Airworthiness Division

Civil Aviation Authority

Civil Aircraft Inspection Procedures

Part I - Basic

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June, 1986

CHECK LIST OF REFERENCES

Because the numbers of some Leaflets were changed when CAIP was divided into Parts I and II, cross-references to them in other Leaflets became incorrect. It was not considered practical to re-issue a large number of Leaflets solely for the sake of altering cross-references and information on the change of numbers was therefore included in the List of Leaflets.

Subsequent re-issues of Leaflets have considerably reduced the number of incorrect cross-references and those that remain are shown in the following Table. The Table will be amended as further Leaflets are re-issued with corrected cross-references.

Reference Is Made In	*To*	*Should Now Be To*
BL/6-15, 1.2	AL/4-1	AL/3-21
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BL/9-1, 5.7	AL/7-5	BL/6-27
AL/3-2, 1.3	AL/3-1 and AL/3-4	AL/3-7 in both instances
AL/3-2, 7	BL/5-2	BL/6-14
AL/3-6, 1.1	AL/4-1	AL/3-21
AL/3-9, 1	EEL/2-1	EEL/1-7
AL/3-19, 1.1	AL/4-1	AL/3-21
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AL/7-8, 6	BL/5-1	BL/6-13
AL/7-12, 3.2 NOTE	AL/3-1 and AL/3-5	AL/3-7 in both instances
AL/7-12, 3.4.5	AL/3-1	AL/3-7
" "	BL/5-1	BL/6-13
AL/7-13, 8.1.4 NOTE	AL/9-1	AL/7-14
EL/3-1, 1.3	EL/5-3	EL/5-2
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*EEL/1-6, 1.2	EEL/1-5	EEL/1-3
" "	EEL/2-1	EEL/1-7
RL/3-1, 3.1	RL/3-2	RL/3-2 is cancelled
GOL/1-1, 7.7	AL/11-13	AL/11-3

*Some copies only

Issue 20.

January, 1981.

FOREWORD

1 INTRODUCTION Civil Aircraft Inspection Procedures, hereinafter referred to as the 'Inspection Procedures' or 'Leaflets' are published by the Civil Aviation Authority (CAA). The Leaflets give information on a variety of matters concerned with the inspection of civil aircraft during manufacture, overhaul, repair and maintenance. Leaflets which may assist and increase the knowledge of the reader on fundamental subjects such as workshop methods and processes are also included.

1.1 The information is essentially of a general nature which does not include detail on specific types of aircraft and engines, specialised equipment and component parts fitted to civil aircraft. Manuals, published by the appropriate constructors and manufacturers, should be consulted for detailed information.

1.2 The interpretation of the Leaflets and the application of the information is greatly dependent on the background knowledge of the reader. In preparing the Leaflets it is assumed that the reader is familiar with the general engineering practices and working procedures of the civil aircraft industry. Nevertheless, a certain amount of background information is provided where this is considered necessary for the understanding of the text, exceptions being where a Leaflet deals with a specialised subject (e.g. Leaflet RL/2-1, ADF Loop Aerials, where it is assumed that the reader will be familiar with radio theory and practice) or where it is known that adequate text books are readily available.

2 LAYOUT The Inspection Procedures are presented as numbered Leaflets contained in two separate Parts:—

(a) **Part I.** This is the Basic Part of the Civil Aircraft Inspection Procedures and contains Leaflets on airworthiness procedures and general aeronautical engineering practices. All Leaflet numbers in the Basic Part are prefixed by the letters **'BL'**. This Part may be used without any reference to Part II.

(b) **Part II.** This Part contains Leaflets on technical matters connected with aircraft, aircraft systems and equipment, engines, propellers and radio. The Leaflets are grouped into sub-sections and each Leaflet number is prefixed by letters according to its particular sub-section. Part II is dependent on Part I for information on administrative procedures and basic engineering practices and references are made in Part II Leaflets to Part I subject matter.

2.1 As a result of the division of CAIP into two Parts, Leaflets which have been re-positioned do not follow the sequence of letters and numbers of the Section as listed, and in some cases the titles of Leaflets do not agree with those printed in the Lists of Leaflets. The information in the right hand columns of the Lists gives the actual letters/numbers printed on the Leaflets. The new letters/numbers, and titles where applicable, will be printed on the next issues of the particular Leaflets.

NOTE: Reference to the List of Leaflets should be made in every case for information on the number and title of a Leaflet and its position in the volume.

3 AMENDMENTS Leaflets are reviewed periodically to ensure that the information contained in them remains valid. Leaflets which require amendment are re-issued under

a raised issue number and marginal lines are used to indicate material differences between issues. Those Leaflets which are reviewed and found not to require amendment are retained, and a statement indicating the date of the review is added against the entry in the appropriate List of Leaflets.

4 PUBLICATION AND DISTRIBUTION Subscribers may hold Part I only *or* both Parts I and II. Part II is not issued separately because of the essential cross-references to procedures in Part I.

4.1 Further copies of CAIP may be obtained from the CAA, Printing and Publication Services, Greville House, 37 Gratton Road, Cheltenham, Glos. GL50 2BN. Details of all Airworthiness Publications published by the CAA together with prices, subscription rates and the address to which applications should be made, are contained in Airworthiness Notice No. 6. Unless other arrangements have been made, a remittance should accompany the order.

5 ENQUIRIES Any enquiries regarding the technical content of the Leaflets should be addressed to the Civil Aviation Authority, Airworthiness Division, Brabazon House, Redhill, Surrey RH1 1SQ. In countries other than the United Kingdom, the airworthiness authority of the country concerned should be approached in all cases where it is recommended in the Leaflets that the CAA should be consulted.

6 COPYRIGHT Civil Aircraft Inspection Procedures are copyright and may not be reproduced without permission of the CAA.

BL/1-4

Issue 3.

16*th May,* 1975.

BASIC

AIRWORTHINESS PROCEDURES

ENGINEERING DRAWINGS

1 INTRODUCTION The purpose of an engineering drawing is to record and convey the designer's requirements. The drawing must, therefore, include sufficient information to enable production planning, manufacture, assembly, testing and inspection of the particular component or assembly to be carried out. So that there can be no misinterpretation of drawings, it is essential that both the person preparing the drawing and the person using the drawing should have a knowledge of the terms, symbols, abbreviations, and methods of presentation. This Leaflet gives general guidance on the various aspects of engineering drawings, and should be considered in conjunction with any special methods used by the design office responsible for a particular drawing. This Leaflet is not intended as a standard for drawing offices, but should be regarded as a general guide to drawing procedures and interpretation.

NOTE: This Leaflet deals with general engineering drawing procedures, and does not include information on specialised subjects, such as electrical or electronic drawing practice, computer produced lofting, or numerically controlled tapes.

1.1 Drawing practice in the United Kingdom generally conforms to British Standard (BS) 308. The particular requirements for companies within the aerospace industry in the UK, are covered in the recommendations contained in the Society of British Aerospace Companies' (SBAC) Technical Specification (TS) 88. Design organisations amend both the BS and SBAC drawing systems to suit their own particular requirements, and generally produce their own Drawing Office Standards.

1.2 For current projects the International Organisation for Standardisation (ISO) system for dimensioning and tolerancing of drawings is used, but, at the present time, Imperial units, terms, and tolerances, may be found on many drawings.

1.3 The abbreviations listed in Table 3, and the conventional representations of some standard features shown in Figures 10 and 15, are in accordance with BS 308, and will be found on most drawings. The terms and symbols used for tolerances in accordance with ISO recommendations, are shown in Table 5.

2 THE AUTHORITY OF THE DRAWING Civil aircraft manufactured in the United Kingdom are constructed from parts and components which have been manufactured to approved drawings. Design drawings and associated documents are, normally, produced by an organisation which has been approved by the Civil Aviation Authority, in accordance with British Civil Airworthiness Requirements (BCAR).

2.1 BCAR prescribes that all calculations on which the airworthiness of an aircraft depends, must be independently checked. Thus the design drawing itself is subject to a system of inspection, as are the parts produced to its requirements.

2.2 Drawings are used by Purchasing Departments, Production Engineers, Planners, Inspectors, and personnel engaged on the manufacture and assembly of components. A drawing must, therefore, contain all the necessary dimensions, limits of accuracy, classes of fit, material specifications, and any other information likely to be required by any of the departments concerned, so that they may carry out their respective responsibilities without reference back to the Design Department.

2.3 Any deviation from the approved drawings or associated documents during manufacture, must be covered by a Concession, the procedures for which are described in Leaflet **BL/1-5.** During overhaul, modification, maintenance and repair, the approved Organisation, or the appropriately licensed engineer, should ensure that all replacement parts, or repairs carried out, are in accordance with the approved drawings and associated documents.

3 TYPES OF DRAWINGS There are four types of drawings recommended in BS 308; single-part (unique parts or assemblies), collective (parts or assemblies of essentially similar shape, but of different dimensions), combined (a complete assembly including all individual parts on a single drawing), and constructional (an assembly drawing with sufficient dimensional and other information to describe the component parts of a construction). A complete set of drawings for an aircraft, and any documents or specifications referenced on the drawings, present a complete record of the information required to manufacture and assemble that aircraft, and they also form part of the inspection records. The manner in which a set of aircraft drawings is arranged, enables any particular component, dimension, procedure or operation, to be traced.

3.1 A main 'general arrangement' drawing of the aircraft, and 'general arrangement' drawings of the main assemblies and systems, are provided. These drawings usually contain overall profile particulars only, with locations and references of the associated main assembly and installation drawings; they provide a guide to the identification of drawing groups used by the particular design organisation.

3.2 Main assembly drawings may also contain profile particulars only, but will include the information required for the assembly of individual parts of sub-assemblies. The sequence of assembly is given where appropriate, but the information contained in single part or sub-assembly drawings, is not repeated. Parts as such are referenced, but, in the case of sub-assemblies, only the sub-assembly will be referenced and not its individual parts.

3.3 Installation drawings are issued to clarify the details of external dimensions and attitudes of components, locations, adjustments, clearances, settings, connections, adaptors, and locking methods between components and assemblies.

3.4 Sub-assembly drawings are issued to convey specific information on the assembly of component parts. When the method of assembly entails welding, or a similar process, the drawing will include details of any heat treatment or anti-corrosive treatment that may be necessary. Sub-assembly drawings are sometimes issued in connection with spares provisioning, and also in cases where assembly would be difficult without special tools, jigs or techniques.

3.5 Drawings of individual parts contain all the information necessary to enable the parts to be manufactured to design requirements. The material specification, dimensions and tolerances, machining details and surface finish, and any treatment required, will all be specified on the drawings.

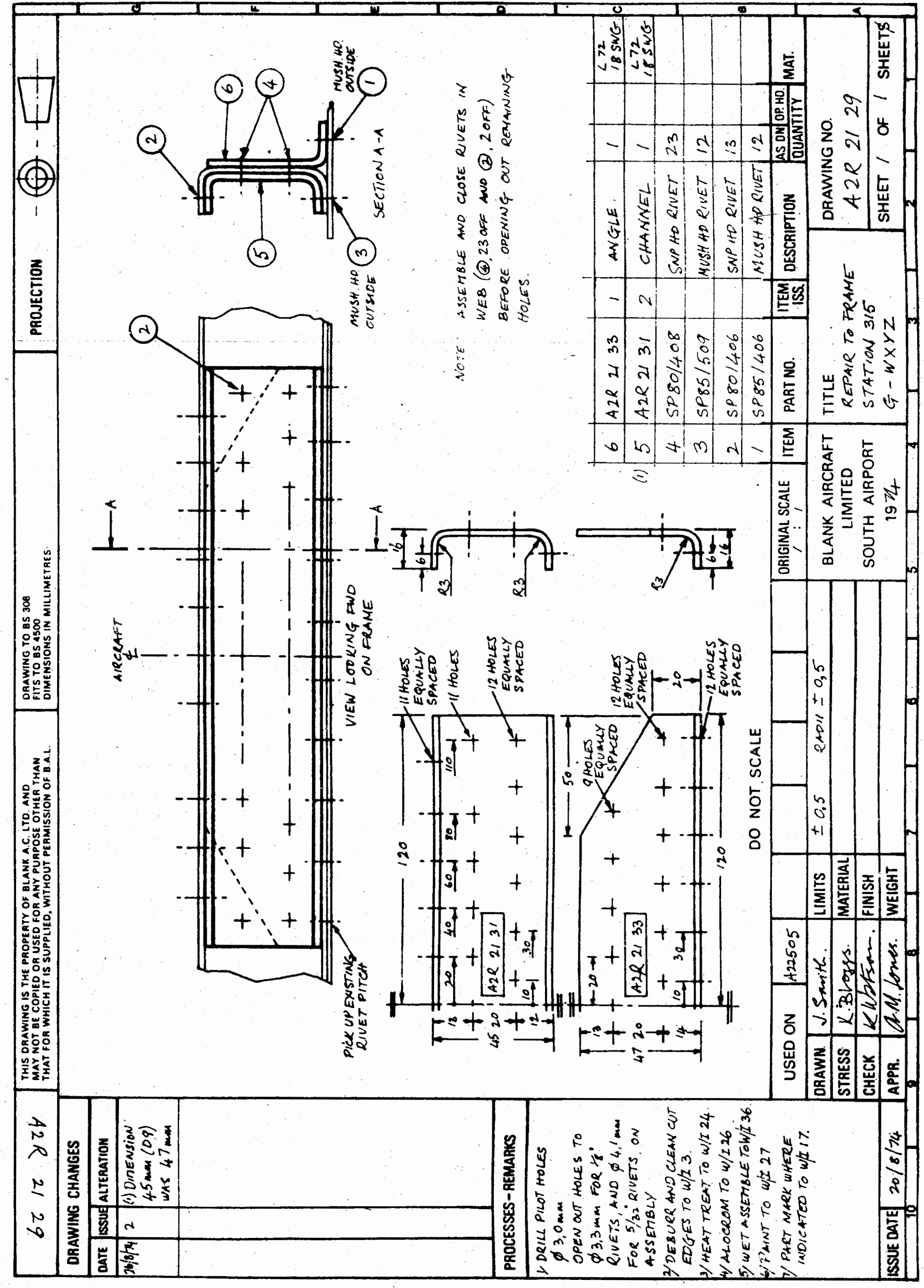


Figure 1 TYPICAL ENGINEERING DRAWING

4 DRAWING SYSTEMS Section A of BCAR, prescribes that each drawing must bear a descriptive title, drawing number, issue number, and the date of issue, it also prescribes that all alterations to drawings shall be made in accordance with a drawing amendment system which will ensure amendment to design records. If an alteration is made, a new issue number and date must be allocated to the drawing. To comply with the requirements, procedures must be introduced to progressively amend the total definition of the product in terms of its associated list of drawings at specific issues. Each particular variant of a product, and its state of modification, must be identifiable in relation to the appropriate list of drawings. The following paragraphs amplify these procedures, and explain the purposes of various parts of a drawing, together with the systems used and the methods of presentation. A typical drawing which illustrates many of the features with which this Leaflet is concerned, is shown in Figure 1.

4.1 **The Drawing Number.** No two drawings should bear identical numbers, and a design office should maintain a register of all drawings issued. The drawing number has three features, the project identity (A2 in Figure 1) the group breakdown (21 in Figure 1), and an individual register number (29 in Figure 1). TS 88 describes an acceptable numbering method, but considerable discretion is allowed for particular design office requirements. In Figure 1, A2 indicates the aircraft type, R indicates a repair, 21 indicates the front fuselage, and 29 indicates the register number in this group of drawings. Except for repair drawings, the drawing number is also, generally, the part number of the item.

4.1.1 **Handed Parts.** Drawings of handed parts usually have the left hand (port), upper, inner, or forward part drawn, this item taking the odd number, and the opposite hand the consecutive even number. Parts which are not handed have an odd drawing number. The drawing sheet bears the legend 'AS DRAWN' and 'OPP HAND' in the item quantity column. Where necessary the handed condition is indicated by a local scrap view or annotation.

4.1.2 **Sheet Numbers.** Where a complete drawing cannot be contained on a single sheet, successive sheets are used. The first sheet is identified as 'SHEET 1 of X SHEETS', as applicable, and subsequent sheets by the appropriate sheet number. Where a schedule of parts applicable to all sheets, is required, it appears on Sheet 1.

4.2 **Drawing Changes.** Any change to a design drawing, other than the correction of minor clerical errors, must be accompanied by a new issue number and date. New parts added to the drawing, or 'drawn on' parts affected by the change, take the new issue number, and parts which are not affected retain the original issue number. In all cases where interchangeability is affected, a new drawing number and part number are allocated.

4.2.1 Details of the drawing changes are recorded in the appropriate column on the drawing, or recorded separately on an 'Alteration Sheet', which is referenced on the drawing. Changes are related to the change number quoted in the change of issue columns on the drawing, and the marginal grid reference is given to identify the altered features.

4.2.2 The issue 'number' may sometimes be represented by a letter. Some organisations use alphabetical issues for prototype aircraft drawings, and numerical issues for production aircraft drawings; thus all drawings of a prototype aircraft become 'Issue 1' when production commences.

4.2.3 An alteration to a single part drawing may also result in changes to associated drawings; in addition, it may be necessary to halt manufacture or assembly of the product. The drawing office system usually makes provision for the proper recording of drawing changes, by publishing, concurrently with the re-issued drawing, an instruction detailing the effects these will have on other drawings, on work in progress, and on existing stock. As a further safeguard, some organisations publish Drawing Master Reference Lists, which give details of the current issues of all drawings which are associated with a particular component or assembly.

4.3 **Part Referencing.** Every item called up on a drawing is given an item number, which is shown in a 'balloon' on the face of the drawing, as illustrated in Figure 1. No other information is given in or adjacent to the balloon, with the exception of information necessary for manufacture or assembly, such as 'equally spaced', 'snap head inside', or the symbol 'ND', which indicates that no separate drawing exists for the part.

4.3.1 A schedule of parts is usually given in the manner shown in Figure 1, or on a separate sheet of the drawing (see paragraph 4.1.2).

4.3.2 As an alternative to the system described above, grid references may be given in the list of parts; in such instances the actual part numbers appear in the balloons. Where a part occurs a number of times on a drawing, e.g. as may be the case with rivets, bolts, etc., it may be impractical to list all grid references, in which case this column is left blank.

4.3.3 In instances where ND parts are shown as items on a drawing, the part number of such items may be that drawing number, followed by the drawing item number. Alternatively the part may be given its own part number, but will be identified as an ND part, e.g. 'A1 31 101 ND'. The information required for the manufacture of an ND part is contained in the description and material columns of the drawing, but reference may also be made to other drawings, where necessary.

4.3.4 Materials such as locking wire and shimming, which are available in rolls and sheets, will be detailed by specification number in the 'Part No' column, and the quantity will be entered as 'As Required', or 'A/R'. Standard parts to BS and SBAC Specifications will be detailed by the appropriate part numbers, but will not be drawn separately.

4.4 **Drawing Queries.** Drawing queries may arise through mistakes in draftsmanship, through ambiguity or through inability to purchase, manufacture, or assemble the items as drawn. Design Office procedures must be introduced which cater both for raising queries, and for providing satisfactory answers to those queries.

4.4.1 Drawing queries are usually raised on a Drawing Query Form, which is passed to the Design Office for action. The answer to the query may be an immediate provisional one, detailed on the query form; a temporary, fully approved answer, issued by means of a Drawing Office Instruction, and having the same authority as the drawing to which it refers; or a permanent answer provided by means of a new or re-issued drawing.

4.4.2 Drawing Query Forms and Drawing Office Instructions should be suitably identified, and should be referenced on the amended drawing. The effects on other drawings, on existing stock, and on work in progress, should be included in the answer to the query.

4.4.3 The number of Drawing Query Forms or Drawing Office Instructions permitted on a drawing, should be limited, and a new or re-issued drawing should be completed as soon as possible.

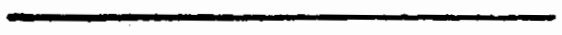
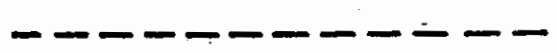
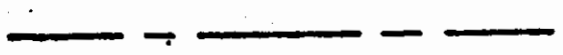
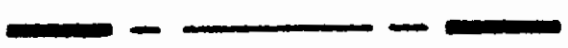
5 INTERPRETATION OF DRAWINGS The following paragraphs indicate some of the general drawing practices used on aircraft drawings. These practices are in accordance with the recommendations contained in BS 308 and TS 88, but many drawings will have been issued to previous British or foreign standards, and some degree of interpretation may be necessary. In cases of doubt the Drawing Office Handbook, or similar publication issued by the relevant Design Organisation should be consulted.

5.1 **Scale.** Drawings are normally drawn to a uniform scale, and this is normally shown in the 'ORIGINAL SCALE' box on the drawing, in the form of a ratio, e.g. 1:2 (i.e. half size). Where details or views are drawn to a different scale, this should be clearly stated on the drawing. Aircraft drawings are often full size, i.e. 1:1, but no drawing should be measured to obtain a particular dimension which is not shown; the omission should be referred to the Design Office. On earlier drawings the scale may be represented by a fraction, e.g. ¼, which is 1:4.

5.2 **Lines.** The types and thicknesses of lines recommended in BS 308 are shown in Table 1. Drawings are often completed in pencil, however, and line thickness may, in practice, vary considerably, especially after the drawing is reproduced.

TABLE 1

TYPES OF LINES

Example	Description	Width (mm)	Application
	Continuous (thick)	0·7	Visible outlines and edges.
	Continuous (thin)	0·3	Fictitious outlines and edges, dimensions and leader lines, hatching, outlines of adjacent parts and revolved sections.
	Continuous irregular (thin)	0·3	Limits of partial views or sections when the line is not on axis.
	Short dashes (thin)	0·3	Hidden outlines and edges.
	Chain (thin)	0·3	Centre lines and extreme positions of moveable parts.
	Chain (thick at ends and changes of direction, thin elsewhere).	0·7 0·3	Cutting planes.
	Chain (thick)	0·7	Indicates surfaces which have to meet special requirements.

5.3 **Projections.** The majority of drawings produced for aircraft purposes show the parts in third angle orthographic projection (paragraph 5.3.1), but a number of older drawings may have been produced in first angle orthographic projection (paragraph 5.3.2). Both systems show objects as they actually are, both in size (unless for convenience the drawing is scaled up or down) and shape, when viewed in the vertical and horizontal planes. The projection used for a drawing must be clearly stated, and the appropriate international projection symbol must be placed in a prominent position on the drawing. Any views not complying with the projection stipulated, e.g. a view showing the true shape of an inclined face, are generally marked with an arrow, and suitably annotated.

5.3.1 **Third Angle Projection.** The principle of third angle projection is shown in Figure 2. Each view represents the side of the object nearest to it in the adjacent view.

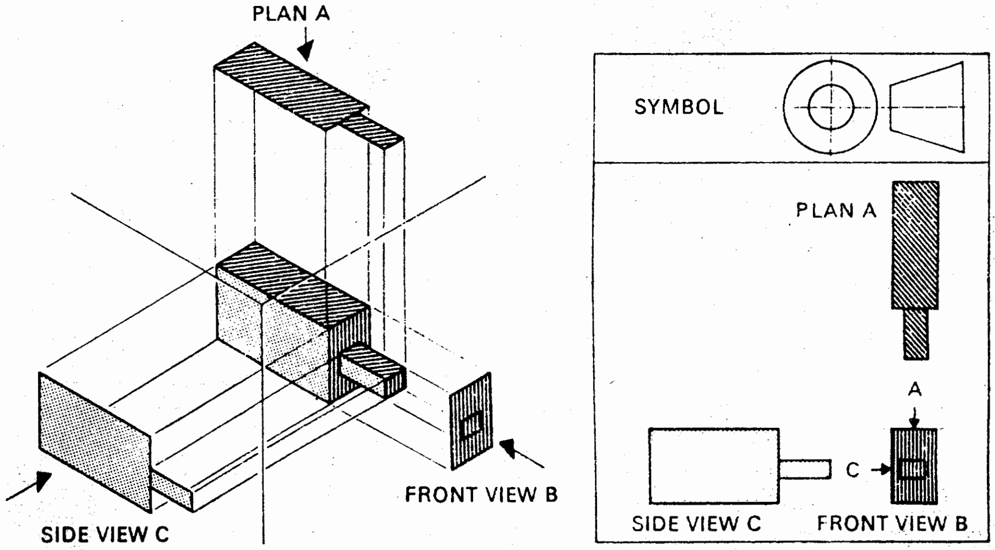


Figure 2 THIRD-ANGLE PROJECTION

5.3.2 **First Angle Projection.** The principle of first angle projection is shown in Figure 3. Each view represents the side of the object remote from it in the adjacent view.

5.3.3 **Isometric Projections.** These are pictorial views of an object, which are drawn with the three axes inclined, usually at an angle of 30°, to the plane of projection. The central drawing in Figure 2 and in Figure 3, is an isometric projection. Isometric views are sometimes used in drawings to indicate the position that the component occupies in the aircraft, or as a guide to understanding a complicated drawing.

5.4 **Views.** In general, all principal elevations are drawn looking at the left side of the aircraft, and the left hand item of handed parts is drawn. Other views are clearly annotated, e.g. 'view looking forward on frame'. The number of views shown on a drawing will depend on the complexity of the part, although two views may often be sufficient. In some cases the three main views (Figures 2 and 3) may be insufficient to clarify all the details necessary, and a number of sectional or auxiliary views may be necessary.

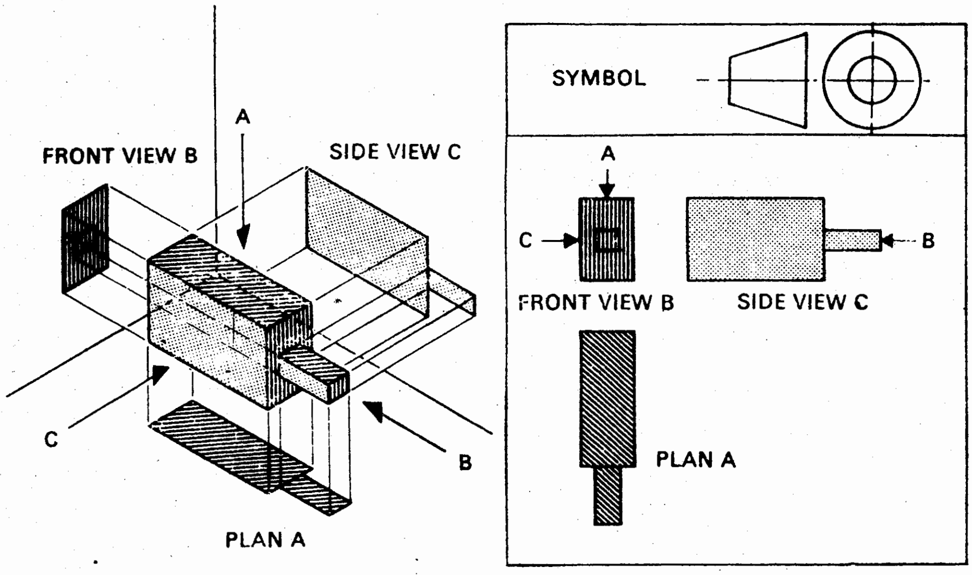


Figure 3 FIRST-ANGLE PROJECTION

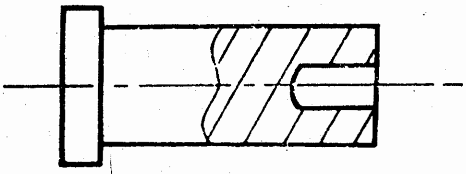


Figure 4 PART SECTION

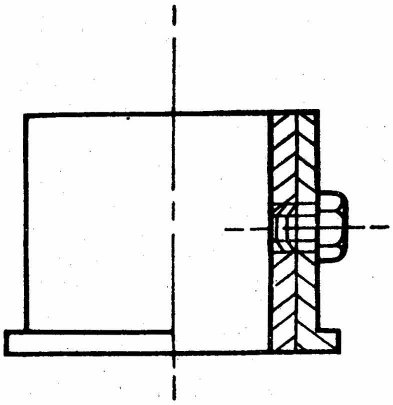


Figure 5 HALF SECTION

5.4.1 **Sectional Views.** A sectional view may show a plan or elevation in complete section, the plane of the section being along one of the main centre lines. Where full sectioning is considered unnecessary, a part or half section may be used, and staggered sections are often used to illustrate particular features. Typical sectional views are illustrated in Figures 4, 5 and 6.

(a) Hatching lines are normally used to indicate the exposed section, but these may be omitted if the drawing is clearly understandable without them. Hatching lines are usually drawn at 45° to the axis of the section, and adjacent parts are hatched in different directions.

(b) Bolts, rivets, shafts, ribs, and similar features are not normally shown in longitudinal section.

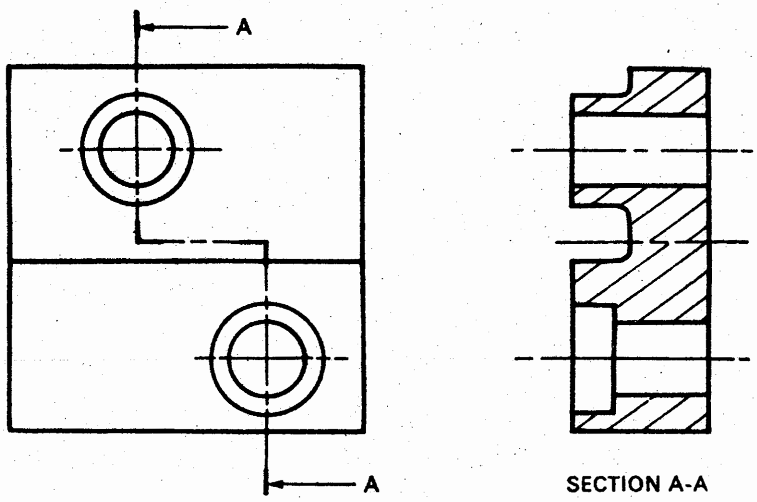


Figure 6 STAGGERED SECTION

5.4.2 **Auxiliary Views.** Neither a plan nor an elevation will show the true shape of a surface inclined to the plane of projection. The true shape of such a surface is shown by means of an auxiliary view, the auxiliary plane being imagined as being parallel to the surface being illustrated, as shown in Figure 7.

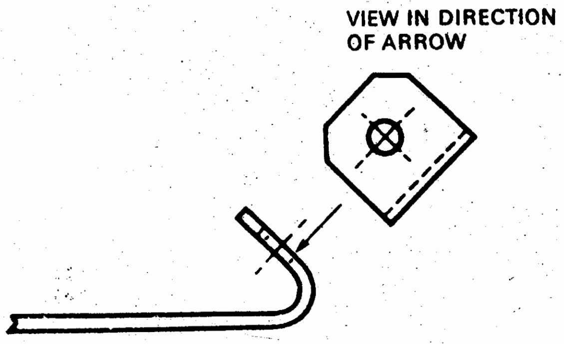


Figure 7 AUXILIARY VIEW

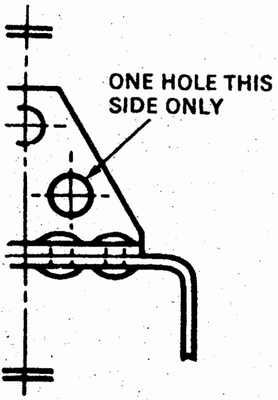


Figure 8 SYMMETRICAL PARTS

5.4.3 **Symmetrical Parts.** Parts which are symmetrical, or nearly so, may not be fully drawn. Sufficient information is normally provided by drawing one half or segment of the part; any asymmetry being identified by a note. Figure 8 shows a symmetrical part, and illustrates the method of defining the line of symmetry.

5.4.4 **Repetitive Information.** Where several features are repeated in a regular pattern, such as rivets, bolts, or slots, only the number required to establish the pattern may be shown, by marking their centrelines. Any further information will be given in a note. Figure 9 shows a typical skin joint which could be drawn in this manner.

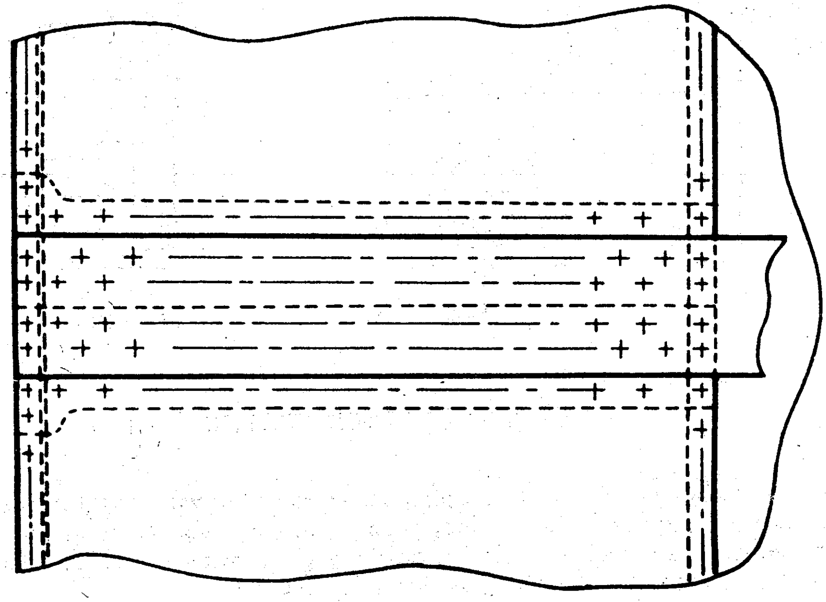


Figure 9 REPETITIVE FEATURES

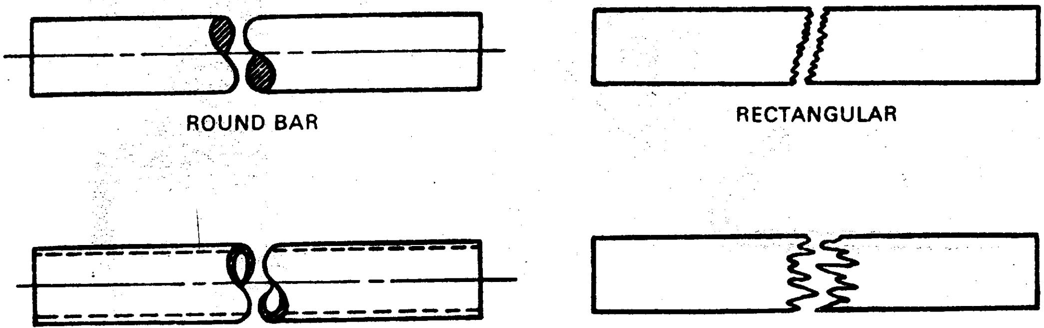


Figure 10 BREAK LINES

5.4.5 **Break Lines.** Break lines are used where it would be inconvenient (because of limited space) to draw long lengths of standard section. The types of break lines used for various components are shown in **Figure 10.**

5.5 **Dimensioning.** All dimensions necessary for the manufacture of the part or assembly are given on the drawing; it should not be necessary to deduce any dimension from other dimensions. To avoid confusion, dimensions are normally given once only. The units of measurement used are usually stated on the drawing, to avoid repetition, but any dimension to which this general statement does not apply will be suitably annotated. Dimensions are placed so that they may be read from the bottom or right hand side of the drawing.

5.5.1 When dimensions are given from a common datum, one of the methods shown in Figure 11 is normally used. Chain dimensioning, i.e. dimensioning between adjacent holes, is not often used, since it allows a build up of tolerances, which may not be acceptable. An alternative method, used with riveted joints, is to locate the end holes and add a note such as '11 rivets equally spaced'; this method is useful on curved surfaces.

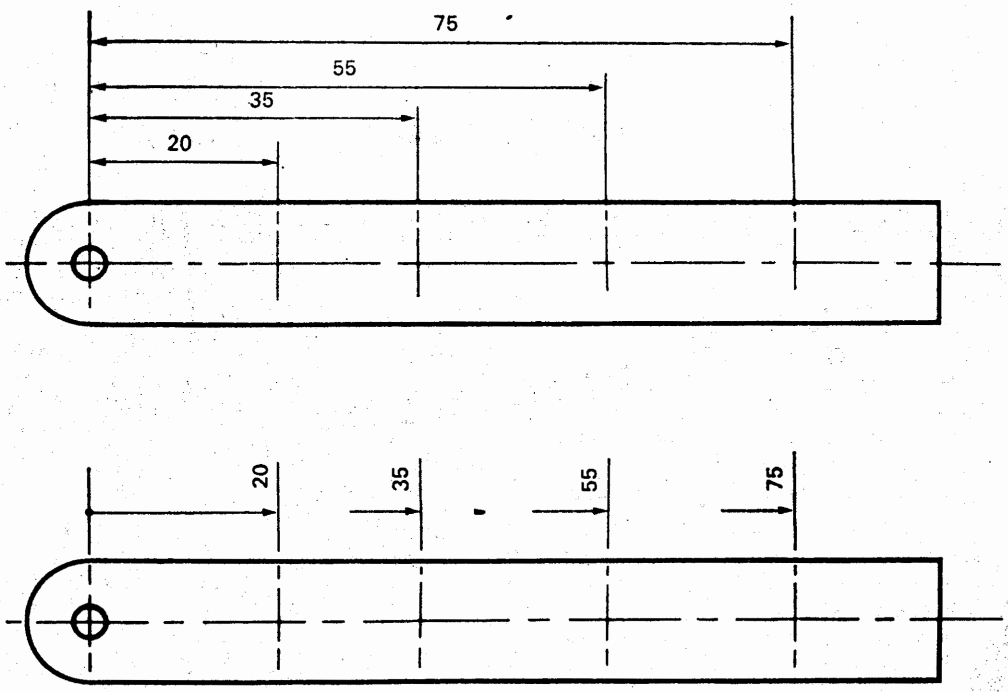


Figure 11 DIMENSIONING FROM A COMMON DATUM

5.5.2 Machined components are usually measured by a system of functional and non-functional dimensions. The functional dimensions are those which directly affect the function of the component, e.g. the length of the plain portion of a shouldered bolt. A non-functional dimension would be the depth of the bolt head, and other dimensions chosen to suit production or inspection. Auxiliary dimensions may also be given, without tolerances, for information.

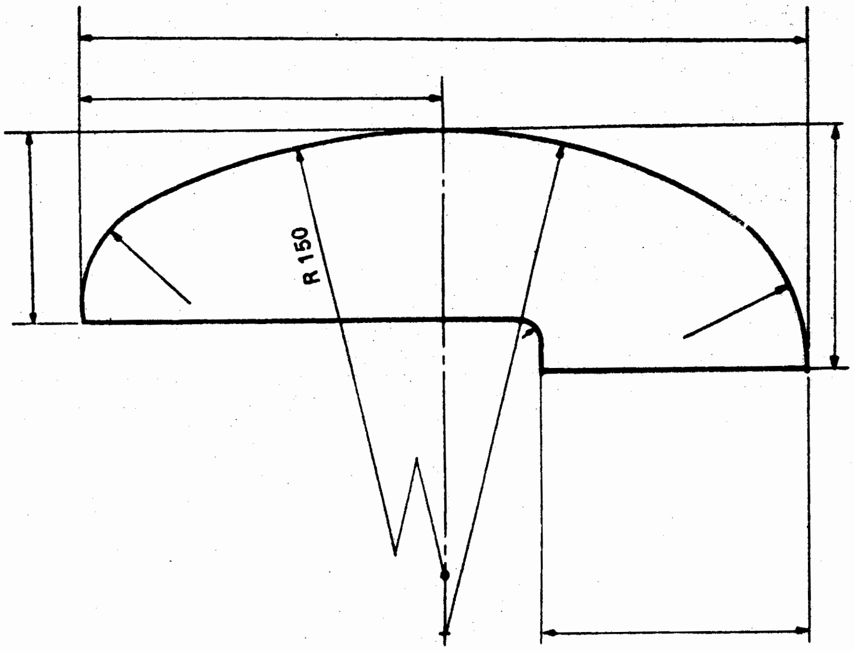


Figure 12 DIMENSIONING PROFILES BY RADII

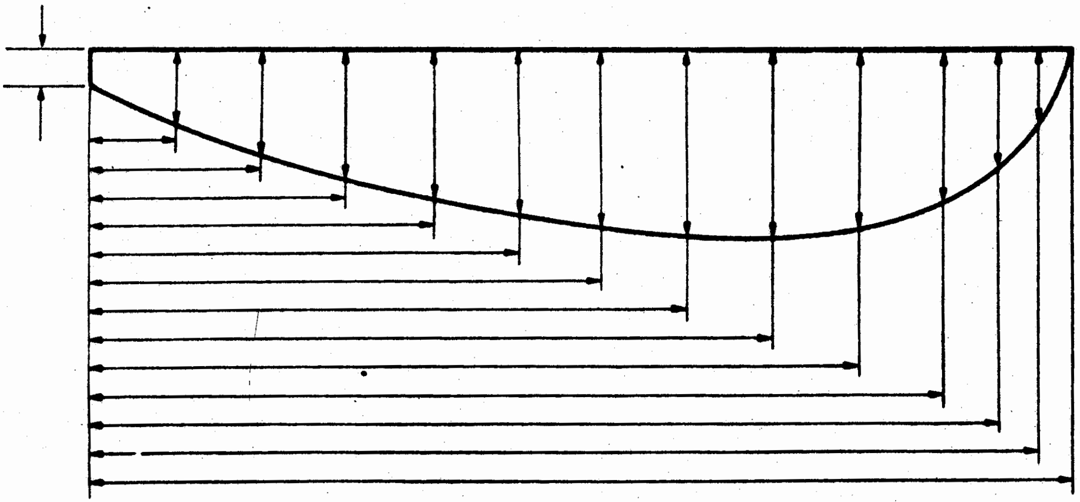


Figure 13 DIMENSIONING PROFILES BY ORDINATES

5.5.3 **Dimensioning of Curved Profiles.** Items the profiles of which are curved, are where practicable, dimensioned by means of radii, as shown in Figure 12. Where a radius is very large, and the centre of the arc could not be shown on the drawing, the method shown for the R150 dimension in Figure 12 may be used; the portion of the radius which touches the arc being in line with the true centre. Where this method cannot be employed, a system of ordinates may be used, as shown in Figure 13. The radii method is usually preferred, since accurate arcs can be produced; whereas with the ordinate system, deviations from the required curve may occur as a result of connecting the plotted points.

5.6 **Dimensional and Angular Tolerances.** A general tolerance is usually given for all dimensions on a drawing, and may be found in the appropriate box on the printed layout. Where the general tolerance is inadequate or restrictive, an individual tolerance may be given to a dimension.

5.6.1 Tolerances may be expressed by quoting the upper and lower limits, or by quoting the nominal dimension and the limits of tolerance above and below that dimension. Examples of both linear and angular tolerances are shown in Figure 14. Geometric tolerances are dealt with in paragraph 5.11.

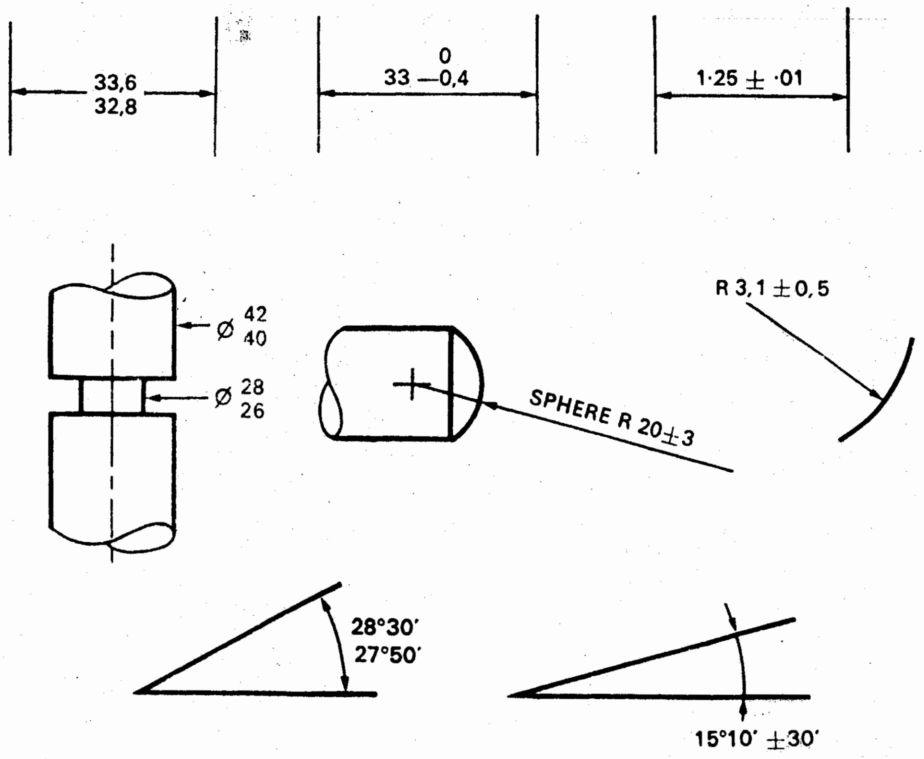


Figure 14 DIMENSIONAL TOLERANCES

5.7 **Machining and Surface Finish.** When a machining operation is required on a particular surface, the symbol √ is used, and is located normal to that surface. When the component is to be machined all over, the symbol √ ALL OVER is used, and, in some cases, the type of machining is indicated with a note such as √ LAP

5.7.1 The machining symbol is also used to indicate the surface finish required; the maximum roughness figure being added to the symbol thus: $\overset{4}{\surd}$. The surface finish quoted on a particular drawing depends on the system being used. The relationship between the various systems is included for reference in Table 2. The centre-line average (CLA) method of surface finish measurement is generally used **(Leaflet BL/3-3).**

TABLE 2

SURFACE TEXTURE EQUIVALENTS

Nominal	micrometre	0·025	0·05	0·1	0·2	0·4	0·8	1·6	3·2	6·3	12·5	25	50
Values	microinch	1	2	4	8	16	32	63	125	250	500	1000	2000
Roughness Number		N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12

5.8 **Abbreviations and Symbols.** In order to save time and drawing space when compiling a drawing, a number of abbreviations and symbols are used. Table 3 lists the main abbreviations and symbols which will be found on both currently produced and older drawings.

5.9 **Conventional Representations.** Common features, which may appear several times on a drawing, are seldom drawn in full, since this would take up space, and drawing time, unnecessarily. These features are shown by conventional representations, some examples of which are illustrated in Figure 15.

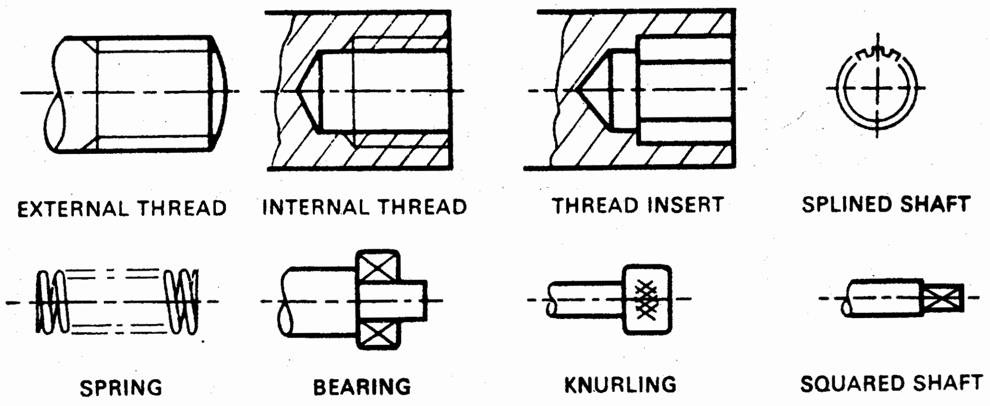


Figure 15 CONVENTIONAL REPRESENTATIONS

5.10 **Process and Identification Markings.** Drawings will often call for identification markings on parts, and will indicate both the position of the markings and the method of application, e.g. rubber stamp. In addition, it is sometimes necessary to mark the component to show that a particular process has been carried out, and this will also be specified on the drawing. Symbols are normally used for this purpose, and some of the more common ones are shown in Table 4. Some Design Organisations may use different symbols or code letters, which should be obtained from the Drawing Office Handbook, or similar publication, produced by the organisation concerned.

5.11 **Geometric Tolerances.** It is sometimes necessary to place tolerances on both geometric features and dimensions, in order to adequately control the shape of a part. On older drawings this was done by annotating the feature to be toleranced, e.g. POSN. TOL, and by adding notes to the drawing, in order to specify the tolerance and the method of checking. On newer drawings, the international system recommended BS 308 is used, and this method is outlined in the following paragraphs.

