INTRODUCTION This Leaflet gives general guidance on the installation, siting and maintenance of wire, rod, blade and rail type aerials used in conjunction with such equipment as High Frequency (HF) and Very High Frequency (VHF) communications, Automatic Direction Finding (ADF) and Marker Beacon receivers. Guidance is also given on the maintenance and repair of aerial masts manufactured wholly, or in part, of fibreglass-resin laminate. This Leaflet does not include information on aerials designed for use with radar equipment or navigation equipment such as Loran, Doppler, Distance Measuring, etc.

1.1 Full details of the procedures to be adopted for specific installations of the equipment referred to in this Leaflet, are contained in relevant aircraft and equipment Maintenance Manuals; this Leaflet should, therefore, be read in conjunction with these documents. Reference should also be made to the following Leaflets, British Standards and DTD Specifications which contain information closely associated with the equipment and practices covered by this Leaflet.

BL/4-1	Corrosion—Its Nature and Control
BL/4-2	Corrosion—Removal and Rectification
BL/4-3	Corrosion—Methods of Protection
BL/6-24	Cables—Splicing and Swaging
BL/6-26	Doping
EEL/1-6	Bonding and Circuit Testing
BS 2S97	2½ per cent nickel-chromium-molybdenum steel
BS 3S106	3 per cent chromium-molybdenum steel
BS 3X17	Varnish for Aeronautical Purposes
DTD 856A	External finishes for Radomes
DTD 926B	Process Specification for External Finishing of Radomes

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet **RL/2-2,** Issue 1 dated 1st April 1958, Leaflet **RL/2-3,** Issue 1 dated 1st April 1958, and Leaflet **RL/2-4,** Issue 2 dated 1st February 1960.

2 WIRE AERIALS Wire aerials may be of the trailing type or of the type which are fixed, e.g. between a mast and the tip of a fin. Guidance on their installation and maintenance is given in the following paragraphs. Since trailing aerials now have only very limited application, the information given is restricted to that necessary to ensure the continued serviceability of existing installations.

2.1 **Trailing Aerials.** A trailing aerial normally consists of a length of stainless steel or tungum cable, usually seven stranded, of approximately 250 lb. breaking load. In some cases phosphor-bronze cable is used. The aerial is wound on a drum, and has its free end weighted for extension purposes, by a number of lead beads or, in some cases, by a drogue. The aerial is so designed that it can be unreeled in flight without fouling the aircraft structure.

2.1.1 **Fairleads.** Trailing aerials are fed through the aircraft skin, via insulated fairleads manufactured either of a non-metallic material or of metal covered with polythene. A clearance must be provided between the fairlead and the skin, the extent of which should be determined by the power of the transmitter and the material of the fairlead. Fairleads should be kept clean at all times, and should be inspected periodically for cracks, as dirt and cracks will not only cause mechanical interference with the reeling of the aerial, but will also provide leakage paths to the aircraft skin. To maintain efficient insulation, fairleads should be re-coated periodically with a suitable varnish, e.g. a varnish containing a phenolic resin.

2.1.2 **Bead Weights.** Bead weights are threaded on to a short length of stranded steel cable, which is attached to the main aerial cable. Two arrangements of bead weights are generally employed; one of which is suitable for power-operated trailing aerials, and the other for manually operated aerials. The arrangement for the former type consists of six lead beads sandwiched between a single brass end bead and a retaining stop. These are threaded on to a stranded 15 cwt. steel cable, making up an assembly having a total weight of about 2½ lb. The lighter assembly used on manual systems consists of fifty lead beads and one brass bead threaded on to a 5 cwt. cable, as shown in Figure 1, the total assembly weighing about 22 oz. In both assemblies, the beads should be secured to the cable in the manner described in the following paragraphs.

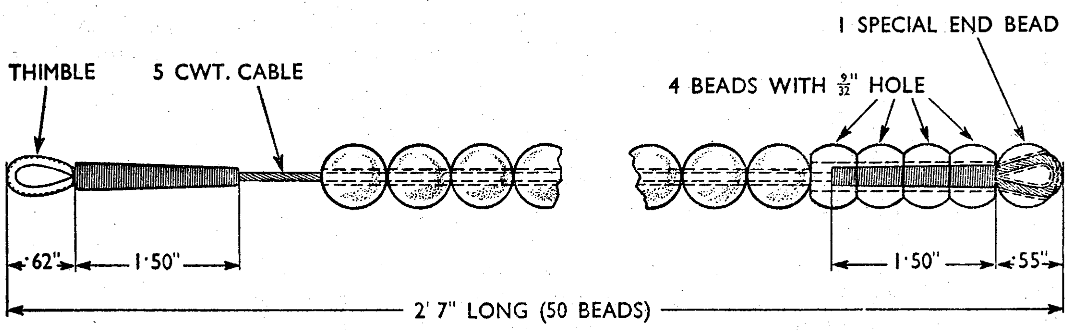


Figure 1 BEAD WEIGHT ASSEMBLY FOR MANUALLY OPERATED TRAILING AERIAL

(i) The cable should first be wrapped around the groove in the brass bead, and then spliced by the method given in Leaflet **BL/6-24.** The splice should be clean and free from projecting ends. It should be covered with two turns of linen fabric, and whipped with two layers of waxed No. 12 linen thread. The holes in the first four of the lead beads should be enlarged to $\frac{9}{32}$ inch diameter to slide over this splice, and pulled down hard against the brass bead. The remainder of the beads should then be threaded on, leaving enough cable at the free end to make another splice.

(ii) The free end of the cable should now be looped back on itself, and spliced to provide an attachment point for the aerial wire. The smallest possible loop should be used, and a thimble should be incorporated in the loop as a means of reducing chafing between the aerial cable and the bead cable.

(iii) With the exception of the end bead, and of those containing the enlarged holes, the beads should be free to rotate, but grease should not be used on the beads which enter into the fairlead, since the lead beads will deposit a lead film inside the fairlead which, in due course, will cause insulation failure. The use of grease on bead weights is, however, permissible when the fairlead is of such a type (e.g. one equipped with an automatic electric winch) that the bead weights cannot enter it.

2.1.3 **The Aerial Wire.** Because aerial wires do not lend themselves to splicing by conventional methods, a special splice is used to join the aerial wire to the spliced end of the bead cable. The free end of the aerial wire should first be given two turns around the spliced loop of the bead cable, and then wrapped once around itself. The end should then be unstranded and laid back along the wire. Finally each strand in turn should be wrapped over the wire for a distance of $\frac{3}{8}$ inch, an alternate direction of winding being used for each strand. This wrapping procedure should continue until all the strands are used. The stages and method of the splice are shown in Figure 2. The splice should be finished by whipping the exposed end of strand No. 7 for a distance of $\frac{3}{8}$ inch with waxed twine knotted every half turn. In no circumstances should the joint be soldered.

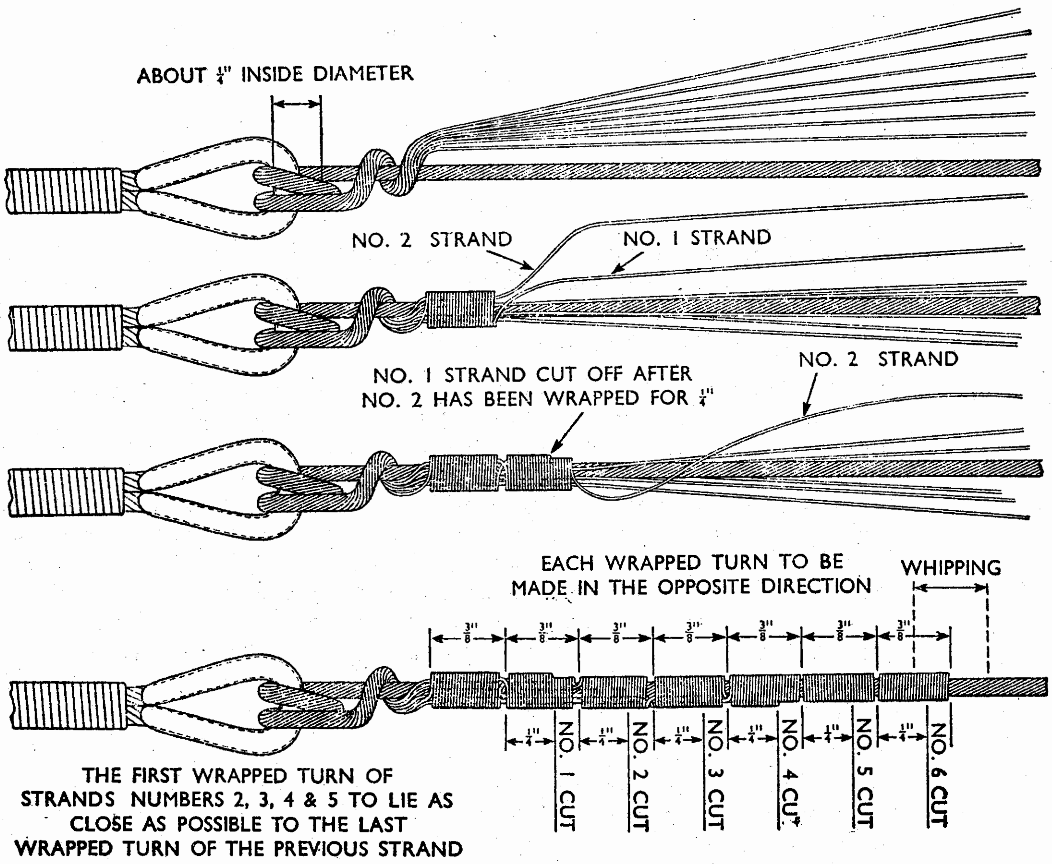


Figure 2 SPLICE FOR ATTACHMENT OF STRANDED AERIAL CABLES

2.2 **Fixed Wire Aerials.** Fixed wire aerials may be manufactured from seven-stranded phosphor-bronze, tungum, or stainless steel cable, but it is more usual to use single strand, copper-plated, high tensile steel wire. In some aircraft, solid drawn aluminium alloy aerials may be used.

2.2.1 **Stranded Cable Aerials.** Of the seven-stranded cables, it should be noted that the ultimate tensile strength of phosphor-bronze is only about three-fifths that of tungum or stainless steel, and it is recommended that phosphor-bronze should not be used where the span of the aerial exceeds 50 feet, calculated on the normal tensioning basis of 1 lbf per foot span. The Radio Frequency (RF) resistance of steel is very high and this results in a loss of radiated power. Table 1 shows the relative RF resistance of various types of aerial wire, and from this the inefficiency of stainless steel is evident. Where aerials of optimum length can be employed, e.g. trailing aerials or aerials of sufficient span, strength considerations may dictate the use of steel, but, in instances where aerials may be severely limited in their effectiveness as a result of their length being restricted by aircraft structural features, the CAA recommends that wire with less RF resistance should be used.

TABLE 1

Frequency	RF Resistance (ohms/ft)		
(MHz)	Stainless Steel	Phosphor Bronze	Tungum
2	0·48	0·118	0·198
4	0·62	0·160	0·275
6	0·85	0·220	0·375
8	1·00	0·270	0·440
10	1·40	0·310	0·550
12	1·40	0·320	0·530
14	1·70	0·370	0·620
16	2·25	0·470	0·740

(i) **Uncovered Stranded Aerials.** These aerials are susceptible to rain static, but are less likely to corrode than aluminium alloy wires (paragraph 2.2.2). They should be inspected along their length for broken strands, corrosion, or other faults which can reduce the mechanical strength of the cable.

(ii) **Covered Stranded Aerials.** The practice of covering stainless steel stranded aerials is adopted as a means of reducing rain static (paragraph 2.2.2) and corona discharge. The cable is covered with a material of high dielectric strength (usually a polythene plastic such as alkathene) along its length, and special terminal insulators are used. These aerials, whilst reducing rain static and corona discharge, only do so while their insulation remains intact; even small punctures will intensify the problem of corona discharge. Usually the first indication of defective insulation is the increased noise level in the receiver; particular attention should be paid to crew reports on this matter. Since there is no satisfactory method of repairing the polythene covering, renewal of the complete cable is the only remedy. The terminal insulators should be renewed whenever cracks are found in them, and should be filled with silicone grease to prevent the ingress of moisture.

(iii) **Covered Single Strand Aerials.** Single-strand, copper-plated, high tensile steel wire covered with opaque polythene offers certain advantages and is used in many types of aircraft. It is officially designated "Electrical Wire WS-25/U, Specification MIL-E-6370," and should not be confused with a similar wire of lower breaking load designated WS-5C/U. Aerials made of this wire should be used in conjunction with chuck-unit tethering (see paragraph 2.2.3 (iii) (c)), and the aerial manufacturer's instructions on tensioning should be followed. A convenient working rule is to tension to 1 lbf per foot of span, thus keeping the ratio dip/span constant. Since this wire has a high ultimate tensile strength, there is no danger of overloading the aerial over any typical aircraft span. Although the wire may be tensioned to a high figure, it is advantageous to use a spring tension unit of the type described in paragraph 2.2.4 (i).

2.2.2 **Solid Drawn Aluminium Alloy Aerials.** These aerials are simple to connect, but care must be taken to avoid contact with dissimilar metals at the terminations. Aerials of this type suffer from three defects: (i) when charged raindrops contact the aerial, the drops transfer their charge to it, giving rise to "rain static", (ii) fatigue may occur when the aerial is out of line with the slipstream, e.g. when it is fitted from a central mast to the fins of double-finned aircraft, and (iii) the aluminium alloy is subject to corrosion. The aerial should be inspected for corrosion at frequent intervals, and if it is found, but is not severe, it should be cleaned off and the wire protected by brushing on a nitro-cellulose lacquer (see Leaflets **BL/4-1, BL/4-2** and **BL/4-3**).

2.2.3 **Fixed Aerials for HF Communication.** For the reasons given in paragraph 2.2.1, fixed wire aerials for HF communication equipment should not be made from stainless steel cable. HF aerials are positioned above the fuselage and usually consist of a single span of wire running parallel to the longitudinal axis of the aircraft. A single span aerial is normally of sufficient length to permit loading throughout the HF band, but there are instances where a longer effective length is required. In such cases it is usual to provide twin forward masts and a common connection on the leading edge of the fin. However, in aircraft having twin fins, a single forward mast may be provided, the aerials being connected to both fins. HF aerials are usually fed from the forward attachment, although occasionally special circumstances necessitate feeding from the fin termination. The following paragraphs deal primarily with the maintenance of single span aerials, but most of the information is also applicable to double span installations.

(i) **Aerial Masts.** To provide adequate stand-off from the fuselage at high voltages, and to improve and maintain insulation, a mast is usually provided for the forward termination of the aerial. Aerial masts may be constructed of a shell of non-hygroscopic, insulating dielectric material surrounding a down-lead rod of brass or cadmium-plated steel. Because of the poor insulating qualities of the rod material, the rod is encased in a tube of polythene or porcelain, suitably terminated at each end for connection to the aerial circuit. The shell material is usually a fibreglass-resin laminate.

(a) The leading edges of masts made from resin impregnated fibreglass cloth tend to suffer severe pitting from rain erosion and should be inspected for this defect at regular intervals. These masts are usually covered with neoprene and are often painted white to reduce the adverse effects of sunlight on the neoprene. Information on the repair of these masts is given in paragraph 8 of this Leaflet.

(b) The interior of some masts is protected against moisture condensation by containers of silica gel crystals. These crystals should be inspected for moisture saturation (indicated by a change of colour from blue to pink or white) and should be renewed when there is evidence of the change. Hollow aerial masts are generally provided with a water drain path through the base which must be kept free from sealant and paint.

(ii) **Deck Insulators.** Sometimes masts are provided purely as tethering posts for aerials, and the aerial down-lead is a separate wire connected to a deck insulator. If a deck insulator of the required insulation value is not available, one of lesser value may be used, provided that it is mounted on a non-conducting plate of acrylic sheet (or similar material) of about 6 inch diameter. The down-lead to the deck insulator should be as direct as possible, and not in tension.

(iii) **Aerial to Mast Connection.** There are several methods by which the aerial can be connected to the mast, e.g. the methods illustrated in Figure 3 and chuck-unit tethering.

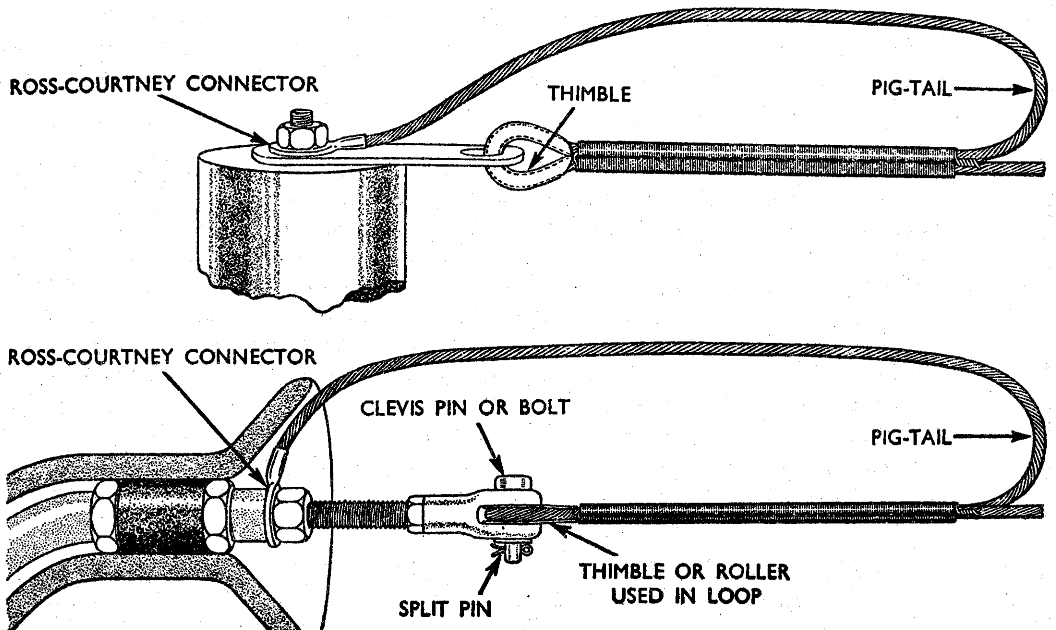


Figure 3 AERIAL TO MAST CONNECTIONS

(a) The connections shown in Figure 3 are made to fittings which function as an extension of the down-lead rod, but because of the risk of poor contact between the thimble and the extension piece, the CAA recommends the use of a continuous type "pigtail".

(b) The typical aerial-to-mast connections shown employ the continuous type of pigtail. The cable is placed around the thimble, and sufficient length is left to provide the pigtail. The cable is secured by at least 2 inches of whipping, the whipping being done with a strand of wire of the same material as the aerial. About 3 inches of the whipping wire should be placed along the cable, then, commencing from the thimble end, the wire should be wrapped over itself as shown, until 2 inches of the cable has been whipped, after which the two ends should be twisted together and cut to a suitable length.

(c) Chuck-unit tethering is used on some types of fixed wire aerials. Chuck units are designed so that it is only necessary to insert the bare end of the wire (either solid or stranded) for the chuck to grip it tightly, the grip increasing with increased tensile load up to the breaking point of the wire. Some units incorporate T- or angled-junctions for down-lead connections. Units should be inspected for cracks, corrosion and accurate fitting of the chuck jaws, and should be lubricated with a silicone grease in accordance with the manufacturer's instructions.

(d) Crimped connections for aerial wire are only acceptable if the method of crimping is strictly in accordance with drawings issued by an approved Organisation. It must be demonstrated that the crimped connection will not fail before the aerial wire, when the wire is loaded under tension.

(e) Where moulded insulators are used along the aerial, the method of connection to and from these is by means of the splice shown in Figure 2.

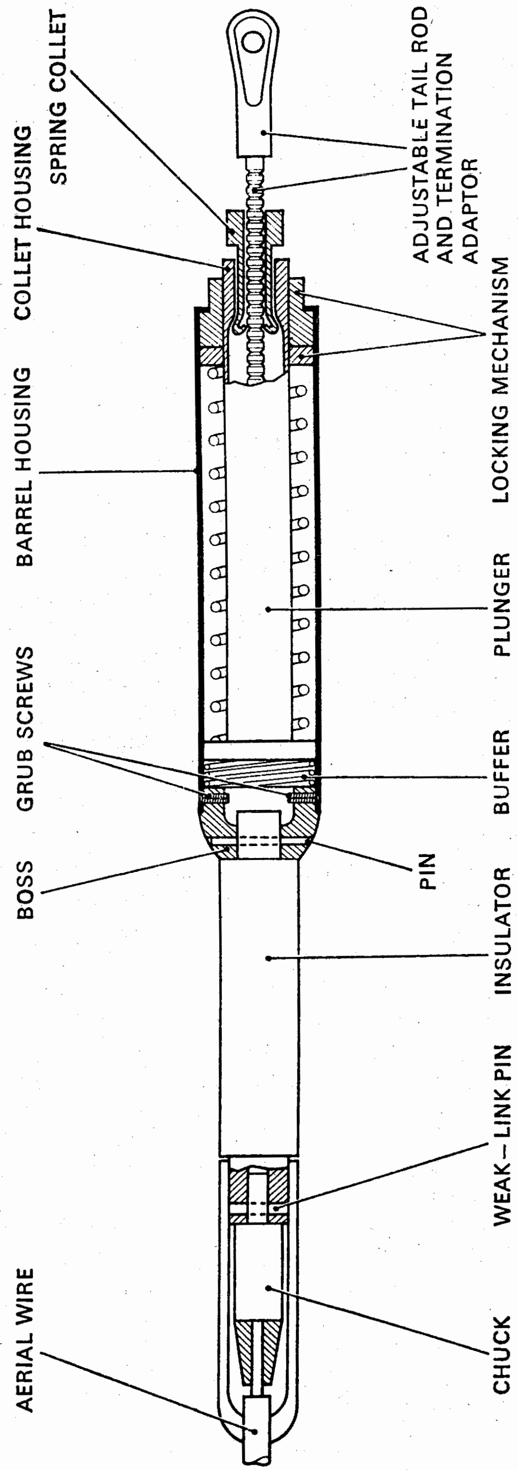
(f) Aerial wire should be removed from a chuck unit by means of the special extractor tool provided by the wire manufacturer.

2.2.4 **Aerial Tensioning Devices.** The rear tethering point of a fixed wire aerial incorporates a tensioning device to ensure uniform tension of the wire under all conditions of expansion or contraction, or of airframe structural deflections. Tensioning devices may be built-in by the aircraft manufacturer or may consist of separate external tensioning units. Tensioning units may consist of a rubber cord or bungee, which is coupled between the aerial wire and the aircraft structure, or they may be of the spring tension type. Of the two types of unit, the latter is the more widely used, since its tensioning characteristics are more efficient, and its weather-resistant properties are greater.

NOTE: For the maintenance of built-in tensioning devices, reference should be made to the relevant aircraft Maintenance Manual.

(i) **Spring Tension Units.** These units load the aerial wire by means of a metal spring, which may either be exposed, or enclosed in a barrel housing as in the type of unit shown in Figure 4. The spring is located between a plunger and a locking mechanism, the plunger being connected to a serrated tail rod and termination adaptor, via a spring collet and collet housing. The collet grips the tail rod in such a way that the greater the tension of the aerial the firmer is the grip. The tail rod can only be withdrawn by pressing the collet into the plunger, thereby allowing its jaws to spring away from the rod serrations. The forward end of the barrel housing is closed by means of a boss held in position by two grub screws. A small buffer spring is inserted between the boss and the plunger to prevent damage if the aerial tension is suddenly released. An insulator is connected at one end to the barrel boss by means of a spigot and pin, and at the other end provision is made for the attachment of the aerial wire chuck unit. The chuck unit attachment incorporates a copper pin which serves as a weak-link device designed to shear when the tension exceeds 160 to 180 lbf, the object being to ensure that, if a break occurs, it will be at the rear end of the aerial. In some types of tension unit, an overload protection device may also be incorporated to provide two-stage protection against overload, as well as a visual indication that the weak-link pin has sheared.

(a) To install a tension unit, the tail rod should first be freed and removed from the barrel housing by pressing the spring collet into the plunger; it should then be secured to the appropriate tethering point on the aircraft. The tail rod should then be re-inserted in the housing, leaving the serrations exposed


SPRING COLLET
ADJUSTABLE TAIL ROD AND TERMINATION ADAPTOR
COLLET HOUSING
LOCKING MECHANISM
BARREL HOUSING
PLUNGER
GRUB SCREWS
BUFFER
BOSS
PIN
INSULATOR
WEAK–LINK PIN
AERIAL WIRE
CHUCK

for a length of 2 to 4 inches, depending on the type of unit. The wire should be cut to the required length and secured in the chuck, then pressed down so as to compress the spring and leave the plunger projecting from the barrel housing by an amount specified for the particular unit. The plunger should then be locked in this position by rotating the locking mechanism a half turn by means of a $\frac{5}{16}$ inch BSF spanner. When pressure on the aerial wire is released, the wire will continue to hang slack, and this slack should be taken up by pushing the tension unit back over its tail rod as far as possible. In order to check that the spring compression provides the required tension, the locking mechanism should be turned to release the plunger and the projection measured. The dimensions obtained should be in accordance with those specified for the type of unit; typical dimensions vary from $\frac{7}{8}$ inch to $1\frac{1}{8}$ inch.

(b) At the periods specified in the approved Maintenance Schedule, tension units should be checked for security of attachment and for signs of damage and corrosion. Tension units should also be checked to ensure that the plunger is free to move. This can be tested by pressing down on the aerial wire at a point about 2 feet away from the tension unit. In installations where the rear end of an aerial is earthed, the appropriate electrical connections should be checked for security, and the resistance, when measured between the aerial wire and earth, must not exceed 0·1 ohm. Where the unit incorporates an overload protection device, this should be inspected to ensure that the yellow warning band is not exposed. An exposed band indicates failure of the tension unit weak-link pin thereby requiring removal of the complete tension unit for overhaul. Such failures should be recorded, and if more than one failure occurs on the same aircraft the cause should be investigated. Should several failures occur it may be necessary to re-site the aerial. Weak-link

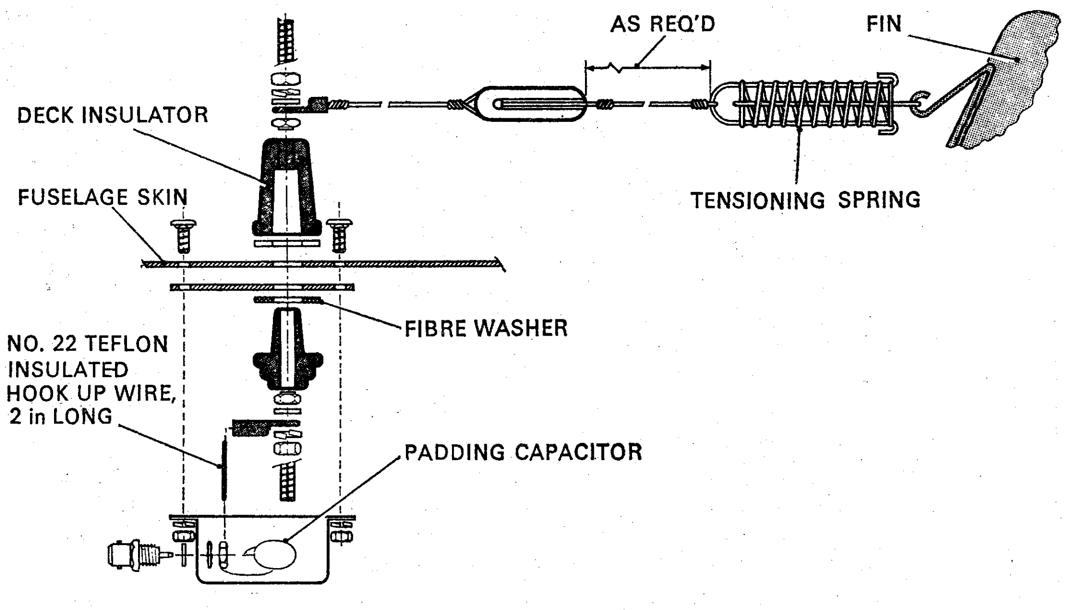


Figure 5 WIRE TYPE ADF SENSE AERIAL

pins should be examined during major inspections for signs of excessive loading and shearing, and should be replaced if necessary.

2.2.5 **ADF Sense Aerials.** Wire ADF sense aerials are designed primarily for use on light aircraft, and consist of a straight wire approximately 12 feet in length, usually end-connected between the fuselage and fin. In some cases, the wire may be connected between stand-off masts beneath the fuselage. A typical assembly using an uncovered single-strand copper wire is shown in Figure 5. No weak-link is provided, but any overload on the wire should result in detachment of the end clip supporting the tensioning spring.

NOTE: The use of this type of aerial is not recommended where reliable ADF performance in all weather conditions is required, as no protection against ice build-up is provided on the deck insulator, and the wire is not insulated against the effects of precipitation static.

(i) During inspection, the wire attachment at the deck insulator should be checked for signs of water and corrosion, and should be dismantled for cleaning if necessary. The wire should be examined for signs of wear at each termination, and for corrosion along its length. To prevent seizure, the tensioning spring should be regularly lubricated.

3 VHF COMMUNICATION AERIALS The external aerials used for VHF communication equipment are either of the rod (whip) or blade type of a length approximately equal to one-quarter-wavelength within the normal frequency band of 118 to 136 MHz.

3.1 **Rod Aerials.** Rod aerials are manufactured of high grade steel, usually having a tensile strength of at least 65 tonf/in², and complying with British Standards 2S97 and 3S106. Aerials vary in length from 22 inches to 38 inches and, depending on the type, the diameter of the rod may be stepped down, or may be uniformly tapered, so as to reduce the incidence of breakages. Protection against corrosion is usually provided by either a heavy coating of cadmium or a plastic sheath. Some types of aerial have the rod enclosed in a fibreglass sheath which is reinforced with resin.

3.1.1 **Rod Aerial Mountings.** The method of mounting varies between aerials and the type of aircraft in which they are to be installed; reference should, therefore, always be made to the relevant Maintenance Manuals. In general, aerial rods extend through a hole in the fuselage skin which is locally reinforced, and are clamped between a base or mounting bollard by means of a coupling nut or a bolted securing ring. The base or bollard of an aerial also provides for the attachment of the aerial co-axial cable. Figure 6 illustrates a typical rod aerial and mounting. The rake of the aerial can be adjusted by fitting spacers which are machined to the appropriate angular dimensions; typical angles are 15°, 20° and 30°.

(i) In some instances it may be necessary for a rod aerial to be flexibly mounted in order to obviate the effects of aerodynamic vibration or flutter. Figure 7 illustrates an anti-flutter installation which permits the aerial to move in a lateral direction, its movement being controlled by a rubber damper. The mounting is suitable for installation in all aircraft where the maximum cabin pressure differential does not exceed 6·5 lbf/in². If guards are to be fitted to prevent the build-up of ice on the aerial, care should be taken to ensure that the movement of the weather-proofing grommet is not restricted.

(ii) For the mounting of rod aerials on wooden or fabric covered aircraft, the siting considerations referred to in paragraph 3.3.1 may be used as a guide, but do not necessarily apply. Variations in construction and layout are so great that individual consideration of each type is essential.

(a) The radiation efficiency of the aerial is somewhat impaired with wooden and fabric covered types of aircraft. This condition can be improved by presenting a ground plane to the aerial, and, in order to do this, a counterpoise mat or strip, centrally disposed under the rod, is required (see Figure 8). The counterpoise should consist of a circle of copper gauze of 24 inch radius, or of 4 to 8 radiating members of copper strip, which should be attached to the underside of the covering by a suitable method. The connection of the counterpoise to the bollard should be through the mounting bolts, ensuring a good connection to the aerial base.

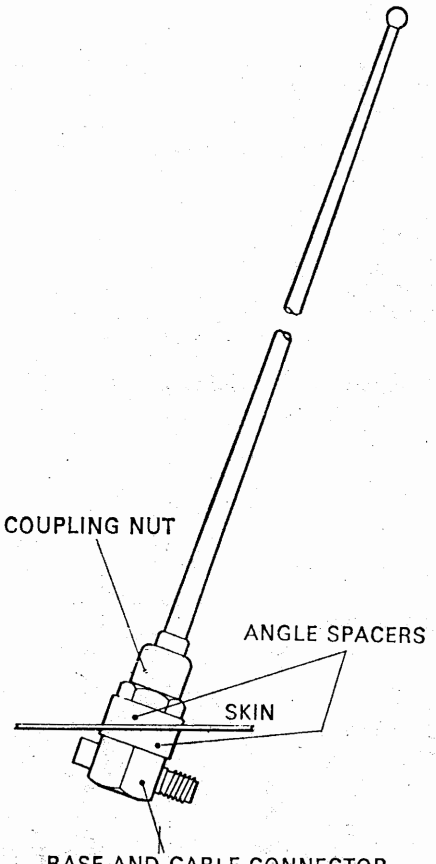


Figure 6 TYPICAL ROD AERIAL

3.2 **Blade Aerials.** Blade aerials cover a broader frequency range than rod aerials and are designed to provide a more acceptable Voltage Standing Wave Ratio (VSWR). When mounted on either the top or bottom of the fuselage, a vertically polarised, omni-directional radiation pattern is obtained. The construction of aerials varies between manufacturers' designs, but in general, the radiating elements are embedded in poly-urethane foam and encased in a resin-bonded fibreglass shell, the external surface of which is protected by a polyurethane or epoxy resin paint. The shell is raked rearwards and has a drilled flange at the base which carries the appropriate cable connector, and provides for attachment of the aerial to the fuselage skin. Leading edge protection is provided in the form of a plastic or stainless steel strip.

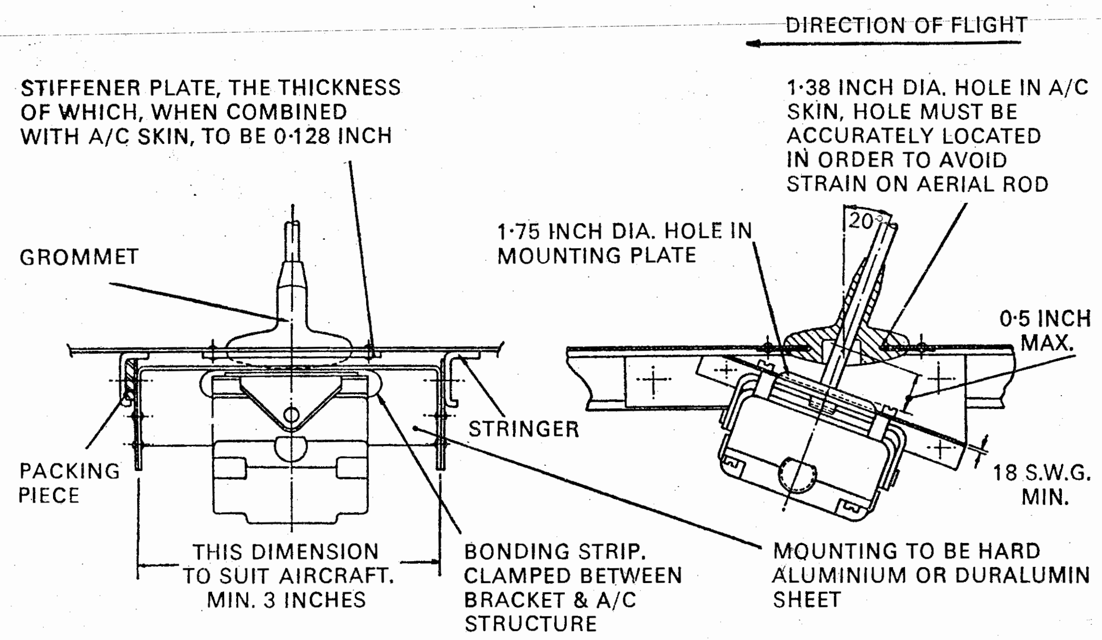


Figure 7 FLEXIBLE MOUNTING

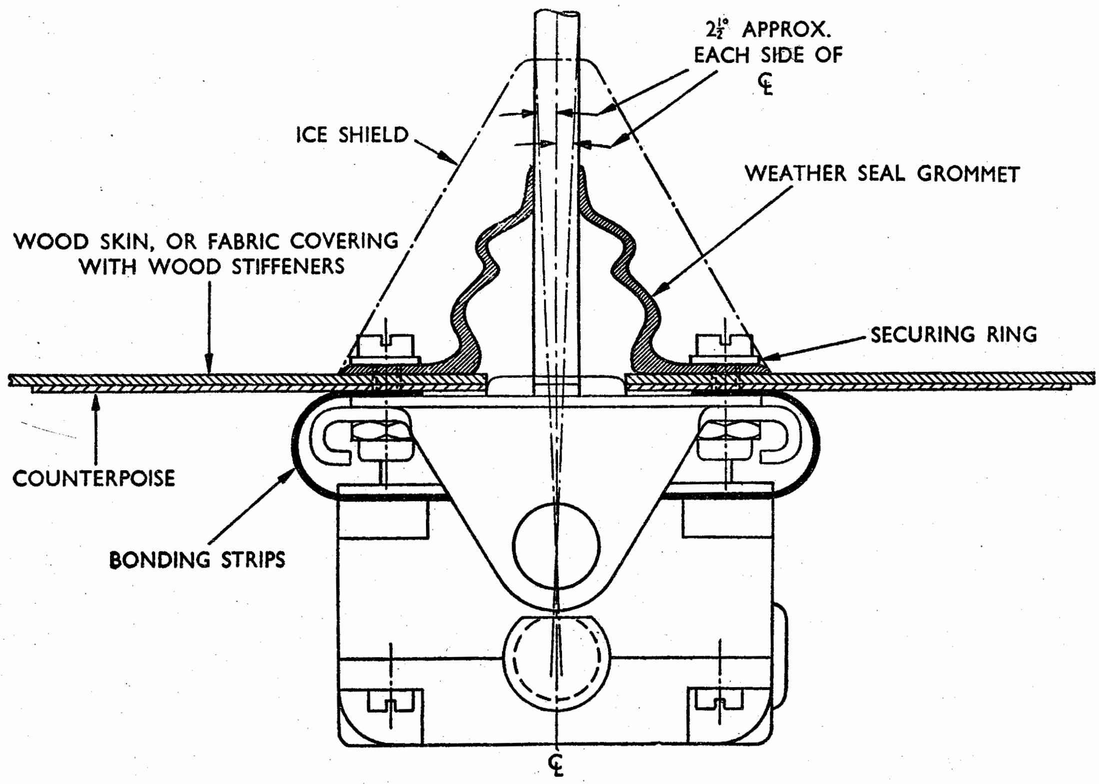


Figure 8 AERIAL MOUNTING WITH COUNTERPOISE

3.2.1 Aerials should be installed in a suitably reinforced skin area, in accordance with the relevant installation drawings. The mating surfaces must be perfectly clean, and, in order to prevent moisture or water from entering the aircraft, and to guard against the loss of air from pressurised structures, a special sealing gasket should be inserted between the aerial mounting base and fuselage skin. To ensure efficient electrical bonding at radio frequencies, some gasket materials either consist of metal gauze, or are impregnated with carbon or metal particles. Effective RF bonding can also be ensured by fitting spring contacts to the base of the aerial. The procedure to be adopted when applying seals varies between installations and, as full details are normally given in the relevant Maintenance Manuals, reference should always be made to such documents.

3.2.2 At the periods specified in the approved Maintenance Schedule, a blade aerial should be inspected for security of attachment, cracks around fixing holes, and corrosion or other damage to the protective finish of the shell.

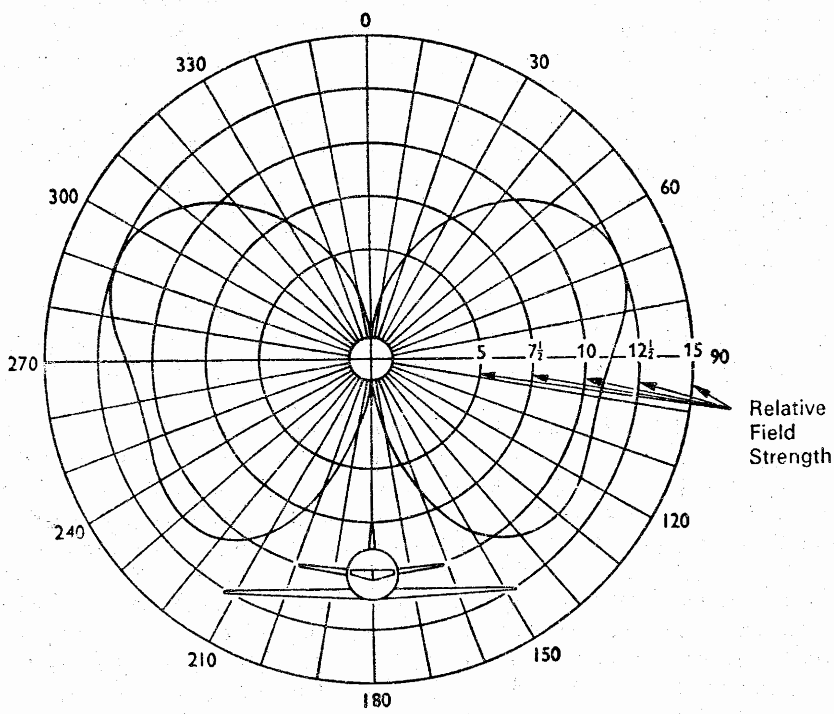
3.3 **Radiation Patterns and Siting of VHF Aerials.** In assessing the performance of an aerial it is usual to measure the field strength in three mutually perpendicular planes, known as the principal radiation planes. Although absolute field strengths could be measured, it is easier, and more usual, to obtain field strengths relative to the field strength in one fixed direction, usually the line of flight of the aircraft. The absolute standard of reference for field strength is based on an aerial giving an equal pattern of radiated energy at all points on the surface of a sphere at the centre of which the aerial is situated. Although such an aerial cannot be achieved in practice, its relation to certain existing aerials can be calculated. Figure 9(a) shows the transverse elevation radiation pattern of a quarter-wavelength rod aerial mounted on the top of a half-wavelength diameter cylinder representing an aircraft fuselage. The radiation pattern in the fore-and-aft elevation plane is dependent on the distance of the aerial from the ends of the cylinder, and will show more shielding as the length increases. With a cylinder tending to infinite length, no radiation is experienced on the shadow side. The azimuth radiation pattern is the most important and when this has been determined a fair approximation of an aerial's radiating properties can be obtained. A typical azimuth pattern is shown in Figure 9(b).

3.3.1 **Siting Considerations.** Considerable modification to both elevation and azimuth patterns is experienced in practice, mainly as a result of the screening effect of the wings. In general, the screening effect is most marked where the VHF aerial is mounted within the planform of the wings, and adjacent to it, e.g. a high wing aircraft with a top fuselage mounted aerial.

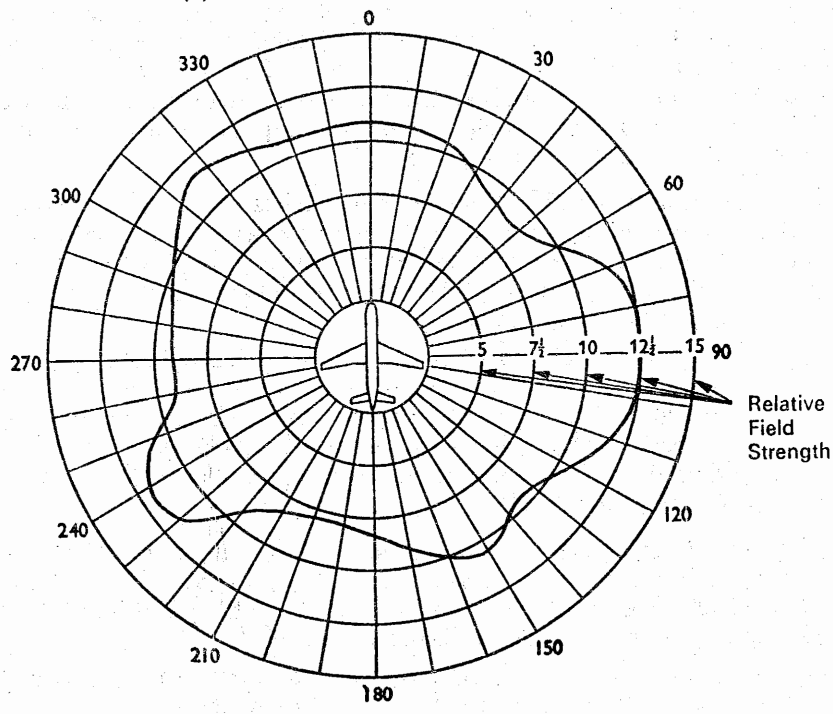
(i) Although a ventrally mounted aerial shows a theoretical improvement in range and distribution over a top mounted aerial, in practice a suitable position is difficult to achieve, and the CAA recommends a top mounted aerial. Aerials should preferably be mounted on the centre line of the fuselage, at or near right angles to the aircraft skin laterally, and within an arc extending from the vertical to 20° aft longitudinally.

3.3.2 **High Wing Aircraft.** For low aspect ratio wings, the fuselage area between leading and trailing edges should, where possible, be avoided, thus limiting the available effective area to between leading edge and cockpit roof, and from trailing edge to within two or three wavelengths of the fin.

(i) With these types of aircraft, ground clearance is usually small, and a large number of aerials may require to be top mounted. The minimum distance between aerials, and between aerials and other protuberances of a similar nature, should be greater than one wavelength. VHF aerials should be mounted aft of essentially forward looking aerials mounted in the same plane.