TABLE 3
ABBREVIATIONS AND SYMBOLS

Term	Abbreviation	Term	Abbreviation
Across Flats	A/F	Pattern number	PATT NO
Assembly	ASSY	Pitch circle diameter	PCD
British Standard	BS	Pneumatic	PNEU
Centres	CRS	Pound (weight)	LB
Centre line	CL or ℄	Radius	RAD or R
Chamfered	CHAM	Reference	REF
Cheese Head	CH HD	Required	REQD
Counterbore	C'BORE	Revolutions per minute	RPM or REV/MIN
Countersunk	CSK		
Cylinder or cylindrical	CYL	Right hand	RH
Degree (of angle)		Round head	RD HD
Diameter—in a note	DIA	Screw threads:	
—as dimension	Ø	British Association	BA
Figure	FIG	British Standard Fine	BSF
Full indicated movement	FIM	British Standard Pipe	BSP
Hardness—Brinell	HB	British Standard Whitworth	BSW
—Rockwell	HR (+scale letter)	Unified Coarse	UNC
—Vickers	HV	Unified fine	UNF
Hexagon	HEX	Unified special	UNS
Hexagon head	HEX HD	Screwed	SCR
Hydraulic	HYD	Second (of angle)	″
Inch	IN or ″	Sheet	SH
Insulated	INSUL	Sketch	SK
Internal diameter	I/D	Specification	SPEC
Left Hand	LH	Spherical diameter	SPHERE Ø
Long	LG	Spherical radius	SPHERE R
Machine	M/C	Spotface	S'FACE
Machined	M/CH	Square	SQ
Material	MATL	Square inch	SQ IN or IN^2
Maximum	MAX		
Max material condition	MMC or Ⓜ	Standard	STD
Millimetre	MM	Standard wire gauge	SWG
Minimum	MIN	Taper	▷
Minute (of angle)		Threads per inch	TPI
Not to scale	NTS	Undercut	U'CUT
Number	NO	Volume	VOL
Outside diameter	O/D	Weight	WT

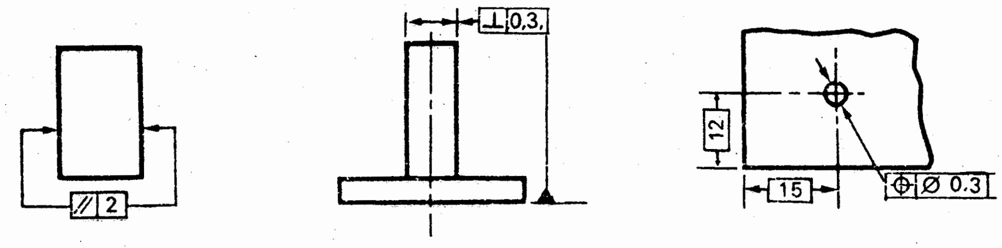
NOTE: Capital letters are normally used on a drawing, for clarity, but lower case letters may be used elsewhere as appropriate.

TABLE 4

PROCESS AND TREATMENT SYMBOLS

Process or Treatment	Symbol
Solution treated and not requiring precipitation	N
Solution treated and requiring precipitation	W
Precipitation treatment	P
Solution treated and precipitated	WP
Annealed	A
Hardened and tempered	HT
Mechanical test	M
Dye penetrant check	PFD
Ultra-sonic test	UFD
Anodic flaw detected	AFD
Cleaned (pipes)	AC 1
Repaired and reconditioned	R
Normalised steel parts	N
Proof loaded	PL
Stress relieved	SR
Pressure test	PT
X-ray flaw detected	XR
Salvaged	S
Electro-magnetic flaw detection	MFD
Welding	W S
Etch inspection of steel	E

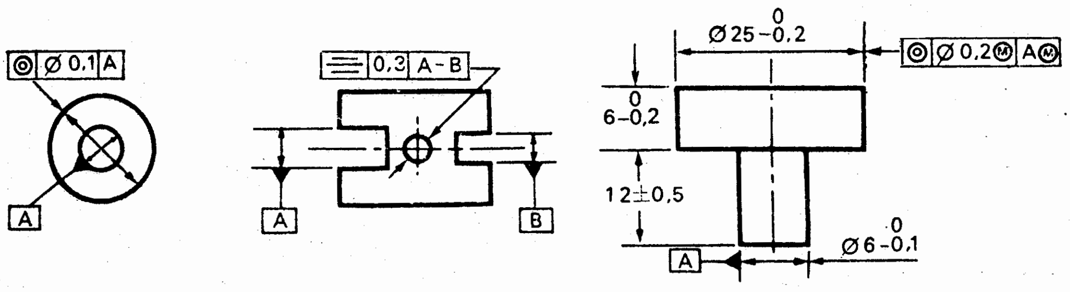
5.11.1 Information relating to a particular geometric tolerance is enclosed within a rectangular frame on the drawing, an arrow from the frame indicating the location of the feature to which the tolerance applies. If the tolerance is related to a particular datum, a leader line is drawn from the frame to the datum position, or the datum is referenced separately, and identified by a letter in the frame. Unless the datum is a dimension, it is defined by a solid equilateral triangle. Examples of the methods of indicating geometric tolerances are shown in Figure 16, and the symbols used to identify the characteristic to which the tolerance is applicable are listed in Table 5. Detail (f) in Figure 16 shows a completely dimensioned component.



(a) PARALLELISM

(b) PERPENDICULARITY

(c) POSITION



(d) CONCENTRICITY

(e) SYMMETRY

(f) COMPLETELY DIMENSIONED PART

Figure 16 GEOMETRIC TOLERANCES

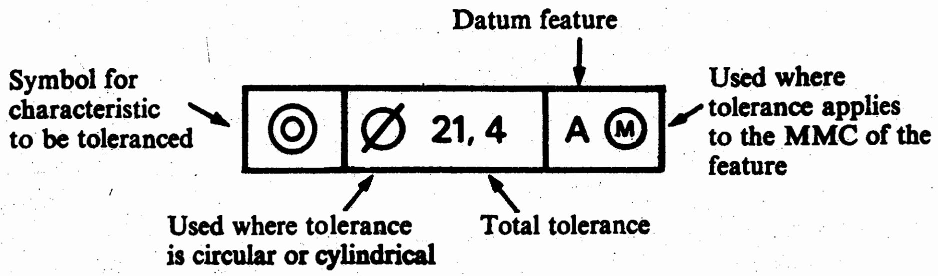
5.11.2 As a guide to the interpretation of a geometric tolerance, reference may be made to detail (e) of Figure 16. This indicates that a symmetry tolerance of 0·3 mm is required, with respect to datum features A and B. This tolerance indicates that the axis of the hole must be between two parallel planes, 0·3 mm apart, which are symmetrically disposed about the common median plane of the slots in the end of the part. The hole could also, if necessary, be marked to indicate a symmetry tolerance at 90° to the plane specified, and the tolerance for this could be different.

5.11.3 The symbol (M) in detail (f) of Figure 16, indicates that the tolerance applies only to the maximum material condition of the dimension or datum feature, and may be greater at the actual finished size.

TABLE 5
GEOMETRIC TOLERANCE SYMBOLS

Feature	Type of tolerance	Characteristic	Symbol
Single	Form	Straightness	—
		Flatness	▱
		Roundness	○
		Cylindricity	⌭
		Profile of a line	⌒
		Profile of a surface	⌓
Related	Attitude	Parallelism	//
		Squareness	⊥
		Angularity	∠
	Location	Position	⌖
		Concentricity	◎
		Symmetry	⌯
	Composite	Run-out	↗
Maximum material condition			Ⓜ
Dimension which defines a true position			□

Tolerance Frame



BL/1-5

Issue 3

December, 1983

BASIC

AIRWORTHINESS PROCEDURES

CONCESSIONS DURING MANUFACTURE

1 INTRODUCTION This Leaflet gives guidance on the application, authorisation and recording of concessions. The procedures described are acceptable to the CAA and are recommended for use where appropriate.

NOTE: It is common for operators of aircraft to use the word 'concession' when referring to dispensations from CAA requirements for aircraft maintenance; for example, temporary extensions of overhaul lives or maintenance check cycles. Special procedures apply to these dispensations which are not related to the concession procedures described in this Leaflet.

2 DEFINITIONS The following definitions relate to terms used in this Leaflet.

2.1 **Concession.** A concession is an authorisation to accept a limited quantity of materials, parts, assemblies and equipment which may not be strictly in accordance with the relevant drawings, specifications or other documents that define the design.

2.2 **Responsible Design Organisation.** An Organisation acceptable to the CAA for the raising of designs for aircraft, engines, controlled items of equipment or modification of such products. The Organisation would normally have been approved to the appropriate paragraphs of British Civil Airworthiness Requirements (BCAR), Sub-section A8.

3 GENERAL For an aircraft to qualify for the issue or renewal of a Certificate of Airworthiness, it is essential for all materials, parts, assemblies and equipment to have been inspected and accepted as conforming to the appropriate drawings and specifications. It is possible that some materials or items may not have been manufactured in accordance with the requirements of the drawings or specifications. These may, nevertheless, be acceptable provided that in the opinion of the Responsible Design Organisation having responsibility for the design and the quality standard the items will fulfil the design purpose, and the divergence from the relevant drawings and specifications is properly authorised and recorded.

4 BASIC PRINCIPLES All concessions must be authorised by the Responsible Design Organisation. In this matter the main responsibility is to establish an acceptable standard of quality for the products compatible with the design requirements. To achieve this, concessions should be authorised with discretion and kept to a minimum.

4.1 When a concession is authorised by the Responsible Design Organisation, it is implicit that the divergence from standard does not reduce the airworthiness level below the specified design minimum.

4.2 A copy of each concession must be retained by the authorising Responsible Design Organisation.

4.3 Concessions are not approved by the CAA, but in exceptional cases the advice of the CAA is sought. In the course of their supervisory duties the CAA Surveyors review the records of concessions, particularly before the issue of Certificates of Airworthiness.

5 CONCESSION PROCEDURE The Responsible Design Organisation should devise an application form with a title which indicates its function in relation to concessions. The same form also serves as 'Authority to Accept' when signed by the qualified representative of the Organisation. The form normally contains provision for the following information:—

(a) Name of firm. (Additionally, provision should be made for a sub-contractor using the form to enter his name.)

(b) Design Department Reference Number of concession authorisation.

(c) Date of application for the concession.

(d) Identity of the material, or part(s), which are the subject of the application, i.e. serial, part or drawing numbers.

(e) Quantity of material affected.

(f) Details of the divergence from the drawings or specifications.

(g) Effect on interchangeability.

(h) Concession(s) previously granted on these items.

(j) Authorised recovery action.

(k) Signature and observations of the responsible design personnel.

(l) Date of authorisation.

NOTE: Where necessary, adequate sketches should be provided to define precisely the divergence from drawings or specifications and the authorised recovery action.

5.1 Although requirements for concessions are often initiated by production departments, it is normally the responsibility of the quality assurance or inspection department to decide whether a concession should be sought.

5.2 After submission of the application the appropriate person(s) of the Responsible Design Organisation and quality assurance/inspection department(s), should declare on the form whether or not the particular concession is acceptable. It is essential that sufficient information is given, if necessary by appendices to the form, to leave no doubt about the standard to which the material or parts may be accepted.

5.3 A suitable reference numbering system should be in operation to provide identification for the authorisation of the particular concession.

5.4 It is the responsibility of the Responsible Design Organisation to decide which concessions should be recorded in the inspection records of particular components, assemblies or parts. In the case of components or assemblies which have serial numbers, any applicable concession reference numbers should be recorded in the relevant history record card or its equivalent.

BL/1-7

Issue 3

December, 1983

BASIC

AIRWORTHINESS PROCEDURES

STORAGE CONDITIONS FOR AERONAUTICAL SUPPLIES

1 INTRODUCTION This Leaflet gives guidance on acceptable conditions of storage for aeronautical supplies. Generally, the Leaflet deals with the specific aeronautical materials and parts in alphabetical order, which may be used in the absence of any specific manufacturer's recommendations:—

1.1 Leaflet **BL/1-6** contains general information on procedural matters related to storage. Guidance on the identification marking of aircraft parts is given in Leaflet **BL/2-1** and on the standard colour schemes for metallic materials in Leaflet **BL/2-2**. Additional information on storage conditions may also be found in individual Leaflets of the Part II – "Aircraft" Series.

1.2 The correct handling of materials, especially the high strength aluminium alloys, is of extreme importance. Great care is necessary during loading and unloading and storage at the consignee's works to ensure that the material is not damaged by chafing, scratching, bruising or indentation, and that it is not excessively strained by bending, otherwise the mechanical properties of the material may be seriously affected. Heavy forgings, extrusions and castings should be carried and stored singly, ensuring that there is adequate support to maintain the material in its intended shape without strain.

2 GENERAL STORAGE CONDITIONS The conditions of storage of aircraft supplies are important. The premises should be clean, well ventilated (see paragraph 3.13) and maintained at an even dry temperature to minimise the effects of condensation. In many instances the manufacturer will specify the temperature and relative humidity in which the products should be stored. To ensure that these conditions are maintained within the specified range, instruments are used which measure the temperature and relative humidity of the store room.

2.1 **Temperature and Relative Humidity.** When required, the temperature and humidity should be checked at regular intervals by means of a hygrometer which measures the amount of humidity in the atmosphere. The wall-type of hygrometer is normally used and consists of wet and dry 'bulbs'; the dry bulb records the actual temperature, and a comparison between this reading and that registered by the wet bulb, when read in conjunction with a table, will indicate the percentage of relative humidity present in the atmosphere.

2.2 **Protective Materials for Storage Purposes**

2.2.1 **Vapour Phase Inhibitor (VPI).** This is a method of protection against corrosion often used for stored articles made of ferrous metals.

(a) VPI protects by its vapour, which entirely covers any article in an enclosed space. Direct contact of the solid VPI with the metal is not required. Although moisture and oxygen are necessary for corrosion to take place, VPI does not react with or remove either of them, but operates by inhibiting their corrosive action.

(b) The method most commonly used is treated paper or board, the article to be protected being wrapped in paper which has been treated with VPI or, alternatively, enclosed in a box made of VPI treated board, or lined with treated paper.

NOTE: Protection of parts by the VPI process should only be used where it is approved by the manufacturer of the part.

2.2.2 **Protective Oils, Fluids, Compounds.** Where oils, fluids or compounds are used as a temporary protection on metal articles, it should be ascertained that the material and the method of application is approved by the manufacturer of the article. Where protective oils, fluids or compounds have been used, deterioration of such fluids or compounds by handling can be minimised by wrapping in a non-absorbent material (e.g. polythene, waxed paper), which will normally increase the life of such temporary protectives by inhibiting drying out. When parts or components are stored for long periods they should be inspected at intervals to ensure that the condition of the coating is satisfactory.

2.2.3 **Desiccants.** The desiccants most commonly used in the protection of stored parts or components are silica-gel and activated alumina. Because of their hygroscopic nature these desiccants are capable of absorbing moisture either inside a packaging container or a component, thereby preventing corrosion.

(a) Desiccants should be inspected and/or renewed at specified periods or when an air-tight container has been opened. It is important when inspecting or changing a desiccant that the prescribed method is used to avoid the entry of moisture into a dry container.

(b) **Tell-Tale Desiccant.** This indicating type of desiccant is prepared with a chemical which changes colour according to its moisture content. The following table gives guidance on the relative humidity of the surrounding air.

Colour	Surrounding Relative Humidity (%)	Moisture Content of Silica-Gel (%)
Deep Blue	0–5	0·2
Blue	10	5·5
Pale Blue	20	7·5
Pinkish Blue	30	12·0
Bluish Pink	40	20·2
Pink	50	27·0

(c) Silica-gel and activated alumina can be reactivated by a simple heat treatment process. The time and temperature required to effectively dry the desiccant should be verified with the manufacturer, but a general guide is 135°C for at least two hours for silica-gel and 250°C for four hours for activated alumina. The desiccant should then be placed in a sealed container until it has cooled, after which it should be completely reactivated.

2.3 **Racks and Bins.** Open racks allow a free circulation of air and are preferable when the nature of the stock permits their use. The painted metal type of bins is more suitable than the wooden type, since with the latter there is a risk of corrosion due to mould or dampness. Polyethylene, rigid PVC, corrugated plastics or cardboard bins may also be used. Many moulded plastics bins can also be fitted with removable dividers which will allow for the segregation of small parts whilst making economic use of the space.

2.4 **Rotation of Issue.** Methods of storage should be such that batches of materials or parts are issued in strict rotation, i.e. old stock should be issued before new stock. This is of particular importance for perishable goods, instruments and other components which have definite storage limiting periods.

2.5 **Storage Limiting Period.** The manufacturers of certain aircraft units impose storage limiting periods after which time they will not guarantee the efficient functioning of the equipment. On expiry of recommended storage periods the parts should be withdrawn from stores for checking or overhaul as recommended by the manufacturer. The effective storage limiting periods of some equipment may be considerably reduced if suitable conditions of storage are not provided. Therefore, storage limiting periods quoted by manufacturers can only be applicable if the prescribed conditions of storage are in operation, and users should develop suitable limiting periods from their own experience.

2.6 **Flammable Materials.** All materials of a flammable nature, such as dope, thinners, paint, etc., should be kept in a store isolated from the main buildings. The precautions to be taken vary with the quantity and volatility of the materials, and such stores should comply with the requirements of HM Inspector of Factories and the Area Fire Authority.

2.7 **Segregation of Stock.** Care should be taken to segregate materials which may have deleterious effects on other materials, e.g. carboys of acid should not be placed in a store where escaping fumes may affect raw materials or finished parts; phenolic plastics should be segregated from cadmium-plated steel parts to prevent corrosion of the steel parts; magnesium alloys should not be stored in the vicinity of flammable materials.

2.8 **Packaging of Stock.** Stock should normally be packaged from the following:

(a) **Materials:** Plastics film, "Jiffy" bags, lanolin grease impregnated cloth, plastics film lined paper envelopes, etc.

(b) **Methods:** Oiling and placing in jars or plastics bags, individual packaging of seals, etc.

NOTE: Magnesium fittings should not normally be kept in sacks, as the materials used in making the sacks may cause corrosion of the fittings.

2.9 **Materials in Long Lengths.** It is particularly important that long lengths of material, such as extrusions, tubes, bars, etc., should generally be stored vertically, which tends to reduce problems caused by bow and handling damage. Care should also be taken when placing the material in the storage racks to prevent indentations and scratches, especially when handling the high strength aluminium alloys.

3 STORAGE CONDITIONS FOR SPECIFIC MATERIALS AND PARTS This paragraph gives guidance on recommended methods of storage for various materials and parts.

3.1 **Ball and Roller Bearings.** Ball and roller bearings should be stored in their original wrappings in dry, clean conditions with sufficient heating to prevent condensation caused by significant temperature changes.

3.1.1 If the wrapping has become damaged or if it is removed for inspection of the bearings, the bearing (providing it does not incorporate rubber seals) should be soaked and swilled in white spirit to remove storage grease and/or dirt. It is permissible to oscillate or turn the races slowly to ensure thorough cleaning, but the bearing should not be spun in this unlubricated condition because the working surfaces may become damaged. A forced jet of white spirit may be used to advantage but an efficient filter should be provided in the cleaning system.

3.1.2 In certain cases it may be preferable to clean very small bearings with benzene, but if this fluid is used, consideration should be given to the fire hazard and possible toxic effects.

NOTES: (1) There are certain proprietary light white spirits which are suitable for use with very small bearings and which eliminate some of the dangers associated with the use of benzene.

(2) Miniature steel balls and special high precision balls are immersed in instrument oil contained in plastics phials with screw-on caps.

3.1.3 After cleaning, the bearings should be inspected for signs of corrosion and then re-protected with a compound of mineral oil and lanolin and wrapped in greaseproof paper. Many miniature bearings, especially those used in instruments, are susceptible to brinelling. When such bearings have become suspect or contaminated they should be discarded.

NOTE: In many instances orders for bearings are endorsed with a requirement that special grease should be applied by the manufacturer. If this grease is removed for any reason, it is essential that grease of the correct specification is re-applied.

3.2 Aircraft Batteries

3.2.1 **Lead-Acid Batteries.** A charged battery which is to be stored for any length of time should be in the 'fully charged' condition. Before storing, the electrolyte levels should be checked and the battery bench-charged in accordance with manufacturer's instructions. When fully charged, the battery should be stored in a cool, dry, well ventilated store on an acid-resistant tray. Batteries may also be stored in the dry, uncharged state. Additional points to note are as follows:

(a) Every four to six weeks (depending on manufacturer's instructions) the battery should be removed from storage and fully recharged, i.e. until voltage and specific gravity readings cease to rise.

NOTE: Damage to the battery will occur if it is allowed to stand idle beyond the period for charging specified by the manufacturer.

(b) Regardless of periodic check charges, the battery should be given a complete charge and capacity check immediately before being put into service.

(c) For new batteries, a complete capacity test to the manufacturer's instructions should be made every six months, but if the battery has been in service this test should be made every three months.

(d) Every 12 months, or earlier if a leak is suspected, an insulation resistance test should be carried out to the manufacturer's instructions.

(e) If the conditions mentioned in the previous paragraphs are observed, a battery may remain in storage up to 18 months. A battery should not be allowed to stand in a discharged condition, and electrolyte temperatures should not exceed 48.8°C.

NOTE: Trickle charging at low rates is not recommended as damage will occur if idle batteries are subjected to this form of charging. Further information on lead-acid batteries is given in Leaflet **EEL/1—1.**

3.2.2 **Silver-Zinc Batteries and Silver-Cadmium Batteries.** These batteries should be stored in clean, dry, cool and well ventilated surroundings, not exposed to direct sunlight or stored near radiators.

(a) New batteries will normally be supplied in the dry condition with the electrolyte contained in polythene ampoules. If possible, new batteries should be stored in their original packaging together with the related ampoules of electrolyte. For storage periods of more than two years, special instructions should be requested from the manufacturers.

(b) Filled and formed batteries required for use at very short notice may be stored in the charged condition. Manufacturers normally recommend that such batteries should be discharged and recharged every four to six weeks. The manufacturer's schedule of maintenance should be applied to batteries stored in the charged condition.

(c) Batteries to be stored out of use for protracted periods should be discharged at the 40-hour rate until the voltage level, measured while discharging, falls below the equivalent of 0·8 volt per cell.

(d) Before storing batteries, the electrolyte level should be adjusted to near the maximum specified by topping up, using a potassium hydroxide solution of 1·300 s.g.

(e) The need for care in handling potassium hydroxide, because of its caustic content, is stressed. After topping up or filling, the top of the batteries should be cleaned and the connections and terminals lightly smeared with white petroleum jelly. In no circumstances should sulphuric acid or acid contaminated utensils be used in close proximity to silver-zinc or silver-cadmium batteries.

3.2.3 **Nickel-Cadmium Batteries.** This type of battery can be stored for long periods without damage, in any state of charge, provided the storage place is clean and dry and the battery is correctly filled.

(a) For the battery to be ready for use in the shortest possible time, it should be fully charged, correctly topped up, and then discharged at normal rate for a period of one hour before storage.

(b) The battery should be cleaned and dried and the terminals and connectors lightly smeared with pure mineral jelly.

(c) The battery should be inspected at intervals of six to nine months and topped up if necessary.

(d) Before going into service, the battery should be given a double charge and capacity check as recommended by the manufacturer of the particular type of battery.

(e) The battery should be stored on a shelf or rack, protected from dirt or dust, and where metallic objects such as bolts, hand-tools, etc., cannot drop onto the battery or touch the cell sides.

NOTE: The above refers to pocket plate nickel-cadmium cells and not to sintered plate nickel-cadmium cells, for which reference should be made to the manufacturer's instructions.

3.2.4 **Precautions.** It should be noted that sulphuric acid will destroy alkaline batteries; therefore, utensils which have been used for this acid should not be used with such batteries. It is also important to avoid any contamination from the fumes of lead-acid types of batteries. (See Leaflet **EEL/2-1.**)

3.3 **Braided Rubber Cord.** Braided rubber cord should be stored in a cool, dark place with an even temperature preferably not exceeding 18°C with relative humidity of approximately 65%. The cord should not come in contact with any radiant heat, grease, oil, water, organic solvents or corrosive materials.

NOTE: Storage at elevated temperatures may cause permanent deterioration of the rubber, and prolonged storage at low temperatures will cause temporary stiffening of the rubber.

3.3.1 **Storage Limiting Period.** Braided rubber cord has a storage limiting period of four years if stored in good conditions. Cord which has been issued from stores within the four year period from the date of manufacture may remain in service until the expiry of five years from that date.

(a) The date of manufacture of cordage can be determined by the colour of the threads in the cotton outer casing; light blue 1966; black 1967; mid-green 1968; heliotrope (purple) 1969; and yellow 1970. After 1970 the colours are repeated in the same sequence for a further five years and subsequently until further notice.

(b) The number of coloured threads indicate the quarter of the year in which the cord was manufactured, e.g. one thread indicates the cord was made between 1st January and 31st March inclusive.

NOTE: Details are given in British Standard Specification F51, Light Duty Braided Rubber Cord for Aeronautical Purposes.

3.4 **Compressed Gas Cylinders.** Stores which are used for storage of compressed gas cylinders should be well ventilated. The cylinders should not be exposed to the direct rays of the sun and no covering should be used which is in direct contact with the cylinders. Cylinders should not be laid on damp ground or exposed to any conditions liable to cause corrosion. Gas storage cylinders should normally be fitted with a transportation/storage cap over the shut-off valve to help prevent handling damage and contamination of parts which could cause a risk of explosion or fire. Portable gas cylinders (e.g. therapeutic oxygen, fire extinguishers) should be stored on racks and, where appropriate, control heads and gauges should be protected against impact.

3.4.1 No heating is required in stores where compressed gas cylinders are kept, unless specified by the manufacturer.

3.4.2 Lighting for stores containing combustible gas cylinders (i.e. acetylene) should be flameproof, or installed outside the building, lighting the interior through fixed windows.

3.4.3 Store rooms should be constructed of fireproof materials and the cylinders so placed to be easily removable in the event of fire. The store should be at a distance from corrosive influences, e.g. battery charging rooms.

3.4.4 Full and empty cylinders should be stored in separate rooms, and appropriate notices displayed to prevent confusion.

3.4.5 Oxygen and combustible gases such as acetylene should not be stored together. Acetylene cylinders should be stored in the upright position.

3.4.6 Oxygen cylinders are generally rounded at the bottom, thereby making it unsafe to store in an upright position without suitable support. If cylinders are stacked horizontally special wedges should be used to prevent the cylinders rolling, and the stack of cylinders should not be more than four high.

3.4.7 Breathing oxygen and welding oxygen should be segregated and properly labelled to avoid confusion. In some cases welding oxygen may be used for testing oxygen components not installed in the aircraft, but welding oxygen should not be used in aircraft oxygen systems.

3.4.8 **Precautions.** If cylinders are exposed to heat, the gas pressure will increase and the cylinder walls may be weakened, causing a dangerous condition. Cylinders should be stored at some distance from sources of heat such as furnaces, stoves, boilers, radiators, etc.

(a) Oil or grease will ignite in the presence of oxygen, and if the latter is under pressure an explosion may result. Cylinders should be kept away from sources of contamination, such as oil barrels, overhead shafting, hydraulic components or any container or component that may contain oil or grease.

(b) Smoking, exposed lights or fires should not be allowed in any room where compressed gases are stored, and oily or greasy clothes or hands should be avoided when handling the cylinders.

(c) Grit, dirt, oil and water should be prevented from entering the cylinder valves.

(d) When returning any cylinder that may have been accidentally damaged or overheated, the supplier should be notified so that any necessary action may be taken before refilling.

3.5 **Electrical Cables.** Where electrical cables are stored in large reels it is necessary that the axis of the reels are in a horizontal position. If stored with the axis vertical there is a possibility that the cable in the lowest side of the reel will become crushed.

3.6 **Fabric.** Fabric and fabric covering materials (e.g. strips and thread) should be stored in dry conditions at a temperature of about 21°C away from direct sunlight. Discoloration, such as iron mould, is sufficient to cause rejection of the material and this may be caused by unsuitable storage conditions. Most synthetic fibre fabrics should be stored away from heat sources. Rubber proofed fabrics should be stored away from plasticised materials such as PVC as it is known, in some cases, for plasticisers to leach from some plastics and have an adverse affect on rubbers.

3.7 **Forgings, Castings and Extrusions.** All large forgings, castings and extrusions should be carefully and separately stored on racks to avoid superficial damage.

NOTE: The high strength aluminium alloys are susceptible to stress corrosion when in the solution treated condition, and it is important that parts so treated should be coated with a temporary protective such as lanolin.

3.7.1 Aluminium alloy forgings which are anodised normally need no protection in a heated store. Finished details should be protected in accordance with DEF STAN 03-2.

3.7.2 Aluminium alloy castings in store should not be contained in sacks or absorbent packages. It is not normally necessary to protect castings before machining, but finished details should be protected as for forgings in paragraph 3.7.1.

3.7.3 Aluminium alloy extrusions should be protected in store with a lanolin and mineral oil solution (DEF STAN 80-34) and as finished details with DEF STAN 03-2 as in paragraph 3.7.1.

3.8 **Instruments.** The smaller types of instruments are usually delivered in plastic envelopes and these should be used during storage to minimise the possible effects of condensation. The transit containers of the larger instruments contain bags of silica-gel (paragraph 2.2.3) to absorb moisture which may enter. The gel should be examined periodically, and if its colour has changed from blue to pink it should be removed, dried out and replaced, or renewed. It is essential that all instruments should be stored in a dry, even temperature, and that the storage limiting period recommended by the manufacturer is not exceeded.

NOTE: Whenever possible instruments should be kept in transit or similar cushioned containers until required for fitment to an aircraft.

3.8.1 In the absence of any specific recommendation by the manufacturer the storage limiting period for instruments should not exceed three years and on completion of this time the item should be re-certified in accordance with the relevant Overhaul Manual. Additionally, any equipment containing gyro assemblies should be exercised and gyro wheels run for a period of 24 hours at the completion of periods not exceeding each 12 months of storage.

3.9 **Oil Coolers and Radiators.** Oil coolers and radiators are normally filled with an inhibiting fluid during storage; the fluid used should be in accordance with the manufacturer's instructions. The components should not be stored on the floor, but placed on raised wooden supports to permit a free circulation of air and minimise the possibility of damage to the matrices.

3.10 **Paints and Dopes.** For the storage of paint and related materials (i.e. all low flash point materials) it may be necessary to obtain a licence to comply with the requirements of the Petroleum Act. Paints should be kept in a dry store at a controlled temperature between 7 and 23°C.

3.10.1 Paint containers should be marked with the date of receipt so that the oldest batches may be used first, as pigments tend to 'settle out' when paint is stored. A simple method of avoiding settlement is to invert containers at regular intervals, e.g. once a month.

3.10.2 **Toxicity of Solvents.** If paints are handled or mixed in a confined space it is important to ensure adequate ventilation during such operations as the fumes from volatile liquids are harmful if inhaled in sufficient concentration.

NOTE: A point frequently overlooked in ventilating a paint store is that most solvents are heavier than air, so that ventilation is more efficient downwards than upwards.

3.10.3 Provided paints and dopes are suitably stored in their original sealed containers, the storage limiting period is normally 12 months in the United Kingdom, but this may vary elsewhere; for example, in tropical conditions the period is normally six months.

3.11 **Pipes.** Rigid pipes should be adequately supported during storage to prevent distortion. Flexible pipes should, unless otherwise stated by the manufacturer, be suitably wrapped, for example, in a sealed plastics sleeve before being stored in a darkened room, maintained at a temperature of approximately 15°C. In hot climates, flexible pipes should be stored in cool places where air circulates freely, since high temperatures tend to accelerate surface hardening of the outer cover.

3.11.1 Flexible pipes should be stored in a completely unstressed condition and, where possible, should be suspended vertically (see also paragraph 3.13.14).

3.11.2 The ends of all pipes should be blanked, using a type of blank which does not allow it to be left in position when the pipes are fitted. The use of rags or paper for this purpose is prohibited. The blanks should not be removed until just prior to fitting the pipe.

3.12 **Pyrotechnics.** Pyrotechnics should be stored in a dry, well ventilated building and kept at constant room temperature. The building should conform to the local by-laws laid down by the Local Authority.

3.12.1 At the periods specified by the manufacturer, pyrotechnics should be examined for any signs of damp or other external damage.

3.12.2 With paper-cased items, such as signal cartridges, the effect of damp is usually indicated by softening or bulging of the outer case and evidence of staining.

3.12.3 With metal-cased items, the effects of damp may often be indicated by traces of corrosion or tarnishing of the case and/or staining of the instructions label.

3.12.4 All pyrotechnics gradually deteriorate in time, although such deterioration will vary with factors such as quality or type of composition, degree of protection afforded by the containers, etc. For this reason a proportion of the items should be proof-tested at regular intervals as specified by the manufacturer; the items will also have a maximum serviceable life, regardless of proof testing, which should not be exceeded.

NOTE: The most likely effect of storage deterioration is a loss of brightness and range.

3.13 **Rubber Parts and Components Containing Rubber.** The following storage conditions are generally acceptable for a wide range of components containing rubber in their construction or parts made of rubber. In many cases manufacturers make special recommendations and these should also be observed. (Further information can also be found in BS F68 and F69.)

3.13.1 **Temperatures.** The storage temperature should be controlled between 10 and 21°C and sources of heat should be at least three feet from the stored article (unless screened) to minimise exposure to radiant heat. Some special rubber materials (e.g. neoprene) may withstand a wider range of temperature satisfactorily, i.e. –12 to 26°C, but before any rubber part is exposed to these temperatures the manufacturer's recommendations should be verified. This particularly applies to any special precautions necessary when thawing parts which have been subjected to the lower temperatures.

3.13.2 **Humidity.** The relative humidity in the store room should be about 75%. Very moist or very dry conditions should be avoided.

3.13.3 **Light.** Rubber parts should not be exposed to direct daylight or sunlight. Unless the articles are packed in opaque containers, store room windows or skylights should be screened or covered with a suitable transparent red or amber coating. Store rooms should be kept as dark as practicable. Use of artificial light which has a high ultra-violet level should be avoided.

3.13.4 **Oxygen.** Isolation from atmospheric oxygen greatly increases the storage limiting period of rubber parts. Where possible, parts should be packed in airtight containers or wrappings using talc or french chalk. Where parts are packed in airtight tins, the tins should be lined with wax paper or polythene to avoid direct contact with the metal.

3.13.5 **Ozone.** Exposure to air containing ozone even in minute quantities should be avoided. Storage rooms should not contain any apparatus liable to generate ozone, such as high voltage electrical equipment, electric motors or other plant which may give rise to electrical sparks. Free access to outdoor air, which in temperate climates always contains ozone, should be avoided. Still indoor air is normally ozone-free because wall and ceiling coverings and organic materials rapidly destroy ozone.

3.13.6 **Deformation.** Rubber parts should be stored in a 'relaxed' position free from compression or distortion, with the least possible deformation. Deformation greatly aggravates the action of ozone and also leads to permanent changes in shape and dimensions. Articles received prepacked in a strain-free condition can, with advantage, be stored in their original packing, as long as they are clearly identified and labelled.

3.13.7 **Contamination.** Rubber parts should not come in contact with liquids or vapour concentrations during storage even though they may be subsequently used in contact with a similar fluid. Contact with copper, brass or corroded iron or steel, or with any compounds of manganese, should be avoided.

NOTE: **If deterioration of seals is suspected, it can usually be verified by stretching the seals to 20% of their internal diameter. If cracks are visible under x10 magnification, the seals should be rejected.**

3.13.8 **Hydraulic and Pneumatic System Components.** Hydraulic and pneumatic components generally have a nominal seven year shelf life which may usually be extended for periods of two years by inspections.

NOTE: **The maximum service life of seals is usually to be found in the approval Maintenance Schedule.**

3.13.9 In many instances, hydraulic components are stored filled with hydraulic fluid which may leak slightly from the component; it is therefore important to ensure that fluid will not come into contact with other stored items.

3.13.10 If the stored component is filled with a fluid other than that used in the aircraft system (e.g. DTD 5540 is a hydraulic component storage fluid only) the component should be clearly labelled to ensure the removal of all traces of storage fluid prior to installation in the hydraulic system.

3.13.11 To avoid adhesion and to exercise the seals, in some cases it is recommended that the component should be operated several times at three-monthly intervals. If the seals are square or rectangular, special care should be used in the initial operation as experience has shown that there is a tendency for seal stiction on its bearing surface and, if the part incorporating the seal is moved rapidly, the seal may tend to rotate and be damaged. This applies also where spring-loaded seals are concerned; growth of the rubber may result in damage to the sealing lip.

3.13.12 **Tyres.** 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. Where tyres are delivered in bituminised hessian wrappers, the wrappers should be left on during storage.

3.13.13 **Inner Tubes.** Inner tubes should be stored in the cartons in which they were received, but where this is not possible the tubes should be lightly inflated and stored inside covers of appropriate sizes to prevent damage. Tubes should not be secured in a fixed position (such as a tight roll) by rubber bands or tapes as this may cause the rubber to crack.

3.13.14 **Storage of Rubber Hose and Hose Assemblies.** Unless otherwise specified by the manufacturer, rubber hoses should be inspected and tested every two years; they should also be inspected and tested immediately prior to installation.

(a) **Storage Conditions.** Hose and hose assemblies should be stored uncoiled and supported to relieve stresses. Air should circulate freely about the hoses unless they are contained in plastics envelopes. Temperatures in the store should be controlled as detailed in paragraph 3.13.1.

NOTE: Care should be taken to ensure that the plastics envelopes selected are compatible with the hose material, since some, including PVC, can have a deleterious effect on rubber.

(b) **Sealing Blanks.** The correct sealing blanks should always be fitted to items in store. Plugs and caps conforming with AGS specifications are suitable but, where standard blanks cannot be fitted, the blanks used must be so designed that they cannot enter the pipe or be left in position when the assembly is coupled up. It is also important that the material used for blanking purposes will not 'pick-up' or leave small particles inside a coupling after long periods of storage. Tape, rag or paper should not be used.

(c) **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 and instructions concerning this procedure are normally attached to the assembly. If a hose assembly is enclosed in an airtight plastics envelope, this should not be removed until the hose assembly is to be fitted. If this envelope becomes damaged during handling, it should be resealed or renewed after any desiccant inside has been checked for condition.

(d) **Markings on Hose.** Various methods are employed to mark the date of manufacture on hoses. It is sometimes 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 'picks' are woven in black and some in colour which indicates the month and year of manufacture, as required by the appropriate Specification.

3.13.15 **Cleaning.** Any cleaning of rubber parts and components containing rubber, after storage, should be done with water, soap solution or methylated spirits. If synthetic detergents are used, care should be taken to select those that are not harmful to rubber. Petrol (or other petroleum spirit), benzene, turpentine, etc., should not be used, nor may cleaning be carried out with sharp or abrasive objects such as wire brushes or emery cloth. Disinfectants should not be used. After cleaning, articles should be rinsed in water and dried at a distance from any direct heat.

3.14 **Sheet, Bar and Tube Metal.** It is recommended that sheet material should be stored on edge in racks; care being necessary to prevent the bending of single sheets. Flat stacking is not recommended (unless suction pads are used to lift the sheets) since sheets are almost invariably slid from the stack, often resulting in detrimental scratches on the sheet removed and on the adjacent sheet. Where vertical storage is employed, the material should be kept clear of the floor to prevent possible damage by scraping, splashing from disinfectants used for floor cleaning (which may cause corrosion) and the possibility of edge corrosion, which can occur with light alloy materials when in contact with composition floors. Temporary protectives, such as grease, paper or plastics coating, should be left in position until the material is required for use. If the temporary protective becomes damaged or partially removed, it should be restored without delay, and a periodic inspection of stock should be made.

3.14.1 There may be some merit in storing the sheet material in the transit cases. After the initial checking of the sheets, the case should be closed to eliminate dust/dirt which can cause surface scratching during handling operations.

3.14.2 Metal bars should be stored in racks either horizontally or vertically, well supported along the length when stored horizontally to prevent bending under weight. Metal tubing is normally stored in racks, well supported, the smaller diameter tubing being wired along the length, in bundles, to prevent damage.

NOTE: Floor cleaning fluids containing chlorides should not be allowed to contact metallic materials, particularly austenetic steel as a brittle fracture may eventually result.

3.15 **Sparking Plugs.** The plugs should be treated with light oil or other suitable corrosion inhibitor. The inhibitor should not come into contact with the plug screen, but the electrode end of the plug may be filled with oil and then emptied prior to fitting the caps. Plugs receiving this treatment should be washed out with tricloroethylene or carbon tetrachloride before use. Protector caps should be screwed on both ends of the plugs to prevent the ingress of moisture or foreign matter. The plugs should be stored in a warm dry place, preferably in a heated cupboard, as an additional precaution against the ingress of moisture.

3.16 **Survival Equipment.** Survival equipment should be stored in a room which can be maintained at a temperature between 15 and 21°C, and which is free from strong light and any concentration of ozone.

3.16.1 **Preparation for Storage.** The manufacturer's instructions should be carefully followed when preparing survival equipment for storage. These instructions normally include: ensuring that the component is completely deflated; removing easily detachable components; fitting protection blanks or pads to inflation valves and other connections; dusting the component with french chalk and folding it loosely; wrapping in waterproof paper; and placing it on a shelf above the floor.

3.16.2 A tie-on label should be attached to the wrapping stating:

(a) The type, serial number and part number of the equipment.

(b) Date of inspection and inflation tests.

(c) Date of overhaul.

(d) Date of component overhaul.

(e) Date of next inspection and/or test.

NOTE: The components should be stored with the equipment but it is preferable that any CO_2 cylinders be fitted with a transit cap and stored separately.

3.16.3 Under no circumstances should life-jackets or liferafts be stored one on top of the other without a separation of corrugated paper or similar shock absorbing material.

(a) In the case of liferafts, not more than three should be stored on top of each other.

(b) In the case of life-jackets, up to ten may be stored on top of each other.

(c) Owing to the light texture of life-jackets, it is important that they should be handled with care to avoid damage.

3.16.4 **Storage Limiting Period.** The period is normally six months if packed and stored in accordance with the manufacturer's instructions. At the end of this period survival equipment should normally be:

(a) Opened up and inspected before further storage.

(b) Inspected, tested and overhauled prior to being operationally packed for stowage in aircraft.

3.16.5 Liferafts and life-jackets not operationally packed and placed in storage for more than ten days after the last test should be re-tested before installation in an aircraft.

3.17 **Tanks (Flexible).** The precautions to be taken during storage will depend on the type of tank and the packaging method (if any) used. Some manufacturers of flexible tanks specify that the tanks should be coated with a special preparation if they are to remain empty for more than two or three days, and that this preparation should be removed before the tanks are put into service.

3.17.1 Manufacturers also specify a 'long term' or 'short term' storage procedure contingent upon special requirements.

3.17.2 'Short term' storage is the period between transport of the tanks from the manufacturer's works and delivery for immediate installation by the aircraft firm.

3.17.3 'Long term' storage covers the period during which the tanks are held following receipt by the aircraft firm before installation, or shipment to locations at home or abroad, involving an extended period of storage prior to installation.

3.17.4 Flexible tanks can be divided into two categories for packaging and storage purposes:

(a) Tanks that can be folded, e.g. those not fitted with rigid internal members, heavy coverings or fittings which would preclude satisfactory folding.

(b) Tanks with heavy protective coverings, or fitted with rigid internal members, anti-surge valves, gauge units, etc.

3.17.5 **Folding and Packing.** When packing a tank for storage purposes it is important to fold it in such a way that no strain or creasing is imposed on the folded areas, and in many instances folding diagrams are provided. All openings should be sealed with the specified blanks and corrugated cardboard interposed between the folds.

(a) After folding, the tank should be encased in an airtight wrapping, such as a polythene bag, and sealed.

(b) The tank in its airtight envelope should then be placed in a cardboard box which should also be sealed.

(c) Flexible tanks which are unsuitable for folding because of internal or external fittings, etc., are often packed in an air-inflated state suitably supported in sealed cases. This method of packing is used only for short term storage. For long term storage of this type of tank, the manufacturer's instructions should be followed which will vary with the shape and type of tank concerned.

3.17.6 **Storage Conditions.** Generally, flexible tanks should be stored in the original airtight containers supplied by the manufacturer and if this is not possible a similar airtight storage container should be used. The manufacturer's instructions should be observed closely. The tanks should be stored in cool, dry, draught-proof conditions, at a temperature not exceeding 25°C and preferably below 15°C.

3.18 **Tanks (Rigid).** Rigid tanks should be carefully cleaned and any moisture dried out before storage. All apertures should be sealed with closely-fitting blanks. A silica-gel cartridge attached to a blank and placed inside the tank assists in preventing internal condensation and subsequent corrosion.

3.19 **Timber.** Plywood panels should be stored flat, away from all sources of heat or damp. Other timber sections should be stacked with spacers between each section to permit the free circulation of air. The timber should be checked periodically for moisture content (see Leaflet **BL/6-6**).

3.20 **Transparent Acrylic Panels.** Acrylic sheets should be stored on edge, with the protective paper left in position as 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 not exceed 12 sheets.

3.20.1 Curved panels should be stored singly with their edges supported by stops to prevent 'spreading'.

3.20.2 There are several proprietary lacquers available for the protection of acrylic panels and shapings during handling and storage, including those complying with specifications DTD 900/5592. Protective paper may also be used and, 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.

3.20.3 Material in storage should not be exposed to strong sunlight, particularly when the light shines through a glass window. This could cause a 'lens' formation resulting in local over-heating to the detriment of the material.

3.20.4 Acrylic materials should not be stored with certain other materials because of the adverse effects which may arise from the vapours given off. A typical list of these materials is as follows:

Acetone
Ammonia Vapour
Amyl Acetate
Aviation Gasoline
Aviation Turbine Fuel
Benzene
Butyl Acetate
Carbon Tetrachloride
Cellulose Paints
Cresol
Deoxidine Materials
Dopes
Ethyl Alcohol
Glacial Acetic Acid
Methyl Alcohol
Nicotine
Rust Remover
Skydrol 500, and similar fluids
Synthetic Finishes
Thinners
Trichloroethylene

3.20.5 When sheets are handled or moved they should be lifted off (not drawn from) the adjacent sheet. The vulnerability of transparent plastics to surface damage by scratching and bruising should be impressed on all personnel handling the material.

3.21 **Windscreen Assemblies.** All types of windscreen panels should be carefully protected from scratches, abrasions or other damage as small scratches or abrasions may considerably weaken the panels and impair their optical qualities. The manufacturer's recommendations relating to packaging or protective wrapping for storage purposes should be carefully followed.

3.21.1 **Glass Panels and Windscreen Assemblies.** All types of glass panels should be carefully protected from scratches, abrasions or other external damage.

3.21.2 **Sandwich Type Windows.** Sandwich type windows should be stored vertically in dry conditions, each window having its own desiccant cartridge attached, which should be inspected and renewed at specified periods. Spare windows are usually despatched with desiccant cartridges attached and these should not be removed until the window is to be connected to the aircraft desiccation system.

(a) Windows in transit should be allowed to 'breathe', this being particularly important when windows are transported by air, as considerable atmospheric pressure variations may be encountered.

(b) In addition to desiccant breathing cartridges, some manufacturers build into each window airspace another desiccator which consists of small discs of activated alumina strung on wire and encased in a cylindrical fabric stocking. Normally the desiccator does not require renewing.

3.21.3 **Electrically Heated Windscreens.** Extreme care is necessary in handling and storing windscreens. It is generally recommended that windscreens are stored in the manufacturer's packing, which usually consists of protecting both surfaces with adhesive polythene, wrapping in acid-free paper and cellulose wadding and storing in reinforced cartons.

(a) The panels should be stored separately in their cartons on racks, away from any strong light at a controlled temperature of approximately 10 to 21°C in well ventilated conditions.

(b) It is important that during handling or storage the thick glass laminate is kept uppermost to prevent delamination and that the polythene film is not removed until the panel is fitted to the aircraft.

3.22 **Wire Rope.** Wire rope should be stored in dry, reasonably well ventilated and temperature controlled conditions to prevent condensation. Wire ropes should not be stored where they might be exposed to the corrosive influence of acid fumes, steam or other corrosive agents, and should never be placed on a stone or concrete floor.

3.22.1 Wire rope in store should be inspected periodically for signs of corrosion or other damage and, where a wire rope dressing has been used, this should be renewed when necessary.

3.22.2 Wire rope should be wound on a reel, the diameter of which will be specified by the manufacturer according to the size and type of rope (usually 40 to 50 times the diameter of the rope).

3.22.3 If reels are made locally, it is important that oak, chestnut or western red cedar are not used in their construction as these timbers may corrode the wire rope. The inside of the reel should be lined with waterproof paper.

3.22.4 When unwinding wire rope, a spindle should be placed through the centre of the reel and fixed so that the reel is free to rotate and the free end of the cable can be pulled out in direct line with the reel. The cable should not be unwound by paying off loose coils, or by pulling the wire away from a stationary reel laid on its side. When cut-off lengths of wire rope are hand coiled, the coils should be of a diameter not less than 50 times the diameter of the wire rope concerned, with a minimum of 152 mm (6 in) diameter. When hand coils are unwound, the coil should be rotated so that the wire rope is paid out in a straight line. If the wire rope forms a loop on itself, this indicates a localisation of turn and should be eliminated by taking the turn out and not by pulling straight.

3.22.5 Before cutting the cable to length, it should be bound either side of the proposed cut to prevent loss of tension from the woven strands.

BL/1-11

Issue 2

June, 1986

BASIC

AIRWORTHINESS PROCEDURES

WEIGHT AND BALANCE OF AIRCRAFT

1 INTRODUCTION

1.1 **General.** The purpose of this Leaflet is to provide guidance on the weighing of aircraft to determine the Basic Weight and corresponding centre of gravity (c.g.). The need for accuracy when weighing aircraft is extremely important, as incorrect data could cause subsequent overloading of the aircraft resulting in an increase of structural loads, and a reduction in performance. The topics discussed in the Leaflet are as follows:—

Paragraph	**Topic**
1	Introduction
2	Requirements
3	The Principles of Aircraft Weight and Balance
4	Weighing Equipment
5	Determination of Basic Weight and Centre of Gravity
6	Change in Basic Weight
7	Loading of Aircraft
Appendix	Typical Weight and Centre-of-Gravity Schedule

1.2 **Definitions.** The following is a list of definitions of the terms used in this Leaflet:—

(a) **Basic Equipment.** Basic Equipment is the unconsumable fluids (e.g. coolant and hydraulic fluid) and equipment which is common to all roles for which the operator intends to use the aircraft.

(b) **Basic Weight.** Basic Weight is the weight of the aircraft and all its Basic Equipment, plus that of the declared quantity of unusable fuel and unusable oil. In the case of turbine-engined aircraft and aircraft the Maximum Total Weight Authorised (MTWA) of which does not exceed 5700 kg (12 500 lb), it may also include the weight of usable oil.

(c) **Variable Load.** Variable Load is the weight of the crew and of items such as crew baggage, removeable units, and other equipment the carriage of which depends upon the role for which the operator intends to use the aircraft for a particular flight.

(d) **Disposable Load.** Disposable Load is the weight of all persons (e.g. passengers) and items of load, including fuel and other consumable fluids carried in the aircraft, other than the Basic Equipment and Variable Load.

(e) **Maximum Total Weight Authorised (MTWA)** is the Maximum Total Weight Authorised for the aircraft and its contents, at which the aircraft may take off anywhere in the world, in the most favourable circumstances in accordance with the Certificate of Airworthiness or Flight Manual.

(f) **Reaction.** The load at each separate weighing point.

2 REQUIREMENTS

2.1 The requirements relating to the weighing of aircraft and the establishment of a Weight and Balance Schedule are prescribed in British Civil Airworthiness Requirements (BCAR) Section A, Chapter **A5—1**. An interpretation of those parts of Chapter **A5—1** which are pertinent to this Leaflet is given below.

2.2 Aircraft must be weighed to determine the Basic Weight and the corresponding c.g. position when all the manufacturing processes have been completed. Aircraft, the MTWA of which exceeds 5700 kg (12 500 lb) must be re-weighed within two years after the date of manufacture and, after this, a check weighing must be carried out at intervals not exceeding five years and at such times as the CAA may require. Aircraft, the MTWA of which does not exceed 5700 kg (12 500 lb) must be re-weighed as required by the CAA.

2.3 In making decisions on weighing, the CAA considers the history of the aircraft, its flying performance, and the probable effect on the weight after a major overhaul, or embodiment of a modification, repair or replacement.

2.4 Certain types of aircraft may be weighed on a sampling basis (i.e. a representative aircraft, as weighed, would be acceptable for others of the same standard) by agreement with the CAA.

2.5 An alternative arrangement to the periodical check weighing of individual aircraft is for the operator to establish a fleet mean weight (i.e. Basic Weight) and fleet mean centre-of-gravity position. The initial fleet mean weight is based on the mean of the weights of all the aircraft of the same type in the fleet which is revised annually by sample weighing (see BCAR Section A, Chapter **A5—1**, Appendix No 1).

2.6 When an aircraft is weighed, the equipment and other items of load such as fluid in the tanks must be recorded. This recorded load should not differ significantly from the Basic Equipment List associated with the Weight and Centre-of-Gravity Schedule (see paragraph 2.9). In circumstances where there is a significant difference between the Basic Weight of the aircraft and the operating weight (i.e. Basic Weight plus the Variable Load) not accountable to structural changes brought about by modifications/repairs, the CAA may require that the actual weights of the Variable Load items be ascertained.

2.7 All records of the weighing, including the calculations involved, must be available to the CAA. The records are retained by the aircraft manufacturer, overhauler or operator, and when the aircraft is weighed again, the previous weighing records must not be destroyed but retained with the aircraft records. Operators must maintain records of all known weight and c.g. changes which occur after the aircraft has been weighed.

2.8 Weight and Balance Report

2.8.1 Before the issue of a Certificate of Airworthiness for a prototype, prototype (modified) or series aircraft, where the MTWA exceeds 5700 kg (12 500 lb), a Weight and Balance Report must be prepared by a CAA Approved Organisation.

2.8.2 The Weight and Balance Report is intended to record the essential loading data to enable a particular aircraft to be correctly loaded, and to include sufficient information for an operator to produce written loading instructions in accordance with the provisions of the Air Navigation Order (ANO). The Weight and Balance Report applies to the aircraft in the condition in which it is to be delivered from the constructor to the operator.

2.8.3 The Weight and Balance Report must include the following items:—

(a) Reference number and date.

(b) Designation, constructor's number, nationality and registration marks of the aircraft.

(c) A copy of the Weighing Record.

(d) A copy of the Weight and Centre-of-Gravity Schedule (see paragraph 2.9) including the Basic Equipment List if this is separate from Part A of the Schedule.

(e) A diagram and a description of the datum points which are used for weighing and loading, and an explanation of the relationship of these points to the fuselage frame numbering systems and, where applicable, to the Standard Mean Chord (SMC).

NOTE: SMC is also referred to as the Mean Aerodynamic Chord (MAC).

(f) Information on the lever arms appropriate to items of Disposable Load. This will include the lever arms of fuel, oil and other consumable fluids or substances in the various tanks (including agricultural material in hoppers), which, if necessary, should be shown by means of diagrams or graphs, lever arms of all passengers in seats appropriate to the various seating layouts, mean lever arms of the various baggage holds or compartments.

(g) Details of any significant effect on the aircraft c.g., of any change in configuration, such as retraction of the landing gear.

2.9 Weight and Centre-of-Gravity Schedule

2.9.1 A Weight and Centre-of-Gravity Schedule details the Basic Weight and c.g. position of the aircraft, and the weight and lever arms of the various items of load, including fuel, oil and other fluids. The Schedule is normally divided into Part A — Basic Weight, Part B — Variable Load and Part C — Loading Information (Disposable Load).

(a) A Weight and Centre-of-Gravity Schedule shall be provided for each aircraft, the MTWA of which exceeds 2730 kg.

(b) For aircraft not exceeding 2730 kg MTWA, either a Weight and Centre-of-Gravity Schedule shall be provided or alternatively a Load and Distribution Schedule which complies with BCAR Section A, Chapter **A5—1**, paragraph 6.1.

(c) For new aircraft which exceed 2730 kg, but do not exceed 5700 kg, the information contained in Parts B and C of the Schedule may be given as part of the Weight and Balance Report.

2.9.2 A Weight and Centre-of-Gravity Schedule must provide the following. Each Schedule must be identified by the aircraft designation, the nationality and registration marks, or if these are not known, by the constructor's serial number. The date of issue must be on the Schedule and it must be signed by an authorised representative of a CAA Approved Organisation or a person suitably qualified and acceptable to the CAA, and if applicable, a statement shall be included indicating that the Schedule supersedes all earlier issues. It is also necessary to refer to the date or reference number (or both) of the Weight and Balance Report, or other acceptable information upon which the Schedule is based.

2.9.3 Operators must also issue a revised Weight and Centre-of-Gravity Schedule when it is known that the weight and c.g. has changed in excess of the maximum figure agreed by the CAA as applicable to a particular aircraft type. If the aircraft has not been re-weighed, the revised Weight and Centre-of-Gravity Schedule must state that it has been calculated on the basis of the last Weight and Balance Report and the known weight and c.g. changes. A record of the calculations involved should be retained for future reference.

2.9.4 A copy of the Schedule is to be retained by the operator with a further copy sent to the CAA Airworthiness Division which shall include any related list of Basic Equipment. Furthermore, for aircraft the MTWA of which does not exceed 5700 kg (12 500 lb) a copy of the Weight and Centre-of-Gravity Schedule must be included in the Flight Manual. If a Flight Manual is not a requirement the Schedule must be displayed or retained in a stowage which is identified in the aircraft. A similar arrangement is often used for larger types of aircraft.

2.9.5 A typical Weight and Centre-of-Gravity Schedule for an aircraft the MTWA of which does not exceed 2730 kg is shown in the Appendix to this Leaflet.

3 THE PRINCIPLES OF AIRCRAFT WEIGHT AND BALANCE

3.1 Principles of Balance

3.1.1 The theoretical principle of the weight and balance of aircraft is basically very simple, and can be compared with that of the familiar scale (as depicted in Figure 1) which, when in balance will rest horizontally on the fulcrum in perfect equilibrium provided that the two pans suspended from the beam are of equal weight and distance from the fulcrum.

3.1.2 In aeronautical terms the fulcrum can be equated to the aircraft c.g., and the weights, with the loads imposed thereof on the structure.

3.1.3 Because of the design tolerances built into aircraft, the Weight and Balance is not as critical as that of the scales in Figure 1, although it is important that they remain within those tolerances for reasons of safety, performance, and economy.

3.1.4 From Figure 1 it can be understood that the influence of weight, in relation to balance, is directly dependent upon the distance of the weight from the fulcrum.

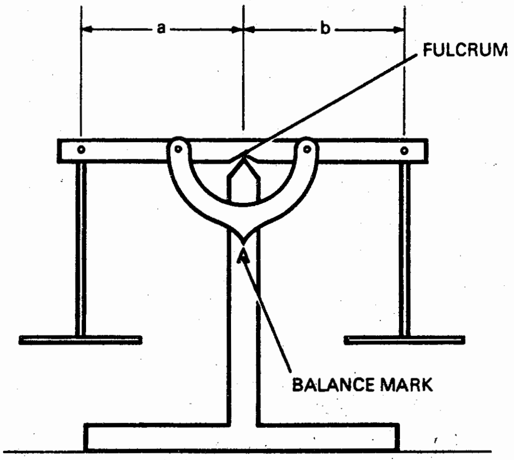


Figure 1 SIMPLE SCALE

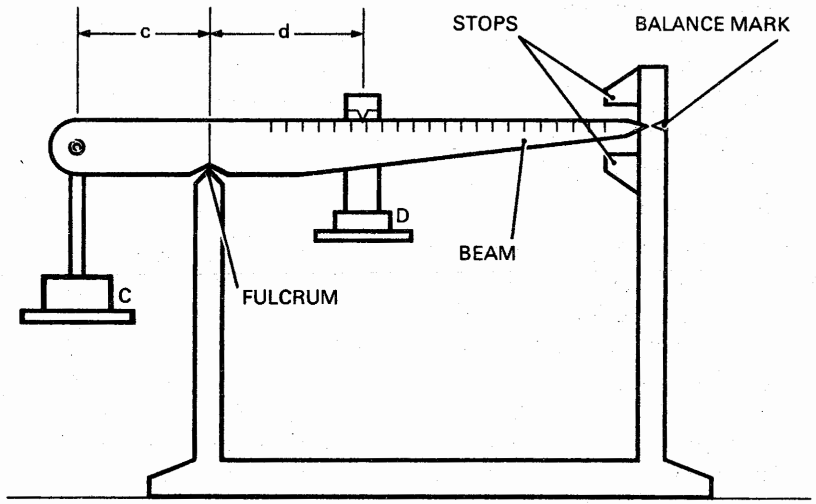


Figure 2 STEELYARD

3.1.5 Unlike the scales in Figure 1, aircraft, (apart from some helicopters) cannot practicably be suspended in such a way as to determine the relative weight, balance, and c.g. However, it can be achieved mathematically.

3.1.6 The steelyard shown in Figure 2 has a known weight "D" and, a known weight "C" set at a specific distance "c". Under normal circumstances to determine the distance required to balance "C", the known weight "D" is moved along the beam until the weight of "D" and its accompanying lever arm are equal to the weight of "C" therefore aligning the beam with the balance mark. Once achieved the distance "d" can then be read from the graduated scale.

3.1.7 Mathematically the distance can be found as follows:—

$$d = \frac{Cc}{D}$$

Where C = 50 lb

c = 10 inches

D = 20 lb

$$\frac{Cc}{D} = \frac{50 \times 10}{20}$$

$$d = \underline{25 \text{ in.}}$$

3.2 Moments

3.2.1 The distance from the fulcrum is called the 'arm' and this distance, multiplied by the weight, is the turning effect or 'moment' about the fulcrum. The c.g. of the balanced system is the position at which the weight resting on the fulcrum may be taken to act, and will lie in a plane drawn vertically through the fulcrum. The conventional signs which are applied to arms and moments in relation to their direction from the c.g. datum are as follows:—

(a) **Horizontal** (−) forward and (+) aft of the datum.

(b) **Vertical** (−) below and (+) above the datum.

(c) **Transverse** (−) right and (+) left of the datum.

3.2.2 In a similar way to the balancing of weights, the horizontal c.g. of a system of weights can be found by calculating the moment of each weight from a selected position (e.g. reference datum) and dividing the total moment by the total weight.

NOTE: In aeronautical terms all arms forward of the reference datum are designated negative (−) and all arms aft of the datum are designated positive (+).

3.2.3 Illustrated in Figure 3 is a constant cross-section beam 80 in long and weighing 8 lb, upon which have been placed 5 loads weighing 2 lb, 6 lb, 1 lb, 4 lb and 3 lb respectively, which are 5 in, 20 in, 30 in, 60 in, 70 in, from the left-hand end of the beam, which in this example is the c.g. reference datum. It should be noted however, that although any plane normal (i.e. perpendicular) to the beam's horizontal axis could have been selected as the reference datum, the position chosen is one of convenience, and therefore all moment arms in this example are positive (+). As the beam is of a constant cross-section, the c.g. of the loaded beam in Figure 3 can be found as follows by:—

(a) calculating the moment of each load, i.e. multiplying the weight by arm (distance from the reference datum),

(b) calculating the total weight by adding together the weight of each load,

(c) adding together the moment of each load, and

(d) dividing the total moment by the total weight.

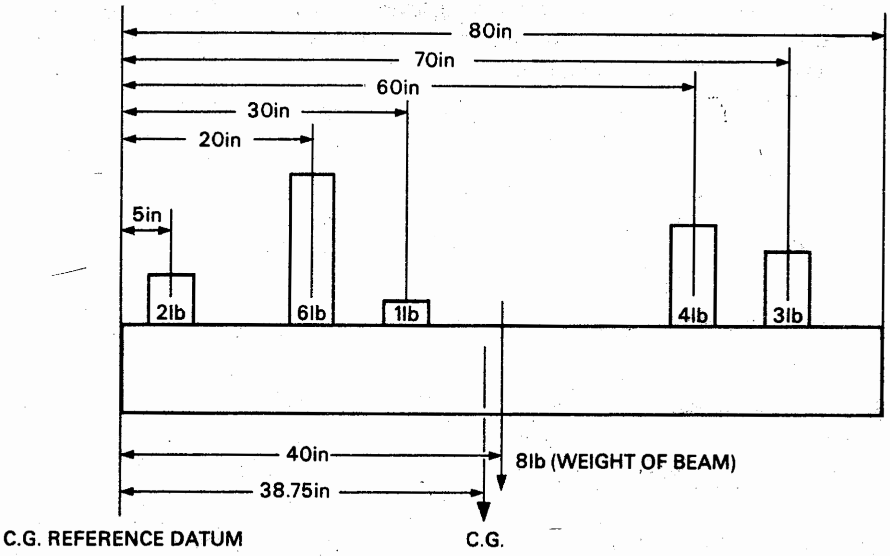


Figure 3 CENTRE OF GRAVITY OF BEAM

Item	Weight (lb)	Arm (in)	Moment (lb in)
Beam	8	40	320
1st load	2	5	10
2nd load	6	20	120
3rd load	1	30	30
4th load	4	60	240
5th load	3	70	210
TOTALS	24		930

$$\therefore \quad \frac{930 \text{ lb in}}{24 \text{ lb}} = 38{\cdot}75 \text{ in}$$

∴ the c.g. of the loaded beam is 38·75 in from the reference datum.

NOTES: (1) The arm of the beam is taken as half its length.

(2) The units of weight, arm and moment used in this and subsequent paragraphs are the pound (lb), inch (in) and pound inch (lb in) respectively. Other units, such as the kilogramme (kg) and metre (m) may be used where this is more convenient for the operator but, whichever units are used, it is essential that the same units are used throughout the calculations.

3.3 Aircraft Weight and Centre of Gravity

3.3.1 The weight and c.g. of an aircraft is calculated in the same way as for the loaded beam in Figure 3. The Basic Weight and c.g. of the aircraft corresponds to the weight and c.g. of the beam, and the Variable and Disposable Loads correspond to the beam loads. Furthermore before each flight the total weight and moment of these items must be determined, and the c.g. of the aircraft calculated to ensure the aircraft remains within the approved limits. If for example, the c.g. was too far forward, it would result in a nose-heavy condition which could be potentially dangerous (particularly during take-off and landing), cause a general reduction in the performance of the aeroplane, and effect an increase in fuel consumption as a result of the drag caused by excessive balancing of the elevator trim. Where rotorcraft are concerned, a c.g. too far forward could result in excessive strain on the main rotor shaft and a general lack of control. The c.g. too far aft results in a tail-heavy condition which, with the tendency of the aeroplane to stall, makes landing more difficult, may result in a reduction in performance, and cause an increase in fuel consumption. In the case of rotorcraft it will reduce the forward speed and also the range of effective control.

3.3.2 The operational limitations for the fore and aft positions of the c.g. are defined in the aircraft Flight Manual or other document associated with the Certificate of Airworthiness, such as the Owner's Manual. Where no such document exists, the limitations are specified in the Certificate of Airworthiness.

3.3.3 Fortunately it is not necessary for an aircraft to be perfectly balanced to achieve stable flight, i.e. to an exact c.g. position. The permissible variation is called the Centre-of-Gravity Range. This is specified by the manufacturer for each aircraft type and is determined by the need to comply with various airworthiness design requirements.

4 WEIGHING EQUIPMENT

4.1 General

4.1.1 There are four main types of weighing equipment which may be used for weighing aircraft, weighbridge scales, hydrostatic weighing units, electrical and electronic weighing equipment based on the strain gauge principle. Since considerable errors can arise if small loads are checked with equipment designed for heavy loads, and scales may be calibrated in increments too coarse for accurate calculation, the capacity of the weighing equipment should be compatible with the load.

4.1.2 All weighing apparatus should be checked, adjusted and certified by a competent authority at periods not exceeding one year and, in addition, the zero indication should be checked for accuracy before any weighing is commenced.

4.2 **Weighbridge Scales.** This equipment consists of a separate weighing platform for each wheel or bogey on the aircraft, the weight at each reaction point being recorded directly on the balance arm. On some equipment a dial indicator is also provided. Large aircraft are normally weighed in a hangar, using either portable weighbridge scales or weighbridges set permanently into the floor at appropriate positions with their platforms level with the floor. The aircraft may then be rolled directly onto the platforms without the need for special equipment.

NOTES: (1) Care should be taken when moving portable weighbridge scales to prevent them becoming out of balance.

(2) It is advisable to set the approximate load on each balance arm before releasing it. Failure to do this could cause damage to the knife edge.

4.3 Hydrostatic Weighing Units

4.3.1 The operation of these units is based on the hydraulic principle that the fluid pressure in a cylinder in which a piston is working depends on the area of the piston and the load applied to it. The units are interposed between the lifting jacks and the aircraft jacking points, the weight at each position being recorded on a pressure indicator. The indicator may record directly in units of weight or may be a multi-rotational type where the readings are converted to weight by means of a conversion table peculiar to each particular unit.

4.3.2 It is important that the lifting jacks are exactly vertical and the units correctly positioned, otherwise side loads may be imposed on the weighing units and may affect the accuracy of the readings.

4.4 **Electrical Weighing Equipment.** Equipment of this type incorporates three or more weighing cells, each of which contains a metallic element of known electrical resistance. Aircraft load is measured with the variation in resistance with elastic strain by means of a galvanometer, the scale of which is calibrated in units of weight. As with the hydrostatic weighing units, the weighing cells are interposed between the lifting jacks and the aircraft jacking points and similarly care is necessary to ensure that no side loads are imposed upon them (see paragraph 4.3.2).

4.5 Electronic Weighing Equipment

4.5.1 This type of weighing equipment combines elastic strain load cells as described in paragraph 4.4 into weighbridge-type platforms which are placed either as a single unit or combination of units beneath the wheels of the aircraft undercarriage.

4.5.2 Each platform, is electrically connected to an instrumentation unit, which digitally displays the selected platform load. The number of platforms required to weigh an aircraft by this method is determined by the size of the aircraft. For example, a very large transport aircraft may require as many as 18 or more platforms to accommodate the wheel multiples of the undercarriage. The number of units that can be used is, however, limited by the terminal facility of the instrumentation unit.

4.5.3 As there is generally a requirement for aircraft weighing equipment to be portable, the platforms are normally constructed of high strength lightweight materials, with the load cells interposed between the platform table, and the base unit. Where a platform is unevenly loaded (because of structural movement or undercarriage positioning), a greater load imposed on one side of the platform will be automatically compensated for by the lesser load on the other side.

NOTE: The displayed load (or reaction) on the instrumentation unit for each platform, is a dedicated computation of all load cell inputs from that particular platform.

4.5.4 The positioning of aircraft onto electronic weighbridge platforms may be accomplished by one of the following methods:—

(a) by towing the aircraft directly onto platforms permanently set into the hangar floor (sometimes in specific appropriate positions),

(b) by supporting the aircraft on jacks and, where facilities allow, lowering the hangar floor, positioning the platforms below the extended undercarriage and then raising the hangar floor until all the weight of the aircraft is supported by the platforms, or

(c) by towing the aircraft up purpose-made ramps (approx 6%) onto the platforms.

4.5.5 The function of the instrumentation unit is to:—

(a) compute and display the loads imposed upon on each platform,

(b) provide a facility for the fine calibration of the platforms to a zero datum,

(c) record and print out the indicated data.

NOTE: Some instrumentation units (subject to the necessary inputs) also have the capability to compute both the total weight and the relative c.g. of the aircraft.

5 DETERMINATION OF THE BASIC WEIGHT AND CENTRE OF GRAVITY

5.1 **General.** Modern aircraft may be weighed using any of the equipment described in paragraph 4. Arms from the c.g. datum are predetermined distances and therefore physical measurement is seldom required. However, when weighing certain types of aircraft on their wheels, it may be necessary to take measurements due to the possibility of landing gear compression or deflection altering the length of the lever arm. Furthermore before weighing is commenced, reference should be made to the manufacturer's recommended weighing procedures.

NOTE: It is important for large fixed-wing transport aircraft to be level in both the longitudinal and lateral planes when being weighed. However, for light fixed-wing aeroplanes the emphasis is normally on the longitudinal plane.

5.2 Preparation for Weighing

5.2.1 The aircraft should be in the condition described in the Weight and Centre-of-Gravity Schedule, fluids such as engine oil, or fuel being partially or completely drained in accordance with the manufacturer's requirements, and equipment positioned at its normal operational location.

5.2.2 It is important to carry out the weighing of aircraft inside a closed hangar, and where possible, it is recommended that the aircraft is positioned in the hangar several hours before weighing so that it can assume an even temperature and be free from moisture. If weighing in the open is unavoidable, it should be carried out on a firm level site when wind force is at a minimum with the aircraft completely dry (i.e. not affected by frost or dew) and several readings should be taken at each reaction point to obtain a reliable average figure. Also particular care should be exercised if plumb bobs are to be used for taking measurements.

5.2.3 In order to obtain consistent results from different weighings it is essential that an aircraft is placed in the 'rigging' position (i.e. with the longitudinal axis parallel to the floor). Jigged positions are normally built into an aircraft structure for levelling purposes and these may be used in conjunction with a spirit level or plumb bob and scale. Instructions supplied by the relevant aircraft manufacturer on levelling procedures and the positioning of equipment should be carefully followed and adhered to.

5.2.4 It should be noted, however, that some light aeroplanes with tail-wheel landing gear, have a negative load on the tail when in the rigging position as a result of the c.g. being forward of the main wheel centres. In such cases, and where it is not possible to use a jack at the nose of the aeroplane, a spring balance should be anchored securely to the ground and attached to the tail wheel axle to determine the extent of the negative reaction. Since this is a minus load, it should be deducted from the total weight, and must be treated as a minus quantity when calculating the c.g. position.

NOTES: (1) The weight of the spring balance, and any rope used to secure it to the aircraft, must be added to the spring balance reading.

(2) Two positions weighings, i.e. datum horizontal and nose up or down, are sometimes used when it is necessary to determine the vertical c.g. position, but this is not normally carried out by operators.

5.3 Weighing on Weighbridge Scales or Platforms

5.3.1 This is normally carried out with the aircraft resting on its wheels, but is often necessary to jack the aircraft at either the nose or tail to level it longitudinally. In the circumstances where the normal aircraft attitude is almost level, the manufacturer may recommend that the tyres or oleo struts are partially deflated to obtain the corrected position. The weight of any equipment used for levelling must be deducted from the weight recorded at the particular scale. The example given in Figure 4 is a nosewheel aircraft on which, because of landing gear deflection, it is required to measure the distance between reaction points.

5.3.2 **Electronic Platform Weighing Equipment.** To achieve the degree of accuracy possible with this type of equipment careful preparation is important and this will include:—

(a) checking and adjusting the platforms to a horizontal level in the longitudinal and lateral planes,

(b) switching on the instrumentation unit prior to weighing to allow for temperature stabilisation of electronic circuits as specified by the relevant equipment manufacturer,

(c) adjusting and setting each platform to zero datum point through the instrumentation unit,

(d) correcting the aircraft's longitudinal level,

(e) ensuring the hangar is free from destabilising draughts e.g. hangar doors ajar, warm/cold air blowers, etc.

NOTE: After the aircraft has been weighed and removed from the platforms, a platform zero datum check at the instrumentation unit should be repeated.

5.3.3 With the main wheels located centrally on the weighbridge platforms and wheels checked, the wheel brakes should be released and the nose raised or lowered until the fuselage is longitudinally level. Plumb bobs should be suspended from the centrelines of the main wheel axles on the inner side of the wheels, and the two positions marked on the floor (see Figure 5). The midway point between these two marks represents the rear reaction point. A plumb bob suspended from the centrelines of the nose-jacking point will enable the distance between the front and rear reaction points to be measured (see Figures 4 and 5).

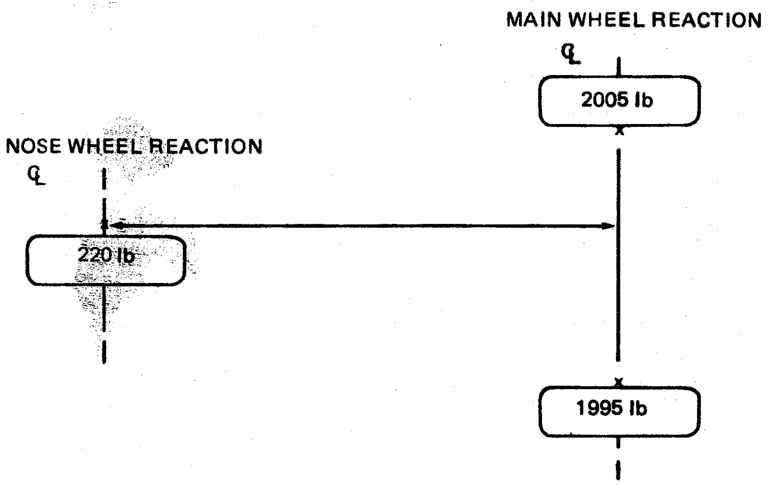
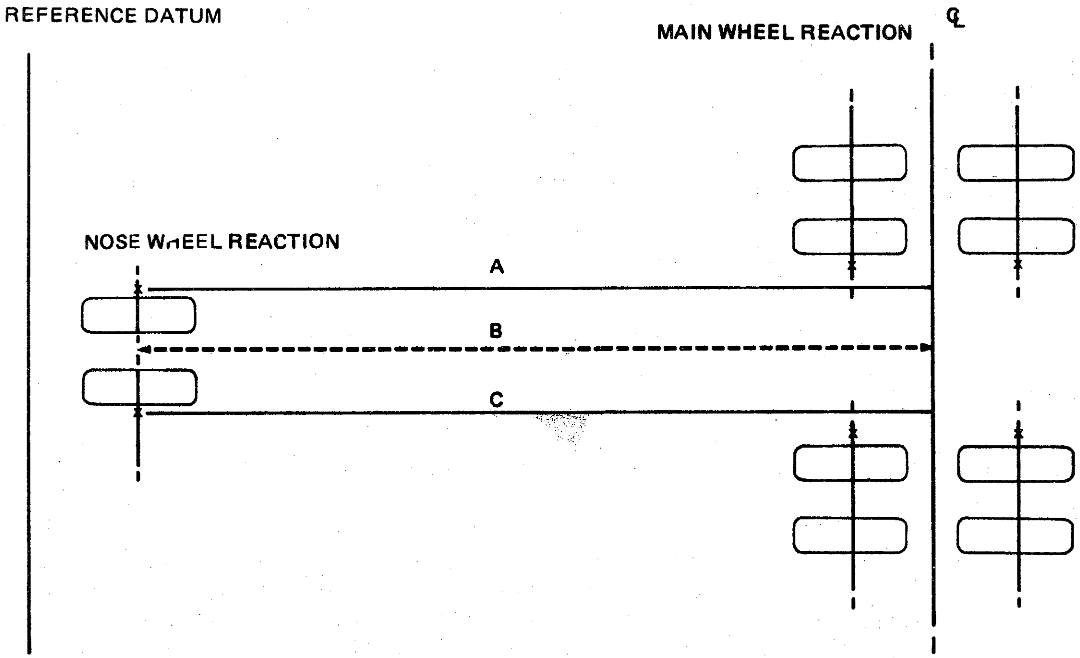


Figure 4 LIGHT AIRCRAFT



NOTE: The distance C between the front and rear reaction is a mean of the distances A and B, i.e. $C = \frac{A+B}{2}$

Figure 5 HEAVY AIRCRAFT

5.3.4 The c.g. can then be found by the following formula:—

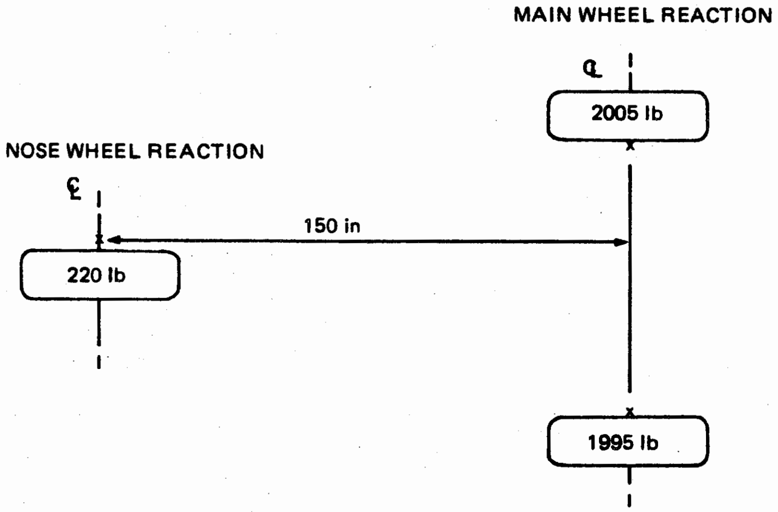
$$\frac{A \times B}{C}$$

Where A = distance between front and rear reactions

B = weight at the nose or tail wheel

C = Basic Weight.

For example:—



A = 150 in

B = 220 lb

C = 4220 lb (i.e. 220 + 1995 + 2005)

Figure 6 CENTRE OF GRAVITY RELATIVE TO THE MAIN WHEELS

Thus:
$$\frac{A \times B}{C} = \frac{150 \times 220}{4220 \text{ lb}}$$
$$= \frac{33\,000 \text{ lb in}}{4220 \text{ lb}}$$
$$= 7{\cdot}82 \text{ in}$$

∴ the c.g. is 7·82 in forward of main wheel centreline.

5.4 Reference Datums

5.4.1 Whenever a c.g. distance is reference to the main wheel centreline it should always be corrected to relate to the reference datum, and its associated moment calculated. The purposes of this correction are twofold. Firstly, in terms of measurement, it relates the c.g. to the reference datum. Secondly, in terms of total moment (and Basic Weight), it establishes the necessary mathematical datum point for subsequent calculations with regard to the operation and maintenance of the aircraft.

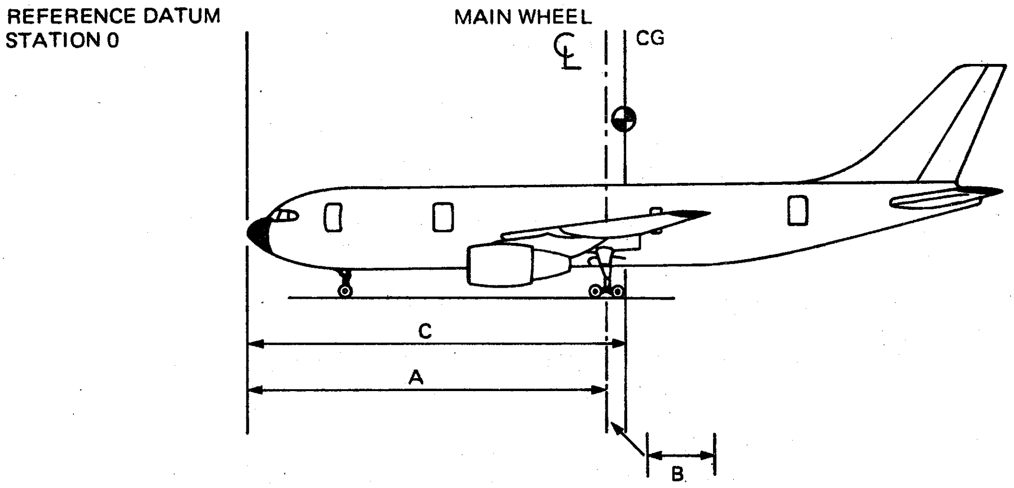
5.4.2 Centre of gravity correction to the reference datum is achieved by:

(a) suspending a plumb bob from the reference datum,

(b) measuring the distance, parallel to the aircraft's longitudinal centreline, from the reference datum to the main wheel reaction point centreline and,

(c) either adding or subtracting this measurement to or from the distance of the c.g. from the main wheel centreline.

Example 1:



A = 626 in forward of the main wheel reaction

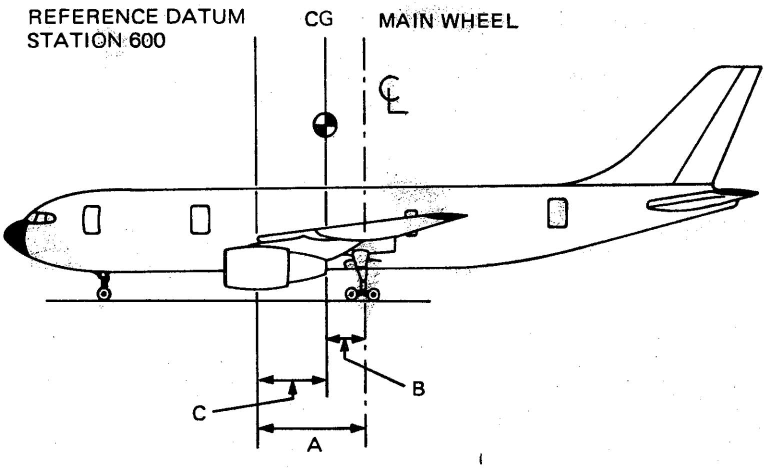
B = 50 in aft of the main wheel reaction

C = A + B

∴ the c.g. is 676 in aft of the reference datum

Figure 7 CENTRE OF GRAVITY CORRECTION TO THE REFERENCE DATUM

Example 2:



A = 260 in forward of the main wheel reaction

B = 100 in forward of the main wheel reaction

C = A − B

∴ the c.g. is 160 in aft of the reference datum

Figure 8 CENTRE OF GRAVITY CORRECTION TO THE REFERENCE DATUM

5.4.3 Total moment can then be found by the following calculation:—

Arm of the c.g. from the reference datum x Basic Weight.

For example, if a hypothetical Basic Weight of 84 000 lb is attached to the aircraft shown in Figure 7, the calculation would be as follows:—

Arm of the c.g. from reference datum = 676 in

Basic Weight = 84 000 lb

= 84 000 x 676

Total Moment = 56 784 000 lb in

Accordingly the Weight and Centre-of-Gravity Schedule will state:—

Basic Weight : 84 000 lb

Centre of Gravity : 676 in aft of the reference datum

Total Moment about the datum : 567 840 lb in/100

NOTE: Once the c.g. and its related moment have been established any subsequent changes to the aircraft in terms of loading, fuel uplift or modification etc. can be re-calculated from the original Basic Weight and moment (see paragraph 6 for further details).

5.4.4 The most commonly used reference datum adopted by the majority of aircraft manufacturers is, at, or forward of, the nose of the aircraft (e.g. fuselage station zero); therefore the following will apply:—

(a) all items of equipment whether basic or additional, will be preceded by a "+" sign (i.e. aft of the datum) thereby simplifying weight and balance computations;

(b) the moment of any item can be easily calculated by its weight and distance relative to its fuselage station;

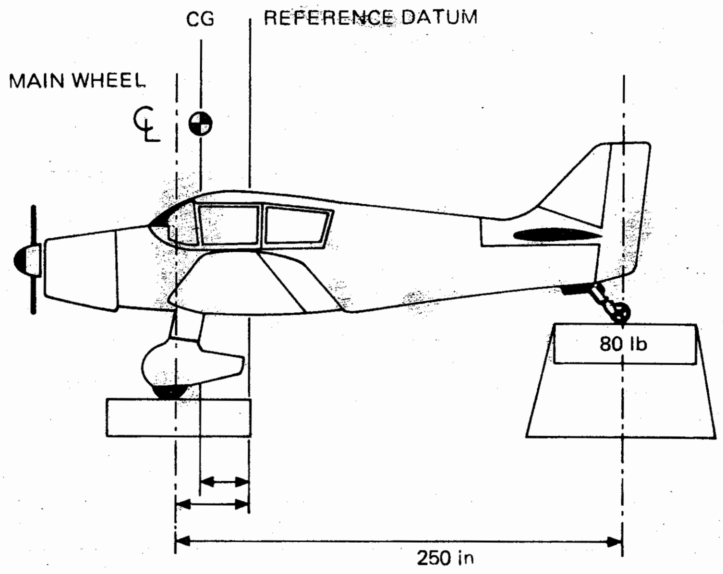
(c) it also offers an accessible point for the purposes of measurement and,

(d) will remain a common location for future "series" aircraft, of the type.

5.5 Tail-wheel Aircraft

5.5.1 Illustrated in Figure 9 is a typical tail-wheel aircraft positioned in a level attitude on weighbridge type platforms, with a reference datum aft of the main wheel centreline.

NOTE: When it is not possible to suspend a plumb bob from the nose-jacking point, due, for example, to the jack or the trestle being in the way, a measuring point should be found by suspending the plumb bob at a predetermined distance from the jacking point, this distance being used to determine the distance between the reaction points.



The weight at the right main wheel reaction	698 lb
The weight at the left main wheel reaction	702 lb
The weight at the tail wheel reaction	80 lb
TOTAL WEIGHT	1480 lb

Figure 9 TAIL-WHEEL AIRCRAFT

5.5.2 To locate the c.g. of this type of aircraft the formula described in paragraph 5.2.4 can be adopted, i.e. tail-wheel distance A is multiplied by the tail-wheel weight, the result of which is divided by the basic weight as follows:—

$$\text{c.g.} = \frac{\text{A x B}}{\text{C}}$$

Where A = 250 in

B = 80 lb (weight at the tail wheel)

C = 1480 lb

$$= \frac{250 \text{ x } 80}{1480}$$

$$= \frac{2000}{1480}$$

$$= 13{\cdot}513 \text{ in}$$

∴ the c.g. is 13·513 in aft of the main wheel reaction, or alternatively 18·487 in forward of the reference datum (i.e. 32 in minus 13·513 in).

Or alternatively (see paragraph 5.6),

$$\text{c.g.} = \frac{\text{Total Moment (TM)}}{\text{Total Weight (TW)}}$$

	Weight (lb)		Arm (in)		Moment (lb in)
Right main wheel	698	x	(–) 32	=	(–) 22 336
Left main wheel	702	x	(–) 32	=	(–) 22 464
SUB TOTAL	1400				(–) 44 800
Tail wheel	80	x	(+) 218	=	(+) 17 440
				=	(–) 44 800
					(+) 17 440
TOTAL	1480				(–) 27 360

$$\text{c.g.} = \frac{\text{TM}}{\text{TW}} = \frac{27\ 360}{1480}$$

$$= (–)\ 18{\cdot}487 \text{ in}$$

∴ the c.g. is 18·487 in forward of the reference datum.

5.6 An Alternative Method of Weight and Balance Calculation

5.6.1 There are various alternative methods to calculate the c.g. and moment of aircraft to that prescribed in the preceding paragraphs, once the basic weights and measurements have been established.

5.6.2 In the following example, the aircraft graphically described in Figure 10, is identical to that shown in Figure 6 except for the added reference datum. The method of calculation is the same as that used in paragraph 5.7, except that the subject aircraft has, as appropriate to this section, been weighed on platforms as opposed to aircraft jacks.

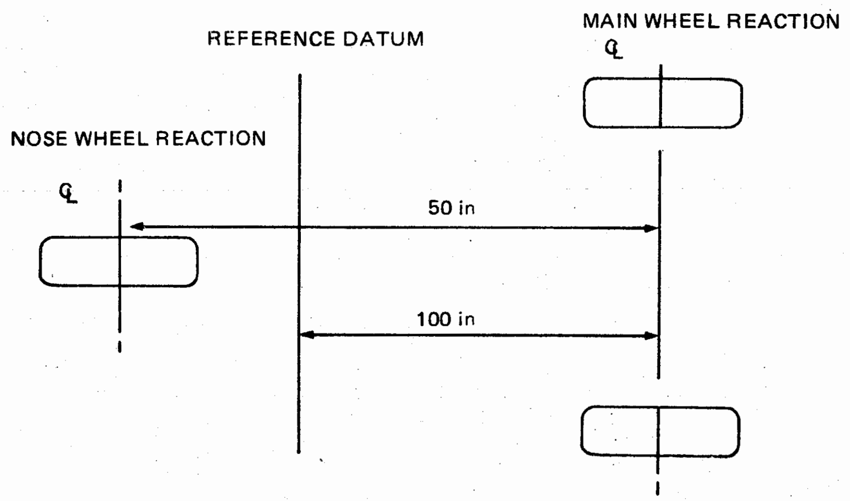


Figure 10 CENTRE OF GRAVITY RELATIVE TO THE REFERENCE DATUM

$$\text{c.g.} = \frac{\text{Total Moment (TM)}}{\text{Total Weight (TW)}}$$

	Weight (lb)		**Arm (in)**		**Moment (lb in)**
Left main wheel	1995	x	(+) 100	=	(+) 199 500
Right main wheel	2005	x	(+) 100	=	(+) 200 500
SUB TOTAL	4000				(+) 400 000
Nose wheel	220	x	(–) 50	=	(–) 11 000
TOTALS	4220				(+) 389 000

$$\frac{\text{TM}}{\text{TW}} = \frac{389\ 000 \text{ lb in}}{4220 \text{ lb}}$$

= (+) 92·180 in aft of the reference datum.

Accordingly, the Weight and Centre-of-Gravity Schedule will state:—

Basic Weight : 4220 lb

Centre of Gravity : 92·180 in aft of the reference datum

Total Moment about the datum : 3890 lb in/100.

5.7 Weighing on Aircraft Jacks

5.7.1 It is important when weighing aircraft on jacks to strictly observe the procedures specified by the relevant aircraft manufacturer. Reference should also be made to CAIP Leaflet **GOL/1—1** — Aircraft Handling. Suitable adapters should be fitted to the aeroplane jacking points and the weighing units of adequate capacity fitted to jacks. The jacks should then be positioned under each jacking point, and the zero indication of the weighing units verified. The attitude of the aeroplane should then be checked by means of levels or plumb bobs as appropriate. The aeroplane wheel brakes should then be released and the jack situated at the lowest jacking point raised until the aeroplane is level. The remaining jacks may then be raised to contact their respective jacking points. All jacks should then be raised slowly together (maintaining a level attitude) until the aircraft wheels are clear of the ground. When final adjustments have been made to level the aircraft, readings should be taken from each weighing unit, after which the aircraft may then slowly be lowered to the ground. To ensure that representative readings are obtained when using hydrostatic units or load cells, it is essential that a second weighing is carried out.

NOTE: When electrical weighing cells are being used it is often recommended that they should be switched on 30 minutes before commencing weighing operations, in order that the circuits have time to stabilise.

5.7.2 The weight and c.g. of the aeroplane can then be calculated as in the example given below, for an aircraft whose c.g. reference datum is quoted as fuselage station zero and on which the jacking points are situated at 50 and 180 in aft of the datum.

$$\text{c.g.} = \frac{\text{Total Moment (TM)}}{\text{Total Weight (TW)}}$$

	Weight (lb)		Arm (in)		Moment (lb in)
(a) Left jack reaction	1995	x	(+) 50	=	(+) 99 750
(b) Right jack reaction	2005	x	(+) 50	=	(+) 100 250
(c) Tail jack reaction	900	x	(+) 180	=	(+) 162 000
TOTAL	4900				(+) 362 000

$$\text{c.g.} = \frac{\text{Total Moment (TM)}}{\text{Total Weight (TW)}} = \frac{362\ 000\ \text{lb}}{4900\ \text{lb}}$$

$$= 73{\cdot}88\ \text{in}$$

Accordingly, the Weight and Centre-of-Gravity Schedule will state:—

Basic Weight : 4900 lb

Centre of Gravity : 73·88 in aft of the reference datum

Total Moment about the datum : 3620 lb in/ 100.

5.8 Weighing Rotorcraft

5.8.1 Rotorcraft are normally weighed in a similar way to fixed-wing aircraft, four jacking points being located in the fuselage near the wheels. The c.g. datum is, however, normally located on the vertical line through the centroid of the main rotor and is marked on the side of the fuselage. Moments may therefore be either positive or negative and the permissible c.g. range extends either side of the datum.

5.8.2 The hydrostatic weighing of rotorcraft by the single point method can be used when permitted by the manufacturer. The process consists of suspending the craft from a single hydrostatic weighing unit at the rotor head. The c.g. is determined by measuring defined angles, and then entering the results into tables supplied by the manufacturer.

5.8.3 To ensure that the rotor blades are symmetrically located about the rotor axis it is usually necessary to fit locks to the rotor head. The weight of these locks must be taken into account when calculating the c.g. position.

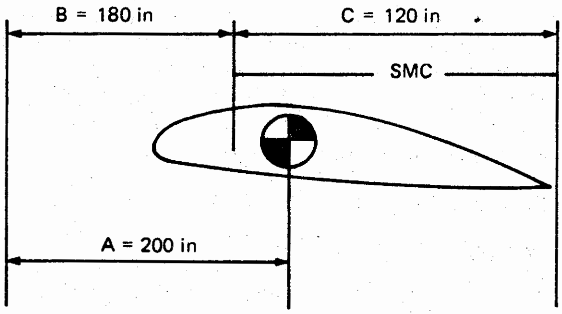
5.8.4 On some rotorcraft it may also be necessary to determine the vertical and transverse positions of the c.g., and the manufacturer's instructions regarding the method of calculation should be followed.

5.9 **Standard Mean Chord.** Since the c.g. is an aerodynamic consideration, its position is sometimes additionally specified as a percentage of the Standard Mean Chord (SMC) of the wing, measured aft from the leading edge (see NOTE to paragraph 2.8.3). The percentage SMC may be calculated as follows:

$$\frac{A - B}{C} \times 100$$

Where A = distance of the c.g. from the reference datum
B = distance of the SMC leading edge from the reference datum
C = the length of the SMC.

For example:



$$\therefore \frac{A - B}{C} \times 100 = \frac{200 - 180}{120} \times 100$$

$$= \frac{20}{120} \times 100$$

$$= 16{\cdot}6\%$$

Figure 11 STANDARD MEAN CHORD

6 CHANGE IN BASIC WEIGHT

6.1 **General.** When an item of Basic Equipment is added, removed or repositioned in an aircraft, calculations must be made to determine the effect on both Basic Weight and c.g. This information should then be used to prepare a revised Weight and Centre-of-Gravity Schedule (Part A) (see paragraph 2.9).

6.2 **Modifications.** Where the total weight and moment for additional equipment is not quoted in the appropriate Modification Leaflet, the equipment, and any parts used for attachment purposes, such as brackets, nuts, bolts, rivets, sealant, etc., must be accurately weighed. The position of the additional material must then be determined, and its moment calculated relative to the c.g. datum.

6.3 In order to find the new Basic Weight and moment of the aircraft, the weight and moment of the equipment added or removed must be considered in relation to the original Basic Weight as follows:—

(a) When equipment has been added the weight must be added to the original Basic Weight; if the arm of the new equipment is positive (i.e. aft of the c.g. reference datum) then the moment must be added to the original moment, whereas if the arm is negative (i.e. forward of the c.g. reference datum) then the moment must be subtracted from the original moment.

(b) When equipment has been removed the weight must be deducted from the original weight; if the arm of the equipment was positive then the moment must be deducted from the original moment whereas if the arm was negative then the moment must be added to the original moment.

(c) The new c.g. position is calculated by dividing the new total moment by the new basic weight.

NOTE: It may be found convenient to use mathematical signs to confirm the final action in the above calculations. For example, if equipment is added "+" and its arm is positive (+), since + x + = +, then its moment must be added to the original moment, but if equipment is removed "–" and its arm was positive (+), since – x + = –, then its moment must be subtracted from the original moment.

6.4 Examples of Alterations to Basic Weight

6.4.1 The following examples are for an aeroplane whose:

(a) Basic Weight is 15 700 lb,

(b) c.g. reference datum is at fuselage station 105, i.e. 105 in aft of fuselage station zero,

(c) c.g. is at station 130 i.e. + 25 in aft of the reference datum.