(a) TRANSVERSE ELEVATION PLANE



(b) AZIMUTH PLANE

Figure 9 **RADIATION PATTERNS**

(ii) Propeller modulation may adversely modify radiation patterns, and suitable wavelength clearance should therefore be allowed between aerials and propellers.

NOTE: Propeller modulation is caused by a variation in the high frequency currents induced in the propeller blades each time they reach a vertical position, causing the radiation pattern to vary in synchronism. The effect is most marked when the length of the blades is comparable to the wavelength.

3.3.3 **Low Wing Aircraft.** Top mounted aerials should be positioned between the cockpit roof and to within two or three wavelengths of the fin, subject to the limitation imposed by propeller modulation. The minimum interference distance between aerials and protuberances is as quoted in para. 3.3.2(i).

3.3.4 **General.** When assessing the proposed location for an aerial, consideration should be given to the potential screening which may arise from the close proximity to the aerial of the undercarriage, flaps, etc., and of the fuselage itself in certain aircraft attitudes. Attention should also be given to potential mutual interference between aerials.

(i) The area aft of effluxes of waste products should be avoided. Aerials should be mounted clear of loading bays, inspection panels, and areas where they might be damaged by aircraft steps, refuelling tankers, etc.

(ii) When twin VHF equipment is installed in an aircraft, a separate blade or rod aerial should be provided for each installation but, if preferred, a single blade aerial incorporating a co-axial changeover relay may be utilised.

NOTE: The use of a single rod aerial is not recommended, because of the possibility of losing the aerial through ice accretion or fatigue.

(iii) Some degree of "mis-match" is inevitable between an aerial and its feeder and the transmitter aerial circuit, but choice of the correct type of aerial, and careful design of the installation can result in a VSWR down to 2½ to 1, or better.

3.3.5 **Drag Load.** The approximate drag load of an aerial can be determined by the following formula:—

$$D = \cdot000327\ AV^2$$

(The formula includes a 90% reduction factor for the streamline shape of an aerial)

Where D is the drag load on the aerial in lbf.

A is the frontal area of the aerial in ft², and

V is the V_{NE} of the aircraft in mph.

Example: An aerial having a frontal area of 0·135 ft², at 250 mph

$$\begin{aligned} D &= \cdot000327 \times 0\cdot135 \times (250)^2 \\ &= \cdot000327 \times 0\cdot135 \times 62{,}500 \\ &= 2\cdot75 \text{ lbf.} \end{aligned}$$

4 RAIL OR TUBE AERIALS Horizontal rail or tube aerials are principally intended for airborne reception of ADF sense signals, but are equally suitable for any other application requiring a capacitance-type aerial. The aerials are generally fitted under the fuselage, using either two or three fibreglass moulded stand-off masts. The aerials should be located in such positions that they will not be damaged by, or interfere with, loading steps, doors, or inspection panels, and where they will not be in the path of ejected waste fluids, e.g. from toilet or galley drains. The lead-in mast can be positioned forward, aft, or intermediate, according to convenience of mounting. Care must also be taken to site these aerials so that, ideally, the ADF "turn round" occurs when the aircraft is directly over the beacon. It should be borne in mind that, whereas a slightly early turn round is acceptable, a late one is not.

NOTE: The position of such aerials may be critical, and guidance on siting should be sought from the manufacturers of the equipment.

4.1 In order to determine aerial requirements in terms of height and length, it is usual for manufacturers to quote the minimum performance of their equipment in picofarad metres or "hicaps" as these units are more commonly called. The hicap is a sensitivity factor equal to the product of the effective height of the aerial in metres and its capacity in picofarads. The factor is of particular use in the design of these aerials where the stand-off distance from the fuselage is sensibly constant along its length. Table 2 gives values in hicaps per foot for typical sense aerials mounted on flat metal sheet.

TABLE 2

	Hicaps per Foot of Aerial		
Height (in.)	Wire 0·05 in. dia.	Rod 0·375 in. dia.	Rod 0·5 in. dia.
4	0·295	0·450	0·490
5	0·365	0·540	0·575
6	0·420	0·615	0·660
8	0·530	0·760	0·820
10	0·640	0·910	0·965
15	0·920	1·280	1·360
20	1·175	1·600	1·690
30	1·640	2·150	2·280

4.2 **Curvature Factor.** The pick-up of an aerial mounted on a curved fuselage will be greater than that of an aerial mounted on a flat sheet and some correction must be made to the values in Table 2 which will increase the effective hicap value per foot.

4.2.1 Formulae are available from which this factor can be computed with a fair degree of accuracy, but it is recommended that installation designers should consult the equipment manufacturer before applying such formulae, since they have a limited use and can be modified by a number of factors. Aerials mounted vertically on rectangular fuselages can be displaced either side of the centre line without decreasing the curvature factor, but displacement of aerials away from the centre line of circular section fuselages reduces the factor proportionally as the cosine of the angle.

4.2.2 For a medium-sized aircraft an aerial with 10 inch masts on the centre line would have a factor of 1·86 reducing to 1·75, displaced 20° either side of the centre line. Aerials mounted close to the wing root on low wing aircraft can, however, reduce the factor to as low as unity. In the absence of specialised information, a maximum factor of 1·5 is recommended.

4.3 **Aerial Capacitance.** The capacitance of an aerial can be determined by the following formula:—

$$C_a = \frac{L}{4{\cdot}144 \log_{10} \frac{4H}{D}}$$

where, C_a = capacitance in picofarads (pfs)

L = length of aerial

H = height of aerial above metal skin

D = diameter of aerial

Small additions (5 to 10 pfs) should be made to allow for the capacitance of lead-in masts and dead-end masts.

4.3.1 Manufacturers of ADF equipment for General Purpose Category aircraft normally specify the aerial length required, or make provision for the installation of additional capacitance. Separate aerial and feeder capacitance, or a combined figure, may be specified but no height requirements are stated since most aerials are assumed to be located between fuselage and fin.

4.3.2 When measuring aerial and feeder capacitance for ADF purposes, the use of a capacitance bridge with an operating frequency of 200 kHz is recommended.

5 VOR AND ILS AERIALS VOR (VHF Omni-Range) navigational systems utilise unipole aerials which are required to receive horizontally polarised waves and are therefore mounted horizontally. They operate in the frequency band 112–118 MHz and basically consist of a steel blade or rod. The ILS (Instrument Landing System) utilises two aerials which are also horizontally polarised but operate in different frequency bands. One aerial receives localiser signals in the band 108–112 MHz, while the other receives glide slope signals in the band 328–336 MHz.

5.1 As the requirements of both VOR and ILS localiser equipments are similar, and particularly since they have adjoining frequency bands, it is usual to combine them into either a V- or U-shaped horizontal dipole for mounting on the top or bottom of a fuselage, or as a plate-type unit for flush-mounting. In some cases, the arms of the dipole may be separate so as to be mounted one each side of a fin; the two are connected to a single cable by suitable phasing links. Glide slope aerials are separate units, and are mounted in the fuselage nose section.

5.1.1 The position of combined VOR/LOC aerials is governed mainly by the radiation pattern of the glide slope aerial, and also by the location of the VHF communication aerials. In general, a position as far forward as possible must be made available, taking into account such factors as degree of curvature of the fuselage nose, screening effect of the wings, and propeller modulation.

6 MARKER BEACON AERIALS A marker beacon aerial may be a simple wire or horizontal rod, an encapsulated tuned circuit, or a suppressed plate. It is located under the fuselage and may be connected to either one or two receivers.

6.1 The dimensions for a 75 MHz Fan Marker aerial are standardised at 75·5 inches total length with the lead-in tapped at 35·5 inches. This is suitable for matching to 50 ohm co-axial cable. However, these aerials have been found to be not critical in regard to length, in fact the pick-up may be excessive and result in artificial broadening of the marker beacon cone. Often an end-fed quarter wave aerial gives satisfactory results. The installation of a fixed-wire marker aerial may utilise two stub masts for the end supports, with a further stub mast for the lead-in, or, alternatively, two stub masts with a spliced pigtail lead-in to a deck insulator (see paragraph 2.2.3 (ii)).

6.2 Encapsulated aerials consist of a circuit, pre-tuned to 75 MHz, which is tightly sealed in a plastic foam-filled shell. When installing this type of aerial, good contact must be made between the aerial and the fuselage skin. Provision is made for matching an aerial to the feeder by means of a trimming control on the aerial and, after installation, the control must be adjusted for maximum signal at the receiver.

6.3 For the reception of marker beacon signals in high speed aircraft, a plate type aerial recessed into a cavity underneath the fuselage is usually employed. The aerial is insulated from the surrounding structure, and a fibreglass cover is fitted over the cavity. A trimming capacitor is normally provided for matching the aerial to the feeder in a similar manner to that adopted for an encapsulated aerial. The fibreglass cover should be removed at intervals to check that the sealing is adequate, and that moisture has not entered. A check should also be made on the condition of the protective coating applied to the cover and, if necessary, the coating should be renewed in the manner prescribed in the aircraft Maintenance Manual.

7 AERIAL EARTHING AND STATIC DISCHARGE DEVICES These devices are provided to minimise the damaging effects of lightning strikes, and also to dissipate accumulations of static charges in aerials most commonly used for high-power HF Communications equipment. These devices may either be incorporated within radio equipment or mounted at the lead-in terminal locations of aerials. They may be of three principal types: (i) electrically operated earthing switches, or relays, (ii) gas filled spark gaps and (iii) static discharge resistors.

7.1 **Ele ically Operated Earthing Switches or Relays.** These should be of an approved type and should always be mounted at the base of the lead-in insulator or mast. With the open type of switch, a rigid mounting is required for the associated relay unit and the aerial contact assembly should be bolted to the base of the lead-in rod. It is essential to ensure that twisting of the lead-in rod, which may result in the rotation of the aerial contact, cannot take place.

7.2 **Gas-Filled Spark Gaps.** Gas-filled spark gaps may be fitted instead of aerial earthing switches or relays; they are automatic in operation, and have no moving parts. It should be noted that the maximum transmitter voltage must not be sufficient to operate the spark gap under the conditions defined in Chapter **R4-5** of British Civil Airworthiness Requirements.

7.2.1 The unit should be mounted as closely as possible to the aerial lead-in terminal, whilst the earthing terminal should be secured to a suitable rib or stringer, and not directly to the skin, unless the latter is suitably reinforced. The location of a spark gap should be such that it provides a more direct path to earth for a lightning strike on the protected aerial, than any path through the associated equipment.

NOTE: Open spark gaps must not be fitted in any part of the aircraft where they would constitute a fire hazard.

7.2.2 Brackets and clips made locally to receive spark gap dischargers should be manufactured of silver-plated co r wire and should have a minimum cross-sectional area of 0·009 square inches, this figure normally being exceeded in practice to impart stiffness to the mounting. Prominent edges and corners of all fittings should be radiused and adequately spaced from any earthed metal or component, to avoid both high-voltage arcing within the aircraft during transmission and the possibility of lightning discharging directly to the structure.

7.2.3 In some types of aircraft, particularly those using a suppressed type of HF aerial located at the top of a fin, a spark gap type of lightning arrester is installed at the aerial location. A window is normally provided at the side of the fin to permit inspection of the arrester.

7.3 **Static Discharge Resistors.** In order to dissipate an accumulation of static charge in aerials, a conducting path from aerial to earth must be provided in installations where the following conditions apply:

(i) The equipment to which the aerial is connected does not provide a path to earth.

(ii) An arrangement of earthing switches leaves an aerial isolated from an equipment which would normally provide the path.

NOTE: The practice of designing a relay to revert to "Receive" when the equipment is switched off is by no means universal, and the point should be checked during the installation of the system.

7.3.1 Static discharge resistors are designed to provide a permanent conducting path, and are normally incorporated within the radio equipment. The prescribed value and rating of resistors is given in Chapter **R4-5** of British Civil Airworthiness Requirements.

7.3.2 The general guidance given in paragraphs 7.2.1 and 7.2.2 regarding the mounting of spark gaps, is equally applicable to the mounting of resistors. However, when resistors having a thick soldered ring at each end are used, it is recommended that these should be mounted in spring clips designed to accommodate the end rings.

8 REPAIR OF RESIN-BONDED FIBREGLASS MASTS Aerial masts manufactured from resin-bonded fibreglass have excellent insulating qualities and high tensile and compressive strength, but the material is prone to damage by the erosive action of raindrops, sand and dust, which may be driven at high velocities into the surfaces of the mast which are normal to the line of flight. These elements gradually penetrate the layers of glass-cloth, causing peeling of the laminates or, after prolonged exposure, complete disintegration.

8.1 **Neoprene Protective.** Deterioration of the fibreglass laminate as a result of erosion can be considerably retarded by the use of a neoprene protective which complies with Material Specification DTD 856A, and which should be applied to the surface of the laminate as detailed in Process Specification DTD 926B.

8.1.1 When masts protected with neoprene are exposed to sunlight, the matt-black finish of the neoprene absorbs heat to such an extent that the strength of the underlying glass-resin laminate may be impaired; to prevent this the mast can be further protected with a white paint finish.

8.1.2 A suitable painting scheme consists of two undercoats of flat paint and a top coat of oil-bound high-gloss paint. Care should be taken to ensure that both paints are produced by the same manufacturer, and are in fact suitable for use together. Paints having a cellulose base should not be used, since cellulose has a detrimental effect on neoprene.

8.2 **Repair of Neoprene Protective.** Should the neoprene become damaged to such an extent that the surface of the glass fibre laminate is exposed, the mast should be removed from the aircraft at the earliest opportunity for repair. Because of the extent of control which is necessary over the neoprening process, i.e. temperature, humidity, method of application and subsequent curing, it is strongly recommended that aerial masts rendered unserviceable by eroded, or otherwise damaged, neoprene or fibreglass laminate, should be returned to the manufacturer of the mast for repair. Where such action is impractical for small repairs, the repair procedure given in the following paragraphs should be employed. Integral lead-in components cannot be repaired.

8.2.1 Figure 10 illustrates a typical area of damage and the type of repair permissible. The erosion of the neoprene is most likely to occur on the aerial mast leading edge, where this is within an included angle of 60° to the line of flight; the repair should be made beyond this area to ensure that the weaker mating edges of the old and new neoprene are not exposed to the full erosive action.

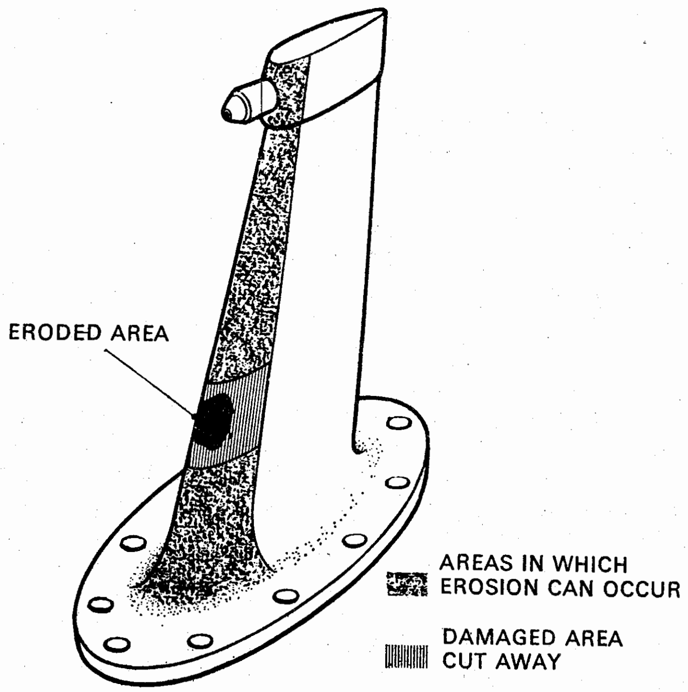


Figure 10 AREAS OF DAMAGE

8.2.2 The white paint should be removed from, and at least 0·5 inch beyond, the area to be repaired, by rubbing down with wet carborundum waterproof paper No. 220C. Any resistant paint should be cleaned off with methylated spirit.

NOTE: Methylated spirit is a safe solvent, but cellulose or highly volatile cleaning agents will damage the neoprene.

8.2.3 One hour should be allowed for the methylated spirit to dry out thoroughly, after which the square of damaged neoprene should be cut out, ensuring that the edges do not lift. If the cut edge does not adhere to the underlying laminate, more neoprene should be cut away until this condition is achieved.

8.2.4 The exposed surface of the laminate should be cleaned with toluene, but care must be taken to ensure that the toluene does not come into contact with the neoprene. This can be prevented by masking the edges of the neoprene.

8.2.5 A neoprene primer of the type recommended in DTD 926B should be applied to the laminate, using only enough thinners to permit ease of working, and taking special care to ensure that the primer does not come into contact with the edges of the neoprene. One hour should be allowed for the primer to dry before the neoprene is applied.

8.2.6 The neoprene should be applied with a fine camel hair brush, allowing one hour between each coat, until the desired thickness is achieved. Approximately 20 coats each of about 0·001 inch thickness, will be required, and each coat should overlap the cut-away area by about 0·25 inch.

NOTE: Thinners must not be mixed with neoprene.

8.2.7 The neoprene has an accelerator added which produces a cured film at room temperature, but curing can be accelerated with heat, the time taken to effect the curing depending on the temperature. About seven days is necessary to produce a completely cured coating, and, until this period has elapsed, the mast should not be repainted.

8.3 **Renovating White Paint.** It is necessary to renew the white paint only when more than 25 per cent has been lost or when appearance is of importance. Prior to repainting, the whole mast should be rubbed down with No. 220C carborundum waterproof paper, wetted to remove the gloss paint. The mast should then be dried and repainted as recommended in paragraph 8.1.2.

8.4 **Insulation Tests.** On completion of the repair the insulation of the mast should be checked as detailed in the relevant Maintenance Manual.

RL/2-3

Issue 1.

15*th November*, 1974.

AIRCRAFT

RADIO

SCREENED ROOMS FOR RADIO MAINTENANCE

1 INTRODUCTION This Leaflet gives general guidance on the purpose, design and construction of screened rooms for radio workshops. The purpose of screened rooms, or "cages" as they are more often called, is to prevent undue radiation of radio frequency signals from equipment operated inside the room, since such radiation may be unlawful, and may cause interference to radio users in the locality. In addition, the screening is an attenuator of interfering signals and noise from outside the room, and thus provides an interference-free region for delicate adjustment and measurements.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet **RL/5-1,** Issue 1 dated 15th February 1961.

2 ATTENUATION The degree of attenuation obtained is usually referred to as "Insertion Loss" and is measured in decibels (db).

NOTE: The term "decibel" is used throughout this Leaflet to express a voltage ratio and is not a reference to any particular level of voltage.

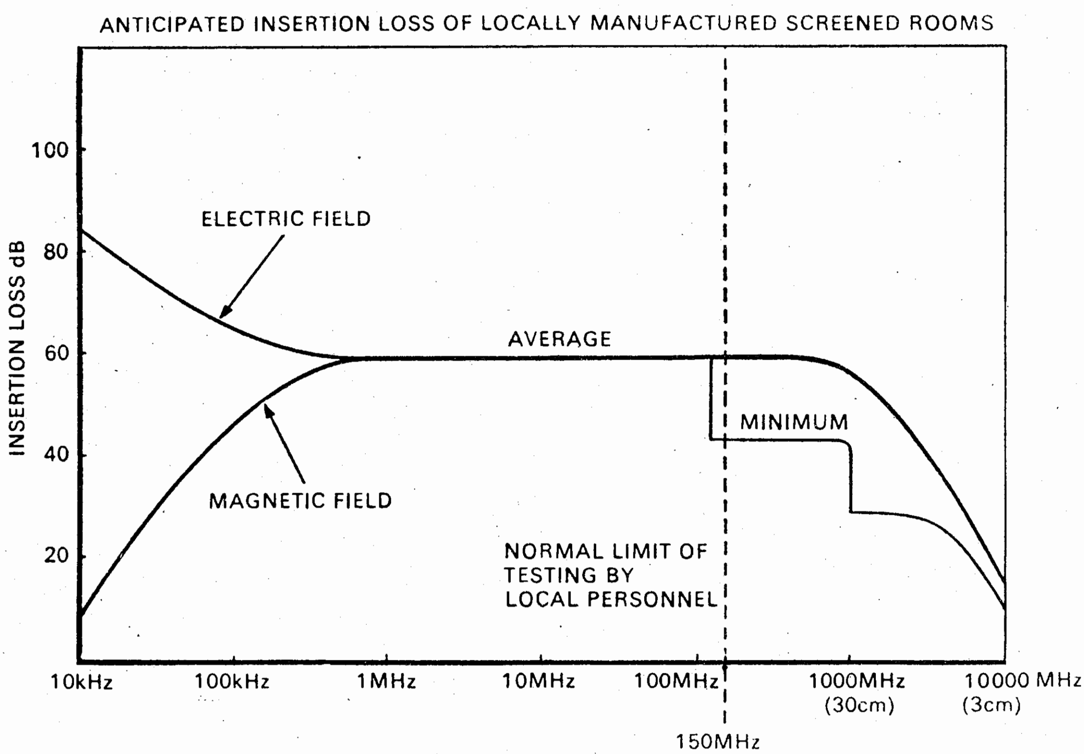


Figure 1 GRAPH OF INSERTION LOSS OF A DOUBLE-SCREENED ROOM

2.1 An insertion loss of 60 db gives a voltage reduction equivalent to a ratio of 1,000:1. This is usually adequate for the suppression of radiation from within the cage, and for the calibration of equipment having sensitivities of the order generally encountered in aircraft radio, even in localities of high "man-made" interference.

2.2 The portion of the radio frequency spectrum over which attenuation is usually required is between 10 kHz and 400 MHz. For a one-man cage of 6 feet 6 inches cube, direct measurements can be made below 150 MHz using suitable field strength meters, or by receivers similar to the type under test. Above this frequency measurement becomes more difficult, since the screened room will resonate as a cavity resonator. The resonant frequency will depend on the size of the room, its contents and the space between the inner and outer screens. To determine such resonances it would be necessary to sweep the entire band instead of relying on spot checks. With large cages the resonance frequency may be as low as 10 to 15 MHz, and more careful testing will be necessary.

2.3 Figure 1 shows the insertion loss expected of a typical double-screened room, the internal measurements of which are in the form of a 6 feet 6 inches cube. This is a suitable size for most overhaul Organisations. The figures given relate to an empty room in which power supplies, heating and compressed air pipes have not been installed.

3 SITING CONSIDERATIONS The site of the screened room may have to be related to the position of a previously erected radio workshop, but in any case the factors outlined in the following paragraphs should be borne in mind.

3.1 The efficiency of the room will be reduced if it is situated in a region of high "man-made" static.

3.2 The screened room should not be positioned adjacent to spark-plug testing equipment, battery-charging petrol-electric equipment, or an electrical overhaul shop, since these are all sources of interference.

3.3 Main trunking for telephone wires or power cables is a source of interference, and should be avoided if possible.

3.4 The use of fluorescent tube lighting in the vicinity of the room is undesirable.

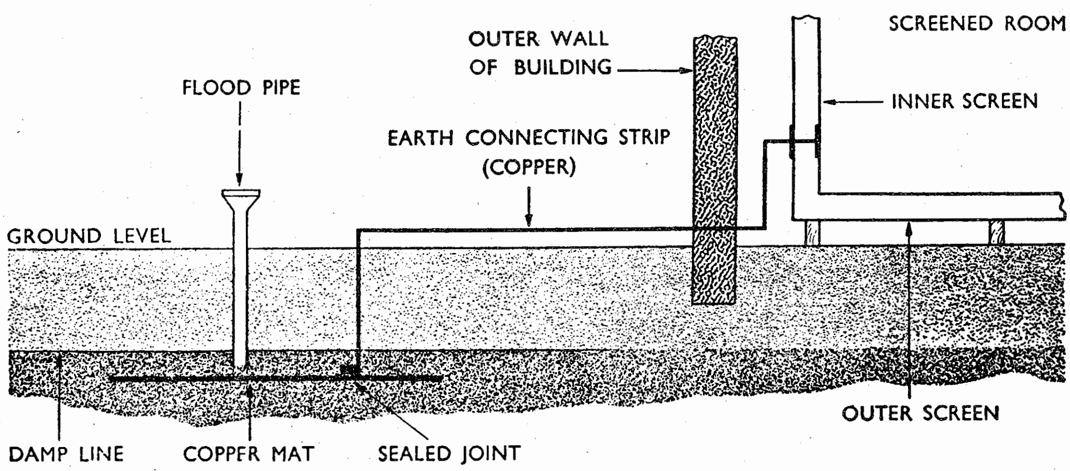


Figure 2 TYPICAL EARTHING ARRANGEMENT

3.5 The room should, where possible, be on the ground floor and adjacent to an outer wall, so that the earth strip bonding the screened room to the main earth is as short as possible (see paragraph 4).

4 **EARTHING** For earthing purposes a copper mat or plate should be sunk into the earth to a depth which will ensure consistent damping; a typical earthing arrangement is shown in Figure 2. After the test described in paragraph 6 has been conducted, the screens should be connected to the earthing mat by an earth strip of the shortest possible length.

4.1 Care should be taken to use a material for the earth strip that will not create a potential of more than 0·25 V with the material to which it is joined. If the connections are made by welding or soldering, they should be thoroughly cleaned to remove all traces of flux residue, and should then be covered completely with a sealing compound or other insulating covering.

4.2 In well-drained locations, it is recommended that a pipe should be sunk over the earth mat to permit occasional flooding of the mat.

4.3 In instances where an outside wall position is not available, an earth mat should be positioned under the floor of the main building or, alternatively, the room may be connected to earthing spikes.

4.4 Care must be taken to ensure that both screens are bonded together at the same point and over a good contact area. Suitable methods are welding, soldering or by bolting to the plates welded to the screen. The bonding of the screens at one point may cause some difficulty in aligning the earth strip with the mains input point (paragraph 7) since normally the lead-through filter will bond the screens together. Local requirements or Government regulations may preclude the feeding of a.c. mains supply below a certain height, in which case the earth strip should be run up the outer screen and bonded to it from top to bottom.

4.5 Bonding points should be provided in the room at bench height for the connection of equipment earth contacts or cases.

NOTE: Test equipment may require an earthing connection from its case to the inner screen in addition to the earthed mains supply plug.

5 **CONSTRUCTION OF SCREENED ROOM** In theory, a single-walled screened room constructed of copper or aluminium sheet is suitable, and would meet most requirements, but in practice there are a number of factors which may make its use undesirable, e.g. the possibility of the occupant suffering from claustrophobia, the necessity of individual heating and lighting and, possibly, the installation of an extractor fan, and the fact that communication with the occupant would be difficult.

5.1 In view of the above, the use of a double-walled room constructed of well-seasoned timber, using wooden dowels instead of nails or screws where possible, and having screens manufactured of close-mesh copper, expanded aluminium or galvanised expanded steel, is recommended. The mixing of these various materials is not recommended, since any electrolytic action between them will cause noise. In such a structure, the inner and outer screens should be spaced 3 inches apart.

NOTE: Rooms have been constructed of ½ inch mesh steel wire but, in general, such a structure has no inherent strength and tends to warp and sag. In addition, it is difficult to bond the structure satisfactorily. Electrically, this material gives poor insertion loss figures, and its use is not recommended.

5.2 The room should be raised from the floor of the main building by wooden beams, or other insulating media, and all screened joints should be bonded by welding or soldering, for preference, although clamping is quite satisfactory if sufficient care is taken.

5.3 If steel staples are used to attach the screen material to the frame, it should be ensured that the staples are galvanised, as any rusting may cause noise.

5.4 **Doors.** Special care should be taken when fitting doors of screened rooms, as a good fit at all points is essential for good attenuation. Hinged doors may be employed, and they should consist of a 3 inch deep wooden frame, covered on both sides with screening material, and bonded to the walls of the room by any suitable method, e.g. by using the hinge as one bond, and spring copper or bronze draught excluder strip as the remaining bond, or by using the method illustrated in Figure 3. It should, however, be borne in mind that such doors occupy space in a possibly restricted workshop, are clumsy, and are difficult to construct with a locking mechanism which can be operated from both sides. Sliding doors are generally found to be more convenient.

NOTE: Where screened rooms of proprietary design are installed, the manufacturer's recommendations regarding methods of erection and testing should be followed.

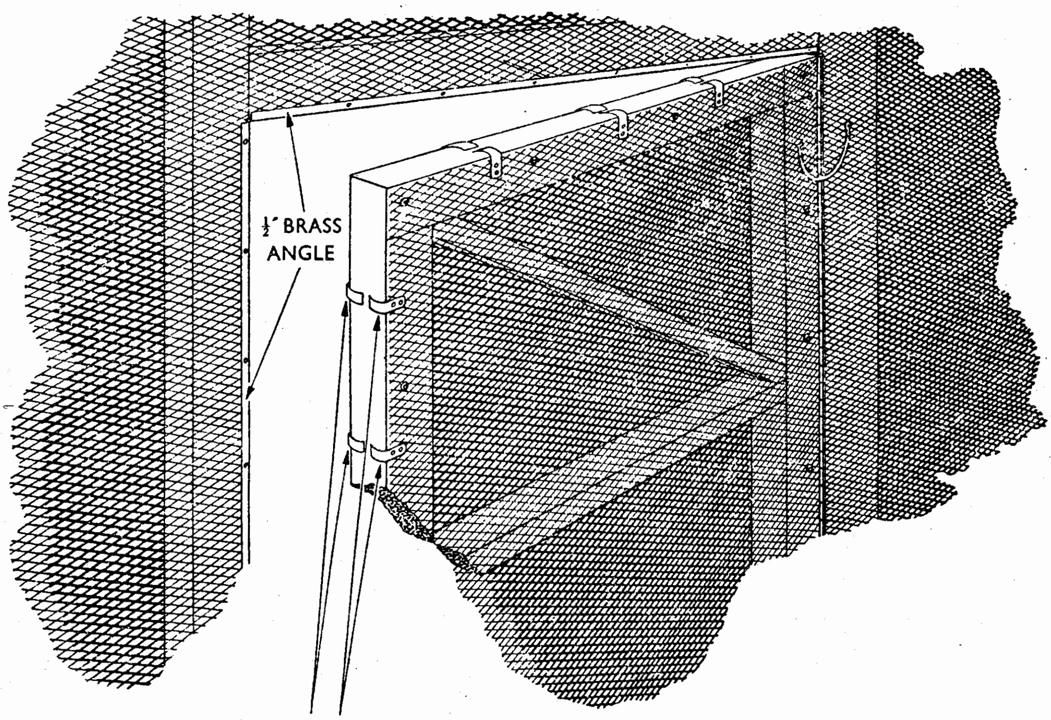


Figure 3 METHOD OF BONDING DOOR

6 INITIAL TESTING At this stage in the construction of the screened room, i.e. before any equipment or services are fitted, it will be of advantage to obtain a rough estimate of insertion loss. However, before commencing the test, and before connecting the main earth strip to the cage, a careful check should be made on the efficiency of all bonded joints and on the operation of the door and its bonding. With the door closed, the insulation of the inner and outer screens should be checked with a 500 V insulation-resistance tester, and a reading of more than 10 megohms should be obtained. On completion of the check, the earth should be connected to the screens.

6.1 The test should be made as follows:—

(i) Select a suitable battery-driven communications receiver and connect it to a horizontal wire aerial 6 feet in length.

(ii) With the automatic gain control switches off, and the receiver connected to an output power meter, tune in a number of powerful transmitters, either continuous wave or tone modulated, and adjust gain for a high output.

(iii) Transfer the set-up into the screened room and check the resulting attenuation.

The range of attenuation will be limited by the field strength of the transmitters, and by the output power capabilities of the receiver, but figures of 25 to 35 db should be reached, and complete suppression of signals should be obtained.

6.2 A cage in this initial state should easily be capable of attenuation figures double those given in paragraph 6.1 and therefore incomplete suppression is most likely as a result of leaks in the screening. It is important to bear in mind that filtered power supplies and other services fed to the cage will considerably reduce its attenuation efficiency.

7 SERVICES The electrical supplies normally required inside a screened room consist of a single-phase, 230 V a.c. supply, heavy duty 24 V d.c. supplies, and either a single phase or a three-phase supply of 115 V, 400 Hz. Services such as compressed air, water and gas heating may be required, but their installation presents no major problems provided that they are introduced at the main earth point and are securely bonded to both screens. All power supplies fed into the cage should be filtered by interference suppressors (see paragraph 8).

7.1 **A.C. Mains Supply.** A 200–250 V, 50 Hz a.c. supply is required to operate test instruments, and for individual bench lighting and heating. All supplies should be run in seamless conduits to three-pin sockets, and, where required, to fully-screened anglepoise lamps. All sockets and conduits should be bonded to the inner screen. Heating in the cage should be of the metal-clad strip type, wall-mounted below bench level. All power supplies should be run at or below bench level, and, if roof lighting is required, this should be provided outside the cage. Ring main connection of a.c. supplies is not recommended.

7.2 **Battery Supply.** Heavy-duty cables for a 24 V d.c. supply with a common negative may be run unscreened from a large storage battery situated outside the screened room. The feed-through point, consisting of co-axial capacitor filters, should be adjacent to the other feeds and the earth point. A ring main connection is inadvisable, and is, in any case, difficult to achieve unless a loop is introduced at the door.

7.2.1 The cables should be run, unscreened, inside the cage, at bench level to avoid long "spurs" off the main cable and consequent voltage drop.

7.2.2 Where noise is still evident inside the screened room, it is possible, where the storage batteries are large enough, to take all measurements with the charging supply switched off; alternatively, the batteries may be brought into the room.

7.3 **Alternator Supply.** Single-phase and three-phase alternator supplies are normally obtained from a motor-driven alternator situated at a distance from the screened room. If the alternator is in close proximity to the room, it is generally boxed in to suppress whine. Cables from externally situated alternators should be run into the room by the most direct route; loops made by running cables round walls or along ceilings should be avoided. Interference-free alternators may be operated inside the screened room, but it should be borne in mind that it is not possible to run the motor without creating a strong interference field. The motor may be positioned outside the screened room and connected to the alternator by an insulated connecting shaft through the screens. If this is done care should be taken to shield rotating parts, and to prevent earthing of the screens.

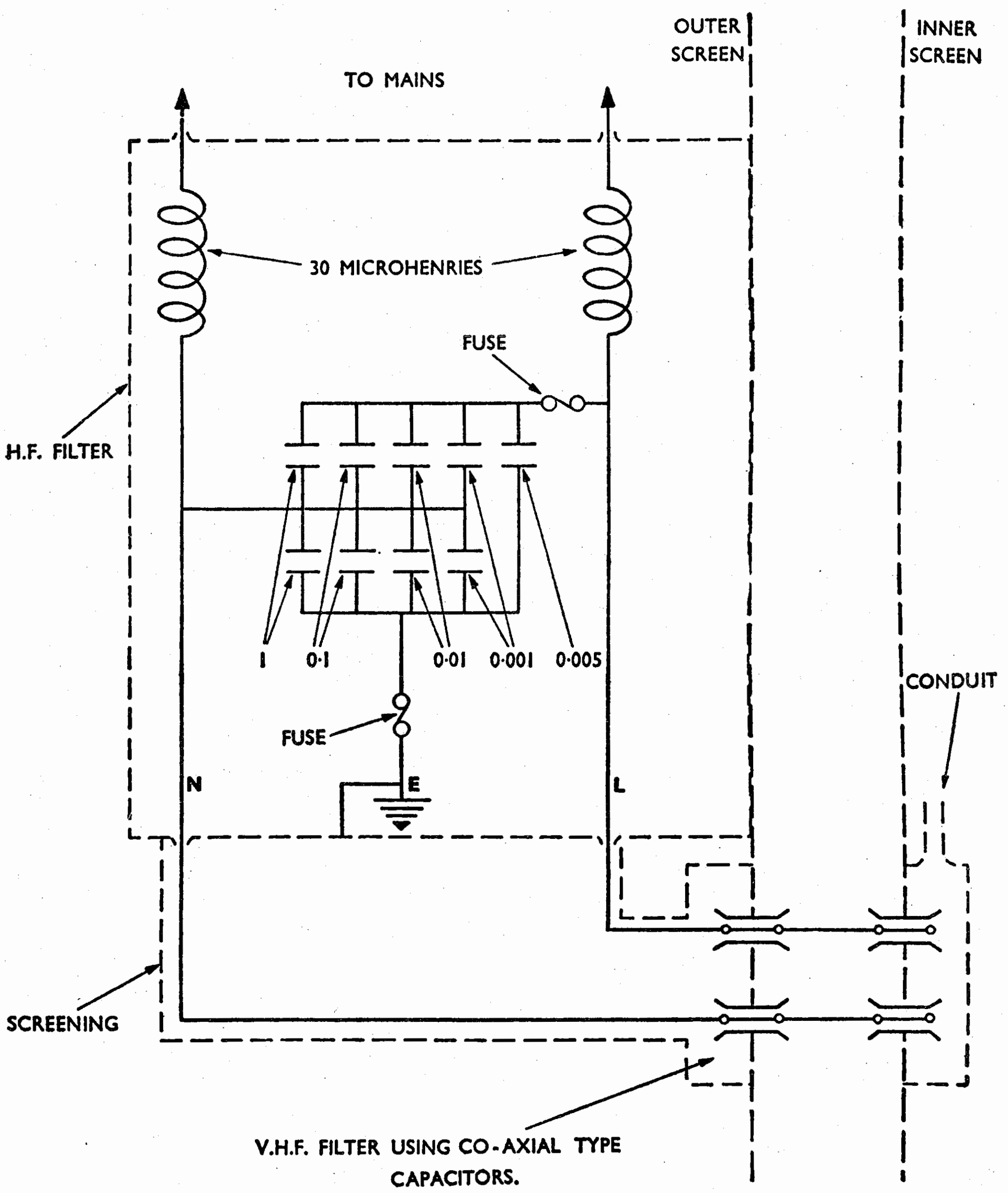


Figure 4 STANDARD FILTERING METHOD

7.4 **Alternator Power Sources.** A.C. mains-operated power supply units can often be made locally or obtained from specialist manufacturers. In addition, a range of transistor power units, which can be operated from 24 V sources from inside the screened room, is available. These units should be well filtered at both the input and output sources, and should be enclosed in metal boxes bonded to the inner screen of the room.

8 RADIO INTERFERENCE SUPPRESSION The efficiency of the room, as a suppressor of radio noise, depends to a very large extent on the efficiency of the suppressors or filters which must be fitted to all electrical supplies at their point of entry into the room.

8.1 The by-passing of the interference voltage is achieved by providing a low impedance path to earth, the magnitude of the impedance being dependent on the frequency. The ratio output noise volts/input noise current is known as "Transfer Impedance" and the value must be kept in the region of 1 ohm or less at all frequencies.

8.2 Practical two-terminal foil capacitors have appreciable self-inductance, and standard suppressors utilize a series of capacitors in conjunction with an inductor to cover the frequency range specified. These suppressors are designed to cover the medium and high frequency range, and must be used in conjunction with a very high frequency suppressor, using co-axial type capacitors.

8.3 Figure 4 indicates the standard method of filtering a single-phase mains supply into a screened room with proprietary suppressors. Three-phase 400 Hz supplies and d.c. supplies can be treated similarly, having regard to supply current requirements.

8.4 Co-axial type capacitors (see Figure 5) simplify suppressor design, and suppressors which give good transfer impedance characteristics between 150 kHz to 150 MHz can be made locally.

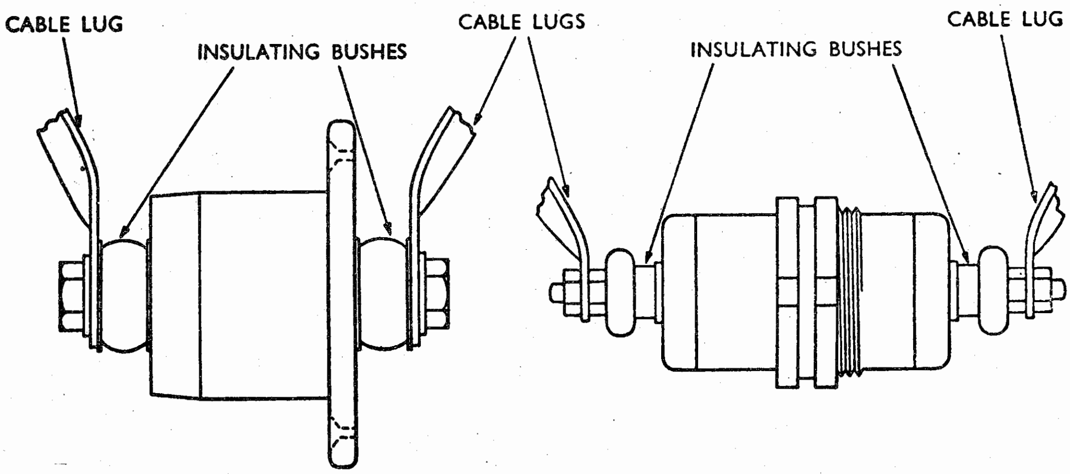


Figure 5 TYPICAL CO-AXIAL TYPE SUPPRESSOR CAPACITORS

8.5 All power supplies into the screened room should be fed through separate two or three element filters (Figure 6). Capacitors can be obtained having current ratings of up to 60 amps, but, for currents greater than this, two capacitors may be connected in parallel at each end, and large copper straps should be used to avoid heating of the end caps. Filter boxes should be constructed from a metal which will not create excessive contact potential with the cage screening material, and the seams of filter boxes should be welded.

8.6 The capacitor mounting screens should be bonded to the main structure of the box. The box length is dependent on the size of the capacitors and of the inductor, and on the distance between the inner and outer screens of the room. The width and depth of each section can be the same, but must be twice the diameter of the inductor to minimise short circuit turn effect.

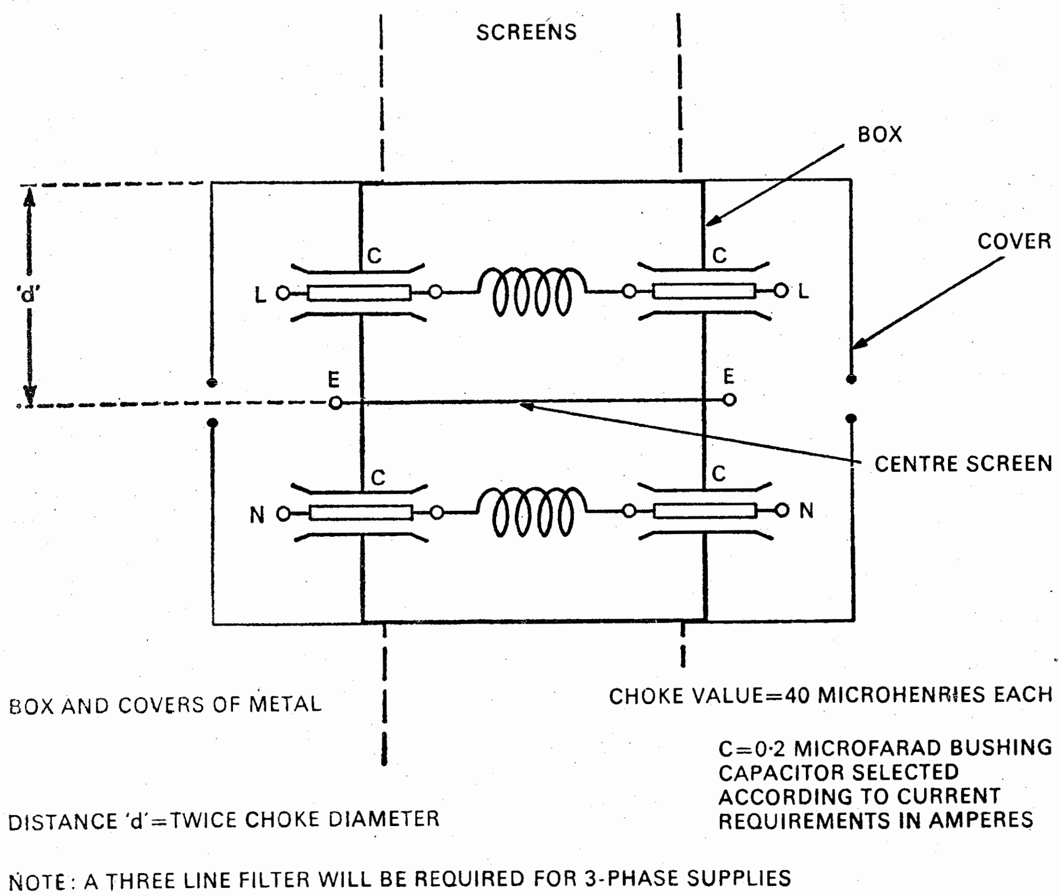


Figure 6 TWO-LINE FILTER FOR A.C. MAINS OR D.C. SUPPLIES

8.7 The separate assemblies, consisting of two-element filters for a.c. mains and l.t. supplies, or of a three-element filter for a three-phase supply can, if necessary, be mounted through a screened room at one point (see Figure 6). The main earth strap (see Figure 2) is then brought to the same point. Alternatively, each filter box can be mounted on the outer wall of the screened room, and the supplies can be fed through the screens inside metal conduits. The conduits should both make good electrical contact with the filter boxes and both screens, and have a very much reduced area for the earthing of the screens. Further filtering can be achieved by the use of an electrostatically screened transformer in the a.c. mains input.

NOTE: The wiring and testing of a.c. mains circuits should be in accordance with Government requirements.

9 TESTING THE SCREENED ROOM From Figure 1, it will be noted that at about 1 MHz the magnetic field becomes important and, because of this, testing below this frequency is performed with a loop aerial. Above this frequency it is more usual to measure the electric field, and this is done with a simple vertical or horizontal rod, or wire, aerial. The method of testing involves the use of two identical aerials, one inside the room and the other outside, a comparison being made between them.