6.4.2 **Example 1.** A radar system is installed in the aeroplane which comprises:—

(a) a radar set which weighs 32 lb and is located aft of the reference datum at fuselage station 125, with

(b) a controller which weighs 2 lb and is located at fuselage station 65, forward of the reference datum, plus

(c) a scanner which weighs 25 lb and is located at fuselage station 12, forward of the reference datum.

	Weight (lb)	Arm (in)	Moment (lb in)
Original aircraft	15 700	(+) 25	(+) 392 500
Added items (a)	+ 32	(+) 20	(+) 640
(b)	+ 2	(–) 40	(–) 80
(c)	+ 25	(–) 93	(–) 2 325
Revised Basic Weight and moment	+15 759		(+) 390 735

With the revised Basic Weight and moment the c.g. can be calculated as follows:

$$\text{c.g.} = \frac{\text{TM}}{\text{TW}}$$

$$= \frac{390\ 735}{15\ 759}$$

$$= 24{\cdot}79 \text{ in.}$$

Accordingly, the revised Weight and Centre-of-Gravity Schedule will state:—

Basic Weight : 15 759 lb
Centre of Gravity : 24·79 in aft of the reference datum
Total Moment about the datum : 3096 lb in/100.

6.4.3 **Example 2.** The aeroplane's heating and air conditioning unit is removed from fuselage station 65 to fuselage station 180.

	Weight (lb)	Arm (in)	Moment (lb in)
Original aircraft	15 700	(+) 25	(+) 392 500
Item removed	– 120	(–) 40	(+) 4800
Item replaced	+ 120	(+) 75	(+) 9000
Revised Basic Weight and moment	+15 700		(+) 406 300

With the Basic Weight unchanged and a revised moment the calculations are as follows:

$$\text{c.g.} = \frac{\text{TM}}{\text{TW}}$$

$$= \frac{406\ 300}{15\ 700}$$

$$= 25{\cdot}87 \text{ in.}$$

Accordingly the revised Weight and Centre-of-Gravity Schedule will state:—

Basic Weight : 15 700 lb
Centre of Gravity : 25·87 in aft of the reference datum
Total Moment about the datum : 4063 lb in/100.

7 LOADING OF AIRCRAFT

7.1 **General.** In accordance with the Air Navigation Order, the Commander of an aircraft registered in the United Kingdom must satisfy himself, before the aircraft takes off, that the load carried is of such weight, and so distributed and secured, that it may safely be carried on the intended flight. To ensure this, the Variable and Disposable Loads must be added to the Basic Weight and c.g. of the aircraft and the total weight and c.g. determined. If the aircraft exceeds 5700 kg MTWA or has a seating capacity of 12 or more persons, the loading is based on assumed weights for persons and baggage, otherwise the actual weights must be used. For further information see Air Navigation Order (General) Regulations.

7.2 Small Aircraft

7.2.1 On small aircraft the calculations are fairly simple since the only item which alters appreciably during flight is the fuel quantity. Calculations should include all the variable and disposable items, at both maximum and minimum fuel states, to ensure that the c.g. will remain within the limits as fuel is used up.

NOTE: To minimise the calculations involved, some aircraft Operating Manuals include a graph of the c.g. limitations in the form of a weight/moment envelope.

7.2.2 On some aircraft the loadings which will give the maximum forward and aft c.g. positions are included in the weight and balance data. For example, on most four seat aircraft the maximum forward c.g. position is reached with the pilot only, no baggage and minimum fuel, and the maximum aft c.g. is normally obtained with pilot and two rear seat passengers, maximum baggage and maximum fuel. Provided these loadings are within limits it will not normally be necessary to calculate weights and moments before each flight. However, in the fully laden condition the maximum weight or aft c.g. limits may be exceeded, therefore, it may be necessary to offload passengers, baggage or fuel, depending upon requirements of a particular flight.

7.3 Large Passenger and Cargo Aircraft

7.3.1 With large aircraft the moment of items such as fuel, passengers and cargo are considerable and the procedures for determining a particular loading become complicated. In addition to the longitudinal c.g. calculation it is also usually necessary to ensure that distribution of fuel and cargo is satisfactory in a transverse (lateral) direction. Most airlines employ a specialist section dealing with loading calculations, whose responsibility it is to produce a load sheet for each flight.

7.3.2 The main item of variable moment during flight is the fuel, and although correct management of the fuel system will minimise c.g. movement, some variations will remain due to the impracticability of locating all fuel near the c.g. on modern swept-wing aircraft. The critical points in the c.g. envelope are caused by fuel usage and variations in specific gravity, these variations are calculated and applied to the envelope to curtail its boundaries.

7.3.3 The c.g. limitations are further curtailed by fixed allowances for other variable items such as the following:

(a) Seating allowance, which is calculated to provide for out-of-balance seating loads resulting from empty seats or passenger weight variation.

(b) Flight allowance, which is provided to allow for the normal movement of crew and passengers during flight.

(c) Moment changes due to operation of the landing gear or flaps.

7.3.4 Weights and moments of passengers and cargo are then calculated, the cargo being arranged within the fuselage or holds in such a way that the total weight and moment of the loaded aircraft fall within the curtailed limitations. The heavier pieces of cargo or pallets are normally located close to the c.g. to restrict their effect, due attention being paid to floor loading limitations, strength, and number of lashing points, etc.

7.3.5 On some aircraft it is also necessary to predetermine the order of loading fuel, cargo and passengers, in order to ensure that the structural limits are not exceeded, by excessive out-of-balance forces tending to tip the aircraft on its tail.

7.3.6 A Load Sheet, similar to the one shown, is prepared for each flight, the weights and moments with zero fuel and maximum fuel being entered in the c.g. envelope to ensure satisfactory balance and performance throughout all phases of flight, i.e. take-off, climb, cruise and landing.

TYPICAL LOAD SHEET

	Weight (lb)	Arm (in)	Moment (lb in/1000)	CG (% SMC*)
Basic Weight	100 000	210	21 000·00	29·2
Variable Load				
Pilot	165	100	16·50	
Navigator	165	100	16·50	
Engineer	165	120	19·50	
Steward	165	300	49·50	
Crew baggage	100	110	11·00	
Passenger seats, 50 1st class	450	170	76·50	
100 tourist	600	280	168·00	
Drinking water	250	130	32·50	
Liferaft	300	410	123·00	
Emergency transmitter	30	120	3·60	
Service equipment (food etc.)	200	400	80·00	
Operating Weight	102 590	211	21 596·60	30·0
Disposable Load				
Passengers, 1st class (35) ..	5 775	160	924·00	
Tourist (83) ..	13 695	270	3 697·65	
Cargo No 1 hold	500	100	50·00	
No 2 hold	450	200	90·00	
No 3 hold	500	280	140·00	
No 4 hold	400	350	140·00	
Zero Fuel Weight	123 910	215	26 638·55	33·3
Fuel Nos 2 and 4 tanks	10 000	150	1 500·00	
Nos 1 and 3 tanks	10 000	200	2 000·00	
Reserve tanks	5 000	240	1 200·00	
Take-off Weight	148 910	210	31 338·55	29·2

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*SMC is explained in paragraph 5.9. In this example % SMC is derived from the formula $\frac{(\text{c.g. arm} - 175) \times 100}{120}$ (i.e. length of the SMC is 120 in and its leading edge is 175 in aft of fuselage station zero).

APPENDIX

TYPICAL WEIGHT AND CENTRE-OF-GRAVITY SCHEDULE FOR AIRCRAFT MTWA EXCEEDING 2730 kg

Reference : NAL/286

Produced by : Loose Aviation Ltd

Aircraft Designation : Flynow 2E

Nationality and Registration Marks : G-BZZZ

Constructor : FLY Co Ltd

Constructor's Serial : 44

Maximum Total Weight Authorised (MTWA) : 7300 lb

Centre-of-Gravity Limits : Refer to Flight Manual Reference Number 90/946

PART 'A' BASIC WEIGHT

The Basic Weight of the aircraft (as calculated from Weight and Balance Report/Weighing Record NAL/W/95* dated 31 August 1977) is	: 5516 lb.
The c.g. of the aircraft (in the same condition at this weight and with the landing gear extended) is	: 127 in aft of datum
The total moment about the datum in this condition is	: 7015 lb in/100.

NOTE: The datum is at fuselage station 0 situated 114 in forward of the wing leading edge. This is the datum defined in the Flight Manual. All lever arms are distances in inches aft of datum.

The Basic Weight includes the weight of 5 gallons of unusable fuel and 1 gallon of unusable oil and the weight of the following items which comprise the list of Basic Equipment:—

Item	Weight (lb)	Lever Arm (in)
2 Marzell propellers type BL-H3Z30	127 each	76
2 engine driven 100 ampere alternators	27 each	117
1 13 Ah Ni-Cd battery CB-7 etc.	31 etc	153 etc

PART 'B' VARIABLE LOAD

The weight and lever arms of the Variable Load are shown below. The Variable Load depends upon the equipment carried for the particular role.

Item	Weight (lb)	Lever Arm (in)	Moment (lb in/100)
Pilot (one)		108	
De-icing fluid 1½ gal	12	140	17
Life-jackets (seven)	14	135	19
Row 1 passenger seats (two)	60	173	104
Row 2 passenger seats (two)	60	215	129
Row 3 passenger seats (two)	60	248	149
Table	8	256	20
One stretcher and attachments (in place of seat rows 2 and 3)	45	223	100
Medical stores	15	250	37

---

*Delete as appropriate

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PART 'C' LOADING INFORMATION (DISPOSABLE LOAD)

The total moment change when the landing gear is retracted in lb in/100 is: −18. The appropriate lever arms are:—

Item	Weight (lb)	Lever Arm (in)	Capacity (imp gal)
Fuel in tanks 1 and 2	1368*	145	190
Engine oil	50*	70	5·5
Forward baggage		21	
Rear baggage		261	
Passengers in Row 1 seats		171	
Passengers in Row 2 seats		213	
Passengers in Row 3 seats		246	
Patient in stretcher		223	

*Densities — Petrol 7·2 lb/imp gal; kerosene: 8·1 lb/imp gal; Oil: 9·0 lb/imp gal.

NOTE: To obtain the total loaded weight of the aircraft, add to the Basic Weight and the weights of the Variable and Disposable Load items to be carried for the particular role.

This Schedule was prepared (date) .... and supersedes all previous issues.

Signed .... Inspector/Engineer

on behalf of ....

Approval reference ....

NOTE: (Not part of the Example Schedule). In Part 'B' Variable Load of this Schedule, the actual weight of the pilot is required in accordance with the Air Navigation (General) Regulations for aircraft the (MTWA) of which does not exceed 5700 kg or with less than 12 persons seating capacity. Hence the pilot's weight and moment are omitted in the example.

BL/1-12

Issue 2

December, 1983

BASIC

AIRWORTHINESS PROCEDURES

CLEAN ROOMS

1 INTRODUCTION The higher reliability requirements specified for aircraft system components and, in particular, those associated with complex electronic (see Leaflet **MMC/1-4**), instrumentation and mechanical systems, necessitated the development of techniques for controlling contamination which in various forms is a common cause of component failure. It also became necessary to apply these techniques to selected areas of manufacturing and aircraft operating organisations in which the various processes of manufacture, overhaul and testing can be carried out under controlled environmental conditions. Such selected areas are referred to as Clean Rooms, the design and construction of which form part of an independent and highly specialised field of work to British Standard BS 5295 Parts 1, 2 and 3.

1.1 The information given in this Leaflet is intended purely as a guide to the subject of Clean Rooms. The following general aspects are covered:

	Paragraph
Sources of Contamination	2
Control of Contamination	3
Size of Contaminants	4
Classification of Air Cleanliness	5
Classification of Clean Rooms	6
Environment and Comfort Control	7
Air Handling Systems	8
Layout of Clean Rooms	9
Construction of Clean Rooms	10
Clean Room Furnishings	11
Clean Room Garments	12
Clean Work Stations	13
Clean Room Operation	14
Maintenance of Clean Rooms	15

2 SOURCES OF CONTAMINATION Any substance that causes failure or malfunctioning of a component is a contaminant, the particles of which may take a variety of forms and stem from many sources.

2.1 **Air.** The air which continually surrounds the components may be considered as a contamination storehouse containing dirt and dust particles, organic and inorganic vapours.

2.2 **Manufacture.** Contaminants are produced during all manufacturing processes, and particles, such as swarf resulting from a machining operation, or particles forced into the surface of a component during a pressing or heating process, can be of such a nature that their effect can be immediate or delayed. Depending on the composition of the particle and component materials, the alloys or compounds formed by interaction can result in serious loss of a component's structural strength over a period governed by the rate of diffusion.

2.3 **Assembly.** During the assembly process the possibility of introducing contaminants is probably greatest because of exposure to the highest levels of contaminant sources. In the soldering process for example, the vaporisation of flux causes particles to escape into the surrounding air which, on cooling, condense as droplets on a nearby cold surface of the component. Depending on the location of the particles and the forces applied to them, they can act as a contaminant with an immediate or delayed effect.

2.3.1 The use of jointing adhesives can also produce contamination similar to that of a soldering process. In addition, vapours can be given off which can migrate to other portions of an assembly and act as a delayed-action contaminant.

2.3.2 Assembly of components using threaded joints can produce fibre-shaped fragments or flakes as a result of an effect similar to wire drawing. For extremely close fit or for balancing purposes, it may be necessary to fit individual parts of a component together by grinding, lapping or honing operations. In any such operation, contaminant particles can be dispersed in the atmosphere, suspended in fluids, adhere to the surfaces of component parts, or become embedded into the surfaces.

2.3.3 Assembly of components in jigs, or while being handled or supported by tools, may result in deformation of surfaces and production of contaminant particles. For example, if during tightening of a bolt, slippage of the spanner jaws occurs, particles are produced from the bolt head. Particles are also produced from the heads of bolts or screws and component surfaces during final tightening.

2.4 **Storage and Transit.** During the storage period of assembled components and of associated independent parts, contamination can occur in several ways notwithstanding the use of protective coverings or containers. Particles from the air may be deposited as a result of gravitational settling and also as a result of electrostatic effects. Improperly cleaned containers or covers may transfer particles to components, in particular where padded containers and plastics containers are used. In the first case, the contours of the container may trap particles which are not released until the component causes deformation of the padding. In the second case, plastics containers may pick up particles from the air due to electrostatic charging, and hold them until transferred to the packed component.

2.4.1 Containers which are not hermetically sealed are subject to a 'breathing' cycle as the temperature of the container varies. During the intake portion of the cycle, particles in the air surrounding the container may be drawn into a position where they can contaminate the component.

2.4.2 The movement of packed containers during transit is also a source of contamination since it may dislodge contaminant particles not previously cleaned off, or create new particles by abrasion.

2.5 **Component Cleaning Processes.** A cleaning process is actually a process of transforming contamination from a high level of concentration to a lower one; therefore, tolerance levels must be considered relative to the component's function and required operational accuracy.

2.5.1 The transfer of contaminant particles is dependent on the methods used in the cleaning process, i.e. whether wiping or polishing with an absorbent or collecting material (dry cleaning transfer) or cleaning by means of a liquid (wet cleaning transfer). Problems exist in each of these processes.

2.5.2 The ways in which dry cleaning can contaminate include the following:
(a) Removal of fibrous particles from the cleaning material.
(b) The material, after use, may have a particle concentration sufficiently high so that as much contamination is left on the component as is removed.
(c) Wiping or polishing action can cause particle adhesion as a result of electrostatic charges.
(d) Particles can be moved about on a component surface without necessarily being lifted from the surfaces.

2.5.3 In the wet cleaning process, the contaminated surfaces are exposed to clean fluid which will wet the particles and the surfaces. The fluid or the component is then agitated so as to pull particles from the surfaces. After a specified period the component is withdrawn and the surfaces are dried. The ways in which wet cleaning can contaminate include the following:
(a) It is often difficult to obtain clean fluid and to keep it clean when handling it.
(b) Agitation of the fluid is normally done by ultrasonic means, but there is a possibility of re-contamination if the amplitude of agitation is not large enough to remove particles an appreciable distance from the surface of the component.
(c) Often a wet surface may have particles in the liquid layer that can easily be moved laterally over the surface but are removed from the liquid layer only with great difficulty.
(d) Until the component is dried, any airborne particles will collect on the wet surface and remain.

2.6 **Personnel Activity.** The activity of personnel is probably the greatest single cause of contamination which arises from several sources. The act of walking, or other movements required at a work bench, produces transient air currents which re-distribute airborne particles and the brushing off of particles from many surfaces. Another contaminant source is the shedding of skin and hair particles. The outer layers of skin flake off almost continuously, the flake rate and size depending on the amount of abrasion to which the skin is exposed and its condition.

2.6.1 Exhaled air is another source of contamination since it contains moisture-retaining solid particles and is usually acidic in nature. Perspiration from the skin is a similar hazard.

3 CONTROL OF CONTAMINATION Control of contamination is effected in two ways: by establishing a clean room, which will provide a clean atmosphere and working conditions, and by rigid routines adopted by personnel to prevent process, transfer and associated sources of contamination while working within the area of the clean room.

3.1 The construction of a clean room and its air handling system (see paragraph 8) must be designed to control airborne particles over a range of sizes and suited to the nature of the work performed in the room. Control is accomplished by filtration of the air entering the room, changing the air to remove generated particles, designing walls, floors and furnishings to be resistant to particle generation and retention, protecting components from impact and settling of particles and providing additional areas for cleaning of parts and personnel.

4 SIZE OF CONTAMINANTS The degree to which contaminants are effectively controlled is determined by measurements of the size of particles and the number in a given volume. The conventional unit of measurement is the micrometre (μm). In general, the filtration systems of clean areas are designed to control particles of 0·5 μm and larger in size.

5 CLASSIFICATION OF AIR CLEANLINESS In addition to all principles of air-conditioning, certain specialised cleanliness requirements are defined by standards which establish classes of contamination level to be achieved in the design of a clean room for a specific task. Classifications relate to the number of contaminant particles 0·5 μm and larger in size, present in one cubic metre of air. Four classes of contamination level are generally adopted and these are shown in descending order of cleanliness in Table 1. Special classifications may be used for particle count levels where special conditions dictate their use. A summary of the cleanliness requirements for some typical products is given in Table 2.

TABLE 1

Controlled Environment (Clean room, work station or clean box)	Recommended Air Flow Configurations	Recommended Periodicity for Air Sampling and Particle Counting	Max. Permitted Number of Particles per m³ (equal to, or greater than, stated size)					Final Filter Efficiency %
			0·5 μm	1 μm	5 μm	10 μm	25 μm	
Class 1	Unidirectional	Daily or continuous by automatic equipment	3,000*	Not applicable	Nil	Nil	Nil	99·995
Class 2	Unidirectional	Weekly	300,000	Not applicable	2,000	30	Nil	99·95
Class 3	Unidirectional or conventional	Monthly		1,000,000	20,000	4,000	300	95·00
Class 4	Conventional	3-monthly			200,000	40,000	4,000	70·00
Controlled Area	Normal ventilation	—	—	—	—	—	—	—
Contained Work Station	Unidirectional	To suit required class and application						99·997
Portable Clean Boxes	As selected	To suit required class and application	To suit required class					To suit required class

* Subject to maximum particle size of 5 μm

6 CLASSIFICATION OF CLEAN ROOMS The cleanliness achieved by a clean room is dependent on the air-handling system's capacity to purge the room of contaminant particles. This includes not only effectiveness of the filters and the number of air changes per hour but also the distribution of the air within the room. There are two main methods of distributing air into clean rooms namely, conventional clean rooms and unidirectional-flow clean rooms, and these also serve as the basis of clean room classification.

6.1 **Conventional Clean Rooms.** Conventional clean rooms are based on recognised air-conditioning techniques. The conditioned air is highly filtered and distributed through ceiling-mounted diffuser outlets, and then exhausted from return airducts located near the floor around the periphery of the room (see Figure 1). In addition to direct emission from the diffuser outlets, spreading of conditioned air throughout the room is obtained by secondary mixing of the air caused by thermal effects of warm and cool air currents. This is an advantage from the point of view of maintaining conformity of room temperature conditions, but the turbulence created gives rise to the problem of contaminant particles being re-introduced to the airstream.

TABLE 2

Class	Particles/m³	Product
2	0·5 μm to 10 μm	Air bearings Miniature ball bearings Miniature contacts Floated gyros Hydraulic and pneumatic systems Optics Semi-conductor networks Miniature timing devices
3	1 μm to 25 μm	Hydraulic and pneumatic systems Precision timing devices Stable platforms Gyros
4	5 μm to 25 μm	Ball bearings Electronic components Engine pumps Aerospace instruments Printed circuits Valves Hydraulic and pneumatic systems Precision measuring equipment

NOTE: Class 1 is outside the scope of this Leaflet and would not normally be used.

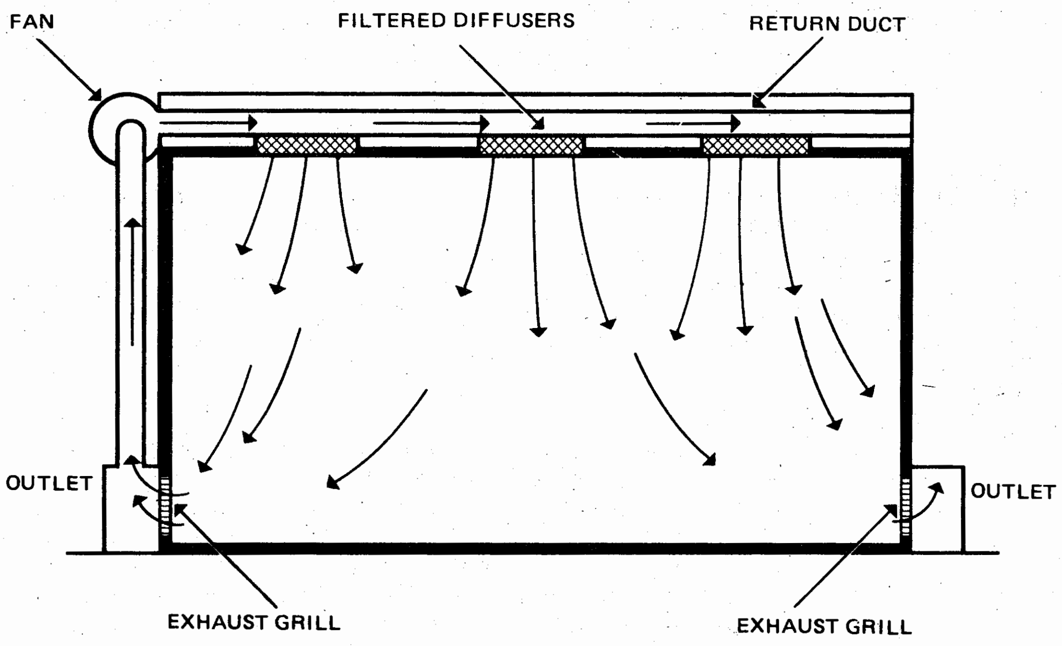


Figure 1 CONVENTIONAL FLOW SYSTEM

6.2 **Unidirectional-flow Clean Rooms.** These rooms have been developed from the conventional type of clean room and are designed to overcome three primary deficiencies associated with it; lack of self clean-up capabilities to effect contamination brought in by personnel and equipment, non-uniformity of airflow patterns and the requirement for rigid control of personnel. The major differences between the layout and operation of the two types of clean room result from the method of air distribution adopted. In a unidirectional-flow room air is introduced through a large filtered diffuser area, moves through the room and is exhausted through an outlet opposite to the diffuser and of equally large area. Such an arrangement ensures that the air moves in a straight or unidirectional-flow. The outlet is connected to return air ducts thus permitting re-cycling of the air. Two alternative airflow systems exist and are illustrated diagrammatically in Figure 2. In the vertical unidirectional-flow (down-flow room) system, the diffuser forms the complete ceiling of the room and the floor is grated to provide the outlet to return ducts. The diffuser of a horizontal flow (cross-flow room) system forms one of the end walls of the room. After passing through the room and then through an exhaust grill, the air is deflected upwards into the return ducts.

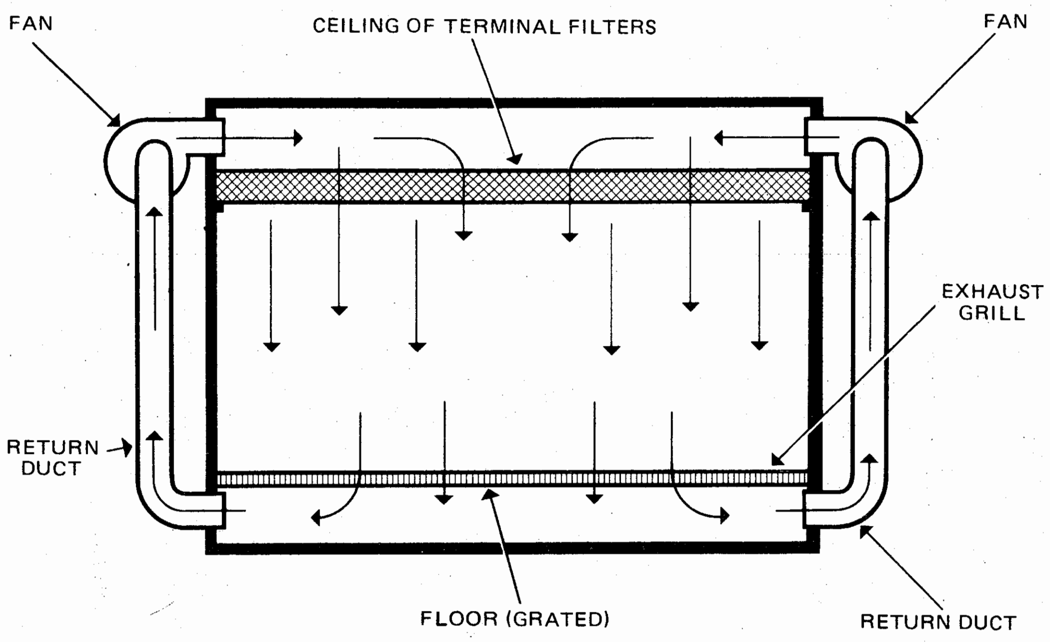
6.2.1 In some designs the use of separate return ducting may be eliminated by adopting the twin cross-flow technique of air distribution as shown in Figure 3. The total clean room area required is divided in half by a wall, with flow in one direction on one side of the wall and flow in the opposite direction on the other side. The end walls are made up of filtered diffusers and exhaust grills, and are disposed so that the clean room itself acts as a return duct.

7 ENVIRONMENT AND COMFORT CONTROL The temperature, humidity and pressure characteristics of the air passing through the air handling system (see paragraph 8) should be controlled to establish an environment suitable for work processes to be carried out in a clean room and for the comfort of clean room personnel.

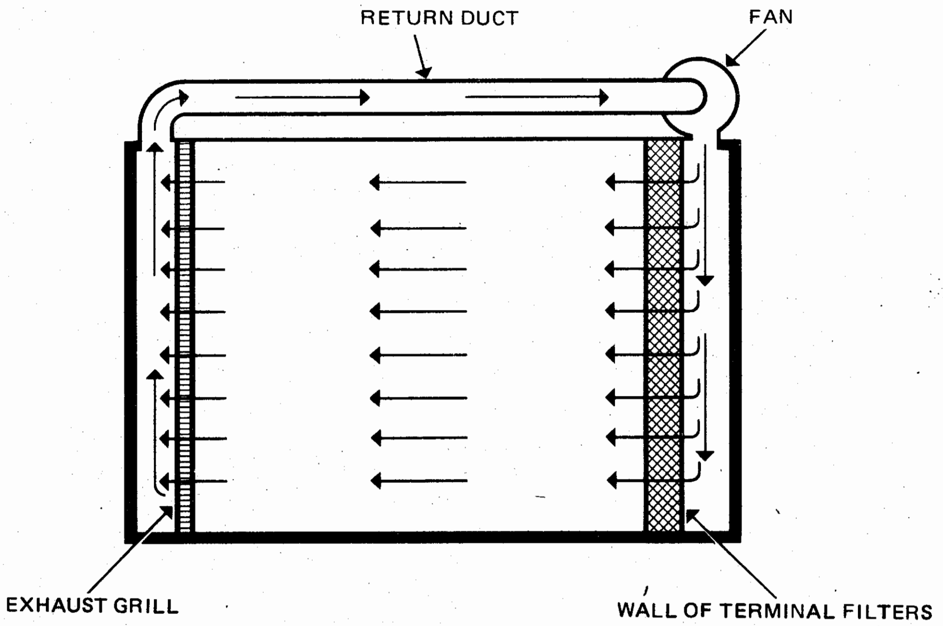
7.1 **Temperature and Humidity.** The selection of temperature and humidity ranges to be controlled are dependent on the design of the component or system and the effects on their functional accuracy under varying environmental conditions. Normally a suitable temperature for working conditions is 20 ± 2°C. Humidity should be controlled and maintained at a relative humidity of 35 to 50% for all classes of clean rooms, contained work stations and clean boxes.

7.2 **Pressure.** Clean rooms are always slightly pressurised in order to maintain the required outward flow of air under closed working conditions and to prevent the entry of contaminant airborne particles when entryways or doors are opened.

7.2.1 Unidirectional-flow rooms should normally have an air velocity of 0·45 ± 0·1 m/s for horizontal flow rooms and 0·30 ± 0·05 m/s for vertical flow rooms. Air pressure for conventional flow rooms should be such that the number of air changes, including re-circulated air, should not normally be less than 20 per hour except for Class 4 rooms where not less than 10 changes per hour may be acceptable.



VERTICAL FLOW



HORIZONTAL FLOW

Figure 2 UNIDIRECTIONAL–FLOW SYSTEMS

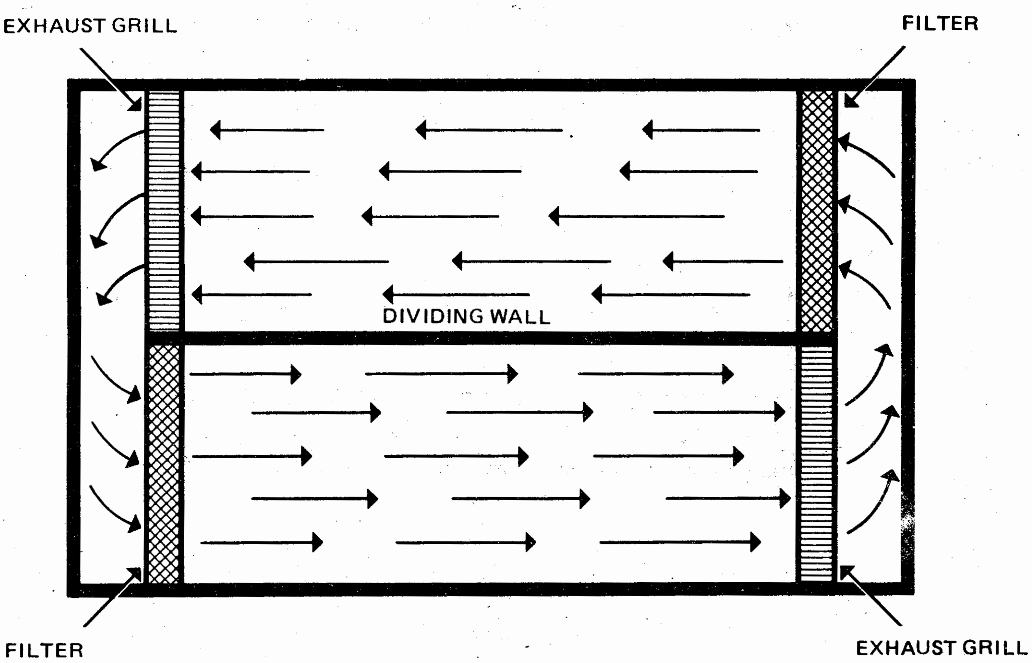


Figure 3 TWIN UNIDIRECTIONAL CROSS-FLOW SYSTEM

7.2.2 Arrangements should also be made to ensure that excessive turbulence is not produced, and every precaution should be taken to obviate the possibility of contaminated air being carried back to the work stations. Contained work stations and portable work boxes should normally conform to the requirements of the type of air flow selected. Air pressure and graduations between successive pressure areas should not normally be less than 15 Pa (1·5 mm water gauge).

NOTE: 25 Pa (2·5 mm water gauge) is normally regarded as adequate but, when selecting the actual pressure, care should be taken to ensure that in-leakage is prevented.

8 **AIR HANDLING SYSTEMS** The primary function of an air handling system for any type of clean room is to control the level of airborne contaminant particles by constantly filtering and re-circulating the air. The arrangement of a system depends on whether it is to be a conventional clean room, unidirectional vertical or horizontal flow clean room. In the basic form, however, it consists of a fan, ducting for inlet and exhaust air and an air filtration system. In some instances, the use of ducting may be minimised by adopting a false ceiling arrangement and by blowing air through the plenum chamber formed between two ceilings, and also by adopting a twin cross-flow system (see paragraph 6.2.1). The air is conditioned to the required temperature and humidity values (see paragraph 7.1) by adopting recognised air-conditioning principles and by the integration of an appropriate air-conditioning plant.

8.1 **Fans.** Fans are usually of the electrically-operated type designed to deliver a constant airflow rate through the clean room as the filter pressure drop increases. They should be mounted external to the ducting, where possible, to avoid heat loading of the air and introduction of further contamination. Care should also be taken to avoid contamination of the atmosphere by gaseous effluents.

8.2 **Ducting.** Ducting is constructed from materials which are non-flaking and corrosion-resistant, stainless-steel and aluminium being commonly used, or should normally be treated to prevent the introduction of contaminants from the duct.

8.3 **Filtration System.** Filtration of airborne contaminant particles is selected on the basis of cleanliness level required and, generally, a system is made up of two principal stages: pre-filter stage and final filter stage. Pre-filtering is carried out at the inlet to the air handling system and at one or more points upstream of the clean room, and final filtering directly at the inlet to the clean room. The filters are specifically designed for clean room systems and are graded at each stage, thus providing control of diminishing size particles. Filtering action depends on the particles contacting and adhering to the fibres or collecting surface of the filter medium which is made from such materials as glass-fibre and asbestos. The filters utilised for final filtering are variously known as super-inception, absolute or high-efficiency particulate air (HEPA) filters, and may be used as individual units or assembled to form a filter bank or module. In the latter case, each unit is connected to a common plenum chamber incorporating its own fan. The number of individual units in a bank is governed by design requirements for the air handling system.

9 LAYOUT OF CLEAN ROOMS The layout of a clean room is governed by many factors arising principally from the manufacturing processes and test procedures to be carried out on specific types of equipment. As a result there are a variety of design and layout specifications to meet the requirements of individual manufacturers and operators of equipment. In their basic form, however, layouts are directly related to the accepted methods of air distribution, i.e. unidirectional-flow and conventional.

9.1 **Unidirectional Clean Rooms.** The layout of a typical clean room facility is illustrated in Figure 4. The area devoted to the facility is arranged in accordance with the operating practices common to all clean rooms, i.e. components and personnel flow progressively from an uncontrolled or 'dirty' environment to one in which the desired level of cleanliness is maintained.

9.1.1 **Personnel Cleaning.** Entrance to the clean room is via a change room the purpose of which is to decontaminate personnel without introducing removed contaminant particles into the clean room. A change room is divided into three distinct areas; an uncontrolled or 'dirty' area, a wash-up (semi-contaminated) area and a change (uncontaminated) area. These areas are arranged so that personnel must follow a definite path for entry into the clean room.

(a) In the uncontrolled area lockers are provided for housing outdoor clothing such as overcoats and raincoats, and also shoe cleaning machines. From the uncontrolled area, entry to the wash-up area is made via an air shower compartment the purpose of which is to remove gross contaminant particles from personnel. The size of the compartment may be large enough to accommodate only one person or a group of persons depending on the number that must enter the clean room in a given length of time. The design of the air shower may vary but, in general, it consists of an air inlet system and an exhaust system operated by independent fans. Air flows through the compartment from air inlet nozzles or louvres mounted in the ceiling or in one wall of the compartment. The entrance and exit doors of the compartment are interlocked so that only one of them can be opened at a time. The closing of the entrance door starts the fan and, until the cleaning cycle is completed, the exit door remains locked. The cycle may, in some cases, be interrupted by a safety override system in the event of an emergency. Air velocities are sufficiently high to cause 'flapping' of clothing but without discomfort to personnel.

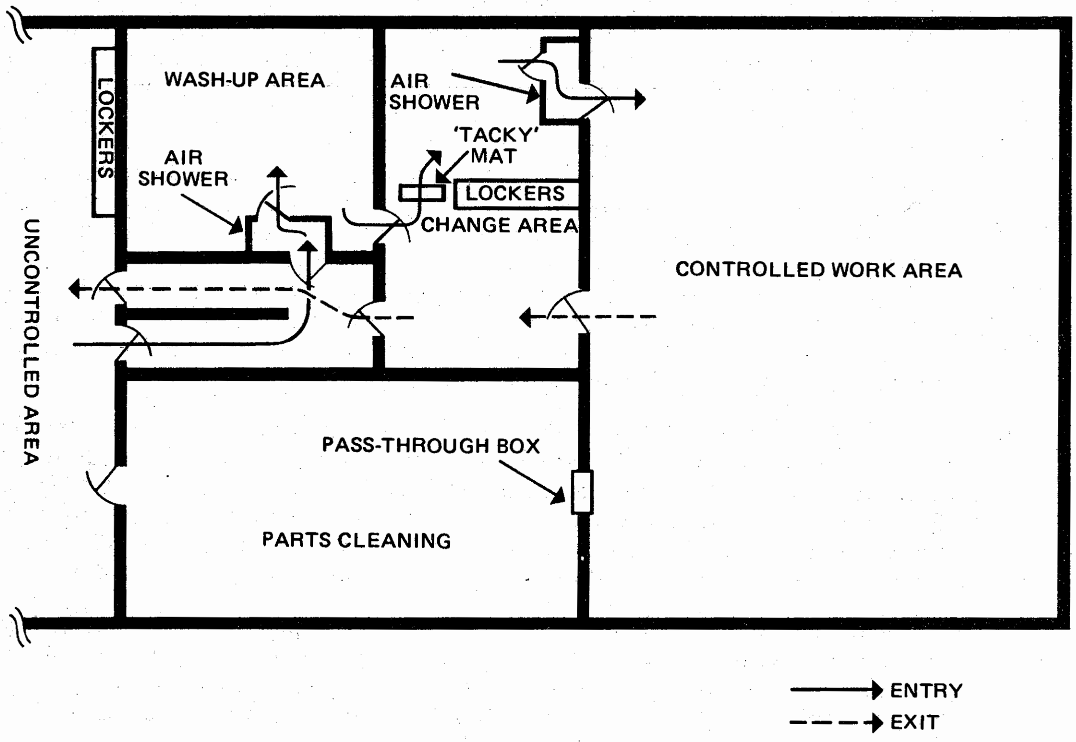


Figure 4 LAYOUT OF A UNIDIRECTIONAL CLEAN ROOM

(b) On leaving the air shower, personnel proceed to the change area via the semi-contaminated area in which washing and toilet facilities are located. These facilities include foot-controlled washstands, liquid-soap dispensing units and heated air hand-drying machines to prevent contamination from towelling. A section of the change area is provided for changing into special clean room garments (see paragraph 12) stored in racks or lockers. The entrance to this section is guarded with a tacky or sticky mat designed to remove residual contaminant particles from the undersurfaces of shoes. Entrance to the clean room after changing is made via another air shower compartment.

9.1.2 **Parts Cleaning.** Prior to entry into a clean room, all parts, tools, equipment, and material must also be decontaminated and it is therefore necessary to provide an additional area adjacent to the clean room. The layout of a parts cleaning room depends largely on the types of component and the number of work processes involved. Similarly, the cleaning methods adopted depend on the type of contaminant, the materials used in the construction of components, and the level of cleanliness required. In general, the room is equipped with the required number of work tables, specialised equipment, cleaning machines and washing facilities for personnel.

(a) The transfer of cleaned components to the clean room is effected by means of a 'pass-through' box forming an air lock in the wall dividing the appropriate areas. Boxes are provided with double windows and doors; an interlock system ensures that only one door can be opened at a time. In some clean room facilities a 'pass-through' box may be of the circular type with a single opening so that the box must be rotated through 180° to insert or remove a component. Since the boxes are designed to prevent a direct opening between rooms, a means of verbal communication between relevant personnel must be provided adjacent to the box. This can be an intercommunication system, a voice diaphragm, or a speaking tube.

9.1.3 **Additional Support Rooms.** Since unidirectional clean rooms require more rigid control to prevent contamination entering, it is usual to make provision for additional support rooms such as offices, lunch rooms, rest rooms, etc. The construction of these rooms follows a similar pattern to that of a clean room (see paragraph 10) although the air handling system is usually not so elaborate.

9.2 **Conventional Clean Rooms.** The use of conventional flow clean rooms eliminates the necessity for support areas such as air showers and special changing rooms and, as may be seen from the typical conventional layout illustrated in Figure 5, increased working area is available and entry procedures are much simpler. The main entrance is situated at the air outlet or 'dirty' end of the room and personnel can pass through this directly from a locker room and change area. Work benches and equipment are disposed so that the cleanest operations are carried out closest to the filter bank forming the end wall, while dirty operations such as soldering, cleaning, etc., are performed toward the outlet end of the room. Parts cleaning and preparation may be performed in a manner similar to that adopted for a unidirectional clean room (see paragraph 9.1.2) or carried out in a parts cleaning room situated within the clean room itself.

10 CONSTRUCTION OF CLEAN ROOMS The construction of clean rooms involves the application of specifically developed building techniques, air-conditioning installation practices and careful selection of construction materials. This is normally undertaken by a specialist organisation working to the detailed BS 5295 Parts 1, 2 and 3 and the specification of a user organisation. The details given in the following paragraphs are therefore intended as a guide to the factors related to general constructional features.

10.1 **Noise and Vibration.** Careful consideration must be given to clean room location in relation to other work areas and the effects of noise and localised ground vibrations. Noise and vibration generated by equipment, machinery, support and administrative areas must also be considered. If vibration insulation devices are to be employed these must not generate or collect dust. Special attention must be given to the framing system of super-structures in order to prevent vibration transmission through ceilings, walls and floors into the main structure. The maximum noise level of the room, work station or clean air device, in an operational but unmanned state should not normally exceed 65 dB.

10.2 **Floors.** Floors should have long life and be highly resistant to breakdown under the shear forces created when personnel walk across them. Vinyl is particularly suitable for floors since it is tough and resilient. Floors should have a smooth surface which is easy to clean and will not collect dust. The junction between floors and walls should be radiused to facilitate cleaning operations. Joints between floor sections should be tight and sealed.

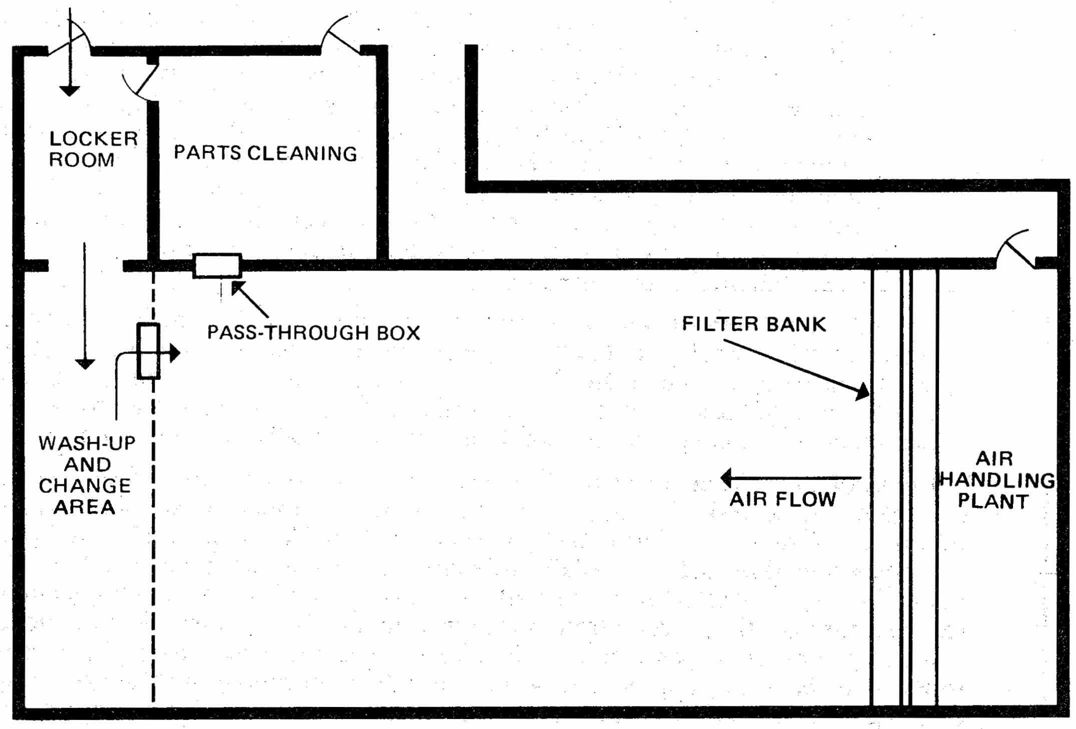


Figure 5 LAYOUT OF A TYPICAL CONVENTIONAL CLEAN ROOM

10.3 **Walls.** Walls should be covered with materials which will produce a smooth, durable surface which does not chip or flake. Stainless steel, vinyl coating, high-gloss paint, melamine decorative laminate, painted hardboard and tiles are some of the materials which are suitable. Window frames, doors and door frames may be constructed of steel, aluminium or other highly durable material, and should be set flush with the interior of the walls. The use of timber in structural elements is discouraged because it is unstable in areas where there is a change in humidity. The introduction of large volumes of console type equipment can increase the heat load of a clean room and provide possible collection and sources of contamination. Such equipment may be built into a wall thus placing the heat load outside the room and also permitting maintenance of the equipment without the necessity of entering the clean room. Gaskets should be fitted around the equipment to prevent excess loss of room air.

10.4 **Ceilings.** Since ceilings are not subjected to potential impact, they may be surfaced with any material that is easily cleaned and does not produce or collect dust. Ceiling panels should be provided with gaskets and clamped to ensure adequate sealing, allowance being made for subsequent removal and replacement.

10.5 **Lighting.** Lighting fixtures of the fluorescent type should be used and of ratings which will provide adequate light intensity at bench level of not less than 3,000 lux. Fixtures may be installed to permit servicing from within the clean room, or supported in tracks above the ceiling so that they can be slid out for servicing without entering the clean room.

10.6 **Utilities.** The distribution of utilities such as water, electrical power, vacuum and compressed air supplies must be properly planned to ensure that all required work locations are served without interference with room air distribution and work flow.

11 CLEAN ROOM FURNISHINGS Furnishings such as work benches, chairs and containers for component parts require careful selection, design and choice of materials for their construction. The main structure of work benches and chairs should be of metal and designed in such a way that contaminant particles cannot accumulate. Items that can expect to be bumped, knocked, abraded, etc., by personnel should possess a tough, resilient, low-particle generating surface such as stainless steel, melamine decorative laminate type material, or material of equivalent surface qualities.

12 CLEAN ROOM GARMENTS Clean room products can be readily contaminated by particles from clothing and it is therefore necessary to make provision for the wearing of protective garments. These take the form of smocks, overalls, caps and hoods. In addition, 'boottee' type shoe covers, separate clean room shoes and gloves must also be provided. The extent to which all the garments are used depends on the type of clean room, class of cleanliness to be achieved and the work processes carried out.

12.1 **Design.** The garments are of special design to prevent the transfer of contaminant particles from personnel and at the same time to provide the maximum of comfort. The materials from which they are fabricated are usually selected from the range of available man-made fibres which exhibit such properties as non-flammability, limited linting, and negligible electrostatic generation. These materials are available under a variety of trade names. Typical design requirements for clean room garments are given in the following paragraphs.

12.1.1 **Smocks.** Smocks should be of simple design, with no pockets and with as few seams as possible. Seams should leave no open end of material which might become frayed and give off lint or loose strands. In addition, seams should be double-stitched with thread of the same fibre as the garment. Adjustable neck bands and cuffs should be provided in preference to collars and loose sleeves and must provide a snug fit when worn.

12.1.2 **Overalls.** Overalls should have a full-length zip fastener with flap front and be provided with adjustable neck bands and cuffs. If overalls are to be used with shoe covers, the overalls should fit inside the covers. Overalls to be used with clean room shoes should be designed so that the legs of the overalls meet and slightly overlap the shoes.

12.1.3 **Caps.** These should be of the style worn in hospital operating rooms. They should fit snugly around the head, covering the hair to prevent hair particles and dandruff falling into the clean room area.

12.1.4 **Hoods.** Hoods should be designed to confine all hair under them to eliminate contamination by hair particles and dandruff, and to fit snugly inside overalls to provide complete coverage of personnel; if beards are permitted, masks must also be provided.

NOTE: Garments are usually white although in some cases a sea green colour may be chosen to minimise glare. As a means of identifying selected personnel, e.g., supervisors or personnel in charge of certain work processes, smocks and overalls may be provided with distinctively coloured neckbands. Coloured caps may also be used as a means of identification.

12.1.5 **Shoe Covers and Shoes.** Covers should be worn over normal shoes and should be high enough to hold the legs of overalls. Covers should have a reinforced sole and be of a type which will prevent personnel from slipping and falling on smooth floors and, for reasons of durability and economy, nylon is recommended as the material. To provide proper fit and comfort, and to achieve optimum cleanliness, covers should be provided with snap fasteners, and laces which can be tied around the legs and above the ankles. As an alternative to shoe covers, shoes can be issued to personnel for exclusive wear in the clean room. They should be simply designed, comfortable, washable and fabricated from materials which will not shed particles due to abrasion and wear.

12.1.6 **Gloves.** When there is a risk of contamination from contact with the hands or fingers, gloves or finger stalls must be used. Such coverings should be comfortable and should enable the user to maintain a delicate finger touch. If plastics is necessary for the 'touch' portion of gloves the remainder should be made of a material that will allow 'breathing' thus preventing overheating of the hands.

12.2 **Garment Storage and Cleaning.** When not in use, clean room garments should not be allowed to come into contact with any possible contaminant. They should always be stored on individual hangers in the lockers provided in changing rooms. Three sets of garments per person should normally be provided: one set in use, one set being cleaned, and one set in reserve.

12.2.1 Cleaning of garments is a specialised technique based on conventional laundering and dry-cleaning processes. Ideally, a laundry should be established as a specialised unit supporting clean room operations, and functioning under similar conditions of decontamination as a clean room. A typical unit is divided into three distinct areas: soiled garment receiving area, washing and dry-cleaning area, and an inspection and packaging area. Soiled garments are placed in polythene bags and transferred to the receiving area through an air lock. The garments are then emptied into specially built tubs and transported to the washing and dry-cleaning area equipped with the appropriate machines. After cleaning and drying, the garments are transferred to the third area for inspection, sampling of contamination level, and packaging and sealing in polythene bags.

13 CLEAN WORK STATIONS These stations are work benches specifically designed to incorporate their own filtered air supply system. They may be utilised in a clean room, in addition to benches or tables based on conventional patterns, or in an uncontrolled environment.

13.1 The design of work stations has been developed from bench- mounted 'dust-free' cabinets, typical examples of which are illustrated in Figure 6. Although these cabinets provide low contamination levels, depending on the type of filter, the problem of contamination while operations are performed inside arises. Contaminants move about in turbulent air and find their way out of the cabinet only at random intervals. Another design, commonly referred to as a 'glove box' is also illustrated in Figure 6. It utilises a recirculating air system and although it produces lower contamination levels than other forms of cabinet, it has the disadvantage of requiring an operator to work through arm ports and the attached gloves.

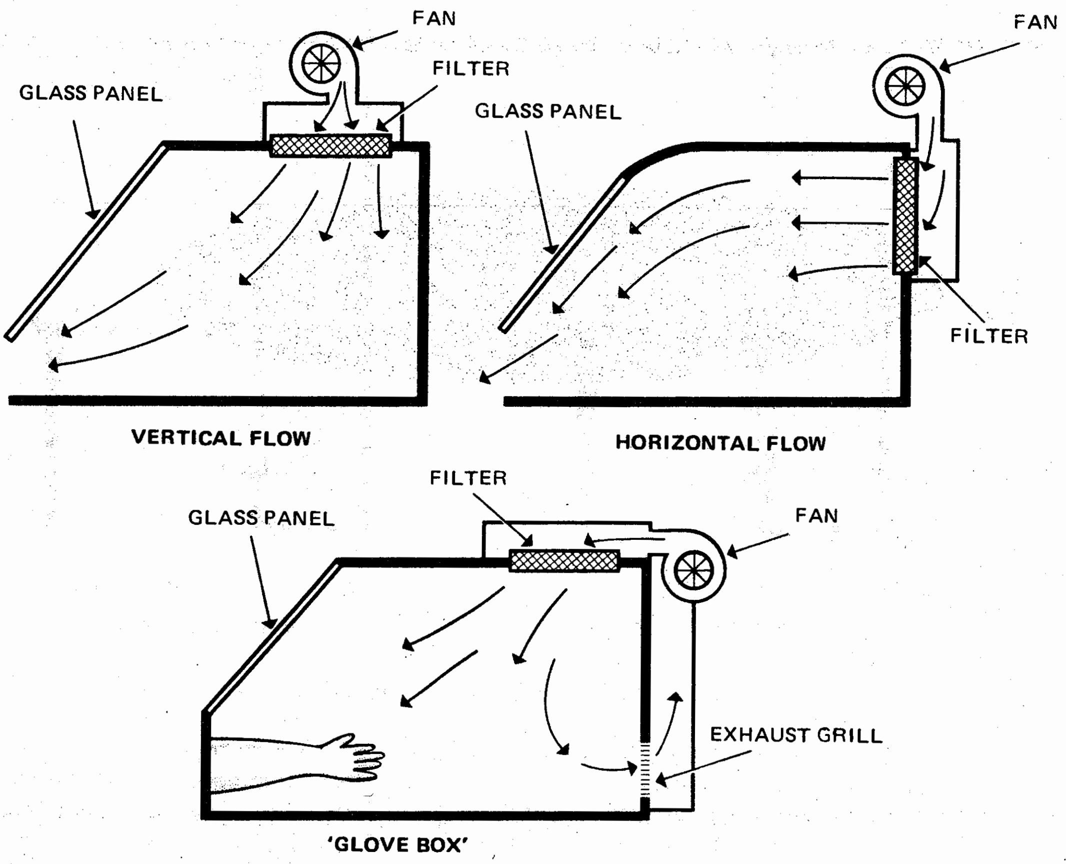
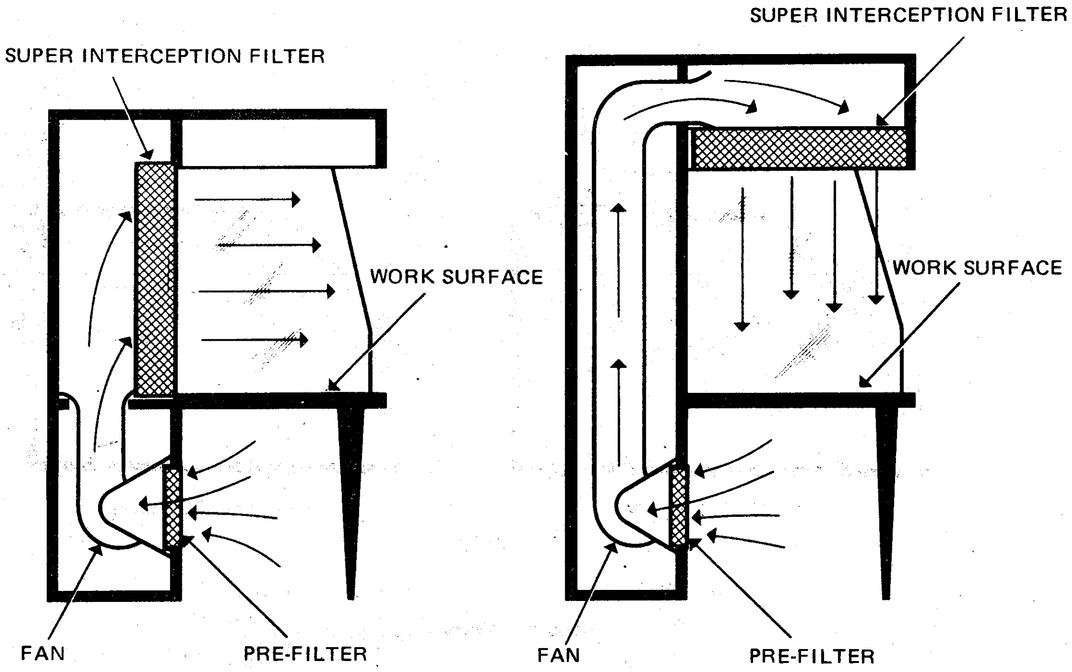


Figure 6 CLEAN WORK BOXES

13.2 Work stations overcome the deficiencies of 'dust-free' cabinets by incorporating an air distribution system which operates on principles similar to those employed in a undirectional-flow clean room (see also paragraph 6.2). The air distribution system consists of a fan and a pre-filter mounted below the work surface, and an outlet with a super-interception filter, mounted so as to produce either a horizontal flow or a vertical flow over the work surface. Figure 7 illustrates both airflow techniques as they are applied to a typical console type of work station. Glass panels form the sides of the work area which, on account of the undirectional-flow technique, is open at the front thus permitting unrestricted movement at the work surface. Illumination of the work area is provided by lighting units enclosed in the canopy above the work surface. Individual switches for lighting units and fans are located at convenient points as also are the controls for the various services required for relevant work processes.



HORIZONTAL FLOW **VERTICAL FLOW**

Figure 7 CLEAN WORK STATIONS

13.3 The selection of a work station best suited to a specific application involves such factors as type of airflow, size of work area, space available, and design and performance of the air distribution system. Units employing horizontal flow are generally less costly than vertical flow units for equal size of work area and can usually be provided with lower overall heights thus making them more suitable when vertical space is a critical factor. When work processes require the exhausting of fumes from the work area, or when recirculation of the air is required, vertical flow units provide for these functions more easily than horizontal flow units. Horizontal flow units, on the other hand, provide better 'clean-up' of a work area than vertical flow units of equal size.

13.4 The most important consideration in selecting a particular size of work station is to ensure that it will provide undirectional-flow over a work area of sufficient width, depth and height to accommodate the component being assembled or tested, and the necessary associated equipment. If several items of equipment must be sited around a component, a vertical flow unit tends to produce less turbulence and moves clean air in the most direct fashion from the filter to the component. The filters are of a type similar to those used in unidirectional clean rooms (see paragraph 8.3).

14 CLEAN ROOM OPERATION In addition to the air handling system, the contamination level in a clean room is kept at an acceptable level by two other methods, namely limiting the contamination entering the room and limiting the contamination generated within the room. Both these methods are controlled to a large extent by the personnel selected for clean room operations. The contamination entering the room is limited by the wearing of proper garments (see paragraph 12), personnel cleaning, parts and equipment cleaning, etc. The contamination generated is limited by restricting movement, proper work techniques, etc. It is therefore necessary to establish routines and disciplines related to personnel selection, personal hygiene, entry procedures, and control of working activities. The extent to which certain of these routines and disciplines are applicable depends on the type of clean room; for example, a undirectional-flow clean room requires more rigid control of entry and clothing procedures than a conventional clean room due to the air handling system used (see paragraphs 9.1 and 9.2).

14.1 **Personnel Selection.** The selection of personnel for clean room duties involves consideration of both physical and human factors, including manual dexterity, visual acuity, patience, concern for detail, attitude toward repetitive operations, and reaction to the rigid disciplines that accompany confinement in a controlled environment. Certain physiological problems must also be considered and some examples which are detrimental to clean room operations are: allergies to synthetic fabrics; allergies to solvents used in cleaning processes; profuse nasal discharge; skin conditions that result in above normal skin shedding or flaking and dandruff; high amounts of acid found in the hands; severe nervous conditions such as itching, scratching or claustrophobia.

14.2 **Personal Hygiene.** The development of personal hygiene is of great importance in clean room operations, not only to limit contamination of vital components but also to maintain a healthy working environment. Personnel with colds, temporary coughing and sneezing, should be assigned to temporary jobs outside the clean room until they are sufficiently recovered. This also applies to personnel having received severe sunburn, to prevent peeling skin from contaminating a component or the surrounding area.

14.3 **Entry Procedures.** Clean rooms are necessarily restricted areas and entry must only be allowed to personnel assigned to them. The procedure to be adopted is governed by the type of clean room. Typical activities associated with entry procedures are as follows:

(a) Removal of outdoor clothing such as overcoats and raincoats and stowage in the lockers provided in the 'dirty' or uncontrolled area.
(b) Checking clothes and shoes for visible contamination such as mud, dirt, sand, etc. Removal of such contamination.
(c) Washing of face and hands using foot-controlled washstands, liquid soap dispensers and air driers.
(d) Passing through air showers and air locks to ensure adequate air scrubbing.
(e) Walking over sticky or tacky mats.
(f) Changing into the requisite clean room garments. In connection with undirectional-flow clean room operations, changing is done in the uncontaminated section of the change room adjacent to the clean room. In conventional clean rooms changing is done in an area located at the 'dirty' end of the clean room.

14.4 **General Rules for Operation.** The following are general rules which should be enforced to assist in the successful operation of clean rooms.

14.4.1 Personal Activities

(a) Hands should be washed often and fingernails kept clean.

(b) The specified clothing should always be worn in the approved manner.

(c) Personal items such as keys, coins, cigarettes, matches, pencils, handkerchiefs and combs should be deposited in lockers prior to changing into clean room garments. Valuable items such as wallets may be carried into a clean room in jacket or trouser pockets provided they are not removed inside the clean room.

(d) Foodstuff should not be taken into a clean room.

(e) Smoking is strictly forbidden.

(f) The wearing of jewellery such as large rings, bracelets, watches, necklaces, earrings, lockets, etc., should be avoided.

(g) Nervous mannerisms such as scratching the head, rubbing of hands or similar actions should be avoided.

(h) Movement of personnel should be restricted as much as possible to prevent stirring settled particles on the clean room floor. This applies particularly to conventional clean rooms.

(j) Solvent contact with hands should be avoided as many solvents remove natural skin oils causing excessive skin 'peeling' or flaking.

(k) Female personnel should not wear or apply fingernail polish or cosmetics in a clean room.

(l) Visitors or clean room maintenance personnel must be authorised to enter a clean room and must follow the specified entry procedures.

14.4.2 Work Activities

(a) All tools including personal tool kits should be kept clean and in good condition and should undergo cleaning processes in accordance with a periodic cleaning schedule. Tools not essential to specific work processes should be excluded from tool kits.

(b) Paper materials should not be allowed in a clean room unless the paper is plastic-coated or covered, sprayed to prevent linting or is a special limited-linting paper. Papers should not be subjected to excessive shuffling, handling, rolling or bending as they can generate excessive amounts of small particles under these conditions.

(c) Pencils and erasers are not allowed. All writing should be with ball-point pens.

(d) Parts of components should be kept in their individual containers until ready for assembly. They should not be left exposed on a work bench or station.

(e) Containers and any component parts surplus to requirements should always be returned to a parts cleaning area for cleaning and re-issue.

(f) Metal objects such as wire clippings and solder splashes should be deposited in waste boxes at the end of each process.

(g) Where cleaning of parts is to be carried out inside a clean room, the type of cleaning equipment and its location within the room should be carefully selected.

15 MAINTENANCE OF CLEAN ROOMS In order to maintain clean rooms to the necessary standards, good housekeeping practices and monitoring of the air handling system are of prime importance. The frequency of cleaning is usually determined by taking into account the change in contamination level that can occur due to the cleaning operation, and the number of air changes per hour. Monitoring of the air handling system should be carried out at the time a clean room is put into initial operation and at regular periods thereafter, when filters have been changed, and when it is evident that down-grading of its operating level is taking place (see Table 3).

TABLE 3

Controlled Environment	Sampling for Particulate Contamination	Temperature	Humidity	Air Pressure
Class 1	Daily or continuous by automatic equipment	Continuous	Continuous	Continuous
Class 2	Weekly	Continuous	Continuous	Continuous
Class 3	Monthly	4-hourly	4-hourly	Continuous
Class 4	3-monthly	12-hourly	12-hourly	Continuous
Contained Work Station	Daily or to suit the product or as Class 2	Dependent on use		Not applicable
Controlled Area	Dependent on use	To meet requirements of personnel and product		Not applicable

15.1 **Cleaning.** Rooms should be cleaned when no work processes are being performed. Minor dry floor and bench vacuuming can be done, if necessary, during normal room operation if the equipment and procedures used ensure a minimum of disturbance to settled particles.

15.1.1 Cellulose mops and sponges can be used with water which meets specific particle-count requirements. High-grade plastics buckets which are not subject to flaking should be used. If ladders are required, they should preferably be of the anodised aluminium type. The use of detergents should be restricted to those which produce the minimum amount of residue after drying. For vacuum cleaning, a central vacuum cleaning system or a specially designed portable vacuum cleaner should be employed.

15.1.2 Cleaning apparatus and utensils are prevalent sources of contamination and their movement in and out of clean rooms should be carefully scheduled. They should be thoroughly cleaned and vacuumed prior to their entry.

15.1.3 The responsibility for cleaning work benches or stations should be delegated to personnel assigned to the benches to prevent improper handling of components and equipment by room maintenance personnel.

15.1.4 Inspection, maintenance and testing of air handling system components should be carried out in accordance with the relevant maintenance instructions, at periods determined by the type of clean room operations, and when downgrading of the contamination level begins to occur.

15.2 **Monitoring of Clean Rooms.** Monitoring refers to the procedures adopted for checking the factors influencing clean room environment. Such factors are the level of contamination, temperature, humidity and pressure. The exact requirements for monitoring and methods to be employed depend on the type of clean room and classification of cleanliness level, and are therefore determined on an individual basis (see Table 3).

15.2.1 **Contamination Monitoring.** This is the most difficult monitoring problem of clean room operation owing to the variations in contamination level throughout a room and also to the many factors which must be considered in selecting a specific monitoring technique. Some of the factors causing variations in contamination level are: filtered air entering a room at one or more locations; contamination being generated in various amounts throughout a room; contaminated air exhausted from a room at one or more locations. The highest level of contamination is not necessarily at the air exhaust locations, since air from a highly contaminated area may be diluted with filtered air prior to its being exhausted. Higher and lower levels of contamination can thus readily exist within a given room. The areas of most concern are those immediately surrounding the component on which work processes are to be carried out.

(a) The locations within a clean room at which sampling of the air is to be taken should be carefully considered in order to obtain a representative contamination level. Samples should be taken at identical times or as near as possible, since contamination levels of areas vary at different periods.

(b) Various techniques may be applied to contamination monitoring and some of those most widely accepted, together with details of principles, are listed in BS 5295 Parts 1, 2 and 3.

15.2.2 **Humidity Monitoring.** This may be achieved by the use of conventional wet and dry bulb thermometers and psychrometric charts. The thermometers may be supplemented, if necessary, by automatic recording devices. Humidity can become troublesome if it is allowed to reach a level where static charges are generated by personnel or where corrosion may be a problem. In general, a humidity level of not less than 40% is desired. For those components where humidity tolerance is critical, special control measures should be employed.

15.2.3 **Pressure Monitoring.** A clean room should always be slightly pressurised and it is therefore necessary to monitor the pressure difference between the room and its outside surroundings. Monitoring may be achieved by a simple U-tube manometer, or a differential pressure gauge calibrated in mm water gauge.

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BASIC

AIRWORTHINESS PROCEDURES

CONDITIONED MONITORED MAINTENANCE

1 INTRODUCTION

1.1 This Leaflet gives general information on the concepts and practices of aircraft maintenance control by the use of Condition Monitored Maintenance, and is derived directly from Civil Aviation Publication CAP 418. Definitions of the terms and abbreviations used in this Leaflet are given in paragraph 5.

NOTE: Defined terms are given an initial capital letter in the text.

1.2 Confidence in continued airworthiness has long been based on the traditional method of maintaining safety margins by the prescription of fixed component lives and by aircraft 'strip-down' policies. The call for changes to the basic philosophy of aircraft maintenance has been greatly influenced by the present day economic state of the industry as well as by changes in aircraft design philosophy allied to progress in engineering technology. These changes have, in turn, resulted in the necessity for the management and control of expensive engineering activities to take a new and more effective form.

1.3 It is from this background that a maintenance process known as Condition Monitoring has evolved. Condition Monitoring is not a separate activity but a complete process which cannot be separated from the complete maintenance programme. It is not just an identification of a single maintenance action but is a basic maintenance philosophy.

1.4 Maximum use can be made of the Condition Monitoring process (which includes a statistical reliability element, see paragraph 3.3), when it is applied to aircraft meeting the following criteria:—

(a) Modern, multi-engined, Transport Category aircraft which incorporate in their design safeguards against the complete loss of the function which a system is intended to perform.

NOTE: These safeguards are provided by the provision of either Active Redundancy or Standby Redundancy. In simple terms the safeguards take the form of more than one means of accomplishing a given function. Systems (or functions within systems) beyond those necessary for immediate requirements are installed. These are so designed that with an Active Redundancy philosophy all the redundant Items are operating simultaneously and, in simple terms, sharing the load to meet the demand. Thus in the event of failure of one of the redundant Items, the demand will continue to be met by the remaining serviceable redundant Items; this process continues up to the extent of the Redundancy provided. The extent of the Redundancy provided, within practical limits, is related to the consequences of complete loss of the system function. (The term 'multiplicity of system function' is sometimes used in this context.) With a Standby Redundancy philosophy only one redundant system is functioning at a time. If a function loss occurs, it is necessary to select (or activate) the functions provided by the 'standby" system(s). The principle is the same as for Active Redundancy and the term 'system redundancy' is sometimes used in this context.

(b) Aircraft for which the initial scheduled maintenance programme has been specified by a Maintenance Review Board and to which a Maintenance Steering Group Logic Analysis* has been applied.

NOTE: For an aircraft type introduced into service by Maintenance Review Board and Maintenance Steering Group procedures and where Condition Monitoring tasks are prescribed, a Condition Monitored Maintenance Programme (the Programme) will have to be established, even for a single aircraft.

1.5 Items which are not directly controlled by Condition Monitoring may be maintained by the traditional Hard Time or On-Condition processes, but the statistical reliability element of Condition Monitoring may, nevertheless, be applied for the purpose of monitoring their performance (but not be prescribed in the Maintenance Schedule as a primary maintenance process).

NOTE: For a statistical reliability element of a programme to be effectively used, a fleet minimum of five aircraft is normally necessary, but this can vary dependent upon the aircraft type and utilisation.

1.6 Further information on the maintenance of aircraft is given in Leaflet **BL/1-8.**

2 PRIMARY MAINTENANCE

2.1 The CAA recognises three primary maintenance processes. They are Hard Time, On-Condition and Condition Monitoring. In general terms, Hard Time and On-Condition both involve actions directly concerned with preventing failure, whereas Condition Monitoring does not. However the Condition Monitoring process is such that any need for subsequent preventative actions would be generated from the process.

2.2 The Processes

2.2.1 **Hard Time.** This is a preventative process in which known deterioration of an Item is limited to an acceptable level by the maintenance actions which are carried out at periods related to time in service (e.g. calendar time, number of cycles, number of landings). The prescribed actions normally include Servicing and such other actions as Overhaul, Partial Overhaul, Replacement, in accordance with instructions in the relevant manuals so that the Item concerned is either replaced or restored to such a condition that it can be released for service for a further specified period.

2.2.2 **On Condition.** This also is a preventative process but one in which the Item is inspected or tested, at specified periods, to an appropriate standard in order to determine whether it can continue in service (such an inspection or test may reveal a need for Servicing actions). The fundamental purpose of On-Condition is to remove an Item before its failure in service. It is not a philosophy of 'fit until failure' or 'fit and forget it'.

2.2.3 **Condition Monitoring.** This is not a preventative process, having neither Hard Time nor On-Condition elements, but one in which information on Items gained from operational experience is collected, analysed and interpreted on a continuing basis as a means of implementing corrective procedures.

2.3 Where a Maintenance Steering Group Logic Analysis has not been applied to a particular aircraft to establish and allocate the primary maintenance processes for each Item, the considerations of (a), (b) and (c) will be applied separately to all Items to determine the acceptability of the primary maintenance process.

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*Should fuller details of the current Maintenance Steering Group process, or the process used in respect of a specific aircraft be required, these would have to be obtained from the regulatory authority responsible for the initial certification of that aircraft, or responsible for any subsequent Maintenance Review Board revisions employing a logic process.

(a) **Hard Time**

(i) Where the failure of the Item has a direct adverse effect on airworthiness and where evidence indicates that the Item is subject to wear or deterioration.

(ii) Where there is a Hidden Function which cannot be checked with the Item in-situ.

(iii) Where wear or deterioration exists to such an extent as to make a time limit economically desirable.

(iv) Where component condition or 'life' progression sampling is practised.

(v) Where limitations are prescribed in a Manufacturer's Warranty.

(b) **On-Condition.** Where an inspection or test of an Item to a prescribed standard (frequently in-situ) will determine the extent of deterioration, and hence the 'condition', i.e. any reduction in failure resistance.

(c) **Condition Monitoring.** Where a failure of an Item does not have a direct adverse effect on operating safety, and where (a) and (b) are not prescribed and no adverse age reliability relationship has been identified as the result of analysis of the data arising from a formalised monitoring procedure or programme.

3 CONDITION MONITORED MAINTENANCE

3.1 **Introduction.** Condition Monitored Maintenance, as a programme, is the formalised application of the maintenance processes Hard Time, On-Condition and Condition Monitoring to specific Items as prescribed in the Approved Maintenance Schedule. The controlling activity of Condition Monitored Maintenance is Condition Monitoring irrespective of whether Condition Monitoring is prescribed as a primary maintenance process in the Approved Maintenance Schedule or not. Condition Monitoring is repetitive and continuous, the key factor in its use being the introduction of aircraft embodying failure tolerant designs, which allow for replacement of some traditional failure preventative maintenance techniques by non-preventative techniques. Condition Monitoring is not a relaxation of maintenance standards or of airworthiness control; it is, in fact, more demanding of both management and engineering capabilities than the traditional preventative maintenance approaches. Each Condition Monitored Maintenance Programme is required to be approved by the CAA.

3.2 Maintenance Activities

3.2.1 There are three types of maintenance activity:—

(a) Maintenance applied at specified periods of time regardless of condition at that time. The maintenance activity may be a periodic overhaul, a bearing change, re-work, repaint, calibration, lubrication, etc. These result from Hard Time requirements.

(b) Periodic examinations, mostly at specified periods of time, but sometimes on an opportunity basis (e.g. when an Item is removed for access) to determine not only the extent of deterioration but also that the deterioration is within specified limits. These result from On-Condition requirements.

(c) Actions applied in response to the analysis of condition clues produced by monitoring in-flight, hangar, workshop and other types of condition information sources. These result from Condition Monitoring requirements.

3.2.2 Condition Monitoring uses data on failures as items of 'condition' information which are evaluated to establish a necessity for the production or variation of Hard Time and On-Condition requirements, or for other corrective actions to be prescribed. Failure rates and effects are analysed to establish the need for corrective actions. Condition Monitoring can be used in its own right to identify the effects of deterioration, in order that steps may be taken to maintain the level of reliability inherent in the design of the Item. Although Condition Monitoring accepts that failures will occur, it is necessary to be selective in its application. The acceptance of failures may be governed by the relative unimportance of the function, or by the fact that the function is safeguarded by system Redundancy.

3.2.3 Maintenance of a particular Item could well be some combination of the three primary maintenance processes (Hard Time, On-Condition and Condition Monitoring). There is no hierarchy of the three processes; they are applied to the various Items according to need and feasibility. Maintenance Schedules which are based on the Maintenance Steering Group principles will have Hard Time, On-Condition, or Condition Monitoring specified as the primary maintenance process for specific systems and sub-systems as well as for individual Maintenance Significant Items. Condition Monitoring can, therefore, be the primary maintenance process prescribed for an Item, in which case it has also to be used for controlling the availability of those functions which are not directly controlled by a prescribed On-Condition or Hard Time process; this control is provided by the statistical reliability element of Condition Monitored Maintenance. Items for which Hard Time and On-Condition are prescribed may, however, have the statistical reliability element of Condition Monitored Maintenance applied, not as a primary maintenance process, but as a form of Quality Surveillance.

3.3 Statistical Reliability Element

3.3.1 The assessment of defect/removal/failure rate trend, of age bands at which Items fail, or the probability of survival to a given life are, in most cases, used to measure the effect or suitability of the primary maintenance processes applied to Items. The assessment is made by examination of rates of occurrence of events such as in-flight defects, incidents, delays, use of Redundancy capability, engine unscheduled shut-downs, air turn-backs, etc., which are reported in accordance with the procedure associated with the reliability element of Condition Monitored Maintenance.

3.3.2 A statistical reliability programme, as an element of Condition Monitoring, is, in practical terms, the continuous monitoring, recording and analysing of the functioning and condition of aircraft components and systems. The results are then measured or compared against established normal behaviour levels so that the need for corrective action may be assessed and, where necessary, taken.

3.4 The Condition Monitored Maintenance Programme

3.4.1 A maintenance programme which provides for the application of Hard Time, On-Condition and Condition Monitoring is known as a Condition Monitored Maintenance Programme. A Programme has two basic functions. Firstly, by means of the statistical reliability element, to provide a summary of aircraft fleet reliability and thus reflect the effectiveness of the way in which maintenance is being done. Secondly, to provide significant and timely technical information by which improvement of reliability may be achieved through changes to the Programme or to the practices for implementing it.

3.4.2 A properly managed Programme will contribute not only to continuing airworthiness, but also to improvement of fleet reliability, to better long-term planning, and to reduced overall costs.

3.4.3 The fundamental factors of a successful Programme are the manner in which it is organised and the continuous monitoring of it by responsible personnel. Because of differences in the size and structure of the various airlines, the organisational side of any Programme is individual to each operator. Hence, it is necessary to detail the organisation and responsibilities in the Programme control documentation.

3.5 Programme Control Committee

3.5.1 Every Programme is required to have a controlling body (usually known as the Reliability Control Committee) which is responsible for the implementation, decision making and day-to-day running of the Programme. It is essential that the Reliability Control Committee should ensure that the Programme establishes not only close co-operation between all relevant departments and personnel within the Operator's own Organisation, but also liaison with other appropriate Organisations. Lines of communication are to be defined and fully understood by all concerned. The Programme objectives and a typical Organisation and Data Flow Chart are shown in Appendix A.

3.5.2 The Reliability Control Committee is responsible for, and will have full authority to take, the necessary actions to implement the objectives and processes defined in the Programme. It is normal for the Quality Manager or the Engineering Manager to head the Committee and to be responsible to the CAA for the operation of the Programme.

3.5.3 The formation of the Committee and the titles of members will vary between Operators. The structure and detailed terms of reference of the Committee and its individual members will be fully set out in the documentation for each Programme. The Committee will usually comprise the Quality or Engineering Manager, the Reliability Engineer or Co-ordinator, the Chief Development Engineer, and the Chief Production Engineer.

3.5.4 The Committee should meet frequently to review the progress of the Programme and to discuss and, where necessary, resolve current problems. The Committee should also ascertain that appropriate action is being taken, not only in respect of normal running of the Programme, but also in respect of corrective actions.

3.5.5 Formal review meetings are held with the CAA at agreed intervals to assess the effectiveness of the Programme. An additional function of the formal review meeting is to consider the policy of, and any proposed changes to, the Programme.

3.6 Data Collection

3.6.1 Data (or more realistically, collected information) will vary in type according to the needs of each Programme. For example, those parts of the Programme based on data in respect of systems and sub-systems will utilise inputs from reports by pilots, reports on engine unscheduled shut-downs and also, perhaps, reports on mechanical delays and cancellations. Those parts of the Programme based on data in respect of components will generally rely upon inputs from reports on component unscheduled removals and on workshop reports. Some of the larger Programmes embrace both 'systems' and 'component' based data inputs in the fullest of detail.

3.6.2 The principle behind the data collection process is that the information to be collected has to be adequate to ensure that any adverse defect rate, trend, or apparent reduction in failure resistance, is quickly identified for specialised attention. Some aircraft systems will function acceptably after specific component or sub-system failures; reports on such failures in such systems will, nevertheless, act as a source of data which may be used as the basis of action either to prevent the recurrence of such failures, or to control the failure rates.

3.6.3 Typical sources of data are reports on delays, in-flight defects, authorised operaations with known defects (i.e. equipment inoperative at a level compatible with the Minimum Equipment List), flight incidents and accidents, air turn-backs; the findings of line, hangar and workshop investigations. Other typical sources include reports resulting from On-Condition tasks and in-flight monitoring (Airborne Integrated Data Systems); Service Bulletins; other Operators' experience, etc. The choice of a source of data, and the processes for data collection, sifting and presentation (either as individual events or as rates of occurrence) should be such as to permit adequate condition assessment to be made relative both to the individual event and to any trend.

3.6.4 Pilot Reports

(a) Pilot Reports, more usually known as "Pireps", are reports of occurrences and malfunctions entered in the aircraft Technical Log (see Leaflet **BL/1-8**) by the flight crew for each flight. Pireps are one of the most significant sources of information, since they are a result of operational monitoring by the crew and are thus a direct indication of aircraft reliability as experienced by the flight crew.

(b) It is usual for the Technical Log entries to be routed to the Reliability Section (or Engineer/Co-ordinator) at the end of each day, or at some other agreed interval, whereupon each entry is extracted and recorded as a count against the appropriate system. Pireps are thus monitored on a continuous basis, and at the end of the prescribed reporting period are calculated to a set base as a reliability statistic for comparison with the established Alert Levels (see paragraph 3.8) e.g. Pirep Rate per 1,000 hr, Number of Pireps per 100 departures, etc.

(c) Engine performance monitoring can also be covered by the Pirep process in a Programme. Flight crew monitoring of engine operating conditions is, in many Programmes, a source of data in the same way as reports on system malfunctions.

3.6.5 Engine Unscheduled Shut-downs

(a) These are flight crew reports of engine shut-downs and usually include details of the indications and symptoms prior to shut-down. When analysed, these reports provide an overall measure of propulsion system reliability, particularly when coupled with the investigations and records of engine unscheduled removals.

(b) As with Pireps, reports on engine unscheduled shut-downs are calculated to a set base and produced as a reliability statistic at the end of each reporting period. The causes of shut-downs are investigated on a continuing basis, and the findings are routed via the Reliability Section to the Power-plant Development Engineer.

3.6.6 **Aircraft Mechanical Delays and Cancellations**

(a) These are normally daily reports, made by the Operator's line maintenance staff, of delays and cancellations resulting from mechanical defects. Normally each report gives the cause of delay and clearly identifies the system or component in which the defect occurred. The details of any corrective action taken and the period of the delay are also included.

(b) The reports are monitored by the Reliability Section and are classified (usually in Air Transport Association of America, Specification 100 (ATA 100) Chapter sequence), recorded and passed to the appropriate engineering staffs for analysis. At prescribed periods, recorded delays and cancellations for each system are plotted, usually as events per 100 departures.

3.6.7 **Component Unscheduled Removals and Confirmed Failures.** At the end of the prescribed reporting period the unscheduled removals and/or confirmed failure rates for each component are calculated to a base of 1,000 hours flying, or, where relevant, to some other base related to component running hours, cycles, landings, etc.

NOTE: Reports on engine unscheduled removals, as with reports on engine performance monitoring, are also a source of data and are reported as part of the Programme.

(a) **Component Unscheduled Removals.** Every component unscheduled removal is reported to the section which monitors reliability (the 'Reliability Section') and will normally include the following information:

(i) Identification of component.

(ii) Precise reason for removal.

(iii) Aircraft registration and component location.

(iv) Date and airframe hours/running hours/landings, etc. at removal.

(v) Component hours since new/repair/overhaul/calibration.

Completed reports are routed daily to the Reliability Section for recording and for continuous monitoring for significant trends and arisings. Components exhibiting abnormal behaviour patterns are brought to the attention of the engineering staff responsible, so that detailed investigations may be made and corrective action may be taken.

(b) **Component Confirmed Failures**

(i) With the exception of self-evident cases, each unscheduled removal report is followed up by a workshop report in which the reported malfunction or defect is confirmed or denied. The report is routed to the Reliability Section. Workshop reports may be compiled from an Operator's own 'in-house' findings and/or from details supplied by component repair/overhaul contractors.

(ii) Where an unscheduled removal is justified the workshop reports will normally include details of the cause of the malfunction or defect, the corrective action taken and, where relevant, a list of replacement items. Many Programmes utilise the same type of report to highlight structural and general aircraft defects found during routine maintenance checks.

3.6.8 **Miscellaneous Reports.** Dependent upon the formation of individual Programmes, a variety of additional reports may be produced on a routine or non-routine basis. Such reports could range from formal minutes of reliability meetings to reports on the sample stripping of components, and also include special reports which have been requested during the investigation of any item which has been highlighted by the Programme displays and reports.

3 7 **Statistical Reliability Measurement.** To assist in the assessment of reliability, Alert Levels are established for the Items which are to be controlled by the Programme. The most commonly used data and units of measurement (Pireps per 1,000 hours, Component Removals/Failures per 1,000 hours, Delays/Cancellations per 100 departures, etc.) have been mentioned in paragraph 3.6. Too much importance should not be placed upon the choice of units of measurement, provided that they are constant throughout the time the Programme runs and are appropriate to the type and frequency of the event. The choice of units of measurement will depend on the type of operation, the preference of the Operator and those required by the equipment manufacturer.

3.8 Reliability Alert Levels

3.8.1 A reliability alert level (or equivalent title, e.g. Performance Standard, Control Level, Reliability Index, Upper Limit) hereinafter referred to as an 'Alert Level', is purely an 'indicator' which when exceeded indicates that there has been an apparent deterioration in the normal behaviour pattern of the Item with which it is associated. When an Alert Level is exceeded the appropriate action has to be taken. It is important to realise that Alert Levels are not minimum acceptable airworthiness levels. When Alert Levels are based on a representative period of safe operation (during which failures may well have occurred) they may be considered as a form of protection against erosion of the design aims of the aircraft in terms of system function availability. In the case of a system designed to a multiple Redundancy philosophy it has been a common misunderstanding that, as Redundancy exists, an increase in failure rate can always be tolerated without corrective action being taken.

3.8.2 Alert Levels can range from 0·00 failure rate per 1,000 hours both for important components and, where failures in service have been extremely rare, to perhaps as many as 70 Pireps per 1,000 hours on a systems basis for ATA 100 Chapter 25—Equipment/Furnishings, or for 20 removals of passenger entertainment units in a like period.

3.8.3 Establishing Alert Levels

(a) Alert Levels should, where possible, be based on the number of events which have occurred during a representative period of safe operation of the aircraft fleet. They should be up-dated periodically to reflect operating experience, product improvement, changes in procedures, etc.

(b) When establishing Alert Levels based on operating experience, the normal period of operation taken is between two and three years dependent on fleet size and utilisation. The Alert Levels will usually be so calculated as to be appropriate to events recorded in one-monthly or three-monthly periods of operation. Large fleets will generate sufficient significant information much sooner than small fleets.

(c) Where there is insufficient operating experience, or when a programme for a new aircraft type is being established, the following approaches may be used.

(i) For a new aircraft type during the first two years of operation all malfunctions should be considered significant and should be investigated, and although Alert Levels may not be in use, Programme data will still be accumulated for future use.

(ii) For an established aircraft type with a new Operator, the experience of other Operators may be utilised until the new Operator has himself accumulated a sufficient period of his own experience. Alternatively, experience gained from operation of a similar aircraft model may be used.

(iii) A recent concept to be applied in setting Alert Levels for the latest aircraft aircraft designs, is to use computed values based on the degree of system and component in-service expected reliability assumed in the design of the aircraft. These computed values are normally quoted in terms of Mean Time Between Unscheduled Removal (MTBUR) or Mean Time Between Failure (MTBF) for both individual components and complete systems. Although these levels tend to be theoretical, they are, of course, based on a considerable amount of testing and environmental engineering and design analysis. Being purely initial predictions they should be replaced when sufficient in-service experience has been accumulated.

(d) There are several recognised methods of calculating Alert Levels, any one of which may be used provided that the method chosen is fully defined in the Operator's Programme documentation.

(e) Typical acceptable procedures for establishing Alert Levels are described briefly in paragraphs (i) to (iii), and some detailed examples of the methods of calculation are shown in Appendix B. It will be seen that the resultant Alert Levels can vary according to the method of calculation, but this need not necessarily be considered to be of significance.

(i) **Pilot Reports (Pireps).** For the following example calculations, a minimum of twelve-months' operating data has to be available, and the resultant Alert Level per 1,000 hours is:

Calculation 1. The three-monthly running average Pirep rate per 1,000 hours for each system (or sub-system), as in the Table of Example 1, is averaged over the sample operating period and is known as the Mean; the Mean is multiplied by 1·30 to produce the Level Alert for the given system. This is sometimes known as the '1·3 Mean' or '1·3$\bar{x}$' method.

Calculation 2. The Mean, as in Calculation 1, plus 3 Standard Deviations of the Mean (as illustrated in Appendix B—Example 1).

Calculation 3. The Mean, as in Calculation 1, plus the Standard Deviation of the 'Mean of the Means', plus 3 Standard Deviations of the Mean (as illustrated in Appendix B—Example 2).

(ii) **Component Unscheduled Removals.** For the following example calculations, a minimum period of seven quarters' (21 months') operating data has to be available, and the resultant Alert Level rate for the current quarter may be set in accordance with any one of the following:

Calculation 4. The Mean of the individual quarterly Component Unscheduled Removal rates for the period of seven quarters, plus 2 Standard Deviations of the Mean.

Calculation 5. The maximum acceptable number of 'Expected Component Unscheduled Removals' in a given quarter, as calculated using a statistical process in association with the Poisson Distribution of Cumulative Probabilities (as illustrated in Appendix B—Example 3).

Calculation 6. The Number of 'predicted Component Unscheduled Removals (or failures)' in a given quarter, as determined by the Weibull or other suitable statistical method.

(iii) **Component Confirmed Failures.** The period of operating experience has to be as in (ii) and the resultant Alert Level rate for the current quarter is the 'corrected' Mean of the individual quarterly Component Confirmed Failure rates for the period, plus 1 Standard Deviation of the Mean (as illustrated in Appendix B—Example 4).

3.9 Re-calculation of Alert Levels

(a) Both the method used for establishing an Alert Level, and the associated qualifying period, apply also when the level is re-calculated to reflect current operating experience. However, if, during the periods between re-calculation of Alert Levels, a significant change in the reliability of an Item is experienced which may be related to the introduction of a known action (e.g. modification, changes in maintenance or operating procedures) then the Alert Level applicable to the Item would be re-assessed and revised on the data subsequent to the change.

(b) All changes in Alert Levels are normally required to be approved by the CAA and the procedures, periods and conditions for re-calculation are required to be defined in each Programme.

3.10 Programme Information Displays and Reports

3.10.1 **General.** As soon as possible after the end of each defined reporting period of a Programme, the Operator is required to produce graphical and/or tabular displays. These displays have to reflect the fleet operating experience for the period under review. The compilation and production of these displays from the day-to-day records has to be such that the essential information for each Item is an accordance with the requirements of the Programme.

3.10.2 The main purpose of displaying the information is to provide the Operator and the CAA with an indication of aircraft fleet reliability in such a manner that the necessity for corrective actions may be assessed. The format, frequency of preparation and the distribution of displays and reports are fully detailed in the Programme documentation. Typical data displays are described in paragraphs 3.10.3 to 3.10.9 and some examples are illustrated in Appendix C.

3.10.3 **Fleet Reliability Summary.** This display (see Appendix C, Figure C1), which is related to all aircraft of the same type in the fleet, is usually produced in tabular form, and should contain the following minimum information for the defined reporting period:

(a) Number of aircraft in fleet.
(b) Number of aircraft in service.
(c) Number of operating days (less checks).
(d) Total number of flying hours.
(e) Average daily utilisation per aircraft.
(f) Average flight duration.
(g) Total number of landings.
(h) Total number of delays/cancellations.
(j) Technical Incidents.

3.10.4 **Aircraft Mechanical Delays/Cancellations.** The purpose of this type of display is to indicate the aircraft systems which have caused delay to or cancellation of flights as a result of mechanical malfunctions. It is normal for each display to show the delays/cancellations as a total for all systems (to represent fleet overall reliability, as in Appendix C, Figure C2) as well as separately for the individual systems. The displays for the separate systems will usually show the delay/cancellation rate for the defined reporting period, the three-monthly moving average rate and, where appropriate, the Alert Level, and will present the information for a minimum period of 12 months.

3.10.5 **Engine Unscheduled Shut-downs.** This display (see Appendix C, Figure C3) is the prime indication of engine in-service reliability and also, to a large degree, of total power-plant reliability. Because of the high level of reliability of engines and the consequently relatively low numbers of unscheduled shut-downs per fleet, both the actual number of shut-downs and the shut-down rate per 1,000 hours for the defined reporting period as a three monthly running average, shown as a graphical display, will provide useful information in addition to that of Appendix C, Figure C3. To be of most use, where dealing with small numbers of unscheduled shut-downs, it is usual to present both types of information in such a way as to show the trend over a two-to-three-year period.

3.10.6 **Engine Unscheduled Removals.** This display is the supporting primary indication of engine reliability and is usually presented in a similar manner to unscheduled shut-downs. Many Operators show scheduled and unscheduled engine removals and unscheduled shut-downs on the same display; this is purely a matter of preference (see Appendix C, Figure C3).

3.10.7 **Pilot Reports (Pireps).** Pireps are presented by system or sub-system (normally identified in accordance with the classifications in ATA 100) in graphical and/or tabular form as a count, or rate, per 1,000 flight hours or 100 departures for the defined reporting period, for comparison with the Alert Level (see Appendix C, Figure C5). Occasionally some Programmes include a Pirep presentation of Fleet Pilot Reports (see Appendix C, Figure C4). This presentation shows the total number of Pireps for all systems and sub-systems and thus gives an overall picture of the total Pireps for the fleet of one aircraft type.

3.10.8 **Component Unscheduled Removals and Confirmed Failures**

(a) There are various methods of displaying component information (both graphically and tabular). The display may be on the basis of each individual component which has been prematurely removed (see Appendix C, Figure C6), or on the basis of the total number of affected components per system (see Appendix C, Figure C7). Experience has shown that a tabular presentation of unscheduled removals and confirmed failures on an individual component basis, preferably giving both numbers and rates per 1,000 hours, of the defined reporting period is the most useful.

(b) The format of any display of component information should be such that:

(i) Both unscheduled removals and confirmed failure rates may be compared with the Alert Levels so as to identify when the Levels are likely to be exceeded.

(ii) Current and past periods of operation may be compared.

3.10.9 **Workshop Reports.** A summary of the results of defect investigations, based on the Workshop Reports (see Appendix C, Figure C8) is normally produced by component type for assessment by the Reliability Committee.

3.11 **Problem Identification.** Having collected the information, and having presented it in a timely manner it should now be possible to identify any problems and to assess the necessity for corrective actions. The information, having been sifted and categorised (normally in ATA 100 Chapter order) as individual events and/or rates of occurrence, can be analysed using engineering and/or statistical methods. The analysis can be made at various stages in the handling of the data to differing degrees. Initially, reports on flight defects, delay causes, engine unscheduled shut-downs, workshop and hangar findings, other operators' experience, etc., should be analysed individually to see if any immediate action is desirable. This initial individual analysis will highlight any need for immediate short term actions, e.g. the preparation of Mandatory Occurrence Reports, safety reports, fleet campaigns, with the long term corrective actions following after the later, collective, stages of analysis.

3.12 **Corrective Action**

3.12.1 The effectiveness of corrective action will normally be monitored by the very process which revealed the need for it—the Condition Monitoring process.

3.12.2 Corrective actions taken to improve the reliability of systems and components, and ultimately that of the fleet, will vary considerably and may typically include one or more of the following:

(a) Changes in operational procedures or improvements in fault-finding techniques.

(b) Changes to the scope and frequency of maintenance processes which may involve Servicing and inspection, system Tests or Checks, Overhaul, Partial Overhaul or bench testing or the introduction or variation of time limits, etc.

(c) Modification action.

(d) Non-routine inspections or adjustment.

(e) Change of materials, fuels and lubricants.

(f) Use of different repair agencies.

(g) Use of different sources of spares.

(h) Variations of storage conditions.

(j) Improvements in standards of staff training and technical literature.

(k) Amendments to the policy/procedures of the Programme.

3.13 **Threshold Sampling**

3.13.1 Threshold sampling is the process whereby a maintenance limitation prescribed in the Maintenance Schedule (e.g. Hard Time) is varied in the light of experience gained from any source (e.g. scheduled and unscheduled maintenance, unscheduled removals). The prescribed maintenance limitation is the 'threshold upper limit', and, dependent upon the experience gained, can be either substantiated or varied. Maintenance activities (e.g. time for removal, extent of restoration) are normally related to actual experience of the Item in service (known as 'the experience age band'). When it is considered that the prescribed maintenance activity may be varied, threshold sampling may be used as a means of establishing confidence in the proposal. If when the threshold upper limit is reached, the condition of the Item is such that a variation is justified, then a new threshold upper limit may be set.

3.13.2 In setting the number of samples and any other qualifying conditions, both engineering assessment of the design and service experience are taken into account. Evidence derived from other activities (e.g. unscheduled removals or removals scheduled for other purposes) will supplement scheduled sampling and the removal itself may, if representative, be substituted for a scheduled sampling removal.

3.13.3 When the optimum period for a particular workshop activity has been determined, threshold sampling will be discontinued and a Hard Time limitation for workshop activity (e.g. Overhaul) will be prescribed.

3.13.4 A typical example of the use of threshold sampling is the control of the 'release for service' periods of certain gas-turbine engines, where some of the units on the engines are subject to individual Hard Time limitations (e.g. turbine disc lives, refurbishing intervals). These individual limitations are, in most cases, established and varied by the process described in paragraphs 3.13.1 to 3.13.3. The outcome is that the engine release period for installation in the aircraft is then fixed by the expiration of the lowest unit Hard Time limitation.

3.14 Quality Management

3.14.1 With the major issues of airworthiness and the economical allocation of vast sums of money being involved, it is essential that Quality Control should be applied as an overall control of the Maintenance Programme. Each Programme will describe the managerial responsibilities and procedures for continuous monitoring of the Programme at progressive and fixed periods. Reviews, to assess the effectiveness of the Programme, will also be prescribed.