9.1 To perform the test, identical aerials of the inverted "L" type should be constructed, the vertical members of which should be at least 4 feet long. The aerials should be erected in the same plane, about 8 to 10 feet apart, one in the room and the other outside. A similar aerial should then be erected midway between the two, also outside the room, and this aerial should be connected to the output terminal of a signal generator.

9.2 A suitable receiver and output meter should be arranged in the screened room, and the outside aerial should be connected to the receiver by means of a double-screened co-axial cable which should be fed into the room at floor level, if possible. The automatic gain control should be switched off.

9.3 The test should be commenced at the high frequency end of the receiver, and the output attenuator of the signal generator should be adjusted until a reasonable output is obtained on the receiver output meter (say 10 milliwatts). The attenuator setting should then be noted.

9.4 The co-axial cable should be withdrawn from the screened room, and the internal aerial should then be connected to the receiver, also using co-axial cable. The output attenuator should be increased until 10 milliwatts is again recorded on the receiver output meter, and the attenuator setting should be noted. The difference in the reading gives a measure of the insertion loss, in decibels.

NOTE: Unless the external aerial feeder cable is withdrawn from the room when testing the internal aerial, erroneous readings will be obtained.

9.5 The foregoing process should be repeated at intervals throughout the frequency range of the receiver, and the results should be recorded. For work-shops having a limited amount of apparatus, accurate testing throughout the radio band will not be possible, but for a room of the size recommended, the insertion loss between 1 MHz and 20 MHz will give a good guide to the efficiency of the room.

9.6 Local leaks can be explored by the use of a small hand-held loop aerial on a wander lead which is connected to a receiver, which in turn is tuned to a powerful local signal. The loop should be held close to the inner screen and moved along the screening seams, around the door frame and at the point of entry of power supplies.

NOTE: Where rooms are used for testing VHF or radar equipment, they must be checked at the particular frequencies used in such equipment, in order to determine room resonances. The normal method of testing cannot be followed at these frequencies, but any resonance will be self-evident when operating receiving equipment, similar to that under test, from outside the room.

RL/2-4

Issue 1.

18*th May,* 1977

AIRCRAFT

RADIO

STATIC DISCHARGERS

1 INTRODUCTION This Leaflet gives information on types of dischargers and general guidance on their installation, siting and maintenance. Full details of the procedures to be adopted for specific installations of dischargers referred to in this Leaflet are contained in relevant aircraft and equipment Maintenance Manuals and, therefore, this Leaflet should be read in conjunction with these documents. Information on the discharge of static from aerials is given in Leaflet **RL/2-2.**

NOTE: **RL/2-4** was previously used for a Leaflet entitled 'External Blade, Rod and Rail Aerials—Installation and Maintenance', the information for which is now included in Leaflet **RL/2-2.**

2 STATIC

2.1 The effects of static electricity are of considerable importance in the design, operation and maintenance of aircraft. Static electricity will cause noise interference in radio communications equipment and can also cause disturbance in other electronic systems.

2.2 During flight, an aircraft picks up static charges because of contact with particles such as rain, snow, ice and dust. The charge results mainly from the high-speed impact or frictional passage of these airborne particles and the charge rate is particularly high when, for example, ice crystals precipitate out from a cold-moist atmosphere (hence the expression 'precipitation static'). Precipitation is termed as 'hard' to distinguish relatively dry particles such as snow, ice, hail and sand, from the wet particles of 'soft' precipitation such as rain and sleet.

2.3 If the surface area of an aircraft was shaped like a sphere possessing a very smooth surface, the surface charge would be uniform and the sphere could be charged to an extremely high potential with respect to the surrounding atmosphere. The field intensity just off the surface would be the same over any part of the sphere. However, an aircraft of practical configuration does not possess a smooth spherical surface and there are in fact numerous protuberances. These protuberances cause a redistribution of the electric field and the field is concentrated at the tip of the protuberance, with a consequent higher field intensity in the atmosphere immediately at the tip. As a result, this portion of the atmosphere could reach such excessive voltage gradients that charge leakage could start and, after ionization, a complete breakdown could occur.

2.4 When an aircraft is struck by hard precipitation, the particles carry away a charge and the aircraft is left with a charge of opposite sign with respect to the surrounding atmosphere. During the charging time the smaller exposed radii of the aircraft extremities and protuberances will reach the corona starting potentials (see Note to paragraph 2.5) and will begin to discharge. If the aircraft is large and fast, and the precipitation is dense and fairly dry, the charging will continue and if the charging rate exceeds the discharge rate the larger radii and/or the less-exposed protuberances will reach their corona starting potential. The discharge currents involved may begin as fractions of a microamp but in some conditions they may reach the order of a milliamp. The charging mechanisms result in a discharge of pulsed radio frequency (RF) energy by corona which, for example, will be heard in the earphones of an automatic direction finder (ADF) receiver as a slow 'popping' noise rising to a crescendo of 'screaming and crying'.

2.5 The energy released by the discharge can be observed in light form. Although visible corona appears as a continuous light, in fact, the release of electrical energy from all corona is in pulse form. The energy is spread over the radio spectrum and is, in the main, contained in the lower frequencies.

NOTE: Corona is accumulative ionization of a small part of the atmosphere surrounding a point and should not be confused with sparking which represents heavier discharge of a more intermittent nature and has its own interference characteristics.

2.6 If the charging mechanism could be removed, the problem of interference from static would be relieved, but this is not possible. However, it is possible to bring about a reduction of the charge and to provide means of discharging the aircraft in a regulated and electrically-quiet manner.

3 TYPES AND FUNCTION OF DISCHARGERS The following paragraphs give details of the types of dischargers and the manner in which they function.

3.1 Older types of static dischargers comprise a stranded cotton wick, chemically impregnated with metallic silver, covered with a protective plastics sheath leaving a short tail exposed. An aluminium anchor plate is fitted to the sheath for attachment to the aircraft. During service, the wick is eroded and thus the discharge efficiency is reduced. To maintain the discharge efficiency, the plastics sheath is progressively trimmed to expose fresh wick fibres. Normally, the sheath is marked with a LIMIT OF TRIM. Figure 1 shows a typical example of a wick discharger.

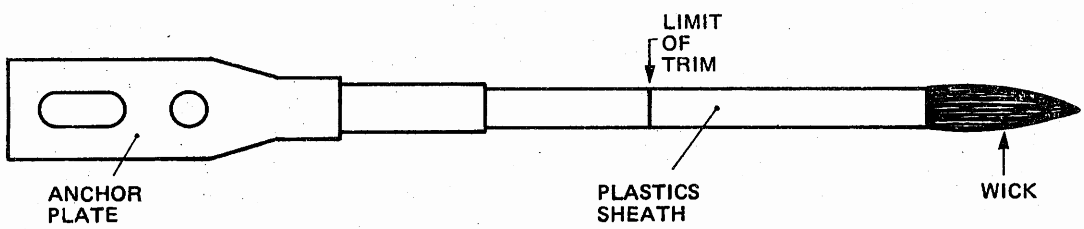


Figure 1 WICK DISCHARGER

3.1.1 This type of discharger is no longer readily available and has been replaced by a discharger of flexible design. The flexible discharger is similar to the rigid discharger described in paragraph 3.2 except that in order to obtain flexibility the glass-fibre rod is replaced by a nylon cord. Flexible dischargers are suitable for use on light aircraft or larger aircraft of moderate speeds where mounting circumstances do not produce unduly severe turbulence.

3.2 Many modern dischargers consist of a tapered glass-fibre rod for mechanical support which is rendered conductive by a coating of material having high electrical resistivity to provide the path back from a discharge tip assembly. The conductive coating is protected by baked-on synthetic finish and in some types is further protected by a heat-shrunk sheath of Skydrol-resistant plastics. Three types of discharger tips are normally used; (a) a minute brush of extremely fine 80/20 nichrome wires, (b) solid carbon which is machined to a 90 degree point, and (c) tungsten needles. The glass-fibre rod is terminated at its thicker end by one of various attachment fittings, assembled together with a conducting cement. Figure 2 shows a typical example of a rod discharger.

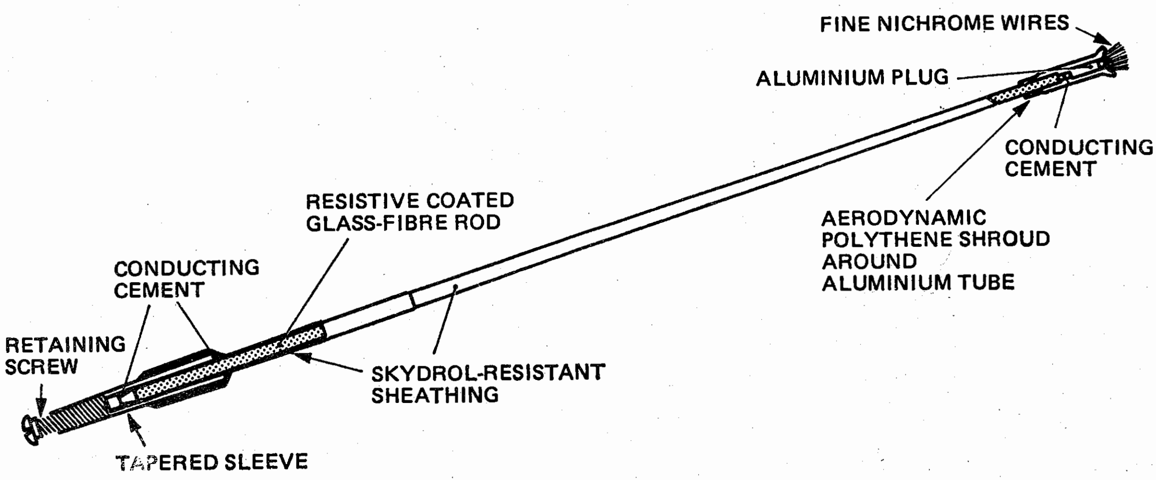


Figure 2 ROD DISCHARGER

3.3 The lightning diverter spike fitted at the apex of nose radomes on some aircraft can be particularly prone to noisy discharge. To minimize the noise from this source, a discharger assembly which can be screwed into the lightning diverter is fitted. This discharger comprises four wire-brush dischargers mounted at the forward end of a rigid dielectric support, and critically angled back so that each wire brush remains well exposed to high electric field intensity while remaining protected by its polythene shroud against bunching of the wires under air pressure. A high-resistance spiral track provides the current path back to the airframe. Figure 3 shows the general arrangement of the dischargers.

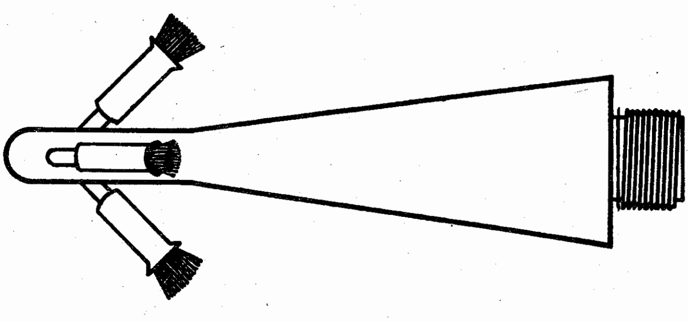


Figure 3 RADOME-MOUNTED DISCHARGER

3.4 Static dischargers are intended to prevent or reduce the radio noise experienced when an aircraft, which has acquired a high electric charge relative to its immediate surroundings, releases this charge by corona breakdown directly from one or more of the aircraft extremities or protuberances. The dischargers provide the means for shifting this discharge point aft of the trailing edge where the RF coupling is at a minimum. The charge travels along the resistive coating over the glass-fibre material to the discharger tip positioned away from the wing or tail surface. Since the dischargers act as low-impedance discharge points, the voltage required to cause and sustain discharging is minimized. The result is a high pulse rate with much lower pulse peaks. Recorded test results have shown a 70,000 volts discharge threshold to have been reduced to 7,800 volts by the use of static dischargers. Dischargers need to be fitted in sufficient numbers to ensure that their total discharge current holds the aircraft potential below the threshold of direct discharge at the higher charge accumulation rates anticipated.

4 SITING It is important that sufficient numbers of static dischargers are fitted and are sited in positions where they can efficiently discharge the static with the minimum of interference being induced into radio aerials. Optimum siting of dischargers can only be determined by a thorough investigation of the characteristics of the particular aircraft type. However, in general, the wing, tail and fin tips, particularly at the trailing edges, are the locations of the greatest potential gradient. Dischargers positioned at these points, with additional units at spacings of 9 inches around these regions will generally give satisfactory results. Dischargers should not be located near to radio aerials unless they are specifically designed to be so located. Table 1 gives details of the number and location of static dischargers on various aircraft.

TABLE 1

Aircraft	Wing Trailing Edge	Wing Tip	Horizontal Stabilizer (Tailplane) Trailing Edge	Horizontal Stabilizer (Tailplane) Tip	Vertical Fin Trailing Edge	Vertical Fin Tip	Tailplane Bullet
Trident 3B	8 on each wing	2 on each tip	3 on each stabilizer	2 on each tip	Nil	N/A	2
BAC 1–11	3 on each wing	1 on each tip	3 on each stabilizer	2 on each tip	Nil	N/A	2
Boeing 707	6 on each wing	2 on each tip	4 on each stabilizer	2 on each tip	4	2	N/A
Boeing 747	12 on each wing	3 on each tip	9 on each stabilizer	4 on each tip	8	4	N/A

5 INSTALLATION

5.1 The discharger units are attached to the aircraft by means of bases machined from high-purity aluminium to obviate problems of electro-mechanical corrosion where there is direct contact with the aircraft skin. The base may be fixed permanently to the aircraft by screws, rivets, a conducting cement, or any combination of these. Where a conducting cement is used, this should be of the type recommended by the manufacturer. A tapered sleeve on the end of the discharger rod plugs into the base and is locked by means of a round-head screw. Where the discharger is to be fitted to wing or horizontal stabilizer tips, an angled sleeve is provided. The base flanges are sufficiently ductile to enable shaping to the aircraft skin contour. Figure 4 shows the general arrangement of a discharger and its base.

NOTE: On certain types of aircraft, e.g. BAC 1-11, the wing tips are made of reinforced plastics and it is important to ensure that the bonding inside the plastics is of sound construction so that where dischargers are fitted to the wing tips there is good bonding between the discharger and the main structure.

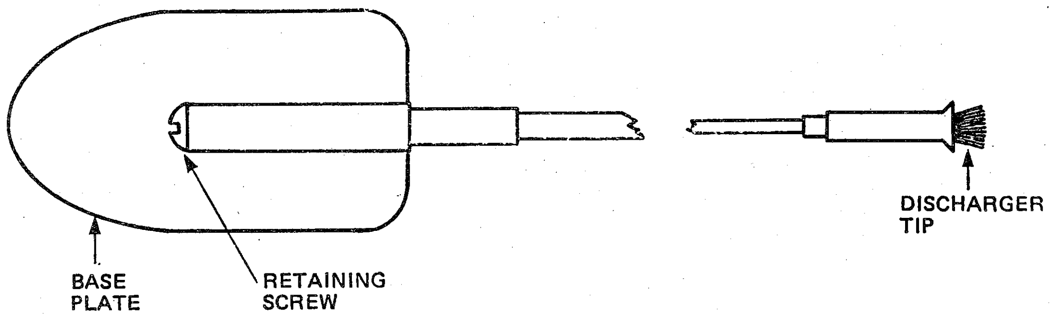


Figure 4 DISCHARGER AND BASE

5.2 Various types of discharger exist which are interchangeable. However, where dischargers are installed on the trailing edge of control surfaces it is important to ensure that replacement of a discharger with a different type does not alter the control-surface balance. This is particularly important on smaller aircraft employing stabilizers where both primary controls and tabs are balanced to fine limits.

6 MAINTENANCE The dischargers should be checked in accordance with procedures detailed in the relevant Maintenance Manual at the periods prescribed in the approved Maintenance Schedule for the particular aircraft. As a general guide the following points should be observed.

6.1 Periodically, a general check should be made to determine that all dischargers are securely mounted, and are not broken or missing.

6.2 The efficient operation of the dischargers is dependent on good electrical contact between the base and the aircraft. The resistance between the base and the aircraft should, in general, not exceed 0·05 ohm. However, provided there is no static interference with the radio systems, a resistance not exceeding 0·1 ohm may be acceptable. If the resistance exceeds the acceptable limit, the discharger should be removed and the contact surfaces cleaned.

6.3 Where dischargers of the tapered glass-fibre rod type are fitted, the condition of the resistive coating between the base and tip, and of the Skydrol-resistant plastics, should be checked for physical continuity particularly at the base and tip joints. The electrical resistance between the base and tip should be within the limits specified by the manufacturer for the type of discharger. Typically, values between 8 and 100 megohms are acceptable for trailing-edge dischargers and 5 to 60 megohms for tip-mounted dischargers.

6.4 Particular attention should be paid to the condition of the discharger tip. In the case of carbon or tungsten tips, if these show signs of damage or erosion the discharger should be renewed. Where the tips comprise nichrome wire brushes, these should be clean and the wires should not be matted together. If the brush is corroded, or clogged with fuel, oil, polish or any other foreign matter, the discharger should be renewed.

6.5 Impregnated cotton-fibre dischargers will erode in service and when this occurs the plastic sheath should be cut back to expose fresh fibres such that a wick length of 1½ inches is obtained. The cotton fibres must not be cut with scissors in order to obtain the desired tip shape as this would compress the silver into comparatively large metallic areas resulting in noisy discharge. A sharp knife or similar tool is suitable for trimming the tip to shape. Generally, this type of discharger is marked with a 'limit of trim' indicating when a new unit should be fitted.

6.6 Dischargers should be checked for lightning damage, which is generally indicated by a burning and roughening of the conductive coating and pitting of the metal base plate. In extreme cases, as a result of lightning, part of the discharger may be burnt away. Any discharger damaged by lightning should be replaced with a new unit.

RL/2-5

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18*th November,* 1977.

AIRCRAFT

RADIO

RADOMES—REPAIR AND ELECTRICAL TESTS

1 INTRODUCTION

1.1 The function of a radome is to provide protection for an antenna and it must also be capable of providing a clear, undistorted, antenna view, with minimum reflection. In addition a radome must be structurally sound, since structural failure can result in aircraft damage. Although radomes are generally thought of as curved structures (e.g. a nose radome for protecting a weather radar antenna), they can also be flat or slightly curved coverings such as those used for the protection of doppler equipment.

1.2 This leaflet gives general guidance on the repair and electrical testing of radomes. Information is also included on measures taken to minimize the damage resulting from the effects of lightning strikes and of erosion resulting from rain and hail. Methods of minimizing the risks associated with lightning strikes on aerials are dealt with in Leaflet **RL/2-2.** Full details of repair and testing procedures referred to in this leaflet are contained in the relevant aircraft and equipment manuals which must, therefore, be read in conjunction with this Leaflet. Leaflet **AL/7-6** also provides information on repair techniques for glass-fibre panels.

2 CONSTRUCTION In general, the radomes used on aircraft may be classified as either 'sandwich' or 'thin wall', and can be regarded as 'tuned' or 'untuned' respectively. To minimize power losses the thickness of a sandwich (tuned) radome is proportional to the frequency of the associated radar system, whereas a thin wall radome, being untuned, is made as thin as structural limitations permit.

2.1 The sandwich type of radome consists of a dielectric core of glass-fibre honeycomb, expanded nitrile ebonite, expanded PVC or polyurethane foam, which is supported on each side by a skin comprising three or more layers of glass-fibre cloth impregnated and bonded with resin. The thin wall type of radome is manufactured from a number of layers of resin-impregnated, glass-fibre cloth. Nose-mounted radomes are generally protected from erosion by covering the nose with a neoprene overshoe, or by a polyurethane coating.

2.2 The thickness, number of layers, and type of glass-fibre cloth used in a radome is determined during the original design. Generally radomes manufactured in the UK employ a plain weave cloth of 0·006 in (0·15 mm) thickness, whereas radomes manufactured in the USA often use a satin weave cloth of 0·008 to 0·011 in (0·2 to 0·28 mm) thickness.

3 INSPECTION FOR DAMAGE

3.1 Damage to radomes can result from rain erosion, lightning strikes, static discharges, impact with ground handling equipment, and other accidental causes. If, for any reason, the outer skin is perforated, differential pressure may result in the ingress of water or moist air. Water or condensed moisture in the cells of a honeycomb structure may freeze as the aircraft ascends, and in freezing could expand and rupture the bond between adjacent cells or skin. As this process continues, further cells could become contaminated by water, and eventually large areas of the radome could be affected. Thus, although the damage may appear superficial over a relatively small area, internal damage may be extensive because of moisture penetration. It is, therefore, important to establish the full extent of any damage. A moisture meter should normally be used to check the extent of moisture penetration, but radiographic techniques could also be used to check the quantity of water present. Before using a moisture meter the surface of the radome should be thoroughly dried, and the probe should be traversed across the inner skin, care being taken to avoid denting, scratching or pitting the surface.

3.1.1 In addition to the effects of damage on structural integrity, any consequent deviation from the design dimensions or dielectric properties of the structure will result in a degradation in microwave performance.

3.2 Where moisture is detected outside the known damaged area, a check should be made to ensure the structural integrity of the skin laminations. This can often be determined by tapping the skin with a small metallic object, which should produce a live resonant tone if the structure is sound but if delamination has occurred, a flat, dead response will be obtained; the results should, however, be treated with caution, and should be compared with a part having a known defect. Any moisture must be thoroughly dried out before making repairs.

3.3 In addition to moisture penetration, delamination can result from fatigue or accidental damage. Where a hole or dent exists there may be delamination. Since certain radomes are relatively flexible, they will often spring back to their original shape after impact; thus any area showing signs of greasy smudges or scratches is suspect and should be investigated. Impact damage can be detected by applying finger pressure over the radome surface. A soft area is an indication of internal damage, a greasy smudge could be evidence of a bird strike, and scratches or abrasions indicate possible impact with such things as hangar doors, refuelling vehicles, etc.

3.4 Radomes can also be damaged by lightning, such damage falling into three basic categories:

(a) **Surface Damage.** This is indicated by scorching of the outer surface as a result of heat transfer.

(b) **Puncture.** If a lightning strike does not track to external metal, the radome will be punctured and the strike may connect to internal hardware, e.g. the radar scanner. As a result of dielectric breakdown, a hole may be burnt through the complete structure, and multiple discharges may leave a distinctive trail of pin holes. Typically, holes with diameters of 3 to 100 mm (0·125 to 4·0 in) may result.

(c) **Internal Damage.** This commonly results from punctures caused by lightning strikes and takes the form of delamination of the internal surface. The damage can extend over areas up to 0·5 m (1·5 ft) away from the location of the hole.

3.4.1 Overall, the type of damage caused by lightning has the effect of weakening the structure and degrading the radar performance. Structural weakening is particularly serious since radome break-up can subsequently occur which, in turn, will affect aerodynamic performance and also possibly lead to engine damage and jamming of control surfaces. A discharge which punctures the radome could also cause serious damage to the radar equipment it houses.

3.4.2 To minimize the damage to radomes resulting from lightning strikes, lightning diverter strips may be fitted. In order that these remain effective it is important to ensure that the electrical bonding to the airframe is sound. Bonding should therefore be regularly checked (paragraph 5.2.3), and in particular, after any major repairs are carried out (see Leaflet **EEL/1-6**).

3.5 Radomes are protected from rain erosion by either neoprene overshoes fitted over the nose area, or by coating the nose area with neoprene or a polyurethane elastomer. In addition, an anti-static coating may be provided to prevent the build-up of static charges, which can lead to discharge damage and radio interference. The condition of overshoes, and protective or anti-static coatings should be regularly checked.

4 REPAIR

4.1 Repairs may be classified as either minor or major depending on the nature and extent of the damage. Minor repairs may be made by suitably qualified line maintenance personnel whereas major repairs will necessitate the return of a radome to an organization approved for the major repair and electrical testing of radomes.

4.1.1 **Minor Repairs.** These apply to nicks, pits, scratches and breaks of the outside protective coating which do not penetrate the radome skins by more than the specified number of layers of glass-fibre, and no moisture penetration is revealed on checking with a moisture meter.

4.1.2 **Major Repairs.** These apply to damage consisting of punctures, delaminations and contamination which exceed minor repair limitations, and burned areas resulting from static discharge or lightning strikes. Major repairs also apply to separation or loss of laminations, and penetration of outer skins, with resultant core damage or inner skin damage, including holes completely through the radome. On completion of major repairs, tests should be carried out to ensure that the electrical performance remains within the acceptable limits (see paragraph 5).

4.2 **Temporary Repairs.** Although all repairs must ultimately be of a permanent nature, temporary repairs may sometimes be permitted to enable the aircraft to proceed to a base where permanent repairs can be carried out. Temporary repairs will, in most cases, degrade the radar performance and are only intended to permit continued use of a radome until a permanent repair can be made. Temporary repairs are usually restricted to cases where, after cleaning out, the hole does not exceed 19 mm (0·75 in) diameter (depending on the location), and if several holes exist, their centres are separated by at least four times the diameter of the largest adjacent hole. A general procedure for making temporary repairs is given in paragraph 4.4.1.

4.3 **Permanent Repairs.** When making permanent repairs to radomes, it is important that the proper materials and tools are used in accordance with the specified repair procedures. A repair should return the radome to a satisfactory condition, both electrically and structurally. Improper repairs can affect such factors as transmissivity, reflection and diffraction, with a resultant degradation of microwave performance. As the design thicknesses of the radome wall may be directly related to the wavelength of the radar energy which passes through it, it is important when making repairs that the design dimensions and contour, including any protective finishes, are maintained.

NOTE: Refer to Leaflet **AL/7-6** for the health hazards associated with the use of resins and glass-fibre materials.

4.4 **Repair Procedures.** The repair procedures to be followed will be dependent on the classification applicable to the damage. General guidance is given in the following paragraphs on the procedures to be followed by suitably qualified personnel when making temporary, minor and major repairs.

4.4.1 **Temporary Repairs**

(a) The damaged area should be thoroughly cleaned and in the case of a hole it should be finished with a slight inward taper.

(b) To provide structural strength, holes should be plugged. For small holes a polysulphide sealant may be used, but larger holes will require a plug made from wood, rubber or other suitable material, as specified in the appropriate Repair Manual.

(c) The repair should be completed by sticking a neoprene patch, approximately 1·6 mm (0·0625 in) thick, on the outer surface, so that it overlaps the damage by 12·5 mm (0·5 in). An adhesive compatible with the repair material should be applied, and should be used as sparingly as possible, consistent with achieving a good bond.

4.4.2 **Minor Repairs**

(a) Prior to undertaking a minor repair, a thorough inspection should be made to check the full extent of the damage. A small hole could be the external indication of a lightning strike or static discharge, and inspection of the inner surface may reveal a burn mark.

(b) The area to be repaired must be thoroughly cleaned prior to undertaking the repair.

(c) If the damage is such that it requires more than paint touch-up to restore the radome to its original condition, then prior to filling with a recommended patching paste or filler putty, all paint should be removed from the surface area concerned, using an approved solvent or by sanding. Extreme care must be taken when sanding to ensure that the glass-fibre laminates are not penetrated and that the structure is not overheated.

NOTE: Paint stripper should not be used unless specifically approved by the manufacturer.

(d) After removal of the paint, the area under repair should be wiped clean with a cloth soaked in methyl ethyl ketone (MEK), or equivalent, and thoroughly dried. Filler paste sufficient for the repair should be prepared in accordance with the manufacturer's instructions. The filler must be of a non-metallic type.

(e) Filler paste should be applied using a plastic scraper, or other suitable tool, and any excess paste should be scraped away to leave the repair flush with the surrounding surface.

(f) When the filler has thoroughly dried, any excess should be sanded smooth to conform with the contour of the radome, and the repair should be completed by re-applying the paint or anti-static coating in accordance with the appropriate specification.

4.4.3 **Major Repairs.** For making major repairs reference should be made to the relevant aircraft maintenance and structural repair manuals and to the general repair procedures given in Leaflet **AL/7-6.** The following paragraphs give general information and guidance on procedures associated with major repairs.

(a) Superficially, the area to be repaired may appear to be relatively small, but damage such as delamination may have occurred beyond the visible area. Checks for delamination should therefore be made and the full extent of the damage should be determined. Where delamination has occurred, it will be necessary to cut out an area of sufficient size to ensure that the repair will extend into a sound portion of the radome.

(b) As a result of skin punctures, holes or other damage, moisture may have entered the structure. Moisture can cause extensive damage beyond the apparent damaged area and, in particular, will often result in delamination. The extent to which moisture has become entrapped should be checked using a recommended type of moisture meter. It should be noted that misleading results can sometimes be obtained where an anti-static coating is applied, and if there is doubt concerning the results, a further check should be made with the coating removed.

(c) Repairs must only be made using materials of the same type, or an approved equivalent, as was used in the original construction. To ensure that the radar performance is not degraded as a result of the repair, it is important that the design dimensions and original contour of the radome are maintained. Paragraphs (i) to (xx) give examples of improper repairs which could result in degradation of radar performance or weakening of the structure.

- (i) Use of materials which are not compatible with the original radome materials.
- (ii) Patches of different thickness.
- (iii) Poor fabrication techniques.
- (iv) Too high a content of air in the lay-up of the patches.
- (v) Repairs overlapping.
- (vi) Holes plugged with resin, screws, metal, wood and plastic plugs.
- (vii) Cuts or cracks simply coated with resin.
- (viii) Tape (including electrical tape) over hole or crack and covered with resin.
- (ix) Oversize patches.
- (x) Too much or too little resin.
- (xi) Exterior coatings too thick, or uneven, or use of metallic base paints.
- (xii) Filled honeycomb cells.
- (xiii) Repairs made without removing moisture or moisture contamination from inside of radome wall.
- (xiv) Abrupt changes in cross-section.
- (xv) Patches projecting above outside contour.
- (xvi) Improper cure.
- (xvii) Wrong size cells or density of honeycomb.
- (xviii) Excessive overlap in honeycomb joints.
- (xix) Poor bonding of skin to core.
- (xx) Gaps in honeycomb core.

(d) The method used for cutting away damage, and for making repairs, will depend on the size of the repair. Generally, it is recommended that where the damage requires removal of an area in excess of 75 mm (3 in) in diameter the 'stepped joint' method be used. For repairs of damage smaller than 75 mm (3 in) in diameter the 'scarf' method may be used. Both of these repair methods are described in Leaflet **AL/7-6**. If the damage necessitates repair to both the inner and outer skins, it is important that the repair to one side is completed before removal of the plies from the opposite side. In addition, the repairs should be made so that the new plies on one side overlap those on the other side, i.e. joints to sound material on one side are positioned away from joints on the opposite side.

4.5 **Overshoes and Protective Coatings.** The following paragraphs give general guidance on the renewal or repair, as appropriate, of overshoes and protective coatings.

4.5.1 **Overshoes.** Although the only satisfactory procedure when an overshoe becomes damaged is to fit a new one, a temporary repair may be made when the circumstances do not permit complete renewal. Such a repair may be achieved by sticking a neoprene patch, approximately 1·6 mm (0·0625 in) thick on the outer face, to overlap the damage by 12·5 mm (0·5 in) using a suitable adhesive as recommended in the appropriate maintenance manual. The extent to which a temporary patch may be used will depend on the contour of the radome in the damaged area, since the patch must take up the radome shape with satisfactory adhesion and freedom from wrinkles. At the earliest opportunity the overshoe must be renewed. The procedures for the removal of an overshoe and the fitting of a new one are given in the appropriate Structural Repair Manual.

4.5.2 **Protective Coatings.** Close inspection of protective coatings may reveal damage in the form of pin-holes. If these are 'touched-in', further damage, e.g. water ingress, may be prevented.

5 ELECTRICAL TESTS Electrical testing of radomes must be carried out in accordance with the manufacturer's instructions, after making major repairs, and whenever the associated radar performance falls below an acceptable level and the radome is suspected of being the cause. Paragraphs (a) to (d) give examples of the types of degradation in radar performance which can result from a poor radome.

(a) **Excessive Ground Clutter.** This may appear as half-moon shaped returns extending across wide angles in the forward portion of the display. As a result the radar capability is reduced when the aircraft is flying at low altitude. Ground clutter is caused by the radome deforming the antenna pattern and increasing the level of side lobe radiation towards the ground. Increased ground clutter can also occur when an aircraft is banked, as a result of beam distortion in areas of the radome other than those normally scanned in level flight.

(b) **Loss of Range.** If the antenna is tilted up to reduce the effects of ground clutter, this may raise the centreline of the radar beam above the level of any distant storms in the path of the aircraft, and thus produce an apparent reduction in range. As much as 25% of one-way power may also be lost through a poor portion of radome.

(c) **Loss of Resolution and Beam Refraction.** As a result of distortion of the radar beam in the azimuth plane, reduced target resolution may occur, and similarly, refraction of the beam may introduce target bearing errors.

(d) **System Problems.** As a result of excessive radar reflections, frequency pulling of the magnetron can occur, the rapid frequency changes causing the local oscillator automatic frequency control to unlock as the antenna rotates. This is seen as intermittent returns on the radar display.

5.1 **Test Requirements**

5.1.1 The area in which the tests are to be made must be free from such objects as servicing stands, vehicles and buildings likely to cause nuisance radar reflections.

5.1.2 The radome stand should be capable of rigidly supporting the radome, and of permitting the radome to be moved a short distance towards and away from the receiving antenna. It should also permit the radome to be rotated in azimuth and elevation, through the angles over which it is required to function when fitted to the aircraft. The stand should present a minimum of interference with the energy received.

5.1.3 The microwave signal source should provide a suitable output signal (typically 100 mW) at the frequency required.

5.1.4 The transmitting and receiving antennae should be separated from one another by a distance calculated in accordance with the formula:

$$\frac{2D^2}{\lambda}$$

where D = Aperture of the larger antenna
λ = Free space wavelength.

NOTE: For a simple parabolic reflector the aperture D may be obtained by measuring the diameter of the reflecting dish.

5.1.5 The antenna receiving system should be the same as the antenna system which the radome houses when fitted to the aircraft. A horn should be used as the transmitting antenna, and the distance between the two antennae should be adjusted to align the first null of the horn radiation pattern along the ground reflection path (see Figure 1). Data showing the position of the null is obtainable from the horn manufacturers.

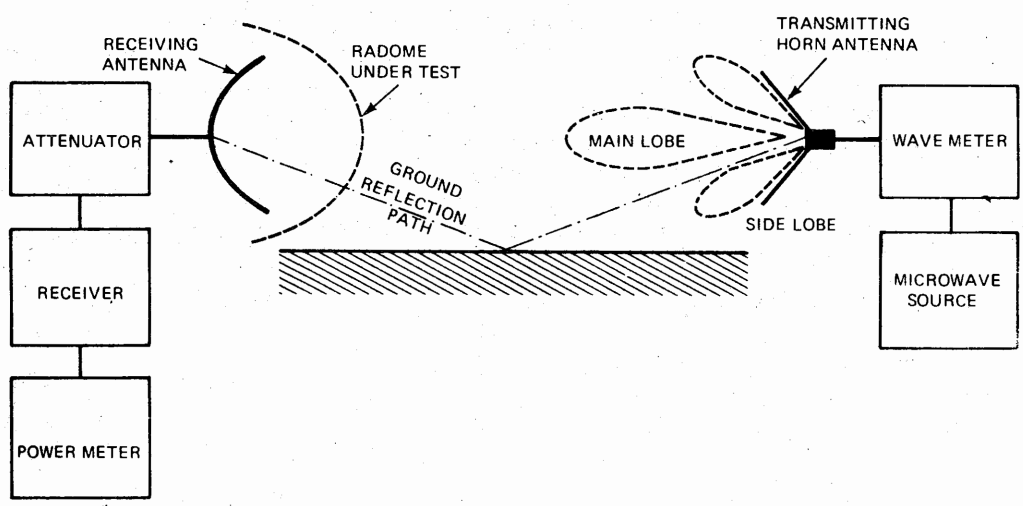

Figure 1 ATTENUATION TEST ARRANGEMENT

5.2 **Test Procedure.** The following paragraphs give general procedures for carrying out attenuation, VSWR and bonding checks on a radome.

NOTE: Microwave energy may damage body tissues, and test personnel should avoid standing in the path of the beam.

5.2.1 **Attenuation.** A typical test arrangement is shown in Figure 1.

(a) With the equipment arranged as shown, the power should be switched on and the equipment should be allowed to warm up, to ensure that it attains a stable operating temperature before carrying out the required tests.

(b) The microwave source should be adjusted to the correct operating frequency at the required power output.

(c) With the radome removed, the two antennae should be aligned in pitch and azimuth, for maximum received power. The attenuator should be adjusted to give an indicated received power of 0 dB.

(d) The radome should be mounted on the stand in the same relative position it would have in the aircraft. The radome should then be moved forwards and backwards slightly, and the maximum and minimum readings on the power meter should be noted. The average of the two readings should not differ from the reference level set in (c) by more than the figure quoted in the relevant Maintenance Manual. The figure obtained may vary depending on whether the radome is stripped or completely finished, i.e. the protective coating and, if applicable, the paint finish have been applied. Typical readings to be obtained should not exceed 0·7 dB for a stripped radome, and 1·0 dB for a completely finished radome. For radomes fitted with a lightning protection spike, typical figures are 1·0 dB and 1·5 dB respectively.

(e) Measurements should also be taken with the antenna turned about its axis to the extreme azimuth and elevation positions at which the radome is required to pass energy when fitted to the aircraft. The results obtained should be within the limits quoted in paragraph (d).

5.2.2 **VSWR** There are several methods which may be used to measure VSWR, including (a) comparison of forward and reflected power levels, detected by a directional coupler, (b) measurement of the standing wave ratio by means of a slotted line, and (c) measurement of standing wave ratio by means of a high directivity bridge. Procedures for measuring the standing wave ratio in the waveguide feed are described in Leaflet **RL/2-7.** Method (a) requires a laboratory standard directional coupler able to discriminate accurately between the forward and reflected signals; this method is liable to error and is not recommended for field measurements. Method (b) is more reliable, and a suitable test arrangement is shown in Figure 2.

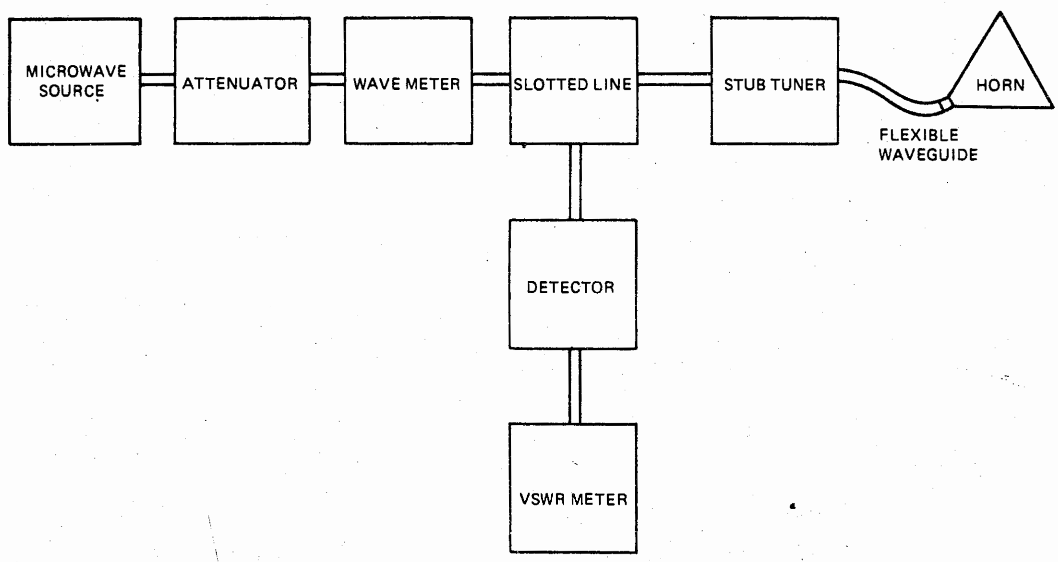

Figure 2 VSWR TEST ARRANGEMENT

(a) Two methods of scanning the radome inner surface are possible. The first requires that the VSWR measuring assembly be connected via a section of flexible waveguide to a horn antenna. The horn is held firmly against the radome inner surface and the measurement is taken. The measurement is repeated at different locations, until a VSWR map of the radome surface is obtained. This method is suitable for 'in situ' checks to detect areas of unacceptably high reflections, but, due to a variation of reflection levels caused by movement of the flexible waveguide, accurate measurement of low VSWRs is not possible. To obtain accurate measurements it is necessary to reduce all unwanted reflections to a minimum before scanning the radome surface. To achieve this objective the second method must be used, in which the VSWR measuring assembly, including the horn antenna, must be rigidly mounted. A VSWR map of the radome surface is then possible by rotating the radome around and in close proximity to the horn antenna.

(b) Typically, for a stripped radome the VSWR in any area should not exceed 1·3:1, and for a completely finished radome should not exceed 1·6:1.

5.2.3 **Bonding Test.** The following checks should be carried out to ensure that the electrical bonding is satisfactory.

(a) Check that the resistance between the aft end of the diverter strip and the bonding plate on the inside surface of the radome does not exceed 0·008 ohm.

(b) Check that between the rear end of the diverter strip and the aircraft skin immediately aft of the radome hinge line the resistance does not exceed 0·01 ohm.

(c) Check that between the forward end of the diverter strip and the aircraft skin aft of the radome hinge line the resistance does not exceed 0·05 ohm.

NOTE: When using a bonding tester, care must be taken not to damage the diverter strips with the point of the probe. Contact should be made by pressing the flat surface of the probe against the strip.

RL/2-7

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AIRCRAFT

RADIO

TRANSMISSION LINES AND WAVEGUIDES

1 INTRODUCTION Transmission lines and waveguides are the means by which radio frequency (RF) energy is guided from one point to another. A typical application is the transfer of energy from a transmitter to its associated aerial. Although transmission lines and waveguides serve the same purpose, the choice of which to use is dependent on the frequency of the energy and the power to be transmitted. Generally, in aircraft applications transmission lines are used for frequencies below 5000 MHz and waveguides for higher frequencies. It should be noted that for dimensional reasons the use of waveguides is impractical at frequencies lower than about 3000 MHz. At frequencies above 5000 MHz, waveguides are preferred because of their lower circuit losses (paragraph 3.4).

2 TRANSMISSION LINES A transmission line consists of two wires, of any length, suitably insulated from each other. A particular case of a two-wire transmission line is a coaxial cable (paragraph 2.4).

2.1 **Two-Wire Line.** Associated with each line there is inductance and resistance which is evenly distributed throughout the entire length of line and, similarly, there is distributed capacitance and conductance between opposite lines. At high frequencies the inductance (L) and capacitance (C) have a much greater effect than the resistive and conductive components which may be ignored and the impedance of the line is equal to $\sqrt{L/C}$ which is known as the characteristic impedance (Zo) and is purely resistive. If the line is terminated in a load impedance equal to Zo all energy is absorbed in the load. For any other value of load a mismatch will exist and the load will not dissipate all the energy and all or part of the energy will be reflected. Figure 1 shows the effect when the line is open circuit at the receiving end. The result of the incident and reflected wave on the line is that standing waves are set up and, in the open circuit case, the voltage standing wave is a maximum and the current standing wave is zero at the end of the line. There would also be a 90° phase difference between the voltage and current standing waves. The voltage standing wave will also be a maximum at half-wavelength intervals from the receiving end. In respect of a transmission line, a wavelength (λ) is defined as that length in which the signal phase changes through 360° and is determined by the physical characteristics of the line. Similarly the voltage standing wave will be zero at odd quarter-wavelength intervals from the receiving end. The current standing wave maximum and zero values are displaced by a quarter wavelength from the voltage standing wave. If a short circuit exists at the receiving end (Figure 2), standing waves are again produced but the voltage and current maximum and zero values are reversed from the open circuit positions. For a load impedance not equal to Zo reflected waves are produced (Figure 3) and the maximum and minimum values of the resultant standing wave will depend on the load (Z_L) which can be a complex quantity; the phase difference at the receiving end between the incident and reflected waves will be determined by the reactive component of Z_L.