3.14.2 There are various methods, both engineering and statistical, by which the effectiveness of the Programme may be evaluated, and these include:

(a) An assessment of the Programme Document (see paragraph 4) and any subsequent amendment (e.g. with a view to possible extra activities).

(b) Surveillance of the Programme activities by the Quality Management Departments

(c) Review by the Programme Control Committee to confirm that corrective action taken are correctly related to the performance trends and to the reports produced.

NOTE: Generally there would be two levels of committee activity, functional and managerial; the functional activity covering the practicality of corrective actions, and the managerial activity covering the overall Quality management of the Programme.

(d) Assessment of reports on incidents and accidents, as these could be potential criticisms of the effectiveness of the Programme.

3.15 **Review of the Programme.** It is normal for each Operator to review the effectiveness of his Programme, in conjunction with the CAA, at annual intervals. At this review consideration will be given to any proposed major changes in the Programme structure and policy so as to obtain the optimum benefits from the operation of the Programme.

4 THE PROGRAMME DOCUMENT

4.1 **Approval.** Approval of the Programme (as identified by the 'Document') will depend on the results of an assessment as to whet~~her or~~ not the stated objectives can be achieved. The approval of the Document then becomes a recognition of the potential ability of the Organisation to achieve the stated objectives of the Programme.

NOTE: The Quality Department of the Organisation, together with the CAA, monitors both the performance of the Programme in practice as well as its continuing effectiveness in achieving the stated objectives.

4.2 **Essential Qualities of the Programme.** Condition Monitored Maintenance Programmes can vary from the very simple to the very complex, and thus it is impractical to describe their content in detail. However, the Document has to be such that the considerations in (a) to (j) are adequately covered.

(a) It generates a precise, specific and logical Quality assessment by the Operator of the ability of the Organisation to achieve the stated objectives.

(b) It enables the CAA initially to accept, and, with subsequent continued monitoring, to have confidence in, the ability of the Organisation to such an extent that the CAA can renew Certificates of Airworthiness, approve changes to the maintenance schedules, etc., in accordance with evidence showing that the objectives of the Programme are being achieved.

(c) It ensures that the Operator provides himself with Quality management of his Organisation.

(d) It provides the Operator with a basis for the discharge of his moral and legal obligations in respect of the operation of aircraft.

(e) It enables the CAA (as the Airworthiness Authority) to discharge its duties and legal obligations in respect of the maintenance aspects of airworthiness, and, where applicable, to delegate certain tasks to the Operator.

(f) The manner of presentation has to be acceptable to the CAA.

(g) With (a) to (f) in mind, it states the objectives of the Programme as precisely as is possible, e.g. "maintenance of designated components by reliability management in place of routine overhaul", "Condition Monitoring as a primary maintenance process".

(h) The depth of description of the details of the Programme is such that:
  (i) The details can be understood by a technically qualified person.
  (ii) Those factors which require formal CAA acceptance of any changes are clearly indicated.
  (iii) All significant non-self-evident terms are defined.

(j) In respect of individuals or departments within the Organisation:
  (i) the responsibility for the management of the Document, and
  (ii) the procedures for revision of the Document, are clearly stated.

4.3 **Compliance with BCAR**

(a) The Document is required to contain at least the information prescribed in BCAR, Section A, Chapter **A6-4**.

(b) The Document may either be physically contained within the Approved Maintenance Schedule, or be identified in the Approved Maintenance Schedule by reference and issue number, in such a manner that the Approved Maintenance Schedule could be deemed to contain it by specific statement and cross-reference.

4.4 **Assessment of Programme Document.** The following questions (not necessarily definitive) may assist in making a preliminary assessment of the adequacy of the Programme Document:

(a) Is the Document to be physically contained within the Approved Maintenance Schedule? If it is to be a separate document, is it satisfactorily linked with, and identified within the Approved Maintenance Schedule?

(b) Are the objectives of the Programme clearly defined? e.g. 'Maintenance of designated Items by reliability management in place of routine overhaul', 'Confidence assessment of overhaul periods', 'Condition monitoring as a primary maintenance process', 'Airworthiness/economic Quality management of maintenance'.

(c) Does the Approved Maintenance Schedule clearly state to which Items the Programme is applicable?

(d) Is there a glossary of terms associated with the Programme?

(e) What types of data are to be collected? How? By whom? When? How is this information to be sifted, grouped, transmitted and displayed?

(f) What reports/displays are provided? By whom? To whom? When? How soon following data collection? How are delays in publishing controlled?

(g) How is all information and data analysed and interpreted to identify aircraft actual and potential condition? By whom? When?

(h) Is there provision within the Organisation for implementation of corrective actions and is this identified within the Document? How are implementation time periods, effects and time for effect manifestation provided for?

(j) Is there a requirement that the Approved Maintenance Schedule be amended, and is the method of doing so included in the Programme, e.g. variation of time limitations, additional checks?

(k) Is there a requirement that Maintenance Manuals be amended and is the method of doing so included in the Programme, e.g. maintenance practices, tools and equipment, materials?

(l) Is there a requirement that the Operations Manual/Crew Manual be amended, and is the method of doing so included in the Programme, e.g. crew drills, check lists, defect reporting?

(m) What provision is made for corrective action follow-up and for checks on compliance with original intention, e.g. those which are not working out in practice, spares provisioning, timetables for the incorporation of modifications?

(n) Who is responsible for the management of the Document?

(o) Is there a diagram of the relationship between the departments and groups concerned with the Programme and does it show the flow of Condition Monitoring data, its handling and the prescribed reaction to it?

(p) Are all of the departments involved in the Programme included and are there any responsibilities not allocated?

(q) What Quality management processes are contained within the Programme in respect of:

   (i) Responsibility for the Document itself and the procedure for its amendment?

   (ii) Monitoring of the performance of the Programme by statistical reliability and other methods?

   (iii) Committee consideration of Programme implementation and monitoring of performance?

   (iv) Consideration of reports on incidents and accidents and other events which can effect airworthiness?

   (v) Programme management and discipline?

5 DEFINED TERMS AND ABBREVIATIONS

5.1 **Introduction.** Those terms and abbreviations in the text which have a specific meaning are defined in this paragraph 5.

5.2 Terms and Abbreviations

5.2.1 **Analysis.** The MSG Logic Analysis.

5.2.2 **ATA 100.** Air Transport Association of America, Specification 100.

5.2.3 **Check.** An examination to determine the functional capability or physical integrity of an item.

5.2.4 **Condition Monitoring.** A primary maintenance process under which data on the whole population of specified items in service is analysed to indicate whether some allocation of technical resources is required. Not a preventive maintenance process, condition monitored maintenance allows failures to occur, and relies upon analysis of operating experience information to indicate the need for appropriate action.

NOTE: Failure modes of condition monitored items do not have a direct adverse effect on operating safety.

5.2.5 **Document.** The Condition Monitored Maintenance Programme document.

5.2.6 **Failure Mode.** The way in which the failure of an item occurs.

5.2.7 **Hard Time Limit.** A maximum interval for performing maintenance tasks. This interval can apply to Overhaul of an Item, and also to removal following the expiration of life of an Item.

5.2.8 **Hidden Function.** An Item is considered to have a "hidden function" if either of the following is applicable:

(a) The Item has a function which is normally active whenever the system is in use, but there is no indication to the flight crew when that function ceases.

(b) The Item has a function which is normally inactive, but there is no prior indication to the flight crew that the function will not be available when required.

5.2.9 **Item.** Any level of hardware assembly (i.e. part, sub-system, system, accessory, component, unit, material, portion of structure, etc.).

5.2.10 **Maintenance Significant Items.** Maintenance items that are judged to be relatively the most important from a safety, reliability or economic stand-point.

5.2.11 **Minimum Equipment List.** An approved list of items which may be inoperative for flight under specified conditions.

5.2.12 **On-Condition/On-Condition Maintenance.** A primary maintenance process having repetitive inspections or tests to determine the condition of units, systems, or portions of structure with regard to continued serviceability (corrective action is taken when required by item condition).

5.2.13 **Overhaul.** The restoration of an item in accordance with the instructions defined in the relevant manual.

5.2.14 **Partial Overhaul.** The overhaul of a sub-assembly of an item with a time controlled overhaul to permit the longer-lifed item to achieve its authorised overhaul life.

5.2.15 **Pireps.** Pilot Reports.

5.2.16 **Programme.** Condition Monitored Maintenance Programme.

5.2.17 **Quality.** The totality of features and characteristics of a product or service that bear on its ability to satisfy a given need.

5.2.18 **Quality Control.** A system of programming and co-ordinating the efforts of the various groups in an organisation to maintain or improve quality, at an economical level which allows for customer satisfaction.

5.2.19 **Quality Surveillance.** Supervision by the customer, his representative, or an independent organisation of a contractor's quality control organisation and methods.

5.2.20 **Redundancy.** The existence of more than one means of accomplishing a given function. Each means of accomplishing the function need not necessarily be identical.

5.2.21 **Redundancy, Active.** That redundancy wherein all redundant items are operating simultaneously rather than being activated when needed.

5.2.22 **Redundancy, Standby.** That redundancy wherein the alternative means of performing the function is inoperative until needed and is activated upon failure of the primary means of performing the function.

5.2.23 **Replace.** The action whereby an item is removed and another item is installed in its place for any reason.

5.2.24 **Scheduled Maintenance.** That maintenance performed at defined intervals to retain an item in a serviceable condition by systematic inspection, detection, replacement of wearout items, adjustment, calibration, cleaning, etc. Also known as "Preventative Maintenance" and "Routine Maintenance".

5.2.25 **Servicing.** The replenishment of consumables needed to keep an item or aircraft in operating condition.

5.2.26 **Test.** An examination of an item in order to ensure that the item meets specified requirements.

APPENDIX A

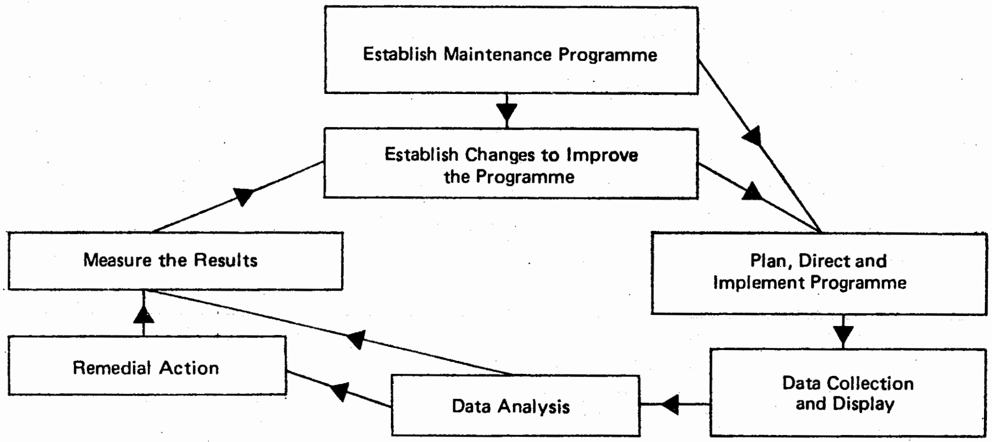

Figure A1 PROGRAMME OBJECTIVES

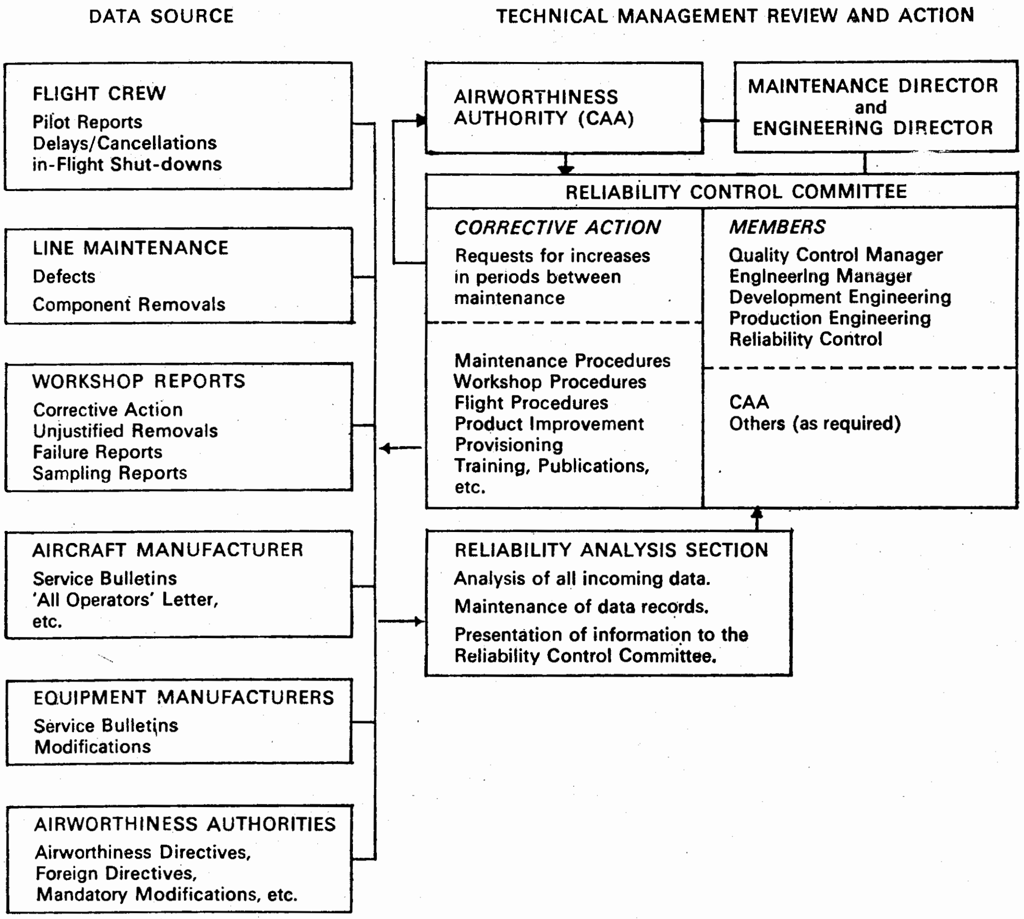

Figure A2 TYPICAL ORGANISATION AND DATA FLOW CHART

APPENDIX B—ALERT LEVEL CALCULATIONS

Example 1—Pilot Reports (Pireps) by Aircraft System per 1,000 Flight Hours

Method: Alert Level per 1,000 flight hours = Mean of the 3 monthly Running Average 'Pirep' Rates per 1,000 flight hours (for past 12 months) plus 3 Standard Deviations.

System: Aircraft Fuel System (ATA 100, Chapter 28)

Month	Pireps (monthly)	Pireps (3 months cumulative totals)	Flight Hours (monthly)	Flight Hours (3 months cumulative totals)	Pirep Rate per 1,000 hr (3 months running average) (x)
Nov	42	—	2,400	—	—
Dec	31	—	2,320	—	—
Jan	58	131	2,350	7,070	18
Feb	46	135	2,300	6,970	19
Mar	58	162	2,560	7,210	22
Apr	26	130	2,600	7,460	17
May	42	126	2,750	7,910	16
Jun	65	133	3,100	8,450	16
Jul	78	185	2,880	8,730	21
Aug	74	217	2,700	8,680	25
Sep	58	210	3,000	8,580	24
Oct	54	186	2,650	8,350	22
Nov	35	147	2,610	8,260	18
Dec	46	135	2,330	7,590	18

N(months) = 12

Σ = Totals

	(x)	$(x-\bar{x})$	$(x-\bar{x})^2$
	18	−2	4
	19	−1	1
	22	2	4
	17	−3	9
	16	−4	16
	16	−4	16
	21	1	1
	25	5	25
	24	4	16
	22	2	4
	18	−2	4
	18	−2	4
Σx =	236	$\Sigma(x-\bar{x})^2$ =	104

$$\text{MEAN}(\bar{x}) = \frac{\Sigma x}{N} = \frac{236}{12} = 19{\cdot}67 \text{ (rounded to 20)}$$

$$\text{STANDARD DEVIATION (SD)} = \sqrt{\frac{\Sigma(x-\bar{x})^2}{N}} = \sqrt{\frac{104}{12}} = \sqrt{8{\cdot}67} = 2{\cdot}94$$

3 SD = 8·82 (rounded to 9)

ALERT LEVEL = Mean + 3 SD = 20 + 9 = $\underline{\underline{29}}$

Example 2—Pilot Reports (Pireps) by Aircraft System per 1,000 Flight Hours

Method: Alert Level per 1,000 flight hours=The Mean (as in Example 1), plus the Standard Deviation of the 'Mean of the Means', plus 3 Standard Deviations of the Mean.

Data as in Example 1

System: Aircraft Fuel System (ATA 100, Chapter 28)

Pirep Rate per 1,000 hr—3 months running Av. (x)	Mean of x (X)	Difference of X from $\overline{X}$ (D)	(D^2)
18	18·5	1·3	1·69
19	20·5	0·7	0·49
22	19·5	0·3	0·09
17	16·5	3·3	10·69
16	16·0	3·8	14·44
16	18·5	1·3	1·69
21	23·0	3·2	10·24
25	24·5	4·7	22·09
24	23·0	3·2	10·24
22	20·0	0·2	0·04
18	18·0	1·7	2·89
18			
	218·0=ΣX	23·7=ΣD	74·79= Σ(D^2)

N (months) now = 11 and thus $\overline{X}$ (the mean of the means) will $= \frac{\Sigma X}{N} = \frac{218}{11} = \underline{19{\cdot}8}$

Σ = Totals

STANDARD DEVIATION OF MEAN OF MEANS

$$= \sqrt{\frac{\Sigma(D^2)}{N} - \left(\frac{\Sigma D}{N}\right)^2} = \sqrt{\frac{74{\cdot}79}{11} - \left(\frac{23{\cdot}7}{11}\right)^2}$$

$$= \sqrt{6{\cdot}80 - 4{\cdot}64} \qquad = \underline{1{\cdot}47}$$

Therefore ALERT LEVEL=MEAN ($\bar{x}$) + STANDARD DEVIATION OF MEAN OF MEANS ($\overline{X}$) + 3 SD

=19·67 (as in Example 1) +1·47+8·82 (as in Example 1)

=29·96 (rounded to 30)

Example 3—Component Unscheduled Removals by Individual Components in a Three-Monthly Period

Method: Alert Level = 95% cumulative probability of the Poisson Distribution based on past 21 months experience* to provide an Alert Level for use as a three-monthly period of comparison.

(a) **Component: Auto-pilot Pitch Amplifier**

number of components per aircraft,	$n = 1$
number of unscheduled removals in past 21 months,	$N = 62$
fleet utilisation hours in past 21 months,	$H = 36840$
number of component running hours in past 21 months,	$T = (n \times H) = 36840$
fleet utilisation hours in current 3 months,	$h = 5895$
number of component running hours in current 3 months,	$t = (n \times h) = 5895$
number of unscheduled removals in current 3 months,	$x = 12$

Mean unscheduled removal rate, $\lambda = \frac{N}{T} = 0{\cdot}00168$

Expected number of unscheduled removals in current 3 months

$$= \lambda t$$
$$= 0{\cdot}00168 \times 5895$$
$$= 9{\cdot}9 \text{ (rounded to 10)}$$

Referring to Figure B1 by entering the graph at $\lambda t = 10$ the intersection with 0·95 (95% probability) gives the maximum acceptable number of unscheduled component removals (A value) for the 3 month period as 15.

By comparing the current value of $x = 12$ one can see that an 'alert' situation does not exist for this component.

(b) **Component: Temperature Control Valve**

$n = 3$, $N = 31$, $H = 36840$, $T = 3 \times 36840 = 110520$, $h = 5895$,
$t = 3 \times 5895 = 17685$, $x = 9$

$\lambda = \frac{31}{110520} = 0{\cdot}00028$, $\lambda t = 0{\cdot}00028 \times 17685 = 5{\cdot}01$ (rounded to 5)

from graph, acceptable A value = 8. Current value of $x = 9$, therefore Alert Level is exceeded.

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*For large fleets the past twelve months experience may be used with a one-monthly period of comparison.

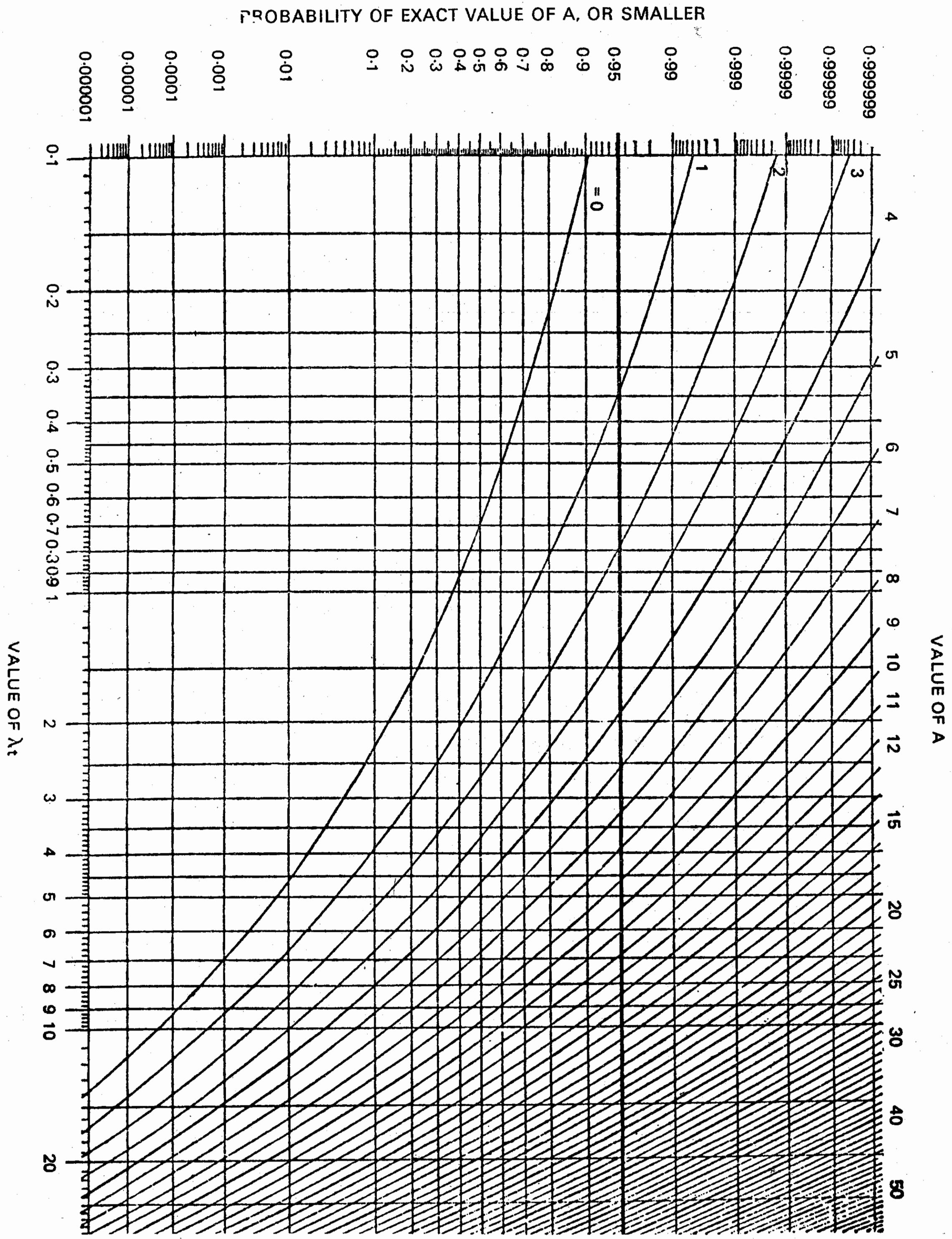


Figure B1 POISSON CUMULATIVE PROBABILITIES

Example 4—Component Confirmed Failures by Individual Components in a Three-Monthly Period

Method: Alert Level = The 'corrected' Mean of the Quarterly Failure Rates plus 1 Standard Deviation of this mean, based on past seven calendar quarters of confirmed component failure rates per 1,000 hours to provide an Alert Level for use as a quarterly period of comparison.

Component: Main Generator

Calendar Quarter	Quarterly Failure Rate (u)	Corrected Rate (C)	(C^2)
2/74	0·21	0·63*	0·397
3/74	3·38	0·38	0·144
4/74	0·42	0·42	0·176
1/75	0·84	0·84	0·706
2/75	0·59	0·59	0·348
3/75	0·57	0·57	0·325
4/75	1·38	0·63*	0·397
	4·39Σ(u)	4·06Σ(C)	2·493$\Sigma(C^2)$

N (months) = 7

Σ = Totals

$$\text{QUARTERLY MEAN FAILURE RATE} = \frac{\Sigma(u)}{N} = \frac{4{\cdot}39}{7} = 0{\cdot}63$$

$$\text{CORRECTED MEAN FAILURE RATE } \bar{C} = \frac{\Sigma C}{N} = \frac{4{\cdot}06}{7} = \underline{0{\cdot}58}$$

$$\text{STANDARD DEVIATION, SD} = \sqrt{\frac{\Sigma(C^2) - \frac{(\Sigma C)^2}{N}}{N - 1}}$$

$$= \sqrt{\frac{2{\cdot}493 - \frac{(4{\cdot}06)^2}{7}}{6}}$$

$$= \sqrt{\frac{2{\cdot}493 - 2{\cdot}355}{6}}$$

$$= \underline{0{\cdot}15}$$

$$\text{ALERT LEVEL} = \bar{C} + 1\,\text{SD} = 0{\cdot}58 + 0{\cdot}15 = \underline{0{\cdot}73}$$

***Where an individual Quarterly Failure Rate falls outside plus or minus 50% of the uncorrected Quarterly Mean Failure Rate (0·63 in this case), then this Mean is to be used as a Corrected Rate in place of the uncorrected Quarterly Failure Rate.**

APPENDIX C—TYPICAL DATA DISPLAYS

AIRCRAFT TYPE:		1976	1977												ACCUM TOTALS
			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
NUMBER OF AIRCRAFT IN FLEET		6	6	6	6	6	6	6							6
NUMBER OF AIRCRAFT IN SERVICE		6	5	5	5	6	6	6							6
NO OF OPERATING DAYS (less checks)		1634	153	144	152	160	186	174							969
FLYING HOURS (hr:min)	Revenue —	13400:39	907	801	1068	1374	1571	1798							7519
	Non Revenue —	39:38	5	4	8	3	0:5	1							21:5
	Training —	97:24	—	24	25	32	12:5	1							94:5
	TOTAL	13537:41	912	828	1102	1409	1584	1800							7635
DAILY UTILIZATION (average/aircraft) (hr:min)		8:17	5:57	5:45	7:15	8:48	8:31	10:20							7:52
AVERAGE FLIGHT DURATION (hr:min)		2:32	2:52	2:43	2:42	2:36	2:23	2:23							2:36
LANDINGS	Revenue —	5277	316	293	395	528	658	752							2942
	Non Revenue —	45	5	2	2	5	2	3							19
	Training —	275	3	55	100	104	34	4							300
	TOTAL	5597	324	350	497	637	694	759							3261
TECHNICAL DELAYS — REVENUE (more than 15 mins)	Number of Movements —	5277	316	293	395	528	658	752							2942
	Number of delays —	134	8	6	9	17	13	16							69
	Total Delay Time —	310·32	38	13	9	27	22	33							142
	Average Delay (%)	2·54	2·53	2·04	2·27	3·22	1·97	2·12							2·35
TECHNICAL CANCELLATIONS		—	—	—	—	—	—	—							—
TECHNICAL INCIDENTS	Interrupted Flights —	7	Nil	Nil	Nil	Nil	Nil	Nil							Nil
	Engine Shut Downs —	Nil	Nil	Nil	Nil	Nil	Nil	Nil							Nil
	Fire Warnings —	Nil	Nil	Nil	Nil	Nil	Nil	Nil							Nil
	Fire Warnings (false) —	Nil	Nil	Nil	Nil	Nil	Nil	Nil							Nil
	Fuel Dumpings —	Nil	Nil	Nil	Nil	Nil	Nil	Nil							Nil
REMARKS															

Figure C1: FLEET RELIABILITY SUMMARY

AIRCRAFT TYPE:	1976	1977											
%	Average	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
5													
4													
3		3·80											
2			2·65										
1	1·73			1·98									

BASE	NO. OF MOVEMENTS			NO. OF TECH. DELAYS			TOTAL DELAY TIME (hr:min)			AVERAGE DELAY (%)			REMARKS
	JAN	FEB	MAR	JAN	FEB	MAR	JAN	FEB	MAR	JAN	FEB	MAR	
Gatwick	171	159	174	9	4	4*	9:50	7:20	11:35	5·26	2·34	2·29	*1 Overseas
Manchester	44	46	17	1	3	0	0:30	2:51	—	2·27	6·52	—	
Berlin	127	59	111	3	—	2	13:19	—	4:21	2·36	—	1·80	
TOTALS	342	264	302	13	7	6	23:39	10:11	15:56	3·80	2·65	1·98	

AIRCRAFT TYPE: ENGINE TYPE:			1976	1977												ACCUM TOTALS 1977	PREVIOUS 12 MONTHS TOTALS
				JAN	FEB	MAR	APR	MAY	JUNE	JUL	AUG	SEP	OCT	NOV	DEC		
		Total Engine Hours	40613	2735	2486	3306	4227	4752	5400							22906	45149
UNSCHEDULED REMOVAL		Total Unscheduled Removals	4	—	—	—	—	—	—							2	4
		Rate per 1000 Eng. Hours	0·10	—	—	—	—	0·21	0·18							0·08	0·08
	REASON	Failure	4	—	—	—	—	1	1							2	4
		Suspect Failure	—	—	—	—	—	—	—							—	—
		External Causes	—	—	—	—	—	—	—							—	—
	INVEST'N RESULTS	Basic Engine Failure	2	—	—	—	—	—	—							1	2
		Non Basic Engine Failure	—	—	—	—	—	—	—							—	—
		Unsubstantiated	1	—	—	—	—	—	—							1	2
	FOLLOW UP ACTION	Rectification	3	—	—	—	—	1	—							1	3
		H.S.I.*	—	—	—	—	—	—	—							—	—
		Overhaul	—	—	—	—	—	—	1							1	1
SCHEDULED REMOVAL		Total Scheduled Removals	4	2	2	1	1	—	—							6	7
		H.S.I.* Time Expired	1	2	—	—	—	—	—							2	2
		Time Expired — Overhaul —	3	—	2†	1	1	—	—							3	5
		H.S.I.* Approved Life	5500	5500	5500	5500	5500	5500	5500							5500	5500
		Overhaul Approved Life	10500	10500	10500	10500	10500	10500	10500							10500	10500
UNSCHEDULED ENGINE SHUT-DOWN		Total Number	Nil	Nil	Nil	Nil	Nil	Nil	Nil							Nil	Nil
		Rate per 1,000 Hours	Nil	Nil	Nil	Nil	Nil	Nil	Nil							Nil	Nil
		Accumulative Rate	Nil	Nil	Nil	Nil	Nil	Nil	Nil							Nil	Nil

† 1 removed for disc mod

*Hot Section Inspection

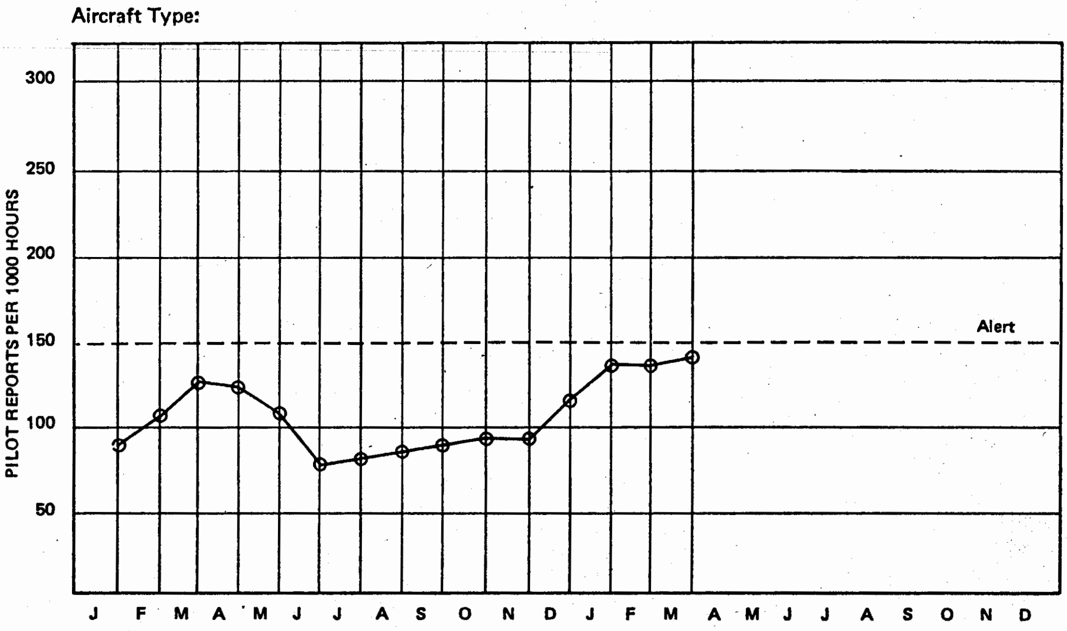


Figure C4 FLEET PILOT REPORTS

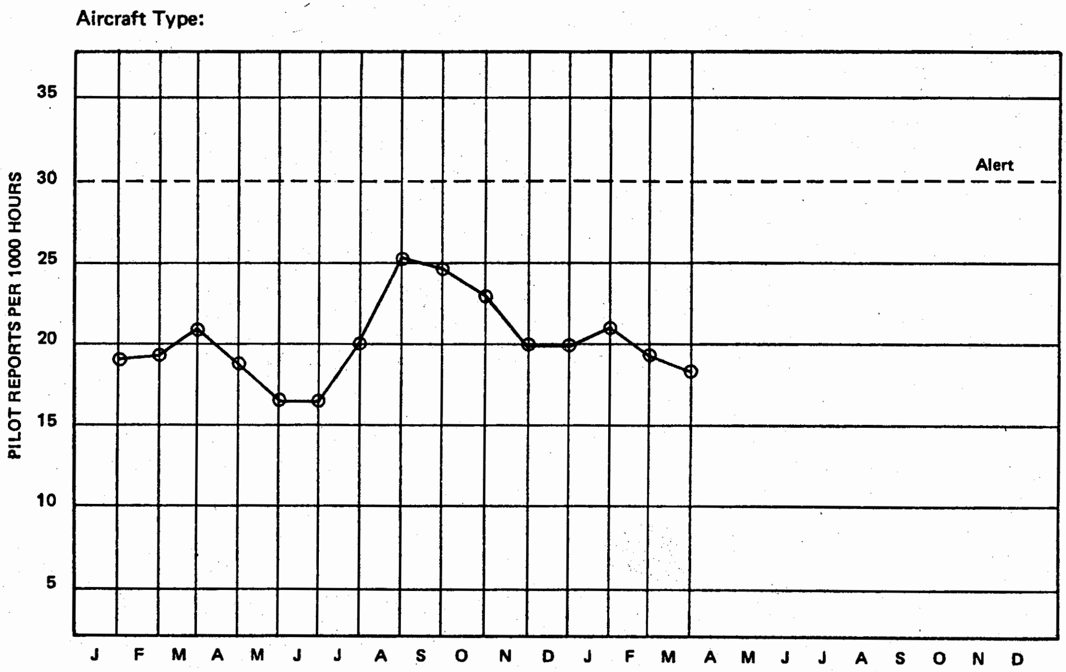


Figure C5 PILOT REPORTS ATA 21—AIR CONDITIONING SYSTEM

AIRCRAFT TYPE:
Air Conditioning/Pressurization (ATA 100. Chapter 21)

SCH. REF.	PART NUMBER	NO PER A/O	COMPONENT / FLYING HOURS	13408			2495							ALERT LEVEL	ACCUMULATIVE COMPONENT CONFIRMED FAILURES SINCE 1.1.74		
			PERIOD	1975			1st Qtr 1976										
				A*	B*	C*	A*	B*	C*		A*	B*	C*		A*	B*	MTBF†
30/4	131046-1	1	Manual Pressure Controller	—	—	—	2	0·80	—	X*				—	2	0·06	16000
30/5	102518-3-1	1	Auto Cabin Pressure Controller	4	0·29		—	—	—					0·60	9	0·28	3555
30/6	10-3280-5-1	2	Cabin Outflow Valve	9	0·26	2	1	—	1					0·50	9	0·14	7110
51/1	178040-2-1	4	Heat Exchanger	3	0·05		—	—	—					0·15	5	0·04	25601
51/2	204050-10-1	2	Air Cycle Machine	2	0·07		—	—	—					0·30	4	0·06	16000
51/5	129150-2-1	2	35° Thermostat Pack Anti-icing	1	0·03		—	—	—					0·30	1	0·015	64020
51/6	321674-3-1	2	Valve — Pack Shut-Off	5	0·11	2	—	—	—					0·30	5	0·08	12800
52/2	541248-2-1	2	Actuator — Ram Air	1	0·03		—	—	—					0·30	2	0·03	32000
52/7	207562-1	2	Fan Cooling Pack	2	0·07		—	—	—					0·30	8	0·13	8000
58/3	18801-5	1	Detector — Air Flow Sensor	—	—	—	—	—	—					—	1	0·03	32000
61/1	321402-1-1	2	Valve/Actuator — Control Mix	—	—	—	1	0·20	—					0·30	5	0·08	12809
61/2	548376-5	1	Controller — Air Temp	1	0·07		—	—	—					0·60	2	0·06	16000
61/9	67321-10-190	3	Temperature Sensor	—	—	—	—	—	—					0·15	1	0·01	96061
62/2	163BL501	2	Indicator — Pack Temp.	—	—	—	—	—	—					0·30	1	0·015	64020
30/7	132322-2-1	1	Fan Venturi	2	0·14		1	0·40	—					0·60	4	0·13	8000
61/3	548392-1-1	2	Cabin Temp. Sensor	1	0·03		—	—	—					0·30	1	0·015	64020
42/1	32-2684-002	1	Cargo Outflow Valve	—	—	—	1	0·40	—					0·60	2	0·06	16000
58/8	123266-2-1/ 123544.1.1	2	Hot Air Check Valve	—	—	—	1	0·20	—					0·30	1	0·015	6402
23/1	500702-4620	2	Gasper Fan	—	—	—	—	—	—					0·60	4	0·06	16000
51/3	178050-2-1	2	Water Separator	—	—	—	—	—	—					0·60	2	0·03	32001
51/4	10-60506-4	2	35° Valve Pack Anti-icing Cont	—	—	—	—	—	—					0·30	—	—	—

*A — No. of unscheduled removals
*B — Failure Rate per 1,000 hours
*C — Non-confirmed Defects
*X — Failure Rate above Alert Level

†MTBF — Mean Time Between Failures

Figure C6 COMPONENT UNSCHEDULED REMOVALS AND CONFIRMED

AIRCRAFT TYPE:		JANUARY 1971			1970 FIRST HALF			1970 LAST HALF		
ATA 100 CHAPTER	ALERT LEVEL	UR*	URR†	FR‡	UR*	URR†	FR‡	UR*	URR†	FR‡
21 — Air Conditioning	·35	2	·53	·33	14	·34	·32	15	·36	·31
22 — Auto-pilot	·80	4	1·33	·33	16	·98	·29	19	·98	·32
23 — Communications	·92	2	·67	·48	10	·57	·48	8	·56	·37
24 — Electric Power	·20	2	·08	·02	8	·06	·02	9	·07	·03
27 — Flight Controls	·30	1	·20	·09	7	·12	·10	6	·10	·08
28 — Fuel	·23	0	·00	·00	2	·64	·30	1	·09	·06
29 — Hydraulic	·38	1	·42	·40	2	·26	·18	4	·46	·22
30 — Ice & Rain Protection	·15	0	·00	·00	2	·14	·08	2	·14	·08
31 — Instruments	·65	4	·63	·34	20	·61	·31	16	·57	·20
32 — Landing Gear	·33	1	·04	·02	7	·05	·03	9	·09	·04
34 — Navigation	·73	3	·66	·21	20	·69	·24	24	·71	·29
35 — Oxygen	·30	2	·66	·32	11	·65	·31	9	·64	·30
36 — Pneumatic	·20	0	·00	·00	2	·01	·01	4	·02	·02
38 — Water/Waste	·24	1	·09	·06	6	·16	·15	7	·17	·16
49 — APU	·48	1	·33	·32	7	·34	·34	4	·26	·29
73 — Engine Fuel & Control	·39	0	·00	·02	4	·10	·06	2	·06	·05
75 — Engine Air	·28	1	·17	·16	5	·16	·14	3	·12	·12
77 — Engine Indicating	·30	5	·42	·17	26	·46	·18	22	·44	·17
79 — Oil	·22	0	·00	·00	2	·04	·02	3	·06	·04
80 — Starting	·50	1	·17	·11	6	·18	·12	3	·09	·10

*UR — Unscheduled Removals

†URR — Unscheduled Removal Rate

‡FR — Confirmed Failure Rate (3 months cum. av.)

Figure C7 COMPONENT UNSCHEDULED REMOVALS

AIRCRAFT TYPE:

SERIAL NO.	AIRCRAFT & POSITION	HRS RUN	DEFECT	RESULTS OF WORKSHOP INVESTIGATION & ACTION TAKEN
1170109	G—	848 TSR* 9375 TSN†	Losing altitude in turns	Test wing levelling not operative; recalibrated.
0290329	G—	11110 TSR 16771 TSN	Rolls rapidly to right when heading hold engaged.	Various internal outputs were drifting and distorted. Replaced tacho, roll CT and resolver, servo amp and valve amplifier.
0920575	G—	99 TSR 4014 TSN	Altitude hold sloppy in turns.	Roll computer out of calibration limits. Mod D to Lateral Path Coupler embodied to improve interface between Sxxxx equipment and Cxxxx receiver.
1280330	G—	36 TSR 7664 TSN	A/C will not maintain heading — ends up with 30° bank.	No fault found but extensive investigation revealed A3A1A2B output 1·5V — should be zero volts.

CONCLUSIONS

All channel assemblies are now sent to Manufacturer for investigation.
Histories are reviewed and any channels which have previous 'NFF'‡ findings are being extensively tested to isolate components which may be drifting out of tolerance. This should result in improved MTBF§, but will probably show more confirmed failures for a while.

REMEDIAL ACTION

	REPORT REF. NO.	PART NO.	ITEM
22-10-14/20 Sheet 1 of 1	1Q75-22-2H	2588812-901	Roll channel assy.

* Time since repaired
† Time since new
‡ 'No fault found'
§ Mean Time Between Failures

BL/2-3

Issue 4.

24th February, 1971.

BASIC

IDENTIFICATION MARKING

BOLTS AND SCREWS OF BRITISH MANUFACTURE

1 INTRODUCTION This Leaflet gives guidance on the identification of bolts and screws complying with British Standards 'A' Series of Aircraft Materials and Components and the Society of British Aerospace Companies 'AS' series of specifications. The Leaflet does not include information on the 'AGS' series since these have been entirely superseded by other standards. Information on the manufacture and testing of bolts and screws will be found in British Standards A100 and A101, entitled "General Requirements for Bolts and Nuts of Tensile Strength not exceeding 180 000 lbf/in^2 (125 hbar)", and "General Requirements for Titanium Bolts", respectively.

1.1 The identification of bolts and screws located on aircraft may not always be an easy task since not all are marked to show the standard to which they conform. This Leaflet sets out to show the features from which positive identification may be made, but it should be understood that items exist, which although identical in appearance, may not be interchangeable. It is also important to understand the direction of stress in a particular bolt since a 'shear' bolt must not be used to replace a 'tension' bolt. If any doubt exists as to the identity of a particular item the appropriate Parts Catalogue should be consulted; replacement of an incorrect part may lead to failure in service.

1.2 It will be found that a number of Specifications are either obsolete or obsolescent, in some instances due to standardisation of a countersunk head of 100° included angle. The replacements are indicated in the tables.

1.3 Information on the identification of nuts of British manufacture is given in Leaflet **BL/2-6.**

1.4 A list of the abbreviations used in this Leaflet is given in paragraph 5.

2 BRITISH STANDARDS This paragraph is concerned with the identification of bolts and screws complying with the British Standards 'Aircraft' (A) series. For ease of reference the paragraph has been divided into two sections, paragraph 2.1 dealing with bolts and screws having either British Association (BA) or British Standard Fine (BSF) threads, and paragraph 2.2 dealing with bolts and screws having Unified threads.

2.1 **Bolts and Screws with BA or BSF Threads.** In this series, BSF threads are used on bolts of ¼ inch diameter and larger; smaller bolts and all screws have BA threads, except that grub screws are also supplied in ¼ inch BSF. BA sizes larger than 2 BA are not specified. Table 1 gives a list of the relevant Standards, superseding Standards and identification data appropriate to the series, and Figure 1 illustrates the types of head used. To find the Standard number of a given item proceed as follows:—
Identify the head from Figure 1, for example '(l)'. Reference to Table 1 shows that '(l)' refers to an A61 bolt. If the illustration applies to more than one specification, further information contained in the table, such as the type of finish, should enable the identification to be completed.

TABLE 1
BA AND BSF BOLTS AND SCREWS

Standard No.	*Description*	*Material*	*Finish*	*Head (Fig. 1)*	*Remarks*	*Thread*	*Normal Size Range*
A17	Hex. hd. bolt	Al Al	anodic	e or f	obsolescent	BA/BSF	6 BA to 1 in BSF
A25	Hex. hd. bolt	HTS	cad	a,b,c or d	replaces A15Y	BA/BSF	6 BA to 1 in BSF
A26	Hex. hd. bolt	CRS	nat	a	replaces A15Z	BA/BSF	6 BA to 1 in BSF
A28	Hex. hd. bolt	Al Al	anodic	g or h	obsolescent	BA/BSF	6 BA to 1 in BSF
A30	Hex. hd. c/t bolt	HTS	cad	i or j	cad h & t	BA/BSF	6 BA to 1 in BSF
A31	Cheese hd. screw	LTS	cad	o	replaces AGS 247	BA	12 BA to 2 BA
A32	Round hd. screw	LTS	cad	n	replaces AGS 245	BA	10 BA to 2 BA
A33	90° csk. hd. screw	LTS	cad	q	replaces AGS 249	BA	12 BA to 2 BA
A34	Raised csk. hd. screw	LTS	cad	p		BA	10 BA to 2 BA
A35	Cheese hd. screw	CRS	nat	o	replaces AGS 896	BA	12 BA to 2 BA
A36	Round hd. screw	CRS	nat	n	replaces AGS 967	BA	10 BA to 2 BA
A37	90° csk. hd. screw	CRS	nat	q	replaces AGS 968	BA	12 BA to 2 BA
A38	Raised csk. hd. screw	CRS	nat	p		BA	10 BA to 2 BA
A39	Cheese hd. screw	Al Al	anodic	o		BA	12 BA to 2 BA
A40	Round hd. screw	Al Al	anodic	n	replaces AGS 564	BA	10 BA to 2 BA
A41	90° csk. hd. screw	Al Al	anodic	q		BA	12 BA to 2 BA
A42	Raised csk. hd. screw	Al Al	anodic	p		BA	10 BA tp 2 BA
A43	Cheese hd. screw	Brass	tinned	o	replaces AGS 246	BA	12 BA to 2 BA
A44	Round hd. screw	Brass	tinned	n	replaces AGS 244	BA	10 BA to 2 BA
A45	90° csk. hd. screw	Brass	tinned	q	replaces AGS 248	BA	12 BA to 2 BA
A46	Raised csk. hd. screw	Brass	tinned	p		BA	10 BA to 2 BA
A55	Grub screw	FCS	cad	none		BA/BSF	6 BA to $\frac{1}{4}$ BSF
A56	Grub screw	CRS	nat	none		BA/BSF	6 BA to $\frac{1}{4}$ BSF
A57	Hex. hd. shear bolt	HTS	cad	k	cad h & t only	BSF	$\frac{1}{4}$ to $\frac{3}{4}$ in BSF
A59	Hex. hd. c/t bolt	HTS	cad	i		BA/BSF	6 BA to 1 in BSF
A60	Hex. hd. shear bolt	HTS	cad	k		BSF	$\frac{1}{4}$ to $\frac{3}{4}$ in BSF
A61	Hex. hd. bolt	Al Al	anodic	l or m	replaces A28	BA/BSF	6 BA to 1 in BSF

2.1.1 In some instances, e.g. A31 to A56 in Table 1, identification can only be effected from the finish applied (mechanical testing apart), or by the labelling on packages.

2.1.2 **Code Systems for Bolts.** The code system used for the identification of the bolts listed in Table 1 consists of the standard number followed by the part number of the particular bolt. The part number consists of a number indicating the nominal length of the plain portion of the shank in tenths of an inch, followed by a letter indicating the nominal diameter (Table 2). Example: The complete part reference number for a $\frac{3}{8}$ inch A57 bolt of length L = 3·1 inch is A57 31J.