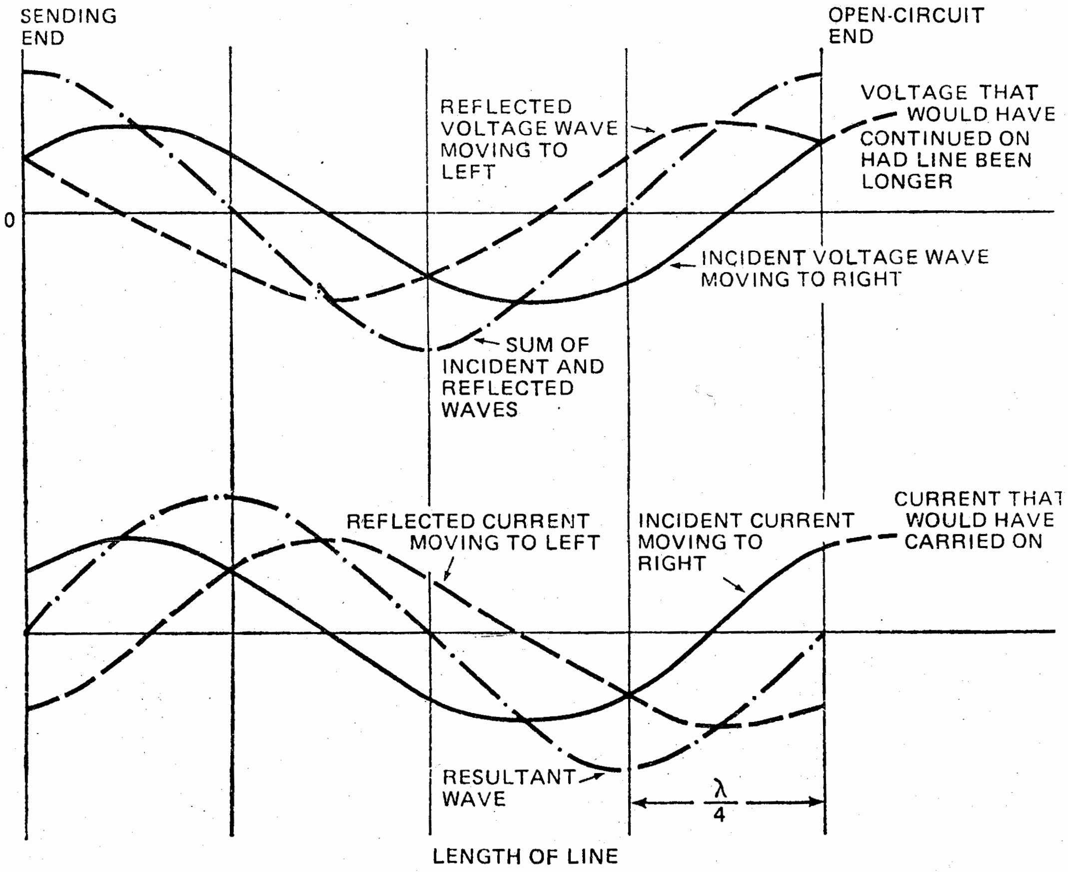


Figure 1 FORMATION OF STANDING WAVES ON OPEN CIRCUIT LINE

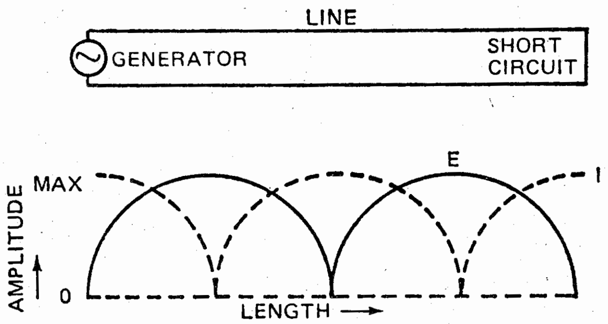


Figure 2 STANDING WAVES ON SHORTED LINE

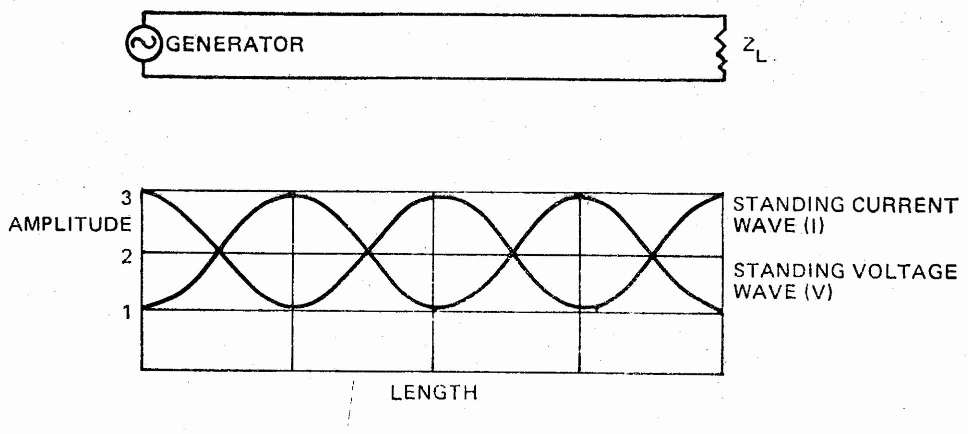


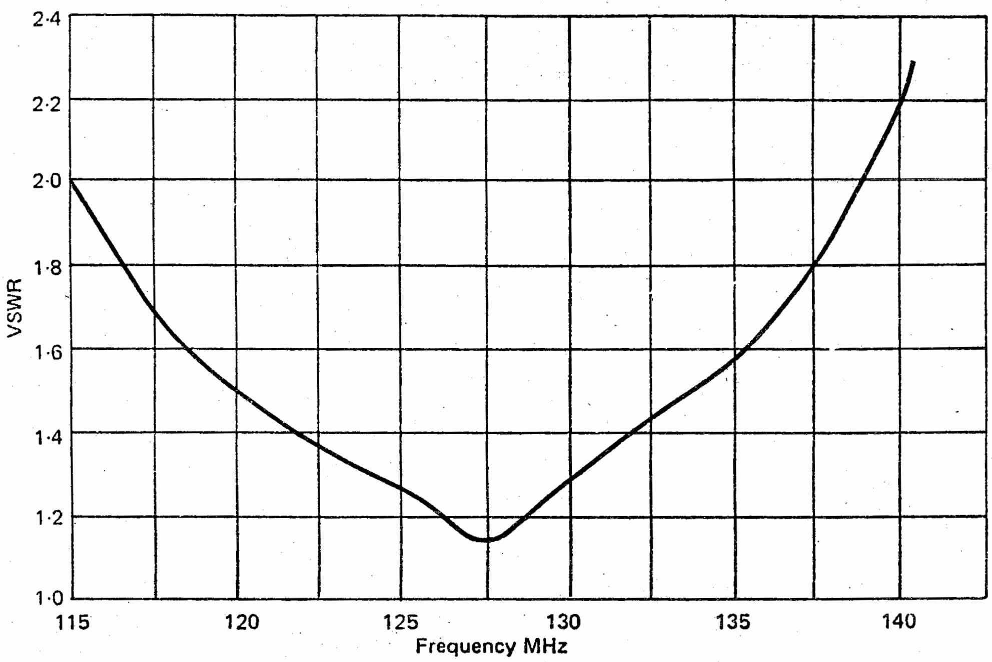
Figure 3 STANDING WAVES ON MISMATCHED LINE. VSWR=3:1

2.2 Standing Wave Ratio (SWR)

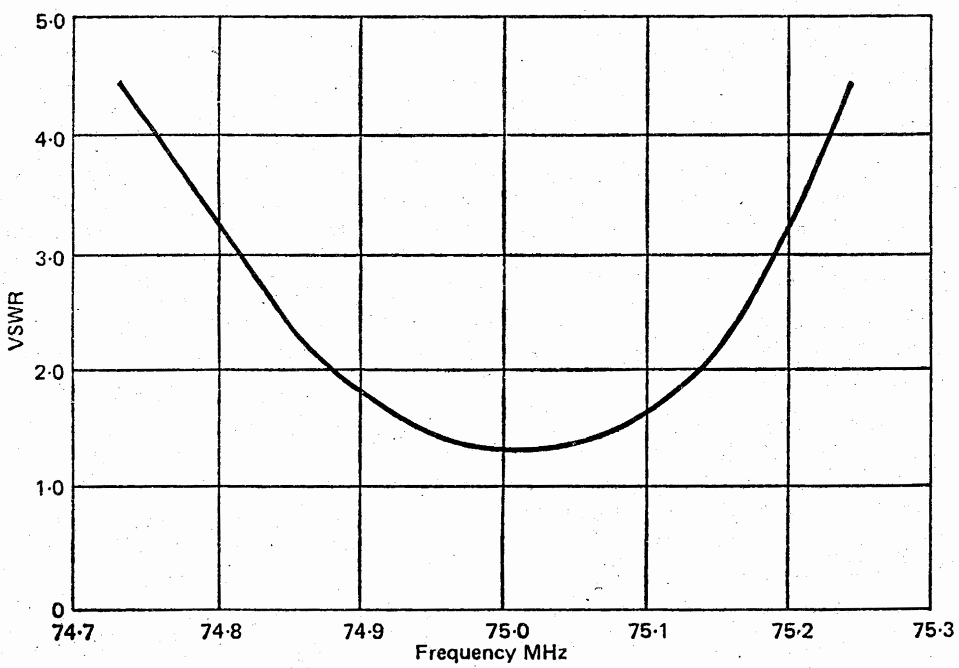
2.2.1 Distribution of the voltage (or current) along a transmission line can usefully be defined in terms of the ratio of the standing voltage maximum (standing current maximum) to the standing voltage minimum (standing current minimum). This quantity is termed the Standing Wave Ratio and, more generally, since voltages are considered, the Voltage Standing Wave Ratio (VSWR). The standing wave ratio $S = \frac{\text{Standing V max}}{\text{Standing V min}}$ where standing V max is the sum of the incident (V_I) and the reflected (V_R) voltages and standing V min is the difference between V_I and V_R and thus the VSWR $= \frac{V_I + V_R}{V_I - V_R}$. From this equation it is seen that a VSWR = 1 indicates that there is no reflection whilst a very high VSWR indicates that the reflected voltage almost equals the incident voltage. Assuming zero attenuation along the line, the VSWR will be infinite when the line is terminated in either an open or short circuit. The example in Figure 3 shows that the ratio $\frac{\text{standing wave voltage max}}{\text{standing wave voltage min}} = \frac{3}{1}$ thus producing a VSWR of 3 : 1. Measurement of VSWR will indicate the existence of reflected waves on the line which, in turn, will indicate the degree of mismatch between the transmitter and load.

2.2.2 Losses along the transmission line will attenuate the incident and reflected signals thus the VSWR will vary along the line. If, as an extreme example, the incident signal is completely attenuated along the line, there can be no reflection from the load. In this example even though a complete mismatch may exist at the load, the VSWR measured at the sending end will be 1, i.e. a perfect match. Methods of measuring VSWR are described in paragraph 5.

2.2.3 In practice, a VSWR of 1 cannot be achieved and in carrying out tests and adjustments on aerials, the lowest practical VSWR is sought. If an aerial is to operate over a band of frequencies, e.g. 118 MHz to 136 MHz, it is preferable to obtain a VSWR which is acceptable throughout the frequency band even though this may not be the minimum obtainable value at certain frequencies. The VSWR curves for two typical aerials used over a band of frequencies are shown in Figure 4.



(A) BROAD-BAND VHF COMMUNICATIONS AERIAL



(B) MARKER BEACON RECEIVER AERIAL

Figure 4 **TYPICAL VSWR CURVES**

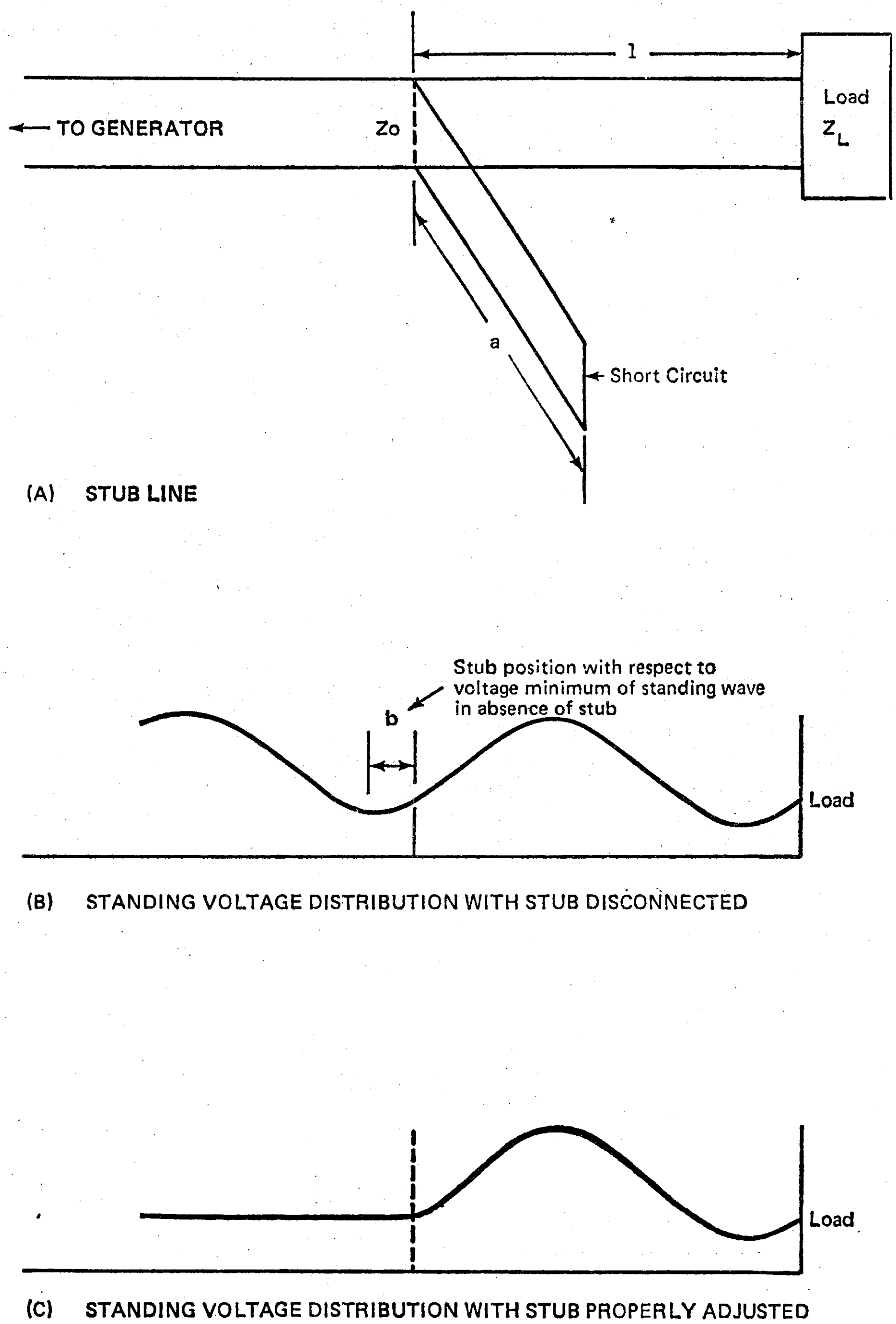


Figure 5 MATCHING BY MEANS OF A SHORT-CIRCUIT STUB

2.3 **Impedance Matching.** Energy is transmitted most efficiently by a transmission line when no reflected wave is present. Generally, the load impedance will not have a resistive value which is exactly equal to the characteristic impedance of the line, thus it is necessary to provide means of matching the load to the characteristic impedance of the line. It should be noted that features which, for matching purposes, are used to increase the bandwidth of an aerial, often reduce the efficiency of the aerial itself. Thus the improved efficiency obtained by correctly matching the line may not lead to an equivalent improvement in overall system performance.

(a) In Figure 5 use is made of the 'stub' and here a short section of short-circuited transmission line is connected in shunt with the transmission line. The stub position and length are so chosen that the input impedance of line 'l', shunted by the input impedance of stub line 'a' will equal the characteristic impedance Zo. Therefore, although the line 'l' and stub 'a' both produce reflected waves they are in anti-phase and cancel so that there is no reflected wave on the generator side of the stub. Any load impedance may be matched in this way provided it is not an open-circuit, a short-circuit or pure reactance.

(b) A method often used to match the unbalanced (coaxial) feeder to a balanced system is the arrangement shown in Figure 6. The arrangement is known as a 'balun', a contraction for 'balanced to unbalanced'. The balun is formed by folding the end of the feeder, one quarter of a wave in length, with the outer (screen) broken at the fold and connected to each aerial element (load Z_L). The inner is continuous and unconnected whilst the screens are shorted together at the extreme end of the stub. Since the outers form a short circuit quarter wave stub, the short at point X is reflected to give a high impedance at points A and B effectively isolating the outer conductor from earth and maintaining the balanced characteristics of the aerial. Similarly, the inner conductor being an open circuit to its outer, effectively at the quarter wavelength point, will be reflected as a short circuit at A thus connecting the feeder cable to the aerial system.

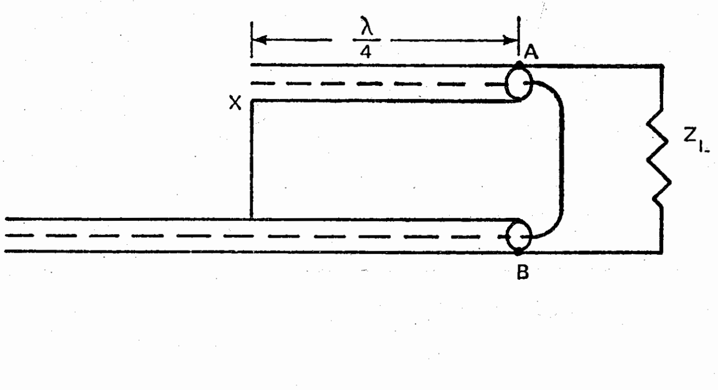


Figure 6 BALUN IMPEDANCE MATCHING

(c) If the load impedance is resistive, or can easily be made resistive by tuning, the matching problem is simplified since all that is required is to transform the actual resistance present to a value that is equal to the characteristic impedance of the line. Techniques which can be used to achieve this include the use of the quarter-wave transformer. A quarter-wave section will always invert any impedance at its receiving end. The section is reactive to frequencies at which it is not a quarter wavelength and is electrically similar to a parallel resonant circuit which, theoretically, has a high impedance at resonance. An open-circuit will present zero impedance at the sending end of the section and a short-circuit will present a very high impedance at the sending end, i.e. open-circuit becomes a short-circuit and short-circuit becomes an open circuit. When a quarter-wave section is terminated in a resistance, inversion still takes place and the resistance seen at the sending end can be calculated from the equation:—

$$Z_S = \frac{Z_O^2}{Z_R}$$

where Z_R is impedance at receiving end
Z_O is characteristic impedance of line.

2.4 **Coaxial Line.** This is the most commonly used type of line for RF transmission. The line may be either rigid (Figure 7) or flexible (Figure 8). At frequencies of the order of 5000 MHz, use is made of the rigid coaxial cable having air dielectric which has a low loss. In this cable the centre conductor is supported with metallic insulators which are quarter-wave sections of coaxial line. Since there is air in the interior, the interior of the line is usually pressurized to keep moisture out. Flexible coaxial cables usually employ polyethylene as the dielectric material. Polyethylene is unaffected by such fluids as acids, alkalis, aviation gasoline, oil, hydraulic brake fluid or sea water. At the lower radar frequencies (of the order of 2000 MHz) the cable losses are low.

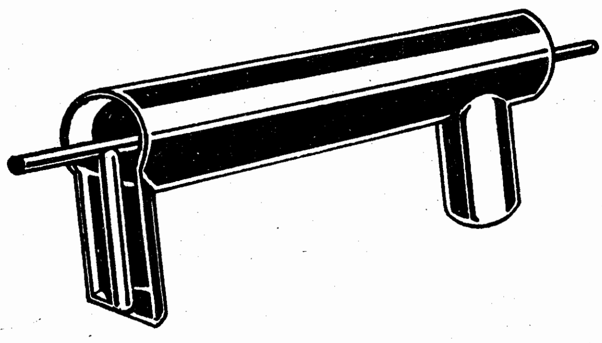


Figure 7 RIGID COAXIAL CABLE WITH METALLIC INSULATORS

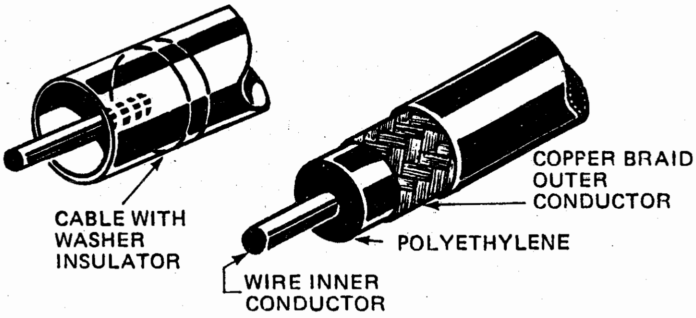


Figure 8 FLEXIBLE COAXIAL CABLES

2.5 **Losses.** In transmission lines, losses may be of three types—copper, dielectric and radiation or induction losses.

2.5.1 **Copper Loss.** One form of copper loss is power loss resulting from I^2R since the resistance of the conductor is never zero. A further loss results from skin effect. Skin effect is the tendency for alternating currents to flow near the surface of a conductor. Since the resistance of a conductor varies inversely with the cross-section, the effective cross-section is less and consequently the resistance is greater. As the frequency is increased this effect becomes more marked. The conductivity of an RF line can be increased by plating it with silver. The majority of the current will flow in the silver layer and the copper will serve mainly for mechanical support.

2.5.2 **Dielectric Loss.** This loss results from heating of the dielectric material (insulation) between conductors. The heating is caused by disturbance of the orbits of the electrons as a result of a potential difference between the conductors. The change in the paths of the electrons requires work (power) which is supplied by the RF power for the line. The losses can be reduced by selecting materials whose atom structure is readily distorted. Such a material is polyethylene which is used extensively in coaxial cables.

2.5.3 **Radiation and Induction Loss.** These losses are similar, both resulting from the fields surrounding conductors. When the field about the conductor is cut by a nearby metallic object, a current is induced in the object with the result that power is dissipated by the object. The power lost is supplied by transformer action from the RF source for the line. Radiation losses result from the fact that some lines of force about the conductor do not return to it when the frequency cycle changes. These lines of force are projected into space as radiation and, as they do not return, the energy they use must be supplied by the RF source. In coaxial lines there is minimal radiation loss since both the electrostatic and magnetic fields are effectively confined within the cable.

WAVEGUIDES A waveguide may be considered to be a two-wire transmission line supported by numerous quarter-wave sections extending above and below the line with each section making contact with the next to form an open-ended rectangular box (see Figure 9). The waveguide will operate over a range of frequencies but there is a lower frequency limit (or cut-off) below which the guide will greatly attenuate energy. The rectangular waveguide width at this cut-off frequency is equal to one half wavelength. In practice, most waveguides are made 0·7 wavelength in the wide dimension. The other dimension is governed by the voltage breakdown potential of the dielectric, which is usually air; common widths are 0·2 to 0·5 wavelength.

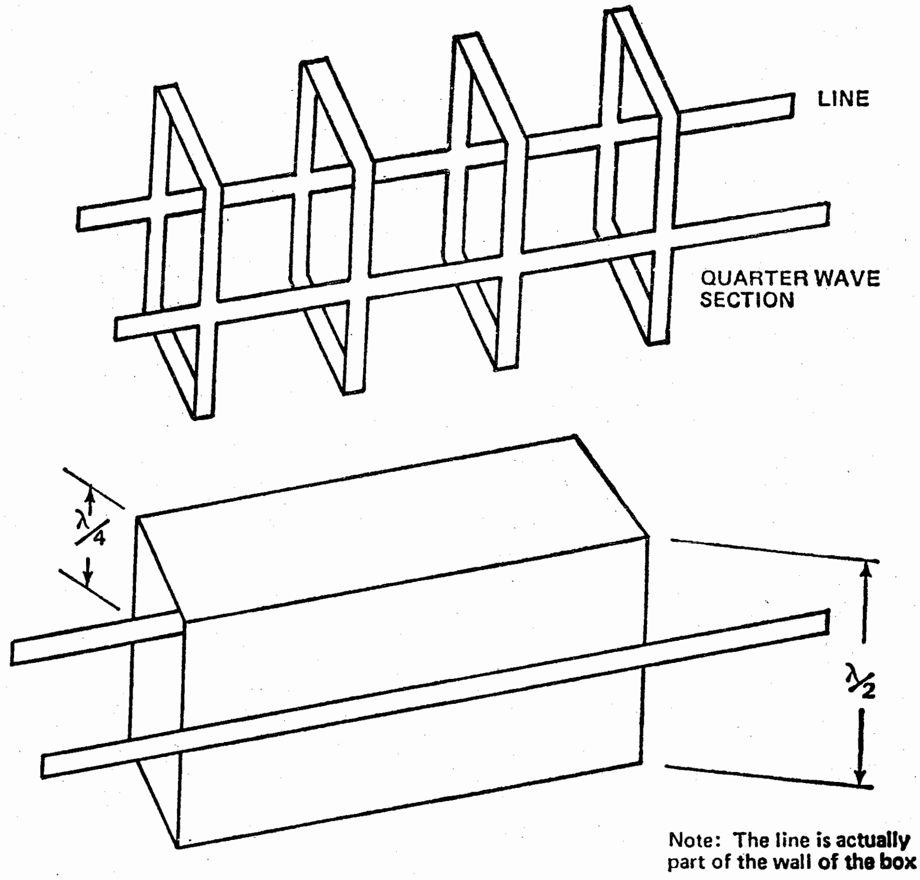


Figure 9 DEVELOPMENT OF WAVEGUIDE BY ADDING QUARTER WAVE SECTIONS

3.1 **Transfer of Energy.** Two fields, the electromagnetic ('h') and the electrostatic ('e'), are always present in a waveguide. Energy is propagated along a waveguide as a series of reflections of the 'e' and 'h' fields from the narrow walls of the guide. For transfer of energy to take place, certain boundary conditions must be satisfied and these are that there must be no electric field tangential to the walls of the guide and that there be no perpendicular component of the magnetic field at the guide surface. These conditions are satisfied by the 'e' field being a maximum at the centre of the guide and falling to zero intensity at the sides and the 'h' field lines being parallel to the guide surface as shown in Figure 10. The number of 'e'-lines in a given area indicates the electrostatic field strength while the number of 'h'-lines in any given cross-section indicates the magnetic field strength. The configuration of the fields is known as a Mode of Operation. For that shown, the configuration is known as the Dominant Mode since it is the easiest to produce.

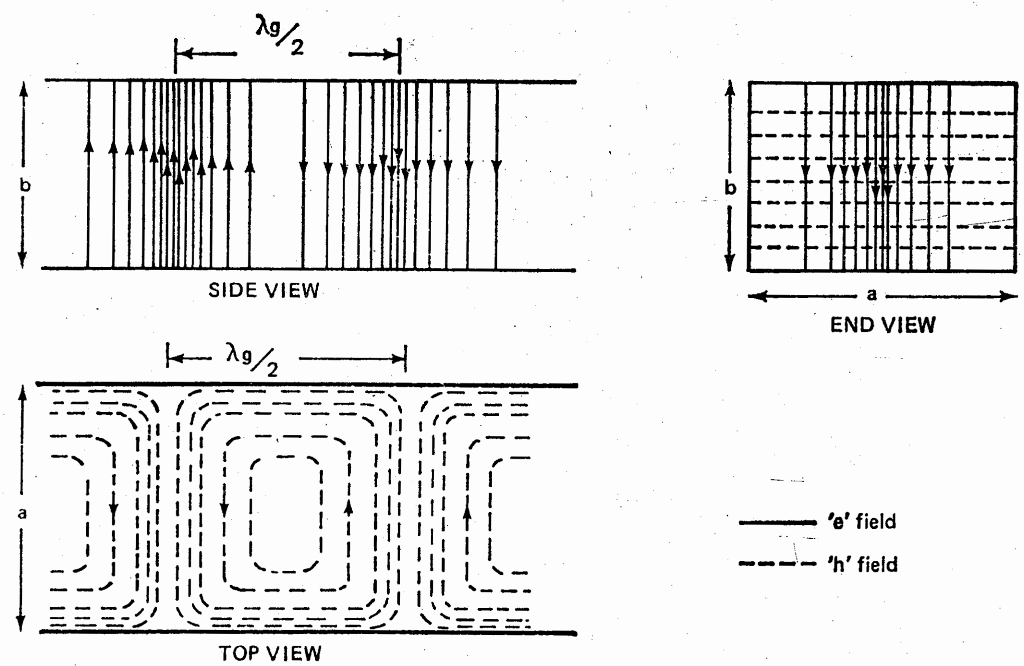
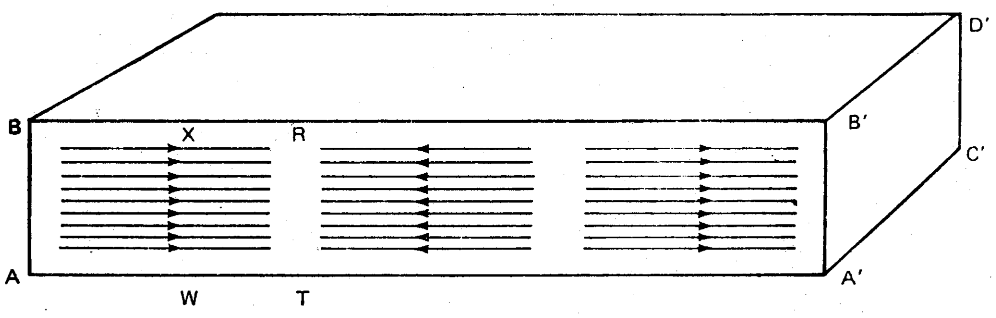
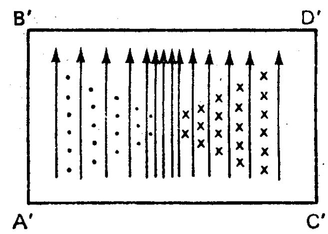


Figure 10 FIELDS IN WAVEGUIDE

3.1.1 Modes are classified as either transverse electric (TE) or transverse magnetic (TM). In a TE mode, all parts of the electric field are perpendicular to the length of the guide and no 'e'-line is parallel to the direction of propagation. The TE mode is sometimes referred to as the H-mode. In a TM mode, the plane of the 'h'-field is perpendicular to the length of the waveguide and no 'h'-line is parallel to the direction of propagation. The TM mode is sometimes referred to as the E-mode. The mode is further defined by the use of two numbers, the first indicating the number of half-wave patterns of the transverse lines which exist parallel to the short dimension of the guide and the second indicating the number of transverse half-wave patterns parallel to the long dimension of the guide. If no change in field intensity occurs, a zero is used. Thus TE_{01} indicates that the magnetic field lies partly along the length of the guide and the electric field is transverse (see Figure 11). The dominant mode is variously described as TE_{01}, TE_{10}, H_{10} or H_{01} since the first figure is sometimes taken to refer to the short side and sometimes to the long side, e.g. TE_{10} is widely used in the USA to specify the dominant mode.



(A) SHORT SIDE OF WAVEGUIDE LOOKING IN H COMPONENT IN DIRECTION OF PROPAGATION



(B) END VIEW

From X to W in (A) the field is uniform and from R to T it is uniform, being zero all along this line. In (A), from A to B there is no concentration as may be encountered in (B) when going from A'B' to C'D'. On this path (A'B' to C'D') there is one definite maximum encountered and thus TE_{01} describes the mode.

Figure 11 TE_{01} MODE

3.2 **Standing Wave Ratio.** The field configuration in a waveguide behaves in the same way as a wave on a transmission line. The magnetic and electric fields travel down the guide and at the end of the guide, if the load is not a matched termination, a reflection is produced which creates a similar field configuration travelling in the opposite direction. The electric and magnetic fields of the guide can be considered as the equivalent of the voltage and current of the transmission line. The super-position of the incident and reflected wave gives rise to amplitude distributions along the guide. A short-circuit at the end of the guide gives a distribution in which the resultant electric field is maximum at distances from the load corresponding to an odd number of quarter wavelengths based on λg, the guide wavelength (the wavelength in the guide is defined as the distance along the axis of the guide between similar field patterns at any instant). The guide wavelength λg, is always longer than the free space wavelength. At the same time, the magnetic field is a maximum at the end and at distances corresponding to an even number of quarter wavelengths. Any resistive load which is not of the correct value to absorb completely the incident wave will produce reflections the amplitude of which will differ from the short circuit case but the maxima and minima will occur at the same places along the guide if the resistive load is less than Zo. If the load is greater than Zo, the 'e' and 'h' maxima and minima will be reversed, since the load is tending towards an open circuit. Loan impedances which have a reactive component will have the minima displaced as in a transmission line. The extent to which a reflected wave is present in a waveguide can be expressed in terms of a standing wave ratio.

3.3 **Attenuation.** In a rectangular waveguide of given dimensions, the attenuation (losses) increases as the wavelength approaches the cut-off value. These losses are skin losses in the guide walls. Generally, wavelengths much shorter than the optimum wavelength attenuate rapidly as a result of increased skin effect per reflection.

3.4 **Losses.** The losses which occur in waveguides are much less than in transmission lines.

3.4.1 **Copper Loss.** In a waveguide there is no centre conductor and the surface area is large, hence when current flows the copper loss is low compared with transmission lines and coaxial cables.

3.4.2 **Dielectric Loss.** Since a waveguide has no centre conductor to support, there is only air inside the guide and as the dielectric loss of air is negligible it follows that the dielectric loss of the waveguide is low.

3.4.3 **Radiation Loss.** The fields are contained wholly within the waveguide just as in a coaxial cable and therefore only a negligible amount of energy is radiated.

3.5 **Impedance.** There are several different ways in which a characteristic impedance can be defined for a waveguide. Each definition gives a different numerical result. For a given guide, the impedance will be a function of frequency irrespective of how it is defined and its value varies with frequency. One definition of impedance is given as the ratio of the strength of the electric field to the strength of the magnetic field:

$$Zg = \frac{\text{Strength of 'e' field}}{\text{Strength of 'h' field}}$$

Another definition of the impedance of a waveguide is the ratio of the maximum value of the transverse voltage to the total longitudinal current flowing in the guide walls for a travelling wave when no reflected wave is present.

3.6 Bends and Joints

3.6.1 **Bends.** Waveguides may be bent in several ways to avoid reflections. One method is to make the bend gradual with the radius of bend greater than 2 wavelengths. Bends may be 90° or less depending upon system requirements. In a sharp 90° bend, normally reflections will occur and to avoid this, the guide is bent twice at 45°, one quarter-wave apart. The combination of the direct reflection at one bend and the inverted reflection from the other bend will cancel and leave the fields as though no reflection had occurred. To cater for special bends, flexible sections of waveguides are often used. These sections can be bent or twisted in any desired direction and they consist of a spiral-wound ribbon of brass with the outside covered in rubber to give it flexibility and to make it both air- and water-tight.

3.6.2 **Joints.** It is not possible to mould an entire waveguide system into one piece for a radar set and thus it is constructed in sections which are connected together by joints. There are three main types of joints; permanent, semi-permanent and rotating.

(a) **Permanent.** This joint is made during manufacture and, when used, the waveguide sections are machined within a few thousandths of an inch and then welded together. The result is a hermetically-sealed and mirror-smooth joint.

(b) **Semi-Permanent.** Where it is necessary for sections to be taken apart for routine maintenance or repair, a semi-permanent joint is used and the most common type is the choke joint. A cross sectional view of a choke joint is shown in Figure 12. It consists of two flanges which are connected to the waveguide at the centre. The right-hand flange is flat, and the one at the left is slotted a quarter wave deep at a distance a quarter wave from the point where the walls of the guide are joined. The quarter-wave slot is shorted at the end and the two quarter waves together become a half wave which reflects a short circuit at the place where the walls are joined together. Electrically, a short circuit exists at the junction of the two waveguides. The two guides can be separated by as much as a tenth of a wavelength without appreciable energy loss and this permits sealing of the interior of the waveguide with a rubber gasket for pressurization.

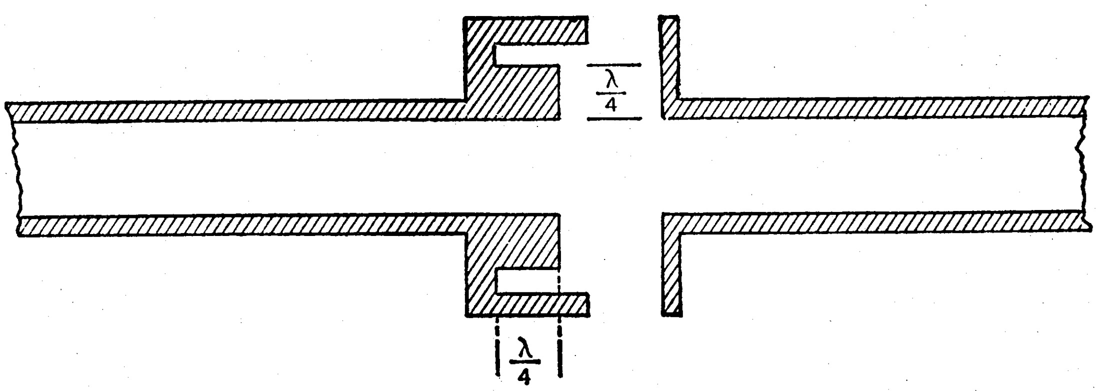


Figure 12 CROSS SECTION OF CHOKE JOINT

(c) **Rotating Joint.** Since the radar antenna rotates, a rotating joint is required for connecting the waveguide to the antenna. A simple method for rotating part of a waveguide system is by using a mode of operation that is symmetrical about the axis as shown in Figure 13. This requirement is met by using a circular waveguide and a TM_{01} mode. In this method a choke joint may be used to separate the sections mechanically and to join them electrically. Airborne radar systems employ rectangular waveguides and hence a different method is required for connecting sections of the waveguide which need to rotate. Two short lengths of circular waveguide can be butted together to form a rotating joint, with transformation to the normal rectangular waveguide at each end. A cross section of such a joint, with a TM_{01} wave in the circular portion and a TE_{01} in the rectangular guide is shown in Figure 14(A). The TE_{01} in the input rectangular guide is transformed into the TM_{01} circular mode as shown. Similarly, the axial 'e' field in the circular section launches a TE_{01} mode into the rectangular output guide. Because of the axial symmetry, the TM_{01} circular mode will present the same field. pattern to the output rectangular guide in whatever direction it may be turned The arrangement gives a reasonably pure TM_{01} mode but a certain amount of TE_{11} wave is however set up in the circular guide which is transferred to the output guide and the amount varies with angle of rotation thus giving rise to variation in output. To suppress the unwanted TE_{11} circular mode, two ring filters are mounted as shown in Figure 14(A). These rings act as resonant rejector. circuits, rejecting the TE_{11} mode while the TM_{01} mode is almost unaffected since its electric field is always perpendicular to the ring. To prevent radiation from the gap between the two circular guides a choke groove is machined as shown. Another form of rotating joint involves the use of a coaxial cable which provides axial symmetry of the fields and circular cross-section for rotation. In the rotating joint, a probe forms the end of the centre conductor and takes energy from one waveguide and delivers it through the cable to another probe in the other waveguide. The centre conductor remains stationary with respect to one waveguide and rotates with respect to the other. To make the rotating electrical connection, the outer conductor is fitted with tubing having a half wave slot which is shorted at the end and reflects a short at the junction of the outer conductors. No mechanical contact is required between the two sections of the outer conductor. The inner conductor is supported by insulating washers. Figure 14(B) shows a cross-sectional view of the arrangement.

3.7 **Pressurization.** Since airborne equipment is flown at high altitudes, temperature changes will cause moisture condensation inside the waveguide. As water causes extremely high losses, the interior of the waveguide must be maintained at a higher pressure than the outside to drive the moisture out and keep it out. To maintain this pressure, all joints must be airtight.

4 LOSS CHECKS There are various methods for performing loss checks on transmission lines and waveguides. The method used will depend on such factors as frequency and accessibility if checks are to be carried out with the system in situ in the aircraft. The following paragraphs describe some of the methods which may be employed.

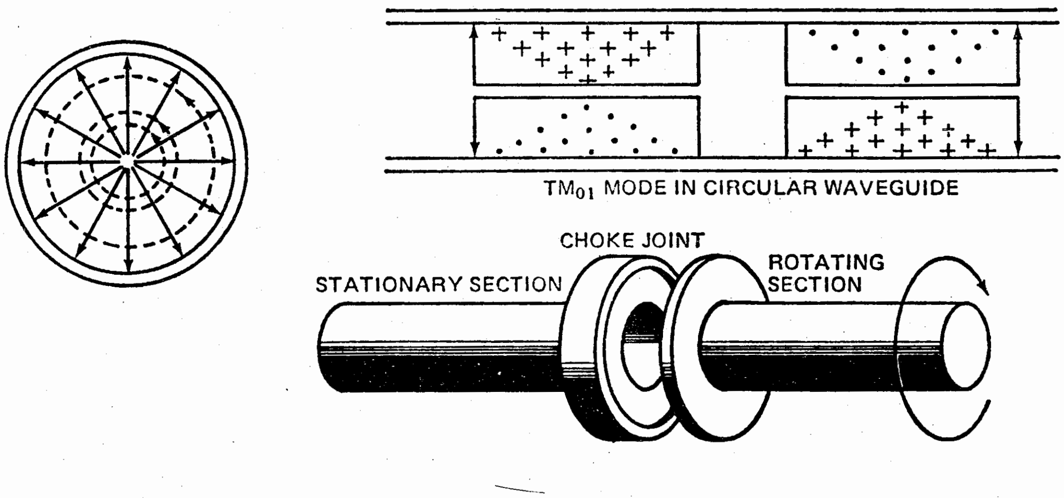


Figure 13 ROTATING JOINT AND TM$_{01}$ MODE IN CIRCULAR WAVEGUIDE

4.1 **Transmission Lines**

4.1.1 **In-Line Wattmeter**

(a) The in-line wattmeter should be compatible with the Zo of the line and be capable of covering the frequency range and the RF power of the system to be tested. Any additional lengths of test line used should have the correct characteristic impedance and be as short as possible, preferably a length which produces a total test section insertion of one half-wavelength or multiples thereof at the frequency used.

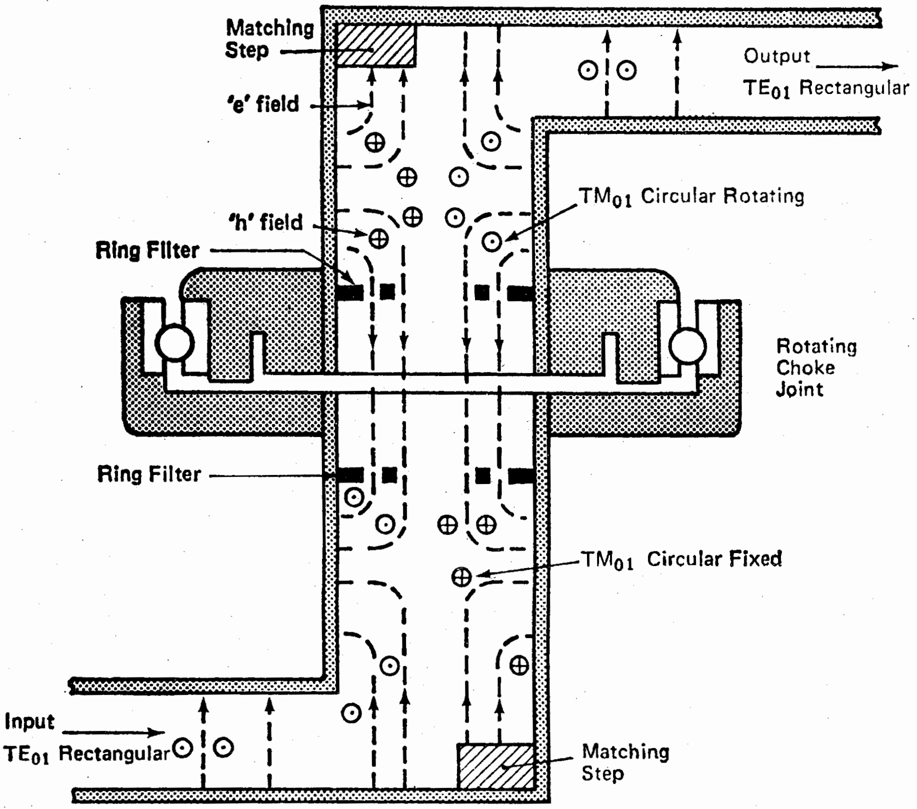
(b) Initially the equipment should be connected with the wattmeter adjacent to the transmitter. With the system transmitting, the forward power should be noted.

(c) The aerial feeder should be re-connected to the transmitter and the wattmeter should now be connected adjacent to the aerial, or adjacent to the aerial tuning unit for HF systems, and the forward power should again be noted with the transmitter on (CW or AM mode for HF systems).

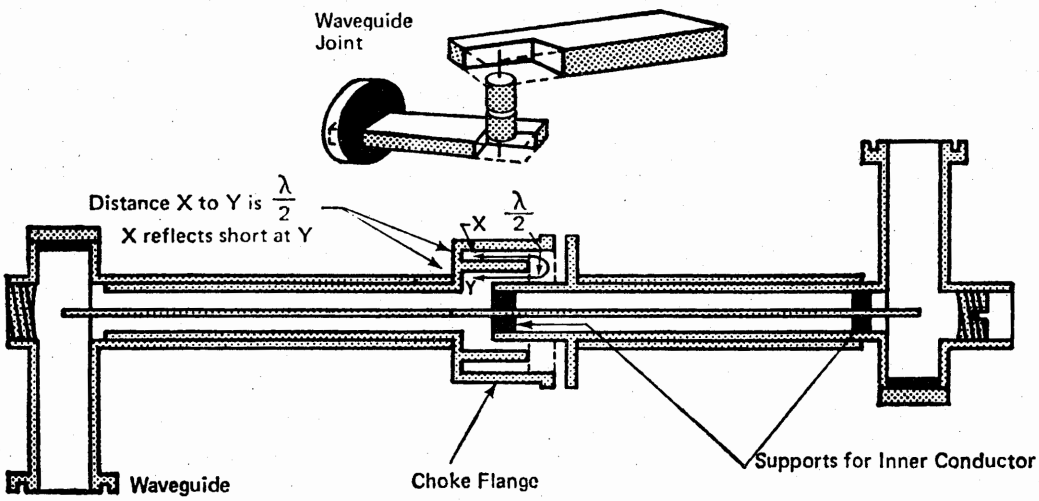
(d) The cable loss may be calculated from the formula:

$$10 \log_{10} \frac{\text{Forward Power at Transmitter}}{\text{Forward Power at Aerial}}$$

(e) Cable loss measurements should be carried out at the centre and ends of the frequency band at which the system operates. Attenuation of aerial feeders may be slightly more than quoted by manufacturers for a given frequency and length as a result of connectors, relays, etc., in the system. It is normal for the attenuation to rise with frequency because of the increase in capacitance loss.



(A) ROTATING JOINT USING CIRCULAR WAVEGUIDE



(B) ROTATING JOINT USING COAXIAL PROBES

Figure 14 ROTATING JOINTS WITH RECTANGULAR WAVEGUIDE

(f) Table 1 gives typical cable loss figures in decibels per 100 feet.

TABLE 1

Frequency	Cable UR 43	Cable UR 67
118 MHz	4·6	2·2
200 MHz	6·5	2·8
300 MHz	8·4	3·7

4.1.2 **Swept Frequency.** Where the system is required to operate over a range of frequencies, use of swept frequency technique is more convenient for checking loss rather than setting an oscillator to various frequencies throughout the band and checking the loss at each frequency. This method uses a sweep generator capable of producing an RF output over the required frequency range. A typical test set-up is shown in Figure 15. Initially the oscilloscope is calibrated with the detector connected directly to the output of the isolator. This adjustment provides a reference point for the test. The section under test is then connected between the output of the isolator and the detector. The oscilloscope controls are now re-adjusted to bring the trace back to the reference line established during calibration. The difference between the new setting and the reference setting is a measure of the loss (or gain) of the section under test.

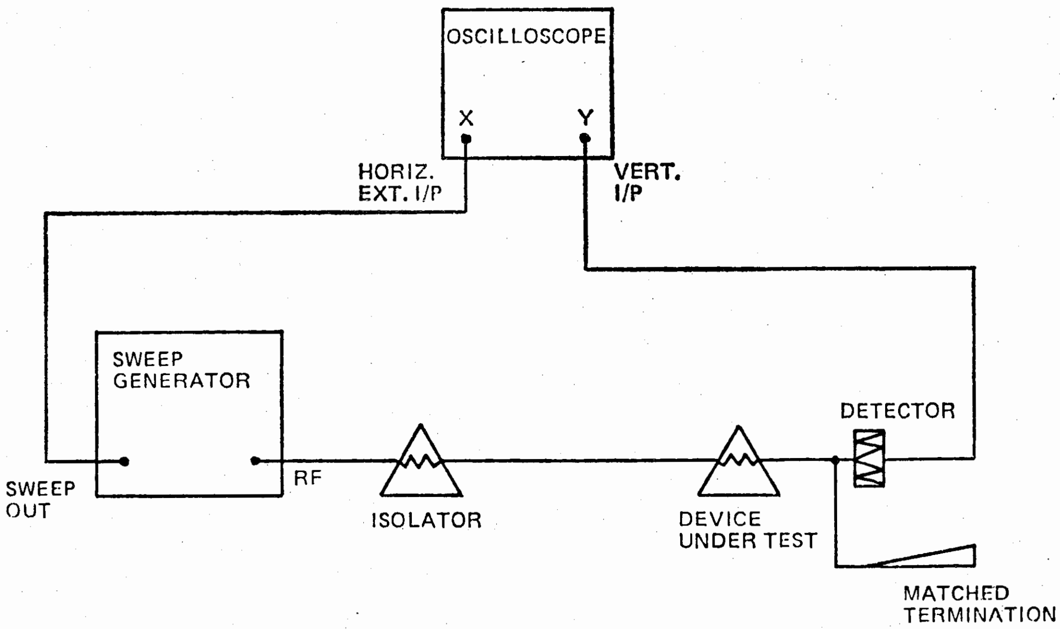


Figure 15 LOSS MEASUREMENT USING SWEPT FREQUENCY TECHNIQUE

4.1.3 If cable loss is required to be measured at a particular frequency or a number of spot frequencies, a simple method employing only a signal generator and a broadband voltmeter may be used. In this method the following procedure is used.

(a) Initially, connect the output of the signal generator to the input of the broadband voltmeter and set up a reference level (V_1) on the meter.

(b) Connect the item to be tested between the output of the signal generator and the input to the voltmeter and note the voltage (V_2) displayed on the meter. The cable loss can then be calculated in dB from the formula:

$$\text{Loss} = 20 \log_{10} \frac{V_1}{V_2}$$

4.1.4 **Time Domain Reflectometry (TDR).** This method is particularly useful where it is required to match a feeder cable to an aerial or where analysis of a feeder performance is required.

(a) The system operates on the principle that any impedance discontinuity along the transmission line will produce a reflection. The method consists of applying a very fast rise-time step voltage to the input of the system under test and monitoring the applied (incident) and reflected voltages on an oscilloscope. This technique shows the characteristic impedance of the line, the position and nature (resistive, inductive or capacitive) of each discontinuity along the line and also whether line losses are series or shunt. The advantage of the system over simple VSWR measurement is that it provides a detailed examination of the line whereas VSWR only gives an overall figure from which, in effect, a figure of merit is established for the transmission system. Figure 16 shows the arrangement for TDR measurements.

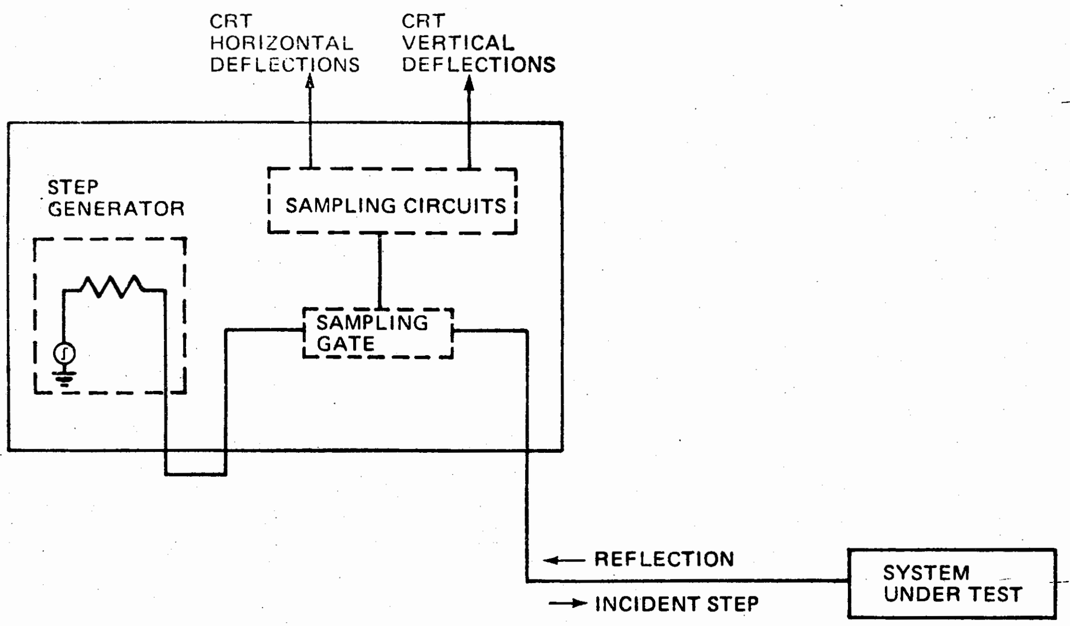


Figure 16 TIME DOMAIN REFLECTOMETRY TEST ARRANGEMENT

(b) The step generator produces a positive-going incident wave which is fed into the system under test. The step travels down the transmission line at the velocity of propagation of the line. If the load is equal to the characteristic impedance of the line, no wave is reflected and all that is seen on the oscilloscope is the incident voltage step. If a mismatch exists, part, or all, of the incident step is reflected. This reflected voltage will be seen on the oscilloscope display algebraically added to the incident step. If the line is terminated in an open circuit, the reflected step will be equal in amplitude to the incident step and will be positive going. If the termination is a short circuit the reflection will again be equal in amplitude to the incident step but will be negative going. Figure 17 shows the oscilloscope display for values of load corresponding to open circuit, short circuit and Z_L not equal to Zo.

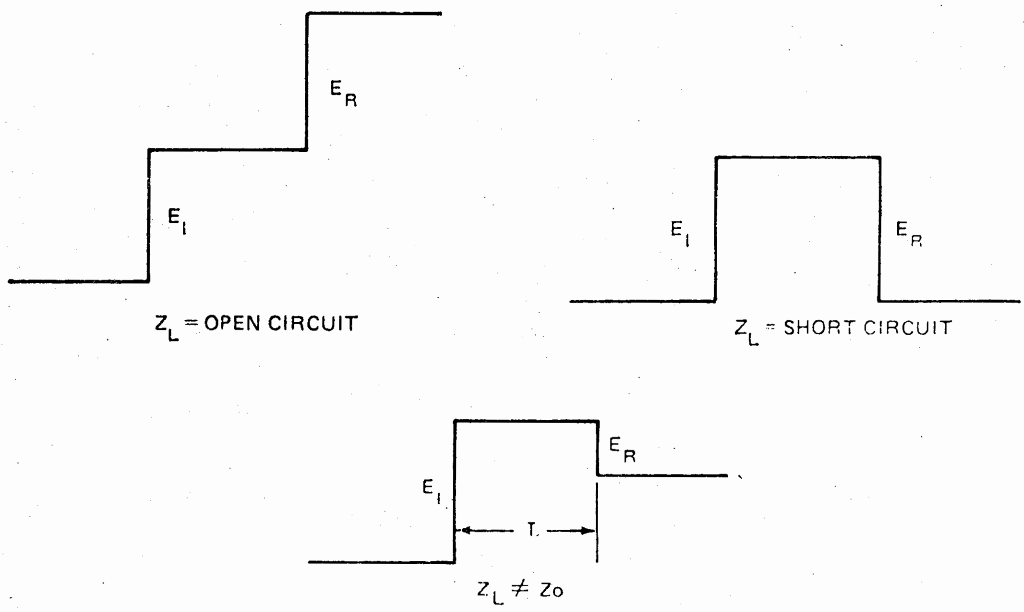


Figure 17 TDR DISPLAYS FOR VARIOUS VALUES OF LOAD

(c) The reflected wave is readily identified since it is separated in time from the incident wave. This time is valuable in determining the position along a line where a mismatch exists. If D is the distance to the fault from the start of a line then,

$$D = V_P \times \frac{T}{2}$$

where V_P = velocity of propagation
T = transit time from start of line to mismatch and back again.

(d) **Interpreting Time Domain Reflections.** Discontinuities, which for the purpose of TDR is the title given to any localized fault which gives rise to a reflection, may be shown as small peaks or bumps (Figure 18). A positive peak or bump indicates a rise in Zo over a short length of line or that there is a series inductance at that point on the line, similarly a negative dip shows a lowering of impedance or a shunt capacitance.

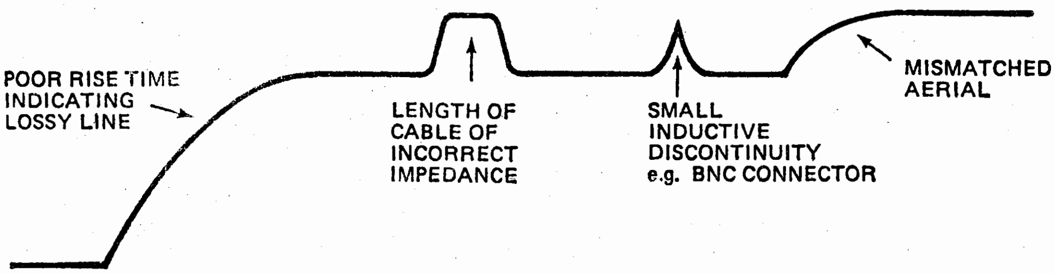


Figure 18 TDR DISPLAY OF VARIOUS FAULTS IN A TRANSMISSION SYSTEM

(i) Experience in the use of TDR is a most valuable asset in the interpretation of reflections. Display wave forms may be affected by several factors such as line attenuation, velocity of propagation for the line, multiple reflections, complex load impedances. Comparison of displays with those for known serviceable aerial systems can be useful in determining the location and magnitude of mismatches or discontinuities.

(ii) Accuracy in distance measuring is dependent on a fast rise-time incident step and long lossy lines can severely degrade rise-time so that both amplitude and shape of reflections are changed. Each discontinuity affects those which follow it, later reflections in a line may be mixed in with re-reflections of earlier discontinuities. Time domain reflectometry is however a recommended method of transmission line or aerial system evaluation. Its use can result in improvement to aerial systems and the speedy diagnosis and rectification of faults.

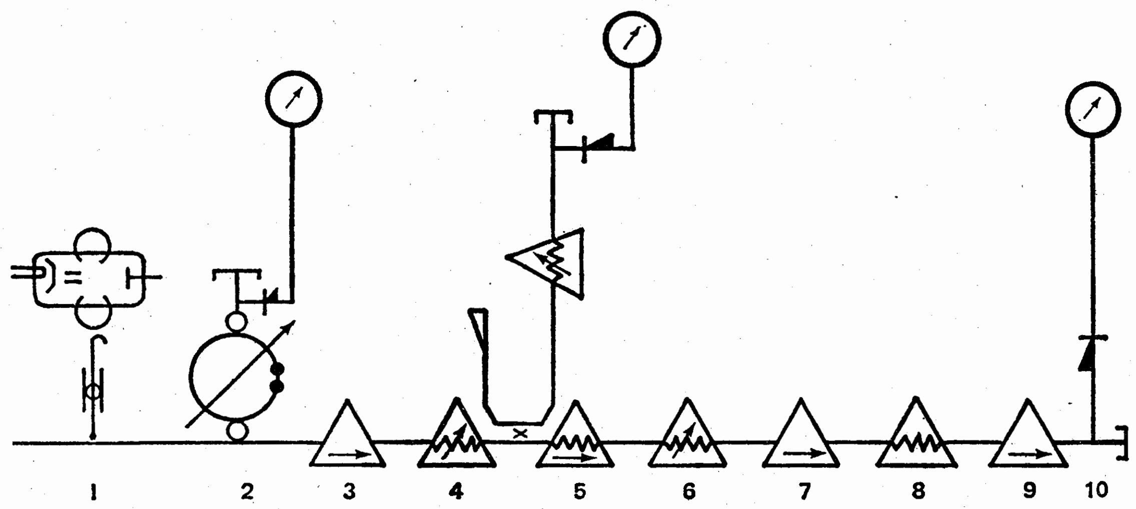


Figure 19 WAVEGUIDE ATTENUATION—TEST ARRANGEMENT

4.2 Waveguides

4.2.1 Attenuation Check

(a) The attenuation (loss) of a length of waveguide or a waveguide system can be measured by substitution. The section to be checked is inserted in the test arrangement shown in Figure 19, and a measurement taken. Removal of the unknown section will result in a changed overall attenuation which can be measured. The difference between the two measurements is the insertion loss of the section.

(b) **Test Arrangement (Figure 19).** Each of the items required in the test arrangement shown has been numbered for the purpose of describing their function and explaining the test method (paragraph (c)).

1. Klystron Oscillator for providing RF power. A stabilized power supply will be required for the Klystron.
2. Frequency measurement and monitor.

3, 5, 7, 9. Isolators. Isolator 3 is used to prevent any mismatch at the end of the line from affecting the frequency or power output of the oscillator; the isolator should be at least 12 dB. Isolator 5 is only necessary if the precision attenuator (6) reflects an appreciable amount of power, which is unlikely with most waveguide attenuators. Isolator 7 is necessary if the unknown section reflects an appreciable amount of power. If it is a bad mis-match the isolator is necessary because any large standing wave pattern in the precision attenuator will give a non-uniform distribution of electric field strength through the attenuator which may alter its calibration. Isolator 9 may be necessary if the crystal receiver is not a good match.

4. Power level setting and monitor by precision attenuator with directional coupler, variable attenuator and crystal receiver.
6. Precision Attenuator.
8. Unknown section of waveguide.
10. Crystal receiver and matched termination.

(c) **Test Method**

(i) Initially, a reference level is set up on the crystal receiver (10) with the unknown section of waveguide (8) connected in the test arrangement and the precision attenuator (6) set to zero.

(ii) The unknown section (8) is removed from the test arrangement and the level on the crystal receiver (10) will rise as some attenuation has been removed. The precision attenuator (6) is adjusted to bring the crystal receiver reading back to the reference level set up in (i). The reading on the calibrated attenuator is then the insertion loss of the unknown section of waveguide. Since the attenuation measurement involves bringing the output of the test arrangement to the same level on the output crystal receiver meter, the measurements are independent of the detector crystal calibration.

(d) **Alternative Test Arrangement**

(i) Figure 20 shows an alternative set-up in which the Klystron signal source is replaced by a sweep generator and the attenuation is displayed on an oscilloscope. With the waveguide section or system connected in the test arrangement the display will represent the attenuation throughout the sweep range.

(ii) To measure the attenuation, a note is first made of the display pattern on the oscilloscope to establish a reference. The unknown section is removed and the rotary attenuator is adjusted to bring the display pattern back to the reference level. The attenuation of the unknown section can be read directly from the rotary attenuator. Typical loss figures for WG 16 waveguide are 0·1 dB/foot for rigid waveguide and 0·15 dB/foot for flexible waveguide.

(iii) As shown in Figure 20 a Bolometer can be used to detect the RF power. The Bolometer is a resistive element which when heated changes its resistance. The change in resistance is measured by a Wheatstone bridge circuit. In its most accurate form, the bridge allows a considerable direct-current flow through the element. Initially it is balanced with no microwave power incident on the device. When measuring power, the element will warm-up, unbalancing the bridge, which can be brought back to balance by reducing the direct current flowing through the element. The power represented by the reduction in current is the same as the microwave power being absorbed by the device. In the circuit of Figure 20 the device is used to provide a deflection source for the oscilloscope 'Y' amplifier. Care must be taken to limit the current through the Bolometer to that recommended by the manufacturer.

(iv) The circuit of Figure 20 can be used with various means of measuring the waveguide attenuation. In one such method the waveguide under test is terminated in a matched load and the output of a crystal detector is fed to the Y input of an X–Y Recorder. Initially the recorder is calibrated with the unknown waveguide out of circuit by plotting calibration lines with the rotary attenuator set to various dB settings over the range of expected attenuation. A plot is then made with the unknown waveguide in circuit and the rotary attenuator set to zero. For WG 16 waveguide, calibration lines would typically be plotted over the range 0·5 dB to 3 dB every 0·5 dB.

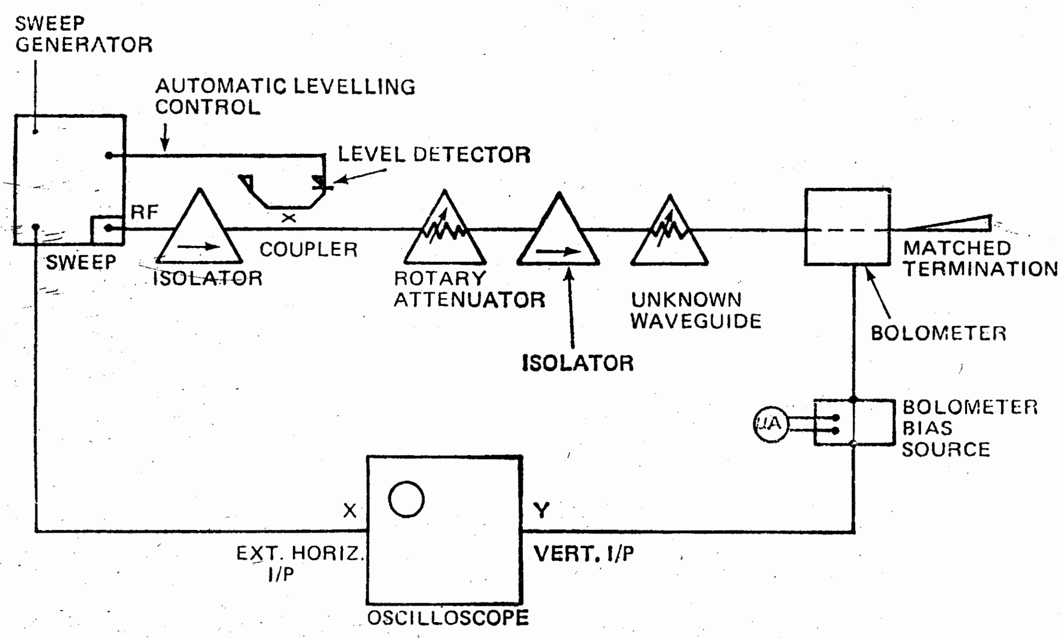


Figure 20 WAVEGUIDE ATTENUATION—ALTERNATIVE TEST ARRANGEMENT

5 VSWR CHECKS As with transmission-line loss checks, the method used to check the VSWR of a transmission line or waveguide will depend on the frequency and accessibility if the system is to be checked in situ in the aircraft. Some of the methods which can be used are given in the following paragraphs.

5.1 In-Line Wattmeter

5.1.1 The in-line wattmeter should have performance characteristics appropriate to the measurement being made. Particular attention should be given to the wattmeter's ability to discriminate between forward power and reflected power, its accuracy at high forward powers and low reflected powers, its impedance and frequency range. Servo-driven peak-reading wattmeters are necessary for pulsed systems.

5.1.2 The in-line wattmeter should be connected adjacent to the transmitter and, with the system transmitting on a free channel (HF systems in the CW or AM mode), the forward power should be noted. Any additional lengths of test cable used must have the correct characteristic impedance and be as short as possible, preferably a length which produces a total test section insertion of one half-wavelength or multiples thereof at the frequency used.

5.1.3 The coupling element should be reversed and, with the transmitter on, the reverse power should be noted. From the nomograph (see Figure 21) provided with the wattmeter the VSWR can be found. If a nomograph is not available the VSWR can be calculated from the formula:

$$\text{VSWR} = \frac{\sqrt{\dfrac{\text{P FORWARD}}{\text{P REFLECTED}}}+1}{\sqrt{\dfrac{\text{P FORWARD}}{\text{P REFLECTED}}}-1}$$

The measurement should be repeated to obtain the VSWR at a minimum of three frequencies spaced across the band of the system under test.

5.1.4 The measurement of VSWR described in paragraphs 5.1.2 and 5.1.3 does not represent the true VSWR at the aerial because attenuation in the aerial feeder will reduce the forward power, and the reflected power. It will however show if there is an unacceptable amount of reverse power at the transmitter. An important point is to use, as criteria, the measured VSWR known to be satisfactory for the installed system rather than the published figure for the aerial alone.

5.1.5 To establish the VSWR of the installed aerial, the wattmeter should be connected adjacent to the aerial, or adjacent to the aerial tuning unit for HF systems, and the procedure of paragraphs 5.1.2 and 5.1.3 should be repeated. An important point to note is that any reflecting surface near the aerial, e.g. air scoops, landing gear, hangar equipment, etc., can reflect power back into an aerial and along the transmission line feeder. The power level can be significantly higher than the reflection caused by normal aerial mismatch, thus misleading readings may be obtained. The possibility of such reflections from metal reinforced glass-fibre components should not be overlooked.

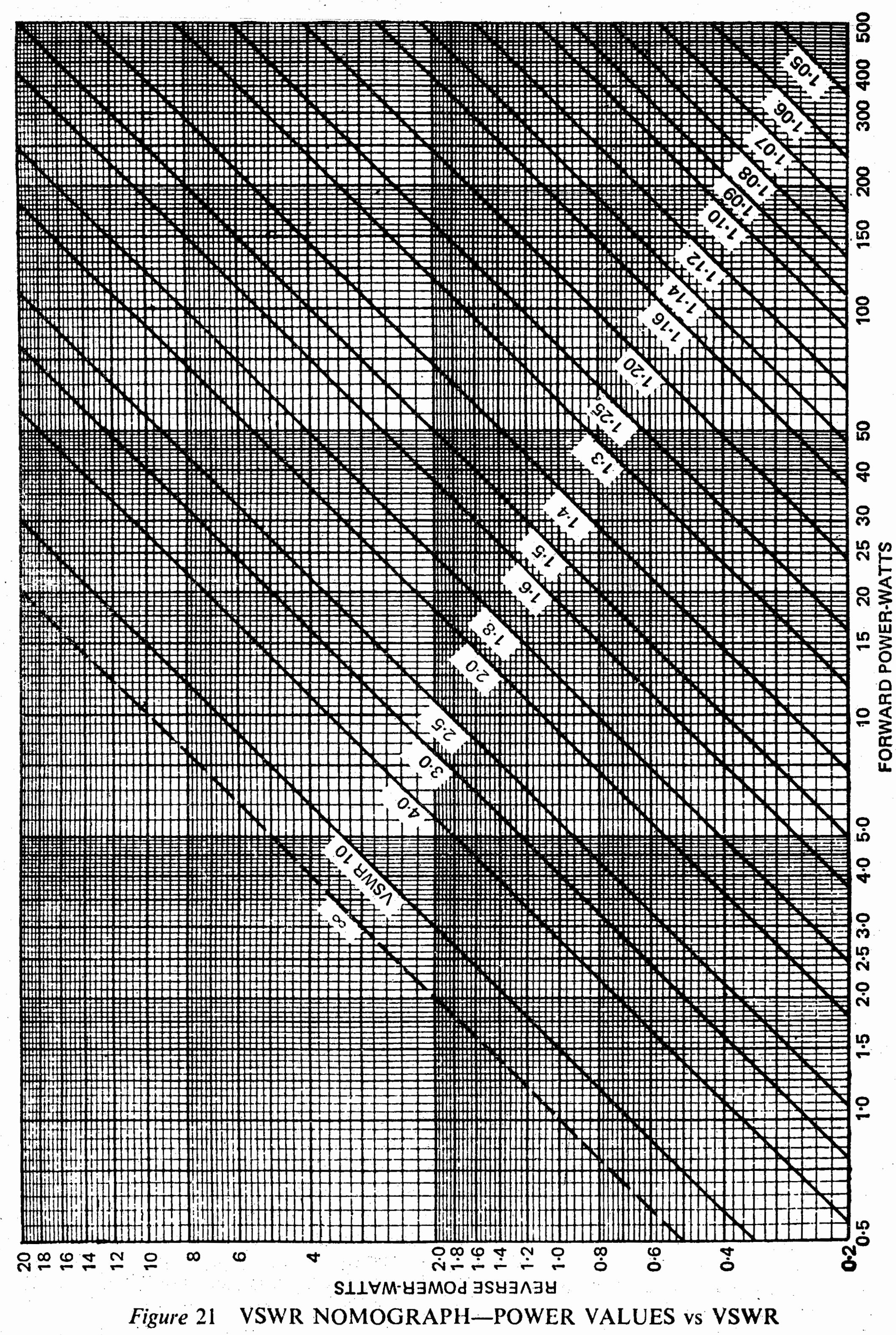


Figure 21 VSWR NOMOGRAPH—POWER VALUES vs VSWR

5.2 **VSWR Bridge.** This method uses an RF version of the Wheatstone bridge circuit to compare the unknown impedance seen at the input end of the system under test with a standard impedance (50 ohms). RF voltage at the appropriate frequency is applied across the bridge and adjusted to maintain constant level during the test. For this constant applied voltage, the out-of-balance voltage of the bridge is a function of the VSWR of the unknown impedance relative to the internal standard impedance. The out-of-balance resultant is rectified and displayed on a meter calibrated directly in VSWR. Measurement does not require adjustment of ratio arms to bring the bridge into balance. The basis of measurement therefore uses the off-balance meter to provide direct reference against an internal standard. The accuracy of the bridge is of the order of 10%. The effect of a standing wave on the line causes the magnitude of the impedance to vary along the line with the maximum value being equal to Zo × SWR and the minimum value equal to $\frac{Zo}{SWR}$. Thus the indicated SWR will vary depending on the length of the feeder. For the most accurate results, it is therefore necessary to connect the bridge directly to the aerial connector when measuring aerial VSWR. Feeders should be checked with a compatible load termination such that any measured VSWR is known to be as a result of the feeder itself.

5.2.1 **Description**

(a) The bridge (Figure 22) consists of two fixed arms R1 and R2 of equal impedance which are high-stability 50 ohm resistors. The third arm is a preselected standard resistance (normally 50 ohms) incorporated within the instrument, and the fourth arm is the system under test. The standard resistance may be replaced by others of different values to permit tests on systems having a non-standard characteristic impedance. Some additional error sources may, however, arise from the ratio arms and connector sockets being no longer optimized.

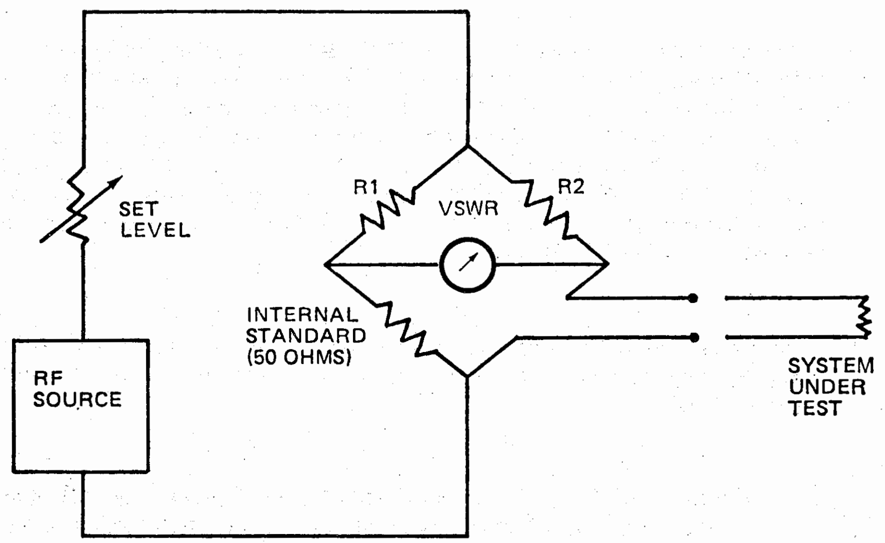


Figure 22 SCHEMATIC OF VSWR BRIDGE CIRCUIT

(b) The calibration of the instrument may be checked and adjusted by connecting an external standard resistance to the test socket. For an instrument having a 50 ohm bridge standard, an external standard resistance of 25 ohms simulates a VSWR of 2:1 and may be used for calibration purposes.

(c) The SET LEVEL control permits adjustment of the RF voltage which the oscillator applies across the bridge, after allowing for the loading produced by connection of the system under test. Adjustment of this control should therefore be made with the system under test connected.

(d) By virtue of its internally-generated RF voltage, the bridge is particularly useful for measurement of receiving aerials and feeders where the absence of a transmitter precludes the use of an in-line wattmeter, e.g. VOR, ILS, Marker. Tests should only be carried out with the aerials in their fully assembled state and with all adjacent structures in position. On aircraft where the rudder mass balance is in close proximity to the VOR–ILS aerial, the rudder should be centralized during the test.

5.3 **Alternative VSWR Bridge Method.** A more elaborate bridge technique employs a sweep signal generator and an oscilloscope to permit display of aerial matching over the complete frequency range in which it is required to operate.

5.3.1 **Description**

(a) In the arrangement shown in Figure 23 the RF comparator bridge is enclosed in a separate unit. Half of the bridge is built-in, while known impedance Z_1 and unknown loads (system under test) are applied to make up the remainder. A standard mismatch is available for calibration and the system incorporates an automatic levelling control (ALC) signal from the bridge which is used to eliminate any error that could be caused by variation in signal level, comparator detector input or feeder discontinuities. A VSWR meter may be incorporated for precise spot frequency measurements.

(b) As in other bridge methods, the detected output signal from the RF bridge represents the degree of mismatch between the reference impedance (Z_1) and the load impedance (Z_2).

(c) This technique may be used to check the VSWR of an aerial or aerial system in-situ but frequently finds application in areas where aerials are being tested during production or prior to fitting to an aircraft. When testing aerials it is essential that they should be well bonded to a large ground plane. Where possible similar methods of attachment should be employed as are used in the aerial's aircraft installation.

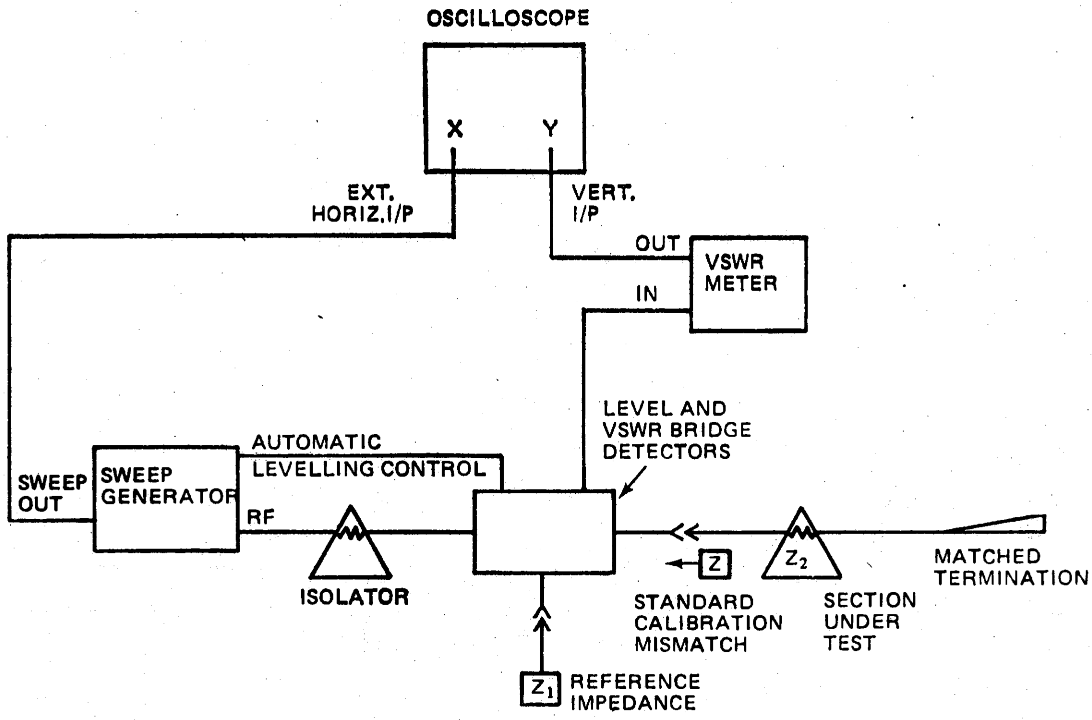


Figure 23 VSWR BRIDGE—SWEPT FREQUENCY TECHNIQUE

5.4 Swept frequency techniques can be used for measurement of VSWR using various methods of display. One such method which makes use of a slotted line with a storage oscilloscope as the display medium is shown in Figure 24. The sweep generator is set to the required sweep range and with RF power on, the slotted line tuning probes are adjusted for as flat a trace as possible. On the oscilloscope, 'write' facility is selected and the intensity and persistence controls are adjusted so that when the carriage of the slotted line is slowly moved from one end of the line to the other a picture is built up as shown in Figure 25. The VSWR at any point is obtained by measuring the dB difference between maximum 'a' and minimum 'b' and converting to VSWR by reference to a conversion table. The VSWR for a particular value of dB can be calculated from the formula:

$$dB = 20 \log_{10} \frac{V_1}{V_2}$$

where $\frac{V_1}{V_2}$ is the voltage standing wave ratio

$$\text{hence, } \frac{V_1}{V_2} = \text{antilog } \frac{dB}{20}$$

for example, if the difference was 1 dB:

$$\frac{V_1}{V_2} = \text{antilog } \frac{1}{20} = \text{antilog } 0{\cdot}0500$$

thus VSWR = 1·122

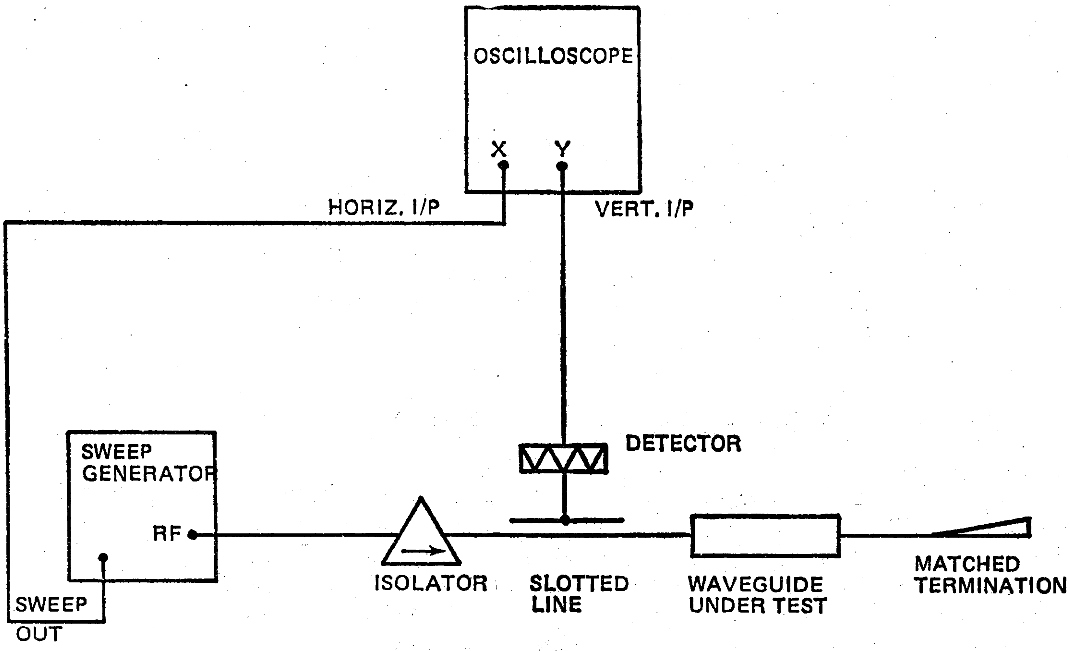


Figure 24 VSWR MEASUREMENT USING SLOTTED LINE

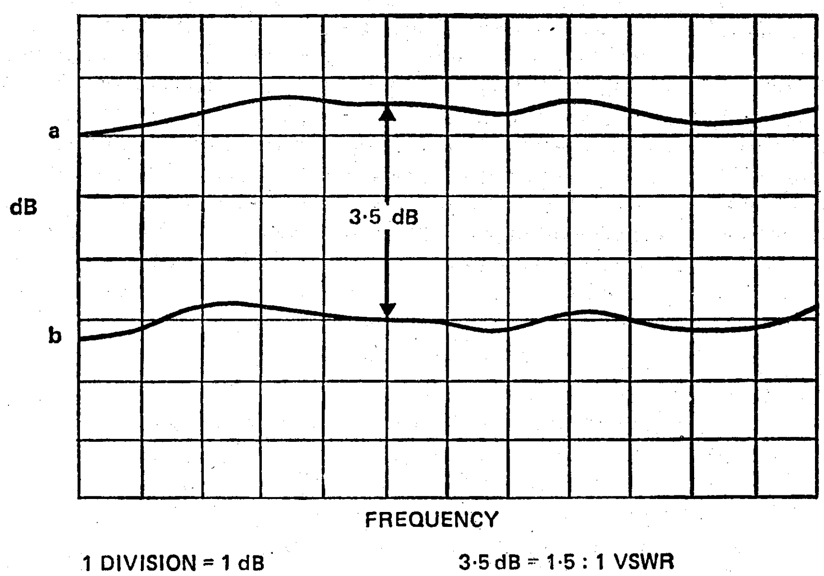


Figure 25 OSCILLOSCOPE DISPLAY USING SLOTTED LINE MEASUREMENT OF VSWR

5.5 By substituting a directional coupler in place of the slotted line in Figure 24, VSWR can be measured using reflectometer technique. Initially, the oscilloscope is calibrated with a short connected to the mainline output of the directional coupler. The device under test is then connected to the output of the coupler and the oscilloscope controls are adjusted to bring the trace as close as possible to the reference line established during calibration. The difference is read directly by adding the setting of the controls to the trace position below the reference line (if the trace is above the reference line subtract that amount from the dB setting). The dB difference figure can be converted to VSWR by reference to a conversion table for the particular coupler or can be calculated from the formula:

$$\text{VSWR} = \frac{\left(\text{antilog}\frac{\text{dB}}{20}\right)+1}{\left(\text{antilog}\frac{\text{dB}}{20}\right)-1}$$

6 WAVEGUIDE PRESSURIZATION CHECK

6.1 A typical set-up for checking leakage of an antenna and waveguide is shown in Figure 26. If the leakage is found to be excessive this may be corrected by renewal of the seal at the suspect joint. If this does not cure the fault, renewal of the part is necessary.

6.2 When checking the waveguide in isolation it is necessary to seal it at one end. Initially, open valve V1, close valve V2 and adjust the pressure source for the appropriate indication on the pressure gauge (typically 15 lbf/in^2). Maintain this pressure in the waveguide.

6.3 Close valve V1 and open valve V2. Observe the flowmeter and check that the air leakage rate does not exceed the value quoted in the relevant Maintenance Manual or manufacturer's instructions (typically not greater than 2 in^3/min).

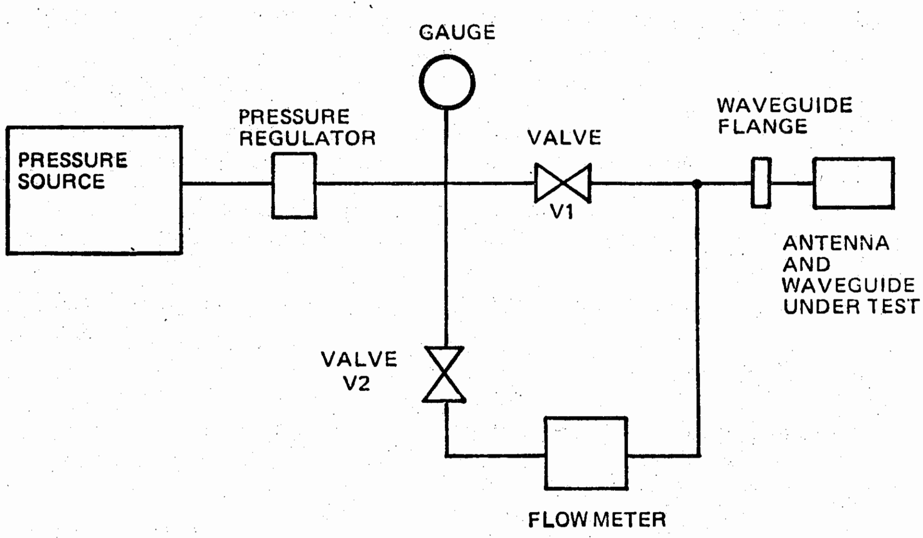


Figure 26 WAVEGUIDE PRESSURIZATION TEST ARRANGEMENT

7 WAVEGUIDE MAINTENANCE

7.1 The necessity to maintain the waveguide in an efficient condition cannot be over emphasized. It is the transmission line between the T/R unit and the aerial and should any losses occur then the efficiency of the radar system is impaired, e.g. maximum range reduced, storm cells not identified. Attenuation in the waveguide reduces the pulse power transmitted from the aerial and also reduces any echo signal between the aerial and receiver.

7.2 There are many points which should be considered when examining the waveguide sections. Any damage or deterioration that changes the impedance or increases the attenuation of the waveguide will affect radar performance. Since the RF current only travels on the thin conducting film of material on the inside surface of the waveguide and choke-joint flange surfaces these should present the best possible conducting properties. Corrosion of the surfaces will increase the I^2R losses thus reducing radiation. Moisture in a waveguide is particularly serious since water causes heavy attenuation and if the moisture is allowed to persist, corrosion will occur. Corrosion is extremely difficult to remove and generally necessitates renewal of affected sections of the waveguide. Maintenance practices should be aimed at preventing moisture from entering the waveguide by sealing it up using rubber sealing rings and by reducing the effect of moisture in the atmosphere in the guide. To absorb moisture content in the atmosphere in the guide, a dehydrator unit containing silica gel crystals may be fitted. The silica gel crystals should be inspected periodically to ensure they are in good condition (blue colour) and if not the dehydrator unit should be renewed. Sometimes a water drain trap is fitted to the waveguide run at a low point to collect any condensation, in which case it should be inspected periodically and emptied if necessary and should also be checked that it is not blocked. Dirt or other foreign matter on the inside surface of the waveguide will also cause attenuation and, to prevent any substance entering the guide when removing units, it is good practice to place plastic covers or bungs over the end of any open guide. Care should be taken in the handling of the waveguide since if the cross sectional dimension of the guide is altered by denting, bending, etc., a mismatch will occur causing energy to be reflected.

7.3 **Waveguide Checks.** In order to maintain the waveguide in the best possible condition, the checks outlined in the following paragraphs should be made when called for by the approved maintenance schedule or when the waveguide is dismantled into sections.

7.3.1 Visually check that no damage such as dents, cracking, distortion, etc., has occurred and that no cracking has occurred where the flanges join the waveguide.

7.3.2 Inspect the condition of the inner surface and flange surfaces, checking that no corrosion has occurred and that all the surfaces are clean, that no scratches are evident and that a good conducting surface exists.

7.3.3 For a flexible waveguide, in addition to the checks of 7.3.1 and 7.3.2, a check should be made to ensure that no perishing or cracking of the outer rubber bonding material has occurred and that the bonding of the rubber to the flanges is satisfactory. A check should be made to ensure that there are no internal breaks by gently flexing the guide and at the same time checking for even flexing along its length. Care must be taken not to overstrain the guide when making flexing checks. Some types of flexible waveguide must not be twisted. If the guide is of a twistable type it should be gently twisted to check that there are no internal breaks.

7.3.4 All rubber sealing rings should be checked to ensure that there is no perishing, hardening or cracking. Any bulkhead coupling seals should be checked for cleanliness and to ensure that there are no cracks, holes or other forms of damage.