TABLE 2
DIAMETER CODE LETTERS

Code	*Size*	*Code*	*Size*
A	6 BA	P	$\frac{9}{16}$ in BSF
B	4 BA	Q	$\frac{5}{8}$ in BSF
C	2 BA	S	$\frac{3}{4}$ in BSF
E	$\frac{1}{4}$ in BSF	U	$\frac{7}{8}$ in BSF
G	$\frac{5}{16}$ in BSF	W	1 in BSF
J	$\frac{3}{8}$ in BSF	X	12 BA
L	$\frac{7}{16}$ in BSF	Y	10 BA
N	$\frac{1}{2}$ in BSF	Z	8 BA

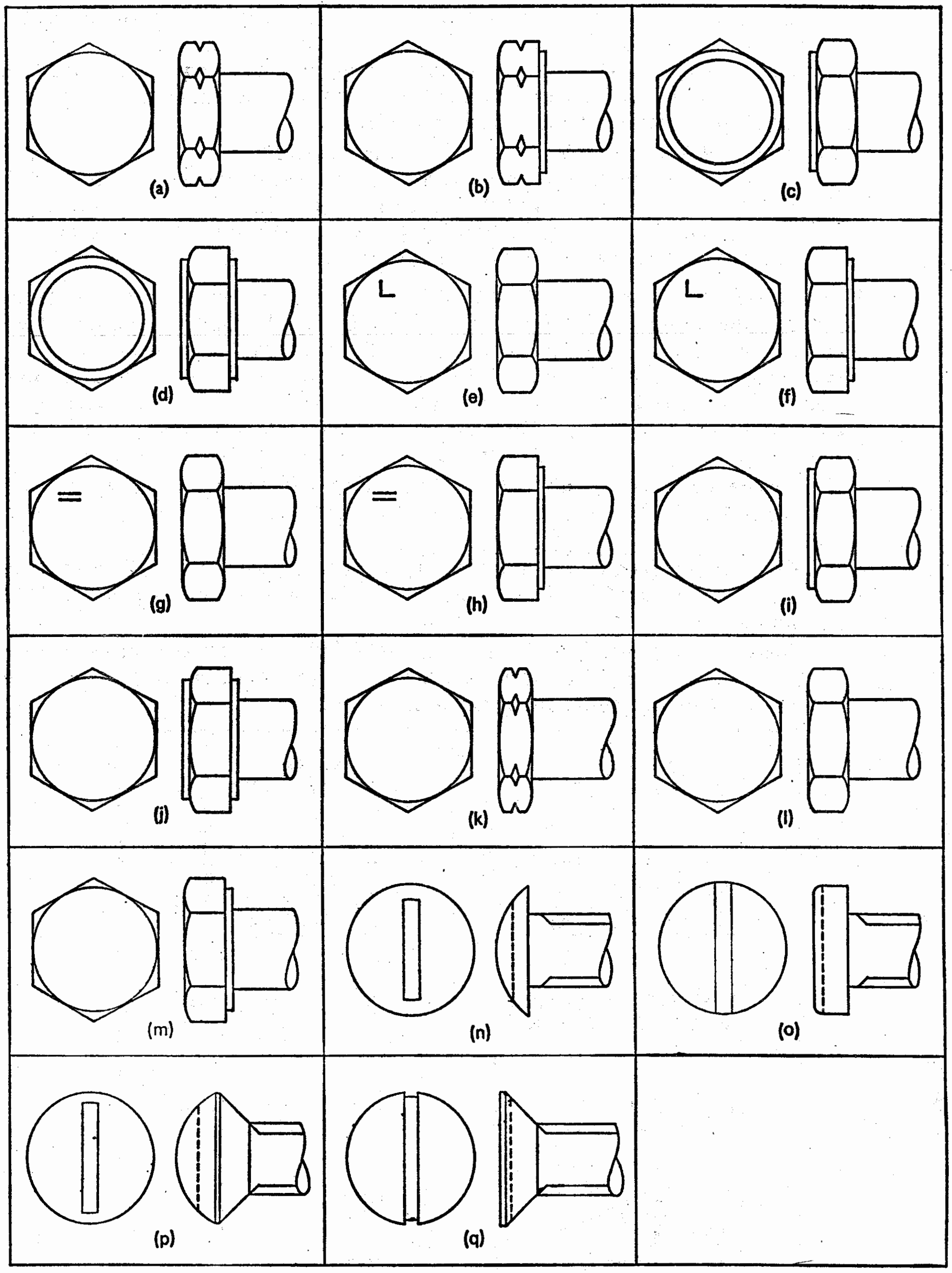


Figure 1 IDENTIFICATION OF BRITISH STANDARDS BA/BSF BOLTS AND SCREWS

(i) All bolts to British Standards A25, A26, A30, A57, A59, A60 and A61 of ¼ inch nominal diameter and over are marked with the appropriate British Standard on the upper face of the head. Additionally, bolts of $\frac{7}{16}$ inch nominal size and larger have the appropriate part number applied to the upper face of the head. Parcels of bolts have the number of the relevant British Standard and the appropriate part number clearly stated on the labels.

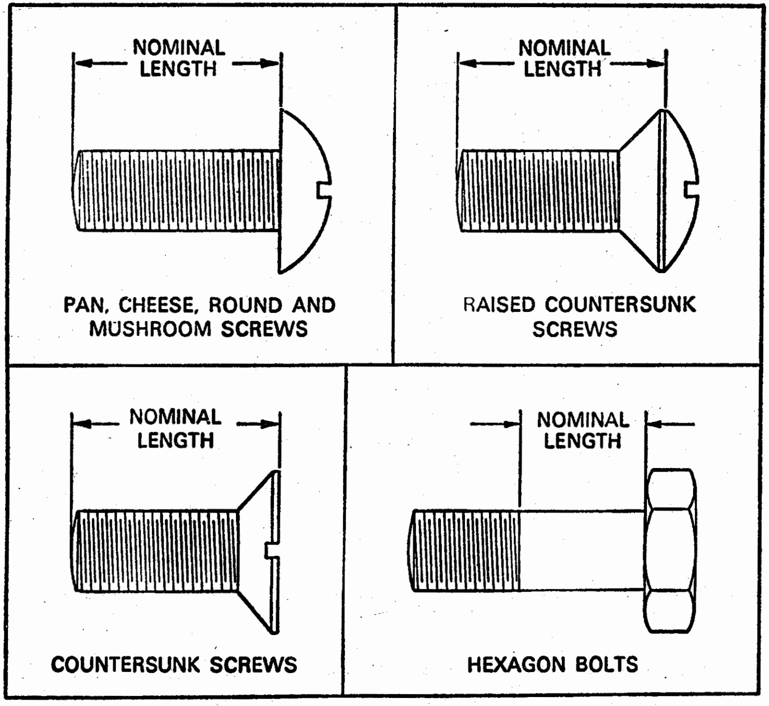
(ii) The positions at which the plain length is measured on hexagon bolts and the overall lengths on various types of screws are indicated in Figure 2. It should be noted that with BA and BSF bolts, the plain portion of the shank includes the thread 'run-out'. A 'washer face' (e.g. Figure 1 (b)) on the undersurface of a bolt head is not included in the plain length of the shank.

2.1.3 **Code System for Screws (A31 to A46).** The code system used for the identification of the screws listed in Table 1 consists of the British Standard number followed by the part number of the particular screw. The part number consists of a number indicating the nominal length of the screw (in thirty-seconds of an inch) when measured as described below (see also Figure 2) preceded by a letter indicating the nominal diameter (Table 2). Example: The complete part referencing number for a 2 BA A41 countersunk head aluminium alloy screw ½ inch long, is A41 C16.

(i) **Cheese and Round Heads.** The nominal length is the distance measured from the underside of the head to the extreme end of the shank, including any chamfer or radius.

(ii) **Countersunk Heads.** The nominal length is the distance measured from the upper surface of the head to the extreme end of the shank, including any chamfer or radius.

(iii) **Raised Countersunk Heads.** The nominal length is the distance measured from the upper surface of the head (excluding the raised portion) to the extreme end of the shank, including any chamfer or radius.



PAN, CHEESE, ROUND AND MUSHROOM SCREWS

RAISED COUNTERSUNK SCREWS

COUNTERSUNK SCREWS

HEXAGON BOLTS

Figure 2 LENGTH OF BA/BSF BOLTS AND ALL SCREWS

2.1.4 **Code System for Grub Screws Complying with A55-A56.** The code system used for these screws consists of the British Standard number followed by the part number of the particular screw. The part number consists of a number indicating the overall length of the screw in sixteenths of an inch, preceded by a letter indicating the nominal diameter. Example: The complete part referencing number for a ¼ inch diameter A55 screw, ½ inch long, would be A55 E8.

2.2 **Bolts and Screws Having Unified Threads.** Table 3 gives a list of current and obsolescent bolts and screws in the Unified range. Figure 3 illustrates the type of head used in this range and also shows the general 'Unified' symbols, including (h) the cylindrical extension (dog point) sometimes used on parts not having hexagon shaped heads. It will be noticed that there are several shapes of hexagon head; these are alternative methods of manufacture and do not necessarily provide a means of identification, although A108 and A111 bolts, which have close tolerance shanks, have a cylindrical extension on top of the head and shear bolts always have thin heads. Bolts and screws of similar shape may be further identified by the material; aluminium alloy is dyed green, high tensile steel is cadmium plated and corrosion resistant steel or brass are normally uncoated. When the British Standard number is not marked on the bolt head, identification should be made as follows:—

Identify the head from Figure 3, for example (g). Reference to Table 3 shows that the bolt could be an A113, A114 or A170. Complete identification is possible in this example from the type of finish; in other instances it may be derived from further information, such as diameter or thread length, contained in Table 3.

2.2.1 **Code System for Unified Bolts and Screws.** The code system used for the identification of the bolts and screws listed in Table 3 consists of the Standard number followed by the part number of the particular bolt. The diameter code shown in Table 4 is used on all parts but the measurement of length varies with different Standards as follows:—

(i) All bolts from A102 to A212 inclusive, nominal length in tenths of an inch followed by the diameter, e.g. an A102, 10-32 UNF bolt with plain length of one inch = A102-10D.

NOTE: Hexagon and mushroom head bolts are also supplied in lengths of 0·05 inch in some specifications, e.g. an A170-½D bolt has a plain length of 0·05 inch.

(ii) All screws from A204 to A221 inclusive, diameter followed by length in thirty seconds of an inch, e.g. a 4-40 UNC A217 screw 1 inch long = A217-A32.

(iii) All bolts from A226 to A232 inclusive, diameter followed by nominal length in sixteenths of an inch, e.g. a ¼ inch UNJF A229 bolt with plain length of one inch = A229-E16.

NOTE: The position at which the nominal length of bolts is measured is shown in Figure 4; screws are measured as shown in Figure 2. It should be noted that the plain portion of the shank, on bolts with Unified threads, does not include the thread run-out.

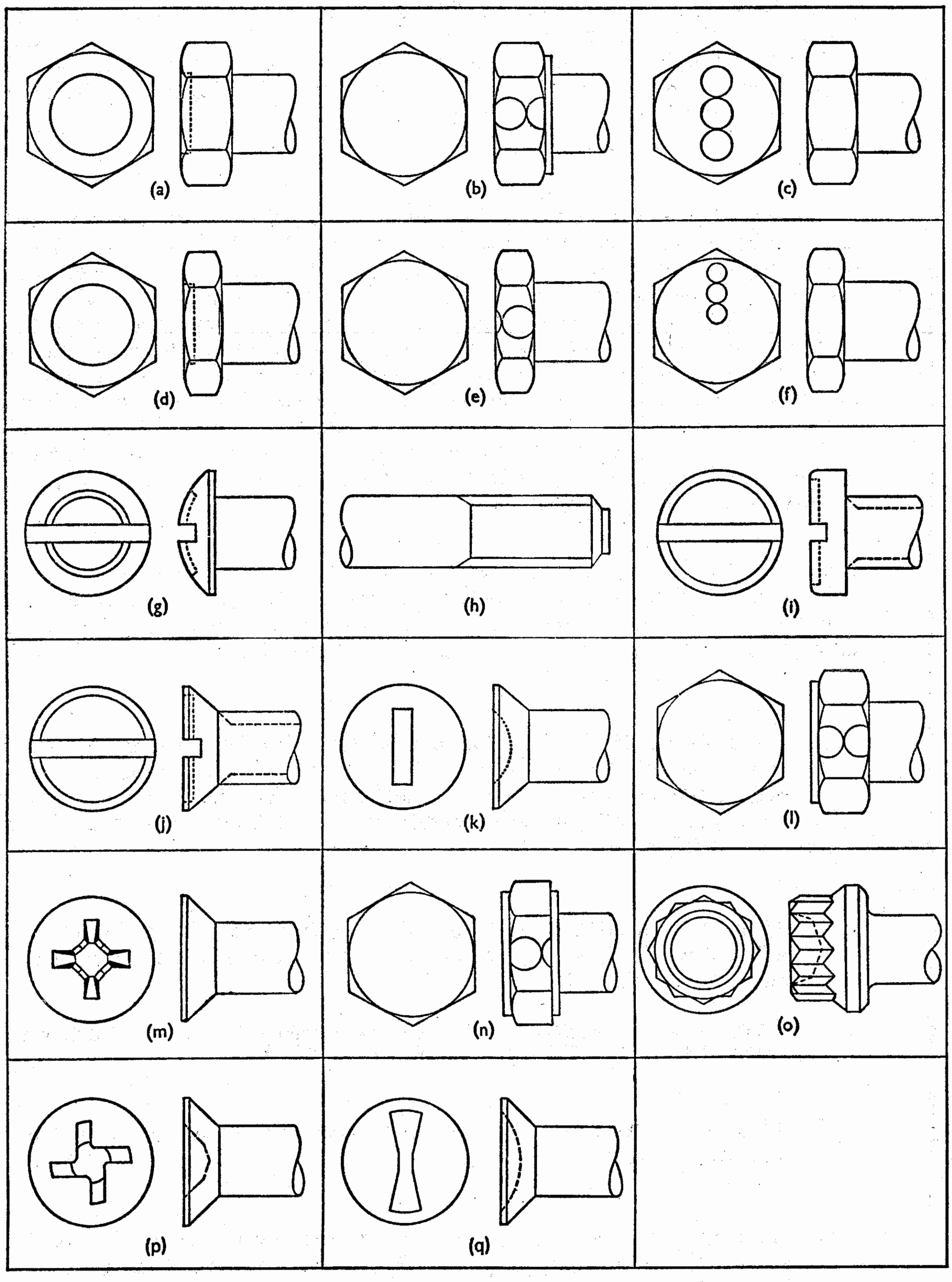


Figure 3 IDENTIFICATION OF BRITISH STANDARDS UNIFIED BOLTS AND SCREWS

TABLE 3

UNIFIED BOLTS AND SCREWS

BS No.	*Description*	*Material*	*Finish*	*Identi-fication (Fig. 3)*	*Remarks*	*Thread and Class*	*Normal Size Range*
A102	Hex. hd. bolt	HTS	cad	a, b or c		Unified, 2A	4-40 to 1 in
A104	Hex. hd. bolt	CRS	nat	a, b or c		Unified, 2A	4-40 to 1 in
A108	Hex. hd. bolt	HTS	cad	l or n	cad hd. and thread only	Unified, 2A	10-32 to $\frac{1}{2}$ in
A109	Hex. hd. shear bolt	HTS	cad	d, e or f		Unified, 2A	$\frac{1}{4}$ to $\frac{3}{4}$ in
A111	Hex. hd. c/t bolt	HTS	cad	l or n		Unified, 2A	10-32 to $\frac{1}{2}$ in
A112	Hex. hd. shear bolt	HTS	cad	d, e or f		Unified, 2A	$\frac{1}{4}$ to $\frac{3}{4}$ in
A113	Mush. hd. bolt	HTS	cad	g, h		Unified, 2A	6-32 to $\frac{5}{16}$ in
A114	Mush. hd. bolt	CRS	nat	g, h		Unified, 2A	6-32 to $\frac{5}{16}$ in
A116	Pan Hd. bolt	HTS	cad	i, h		Unified, 2A	4-40 to $\frac{5}{16}$ in
A117	Pan hd. bolt	CRS	nat	i, h		Unified, 2A	4-40 to $\frac{5}{16}$ in
A119	90° csk. hd. bolt	HTS	cad	j	obsolescent	Unified, 2A	$\frac{1}{4}$ to $\frac{1}{2}$ in
A120	90° csk. hd. bolt	CRS	nat	j	obsolescent	Unified, 2A	$\frac{1}{4}$ to $\frac{1}{2}$ in
A169	Hex. hd. bolt	Al Al	green	b or c	replaces A106	Unified, 2A	6-32 to $\frac{5}{8}$ in
A170	Mush. hd. bolt	Al Al	green	g	replaces A115	Unified, 2A	6-32 to $\frac{5}{16}$ in
A171	Pan hd. bolt	Al Al	green	i	replaces A118	Unified, 2A	4-40 to $\frac{5}{16}$ in
A172	90° csk. hd. bolt	Al Al	green	j, h	obsolescent	Unified, 2A	$\frac{1}{4}$ to $\frac{1}{2}$ in
A173	100° csk. hd. bolt	HTS	cad	k			8-32 to $\frac{1}{2}$ in
A174	100° csk. hd. bolt	CRS	nat	k		Unified, 2A	8-32 to $\frac{1}{2}$ in
A175	100° csk. hd. bolt	Al Al	green	k	replaces A172	Unified, 2A	8-32 to $\frac{1}{2}$ in
A204	100° csk. hd. screw	LTS	cad	j, h		Unified, 2A	0-80 to 10-32
A206	100° csk. hd. screw	CRS	nat	j, h		Unified, 2A	4-40 to 10-32
A208	100° csk. hd. screw	Al Al	green	j, h		Unified, 2A	4-40 to 10-32
A211	100° csk. hd. bolt	HTS	cad	m		Unified, 2A	8-32 to $\frac{1}{2}$ in
A212	Hex.hd. c/t bolt	HTS	cad	b or c	special quality	Unified, 3A	10-32 to $\frac{1}{2}$ in
A217	Pan hd. screw	LTS	cad	i, h	replaces A205	Unified, 2A	0-80 to 10-32
A218	Pan hd. screw	CRS	nat	i, h	replaces A207	Unified, 2A	4-40 to 10-32
A219	Pan hd. screw	Al Al	green	i, h	replaces A209	Unified, 2A	4-40 to 10-32
A220	100° csk. hd. screw	Brass	nat	j, h		Unified, 2A	0-80 to 10-32
A221	Pan hd. screw	Brass	nat	i, h		Unified, 2A	0-80 to 10-32
A226	Hex. hd. bolt	HTS	cad	a, b or c	short thread	Unified, 3A	4-40 to 10-32
A227	Pan hd. bolt	HTS	cad	i, h	short thread	Unified, 3A	4-40 to 10-32
A228	Double hex. hd. c/t bolt	HTS	cad	o		UNJF, 3A	$\frac{1}{4}$ to 1 in
A229	Hex. hd. c/t bolt	HTS	cad	a, b or c		UNJF, 3A	10-32 to $\frac{1}{2}$ in
A230	Csk. hd. c/t bolt	HTS	cad	q		UNJF, 3A	10-32 to $\frac{1}{2}$ in
A232	Csk. hd. c/t bolt	HTS	cad	p		UNJF, 3A	10-32 to $\frac{1}{2}$ in

2.2.2 **Extent of Marking.** The markings actually applied to a bolt depend on the particular specification and whether marking is practical. Adding the code 'A217-Z32' to the head of a 2-64 UNF pan head screw (head diameter 0·155 to 0·167 in), for example, would be very difficult, and having raised characters on a countersunk head bolt would, in certain circumstances, defeat the object of using that shape of head.

(i) **'Unified' Marking.** Most bolts, and screws 4-40 UNC and larger, are marked with a symbol to show that they have 'Unified' threads. The markings consist of contiguous circles (hexagon headed bolts only), a recessed head or shank dog point, and are illustrated in Figure 3.

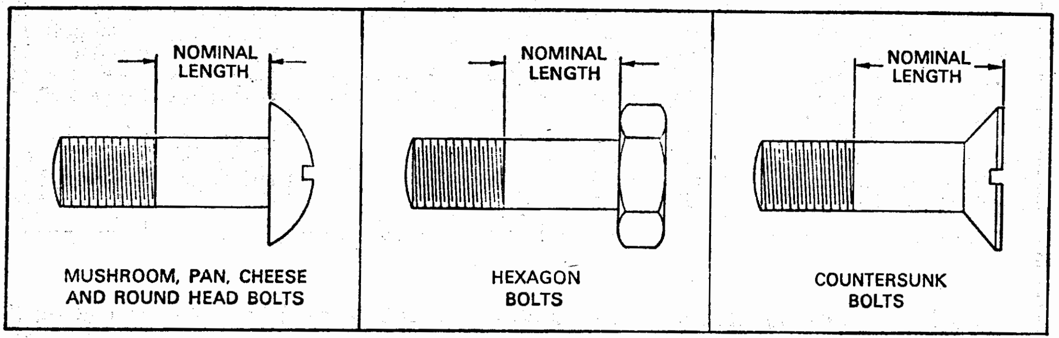
NOTE: At some future date, to be agreed, the 'Unified' marking of screws will be discontinued and identification of these items will be solely from the label on the package.

(ii) **Code Markings.** Most hexagon head bolts 10-32 UNF and larger are marked with the full code, i.e. Standard plus size code, but pan and mushroom head bolts may only be marked with the bolt length and countersunk head **bolts are not usually marked at all.** The code is not applied to **screws, or bolts smaller than 10-32 UNF.**

TABLE 4

DIAMETER CODE LETTERS

Code	Size	Code	Size
Y	0-80 UNF	J	⅜ in UNF (UNJF)
Z	2-64 UNF	L	7/16 in UNF (UNJF)
A	4-40 UNC	N	½ in UNF (UNJF)
B	6-32 UNC	P	9/16 in UNF (UNJF)
C	8-32 UNC	Q	⅝ in UNF (UNJF)
D	10-32 UNF (UNJF)	S	¾ in UNF (UNJF)
E	¼ in UNF (UNJF)	U	⅞ in UNF (UNJF)
G	5/16 in UNF (UNJF)	W	1 in UNF (UNJF)



MUSHROOM, PAN, CHEESE AND ROUND HEAD BOLTS

HEXAGON BOLTS

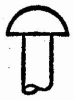
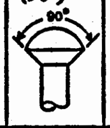
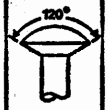
COUNTERSUNK BOLTS

Figure 4 LENGTH OF BS UNIFIED BOLTS

3 **'AS' BOLTS AND SCREWS** This paragraph is concerned with the identification of bolts and screws complying with the Society of British Aerospace Companies 'AS' series of specifications. The specifications provide a range of bolts and screws in sizes and head shapes not found in British Standards specifications. Bolts manufactured from special materials (e.g. heat resistant steel) and having Unified threads are also included.

3.1 Table 5 shows the AS specifications for bolts and screws with BA/BSF threads, together with complete identification details.

TABLE 5
'AS' NUMBERS OF BA/BSF BOLTS AND SCREWS

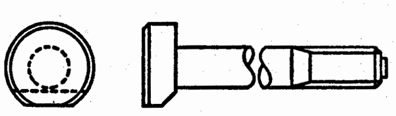
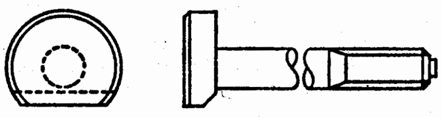
Head	Round 	Mush-room 	Raised Counter-sunk (90°) 	Counter-sunk (90°) 	Raised Counter-sunk (120°) 	Counter-sunk (120°) 	hexagon 	*Material*	*Finish*
Bolts with screwdriver slot or hexagonal head	1247+	1249+	1245+	1243+				Al Al	Anodic
	4565	4566	4564	4563				Al Al	Blue
	1246	1248	1244+	1242			4569‡	HTS	Cad.
	2922	2923	2921	2920				SS	Nat.
							2504+ +	HTS	Cad h & t
Bolts with Phillips recess	3078*+ 4597**	3079*+ 4598**	3295**	3294**	3296**	3297**		HTS	Cad.
Screws with Phillips recess	2991	2992	2994	2993	2995	2996		Mild Steel	Cad.

*1 dot on head
**2 dots on head

+obsolescent
‡2 BA only

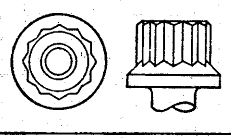
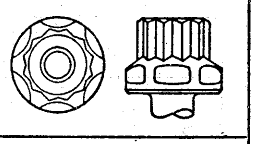
3.2 Table 6 shows the AS specifications for 'round head' bolts with a locking flat and Unified threads. These bolts are manufactured from high tensile steel and are cadmium plated.

TABLE 6
'AS' NUMBERS OF ROUND HEAD BOLTS WITH FLAT (UNIFIED)

 Small head				 Large head			
10-32 UNF	¼ UNF	⁵⁄₁₆ UNF	⅜ UNF	10-32 UNF	¼ UNF	⁵⁄₁₆ UNF	⅜ UNF
6760 to 6804	6895 to 6939	7033 to 7077	7171 to 7215	6850 to 6894	6985 to 7032	7123 to 7170	7264 to 7308

3.3 Table 7 shows the AS specifications for double hexagon head bolts manufactured from heat resistant steel and having UNS or UNJF threads. Requirements for protective treatment vary between specifications, some bolts being silver plated while others have a natural finish.

TABLE 7
'AS' SPECIFICATIONS

			HEAD SHAPE	
Thread	*Type*	*Material*		
UNS Threads (10-32 to ⅜-24 UNS-3A)	Plain	DTD 5066	13000 - 13399	17000 - 17399
		DTD 5026	13400 - 13799	17400 - 17799
		DTD 5077	13800 - 14199	17800 - 18199
	Externally Relieved Body	DTD 5066	14500 - 14899	18200 - 18599
		DTD 5026	14900 - 15299	18600 - 18999
		DTD 5077	15300 - 15699	19000 - 19399
	Close Tolerance Shank	DTD 5066	19400 - 19799	
		DTD 5026	19800 - 20199	
		DTD 5077	20200 - 20599	
UNJF Threads	Plain (8-36 to ⅜-24 UNJF)	DTD 5066	20800 - 21299	
		DTD 5026	21300 - 21799	
		DTD 5077	21800 - 22299	
	Close Tolerance Shank (10-32 to ⅜-24 UNJF)	DTD 5066	22400 - 22799	
		DTD 5026	22900 - 23299	
		DTD 5077	23400 - 23799	

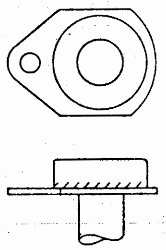
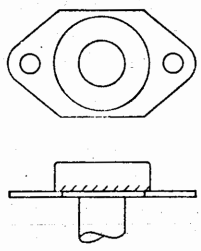
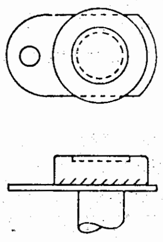
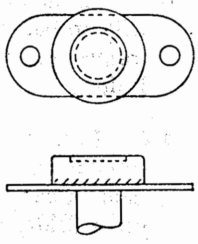
NOTE: The UNS bolts listed in the table have reduced diameter threads for use in high temperature applications and should be fitted with nuts complying with specifications AS20620 to AS 20639.

3.3.1 For purposes of standardisation a further series of heat resistant bolts with UNJF threads is being introduced to replace those with UNS threads. Details of the AS numbers allocated to these bolts are not, as yet, available, but the method of identification will be the same as described for the bolts in Table 7.

3.4 Table 8 shows the AS specifications for anchor bolts manufactured from weldable steel.

3.5 AS1 and AS2 are specifications for titanium bolts having Unified threads, with hexagon and 100° countersunk heads respectively. Both specifications are obsolescent but the bolts may be recognised by the material finish and the marking 'AS1' or 'AS2' on the head, as appropriate.

TABLE 8
'AS' NUMBERS OF ANCHOR BOLTS

BA/BSF		Unified	
			
4752	4753	6735	6736
Weldable bolt is AS 4754		Weldable bolt is AS 6737	

3.6 **Identification Marking.** AS1, AS2 and all the bolts listed in Table 7 are marked with the AS specification to which they conform. Other AS bolts are unmarked except for the 'Unified' symbol which is applied to anchor bolts (recessed head) and the round head bolts shown in Table 6 (shank dog point).

3.7 **Code System.** Although a large number of AS bolts and screws are not marked in any way, codes are necessary for ordering and storage purposes.

3.7.1 The code system used for the identification of the bolts and screws listed in Tables 5 and 8, and for AS1 and AS2 bolts, is the same as that used for British Standards bolts, i.e. AS number followed by a number indicating length in tenths of an inch and a letter indicating diameter (Tables 2 or 4 as appropriate). The length is measured in the same way as for British Standard parts.

NOTE: AS 2504 and 4569 bolts are only manufactured in 2 BA; the diameter code is therefore not required.

3.7.2 Reference to Table 6 shows that a batch of AS numbers is allocated to each diameter of bolt in this series. A separate number within each batch is reserved for a particular length of bolt so that a code system is unnecessary; any particular AS number in this series applies only to a bolt of specified length and diameter. The plain length is graduated in steps of 0·05 inch from 0·05 inch to 0·9 inch, and steps of 0·1 inch thereafter up to 3·4 inch. A 10-32 UNF bolt 1·2 inch long and having a small head will therefore be AS6780

3.7.3 The bolts shown in Table 7 also have a batch of AS numbers allocated to each diameter but in this case the range of available lengths varies between specifications. The length of the bolt is taken as the whole length of the shank, including the thread in sixteenths of an inch up to 2 inches long, and eighths thereafter, each particular size having a unique reference number. It should be noted that this series of bolts has a threaded length greater than that normally found on aircraft fasteners. A minimum length of plain portion is also maintained, so that the thread length in the shorter bolts is reduced below the normal for the particular diameter.

4 **FUTURE TRENDS** Because of the importance of reducing weight in the construction of an aircraft, designers are constantly seeking means of using higher strength or lighter alloys for structural purposes. This trend applies particularly to fasteners and it is apparent that the use of smaller diameter bolts and miniature anchor nuts will become more widespread. It will be accompanied by the use of threads of UNJF form.

4.1 In the field of light alloys, specifications for titanium bolts are being prepared and will probably be drawn up in accordance with existing American practice, within the framework of British Standard A 101, entitled "General Requirements for Titanium Bolts".

4.2 Because of the vast experience gained, particularly in America, in the use of both standard and miniature components, it has been internationally agreed to use Unified inch threads on fasteners. However, with the introduction of metric dimensions in other fields, it is probable that a metric thread series will eventually be accepted.

4.3 As far as identification features are concerned it appears likely that the system used for recent specifications will continue; bolts in the AS series will be marked with a number which will be unique for a particular diameter and length, and bolts in the BS series will use the code at present applied to bolts with UNJ threads.

NOTE: There is no symbol used to differentiate between threads of standard unified or UNJ form.

5 **ABBREVIATIONS** The following is an alphabetical list of abbreviations used in this Leaflet:—

AGS	Aircraft General Standards
AS	Aircraft Standards
Al Al	Aluminium alloy
BA	British Association
blue	dyed blue over anodic film
BSF	British Standard Fine
cad.	cadmium plated all over
cad. h & t	cadmium plated head and thread only
csk.	countersunk
c/t	close tolerance
CRS	corrosion resisting steel
FCS	free-cutting steel
green	dyed green over anodic film
hd.	head
hex.	hexagon
HTS	high tensile steel
LTS	low tensile steel
mush.	mushroom
nat.	natural finish
SS	stainless steel
UNC	Unified coarse thread
UNF	Unified fine thread
UNS	Unified special thread
UNJF	Unified fatigue-resistant fine thread

BL/2-4

Issue 2.

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BASIC

IDENTIFICATION MARKING

IDENTIFICATION MARKINGS ON METALLIC MATERIALS

1 INTRODUCTION This Leaflet gives guidance on the determination of type and positioning of markings on metallic materials, for the purpose of identification during manufacture. This Leaflet should be read in conjunction with CAIP Leaflet **BL/2-2**, which gives information on standard colour schemes and **BL/2-1** which gives information on the processes for identification marking of aircraft parts.

1.1 Chapter **A6—6** of British Civil Airworthiness Requirements specifies that materials used in parts affected by airworthiness requirements shall comply with one of the following specifications:—

(a) British Standard Aerospace Series Specifications.

(b) DTD Specifications.

(c) Specifications approved by the CAA.

(d) Specifications prepared for a material in accordance with BCAR, Chapter **D4—1** for large aeroplanes*, by an Organisation approved for design where the material is to be used in a part designed within the terms of the design approval.

1.2 British Standards Aerospace Series and DTD Specifications make provision for the identification of materials by requiring the mark of the inspector and such other markings as may be necessary to ensure full identification. Manufacturers' Specifications (as in paragraph 1.1 (d)) normally refer to the inspectional clauses of the relevant BS or DTD Specifications and, consequently, similar provision for identification is made.

1.3 To obviate the need for the revision of this Leaflet when new issues of specifications referred to are published, the prefix or suffix indicating the issue number of the specification has been omitted.

2 METHOD OF MARKING Materials should be identified as early as possible in their manufacture.

2.1 The markings most appropriate for materials such as sheet, bar and castings are—

(a) metallic stamp markings,

(b) markings produced by the die or mould used in shaping the material, and

(c) marking by rubber stamp, hand roller or printing machine.

Whichever method of marking is employed, damage to the material must be avoided and particular care should be taken when marking stressed parts of materials.

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*Chapters **K4-1** for light aeroplanes, **G4-1** for rotorcraft, **C2-2** for engines.

2.2 The markings most appropriate for parts and semi-finished materials are—

(a) acid etching,

(b) electro-chemical methods,

(c) vibratory percussion,

(d) grit blasting, and

(e) deposition of iron-copper selenite.

2.3 Incised markings are not recommended for—

(a) stressed parts where the impressions may act as stress raisers and originate cracks,

(b) materials and parts of thin section,

(c) materials or parts of such hardness, surface condition or shape that it is impracticable to apply a well defined marking, and

(d) material ordered to exact sizes where no provision is made for the subsequent removal of the portion containing the incised markings.

NOTE: Electro-engraving of parts is prohibited and metallic stamp and vibratory percussion methods must not be used at highly stressed locations. If it is necessary to mark a part in a stressed region, etching or electro-chemical methods should be employed.

2.4 When metallic stamp marking is used, and this method is preferred for stock or random sizes of material, the marks have to be confined to a minimum area in a suitable position.

2.5 When marking with ink, enamel or paint is permitted, the marking medium has to meet the following criteria:—

(a) It has to be permanent, except for 'non-immersion' markings used with some aluminium-based materials, where the marking is designed to disappear during solution treatment.

(b) It has to have no corrosive or adverse effect on the material and be compatible with any material or substance with which it may subsequently be in contact.

NOTE: For stainless steels, the marking medium has to be free from organic compounds to obviate the possibility of carbon 'pick-up'.

(c) It has to remain legible when any protective process is applied to the material.

2.6 Where material is ordered to sizes which do not permit the identification markings being removed during production of a part, the purchaser may state expressly in his order that the material is to be used in the size as delivered and must not bear any incised markings. In such circumstances the material may be identified by—

(a) the pieces of material being bundled or parcelled and the marks required being stamped on a metal label securely attached to each bundle or parcel,

(b) marking with paint, enamel or ink (see paragraph 2.5), or

(c) one of the etching or electrochemical methods.

3 IDENTIFICATION OF METALLIC MATERIALS TO APPROVED SPECIFICATIONS

The Procedure Specifications in the British Standards Aerospace Series, i.e. HC.100, HR.100, L.100, L.500, S.100, S.500, T.100 and TA.100, contain identification marking clauses which are applicable to all BS Aerospace Series and DTD Specifications for iron, nickel, copper and refractory base alloy castings, wrought heat resisting alloys, wrought aluminium and aluminium alloys, aluminium base and magnesium base ingots and castings, wrought magnesium alloys, wrought steels and wrought titanium and titanium alloys. New issues of approved specifications will include references to the identification clauses of the relevant specification.

3.1 The identification marking of metallic materials other than those covered in paragraph 3 is governed by the individual Approved Specification.

3.2 The identification markings should consist of the specification reference, the inspection stamp (except as indicated in paragraph 4) and such other markings as are necessary to enable the following details to be established:—

(a) Manufacturer.

(b) Cast number (where cast or cast/heat treatment batching is required by the Specification).

(c) Batch number.

(d) Test report number.

3.3 The identification mark of the inspector and the manufacturer's trade or identification mark may be combined in one symbol. Correlation between the relevant approved certificate and test report may conveniently be secured by marking the material with the test report number.

3.4 Additional markings such as those agreed by the supplier and purchaser and stated on the order or drawing may also be applied.

4 IDENTIFICATION OF MATERIAL FORMS The identification markings which are generally applicable to various forms of material, ingots, castings, bars, sheets, etc., are given in this paragraph.

4.1 **Ingots.** Each ingot should be stamped with the marks indicated in paragraph 3.2, except that the inspection stamp may be omitted if the manufacturer's name or trade mark is cast on each ingot and the relevant inspection records are signed by the inspector accepting the ingots.

4.2 **Castings, Forgings and Stampings.** Each casting, forging and stamping which is large enough to be individually marked should bear the marks described in paragraph 3.2 and such other markings as may be stated on the order.

4.2.1 Marks, such as the part number and the manufacturer's name, may be incorporated in the die or mould used in shaping the part. Marks not so applied should be added by means of stamps unless some other method of marking is specified. All stamp markings must be placed where they have the least detrimental effect on the part; such position usually being indicated on the drawing.

4.2.2 Where forgings, stampings and precision castings approximate closely to the finished parts, the method of identification should follow the requirements for the marking of the finished parts, as shown on the drawing. Wherever practicable, compressor and turbine blade forgings should be individually identified, and this is of particular importance where the blade forgings are of similar shape and size and made from closely associated alloys, e.g. the alloys of the Nimonic series. Segregation and identification of stock, 'uses' and forgings for blades throughout the various production and heat treatment stages is necessary.

4.3 **Billets and Bars.** Each billet and bar, the diameter or width across flats of which is greater than 19 mm (0·75 in), should be stamped at one end with the markings detailed in paragraph 3.2.

4.4 **Sheets and Strips.** Each sheet and each coil or strip wider than 19 mm (0·75 in) should be stamped with the markings detailed in paragraph 3.2.

4.5 **Sections.** Each extruded and rolled section, the major sectional dimension of which exceeds 19 mm (0·75 in), should be stamped at one extreme end with the markings detailed in paragraph 3.2.

4.6 **Wire.** Each coil or bundle of wire should bear a metal label stamped with the markings detailed in paragraph 3.2 and such additional markings as may be required by the relevant specification (which may also require colour identification).

4.7 **Tubes.** Each tube, the diameter of which exceeds 25 mm (1 in), or in the case of light alloy and steel tubes exceeds 19 mm (0·75 in), should be stamped at one end with the markings detailed in paragraph 3.2 and with any additional markings required by the relevant specification.

4.8 **Items not Requiring Individual Identification.** As an alternative to individual identification, and provided that the material is from the same cast or batch:

(a) ingots, small castings, forgings, stampings and bars, the diameter or width across flats of which does not exceed 6·5 mm (0·25 in);

(b) sheet and flat strips, the width of which does not exceed 19 mm (0·75 in);

(c) sections, the major sectional dimensions of which do not exceed 19 mm (0·75 in);

(d) tubes, the diameter of which does not exceed 25 mm (1 in), or in the case of light alloy and steel tubes does not exceed 19 mm (0·75 in)

should be either wired together or packed in parcels, as appropriate, and a metal label, stamped with the markings detailed in paragraph 3.2, should be attached to each bundle or parcel.

5 ALUMINIUM-BASED MATERIALS The identification marking requirements for aluminium-based materials are prescribed in British Standards L.100 and L.101, and castings, extruded bars, sections and sections rolled from strip, wire and tubes should, unless otherwise specified, be so identified.

5.1 **Ingots.** Ingots which have a sufficiently clean and smooth face to enable full legibility to be secured, may, at the discretion of the appropriately authorised person, be rubber stamped with the specification reference, preferably at each end of the ingot. The letters and figures should be not less than 13 mm (0·5 in) high and the ink used should comply with paragraph 2.5.

5.2 **Sheet and Strip in Coil Form.** In addition to the identification markings detailed in paragraph 3.2, sheet and strip may be required to be 'all-over' marked by the specification. Where strip is identified by ink markings, marking the material with the Specification reference may be omitted. 'All-over' marking should be carried out in accordance with the relevant clauses of BS L.100 and as detailed in paragraphs 5.2.1 to 5.2.4, unless otherwise agreed between the manufacturer and the purchaser and stated on the order.

5.2.1 Each sheet and each strip in coil form, the width of which is 152 mm (6 in) or greater, should be marked in green ink with the Specification reference and the manufacturer's symbol in figures and letters 13 mm (0·5 in) high. The lines of markings should be at a pitch of 100 mm (4 in). The markings should be arranged in accordance with (a) or (b).

(a) The specification reference and the manufacturer's symbol should appear alternately and should be repeated at intervals of approximately 100 mm (4 in) along each line of marking; the marks being so disposed that the Specification reference in one line is above the manufacturer's symbol in the line immediately below it.

(b) The specification reference and manufacturer's symbol should appear on alternate lines, the marks in each line being repeated with a gap of approximately 25 mm (1 in) between them.

5.2.2 Each sheet and each strip in coil form, the width of which does not exceed 152 mm (6 in) (but not less than 50 mm (2 in) wide), should be marked as in 5.2.1 (a) or (b) at intervals of 100 mm (4 in) approximately along the centre line.

5.2.3 At the option of the manufacturer, each sheet and strip in coil form, the width of which does not exceed 50 mm (2 in) wide, can be 'all-over' marked, individually identified as detailed in paragraph 3.2, or, if from the same batch, bundled together with the required marks stamped on a metal label attached to each bundle.

5.2.4 Sheet and strip in coil form of material 26 s.w.g. and thinner, in the heat treatment condition stipulated by the specification and wide enough to be 'all-over' marked, may be hand marked in green ink along two lines only.

5.3 **Plate and Extrusions.** Plate, not included in the current issue of BS L.100, should, unless otherwise specified, be marked in accordance with the relevant DTD Specification.

5.3.1 For plate fabrication and machining it is advantageous to know both the direction of rolling (not readily apparent with pieces cut to size) and the results of non-destructive testing. The user may require appropriate indications to be marked on each plate; such additional markings should be agreed between the purchaser and manufacturer and stated on the drawing or order.

5.3.2 Extrusions and plate which have been stretched in accordance with the specification or other conditions should be marked with the letters CS in a circle. Bars and sections should be marked at one end and plate should be marked alongside the specification reference. The marks should be made either by rubber stamp (blue or black ink) or by metal stamps, at the discretion of the material manufacturer.

NOTE: See also paragraph 5.5 when the contents of that paragraph are applicable.

5.4 **Forgings.** Forgings should, unless otherwise specified, be finally marked as required by BS L.100. Where individual markings are required, L.100 specifies that the drawing for the forgings should state the position at which the identification marks are to be applied; this is particularly important for forgings in high strength alloys.

NOTE: The method of applying the identification markings should be confirmed where it is not indicated on the drawing.

5.5 **Annealed, Not Aged, and as-Rolled Material.** Material released in other than the heat treatment condition stipulated by the specification should be marked in red by means of a transfer, paint or ink markings with the appropriate term to denote its condition and Approved Certificates covering such material should be clearly annotated "annealed", "not aged", etc., as appropriate.

5.5.1 For sheet and strip in coil form, the red markings in letters 13 mm (0·5 in) high should be repeated at intervals of approximately 101 mm (4 in) in lines midway between the lines of markings detailed in paragraph 5.2.1 to 5.2.3.

5.5.2 For extruded bars, sections and tubing, the red marking should be applied near one end of each length but, where lengths greater than 5 m (15 ft) are supplied, the markings should be applied at each end of each length.

5.5.3 For plate, the red marking should be placed near the specification reference or, where 'all-over' marking is required by the order, repeated at intervals midway between the lines of 'all-over' marking.

5.5.4 Material which is to be bundled and labelled should bear the appropriate wording stamped on the attached label.

5.5.5 The following terms are to be used, as appropriate:—

(a) AS ROLLED. To denote 'as-rolled' material.

(b) ANNEALED. To denote material in the softened condition.

(c) NOT AGED. To denote material solution treated but which requires precipitation treatment.

5.5.6 The method of applying the red markings is left to the discretion of the manufacturer but the medium used should comply with paragraph 2.5.

6 MAGNESIUM-BASED MATERIALS Cast products should, unless otherwise specified, be identified in accordance with the requirements of BS L.101. Wrought products should be identified as required to BS L.500, the contents of paragraph 3.2 being taken into consideration. In general, the guidance given in previous paragraphs is applicable and the markings should be applied before chromate treatment.

7 TITANIUM-BASED MATERIALS Titanium-based materials should be finally marked in accordance with BS TA.100 and order requirements, the contents of paragragh 3.2 being taken into consideration. It is preferable not to use metallic stamping unless otherwise indicated on the order; billets, bars, sheet, etc., may be identified by rubber stamp markings. Where the cross-section is insufficient to enable full legibility to be secured, bars, rods, etc., from the same cast or batch and of the same nominal size may be wired together and the marks required may be stamped on a metal label attached to each bundle.

8 **FERROUS MATERIALS** Steel ingots and wrought products should, unless otherwise specified, be identified in accordance with the relevant procedure specifications, i.e. BS S.100, S.500 and T.100; the identification marking requirements for steel castings are given in the relevant specifications.

NOTE: Leaded steels should be identified with a distinguishing mark "L", "LED" or "LEADED" and the associated Approved Certificate should be appropriately endorsed.

9 **IDENTIFICATION OF METALLIC MATERIALS TO OTHER THAN APPROVED SPECIFICATIONS** Parts for general supplies (i.e. uncontrolled items as specified in Section A, Chapter A3-3 of British Civil Airworthiness Requirements) may be made from materials for which identification marking requirements are not specified. In such cases the appropriate person employed by the materials manufacturer should be guided by the terms of the order, but it is preferable that some form of marking be carried out by the manufacturer to correlate the material with its accompanying release documentation. It is essential, however, that the material is rendered identifiable after delivery to prevent any possible confusion with other material held by the purchaser.

BL/2-6

Issue 3.

24th February, 1971.

BASIC

IDENTIFICATION MARKING

NUTS OF BRITISH MANUFACTURE

1 INTRODUCTION This Leaflet gives guidance on the identification of nuts complying with British Standards 'A' Series of Aircraft Materials and Components, with AGS Specifications and with certain specifications in the Society of British Aerospace Companies 'AS' Series.

1.1 Failure of a fastener through the use of an incorrect nut could cause malfunction and, in certain circumstances, lead to the jamming of controls. It is most important, therefore, that engineers and inspectors should be acquainted with the features by which any particular type of nut may be identified. A nut may have the correct type of thread but it may be unsuitable for some other reasons such as material, temperature classification or length of thread; it is also possible to fit a nut of incorrect size, e.g. a 10-32 UNF nut may fit an 8-32 UNC screw. These dangers may be minimised by constant vigilance during servicing operations.

1.2 For the benefit of engineers engaged on the maintenance of older types of aircraft, information on obsolescent Standards is also included in this Leaflet, together with details of replacement Standards.

1.3 Information on the identification of bolts and screws of British manufacture is given in Leaflet **BL/2-3.**

1.4 A list of abbreviations and terms used in this Leaflet is given in paragraph 7.

2 BRITISH STANDARDS NUTS HAVING BA OR BSF THREADS Table 1 gives a list of relevant Standards and superseding Standards. Identification details are included in the table and the different nuts included in this range are illustrated in Figure 1.

2.1 **Identification.** Identification of a particular nut may be effected from its shape and anti-corrosive treatment; in addition, all nuts larger than $\frac{3}{8}$ inch BSF are marked with the British Standard number, and parcels of nuts are labelled with the complete part number.

2.2 **Code System for Nuts.** The code system used for the identification of the nuts listed in Table 1 (with the exception of A14) consists of the Standard number followed by a letter indicating the size of the thread (Table 2), followed by a letter indicating the type of nut, i.e. P (ordinary nut), S (slotted nut), C (castle nut), and T (thin nut). These type letters are not, however, applied to the nuts. For example, the complete part referencing number used on the drawing, or when ordering $\frac{7}{16}$ inch ordinary A27 nuts is A27LP, but the corresponding marking of the nuts will be A27L.

2.2.1 Where nuts have a left-hand thread the letter 'L' is added to the part number, thus the above example with a left-hand thread would have the part number A27LPL. The letter 'L' is marked on one of the hexagonal surfaces of the nut.