7.4 **Waveguide Installation.** The precautions detailed in the following paragraphs should be observed with respect to the waveguide installation.

7.4.1 In general, the waveguide run should be as short as possible to reduce attenuation and it should be properly supported throughout its length; it is usually recommended that the maximum permissible length should not exceed 30 feet. The waveguide must not be installed so that it is suffering any stress or strain. Special clamps will normally be specified to minimize the risk of guide distortion.

7.4.2 Use of flexible waveguide should be kept to a minimum as it has greater attenuation than rigid guide. It must not be installed so that it is overstrained, i.e. bent or twisted too much, and it must not rub against the structure of the aircraft. Flexible guide is normally specified where relative movement between items of equipment occurs: a check should be made to ensure that the required degree of freedom of the moving parts is not restricted by the guide.

7.4.3 Dehydrator units are sometimes fitted to waveguide runs and in such cases a serviceable unit must be fitted on completion of the installation.

7.4.4 If for any reason the waveguide is opened, plastic covers should be placed over the flanges to prevent the ingress of foreign matter, e.g. dirt, sand, oil. Before trying to re-install the waveguide, a check should be made to ensure that any plastic covers have been removed, otherwise damage may result.

Issue 2.

December, 1979.

AIRCRAFT

RADIO

RADIO WORKSHOPS—BASIC FACILITIES

1 INTRODUCTION

1.1 An organisation may be approved to certify that overhauls, repairs, modifications, replacements, inspections and tests to aircraft, engines, items of equipment or components thereof have been carried out in conformity with acceptable standards/specifications and CAA Requirements, subject to compliance with the procedures in Section A, Chapter A8-3 of British Civil Airworthiness Requirements.

1.2 This Leaflet gives guidance on the basic facilities necessary for radio workshops which are established for the overhaul, repair, modification and inspection of airborne radio and radar equipment, also for the manufacture of interfacing cable harnesses, racking, junction boxes and switch boxes forming complete installations in aircraft. Information is also included on documentation and records used in workshops.

2 GENERAL

2.1 Radio workshops can be categorised into two groups, namely those which are established as an adjunct to an approved Maintenance Organisation of an airline solely to maintain that company's equipment and those which are set up independently by Organisations other than an airline, and which, generally, are more extensive and have a much wider scope especially in respect of overhaul facilities.

2.2 It follows that in an airline radio workshop there will be a high degree of standardisation and specialisation. In addition, the resources of the company may include approved electrical and instrument workshops capable of handling such items as rotary transformers, blower motors, synchro and servo-mechanisms, and delicate instruments for which the radio workshop may not be equipped.

2.3 It frequently happens that where workshops are established as part of an airline maintenance organisation, they become encumbered with equipment, racks, cables and other items all requiring technical attention but which could properly be dealt with in a separate workshop within the maintenance area. It is, therefore, recommended that a separate radio workshop should be set up to handle such items as:—

(a) Operating checks on equipment prior to installation in aircraft.

(b) Verification of reported defects.

(c) Storage of serviceable equipment removed from aircraft undergoing extensive servicing checks.

(d) Servicing of racks, cable harnesses, aerials and other associated items during the general course of maintenance.

2.4 The following Leaflets contain information associated with the subject covered by this Leaflet, and reference should be made to these as appropriate.

BL/1-7	Storage Conditions for Aeronautical Supplies
BL/1-8	Maintenance and Certification of Aircraft
RL/3-2	Workshops—Test Equipment
MMC/1-1	Printed Wiring Boards
MMC/1-2	Printed Wiring Board Repairs

3 ELECTRICAL AND RADIO INTERFERENCE Radio workshops situated on airports and close to hangars, air traffic control buildings, ground radio stations and electrical installations will inevitably be subjected to a considerable amount of radio and/or electrical interference, sufficient at times to seriously affect the testing of sensitive receivers. In addition, the tuning and testing of transmitters into watt-meters and artificial aerials may result in the generation of further interference. It should, therefore, be determined at an early stage whether incoming or outgoing interference is being experienced and suitable suppression and screening should be provided.

3.1 Incoming interference can be dealt with by adequate filtering of all power supplies and by the provision of screened cages. Further information may be obtained from Leaflet **RL/2-3.**

3.2 Outgoing interference can be suppressed by the adequate screening of aerial cables and made-up artificial aerials, or by operation of transmitters inside screened cages. Further information may be obtained from Leaflet **RL/2-3.**

3.3 Engineers must listen out on the transmitter frequency before switching-on and announce the identity of the workshop.

4 PREMISES The premises selected for a radio workshop should provide a stable environment appropriate to aircraft radio equipment maintenance. Corrugated type roofing should be avoided; if, however, this is not possible consideration must be given to sealing and the fitting of false ceilings. There should be no pollution of the air by dust caused, for example, by aircraft engines running-up, by dope or paint spraying operations or by corrosive agents caused by battery charging. In areas where dust-laden air is frequently encountered or in areas of habitual high humidity, air conditioning plant should be installed, particularly in the stores area and assembly and test bay areas. The radio workshop should also be sited such that no unacceptable electrical interference is present in the radio test area (see paragraph 3).

4.1 The overall lighting intensity should be commensurate with the work to be done, particularly so in the region of the detailed inspection areas. Except for positions where exposed rotating machinery will be operating, the lighting may be of the fluorescent type, provided that it is correctly installed and maintained.

4.2 The building should not be prone to dampness and should be heated, preferably by electricity or steam/hot water central heating. The use of solid fuel or oil heaters is not recommended.

4.3 The workshop and its furnishings should be constructed of materials which assist the maintenance of a clean environment. Concrete and unpolished wood floors should be covered or sealed and painted so as to minimise dust.

4.4 Accommodation separate from the radio workshop should normally be provided for the following:—

(a) Quarantine and bonded stores.

NOTE: Special precautions are necessary for the storage and handling of magnetrons and radio-active valves. Magnetrons should be stored in cupboards remote from any equipment, instruments and components, which may be affected by a strong magnetic field.

(b) A store for items of equipment, test panels, instruments, etc., not immediately required.

(c) Battery compartment (when required).

(d) Office equipment, including record system.

(e) Stripping and cleaning bay.

4.5 In addition to the provision of adequate storage space, the main workshop should be segregated on the following lines.

(a) A zone for racks or cupboards for unserviceable equipment. Two classes of unserviceable equipment need to be catered for, firstly items which are awaiting initial inspection prior to being fed into the workshop, and secondly those items on which some work has been completed but which are held up for lack of spares or information. Unserviceable equipment of either class may, in fact, be stored in the quarantine store and, where workshop space is limited, such an arrangement may be preferable. The use of cupboards or anti-static covers for each class of equipment is essential.

(b) A zone for benches suitable for working, inspection and testing.

(c) A zone for covered dust-free benches for instrument assembly.

(d) A zone for technical manuals, bulletins, specifications, modification leaflets and drawings.

(e) A storage zone for fluids, lubricants, pastes, varnishes and general stores.

(f) A zone for staff personal possessions.

5 **TEST BENCHES** Where several benches are to be provided with common power supplies, each bench should have an independent control of the d.c. supply with a voltmeter and ammeter of sufficient accuracy permanently connected to the supply. An earth rail of substantial cross section and having a very low resistance to earth should be provided in addition to the 240-volt main supply earth. All mains wiring should be run through metal conduits and provided with 3-pin outlets. Individual power supplies, from a central source, to each bench should be protected by circuit breakers or fuses but power supplies other than the a.c. mains supply may be protected at the test installations, thus avoiding very large main fuses or circuit breakers.

5.1 Test benches may be designed for working on one type of equipment or of a composite type covering several types of equipment. In the latter case it is usual to provide storage space on or near the bench for the different types of connecting harness. Test installations may also be attached to removable panels of a standard size, thus allowing benches to be adapted to suit different requirements.

5.2 Test instruments should either be placed on raised shelves on the benches to permit ease of adjustment and viewing, or they may be carried on portable trolleys. Depth of worktops should be compatible with the size of equipment to be worked on. Additional space should be provided where installations require the use of back plates with edge connectors or separate plugs and sockets at the rear of the equipment under test.

6 POWER SUPPLIES

6.1 **General.** Where the different supplies terminate in sockets, the use of dissimilar sockets is recommended, with each being clearly identified. It is recommended that, where possible, specialised precision power be supplied by individual bench-mounted supply units. Where this is not possible it should be provided as detailed in the following paragraphs, and should be distributed through the workshop with minimal mutual interference. Monitoring of voltage, frequency and current should be provided at the test benches.

6.2 The power supplies described in (a) to (d) should be made available in most radio workshops.

(a) A 240-volt 50 Hz, single-phase a.c. supply for lighting, heating, mains rectifiers, test instruments, soldering irons and other equipment. This supply should be wired throughout in screened conduit.

(b) A 15-volt and a 30-volt d.c. supply regulated at source under varying loads, the current capacity of the cables being determined by the size of the workshop. These supplies may be obtained from a series of secondary batteries of sufficient capacity and may be charged by mains rectifiers. The output should be ripple free and should be filtered to exclude noise and to reduce transient voltage peaks liable to damage the most sensitive equipment, e.g. transistors, integrated circuits and equipment wiring. It is possible to dispense with the use of batteries by utilising a suitable ripple-free stabilised d.c. power supply unit. To minimise voltage loss along the supply lines the d.c. supply should be run in a heavy duty cable. It should also be possible to vary the voltage at the bench positions so as to enable high/low voltage tests to be carried out to the prescribed limits.

NOTES: (1) A common negative cable may be used for the 15-volt and 30-volt supplies.

(2) Cognisance should be taken of prevailing wind direction relative to the workshop and stores, and the battery room ventilation system, to prevent contaminated air gaining access if battery supplies are to be used.

(c) A 19-volt d.c. stabilised supply for the testing of certain equipment; this is best supplied by individual precision supply units.

(d) A 200-volt 400 Hz, three-phase regulated supply, wired to the benches in screened cable, to provide the following precision a.c. bench supplies:—

(i) 115-volt, 400 Hz, single-phase,

(ii) 115-volt, 400 Hz, three-phase,

(iii) 26-volt, 400 Hz, single-phase.

A frequency meter is necessary where the frequency has to be monitored to within ±3 Hz. As an alternative method of supply, individual static invertors can be wired to benches as required.

7 ANCILLARY SUPPLIES

7.1 **Compressed Air.** A low pressure air supply should be provided for blowing out inaccessible dust from the more robust equipment and components and for use in connection with the assembly of instruments (paragraph 9.1.1). The compressed air may be derived from an extension of a main air supply, but must be filtered and dry.

7.2 **Vacuum Supply.** A vacuum cleaner with a small flexible nozzle should be provided for removing dust from delicate equipment and sub-assemblies in the workshop.

7.3 **Test Installations.** Installations specially designed for the operation of certain items of equipment during fault finding and final tests should be provided. Such installations normally include connectors and cable harnesses made up into a back-plate or connected to the rear of the equipment under test by edge-connectors or individual plugs and sockets. No side members or mounting trays should normally be used unless it is impractical to do without; for example, where the connectors are of the sprung-ball-and-socket type, which require a continual pressure to be exerted to maintain electrical contact. Instruments used as part of the test installation should be of a proven accuracy, certified and marked accordingly, together with the period of validity.

7.4 **Power-Unit Test Rigs.** Special rigs should be provided for measurement of power-units, blower motors, switch drives and step-by-step motors. The rigs will also be required for testing on prolonged running and for bedding-in of brushes.

7.4.1 The essential equipment to be fitted to such test rigs are a.c. and d.c. voltmeters and ammeters, frequency-measuring indicators, tachometers and equipment for applying resistive loads. An oscilloscope or similar device may be necessary where ripple voltage needs to be measured.

7.4.2 Where it is necessary to load power-units by means of switched fixed-resistors, continuously-variable rheostats or by controlling the grid circuit of a suitable power-output valve, the high-tension supply should be derived from the unit under test.

7.4.3 Where certain units, such as switch drives, require a torque test, testers should be provided.

NOTE: Testers made locally should be calibrated using an accurate spring balance.

8 SPECIALISED EQUIPMENT TESTING Airborne equipment of a specialised nature, such as VOR/ILS, DME, Transponders, Doppler and weather radar may need to be tested only at specially equipped bench positions. Careful planning of these positions in relation to the total working area is necessary and careful siting of such benches may be necessary to avoid radio interference with other equipment being tested at other positions.

8.1 **Certification of Radio Equipment.** To enable certification of radio equipment following workshop repair, modification and test, it will be necessary to provide the following:—

(a) Test installations with the necessary harness incorporating the required test points, switches, jacks, etc., as specified in the equipment Overhaul Manual.

(b) Certified test equipment as specified in the equipment Overhaul Manual. Appropriate technical manuals for this test equipment will also be required. For further information on test equipment see Leaflet **RL/3-2.**

(c) Tools, lubricants, solvents and accessories, as specified in the equipment Overhaul Manual.

8.1.1 Procedures should be introduced to control the use of lubricants, solvents, etc. other than those specified in the equipment Maintenance and Overhaul Manuals. The use of such products should only be authorised after appropriate expert advice has been sought.

8.2 Where repair work to be undertaken includes printed circuit boards, a selection of suitable tools should be provided. For information on the repair of printed circuit boards see Leaflet **MMC/1-2.**

9 RADIO INSTRUMENTS The term "radio instruments" is taken, in general, to mean those instruments which operate independently of non-radio aids and flight systems but may include instruments such as radio magnetic indicators where arrangements are made for an approved instrument shop to carry out and certify work on the compass card synchro.

9.1 **Instrument Overhaul**

9.1.1 A small work bench should be provided for the dismantling, inspection, re-assembly and testing of radio instruments. The bench should be fitted with a dust-proof enclosure in the form of a detachable or hinged cover of laminated glass with a gap at the front sufficient for the operator to insert his hands for assembly and sealing work.

(a) A filtered and dried compressed air supply should be available to be brought in at the back of the enclosure to operate at a pressure slightly higher than ambient, and thus provide a means of sealing the cabinet from the ingress of foreign matter. A mirror held up to the air nozzle will show whether or not condensation takes place, and thus determine if the air is dry enough.

9.1.2 Covered trays should be provided for storage of exposed parts of equipment awaiting inspection.

9.1.3 Where instruments are required to be hermetically sealed, the process must be carried out in accordance with the manufacturer's specification.

10 DOCUMENTATION AND RECORDS The minimum documentation and records which is normally required to be provided is described below:—

(a) Worksheets on which the work to be carried out during inspection, modification, overhaul or repair is detailed. For overhauls, a separate sheet may be provided in which the standard overhaul work involved on a particular unit is itemised, the worksheet then being used to call up any additional work found necessary on initial inspection.

(b) Performance sheets on which results obtained during electrical and electronic testing is recorded. Such sheets are also used to record the specification number to which the unit has been tested.

(c) Modification records on which are listed all modifications which have been embodied and those required on the worksheet to be embodied.

(d) Certificates of Compliance which are required to be issued in accordance with Section A Chapter **A4-3** of British Civil Airworthiness Requirements (BCAR). This certification can, in particular organisations, be part of the worksheet and/or performance sheet described above.

(e) Status identification tags or labels for attachment to equipment during storage and transit. These tags or labels normally give details of the equipment including part numbers, serial number, modification status, life used since overhaul, workshop job reference number, related approved certificate number and brief details of work carried out.

(f) Records of all tests and calibrations made on test equipment. Such equipment is normally returned to approved test houses annually and calibration certificates obtained.

(g) The retention of documents is covered in section A, Chapter **A4-3** of BCAR.

(h) **Technical Publications.** Technical publications for workshops are covered in the approval procedures. The following are normally provided for use in radio workshops:—

(i) British Civil Airworthiness Requirements, Sections A and R.

(ii) Civil Aircraft Inspection Procedures.

(iii) Technical descriptive literature and operating manuals of test equipment.

(iv) Maintenance, overhaul and repair manuals.

(v) Spare parts catalogues.

(vi) Modification leaflets and bulletins.

(vii) Servicing leaflets or bulletins, where applicable.

(viii) Such mechanical and electrical specifications as are not included in radio equipment manuals and which may be required for overhaul of specialised components and accessories.

The publications have to be supported by an amendment service and periodical checks also have to be made to ensure that all literature in the library is, in fact, up to date.

GOL/1-1

Issue 1.

18*th November*, 1977.

AIRCRAFT

GROUND OPERATIONS

AIRCRAFT HANDLING

1 INTRODUCTION This Leaflet describes the ground handling tasks which may be necessary during the normal day-to-day operation of an aircraft, and details the procedures and precautions which are generally specified. These tasks vary considerably according to the size and type of aircraft concerned and the layout of the aircraft systems; this Leaflet should, therefore, be read in conjunction with the appropriate Maintenance Manual, where information relating to the particular aircraft will be found.

1.1 A number of Leaflets concerned with various aircraft systems and components, and which also contain information on aircraft ground handling, will be found in Part II of CAIP; these Leaflets should be referred to as necessary.

2 GENERAL The tasks which may be required to be carried out on an aircraft between flights, apart from routine maintenance, cover a variety of subjects, and these are dealt with separately in paragraphs 3 to 8 in this Leaflet. Special ground equipment is often required to enable these tasks to be carried out satisfactorily; in the case of light-aircraft operations this equipment may be of a very rudimentary nature, but when dealing with large transport aircraft more sophisticated equipment may be necessary. Reference to ground equipment will be made in this Leaflet, but the operation and maintenance of the equipment will be dealt with in leaflet **GOL/1-2** when this is issued.

2.1 Preparations for the reception of an aircraft should be made in advance of its arrival. The positioning of aircraft in the reception area should be arranged so that access paths to the aircraft are available for all replenishing vehicles and for the loading and unloading of passengers or cargo as applicable. All equipment likely to be required for the servicing of an aircraft should be readily available and should be in a fully serviceable condition.

2.2 When an aircraft has to be moved into a hangar in order to allow servicing operations or maintenance to be carried out, it should be positioned so as to avoid obstructing access to other working space or necessitating disturbance before the work is complete. Account should also be taken of the location of all necessary facilities such as weighing platforms, electric and pneumatic power sources, and lighting, and of the necessity for providing docks or platforms to enable the work to be carried out.

3 TOWING It is often necessary to move an aircraft without starting the engines, in order to position it for servicing or to enable passengers or cargo to be loaded, and if this operation is not carried out properly, severe damage can be caused to the aircraft. Should it be necessary to call upon the assistance of untrained or inexperienced persons to move the aircraft, the person taking charge should instruct them adequately before starting and ensure that they fully appreciate what they are required to do. Paragraphs 3.1 and 3.2 contain general information on the towing of aircraft and the precautions to be observed, but detailed information relating to the movement of a particular aircraft will be found in the manufacturer's Maintenance Manual for the aircraft concerned.

3.1 **Light Aircraft.** Great care should be exercised when manhandling light aircraft, particularly those constructed from wood and fabric.

3.1.1 On aircraft having a nose-wheel landing gear, a steering arm should be fitted to the nose wheel to guide the aircraft, and force should be applied only to those parts of the structure which are designed to accept it. Force should not be applied to trailing edges of wings or control surfaces, to streamlined wires, or to areas which are marked to prohibit the application of force; an engine should always be regarded as 'live', and, therefore, a propeller should not be used to push or pull the aircraft.

3.1.2 Generally speaking it is better to push an aircraft backwards rather than forwards, since the leading edges of the wings and tailplane are stronger than the trailing edges, but the struts and undercarriages on some aircraft are suitable for pushing the aircraft forwards. The flat of the hands should be used when pushing, so as to spread the load over the largest area, and when pushing on struts or undercarriages the force should be applied as near to the end fittings as possible.

3.1.3 On aircraft with a steerable nose wheel connected to the rudder pedals, care must be taken not to exceed the turning limits, which are normally marked on the nose undercarriage leg. On this type of aircraft it is also important that the rudder controls are not locked during towing operations.

3.1.4 On aircraft which are fitted with a tail skid instead of a tail wheel it is customary to raise the tail by lifting on the tailplane struts near to the fuselage fittings, so that the aircraft is balanced at the main wheels; the aircraft may then be pushed backwards as required. On some aircraft it may also be advisable to place the propeller in a horizontal position, to prevent it striking the ground when the tail is lifted.

3.1.5 When towing a light aircraft by means of a tractor, the correct tow-bar should be connected between the towing attachment at the base of the nose undercarriage leg and the tractor, and a person familiar with the aircraft brake system should be seated in the cockpit/cabin to operate the brakes in an emergency; the brakes should not normally be applied unless the aircraft is stationary. Once the tow-bar is connected, the brakes, and where fitted the rudder lock, may be released, and the aircraft towed forwards at a safe speed, depending on conditions in the vicinity. A close watch should be kept on the wing tips and tail, particularly in confined spaces, to ensure that they do not come into contact with other stationary or moving objects. Care should be taken when negotiating bends, to prevent the limits of nose-wheel movement being exceeded.

3.1.6 In circumstances where the ground over which the aircraft has to be towed is either boggy or very uneven, the strain imposed on the nose undercarriage may be excessive, and it may be necessary to tow the aircraft by means of bridles attached to each main undercarriage. If towing attachments are not provided on the main undercarriage legs, ropes should be passed carefully around the legs as near to the top as possible, and avoiding fouling on adjacent pipes or structure. A separate tractor should be connected to each main undercarriage, and steering should be carried out by means of a steering arm attached to the nose wheel rather than by differential movement of the tractors.

3.2 **Large Aircraft.** Large multi-engined aircraft are usually moved by towing with a tow-bar attached to the nose undercarriage leg, a special tug often being required to provide sufficient tractive effort. The tow-bar is fitted with a shear-pin or bolt, which will shear at a predetermined load to prevent excessive force being applied to the nose undercarriage.

3.2.1 The centre of gravity (C of G) of the aircraft must be determined before towing, to ensure that there is sufficient weight on the nose wheel. Adverse fuel distribution, and the aircraft being in a non-standard condition (e.g. with an engine removed), could affect the C of G position, and a maximum aft limit is generally specified in the relevant Maintenance Manual. Ballast may sometimes be required to achieve a safe C of G position, but the maximum towing weight must not be exceeded.

3.2.2 Before towing is commenced the undercarriage ground locks should be installed, the steering should, if applicable, be disconnected or disabled (usually by removing a steering disconnection pin, by inserting a lock-out pin, or by tripping the associated circuit breaker), and the nose undercarriage shock absorber should be checked for normal extension. In addition, the brake pressure should be checked and, if necessary, built up to the minimum safe pressure (this is often accomplished by operation of an electrically-driven hydraulic pump, which must be used sparingly to prevent the motor overheating). If it is likely to be necessary to turn the nose wheel through a greater angle than the prescribed steering limits, the nose wheel is usually freed by removing the apex pin from the torque links, thus allowing the nose wheel complete freedom of movement, but particular attention must be paid to any limits imposed on aircraft having bogie undercarriages.

3.2.3 When towing the aircraft, two qualified pilots or suitably trained and authorized members of the towing crew should be stationed in the cabin, to operate the brakes and any other aircraft systems which may be required, and to keep a look-out and monitor progress. These persons should be in telephonic communication with the outside ground crew and with the tractor driver. Ground crew should be located at the wing tips and tail to guide the aircraft past any obstructions, and one person should be in overall control of the operation.

3.2.4 The aircraft brakes should be released before the tractor moves off, and towing-speed should be kept down to a safe speed. The radii of turns should be kept as large as possible, to minimize tyre scrubbing and twisting loads on the main undercarriage legs, and care should be taken not to exceed any towing-force limits which may be specified in the relevant Maintenance Manual for various nose-wheel steering angles. Before stopping, the aircraft should be towed in a straight line for a short distance in order to remove any tyre stresses imposed by turning. Once stationary the aircraft brakes may be re-applied, the tractor and tow-bar may be removed, and the nose-wheel steering links refitted and safety locked.

3.2.5 In circumstances where the towing load exceeds the nose-wheel limitations, towing bridles should be attached to the main undercarriage legs and the aircraft should be towed using two tractors, one connected to each main undercarriage leg. A steering arm attached to the nose wheel should be used for steering purposes. Where no special towing attachments are provided, it will often be necessary to remove the fixed doors from the main undercarriage legs to permit attachment of the towing bridles.

3.2.6 In an emergency it may be necessary to move an aircraft from a runway while it has one or more deflated tyres. Provided that there is one sound tyre on an axle the aircraft may be towed to the maintenance area, but sharp turns should be avoided, towing speed should be kept to an absolute minimum, and brakes should be applied very carefully. If an axle is not supported by a sound tyre, however, the aircraft may only be moved the shortest distance necessary to clear the active runway and the wheels with deflated tyres must be removed and serviceable components fitted before towing is continued. After any tyre failure the associated wheel must be inspected (see Leaflet **AL/3-19**), and it may also be necessary to inspect the wheels and tyres which have not failed if the aircraft has landed or been towed with a deflated tyre.

4 PARKING AND PICKETING When an aircraft is out of service and in the open, it should be secured against inadvertent movement and protected against adverse weather conditions. The operations which are recommended in the relevant Maintenance Manual depend on the type of aircraft, the length of time it will be out of service, and the prevailing or forecast weather conditions.

4.1 Between flights it is usually sufficient to apply the parking brakes, lock the control surfaces, and chock the wheels, but in a strong wind light aircraft should be headed into wind. Light aircraft without wheel brakes should be headed into wind and their wheels should be chocked front and rear.

4.1.1 Flying controls on many aircraft are locked by movement of a lever in the cockpit/cabin, which is connected to locking pins at convenient positions in the control runs or at the control surfaces. When this type of lock is not fitted, locking attachments may have to be fitted to the control column and rudder pedals, but a more positive method which is frequently used on older or elementary aircraft, is the fitting of external control surface locks, which prevent control surface movement and thus prevent strain on the control system. All external locks should have suitable streamers attached, to make it visually obvious that the locks are fitted.

4.2 If an aircraft has to be parked overnight or for longer periods in the open, then additional precautions should be taken to guard against the effects of adverse weather. The undercarriage ground locks should be fitted, all openings such as static vents, engine intakes and cooling air intakes should be blanked to prevent the ingress of dirt, birds, insects and precipitation, and all fittings such as pitot heads and incidence indicators should be covered. When severe weather is expected it is recommended that cockpit/cabin covers and wheel covers are also fitted. Blanks and covers for all these components are specially designed for the particular aircraft and, if not visually obvious, are fitted with streamers to guard against their being left in position when the aircraft is prepared for service; servicing instructions should, however, include a pre-flight check to ensure that all covers and locks have been removed.

4.3 Light aircraft should normally be tied down when parked overnight or longer, but this is not usually necessary with large aircraft unless particularly strong winds are expected.

4.3.1 Light aircraft are fitted with picketing rings (or positions for the attachment of picketing rings) at the wings and tail and, on some aircraft, adjacent to the main undercarriage legs. The aircraft should be parked into wind and secured from the picketing points to suitable anchorage points on the ground (heavy concrete blocks or screw pickets). Cable or nylon rope of adequate strength should be used if possible, but if rope made from natural fibres is used, sufficient slack must be left to allow for shrinkage in damp conditions. Additional picketing from the undercarriage legs may be recommended in strong wind conditions and, if so, care should be taken not to damage any pipelines or equipment attached to the legs or wheels.

4.3.2 Large aircraft only require picketing in very strong wind conditions. The aircraft should be headed into wind, the parking brakes should be applied (unless pre-loaded main-wheel chocks are recommended) and cables should be attached from the aircraft picketing points to prepared anchorages. In some cases the picketing cables are special components, and include a tension meter which is used when applying a pre-load to the cable.

4.4 For helicopters, in addition to the actions outlined in paragraphs 4.1 to 4.3, the rotor blades should be tethered whenever possible, since even light gusting winds can cause damage to blades which are free to flap. The collective pitch lever should normally be locked in the fully fine position, and the rotor brake applied. Rotor head and blade covers should also be fitted if the helicopter is parked overnight, and if high winds are expected it should be hangared or the rotor blades should be folded.

4.4.1 On many helicopters the main rotor blades are tethered by aligning one blade along the tail cone, locking the collective pitch lever in fine pitch, and applying the tip covers to each blade, pulling them against the damper stops. Each blade may then be lashed to its respective picketing point, but care must be taken not to pull the blades down excessively; the relevant Maintenance Manual will generally stipulate a maximum distance from the normal drooped position, and this must not be exceeded. The tail rotor is generally tethered by fitting the blade covers and securing them to the associated picketing point or tail skid.

4.4.2 The method of folding the main rotor blades depends on the method of attachment to the rotor head and on the position of each blade; the procedure for a particular helicopter should, therefore, be obtained from the relevant Maintenance Manual. In the folded position the blade tips are generally secured by means of support cradles, which are attached to the tail cone structure.

5 JACKING An aircraft may have to be jacked up for a variety of reasons, including servicing, weighing, changing wheels, and retraction tests, and care is necessary to avoid damaging the aircraft. Jacking points are provided in the wings and fuselage to enable the whole aircraft to be lifted, and, usually, at the nose and main undercarriages to enable individual wheels to be changed. Some aircraft require a jacking pad to be fitted to each jacking point in the wings and fuselage, and adapters to be fitted to the jacks, while in other cases special stirrups or beams may be required to lift individual axles.

5.1 Because of the position of the jacking points, the centre of gravity of some aircraft may, although satisfactory for flight, fall behind the main jacking points and thus be unsatisfactory for jacking purposes. In these cases it may be necessary to add ballast forward of the main jacking points to bring the centre of gravity within limits specified in the relevant Maintenance Manual. In addition, each jacking or steadying point may have a load limit which, if exceeded, could result in structural damage. To avoid exceeding the limiting load at the jacking points it is sometimes necessary to fit hydraulic or electrical load cells (see Leaflet **BL/1-11**) to the jacks, while ballast may have to be used to avoid exceeding the loading limit at a steadying point.

5.2 Micro-switches fitted to the undercarriage legs and operated by the extension or contraction of the shock absorbers, are used to arm or disarm various electrical circuits on an aircraft. If the aircraft is jacked up these circuits will operate as required during flight, and this may not be desirable. These circuits should, therefore, be isolated by tripping the appropriate circuit-breakers or by removing the associated fuses, as necessary.

5.3 As a safety precaution, light aircraft should normally be jacked inside a hangar, but large aircraft may be jacked in the open provided that they are headed into wind and that the surface is level and strong enough to support the weight of the aircraft at the jacking points. A maximum safe windspeed for jacking is generally specified in the relevant Maintenance Manual.

5.4 The following procedure will generally ensure the satisfactory jacking of most aircraft, but account should also be taken of any additional precautions or actions specified in the Maintenance Manual for a particular aircraft. One person should be located at each jacking position and a co-ordinator should supervise the operation. On large aircraft the levelling station (paragraph 6) should also be manned, and all ground crew concerned should be in communication with the co-ordinator, headphones being used when necessary.

(a) Check that the aircraft weight, fuel state and centre of gravity are within the limits specified in the aircraft Maintenance Manual.

(b) Head the aircraft into wind if it is to be jacked in the open, chock the main wheels front and rear, and release the brakes.

(c) If jacking an aircraft in a restricted space, ensure that there is adequate clearance above every part of the aircraft to allow for its being raised, and adequate access and lifting space for cranes or other equipment which may be required.

(d) Connect earthing cables to the earthing points on the aircraft.

(e) Install the undercarriage ground locks.

(f) Fit jacking pads to the aircraft jacking points and adapters to the jacks as required. Load cells should also be fitted to the jacks at positions where a maximum jacking load is specified.

NOTE: The capacity and extension of the jacks should be adequate for the aircraft size and weight. The minimum requirements will normally be stated in the relevant Maintenance Manual.

(g) Position the jacks at each jacking point and raise them until the adapters are located centrally in the jacking pads. Care must be taken to ensure that the jacks are vertical, and that the weight is evenly distributed over the legs of each jack.

(h) Remove the wheel chocks and slowly raise the aircraft, maintaining it in a horizontal attitude as nearly as possible, until the undercarriage legs are fully extended and the wheels are a few inches off the ground. As a safety measure the locking nuts on the jack rams should be kept in close proximity to the jack shoulders as the jacks are raised.

(j) Tighten the jack ram locking nuts, and place supports under the outer wings and rear fuselage as indicated in the Maintenance Manual. The positioning of these supports is most important, as they are usually shaped to fit the undersurface of the wing or fuselage and must be located at a strong point such as a rib or frame; they are not intended to support the weight of an aircraft.

5.5 A 'bottle' jack and an adapter or special fitting are often used when raising a single undercarriage or part of a bogie beam for the purpose of changing a wheel. The remaining wheels should be chocked front and rear to prevent aircraft movement, and it may sometimes be specified that a tail support is located at the rear fuselage jacking point when raising a nose undercarriage. The jack should be raised only sufficiently to lift the unserviceable wheel a few inches clear of the ground (lowering the tail support, when applicable, as the jack is raised). Any applicable safety precautions outlined in paragraph 5.4 should be observed.

5.6 Before lowering an aircraft to the ground, all ground equipment, work stands, supports, etc., should be moved clear of the aircraft structure to prevent inadvertent damage, and the wheels should be rotated by hand to check that the brakes are free. The jacks should be lowered slowly in unison, by opening their pressure release valves, and, to guard against failure of a jack, the locking nuts on the jack rams should be unscrewed while the jacks are lowered and kept within 50 mm (2 in) of the jack heads. The jacks should be fully lowered after the aircraft is resting on its wheels and the pressure release valves should be closed. Chocks should then be placed in position, the jacks, jacking pads and adapters should be removed from the aircraft, and any electrical circuits which were disarmed as a safety measure should be reinstated.

NOTE: Undercarriage shock absorbers occasionally stick in the extended position, and care should be taken not to leave any equipment in a position beneath the aircraft where it could cause damage, until it is certain that the shock absorbers have compressed.

6 LEVELLING For some purposes, such as rigging or weighing, an aircraft must be levelled laterally and longitudinally, and a number of different methods may be employed.

6.1 **Spirit Level.** Many aircraft are levelled by use of a spirit level, which is placed at jigged positions on the airframe structure. On light aircraft the longitudinally level position is generally obtained by placing the spirit level on two pegs or on the heads of two partially withdrawn screws on the side of the fuselage, and adjusting the jacks (or the shock absorber extension or tyre pressures, if the aircraft is resting on its wheels) until the spirit level is centred. The laterally level position is obtained by placing the spirit level on the centre-section spar boom (or other nominated position), and again adjusting the jacks or tyre pressures until the level is centred. With some large aircraft a spirit level may be used in conjunction with special fittings, which are secured to locations in the centre fuselage or in one of the wheel bays; these fittings must be removed before flight and should have warning streamers attached. If adjustments have been necessary to level an aircraft laterally, the longitudinal level should be re-checked.

NOTE: In cases where tyre pressures are adjusted to level the aircraft, care must be taken not to over-inflate or to completely deflate a tyre.

6.2 **Plumb Bob.** On many aircraft a plumb bob is used in conjunction with a levelling plate. The plumb bob is suspended from a fixed position in the cabin roof or upper part of a wheel bay, and hangs over a levelling plate, which may be a permanent fixture or a separate fitting accurately located on the cabin floor or lower part of the wheel bay. The levelling plate is marked with a zero position and scales indicating the adjustments required about the lateral and longitudinal axes to centre the plumb bob.

6.3 **Engineers Transit.** The most accurate means of levelling an aircraft is by the use of an engineers transit (theodolite) in conjunction with range poles or scales located on the aircraft's lateral and longitudinal axes. The transit is set up below the aircraft centreline and between the lateral levelling points, and levelled horizontally. Range poles or scales are then located at the four marked levelling points on the lower surfaces of the fuselage and wings. Sightings are first taken on the lateral range poles or scales, and the main jacks are adjusted until identical readings are obtained. Sightings are then taken on the longitudinal range poles or scales, and the nose jack is adjusted until identical readings are again obtained. The aircraft is then considered level and the transit can be removed.

NOTE: The transit method is also employed when checking alignment of the aircraft structure, graduations on the range poles being used to check dihedral and incidence.

7 SERVICING Servicing may often be carried out in a crowded environment and must be properly organized to ensure that the necessary operations are carried out, to provide adequate safety to passengers and ground crew, and to protect the aircraft from damage. The procedures and precautions generally applicable to the routine servicing of aircraft are dealt with in the following paragraphs.

NOTE: For the purposes of this Leaflet, the term 'servicing' means those operations which are required to check and replenish an aircraft's systems, and to maintain an aircraft in an operational condition. In cases where an aircraft Maintenance Manual is produced in accordance with ATA Specification 100, detailed information on servicing operations will be found in Chapter 12.

7.1 **General.** The maintenance of a satisfactory surface contour and finish on an aircraft is most important, and care is necessary to prevent damage to the outer surfaces and to access panels and fasteners. Walkways are provided on the wings of many aircraft for access to the cockpit/cabin or for servicing purposes, and areas which must not be trodden upon, pushed or pulled, are clearly marked. Mats and suitable rubber footwear must be used when it is necessary to walk on the wings, and every precaution should be taken to prevent damage by tools or servicing equipment. It is also advisable to wear clothing without buttons or buckles which could scratch the wing surface, and without pockets in which loose tools could be carried, since they could fall out and become a loose-article hazard.

7.2 **Ground Equipment.** Many types of ground equipment may be required during aircraft servicing, and all must be compatible with the aircraft systems on which they are to be used. The ground equipment should be kept scrupulously clean and should be maintained in accordance with a schedule recommended by the manufacturer. Delivery pipes from all liquid and gas servicing trolleys should be blanked when not in use and their cleanliness and serviceability should be checked before connection to an aircraft. Fire extinguishers suitable for fuel and electrical fires should always be readily accessible wherever an aircraft is being serviced, and should be subject to regular inspection.

7.3 **Refuelling.** The various methods of refuelling or defuelling an aircraft are fully described in Leaflet **AL/3-17**, but the main precautions to be observed are repeated here for ease of reference.

7.3.1 Before refuelling it should be ensured that the refuelling vehicle contains the correct grade of fuel, as shown at the refuelling points on the aircraft.

7.3.2 Precautions should be taken to provide a path to earth for any static electricity which may be present or which may build up as a result of the fuel flow. The aircraft and the refuelling vehicle should be earthed to a point which is known to be satisfactory, and the earthing wire on the refuelling pipe should be connected to the earth point provided on the aircraft before connecting the refuelling pipe or removing the tank filler cap. The earthing wire should remain in position until after the refuelling pipe is disconnected or the tank filler cap is replaced, as appropriate. When draining fuel into buckets, containers or tanks, these should also be bonded to the aircraft and/or the refuelling vehicle. No radio or radar equipment should be operated while refuelling or defuelling is taking place, and only those electrical circuits essential to these operations should be switched on.

7.3.3 When pressure refuelling, a float switch or fuel level shut-off valve is often used to cut off fuel flow when the tanks are full, or have reached a pre-set level. Since pressure refuelling rates are very high, failure of these components could cause a rapid build-up in pressure and serious damage to the tanks. The tanks of some aircraft are fitted with pressure relief valves which can be checked manually prior to refuelling, but when this is not the case persons engaged in refuelling operations should be prepared to shut off the supply instantly, should the automatic cut-off system fail to operate.

NOTE: When refuelling, the wheel chocks should be moved a short distance away from the tyres, to prevent them being trapped when the tyres absorb the additional weight.

7.3.4 Particular care should be taken when refuelling high-winged light aircraft, since the upper wing surface will not normally be safe to walk on and the filler cap may not be within easy reach. A step ladder or stand should be used to gain access to the filler cap and assist in preventing damage to the wing surface. Use of the steps will also facilitate correct locking of the filler cap.

7.3.5 When a spillage of fuel has occurred, care should be taken to ensure that all traces of fuel and vapour are removed. Any residual fuel should be mopped up and any fuel-soaked lagging or fabric should be removed and cleaned. The effects of the fuel on other parts such as cables, seals, bearings and windows should also be considered and the appropriate action should be taken.

7.3.6 After refuelling an aircraft it is usually recommended that fuel is checked for contamination. Drain valves are provided in the tank sumps, pipelines and filters, by means of which a small quantity of fuel may be drained into a glass jar and checked for the presence of water, sediment and microbiological contamination (see Leaflet **AL/3-17**). Because of the slow rate of settlement of water in turbine fuels it is usually recommended that the tanks are left as long as possible after refuelling before the sample is taken. With turbine-engined aircraft, samples may also be taken to determine the specific gravity of the fuel in the tanks.

7.4 **Connection of Electrical Power.** It is often necessary to connect an external electrical power supply to an aircraft, either for engine starting purposes or to permit operation of the aircraft systems and equipment. Certain precautions must be observed when connecting the external supply, to prevent damage to the aircraft electrical system.

7.4.1 Most light aircraft have direct current (d.c.) electrical systems, and although alternating current (a.c.) is provided for the operation of certain equipment it is not usual for the aircraft to have provision for the connection of a.c. external power. The external power socket is, therefore, usually for the connection of a d.c. supply, which may be provided solely by batteries or from a generator and battery set. The following actions should be taken when connecting an external d.c. supply to a typical light aircraft:

(a) Check the voltage and polarity of the ground supply.

(b) Check that the external power plug and socket are clean, dry and undamaged.

(c) Check that the external supply and the aircraft battery master switch are off and connect the external supply, ensuring that the plug is fully home in the socket.

(d) Switch on the external supply and the aircraft battery master switch, and carry out the servicing operations for which the external power was required.

(e) To disconnect the external supply, switch off the battery master switch, switch off the external supply, disconnect the external power plug, and if the aircraft electrical system is to be used (e.g. after engine starting), switch the battery master switch on again.

7.4.2 Most large aircraft are provided with multi-pin plugs or sockets, by means of which external d.c. or a.c. power may be connected into the aircraft electrical system. The external supply is usually provided by a towed or self-propelled unit, which has its own power-driven generator and can provide d.c. power at various voltages and a.c. power at a particular voltage, frequency and phase rotation. Aircraft electrical systems vary considerably, and the checks which are necessary after connecting the external power will vary between aircraft, but the following procedure is applicable in most cases:

(a) Check that the external supply is compatible with the aircraft system (i.e. it has the same voltage, frequency and phase rotation as the aircraft system), and is switched off.

(b) Check that the external plug and socket are clean, dry and undamaged.

(c) Connect the external plug/socket, ensuring that it is fully mated and secure, and switch on the external power supply.

(d) Check the voltage and frequency of the external supply on the aircraft electrical system instruments, and perform the operations specified in the relevant Maintenance Manual to engage the external supply with the aircraft a.c. system.

(e) To disconnect the external supply, disengage it from the aircraft a.c. system, switch off the external power at source, and remove the external power plug/socket.

7.5 **Connection of Compressed Gases.** Any component containing compressed gas must be handled and serviced carefully, because the sudden release of gas under pressure could have disastrous consequences. Oxygen systems present an additional hazard in that oil and grease are prone to spontaneous combustion in the presence of undiluted oxygen.

7.5.1 The gas pressure required in some components varies according to the ambient temperature, and in order to ensure that the correct working pressure is maintained, the relationship between temperature and pressure is generally presented in the form of a graph, both in the Maintenance Manual and on a placard adjacent to the charging point. In the case of tyres and shock absorbers on large aircraft the required gas pressures may vary according to the aircraft weight and centre of gravity position, and the requirements for a particular aircraft should be obtained from the relevant Maintenance Manual.

7.5.2 Since the rapid compression of a gas produces heat it will affect the gas pressure in a component; heat will be minimized by charging slowly. The sudden release of a compressed gas will have the reverse effect, i.e. lowering its temperature, and this is particularly important when deflating a tyre (see Leaflet **AL/3-18**), as ice may form and block the valve, giving the impression that the tyre is fully deflated when in fact it is still partially inflated. Prior to working on any unit from which compressed gas has been exhausted, the charging valve or valve case should be completely removed.

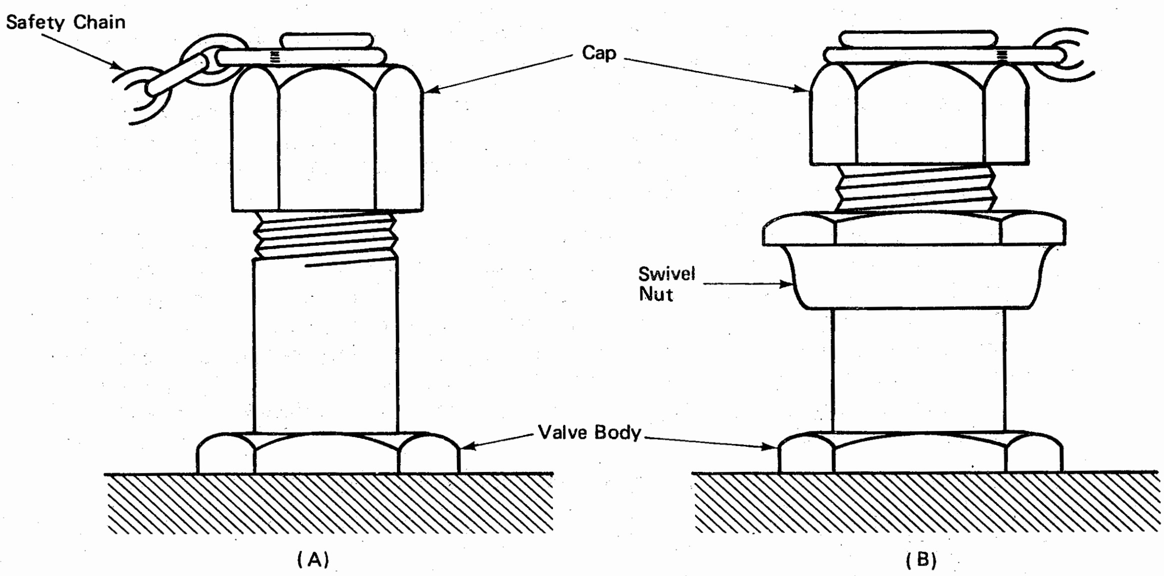


Figure 1 CHARGING VALVES

7.5.3 **Charging Valves.** The valves fitted to components which are charged with gas may be of two types. One is a needle-type valve (Figure 1(A)) which opens and closes automatically, and the other is a poppet-type valve on which the swivel-nut has to be unscrewed one full turn to release the valve stem (Figure 1(B)). A valve cap should always be fitted to prevent the entry of dirt and moisture, and should be removed only when it is necessary to charge the component or to release gas pressure. On no account should the valve body be unscrewed while the component is pressurized, since this could result in the valve blowing out and causing damage or injury.

7.5.4 **Charging Rigs.** A compressed-gas charging rig is generally a self-propelled or towed trolley, on which are mounted one or more high-pressure gas cylinders, a flexible supply hose, a supply shut-off valve, and pressure gauges showing storage cylinder pressure and supply hose pressure. Some rigs are also fitted with a pressure regulator, by means of which the supply pressure may be limited to the maximum required in the component, and this type of rig is used when the aircraft system does not have its own supply shut-off valve and pressure gauges.

7.5.5 **Charging.** Charging a component with compressed gas should be carried out carefully and the following precautions should be observed:

(a) The pressure to which the component is to be charged should be checked according to the ambient temperature, or weight and centre of gravity of the aircraft, as appropriate.

(b) The supply connection should be clean, dry and free from oil or grease; any contamination should be wiped off with a lint-free cloth moistened in a solvent such as methylated spirits.

(c) The aircraft system should be charged very slowly, so as to minimize the rise in temperature.

(d) When the required pressure is reached, the shut-off valve should be closed and the system pressure allowed to stabilize. The pressure should then be checked, and adjusted as necessary.

(e) The supply hose should not be disconnected unless the shut-off valve and the charging valves are closed, because of the dangers associated with rapid decompression. On some rigs provision is also made for relieving pressure from the supply hose before disconnection.

(f) Blanking caps should be fitted to the charging valve and supply hose as soon as they are disconnected.

(g) When charging oxygen systems, adequate and properly manned fire-fighting equipment should be positioned, and if illumination is required, explosion-proof lamps and hand torches should be used.

7.6 **Replenishment of Liquids.** On modern aircraft, replenishment of engine oil, hydraulic fluid, de-icing fluid, water, and other systems containing liquids, is achieved by the use of servicing trolleys which are specially designed for the task and are connected into the system by quick-release couplings; alternatively, and with older aircraft, these systems may be replenished by removing the tank filler cap and pouring in the required liquid. Whichever method is used, the utmost care should be taken to ensure that only the approved liquids are used, and that no foreign matter is allowed to enter the system. Servicing trolleys should be inspected regularly for cleanliness, and their delivery pipes should be capped when not in use; all utensils should be kept scrupulously clean, and should, preferably, be retained for use with one particular liquid.

7.6.1 The quantity of liquid in a system may be indicated by a sight glass, by use of a dip-stick, by its visible level in a filter fitted in the filler opening, or, in some cases, by means of a contents gauge, the transmitter unit for which is mounted in the tank. When required, the system should be replenished to the 'full' level; no system should be overfilled, as this could affect system operation.

7.6.2 Precautions applicable to the replenishment of systems containing liquid are outlined in paragraphs (a) to (d) below:

(a) Some systems are pressurized in normal use, and this pressure should be released before replenishing with liquid.

(b) When replenishing a hydraulic system, it may be necessary to pre-set the hydraulic services to specified positions to prevent overfilling (see Leaflet **AL/3-21**).

(c) Some liquids, such as methanol, synthetic lubricating oils and hydraulic fluid, may be harmful or even toxic if their vapours are breathed in or if they come into contact with the skin or eyes. Particular note should be taken of any warnings of dangers to health which may be contained in the relevant Maintenance Manuals, and the recommended procedures for the handling of these liquids should be observed.

(d) The liquids mentioned in paragraph (c) may also have an adverse effect on paintwork, adhesives and sealant, and thus inhibit corrosion prevention schemes. Care should be taken not to spill any of these liquids, but if a spillage does occur, immediate steps should be taken to mop it up and clean the affected area.

7.7 **Lubrication.** Lubrication should be carried out in accordance with a schedule approved for the particular aircraft, the intervals normally being related to flying hours, with certain positions requiring additional lubrication after ground de-icing operations (see Leaflet **AL/11-13**) and after cleaning the aircraft.

7.7.1 The lubricant to be used, and the method of application, are usually annotated on a diagram of the aircraft in the appropriate chapter of the aircraft Maintenance Manual. The method of annotation is often by the use of mimic diagrams (e.g. an oil can for oiling or a grease gun for greasing) and the type of lubricant is indicated by a symbol.

7.7.2 The utensils used for lubrication purposes should be kept scrupulously clean, and should only be filled with new lubricant. Each utensil or container should be clearly marked with the lubricant it contains, and should be kept solely for that lubricant.

7.7.3 When lubricating a component, care should be taken to ensure that the quantity applied is adequate but not excessive; in some cases a particular quantity may be specified in the Maintenance Manual (e.g. "apply 8 drops of oil . . .") but normally a quantity sufficient to cover the bearing surfaces, as evidenced by the exuding of new lubricant, should be applied. The lubricating point should be wiped clean and dry with a lint-free cloth before applying the oil or grease, and any excess exuding from the component should be wiped off to prevent the accumulation of dirt or foreign matter.

7.8 **Cleaning.** Cleaning an aircraft improves its appearance and aerodynamic qualities, helps to prevent corrosion, and facilitates the detection of fluid leakage. It is, therefore, often included in the servicing schedule.

7.8.1 **Exterior Surfaces.** Before washing down the exterior surfaces of an aircraft, all doors and windows should be closed, all apertures such as air intakes, engine exhausts, fuel jettison pipes, static vents and vent pipes should be blanked, covers should be fitted to pitot heads and sensor vanes, and transparencies should be covered to prevent contamination by cleaning fluids. The structure should be washed down using a cleaning agent recommended by the aircraft manufacturer and mixed according to the instructions provided, caked mud or other foreign matter being removed with lint-free cloth soaked in the cleaning agent. The wash should be followed by swabbing with clean water, and care should be taken to prevent cleaning fluid or water becoming trapped in parts of the structure where corrosion and seizure of mechanisms could result. The aircraft should be thoroughly dried after washing and rinsing, and it is usually recommended that lubrication should be carried out, particularly if pressure hoses have been used.

(a) If it is necessary to remove concentrations of oil or grease, a cloth moistened in solvent should be used, but chlorinated solvents should be avoided since they may be toxic. The minimum quantity of solvent should be applied, since prolonged saturation of parts may have an adverse effect upon adhesives and jointing compounds. When solvents are used, adequate fire-fighting equipment should be available.

7.8.2 **Internal Structure.** Internal structure is generally cleaned with a vacuum cleaner, but a cleaning agent and water may be used when necessary. Only a small area should be washed, rinsed and dried at a time, so as to prevent flooding of the structure and trapping of fluids in inaccessible places. Clean lint-free cloths should be used for all operations and the structure should be finally dried by circulating warm air.

7.8.3 **Engines.** An engine and its compartment should be cleaned by spraying or brushing with solvent or degreasing fluid, after first blanking all vents and apertures in such components as the magnetos and alternator. This solvent should be left on for five to ten minutes, then the engine should be washed with clean solvent and allowed to dry. All controls, hinges, etc., should be lubricated after cleaning, and the engine should not be operated until all solvent has evaporated or otherwise been removed. The precautions stated in paragraph 7.8.1(a) regarding the use of solvents should be observed.

7.8.4 **Upholstery.** Soiled carpets and seats may usually be cleaned by means of a vacuum cleaner and an approved non-flammable air-drying type cleaner or foam-type upholstery cleaner. The manufacturer's instructions for the use of these materials should be carefully followed, and soaking or harsh rubbing should be avoided.

7.9 **Cold Weather Operations.** Particular care is essential in the operation of aircraft when temperatures are likely to fall below freezing point at ground level. When snow or ice is present towing and taxying should be carried out with extreme caution and aircraft movements should be kept to a minimum; parking areas should, if possible, be cleared of snow and ice, so as to prevent aircraft tyres from freezing to the ground. If sand or grit is used to increase the tractive effort of tractors or assist the braking of aircraft, care should be taken to prevent these materials being drawn into operating engines; taxiways and hard standings should be swept to remove any sand or grit after the snow and ice have melted.

7.9.1 **After Flight.** When parking an aircraft, all covers, plugs and ground locks should be fitted as soon as possible. If the airframe is wet or affected by snow or ice, the surface under the covers should be given a light coating of anti-freeze liquid; anti-freeze liquid should not, however, be applied to the windows, since it has an adverse effect on plastics materials. Engine covers should be fitted as soon as the engine has cooled sufficiently, but in the case of turbine engines an inspection should be made for the presence of ice in the air intake, since this could melt while the engine is hot, drain to the lowest part of the compressor, and subsequently re-freeze when the engine cools, locking the lower compressor blades in ice. If ice is present it should be allowed to melt, then removed before finally fitting the covers. Drain valves in the fuel and pitot/static systems should be opened to remove any accumulation of water, and the domestic water and toilet systems and water injection tanks should be drained or treated with anti-freeze liquid as appropriate.

7.9.2 **Before Flight.** All external surfaces must be free of snow, frost or ice before an aircraft takes off, and de-icing operations should be carried out as necessary (see Leaflet **AL/11-3**). Particular care is necessary when an aircraft has been removed from a heated hangar into falling snow since the snow will melt on the warm aircraft then re-freeze as it cools down, forming a thin layer of ice which may not be easily visible. Water systems should be filled with warm water, and all covers should be kept in place until as near to departure time as possible.

8 ENGINE STARTING AND RUNNING An engine should not be ground run more often than is absolutely essential to ensure its serviceability. With a piston engine more wear takes place during cold starts than during normal operation, and with a turbine engine the engine life may be directly related to the number of temperature cycles to which it is subjected. It is, however, frequently necessary to run an engine to check its performance; in these cases and when starting an engine prior to flight, certain precautions are necessary to ensure the safety of the aircraft, of surrounding aircraft and of personnel.

8.1 **General Precautions**

8.1.1 An aircraft should, whenever possible, be headed into wind before starting its engines. This is particularly important with light piston-engined aircraft as the wind direction will affect the engine speed obtained during checks and from certain directions could produce vibration and may adversely affect engine cooling. Turbine-engined aircraft are not usually affected so seriously by wind direction, but a strong tail wind could result in increased jet pipe temperatures during starting; care should also be taken not to engage the starter of a turbo-propeller engine if the propeller is being rotated backwards by the wind.

8.1.2 An aircraft should normally be parked with brakes on and chocks in front of the main wheels. The ground immediately in front of the propellers or intakes, and beneath and behind the aircraft, should be checked for loose gravel or other foreign objects which could be drawn into the engine, cause damage to the propeller, or be blown against other aircraft, buildings and personnel. Jet blast can also have serious consequences, and diagrams will be found in the Maintenance Manuals of turbine-powered aircraft showing the extent and velocity of the blast created at various power settings, and the areas which should be kept clear of personnel and equipment. These diagrams also indicate the extent of the danger areas in front of the engines, which result from intake suction. When specified, intake guards should be fitted to turbine engines when they are run for maintenance purposes. A look-out man should be stationed in front of the aircraft, and should be in visual and/or radio contact with the cockpit/cabin crew.

8.1.3 Whenever an aircraft engine is being started, adequate fire-fighting equipment should be readily available and manned.

8.2 **Piston Engines.** Piston engines are generally fitted with electric starter motors, and an external power source should be connected to the aircraft whenever possible.

When cold, engines should always be turned at least two revolutions before being started, to free the reciprocating and rotating parts and to determine whether a hydraulic lock (oil draining into the lower cylinders) has formed. The engine should normally be turned over by hand but when this is not possible the starter may be used. The magneto switches must be 'off' when turning the engine and the engine must always be treated as 'live', in case the switches are defective and not earthing the magneto primary circuits.

8.2.1 Piston-engine installations vary considerably, and the method of starting recommended by the aircraft manufacturer should always be followed. Engine speed should be kept to a minimum until oil pressure has built up, and the engine should be warmed up to minimum operating temperature before proceeding with the required tests. High power should only be used for sufficient duration to accomplish the necessary checks, since the engine may not be adequately cooled when the aircraft is stationary. After all checks have been carried out the engine should be cooled by running at the recommended speed for several minutes, the magneto switches should be checked for operation and the engine should be stopped in the appropriate manner.

8.2.2 Extreme care is essential when starting piston engines by hand swinging. Many accidents have occurred in this way, and both pilots and maintenance personnel should be given demonstrations and be checked out on this method of starting before being allowed to hand swing a propeller. The engine must always be treated as 'live' and no part of the arms, legs or body should be moved into the propeller disc at any time. No attempt should ever be made to start an engine without someone in the cockpit/cabin to operate the throttle or brakes as necessary, or without chocks placed in front of the wheels. A set sequence of calls and responses should be used to ensure that the ground crew and the pilot are fully aware of the actions being taken.

(a) **Sucking-in.** To prime the engine cylinders, when necessary, the ground crew should stand away from the propeller, face the pilot and call "Switches off, petrol on, throttle closed, suck in". The pilot should repeat these words, carrying out the appropriate actions at the same time. The ground crew should then set the propeller to the beginning of a compression stroke and turn the engine through at least two revolutions. Starting at the position shown in Figure 2, the propeller should be swung by moving the arm (right in this case) smartly down and across the body, turning away from the propeller and stepping away in the direction of movement of the aircraft.

(b) **Starting.** The ground crew should set the propeller at the start of a compression stroke (as in Figure 2), stand away from the propeller, face the pilot, and call "Contact". The pilot should set the throttle for starting, switch on the magnetos, and repeat "Contact". The ground crew should then swing the propeller as outlined in paragraph (a). If the engine does not start, the ground crew should ensure that the magnetos are switched off before re-setting the propeller, and switched on again before making another attempt to start the engine.

NOTE: The manufacturer's manual should be referred to for the operation, during starting, of magnetos which are fitted with impulse starters or retarded contact breakers.

(c) **Blowing-out.** If the engine fails to start through over-richness, the ground crew should face the pilot and call "Switches off, petrol off, throttle open, blow out". The pilot should repeat these words, carrying out the appropriate actions at the same time. The ground crew should then turn the propeller several revolutions in the reverse direction of rotation to expel the mixture from the engine. This will usually entail swinging the propeller up from the 6 o'clock position (approximately), using the opposite hand. The throttle should then be closed, the petrol turned on, and the operations outlined in paragraph (b) continued.

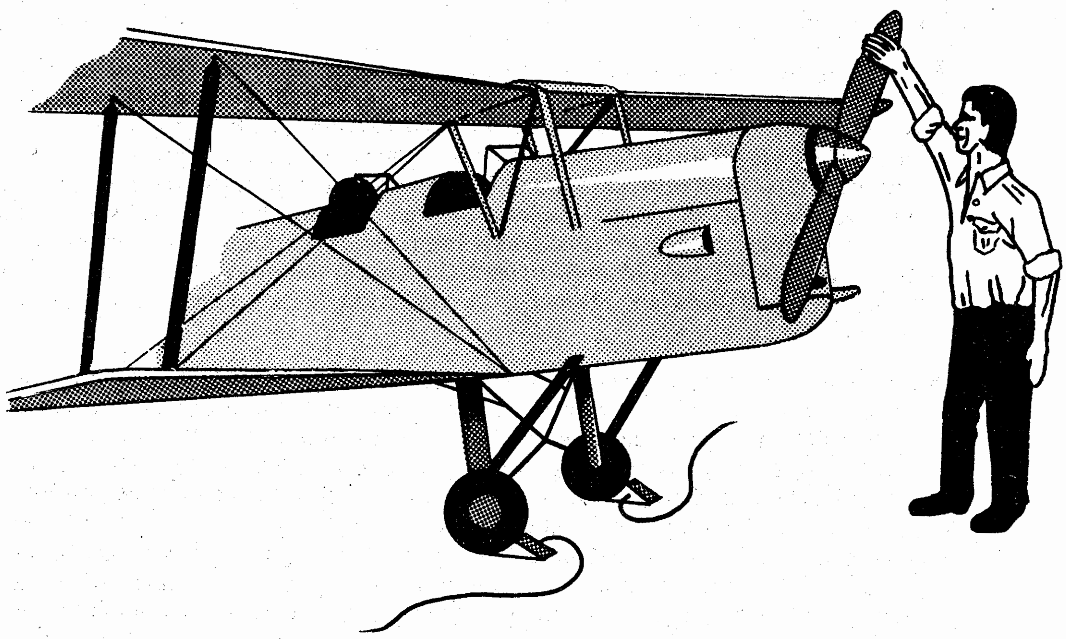


Figure 2 HAND SWINGING

8.3 **Turbine Engines.** Turbine engines may be started by an electric motor or by an air turbine, and may use either an internal power unit or an external power source to provide the necessary power. The danger areas in front of and behind the engines should be kept clear of vehicles and personnel, and if an auxiliary power unit is being used, from the vicinity of this exhaust also. Vehicles supplying electrical power or compressed air should be located in such a position that they can be moved away quickly in the event of an emergency. Qualified personnel should be located outside the aircraft and be in telephonic communication with the cabin crew, so as to be able to provide warning of situations not visible from the cabin and to prevent vehicles or personnel from entering the danger areas. Air intakes and exhaust pipes should be inspected for loose objects or debris before starting the engines. Information on the methods of starting turbine engines and the procedures for ground testing which should be adopted are contained in Leaflet **EL/3-10**.

GOL/1-2

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AIRCRAFT

GROUND OPERATIONS

OPERATION AND MAINTENANCE OF GROUND EQUIPMENT

1 INTRODUCTION This Leaflet gives general guidance on the operation and care of the ground equipment which is used during the servicing and maintenance of aircraft. Most manufacturers publish operating and maintenance instructions in respect of their equipment and this Leaflet should, therefore, be read in conjunction with the appropriate handbook or manual.

2 GENERAL The efficient ground handling of medium and large aircraft is dependent on the use of sophisticated ground equipment to supply, for example, external power for the operation of aircraft services and for engine starting. Facilities provided in hangars, and other equipment such as hydraulic system test rigs are essential for maintenance purposes.

2.1 In order to be available for instant use, all equipment of this nature should be kept serviceable and in good working order. It is recommended that all aircraft operators should employ planned maintenance schemes for their ground equipment, with comprehensive schedules and work sheets. Maintenance activities should be based on the manufacturer's recommendations and a record should be kept for each piece of equipment.

2.2 Where particular types of ground equipment and vehicles carrying ground equipment are fitted with internal combustion engines, particular care should be taken to ensure that these engines are maintained in such a condition that the possibility of sparks or flame being emitted from the exhausts is remote. For certain vehicles the use of flame-damped exhausts may be recommended.

3 GROUND POWER-UNITS The provision of external electrical power to aircraft for engine starting purposes or for the operation of aircraft systems and equipment, is normally by means of an engine-driven generator set mounted on a trailer. The engine is normally coupled to a brushless revolving-field generator, and the power-unit is provided with full controls and instrumentation. Units suitable for static installation are also available and normally comprise a motor-generator unit consisting of a brushless synchronous motor and a brushless revolving-field generator on a common shaft.

3.1 **Power Outputs.** Ground power units are typically capable of supplying a selection of power outputs such as the following:—

(a) **A. C. Outputs**

(i) 75 kVa, line voltage 200, 400 Hz, 3 phase, 0·8 continuous power factor.

(ii) 100 kVa, line voltage 200, 400 Hz, 3 phase, 0·8 power factor for 20 minutes.

(iii) 180 kVa, line voltage 200, 400 Hz, 3 phase, 0·4 power factor for 5 minutes.

(b) **D.C. Outputs**

(i) 28·5 volts:

800 amperes continuous; or
2,000 amperes intermittent.

(ii) 112 volts:

300 amperes continuous; or
1,000 amperes intermittent for 30 seconds; or
1,200 amperes peak instantaneous.

3.1.1 D.C. outputs are usually available simultaneously or independently at continuous ratings, or independently at intermittent ratings; d.c. outputs are not available at the same time as an a.c. output.

3.2 **Trailers.** The trailers, upon which the engine and generator units are mounted, are usually provided with leaf spring suspension, cable operated brakes and steerable front wheels; a suitable canopy, with transparent panels, where required, encloses the equipment.

3.3 **Operating Procedures.** It is essential that personnel who are required to use ground power-units are trained and fully familiar with the operating instructions defined in the appropriate technical manual for the equipment concerned. The following practices would be typical:—

(a) Before starting the engine, the unit should be placed on firm, level ground, the parking brake should be applied and the bonding connection should be connected to the aircraft.

(b) After starting the engine, the oil pressure should be checked and the engine should be allowed to warm up for several minutes before an electrical load is applied.

(c) Oil pressure, coolant temperature and battery charging current should be checked periodically while the engine is running.

(d) When selecting the required a.c. or d.c. power output the manufacturer's procedure should be followed.

(e) When connecting or disconnecting the external power supply to the aircraft, it must be ensured that electrical power is first disconnected from the external power line. On many ground power units a 'power on' indicator is provided to show when power is being supplied to the socket.

3.3.1 The electrical power produced by a ground power-unit is sufficient to cause damage to an aircraft and serious injury to personnel. In addition, careless use of the equipment could result in a discharge of electricity which could lead to the ignition of flammable vapours in the vicinity. It is therefore important that any safety measures contained in the manufacturer's manuals or in notices on the equipment should be observed.

3.4 **Maintenance.** A record should be kept of all ground power-unit running times, and maintenance should be carried out in accordance with the schedule drawn up for the particular equipment. During normal use, the checks outlined in paragraphs 3.4.1 to 3.4.3 should be carried out to ensure continuing serviceability of the equipment.

3.4.1 A daily inspection should include checks on coolant, oil and battery electrolyte levels, serviceability of lamps and indicators, and an examination for damage, leaks and security of attachments. Any bonding connections should be checked for condition and security.

3.4.2 Cables and aircraft connectors are subjected to hard usage and should be inspected weekly for abrasion, tears and general deterioration. The aircraft connector should be examined to check the condition of its insulation and contact tubes, and to ensure that the tubes are not proud of the insulation.

3.4.3 At monthly intervals an electrical quality check should be carried out. This should test the voltage and frequency protection units, phase rotation polarity at the output sockets and current overload. In addition, the resistance and continuity of the bonding lead should be checked.

4 AIR STARTER UNITS Air starter units are designed to start aircraft engines which are equipped with air turbine starters; they can also be used in checks on auxiliary systems, for limited air conditioning or for de-icing. The units generally consist of a turbo-charged diesel engine driving a single-stage compressor, mounted on a truck chassis and enclosed by a suitable canopy. The compressor delivers a continuous flow of warm, oil-free, compressed air. The engine is completely self-contained and has its own electrical system, starter system and fuel supply. A regulating valve controls the delivery air pressure, exhausting all air while the engine is being started (to reduce load), and thereafter maintaining a constant working pressure of 275 to 300 kN/m^2 (40 to 43 lbf/in^2) irrespective of the air take-off. A safety valve fitted to the delivery manifold opens at approximately 325 kN/m^2 (47 lbf/in^2). All instruments, controls and warning lamps are grouped on a control panel.

4.1 **Operating Procedures.** Operating procedures for air starter units will vary according to the particular design, and the manufacturer's instructions and recommendations should always be followed. The following practices would be typical:—

(a) Before starting, the unit should be placed on firm, level ground, and the bonding lead should be connected to the aircraft.

(b) After starting the engine, it should be ensured that oil pressure is building up and that all warning lights are extinguished. The engine should be allowed to warm up for several minutes.

(c) When the engine has warmed up, the throttle should be opened to check that air pressure builds up to normal operating pressure.

(d) During an aircraft starting operation a constant check should be kept on the air pressure gauge, and the starter unit throttle should be adjusted as necessary to maintain normal operating pressure without exceeding the maximum permissible starter unit engine speed.

4.2 **Maintenance.** A record should be kept of engine running hours and engine starting cycles, and maintenance should be carried out in accordance with a schedule drawn up for the particular equipment. A daily inspection should include the topping-up of fuel, coolant and oil systems, and a check for damage, leaks and security of components.

4.2.1 The air delivery hose is generally seamless and lined with silicone rubber, and normally has low temperature flexibility and high resistance to abrasion. However, the rubber will eventually deteriorate, particularly at the ends; shortening the ends by a small amount (approximately 50 mm (2 in)) may rectify this, but other cracking or damage will necessitate replacement. The life of a hose can be prolonged by exercising reasonable care in its use, and by avoiding sharp bends, tautness and twisting.

4.2.2 Inspection of an air delivery hose should be carried out after approximately 50 hours of operation or 600 aircraft starts.

5 HYDRAULIC TEST RIGS The testing of aircraft hydraulic systems requires a controlled and filtered supply of hydraulic fluid at high pressure, and this is normally provided by a specially designed servicing trolley. A typical hydraulic test rig would consist of a 75 kW (100 HP) electric motor operating from a 380/440 volt, 3 phase supply, driving a variable-delivery hydraulic pump through a gearbox, clutch and flexible coupling; the output from the rig would be up to 175 litres/min (38 gal/min) at 20 MN/m^2 (3,000 lbf/in^2), with a filtration of 3 microns. The hydraulic circuit would function by drawing fluid from the aircraft system through a heat exchanger and low pressure filter, and returning it to the aircraft system through suitable flow control valves and flow meters and a high pressure filter; self-sealing, quick-disconnect couplings, installed in the aircraft, permit the connection of flexible hoses from the test rig to the aircraft system. In some cases provision is made for fitting a different pump on the test rig, but usually a rig is designed specifically for one type of aircraft and one type of fluid.

5.1 **Operating Procedure.** Hydraulic test rigs vary considerably in design, and operating instructions for a particular type are usually printed on a plate attached to the trolley and/or contained in a manual or booklet; these instructions should be carefully followed when carrying out a test, since incorrect operation could cause damage to the rig or aircraft system. General guidance on operating procedures is outlined in paragraphs 5.1.1 and 5.1.2.

5.1.1 Before starting a test rig, all flow valves should be closed and, where applicable, the aircraft hydraulic system reservoir air pressure should be checked. Because of the filtration requirements of hydraulic systems, the suction and pressure hoses from the rig should be carefully inspected for cleanliness before they are connected into the aircraft system. The hose connections are fitted with caps which should only be removed immediately before the hoses are connected to the aircraft; the caps should be replaced immediately after the hoses are disconnected from the aircraft.

5.1.2 After starting the electric motor, the pump can be brought on line by operation of the clutch, and pressure will be indicated on the rig pressure gauge. The main rig flow control valve can then be opened and the rig will form part of the aircraft system; enabling functional tests to be carried out by use of the aircraft system selector valves. By utilising additional low-flow valves and low-reading flow meters on the test rig, the measurement and monitoring of internal leakage in the aircraft system components is possible.

5.2 **Maintenance.** Because, during tests, a hydraulic test rig shares the hydraulic system of an aircraft, the degree of filtration, and condition of the pump and fluid, must be at least as good as those in the aircraft. Cleanliness is, therefore, of the utmost importance, and regular quality checks should be carried out on fluid samples from the rig to prevent fluid which is contaminated or degraded by overheating, from being carried, via the rig, from aircraft to aircraft. To ensure satisfactory operation of the rig, the following operations should be carried out on a regular basis:—

(a) The rig should be kept clean and free from leaks. This is particularly important with the hoses and hose connections, which must be capped when not in use and must be checked for cleanliness each time they are coupled to an aircraft.

(b) The filter should be cleaned or renewed regularly according to rig usage, and special procedures such as ultrasonic cleaning, which may be required for wire cloth filters, should be followed. Paper filter elements should be discarded when removed (see Leaflet **AL/3-21**).

(c) All gauges should be subjected to calibration checks at regular intervals.

(d) The condition and functioning of all electrical equipment should be checked at intervals depending on rig usage.

6 AIRCRAFT JACKS There are two main types of jacks used on aircraft, namely tripod jacks and bottle jacks; both types are hydraulically operated. The base of both jacks forms a reservoir for hydraulic fluid, supplying a hand pump which is used to extend the jack ram. A release valve (which is sometimes operated by rotating the pump handle) allows fluid to return to the reservoir and the jack to retract.

6.1 A tripod jack has three equally-spaced support legs and a central vertical column which houses a hydraulic cylinder, the ram of which is threaded and fitted with a locking collar as a safety feature. These jacks are used at main aircraft jacking points and are fitted with an adaptor at the top of the ram which engages the jacking pad on the aircraft; the adaptor is sometimes used in conjunction with a transducer for aircraft weighing purposes.

6.1.1 Tripod jacks may be extended to nearly twice their original height during use, and care is necessary to ensure that the ram is vertical; if it is not, side forces on the jack could result in its toppling over, with serious consequences to the aircraft and to personnel. When the ram is extended or retracted, the locking collar should be kept in close proximity to the top of the tripod, to prevent the collapse of the ram through hydraulic failure; the locking collar should be locked onto the tripod when the ram is fully raised (see also Leaflet **GOL/1-1**).

6.2 Bottle jacks, which are similar in principle to tripod jacks, are made in various sizes and may have a single or double ram depending on the extension required. Bottle jacks are used mainly for raising individual undercarriage legs for the purpose of changing wheels, brake units, etc., and may be used on their own or in conjunction with a special fitting which attaches to the undercarriage leg or bogie beam.

6.2.1 As with tripod jacks, it is essential that the ram is vertical during use and the locking collar is kept close to the jack body.

6.3 **Maintenance.** It is essential that aircraft jacks should be maintained in a serviceable condition at all times, and the following checks are recommended:—

(a) Jacks that stand idle for prolonged periods—exercise over full range and check the operation of the pump and release valve, and check visually for leaks, corrosion and hose condition before use.

(b) Jacks in constant use—visually check for leaks, corrosion, hose condition, etc., at approximately two-monthly intervals.

(c) All jacks should be overhauled and proof loaded every two years.

7 COMPRESSED GAS REPLENISHING TROLLEYS The equipment for replenishing compressed gas systems on aircraft normally consists of a trolley (which may be towed or self-propelled) on which are mounted one or more compressed gas cylinders, together with the necessary storage and supply pressure gauges and valves and, in some cases, a pressure regulator. Because of the dangers associated with the sudden release of a compressed gas, all parts of the trolley directly associated with the storage and supply of compressed gas should be checked daily, and should be kept scrupulously clean.

7.1 Replenishing trolleys should bear suitable markings to clearly identify the specific gas they contain, and should also bear a warning regarding the dangers of frosting when high pressure gas is discharged.

7.1.1 Gauges, valves, regulators, etc., should normally be retained for one type of gas only, and should not be interchanged with similar items on a rig containing a different gas.

7.2 Information on the operation of compressed gas replenishing equipment is contained in Leaflet **GOL/1-1,** and regular inspections should be carried out as follows:—

(a) All high pressure hose and end fittings should be inspected for cleanliness, security and damage.

(b) Storage cylinder pressures should be checked and the cylinders should be re-charged or renewed depending on the facilities available.

(c) A visual check for serviceability should be carried out on all gauges, valves, cylinder clamps, pipes, tyres and the trolley tow bar.

7.3 In addition to the visual inspections, all gauges should be calibrated at regular intervals.

8 TOW BARS Tow bars for large transport aircraft are generally designed specifically for use on a particular aircraft type and can seldom be used on other aircraft types; tow bars for light aircraft are generally capable of being used on a range of aircraft types. Steering arms, which are used to turn the nose undercarriage when an aircraft is being manhandled or towed from the main undercarriage attachments, are not designed for towing and should not be so used; steering arms should, however, be subjected to the applicable maintenance procedures specified for tow bars.

8.1 Tow bars vary considerably in design, but consist basically of a tube or frame with end fittings designed for connection to the aircraft towing fitting and the tug; a 'towing head' connects to the aircraft and a 'towing eye' connects to the tug. The tube or frame usually incorporates a buffer arrangement to prevent shocks being transmitted to the aircraft and one or more shear pins to prevent excessive force being applied to the nose undercarriage of the aircraft. Heavy tow bars are also fitted with jockey wheels to facilitate movement and these may be either mechanically or hydraulically retractable. To prevent damage to the aircraft towing fitting, a plug gauge is provided to enable checks for wear or damage to be carried out on the tow bar attaching hook.

8.2 **Servicing.** Servicing operations should be conducted in accordance with a schedule drawn up for the particular tow bar, and records should be kept of all work carried out. A minor check of all tow bars should be carried out twice-weekly and a major check should be carried out at either three- or six-monthly intervals, depending on the complexity and amount of usage of a particular tow bar. The checks outlined in paragraphs 8.2.1 and 8.2.2 are typical of those recommended for tow bars for large aircraft.

8.2.1 **Twice-Weekly Check.** The following checks should be carried out, as applicable; damaged or excessively worn parts being renewed as necessary:—

(a) Check the towing hook assembly for damage or wear, using the appropriate plug gauge.

(b) Examine the towing head, towing eye and sheer pins for damage.

(c) Examine the jockey wheels and tyres for damage and inflate the tyres to the correct pressure.

(d) Lubricate all pivot points and bearings as necessary.

(e) Check the operation of the hydraulic system and top-up as necessary.

(f) Check the tow bar structure for damage, and touch-up paintwork as necessary.

(g) Check the condition of any cables, switches and connectors attached to the tow bar.

8.2.2 **Three-monthly or Six-monthly Check.** The following checks should be carried out at the appropriate intervals, as determined by experience with a particular tow bar at a particular location.

(a) **Towing Eye.** Check the eye for excessive wear, cracks and damage.

(b) **Towing Head**

(i) Remove the shear pins and remove the towing head.

(ii) Check the shear pin bushes for wear.

(iii) Check the latching lever and mechanism for wear, and lubricate as necessary.

(iv) Check the jaw hook for wear and jaw width, using the appropriate gauges.

(v) Refit the towing head to the tow bar, using new shear pins.

(vi) Check all welds for cracks.

(c) **Main Tube or Frame**

(i) Check for damage and distortion.

(ii) Check the condition of any cables and the operation of any switches.

(d) **Tow bar Jockey Wheel Assembly**

(i) Check the framework for damage and cracks.

(ii) Check the tyres and wheels for damage, and inflate the tyres to the correct pressure.

(iii) Check the wheel bearings for wear, and lubricate as appropriate.

(iv) Check the operation of the assembly, and lubricate all pivot points. Check the hydraulic system for leaks, and replenish as necessary.

(e) **Paintwork.** Check the condition of all paintwork and notices, and repaint as necessary.

9 HANGAR FACILITIES The provision of safe and adequate facilities in hangars is important with respect to both aircraft serviceability and safety of personnel. This paragraph is not concerned with the fixed installations in a hangar, and gives general guidance only on the subjects of mobile transformer/rectifier units (9.1), portable lighting equipment (9.2), compressed air supplies (9.3) and work platforms, staging and rostrums (9.4).

9.1 **Mobile Transformer/Rectifier Units.** In some hangars, mobile transformer/rectifier units are used to provide d.c. power for general use during maintenance work. The units are connected to a mains outlet (usually 440 volts) and can provide power at several selectable voltages for the operation of various d.c.–operated types of equipment and for connection to the external ground supply socket on an aircraft; in some cases the units may also be used to provide power for engine starting.

9.1.1 Mobile transformer/rectifier units should be maintained in a serviceable condition at all times. The input and output cables should be subjected to regular inspections for tears, abrasions and general deterioration, and the mains and aircraft connectors should be examined to check the condition of the insulation and of the contact plugs and sockets. The output voltage at each selectable position should be checked regularly, and any instruments fitted to the unit should be calibrated annually.

9.2 **Portable Lighting Equipment.** Portable lighting equipment is used in most hangars to provide illumination for inspecting or carrying out work on aircraft, and varies considerably in design. Any lighting which is used in areas where flammable or explosive vapours are likely to be present should be of the flameproof (BS 229) or intrinsically safe (BS 1259) types. For work inside aircraft structures, low-voltage hand-held lamps and other inspection aids are often used (see also Leaflet **AL/7–13**).

9.2.1 Portable lighting equipment is usually connected to the standard 240 volt mains, and cables of considerable length may be used, together with extension cables and junction boxes. These cables are prone to physical damage in a working environment and require frequent inspection for cuts, abrasions and general deterioration. The lamp stands or trolleys should be inspected to ensure that the wire mesh protective screens are secure and in good condition, that all connections and switches are secure and functioning correctly, and that any cable restraining clamps or ties are secure, thus preventing force being applied to the electrical connections.

NOTE: Care must be taken not to overload a circuit by the use of adaptors which permit multiple connections to be made.

9.2.2 Loose cable lying on a hangar floor can present a considerable hazard, and lighting equipment which is not in use should be disconnected and its cable should be coiled and secured.

9.3 **Compressed Air Supplies.** Many hangars are fitted with a fixed compressed air supply, which consists of a static engine-driven compressor supplying a reservoir from which compressed air is piped to quick-release fittings located at convenient positions around the hangar. As an alternative, mobile compressors may be provided, with similar components and one or more outlets.

9.3.1 Maintenance of this equipment should be carried out in accordance with a schedule which follows the manufacturer's recommendations and includes the relevant operations outlined in paragraphs 3, 4 and 5.

9.3.2 It is usually important that a compressed air supply is clean and dry, particularly when it is used, for example, for inflating tyres, and particular attention should be given to ensuring that the filters are clean and that the water traps are drained frequently.

NOTE: If the compressed air supply is being used to inflate tyres, a pressure regulator must be incorporated in the delivery line (see Leaflet AL/3-18).

9.3.3 The sudden release of compressed air can be very dangerous, and it is essential that frequent inspections should be carried out to determine the condition of any flexible pipes and to ensure that all quick-release fittings are secure and operate correctly.

9.4 **Work Platforms, Staging and Rostrums.** Large aircraft require the use of sophisticated equipment to provide access to all parts of the structure. The equipment is usually mobile (often being self-propelled) may be designed for use with a particular aircraft type, and may also be provided with built-in power points and other facilities necessary for aircraft maintenance.

9.4.1 The framework of this equipment should be maintained in a safe condition to avoid injury to personnel or damage to the aircraft. All electrical cables and associated switches and connections should be regularly inspected for security and condition.

9.4.2 When assembling any type of access equipment around an aircraft, it is important to ensure that the aircraft brakes are applied or the wheels are chocked to prevent movement and that the equipment is moved carefully into position and secured from movement by whatever means is provided (e.g. braking the wheels or lowering fixed legs). Sufficient space should be left between the aircraft and the equipment to allow for any relative movement likely to result from aircraft maintenance operations.

9.4.3 The edges of the staging or platforms which are likely to be in contact with the aircraft are usually padded to prevent damage to the aircraft skin. This padding should be inspected for condition and security whenever the equipment is used.

10 TYRE PRESSURE GAUGES It is important that aircraft tyres are inflated to the correct pressure, and it is essential, therefore, that the gauges used to check tyre pressures should be accurate.

10.1 'Stick' type gauges can be expected to have errors of up to 4% and are suitable for use on light aircraft and older types of transport aircraft where such errors are acceptable. Gauges of greater accuracy should be used where considered operationally necessary. A suitable type of gauge is a dial-type gauge operating on the Bourdon tube principle; such gauges are available with an accuracy of ½% within the range of pressures specified for these aircraft, and should be used whenever possible.

10.2 A suitable system for checking gauges would be to keep one which has been newly calibrated as a master gauge and to check other gauges by comparison at, for example, weekly intervals (depending on usage). In addition, a gauge should be checked whenever its accuracy is in doubt, and all gauges should, in any case, be re-calibrated annually.

10.3 Gauges should be marked for identification, and records should be kept of all checks and calibrations carried out.

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AIRCRAFT

HELICOPTERS

INTRODUCTION TO HELICOPTER SECTION

1 INTRODUCTION This Leaflet is intended as an introduction to the Helicopter (HCL) Section of CAIP. It points out the main differences between the modes of operation of aeroplanes and helicopters which lead to the need for different maintenance practices, and indicates the Leaflets contained in other Sections of CAIP which may be taken to be applicable to helicopters as well as aeroplanes.

2 FACTORS AFFECTING HELICOPTER MAINTENANCE Although the maintenance aspects of aeroplanes and helicopters are basically similar, certain features must be given particular care in the maintenance of a helicopter. These features are outlined in paragraphs 2.1 to 2.3.

2.1 An aeroplane derives its lift mainly from the air passing around the wings and tailplane, and its thrust from a propeller or turbo-jet engine. Aerodynamic control is exercised by the operation of movable control surfaces, lift spoilers, airbrakes and a variety of high lift devices such as wing flaps, slats, etc. These control surfaces are of rigid construction, are operated only intermittently and because of the nature of their construction have a high degree of reliability. In addition, it is often possible to provide redundancy of some of the components and systems used to activate these control surfaces.

2.2 Unlike the aeroplane, the helicopter derives both lift and thrust from the rotation and manipulation of its main rotor blades through the medium of the rotor head, generally in association with a tail rotor or other anti-torque device. The factors involved in controlling lift, thrust and direction, and those which result from rotation of the main rotor and which have to be taken into account, are blade pitch angle, blade angle of attack, coning angle, rotor torque, blade lead and lag, centrifugal force and Coriolis effect. To obtain control of combinations of these factors requires a complex control system, parts of which can be subject to continuous movement. Because of the nature of helicopter design, helicopters are also subject to vibration, both aerodynamic and mechanical, which adds to the stresses imposed on the structure, systems and components, and increases the incidence of fatigue damage.

2.3 A helicopter thus has a complex rotor head and control system, which have to operate in severe conditions, often without the benefits of the multiple redundancy which can normally be provided on an aeroplane. Maintenance Manuals and Schedules take account of helicopter characteristics, but a thorough knowledge of a particular helicopter and continuing awareness of the potentially more serious effects of corrosion, wear and fatigue, are essential as a background to satisfactory maintenance.

3 LEAFLETS APPLICABLE TO HELICOPTERS Whilst some Leaflets in other Sections of CAIP contain information which is related specifically to helicopters, many refer to aircraft and their systems in general. When the information is meant to be applicable only to aeroplanes, this may be obvious from the text in some cases, but may not be so in others. Paragraphs 3.1 and 3.2 indicate the Leaflets which contain information which, although not specifically identified as such, may be taken to be applicable to the maintenance of helicopters as well as aeroplanes.

3.1 **Part I—Basic.** All Basic Leaflets, except the following, are applicable—**BL/1-11, BL/6-6, BL/6-7, BL/6-25, BL/6-26.**

3.2 **Part II—Aircraft.** All Aircraft Leaflets, except the following, are applicable—**AL/3-7, AL/3-22, AL/3-23, AL/7-1, AL/7-9, AL/7-12, AL/11-1, AL/11-2, AL/11-5, PL/1-1, PL/1-3, PL/1-4.**

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AIRCRAFT

HELICOPTERS

HELICOPTER VIBRATION

1 INTRODUCTION This Leaflet provides an introduction to the fundamentals of vibration analysis as applicable to helicopters and gives guidance on the routine measurement and recording of vibration levels. Whilst certain proprietary damping systems are described, the appropriate manufacturer's manuals should be consulted when it is necessary to make adjustments to such systems.

1.1 The topics discussed in this Leaflet are as follows:—

Paragraph	Topic
2	Principles of Vibration
3	Sources of Vibration
4	Methods of Reducing Vibration
5	Measurement of Vibration
6	Analysis of Vibration
7	Correction of Excessive Vibration
8	Vibration Analysis Recording

2 PRINCIPLES OF VIBRATION

2.1 Vibration may be described as a rapid oscillatory motion, which, in a helicopter may be either aerodynamic or mechanical and may be produced by the main and tail rotors, the transmission and the power-plant. Basic units are necessary to describe vibration in practical terms, and these are discussed in this paragraph 2.

2.1.1 The speed at which vibration takes place is known as the 'frequency' and is expressed in Hertz (Hz); one Hertz is a frequency of one cycle per second, where a cycle consists of movement in one direction followed by a movement in the opposite direction and return to the starting point (see Figure 1). Typical vibration frequencies found in helicopters vary from approximately 3·5 to 1000 Hz, although much higher frequencies are found in certain gearboxes. When dealing with the vibration of a main rotor it is quite common for the frequency to be expressed in terms of the rotor revolutions, e.g. a five per revolution (5/rev or 5R) vibration; 5 cycles of vibration for each revolution of the rotor.

2.1.2 The amplitude of the displacement that takes place during vibration is normally measured from the mean or equilibrium position (see Figure 1), the units used being either inches or mils (1 mil = 0·001 in). However, since it is difficult to measure amplitude directly the related function of 'velocity', expressed in inches per second (in/s or IPS), is often used. Since the velocity is not constant the figure used is the velocity of the point being measured as it passes through the mid-point of its oscillatory motion. Velocity may be related to actual displacement at a given frequency (see 6.2) by evaluating the formula:—

$$D = \frac{V}{2\pi f}$$

where D = displacement amplitude in inches (±)
V = velocity in inches per second
f = circular frequency (Hz)

$$Hz = \frac{rpm}{60} \text{ (cycles/sec)}$$

A typical very severe imbalance of a tail rotor might produce a vibration having a velocity of 4·0 in/s and causing a displacement of approximately ±0·013 in at 3000 rpm.

NOTE: It should be noted that American publications may define amplitude on a peak-to-peak basis and this should be taken into consideration when using any related formulae.

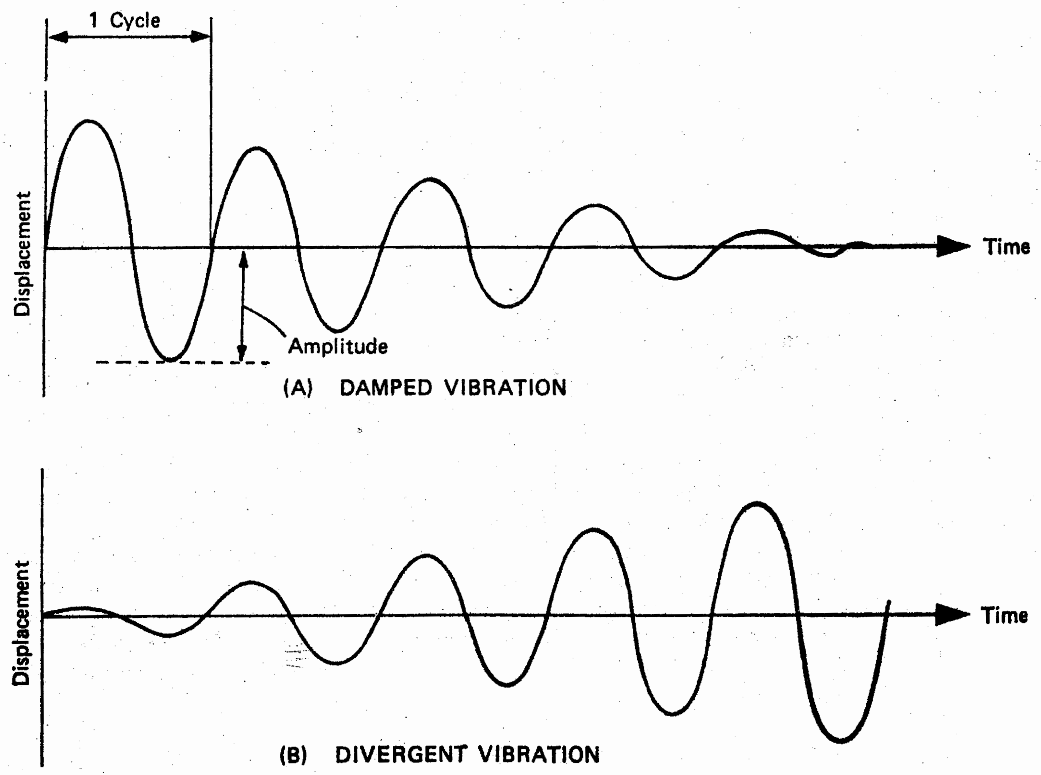


Figure 1 FORMS OF VIBRATION

2.1.3 Another term encountered when dealing with the subject of vibration is 'resonance'. Any object which is flexibly mounted has a natural vibration frequency, that is, a frequency at which it will naturally vibrate when stimulated by an outside source. For example, if a thin wooden ruler overhanging a desk is struck at the end it will vibrate at a particular frequency, which depends on how much of the ruler is overhanging the desk. If a small weight is fixed to the end of the ruler the natural frequency will be lowered. The force with which the end of the ruler is struck will not alter the frequency of vibration but will alter the amplitude. In the case of the ruler, the vibration decays as the stimulation is removed, and this is shown in Figure 1(a). However, should the outside stimulus continue in phase, with the natural vibration, the amplitude of the vibrations will increase to the point where the strength of the ruler is exceeded and it breaks. Where such a situation could exist in a helicopter a means of damping is used to control the amplitude at the resonant frequency. Ground resonance is an example of vibration which can reach a destructive level if, for example, the landing gear dampers are unserviceable.

2.2 The dynamic behaviour of a helicopter structure is illustrated diagrammatically in Figure 2. In Figure 2(a), a spring A and weight B form a system which is suspended from a rotor from which it receives excitation. The predominant excitation frequency (Hz) will be given by the number of blades in the rotor multiplied by the speed of rotation in revolutions per second. Weight B responds to this excitation in a way which is dependent upon the value of the weight and the natural resonant frequency of the weight/spring system. This response could be naturally damped (attenuated) or it could be divergent (amplified). If a further weight C is hung on weight B by means of a further spring D (see Figure 2(b)), then the original response to vibration of weight B will be modified. Weight C will respond in opposition to the exciting force from weight B, and tend to reduce it, or cancel it if the natural frequencies of the two spring/weight systems match each other. Under these conditions the structural response is zero, i.e., the vibration has been absorbed.

2.3 In practice the absorption of vibration in a helicopter is a much more difficult problem, since the structure is not a single homogeneous mass, rotor speed varies, and the main rotor is only one of several sources of vibration; it is thus not possible to eliminate all vibration from a helicopter. Basic vibration resulting from the design is taken into account when establishing safe operating lives for various primary components, although individual helicopters will vary because of engineering tolerances. However, vibration resulting from an out-of-rig condition or from damaged or worn parts, which will either increase the normal levels of vibration above an acceptable threshold or produce vibration at abnormal frequencies, must be eliminated.

2.3.1 An increase in vibration beyond acceptable levels subjects all parts to much higher repetitive stress levels than those for which they were designed, resulting in a greater likelihood of fatigue failure. In the same context the likelihood of failure is increased many times if the component has already suffered an overload or damage in the form of a stress raiser, such as a nick or a scratch, at which there will be a concentration of stress; some materials are more sensitive than others to this type of failure. Self-locking nuts may not remain secure at the increased vibration levels, leading to fretting of the parts they attach. Split pins can chatter in their holes and ultimately fail. Pipes, cables, hoses and controls are more likely to chafe and suffer failure through fatigue. Sensitive instruments and avionic equipment are all likely to experience a lower time between failures in the presence of excessive vibration.

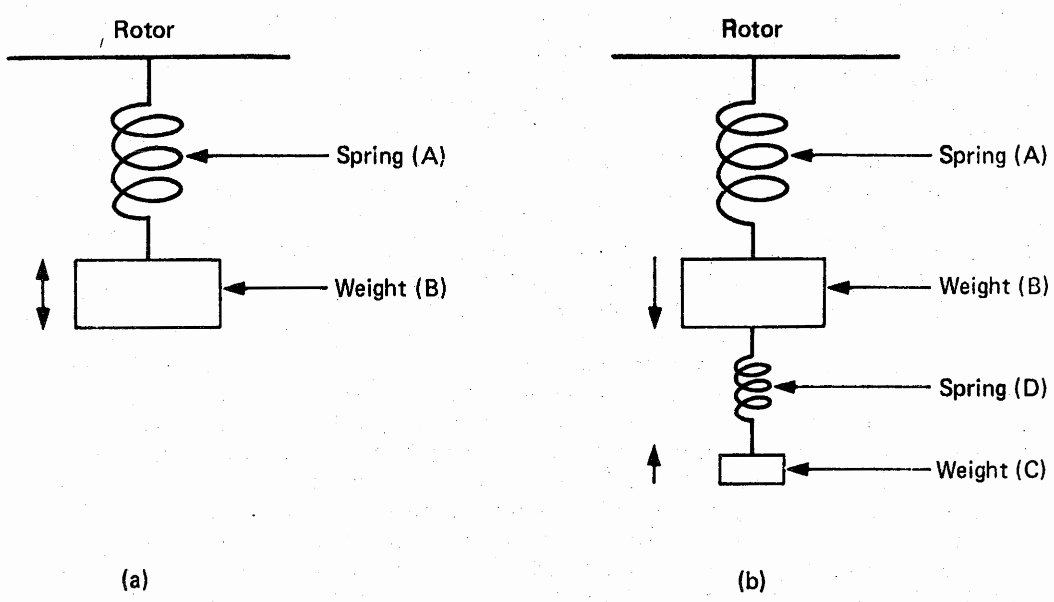


Figure 2 DYNAMIC RESPONSE TO VIBRATION

3 SOURCES OF VIBRATION

3.1 **Aerodynamic Sources.** The primary sources of vibration with an aerodynamic origin are the main and tail rotors. Each blade is of aerofoil section, providing lift (or thrust), and aerodynamic disturbances will cause vibrations of a frequency depending on the speed of rotation and the number of blades in the rotor. For example, a two-bladed, semi-rigid rotor will have an inherent vibration of 2/rev, whilst a five-bladed rotor will have an inherent vibration of 5/rev. However, anomalies relating to one blade only, such as the development of more or less lift in respect of slight variations in aerodynamic shape (which may be caused by minor damage or natural ageing) will produce an additional vibration of 1/rev. In a fully articulated rotor, variations in blade spacing (blade phase) or track, will cause similar vibrations, and if only one blade is affected the vibration frequency will again be 1/rev. The same is true of a tail rotor except that since the rotational speed is higher the actual vibration frequency will be higher. Under some conditions disturbed airflow can cause the vibration of elevators, stabilisers, cowlings and access doors, but more often these will vibrate in sympathy with some other source if their attachments are loose or worn.

3.2 **Mechanical Sources**

3.2.1 **Transmission Sources.** This heading includes, for the purposes of this Leaflet, everything that rotates other than the engines and the aerodynamic sources mentioned in paragraph 3.1.

(a) Rotors may be considered as mechanical components, and vibration may arise from several causes. One primary consideration is balance of the rotating assembly. An out-of-balance tail rotor will produce vibration at a higher frequency than that of a main rotor, and it will be in a different plane. Any wear in rotor head control linkage will permit the development of abnormal vibrations, and once the clearance exists wear will take place at an accelerated rate.

(b) Drive shafts are balanced to prevent excessive vibration, and special assembly techniques are often used with shaft couplings to maintain the balance of the whole assembly. Mis-alignment of a shaft will cause vibration as a result of the slight flexing motion introduced into the shaft. Wear in the shaft support bearings and coupling splines are further sources of vibration in the drive shaft system.

(c) Gearboxes, with components running at different speeds and supported on different kinds of bearings, provide sources of vibration at several frequencies. Due to the accumulation of manufacturing tolerances, gear teeth may vary slightly in position and as a result tooth loadings may vary at different points on the gear. Varying loadings resulting from variations in attitude and airspeed are transmitted through the rotor mast to the supporting bearings, resulting in changes in loading and therefore in vibration. In addition, many gearboxes provide drives for a variety of accessories, such as generators, hydraulic pumps and tachometers; each of these components produces a characteristic vibration, which may vary under differing operating conditions.

3.2.2 **Power-plant Sources.** Power-plants fall naturally into the two divisions of piston engines and turbine engines, each having totally different vibration characteristics.

(a) A piston engine, with one power stroke per cylinder every other revolution of the crankshaft, is a prime source of vibration, the severity of which depends on the number of cylinders; the greater the number of cylinders, the smoother is the running of the engine, since there is a smaller rotation of the crankshaft between firing impulses. Because of the nature of the operating cycle, vibration is not merely transmitted through the engine mountings but a torsional vibration is also transmitted through the crankshaft. For this reason many piston-engined installations incorporate a flexible type of coupling between the crankshaft and the gearbox. The crankshaft itself usually embodies counterweights to absorb torsional vibration.

(b) The turbine engine presents a different vibration case altogether. Whilst the engine is inherently smooth running, the higher rotational speeds mean that the effects of any imbalance are magnified as much as ten times compared with a piston engine. Ingestion damage to compressor blades and creep damage to turbine blades, and wear on bearings and seals, are all causes of abnormal vibration. Similarly, the engine driven accessories can all produce characteristic vibrations.

4 METHODS OF REDUCING VIBRATION Whilst good maintenance practices and attention to detail are the main ways of reducing vibration to an acceptable level, there will always be a degree of vibration inherent in the design of a helicopter. Different manufacturers adopt different methods of damping the basic vibration and these methods are outlined in paragraphs 4.1 to 4.4.

4.1 **Resonant Mass.** The simplest form of vibration damper uses the same principle as the ruler overhanging the edge of a desk (paragraph 2.1.3) where the frequency of vibration can be varied by adding or subtracting mass at the end of the ruler. If the characteristics of the mounting spring and weight (paragraph 2.2) are adjusted to resonate at the basic frequency, then the vibration will be damped and not transmitted to the airframe.

4.1.1 One helicopter has a resonant mass vibration damper mounted under the cabin floor, where it is known as the 'cabin resonator'. Another application of the same principle is to be found in the cyclic controls of a light helicopter, to prevent vibration being transmitted through the control runs. A third variation of the same principle is to be found in the resonant battery mounting used on one large helicopter. In this arrangement the battery itself forms the resonant mass and is supported by three cantilever springs. The spring length is adjustable and is set up during construction using special equipment. Tuning of the vibration absorber to compensate for variations in battery weight is achieved by adding or subtracting weights, weight being added to lower the resonant frequency.

4.1.2 A further application of the same principle is to be found in a type of damper installed on the main rotor head of a small helicopter (see Figure 3). Being mounted on the main rotor head, the vibration damper absorbs much of the excitation at source before it can be transmitted to the rest of the helicopter. In this design a weight is supported in the rotor head by a ball joint which permits it to move in any direction in the horizontal plane. The weight is restrained by three equally-spaced springs, which control its movement and form a tuned system. This system is excited by the vibratory loads developed in the rotor head and responds in opposition to them, thus reducing them.

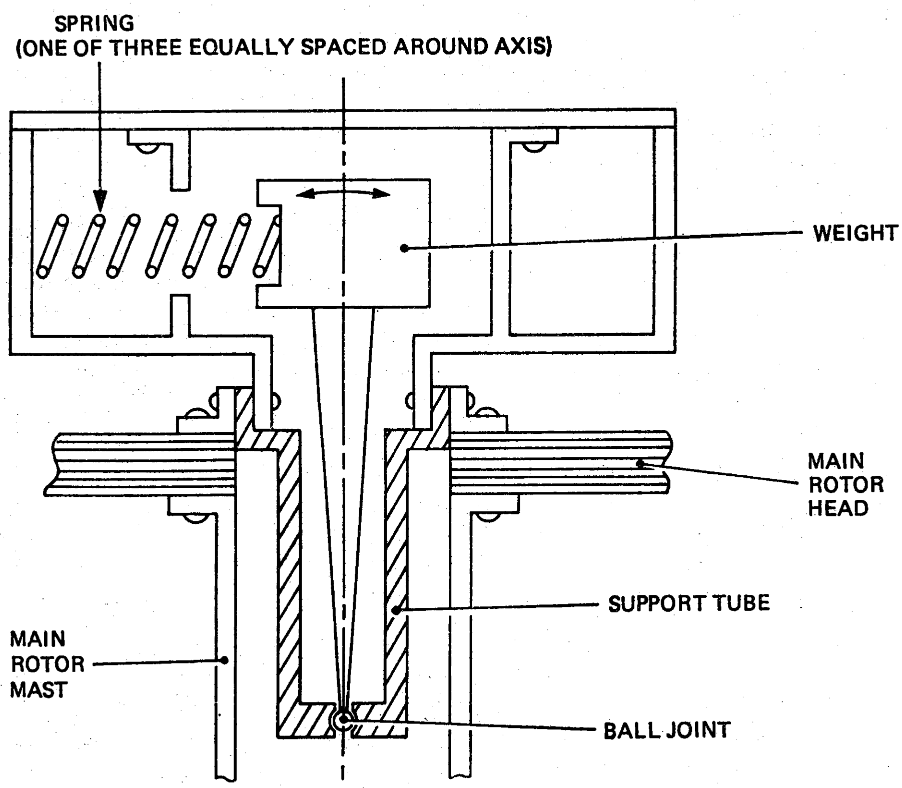


Figure 3 SPRING-LOADED MAIN ROTOR DAMPER

4.2 **Nodal Beam.** The response of a weight tuned by a spring is utilised in other forms of vibration damper systems which, at first sight, appear to have little in common with the systems already described.

4.2.1 In one system, the main rotor and gearbox are coupled to the airframe through a nodal beam, which is used to isolate vertical vibrations (see Figure 4). The principle can be demonstrated with a long thin piece of wood. If the wood is held horizontal at its mid-point and shaken vertically, the ends, because of the flexibility of the wood, will move in opposite directions to the mid-point, that is, they will be out of phase; this will occur when the induced vibration is near to the natural vibration frequency of the piece of wood. The locations in the beam where the motion changes from one direction to another are known as 'nodal points' and here there is no movement. If a helicopter fuselage is attached at these points then it will not be subjected to the vertical vibration induced by the rotor. For a helicopter the beam consists of flexible members at the ends of which are attached inertia weights. The flexible members forming the beam on some helicopters are made of glass fibre, which has a low Young's modulus and high allowable stress, and is relatively easy to form into complicated shapes. The mounting to the airframe is via elastomeric bearings, and the response of the system is adjusted by the use of tuning weights mounted on arms.

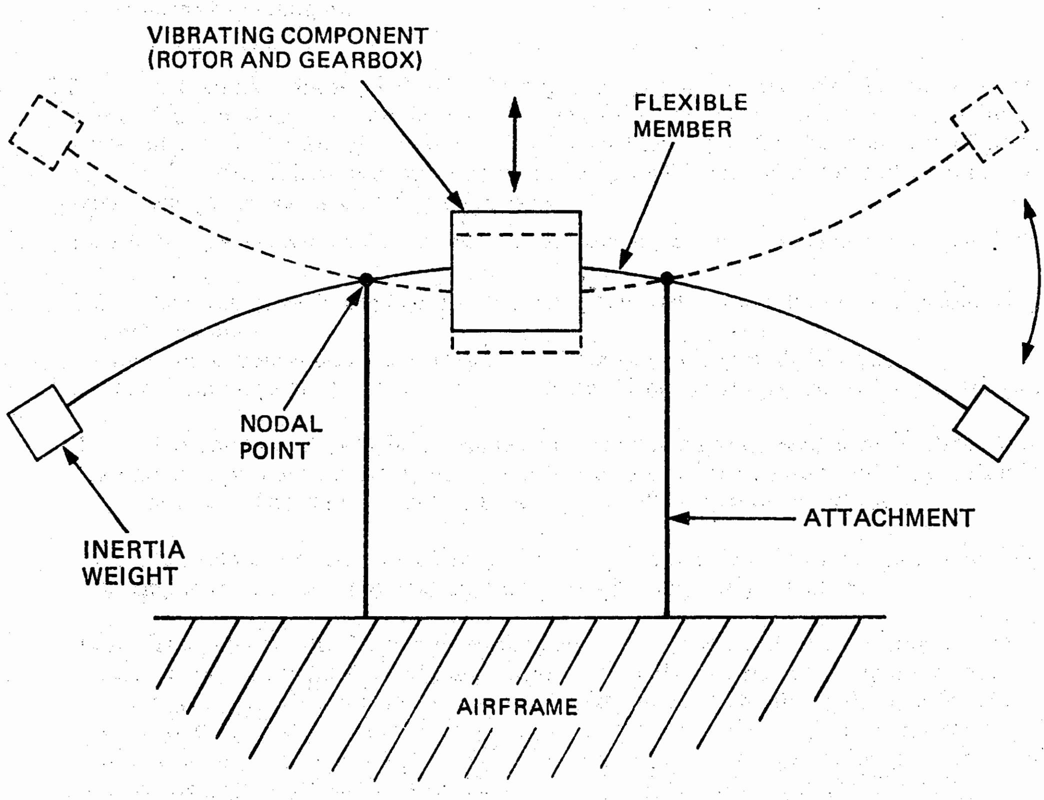


Figure 4 PRINCIPLE OF NODAL BEAM DAMPING

4.3 **Counterweights.** A type of vibration damper in which springs are not used, is incorporated on some types of rotor head and is known by the generic name of 'pendulum dynamic vibration damper'. This is secured to the main rotor hub and shaft, and therefore rotates with it in the same plane as the rotor. It consists of a support forging with a number of radial arms, to each of which is attached a weight, which is loosely mounted and is free to move within restrictions imposed by the mounting bushes. The vibration damper uses the concept of in-plane pendular dynamic weights which generate inertial forces in opposition to the forces generated by the rotor. Since the weights are subject to centrifugal force, which varies with rotor speed, the damping provided by this type of absorber is effective throughout the operating speed range.

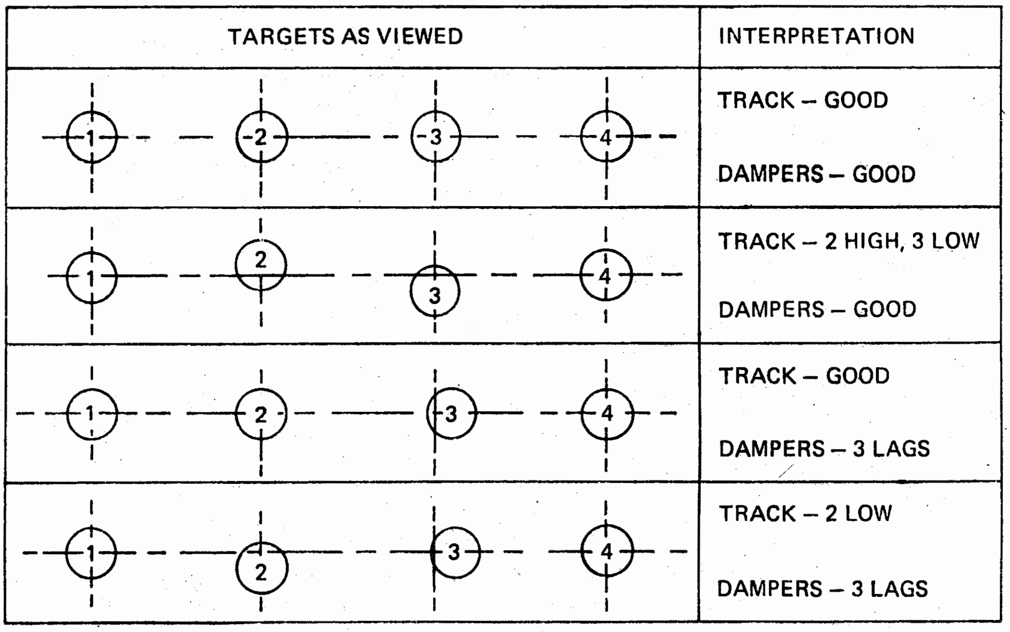
5 MEASUREMENT OF VIBRATION A subjective assessment of the level of vibration in a helicopter may be sufficient in coming to the conclusion that something is wrong, but is inadequate when it becomes necessary to ascertain the cause. Some faults have fairly obvious and well defined symptoms but many can be hard to locate and careful analysis is necessary to identify them. In making such an analysis it is essential that the method used will enable the frequency and velocity of the vibration to be determined. The manner in which this information is used to diagnose faults is dealt with in paragraph 6 but the three main methods of obtaining the information are outlined in paragraphs 5.1 to 5.3. Further information on these equipments may be obtained from the manufacturers' manuals.

5.1 **Hand Vibrograph.** In its basic form, this instrument consists of a steel reed with a weight at one end. It has already been seen that such a device will have a natural vibration frequency that is determined by the length of the reed and the mass of the weight. Varying the length of the reed varies the natural vibration frequency. Measurements should be conducted under the flight conditions in which the vibration is most noticeable (in order to pick up the maximum amplitude), with the instrument placed against the airframe structure as close as possible to the suspected source of vibration. Since vibration may be found in both lateral and vertical planes the test should be carried out first with the instrument in the lateral position and then in the vertical position. The main object of this testing is to identify the fundamental frequency of the vibration in order that its source may be accurately located; a variation of the instrument provides a read-out in the form of a graph, analysis of the indicated waveform is often difficult and requires considerable skill in interpretation when one vibration is superimposed upon another. For many years there was no alternative to this instrument for portable use in the maintenance of helicopters, but latterly the vibrograph has been superseded by electronic instruments.

5.2 **Electronic Vibration Measurement.** In this system, an accelerometer is mounted in the helicopter in either a lateral or vertical (and in some cases the fore and aft) position (for balancing the main rotor the accelerometer is mounted laterally, but for tracking it is mounted vertically) the equipment often provides for two accelerometers to be connected simultaneously, and for the signals to be selected as required. Signals from the accelerometer are processed electronically, and displayed on a meter as 'vibration amplitude', although actually the peak velocity of the vibration is recorded and the scale marking is in inches/second (IPS). In addition to the accelerometer(s) a magnetic pick-up is used to provide a phase reference, i.e. one signal per revolution of the rotor. This signal is fed into a display which shows the phase relationship between the rotor and the vibratory motion and is used to determine the location of the required balance weights. In the case of the main rotor this display, known as the 'clock angle', is in the form of a circle of 24 lights, numbered in the same way as a clock face. Where a tail rotor is being investigated the clock angle is displayed by use of a reflective target (i.e. a patch of reflective material temporarily stuck or otherwise fixed to the rotor blade) on one blade, which is illuminated by means of a strobe light slaved to flash in time with the vibration. The strobe light is also used in conjunction with reflective targets to permit in-flight tracking of the main rotors, including observation of the blade spacing (lead/lag).

5.2.1 When carrying out a fault diagnosis of a main rotor, the rotor track should be checked first, and if necessary corrected, before proceeding with rotor balancing; the tests should be carried out with the helicopter in the hover. Before carrying out either check, the accelerometer(s) should be mounted on the helicopter in the agreed position(s) and the helicopter should be headed into wind on flat, level ground; operation in gusty conditions or wind-speeds above 15 knots should be avoided since these conditions introduce variables which may hide the real fault. The rotor should then be run on the ground at its nominal speed and the equipment rough-tuned to the frequency corresponding to 1/rev of the rotor being checked. The helicopter should then be put into the hover and the equipment fine-tuned and checked using its own internal test facility.

(a) Rotor track is checked by observing the blade reflective targets with the strobe light. Although different modes of operation are generally available, typical usage would present all targets superimposed upon one another at a fixed position in azimuth. If the frequency of the strobe light oscillator is then reduced slightly, the targets will be seen to spread, making them easier to identify and interpret (see Figure 5).



NOTE: Targets of Four-Bladed Rotor as Viewed by Strobe Light and Spread to Aid Identification

Figure 5 BLADE TRACKING

Any error in track or in blade spacing may thus be readily seen and the appropriate corrective action may be taken. In most helicopters the track is adjusted by altering the length of the pitch change rod of the incorrect blade, but in some it may also be necessary to adjust the blade trailing edge trim tab. It is very important that adjustments be made in the sequence recommended by the manufacturer. Incorrect blade spacing is often the result of faulty blade dampers, which should be renewed or repaired as appropriate.

(b) Once the rotor is correctly tracked, two readings may be taken from the balance part of the equipment as follows:—

(i) Phase—note which clock angle light is on (example, Figure 6, 5:30).

(ii) Amplitude—note reading on meter scale (example, Figure 6, 0·15 IPS).

After the helicopter is landed and shut down, these values should then be plotted on a nomogram (see Figure 6), from which it is possible to determine the number or size of balance weights required to be added to achieve balance. It is unlikely that one of the plotted points will lie exactly on a zero line (i.e. the centreline of a blade), so that balancing a rotor will usually involve adding weights to two blades as in the example in Figure 6. When corrections have been made, the check should be repeated until good balance is obtained, as indicated by a reading on the meter which is within the tolerance specified by the helicopter manufacturer. It should be noted that whilst it is still possible to read a definite clock angle the balance can be improved; as the balance improves the clock angle becomes more and more 'jittery'.

NOTES: (1) The helicopter manufacturers provide certain points on a rotor to which weights may be attached for balancing purposes.

(2) The nomogram (or balance chart) is valid for only one type of helicopter, with a specific configuration of accelerometer(s) and magnetic pick-up. There is a separate chart for each helicopter and each rotor.

5.2.2 The equipment may also be used to determine the amplitude and frequency of a vibration from an unknown source. In this case an accelerometer is mounted in the area where the vibration is most obvious and the equipment tuned slowly through the ranges until the meter reading reaches a peak. Knowing the frequency of the vibration, the location of its source may be more readily determined.

5.3 **Vibration Signature Analyser.** This is an extremely useful diagnostic tool particularly when used on a schedule basis. The analyser is a self-contained piece of equipment which measures vibration frequency against peak velocity and automatically produces a permanent record of the test in the form of a graph. The output from the accelerometer is processed electronically by a tuneable band pass filter, which separates vibrations on the basis of their frequency. The filter automatically scans through the selected frequency range and a pen records the result on a card (see Figure 7), which may be kept as part of the helicopter records. This equipment is not an alternative to the electronic vibration measurement equipment but supplements it.

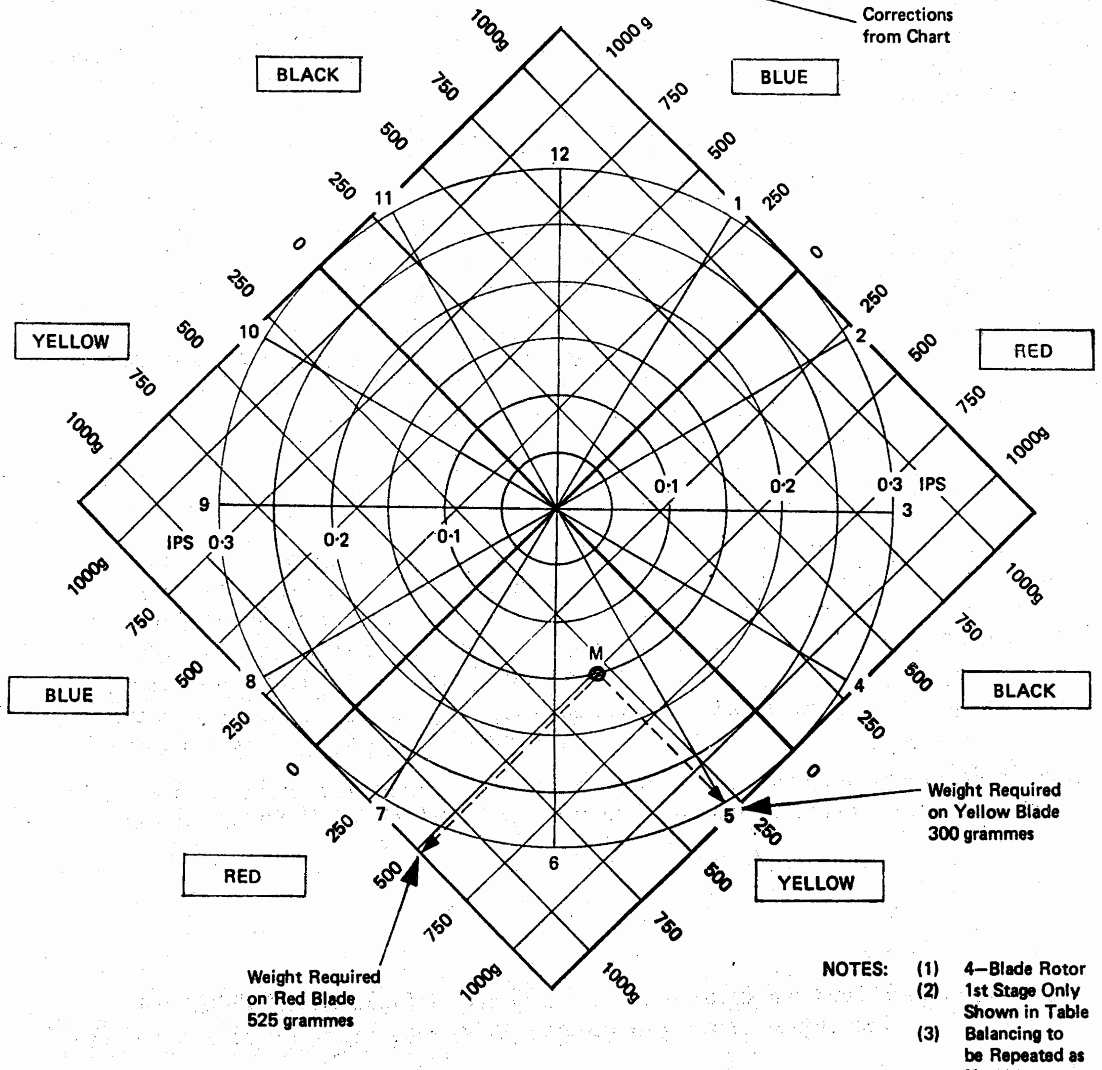
5.3.1 From the signature drawn on the card, a vibration peak at a particular frequency can be readily seen and its source determined. When the fault has been corrected, a further signature record should be made in order to confirm correction of the fault and provide a fresh datum with which to compare future signatures in the event of a suspected fault. One analyser is equipped with two frequency ranges, 0-100 Hz and 0-1500 Hz, and three velocity ranges, 0-0·2 IPS, 0-1·0 IPS and 0-5·0 IPS, the selection being automatically recorded on the card when the machine is in use.

Point 'M' on Chart

BALANCE MEASUREMENT		1	2	3	4	5
BLADE TRACKING		Good				
Balancer	CLOCK ANGLE	5:30				
	AMPLITUDE (IPS)	0.15				

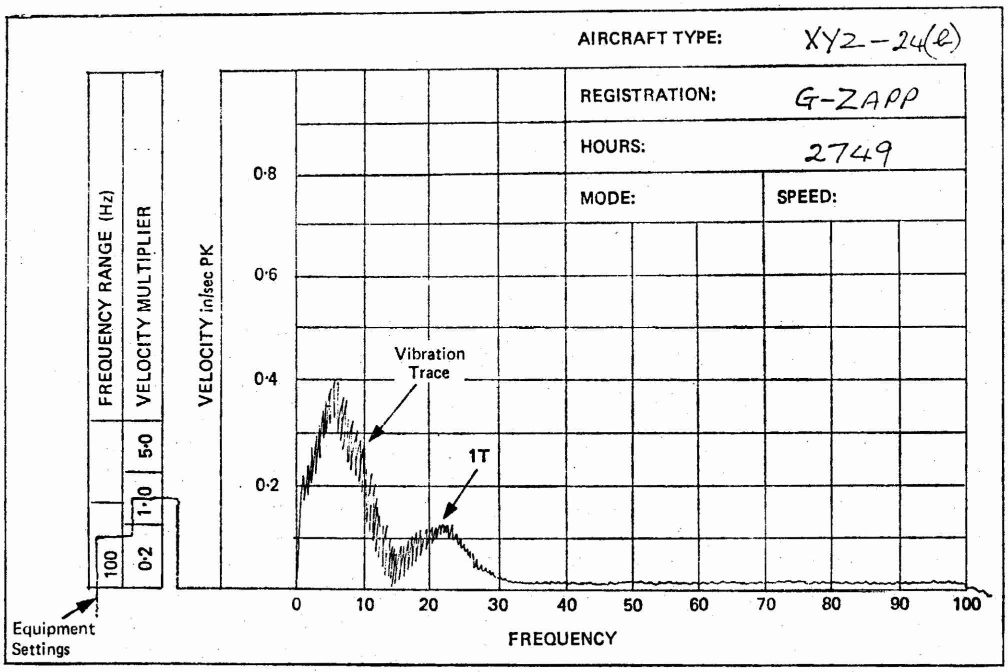
Corrections	RED BLADE	525 g				
	YELLOW BLADE	300 g				
	BLUE BLADE					
	BLACK BLADE					

Corrections from Chart



NOTES: (1) 4—Blade Rotor
(2) 1st Stage Only Shown in Table
(3) Balancing to be Repeated as Necessary

Figure 6 TYPICAL VIBRATION NOMOGRAM



NOTE: Tail Rotor Vibration Peak (1T) = 0·13 in/sec

Figure 7 TYPICAL VIBRATION SIGNATURE RECORD CARD

5.3.2 As with other types of vibration measuring equipment a specific location must be used for the accelerometer, and be used every time if the readings on a subsequent occasion are to be comparable. Normally both lateral and vertical (and in some cases fore and aft) signatures would be obtained on each frequency range, making a total of four signatures. Any significant peaks are then analysed and the faults corrected. In this way a complete vibration history is built up for a particular helicopter and the information can also be used to form the basis of a data bank for each type of helicopter.

5.4 **Calibration.** As with any precision instrument the usefulness of the data collected is determined by the confidence level established in use. Periodic calibration of measuring equipment is essential, although the interval will need to be determined by the frequency of use and the known stability of the particular equipment. The results of such calibration should be recorded so that a history may be built up for a specific instrument, on the basis of which it may be desirable, or necessary, to change the calibration interval. Some electronic filters are known to be subject to frequency drift with changes of temperature and this should be taken into account when recalibrating the equipment.

6 **ANALYSIS OF VIBRATION** Whichever method of vibration measurement has been used with a helicopter two parameters will have been obtained, namely frequency and amplitude (or velocity). With these two parameters it is possible to locate the source of vibration and determine its severity. Since the frequency is a function of the speed of various rotating components on the helicopter, it is possible to use this information to locate the source of the problem.

6.1 **Vibration Classification.** When determining the source of vibration it is usual to classify the frequency of the vibration as low, medium or high. Each range of frequencies may then be associated with particular components in a specific helicopter, although the actual range will be different with different helicopters. For example, low frequency vibrations are normally associated with the main rotor and are of the order of 1-2/rev in a two-bladed machine and 1-5/rev in a five-bladed machine; in terms of actual frequency ranges these could be between 3 Hz and 20 Hz, dependent upon the design of the machine. High frequency vibrations may be associated with the speed of the tail rotor and faster rotating components, whilst medium frequency vibrations will lie somewhere between the two extremes. Different manufacturers suggest different classifications for the medium and high frequency vibrations, the differences generally stemming from the number of blades and the gearing of the tail rotor.

6.1.1 In addition to the frequency and amplitude, the plane of the vibration will also be known. This will narrow the range of possible faults causing a vibration at a specific frequency. For example, in the case of a vibration associated with the speed of the main rotor, a lateral vibration would indicate an out-of-balance rotor, whilst a vertical vibration would indicate that the rotor was out-of-track. To verify the plane of the vibration and so cross check any measurements made the helicopter should be flown at different forward speeds and at different rotor speeds. An out-of-balance condition producing a lateral vibration will be worse at higher rotor speeds, whilst an out-of-track condition will produce a vertical vibration that becomes worse with increasing forward airspeed.

6.1.2 Whilst carrying out the flight test of a helicopter additional checks should be made. With the helicopter in the hover the cyclic stick should be moved slightly out of neutral and it should be noted if it rotates in time with the rotor (a symptom known as 'stick stir'). Typically this is symptomatic of faulty pitch change or flapping hinge bearings. If vibration is felt through the cyclic stick and the fuselage when the blade angle and/or power are rapidly changed in flight, the blade dampers may well be at fault. If the vibration is felt predominantly throughout the fuselage, particularly with rapid changes in the rotor tip path plane, faulty bearings in the flapping or dragging hinges should be suspected. Note should be taken of the circumstances under which vibration occurs or under which its nature is modified, in order to assist in correct diagnosis of the cause.

6.2 **Frequency/Speed Relationships.** To be able to relate the frequency of the measured vibration to the speed of different rotating components requires an intimate knowledge of the particular helicopter. A vibration of the order of 1/rev may be related to the speed of rotation by multiplying the measured frequency (F) in Hertz, by 60, to give the speed in revolutions per minute (rpm). This may be expressed as follows:—

$$\text{rpm} = F\ (\text{Hz}) \times 60$$

A 1/rev vibration is typical of an out-of-balance condition affecting a rotating component. For example an out-of-balance main rotor rotating at 203 rpm will produce a vibration frequency of:—

$$F\ (Hz) = \frac{rpm}{60} = \frac{203}{60} = 3{\cdot}4\ Hz$$

However, not all vibrations are 1/rev. In the case of a condition affecting all five blades in the above rotor the frequency would be:—

$$F\ (Hz) = \frac{rpm \times No.\ of\ Blades}{60} = \frac{203 \times 5}{60} = 16{\cdot}9\ Hz$$

In the same way the frequency produced by the meshing of gear teeth in the gearbox may be calculated if the number of teeth on the gear and the nominal speed of the gear are known. In this way it is possible to produce a table of vibration orders for a specific helicopter and some manufacturers publish such a table in the Maintenance Manual (see Table 1). In identifying the different orders abbreviations are often used, examples of which are as follows:—

1R = 1/rev main rotor
5R = 5/rev main rotor
1T = 1/rev tail rotor
1E = 1/rev engine output shaft
MGB = main gearbox
TRG = tail rotor gearbox

The letter M, used a prefix, would indicate that the vibration emanates from the meshing of the gear identified. For example:— M.TRG identifies the frequency generated by the meshing of the gears in the tail rotor gearbox. It is usual to quote the vibration orders based on speeds related to 100% main rotor speed.

TABLE 1

TYPICAL VIBRATION ORDER TABLE

Frequency (Hz)	RPM	Component
3·4	203	Main Rotor (1/rev)
15·7	939	Main Bevel Gear (MGB)
17·0	—	Main Rotor (5/rev)
20·7	1243	Tail Rotor (1/rev)
50·5	3031	Tail Rotor Drive Shaft
53·2	3195	Input Bevel Gear (MGB) or Rotor Brake Disc
101·0	6060	Oil Cooler Fan (MGB)
140·0	8410	Tail Take-off Freewheel Unit
316·0	—	Nos. 1 and 2 Input Pinion Gears
325·0	—	Engine
832·0	—	Meshing, Tail Rotor Gearbox, (M.TRG)

6.3 **Vibration Level Comparisons.** Having located the source of the vibration from an analysis of the frequency and its plane of vibration, it remains to determine whether the amplitude of the vibration is normal or excessive. In the cases of the main and tail rotors some manufacturers specify a maximum acceptable vibration amplitude, but some do not. For the main rotor, one manufacturer states that the balance may be deemed satisfactory if the vibration level does not exceed 0·05 IPS, whilst for the tail rotor the maximum acceptable level is 0·2 IPS. It should be noted that these figures are concerned only with vibration resulting from unbalance.

6.3.1 It is not recommended that decisions to accept or reject a component should be made solely on the basis of one set of vibration measurement readings. Where measurements are made on a scheduled basis it should be possible to notice a trend from the recorded data and the nature of this trend will be a more reliable indicator as to the action to be taken. A steadily worsening trend would indicate the need for careful monitoring but would not necessarily indicate the need for an immediate component change. However, a sudden, and large increase in the vibration level from, for example, a tail rotor gearbox, would be positive indication of the need for immediate investigation. In any given set of circumstances it should be borne in mind that there may be more than one source of vibration, and that a combination of sources may falsely amplify a specific reading. Such a case underlines the fact that there is no substitute for a detailed knowledge of the vibration history of the helicopter type and preferably of the specific helicopter. Where the Vibration Signature Analyser (see paragraph 5.3) is in regular use, the record cards provide a ready reference to the vibration levels previously experienced, in addition to making it easier to identify any abnormal peaks.

7 CORRECTION OF EXCESSIVE VIBRATION If a rotor goes out of track or balance on a helicopter which has previously flown satisfactorily, the primary cause must be established and corrected before commencing track or balance adjustments.

7.1 In the case of vibration which has been traced to the tail rotor, the investigation should include an inspection of all parts for wear and damage. Items requiring special attention include the pitch change bearings, the pitch change links and spider, tail rotor hub and gearbox attachments. Where mounting bolts are found to be slack it will be necessary to assess whether the slackness is the cause of the vibration or an effect of it. The follow-up work will not only involve re-tightening the bolts but also a check of the bolts, nuts, holes and locking devices for wear and cracks. Care must be taken to ensure that the inspection covers a sufficiently wide area to discover symptoms of secondary damage, such as cracking in the structure of the tail pylon. As items are renewed it is important that fits, clearances and tightening torques specified by the manufacturer are adhered to, in order that the unit shall perform as designed.

7.2 When dealing with vibration problems emanating from a rotor there is little point in trying to correct balance unless it is known that the track is correct and, in the case of a fully articulated head, that the dampers are operating properly. When considering main rotor track it must be ensured that the blades are compatible with one another and, where provision exists, are correctly pre-tracked. With some types of helicopters it is preferable that all blades be of a similar age since this will usually necessitate less correction to individual blades. With some types of tail rotor blades it has been discovered that quite significant weight differences can exist between one blade and another and corrections will be kept to a minimum if they are first matched in sets by weight. Great care should be taken when repainting blades, as a small difference in the thickness of the coating can produce a significant difference in weight.

7.2.1 Once the track and blade spacing are known to be correct, the rotor may be dynamically balanced using electronic vibration measurement equipment. With some main rotors and most tail rotors it is advisable to statistically balance the rotor prior to fitting it to the helicopter; this will reduce the amount of work required subsequently when the rotor is dynamically balanced. If either the track or the balance is changed the other condition should be re-checked, especially when dealing with articulated rotors.

7.2.2 After track and balance are confirmed to be correct in the hover, it will be necessary to fly the helicopter at different speeds, and to adjust the pitch change rods or the blade tabs, in order to achieve correct track in flight at all airspeeds. Some manufacturers publish a chart of step-by-step actions to facilitate the adjustment of rotors; such a chart may be included in the relevant Maintenance Manual.

8 VIBRATION ANALYSIS RECORDING Whilst the measurements made with the various types of equipment described have an immediate application in the rectification of a particular fault, the recording of results in such a way that it is possible to establish acceptable levels of vibration for a helicopter type, and trends in vibration for a specific helicopter, may be more important. In a fleet of helicopters, a vibration history should be built up for each helicopter by taking vibration signatures on a scheduled basis, that is, during the course of normal maintenance. In addition to the regular signature recording, analysis should be carried out in response to a pilot's report of abnormal vibration. From the record cards it is possible to extract a record of velocity at a certain frequency and to plot this on a graph at each successive check. The result will show a trend for the particular frequency selected, and thus indicate the condition of the component producing that frequency. A deteriorating trend would alert maintenance personnel to an impending problem and indicate the need for additional checks, such as, for example, oil analysis, to be carried out.

8.1 In addition to providing the basic data in relation to a specific helicopter the same material should be used to establish fleet averages for a helicopter type. Manufacturers are increasingly providing this kind of information in their Maintenance Manuals in order to assist engineers in making a decision as to whether or not a measured vibration is normal. Generally speaking this information will be in graphical form so that normal levels at specific frequencies may be readily discernible.