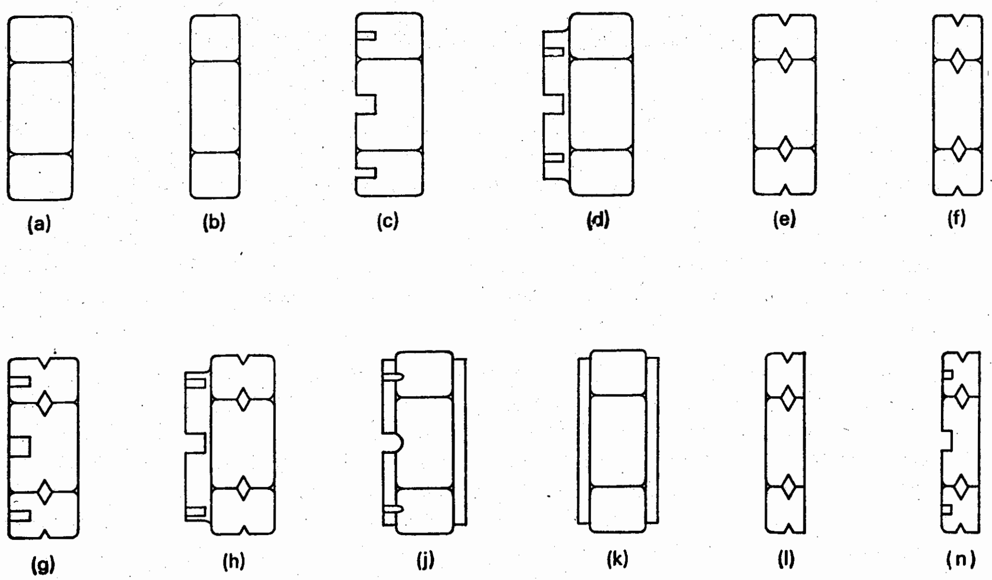
TABLE 1

BA AND BSF HEXAGON NUTS

BS No.	*Types (para. 2.2)*	*Material*	*Finish*	*Remarks*	*Identification (Fig. 1)**	*Size Range*
A14	P and T	Brass	cad or natural	obsolescent	a or b	(i) 10 BA to 0 BA (ii) 4 BA to 1¼ BSF
A24	P, T, S and C	HTSS	natural	replaces A16 Z	e, f, g or h	6 BA to 1 in BSF
A27	P, T, S and C	HTS	cadmium	replaces A16 Y	e, f, g or h**	6 BA to 1 in BSF
A29	P and S	Al Al	anodic	replaces A18	j or k	6 BA to 1 in BSF
A47	P	LTS	cadmium	order as A27 in 2, 4 and 6 BA	a	12 BA to 2 BA
A48	T	LTS	cadmium		b	8 BA to 2 BA
A49	P	SS	natural		a	12 BA to 2 BA
A50	T	SS	natural		b	8 BA to 2 BA
A51	P	Al Al	anodic		a	12 BA to 2 BA
A52	T	Al Al	anodic		b	8 BA to 2 BA
A53	P	Brass	tinned	replaces A14 P	a	12 BA to 2 BA
A54	T	Brass	tinned	replaces A14 T, 2 and 4 BA	b	8 BA to 2 BA
A58	T or TS	HTS	cadmium	shear nut	l or n	¼ to ¾ in BSF

* The BS number is marked on all nuts larger than ⅜ inch BSF.

** a, b, c or d in sizes below ¼ inch BSF.



NOTE: Shear nuts (l) and (n) are 0·2 in thick in all sizes.

Figure 1 IDENTIFICATION FEATURES BA/BSF NUTS

TABLE 2
DIAMETER CODE LETTERS

Code	*Size*	*Code*	*Size*
A	6 BA	P	9/16 in BSF
B	4 BA	Q	5/8 in BSF
C	2 BA	S	3/4 in BSF
E	1/4 in BSF	U	7/8 in BSF
G	5/16 in BSF	W	1 in BSF
J	3/8 in BSF	X	12 BA
L	7/16 in BSF	Y	10 BA
N	1/2 in BSF	Z	8 BA

2.2.2 **Code System for BS A14 Brass Nuts.** In the obsolescent British Standard A14 two ranges of nuts are covered, viz. 0 BA to 10 BA plain and 4 BA to 1¼ inch BSF thin.

(i) In the former (which is superseded by A53) the diameter is indicated by the BA number, and the part number consists of the Standard number followed by the diameter number and the letter 'B'. For example, the complete part reference number used on the drawing or when ordering 4 BA plain nuts, is A14 4B.

(ii) In the second range the 4 and 2 BA nuts are superseded by British Standard A54, but the coding system is similar to that in Table 3, with the exceptions that 'X' and 'Y' are used to denote 1⅛ inch BSF and 1¼ inch BSF nuts respectively, and the letter 'B' is substituted for the usual letter 'T'. For example, a ¼ inch thin nut has a reference number A14 EB.

(iii) Both ranges include nuts with left-hand threads and the information contained in para. 2.2.1 applies also to this series.

TABLE 3
UNIFIED HEXAGON NUTS

BS No.	*Type (para.* 3.2)	*Material*	*Finish*	*Remarks*	*Identification (Fig. 2)**	*Size Range*
A103	P, T, S or C	HTS	cad		a, b, c or d	4-40 UNC to 1 in UNF
A105	P, T, S, or C	CRS	natural	marked with 'Z'	a, b, c or d	4-40 UNC to 1 in UNF
A107	P or S	Al Al	green		a or c	4-40 UNC to 1 in UNF
A110	T or TS	HTS	cad	shear nut	e or f	¼ to ¾ in UNF
A222	P	LTS	cad		a	0-80 and 2-64 UNF
A223	T	LTS	cad		b	0-80 and 2-64 UNF
A224	P	Brass	tinned		a	0-80 and 2-64 UNF
A225	T	Brass	tinned		b	0-80 and 2-64 UNF

* The BS number is marked on all nuts larger than ⅜ inch UNF.

3 BRITISH STANDARDS NUTS HAVING UNIFIED THREADS Table 3 gives a list of the relevant Standards and superseding Standards for ordinary hexagon nuts and Table 4 gives the Standards applicable to stiffnuts of various types. The nuts are illustrated in Figures 2 and 3 respectively.

TABLE 4
UNIFIED STIFFNUTS

Basic Type		*Attachment plate material*	*Temperature Classification, Nut Material and Coating*				
			—75°C to +125°C		—75°C to +200°C		—75°C to + 425°C
			Al Al†	*Brass* or *Bronze*††	*Steel**	*CRS***	
			Anodised	*Tinned*	*Cad plated*		*Silver Plated*
Hexagon	ordinary thin cap		A129 A130 A214	A131 A132 —	A125 A126 A213	A127 A128 —	A180 A181 —
Clinch			A124	A123	A122	—	—
Single lug fixed anchor	ordinary thin		A161 A162	A163 A164	A157 A158	A159 A160	A200 A201
Double lug fixed anchor	ordinary thin cap		A140 A141 A216	A142 A143 —	A136 A137 A215	A138 A139 —	A186 A187 —
Double lug floating anchor	ordinary thin	Al Al	A153 A154	— —	A151 A152	— —	— —
	ordinary thin	Brass	— —	A155 A156	— —	— —	— —
	ordinary thin	Steel	— —	— —	A147 A148	— —	— —
	ordinary thin	CRS	— —	— —	— —	A149 A150	A192 A193
Strip	ordinary thin		A167 A168	— —	A165 A166	— —	— —

* Nut body is made from S 92, S 112, S 113, S 114 or S 117 depending on the size of the nut. Base plate is made from S 510 or S 511 and attachment plate from S 511 or L 72.

** Nut body is made from S 80, base plate and attachment plate from S 521.

† Nut body is made from L 65, base plate and attachment plate from L 72.

†† Nut body is made from B 11, BS 249, BS 250, BS 251 or BS 369. Base plate and attachment plate are made from BS 267 or BS 409.

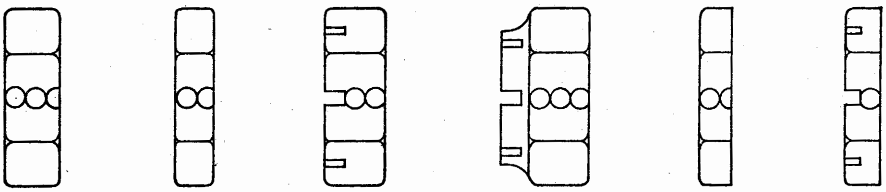
3.1 **Identification.** Nuts with Unified threads may be identified by their shape, type of finish and thread size. Additionally, all nuts other than anchor nuts, 8-32 UNC and larger, are marked with the 'Unified' symbol of contiguous circles. The identification of smaller nuts may be more difficult, for example, an A222, 2-64 UNF nut is similar to an A47, 8 BA nut, and it may be necessary to try the nut on a bolt of known thread to achieve positive identification.

3.1.1 Nuts listed in Table 3, larger than ⅜ inch diameter, are marked with the British Standard number.

3.1.2 Stiffnuts ¼ inch UNF and larger which are manufactured from corrosion resisting steel, are marked with the letter 'Z', either on one flat or on the base plate; when the nut is also silver plated, the letter 'X' is added to or replaces the 'Z'.

3.1.3 Brass anchor nuts are marked with the letter 'B' and all hexagon brass stiffnuts have a washer face (Figure 3).

NOTE: The shape of the friction element on a stiffnut should not be taken as an identification feature. These are usually patented devices and depend on the design favoured by the particular manufacturer. Nut specifications normally only quote the maximum dimensions of the friction element and the frictional unscrewing torque required.



(a) (b) (c) (d) (e) (f)

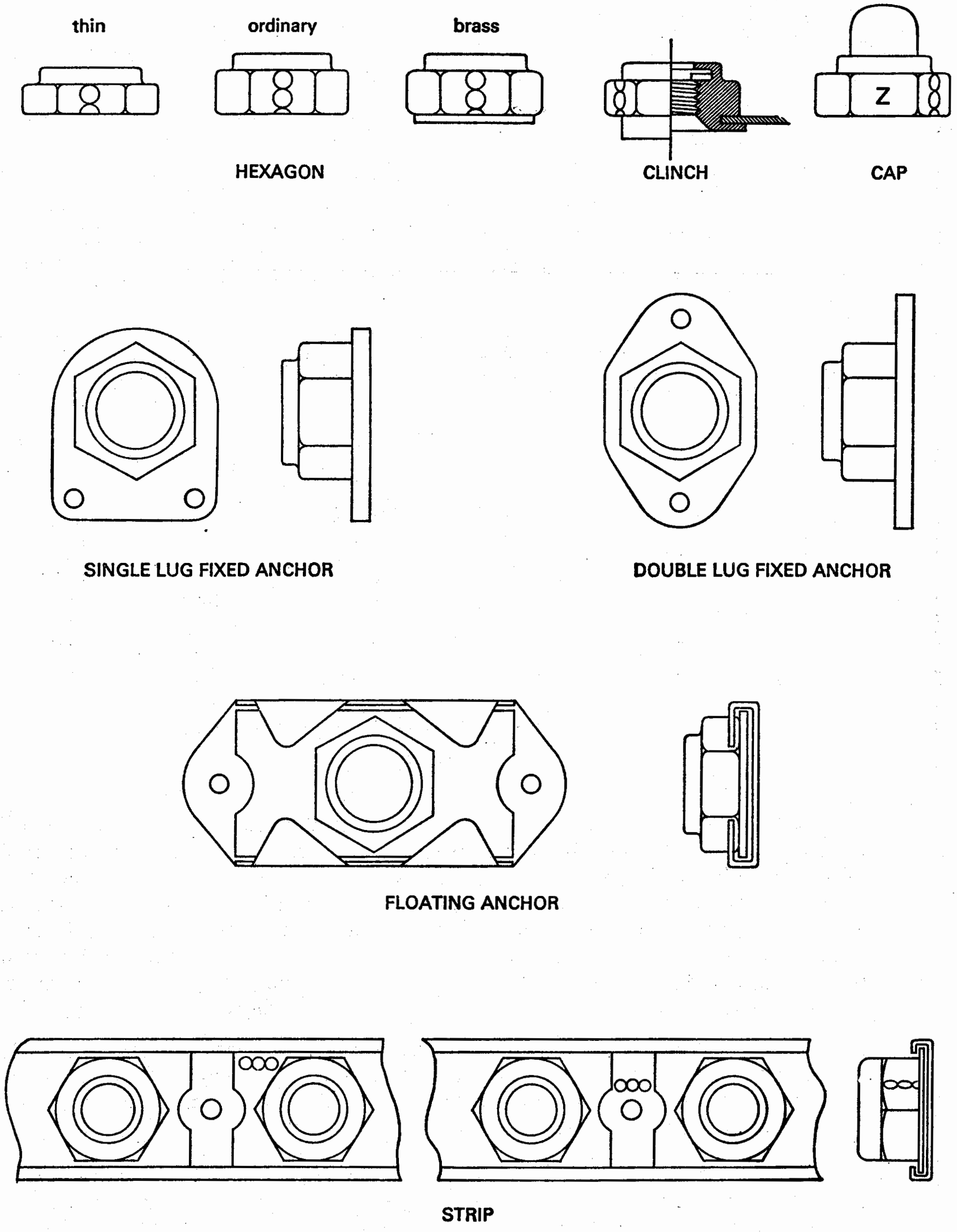
NOTE: Shear nuts (e) and (f) are 0·2 in thick in all sizes.

Figure 2 UNIFIED NUTS

3.2 **Code System.** The code system used for the identification of nuts having Unified threads consists of the British Standard number followed by a letter indicating the size of thread (Table 5), followed, when appropriate, by a letter indicating the type of nut, i.e. P (ordinary nut), S (slotted nut), C (castellated nut) and T (thin nut). These letters are not, however, applied to the nut. For example, the complete part number used on drawings or when ordering a $\frac{7}{16}$ inch UNF ordinary A107 nut is A107 LP but the nut is only marked 'A107'. Where stiffnuts are concerned the part number is not marked on nuts of any size, but over ⅜ inch diameter a letter indicating thread size is applied.

3.2.1 **Clinch Nuts, A122 to A124.** A similar coding system to that described in paragraph 3.2 is used, followed by a number indicating the length of spigot required. A choice of three spigot lengths is specified for each size of nut, depending on the thickness of material through which the nut is to be clinched.

3.3 **Stiffnuts.** As mentioned in paragraph 3.1, hexagon, clinch and strip stiffnuts are marked with a 'Unified' symbol to show the type of thread used. Anchor nuts (fixed or floating) are not so marked as the shape of the base plates is considered to be adequate for recognition purposes; these are much smaller and less angular than those fitted to similar stiffnuts with BA or BSF threads in the AGS range of specifications. In the Unified stiffnuts the base plate is integral with the nut body, but the nut portion of an AGS stiffnut is retained inside a cage.



NOTE: The nut body of any anchor stiffnut may be either hexagonal or round

Figure 3 IDENTIFICATION FEATURES, UNIFIED STIFFNUTS

3.3.1 When it is necessary to differentiate on the drawing or order between metallic and non-metallic friction element stiffnuts in the steel and corrosion-resisting steel (—75°C to +200°C) ranges, the suffix '/66' or '/77' respectively is added to the part reference. For example, the complete part reference for a $\frac{1}{4}$ inch UNF steel nut with a metallic friction element is A125 E/66, and for a nut of the same size with a non-metallic friction element A125 E/77. A part reference without such a suffix indicates that either type of nut may be used.

3.3.2 Stiffnuts complying with British Standards A180, A181, A186, A187, A192, A193, A200 and A201 may be supplied unplated for use in that condition, or for subsequent plating by the user for applications where plating other than silver is required. When ordering such nuts, '/UP' should be added to the reference number. For example, a $\frac{5}{16}$ inch UNF corrosion-resisting steel, thin, double-lug, floating anchor nut unplated, is A193 G/UP.

3.4 **Left-Hand Threads.** Left-hand threads in nuts are indicated by the use of the suffix letter 'L'. Thus the reference number for a 4-40 UNC ordinary brass nut complying with BS A210 would be A210 APL, i.e. the Standard number + the diameter letter + the nut type + left-hand thread. The letter 'L' is also applied to one of the hexagon faces of the nut. There is no provision made for left-hand threads in the specifications relating to stiffnuts.

TABLE 5

DIAMETER CODE LETTERS

UNIFIED THREADS

Code	*Size*	*Code*	*Size*
Y	0-80 UNF	J	$\frac{3}{8}$ in UNF
Z	2-64 UNF	L	$\frac{7}{16}$ in UNF
A	4-40 UNC	N	$\frac{1}{2}$ in UNF
B	6-32 UNC	P	$\frac{9}{16}$ in UNF
C	8-32 UNC	Q	$\frac{5}{8}$ in UNF
D	10-32 UNF	S	$\frac{3}{4}$ in UNF
E	$\frac{1}{4}$ in UNF	U	$\frac{7}{8}$ in UNF
G	$\frac{5}{16}$ in UNF	W	1 in UNF

4 'AS' NUTS

4.1 **Double Hexagon Stiffnuts.** A range of double-hexagon stiffnuts manufactured from heat resistant steel and having UNJF threads, is provided in the SBAC, AS series 20623 to 20630, representing thread sizes 8-36 UNJF to $\frac{9}{16}$-18 UNJF. These nuts are specified for use on the AS series of heat resistant bolts with UNJF threads, and may be identified from the AS number marked on the extended washer portion of the nut. They are illustrated in Figure 4.

4.2 **Ordinary and Anchor Stiffnuts.** A series of AS specifications for lightweight hexagon and anchor stiffnuts has been produced in the range AS 8600 to 8661 (see Table 6). These nuts are manufactured from high tensile steel and are considerably lighter than conventional nuts; all are now manufactured with UNJ threads.

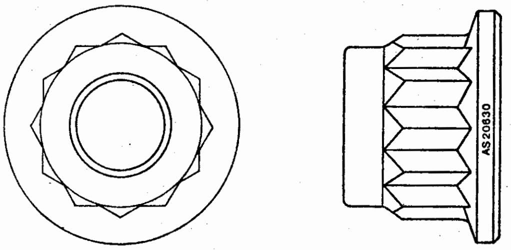


Figure 4 'AS' DOUBLE HEXAGON STIFFNUTS

4.2.1 No markings are applied to the nuts but they are quite different from either the BS or AGS stiffnuts and may be identified purely from their shape (see Figure 5). For storage and ordering purposes the nuts are identified by the AS number, followed by a size code letter as shown in Table 5. A further code is necessary for ordering strip nuts, and this consists of a number representing the distance between nut centres in eighths of an inch, followed by an additional number representing the number of nuts required in a strip. A 10-32 UNF strip nut with 0.75 inch nut spacing and having 10 nuts would therefore be, AS 8612/D/6/10.

4.2.2 As with the BS and AGS stiffnuts, the shape of the friction device is optional, the specification merely stating the maximum or minimum limits as appropriate. A further stipulation with this series of nuts is the maximum permissible weight per 100 units (and weight per inch for strip nut channels).

TABLE 6

'AS' LIGHTWEIGHT STIFFNUTS

	AS Numbers		
Material	*HTS*	*CRS*	*CRS*
Max. rated temperatures	250°C	450°C	250°C
Finish	*Cad.*	*Silver*	*Natural*
Hexagon, flange type	8600	8623	8650
Hexagon	8601	8624	8651
Double lug anchor	8602	8625	8652
Miniature double lug anchor	8603	8626	8653
Single long lug anchor	8604	8627	8654
Miniature single long lug anchor	8605	8628	8655
Miniature single short lug anchor	8606	8629	8656
Corner anchor	8607	8630	8657
Miniature corner anchor	8608	8631	8658
Double lug floating anchor	8609	8632	8659
Miniature double lug floating anchor	8610	8633	8660
Single large lug floating anchor	8611	8634	8661
Strip	8612		

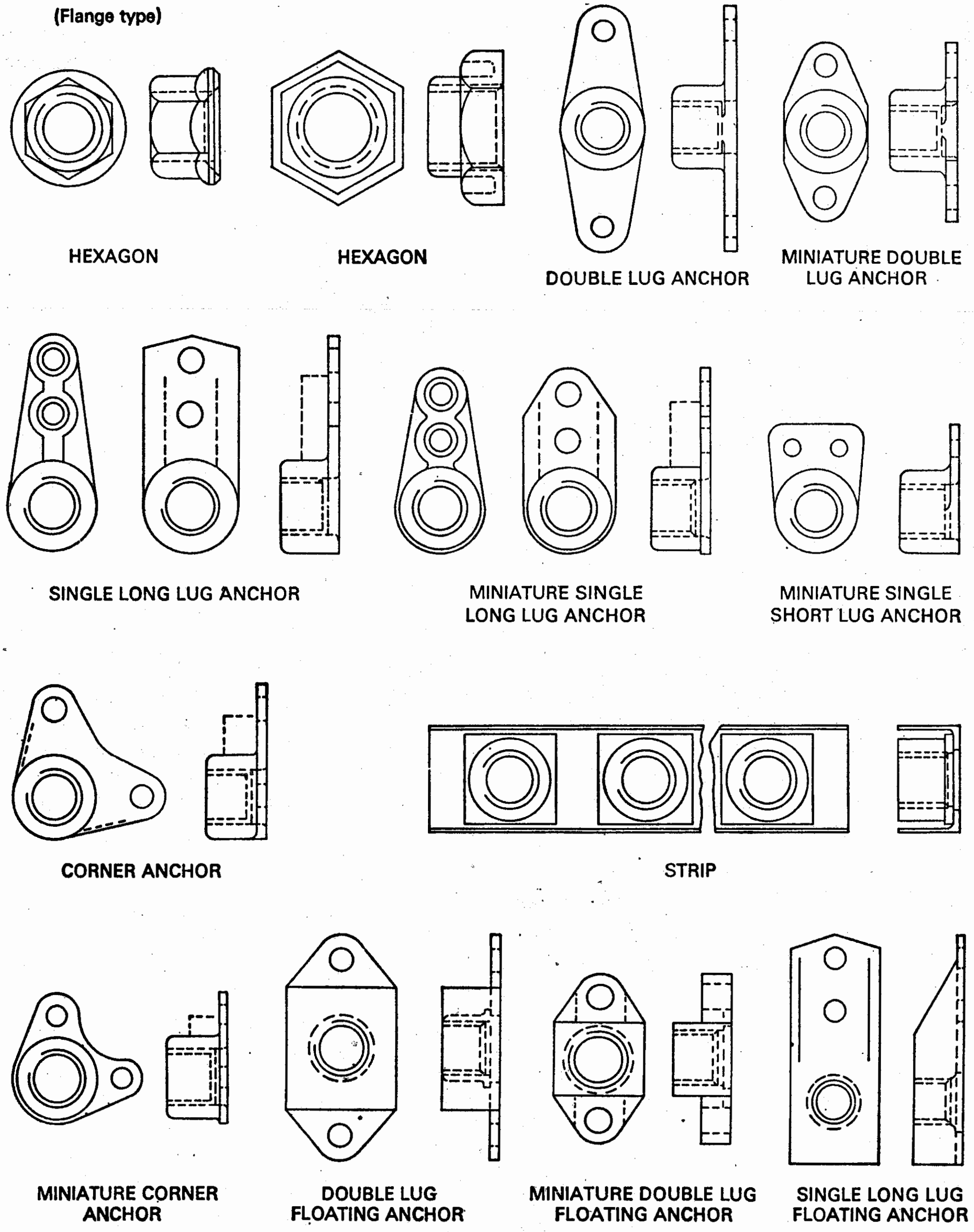


Figure 5 TYPICAL 'AS' LIGHTWEIGHT STIFFNUTS

5 AGS NUTS

5 1 **Stiffnuts.** Table 7 gives a list of the relevant AGS numbers for the various types of stiffnuts in this series; the nuts are illustrated in Figure 6 to show the differences from British Standards stiffnuts AGS stiffnuts have BA or BSF threads

TABLE 7
AGS STIFFNUTS

Type	*AGS Number*				
	Standard	*Thin*	*Csk*	*Cap*	*Csk cap*
Hexagon	2001	2002	2003	2021	2024
Single anchor, single fixing	2004*	2005*	2006*		
Single anchor, double fixing	2018	2019	2020		
Double anchor	2007	2008	2009	2023	
Floating	2012	2013	2014		
Strip	2015	2016	2017		
Clinch	2011				

* obsolescent.

5.1.1 **Code Systems.** The part referencing system consists of the AGS number, followed by a letter indicating the thread size, followed by a number indicating the material Floating anchor nuts are referenced with two material numbers, the first for the attachment plate and the second for the nut. The complete part number for a $\frac{5}{16}$ inch BSF countersunk floating anchor nut with mild steel base plate and light alloy nut would be, AGS 2014/G/13. The diameter code letters are the same as those shown in Table 2 and the material code is as follows:—

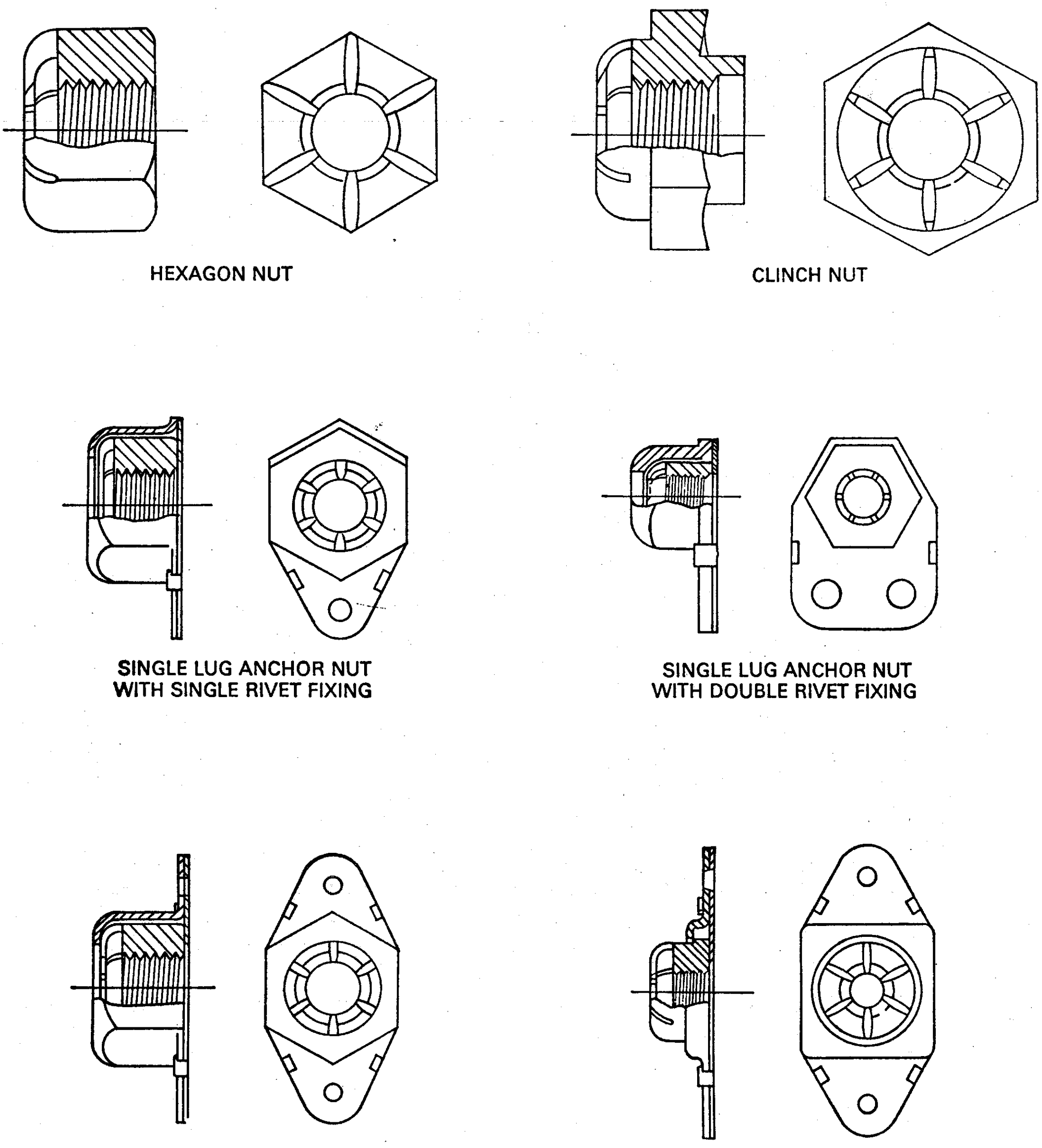
1 Mild steel, cad. plated
2 CRS or monel, cad. plated
3. Light Alloy, anodised and dyed blue
4 Brass or bronze, electro-tinned.

TABLE 8
WING NUTS

Code	*Size*	*Code*	*Size*
A	6 BA (AGS 113 only)	D	$\frac{11}{32}$ in BSF (AGS 120 only)
B	4 BA (AGS 113 only)	E	$\frac{3}{8}$ in BSF (AGS 120 only)
C	2 BA (AGS 113 only)	F	$\frac{13}{32}$ in BSF (AGS 120 only)
A	$\frac{1}{4}$ in BSF (AGS 120 only)	G	$\frac{7}{16}$ in BSF (AGS 120 only)
B	$\frac{9}{32}$ in BSF (AGS 120 only)	H	$\frac{1}{2}$ in BSF (AGS 120 only)
C	$\frac{5}{16}$ in BSF (AGS 120 only)		

5.2 AGS Nuts—Various

5.2.1 Wing Nuts AGS 113 and AGS 120 (Brass Cadmium Coated). AGS 113 relates only to BA sizes, whilst AGS 120 relates only to BSF sizes. The coding system for these nuts consists of the AGS number followed by a letter indicating the size of thread (Table 8). Example: A ¼ inch BSF brass wing nut would be AGS 120/A.



HEXAGON NUT

CLINCH NUT

SINGLE LUG ANCHOR NUT WITH SINGLE RIVET FIXING

SINGLE LUG ANCHOR NUT WITH DOUBLE RIVET FIXING

DOUBLE LUG ANCHOR NUT

FLOATING ANCHOR NUT

Figure 6 TYPICAL AGS STIFFNUTS

5.2.2 **Wing Nuts AGS 3413.** These are cadmium coated brass wing nuts with Unified threads in the sizes 4-40 UNC to ½ inch UNF. The coding system consists of the AGS number followed by a letter indicating the thread size (Table 5).

5.2.3 **BSP Union Lock Nuts, AGS 207 (Mild Steel, cad. plated), AGS 224 (Brass, cad. plated) and AGS 957 (Al Al anodised).** The coding system used for these nuts consists of the AGS number (which indicates the type of material), followed by a letter indicating the thread size. The letters A to E are used, representing the sizes ⅛ inch BSP to ⅝ inch BSP in steps of ⅛ inch. A ½ inch BSP brass lock nut would therefore be AGS 224/D.

5.2.4 **Thin Nuts BSP and Whitworth Form, AGS 1148 (Al Al anodised).** The coding system used for these nuts consists of the AGS number, followed by a letter indicating the thread size (Table 9). Example: A ½ inch BSP nut would be AGS 1148/D.

TABLE 9

THIN NUTS

Code	*Size*	*Code*	*Size*
A	⅛ in BSP	F	¾ in BSP
B	¼ in BSP	G	⅞ in BSP
BB	19 t.p.i. Whit. Form 0.60 o/d	H	1·0 in BSP
C	⅜ in BSP	J	1¼ in BSP
CC	14 t.p.i. Whit. Form 0.75 o/d	K	1½ in BSP
D	½ in BSP	L	1¾ in BSP
E	⅝ in BSP	M	2·0 in BSP

5.2.5 **Union Nuts AGS 1187 (Al Al Anodised), AGS 1216 (Mild Steel, Cadmium treated) and AGS 1217 (Brass, Cadmium treated).** The coding system used for these nuts consists of the AGS number, followed by a letter indicating the thread size (Table 9). Example: A ¼ inch BSP union nut made of brass would be AGS 1217/B.

5.2.6 **L.T. Union Lock Nut, AGS 1710.(Brass, tinned).** This nut is made in one size only, i.e. ½ inch x 26 t.p.i. Whitworth form.

6 FUTURE TRENDS

6.1 The need for saving weight on aircraft structures has led to the widespread use of lightweight fasteners of all types, particularly of self-locking nuts and anchor nuts. The use of lightweight and miniature stiffnuts was pioneered in the United States and although these nuts are readily available in this country, very few of British design are, as yet, manufactured in Great Britain.

6.2 Aircraft manufacturers are tending to make greater use of the UNJ thread form because of its high resistance to fatigue. All future specifications for aircraft fasteners are expected to stipulate this thread and some existing specifications for nuts contain a clause requiring the thread to be of UNJ form after a specified date. Nuts with UNJ threads are fully interchangeable with nuts having standard Unified threads of the same class, the only difference being a slight increase in the minor diameter to accommodate the increased root radius of the external thread.

6.3 In view of the general acceptance of metric dimensions in other fields, it seems likely that the metric thread of UNJ form will eventually be used internationally and result in further specifications for nuts in both the AS and BS series. It is expected that fasteners having metric threads will be identified by marking with the letter 'M'.

7 ABBREVIATIONS AND TERMS USED

AGS	Aircraft General Standards.
Al Al	Aluminium Alloy.
AS	Aircraft Standards of the SBAC.
Attachment Plate	The formed sheet metal plate of a floating anchor nut which is riveted to the structure. It retains the nut body and base plate, allowing a specified amount of movement in relation to the structure.
BA	British Association.
Base Plate	The plate, normal to the axis of the nut, which forms the riveting lugs of a fixed anchor nut. In a floating anchor nut it retains the nut body in the attachment plate.
BS	British Standard.
BSF	British Standard Fine.
BSP	British Standard Pipe.
Cap Nut	A stiffnut, the threaded bore of which is sealed by a metal cap to prevent the leakage of fluids.
Clinch Nut	A self-retaining stiffnut having a spigot at the bearing face which is spread to hold the nut in position.

CRS	Corrosion resisting steel.
Fixed Anchor Nut	A stiffnut which is rigidly attached to the structure.
Floating Anchor Nut	A stiffnut which has a limited amount of movement in a plane normal to the axis of the nut for purposes of alignment.
Friction Element	The portion of a stiffnut, above the nut body, designed to impose friction between the nut and the thread on which it is mounted. The shape of the friction element varies with different designs but must be contained within the maximum plan form and height quoted in the appropriate specification.
HTS	High Tensile Steel. Normally implying a tensile strength in excess of 50 tonf/in^2, but in some specifications the smaller fasteners may be manufactured from material with a lower tensile strength.
HTSS	High Tensile Stainless Steel.
LTS	Low Tensile Steel. Steel with a tensile strength of up to approximately 25 tonf/in^2.
MTS	Medium Tensile Steel. Steel with a tensile strength between that of LTS and HTS.
Nut Body	The portion of a stiffnut containing the screw thread.
SS	Stainless Steel.
Stiffnut	A nut body surmounted by a device which imposes friction between the nut and the thread on which it is mounted so that no other form of locking is required.
Strip Nuts	A row of stiffnuts mounted on a common attachment plate in the form of a continuous strip.
t.p.i.	Threads per inch.
UNC	Unified Coarse Thread.
UNF	Unified Fine Thread.

UNJ	Unified thread with increased root radius for added fatigue resistance. Ranges of fine threads (UNJF) and coarse threads are provided in this series.
UNS	Threads of basically Unified form but differing slightly from the standard Unified series.
Whit.	Whitworth.

BL/2-7

Issue 1.

3rd *December,* 1976.

BASIC

IDENTIFICATION MARKING

STANDARD FASTENERS OF AMERICAN MANUFACTURE

1 INTRODUCTION This Leaflet gives guidance on the identification and coding of bolts, nuts, screws and washers which are manufactured to American National Standards and are used for general aircraft assembly. Many other types of American fasteners are used on aircraft, particularly in the field of light-weight, self-locking nuts and bolts, and these are approved for use by the relevant manufacturer or Airworthiness Authority; these fasteners will not necessarily be marked or identified in accordance with the national standards, but will comply with information published by the particular manufacturer.

2 SPECIFICATIONS Standard aircraft fasteners in America are manufactured in accordance with Government, Military and Civil Specifications. The following series of specifications cover the materials, processes, and component drawings for all standard fasteners:—

Federal Specifications
Society of Automotive Engineers Specifications (SAE)
Aeronautical Materials Division of SAE Specifications (AMS)
Air Force/Navy Specifications (AN)
Military Standards (MIL and MS)
National Aerospace Standards (NAS)

2.1 These specifications provide for a range of fasteners with Unified threads in the UNC, UNF and UNJF series (see Leaflet **BL/3-2** for full details of Unified threads). However, whereas for British aircraft, fasteners are manufactured in a selected range of Unified threads, American fasteners are, in some instances, supplied with both UNC and UNF threads. Extreme care is necessary when matching up nuts with screws or bolts in these series. If not properly identified, then thread gauges must be used to check the thread. Visual comparison of small threads is not recommended.

2.2 The various standards are dealt with separately in this Leaflet, and it should be noted that the AN series has to a large extent been replaced by MS and NAS components.

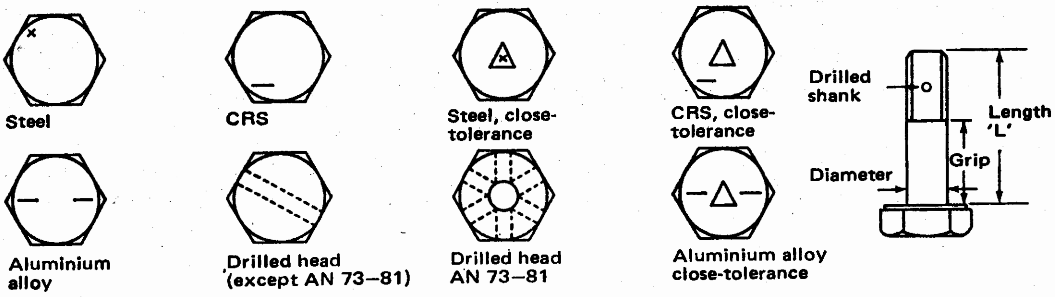
3 AN FASTENERS These specifications are in two series. The early series has numbers from 3 to 9000, with the fasteners occupying a range from 3 to 1000; these fasteners are of comparatively low strength, and are manufactured in steel or aluminium alloy. The steel parts are generally manufactured from low-alloy steel, and if non-corrosion-resistant, are cadmium plated, whilst the aluminium parts are anodised. The later series parts have six figure numbers commencing with 100000, are of more recent design and are generally manufactured from higher-strength materials.

3.1 **Early Series AN Bolts.** Table 1 gives a list of the early series AN Bolts, and Fig. 1 shows the types of heads and the identification marking used to indicate the material from which the parts are made.

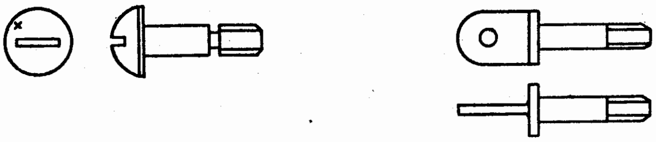
TABLE 1 EARLY SERIES AN BOLTS

AN Number	Type	Material	Process	Nominal Range of Thread Sizes **	Thread
3 – 20	Bolt, hexagon head	Steel	Cad. plated	No.10 to 1¼ in	UNF
		CRS *	Nil		
		Al. alloy	Anodised		
21 – 36	Bolt, clevis	Steel	Cad. plated	No.6 to 1 in	UNF
42 – 49	Bolt, eye	Steel	Cad. plated	No.10 to $\frac{9}{16}$ in	UNF
73 – 81	Bolt, hexagon, drilled head	Steel	Cad. plated	No.10 to ¾ in	UNF or UNC
173 – 186	Bolt, close-tolerance	Steel	Cad. plated thread and head	No.10 to 1 in	UNF
		CRS *	Nil		
		Al. alloy	Anodised		

* CRS = Corrosion-resistant steel. ** See Leaflet BL/3–2 for details of thread designations.



HEXAGON-HEAD BOLTS



CLEVIS BOLT EYE BOLT

Figure 1 EARLY SERIES AN BOLTS

3.1.1 All of the bolts listed in Table 1 may be identified as to type by reference to the head marking or position of the locking wire holes. Diameter may be identified by experience, or by measurement and reference to the specification. Other dimensions such as grip length, head size and thread length, must be obtained from the specification.

3.1.2 **Coding.** For identification purposes the AN number is used to indicate the type of bolt and its diameter, and a code is used to indicate the material, length and thread (where these vary) and the position of the locking wire or cotter pin (split pin) hole.

(a) **Diameter.** The last figure or last two figures of the AN number indicate the diameter of the thread. 1 = No.6, 2 = No.8, 3 = No.10, and 4 = $\frac{1}{4}$ in, and subsequent numbers indicate the diameter in $\frac{1}{16}$ in increments; above $\frac{5}{8}$ in the available sizes are in $\frac{1}{8}$ in steps, but are still coded in sixteenths. Thus an AN 4 is a hexagon head bolt with $\frac{1}{4}$ in thread, an AN 14 is a hexagon head bolt with a $\frac{7}{8}$ in ($\frac{14}{16}$) thread and an AN 182 is a close-tolerance bolt with a $\frac{3}{4}$ in ($\frac{12}{16}$) thread (the numbering in this case starting at 173). An exception to this is the eye bolt, where different diameter pin holes affect the coding; AN 42 is No.10, AN 43 is $\frac{1}{4}$ in, AN 44 is $\frac{5}{16}$ in with a $\frac{1}{4}$ in diameter pin hole, and AN 45 is $\frac{5}{16}$ in with a $\frac{5}{16}$ in diameter pin hole.

(b) **Length.** The length of a bolt as quoted in the specifications, is the overall length from under the head to the end of the shank (L in Fig. 1), but the length is generally regarded as from under the head to the first full thread (excluding the chamfer) and is quoted in $\frac{1}{8}$ in increments as a 'dash' number. The last figure of the dash number represents eighths of an inch, and the first figure of the dash number represents inches. Thus an AN 4–12 is a $\frac{1}{4}$ in hexagon-head bolt $1\frac{1}{4}$ in (i.e. $1\frac{2}{8}$) long, and an AN 12–24 is a $\frac{3}{4}$ in hexagon-head bolt $2\frac{1}{2}$ in long. The total lengths quoted in the specifications for these bolts, is actually $1\frac{9}{32}$ in and $2\frac{21}{32}$ in, respectively. Clevis bolts (AN 21 to 36) do not follow this coding, but the length is indicated in $\frac{1}{16}$ in increments by the dash number; thus an AN 29–9 is $\frac{9}{16}$ in long.

(c) **Position of Drilled Hole.** Bolts are normally supplied with a hole drilled in the threaded part of the shank, but different arrangements may be obtained by use of the following code:—

Drilled shank = normal coding, e.g. AN 24–15.

Undrilled shank = A added after dash number, e.g. AN 24–15A.

Drilled head only = H added before dash number (replacing the dash sign) and A added after dash number, e.g. AN 6H10A.

Drilled head and shank = H added before dash number, e.g. AN 6H10.

(d) **Material.** The standard coding applies to a non-corrosion-resistant, cadmium-plated steel bolt. Where the bolt is supplied in other materials, letters are placed after the AN number as follows:—

C = corrosion-resistant steel (CRS)

DD = aluminium alloy, e.g. AN 6DD10.

(e) **Thread.** Where the bolt is supplied with either UNF or UNC threads, a UNC thread is indicated by placing an 'A' in place of the dash, e.g. AN 74A6.

TABLE 2 EARLY SERIES AN MACHINE SCREWS

AN Number	Type	Material	Process	Head Marking*	Nominal Range of Thread Sizes	Thread
500	Screw, fillister head	Steel	Cad. plated		No.2 to $\frac{3}{8}$ in	UNC
		CRS	Nil			
		Brass	Nil			
501	Screw, fillister head	Steel	Cad. plated		No.0 to $\frac{3}{8}$ in	UNF
		CRS	Nil			
		Brass	Nil			
502	Screw, fillister head (drilled)	Steel	Cad. plated	XX	No.10 to $\frac{5}{16}$ in	UNF
503	Screw, fillister head (drilled)	Steel	Cad. plated	XX	No.6 to $\frac{5}{16}$ in	UNC
505	Screw, flat 82°	Steel	Cad. plated	— —	No.2 to $\frac{3}{8}$ in	UNC
		CRS	Nil			
		Brass	Nil			
		Al. alloy	Anodised			
507	Screw, flat 100°	Steel	Cad. plated		No.6 to ¼ in	UNC and UNF
		CRS	Nil	— —		
		Brass	Black oxide			
		Brass	Nil			
		Al. alloy	Anodised			
509	Screw, flat 100° structural	Steel	Cad. plated	XX	No.8 to $\frac{5}{16}$ in	UNF
		Al. alloy	Anodised			
		Bronze	Cad. plated	= =		
		Bronze	Nil	= =		
510	Screw, flat 82°	Steel	Cad. plated		No.5 to ¼ in	UNF
		CRS	Nil	— —		
		Brass	Nil			
		Al. alloy	Anodised			
515	Screw, round head	Steel	Cad. plated		No.5 to $\frac{3}{8}$ in	UNC
		CRS	Nil	— —		
		Brass	Nil			
		Al. alloy	Anodised			
520	Screw, round head	Steel	Cad. plated		No.5 to ¼ in	UNF
		CRS	Nil	— —		
		Brass	Nil			
		Al. alloy	Anodised			
525	Screw, washer head	Steel	Cad. plated		No.8 to ¼ in	No.8 UNC & UNF No.10 UNF ¼ in UNF
526	Screw, truss head	Steel	Cad. plated		No.6 to ¼ in	UNF and UNC
		CRS	Nil	— —		
		Al. alloy	Anodised			

*Only one symbol may be found on some screw heads

3.2 **Early Series AN Machine Screws.** Screws differ from bolts in being made from a lower strength material, having a looser fit (class 2A thread instead of class 3A) and having a slotted or a cruciform-recessed head, for rotation by a suitably-shaped screwdriver. The thread is usually continued up to the head, but the shank of 'structural' screws (i.e. AN 509 and 525) has a plain portion and may be used in locations where shear loading is present. Some screw heads are marked to indicate the material from which they are made, and these markings are listed in Table 2. The markings, head shape and material will enable identification of a particular screw to be made. Table 2 lists the AN machine screws, and Fig. 2 illustrates the various head shapes. It should be noted that some of these screws are obsolescent, and may not be available in the full range of sizes.

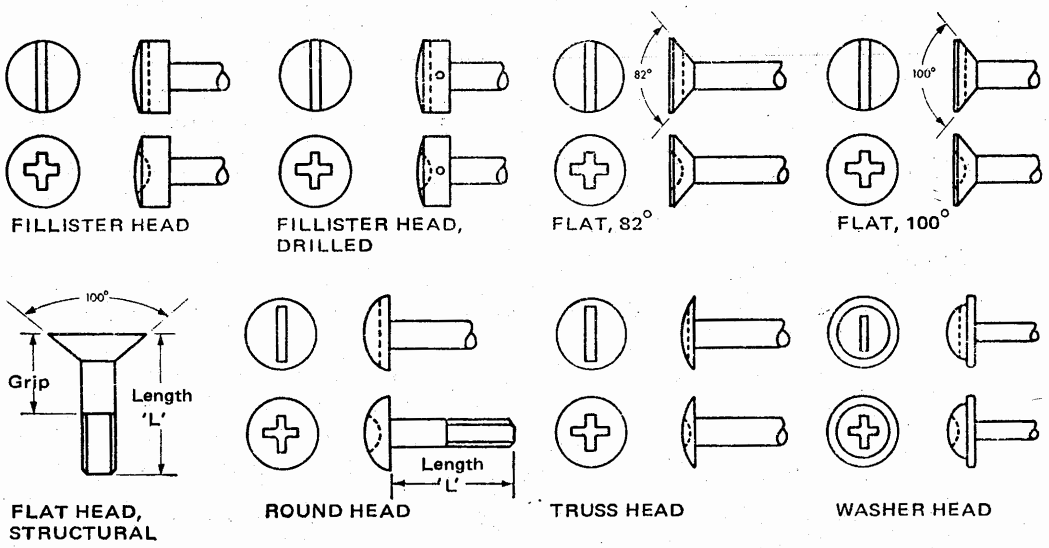


Figure 2 EARLY SERIES AN SCREWS

3.2.1 **Coding.** Screws are coded by the AN number, to indicate the type (e.g. round head), letters to indicate material (and in some cases the shape of the screwdriver recess), and two dash numbers indicating diameter and length. In addition, some are coded to indicate whether the head is drilled or not.

(a) **Diameter.** The coding for the diameter depends on whether the screw is available with only fine or coarse threads, or with either type of thread. Diameter is indicated by the first dash number.

(i) Screws available with only one type of thread are coded by the thread number or diameter in sixteenths of an inch. For example, No.4 (UNC or UNF) = —4, No.10 (UNC or UNF) = —10, $\frac{1}{4}$ in (UNC or UNF) = —416, $\frac{5}{16}$ in (UNC or UNF) = —516, etc.

(ii) Screws available with both coarse and fine threads (AN 507, AN 525 and AN 526) are coded by the thread number or diameter in sixteenths of an inch, followed by the number of threads per inch. For example, No.6–32 (UNC) = —632, No.8–36 (UNF) = —836, $\frac{1}{4}$–20 (UNC) = —420, $\frac{1}{4}$–28 (UNF) = —428, etc.

(iii) AN 525 screws are available in only one coarse thread size (No.8) and this is coded —832. The remaining sizes are coded in accordance with (i).

(b) **Length.** The second dash number indicates the length (L in Fig. 2) of a screw in sixteenths of an inch. AN 509 screws are an exception to this rule, the actual length of the screw being $\frac{1}{32}$ in longer than the size indicated by the code.

(c) **Material.** Material is indicated by a letter (or letters) placed after the AN number as follows:—

Steel = no letter
CRS = C
Brass (unplated), AN 507 = UB, and other screws = B
Brass (black oxide), AN 507 = B
Aluminium alloy, AN 507, 509 and 526 = DD, and other screws = D
Bronze (cad. plated), AN 509 = P
Bronze (unplated), AN 509 = Z

(d) **Head Recess.** Where a screwdriver slot is required the basic code only is used. Where a cruciform recess is required, 'R' is added instead of the second dash.

(e) **Drilled Head.** AN 500 and 501 screws are provided with plain or drilled heads. The letter A before the first dash number indicates a screw with a drilled head.

(f) **Examples of Coding**

(i) An AN 500A6–32 is a fillister head screw with a locking wire hole. It is made of cadmium-plated steel, has a No.6 (UNC) thread, has a slotted head and is 2 in long.

(ii) An AN 507C832R8 is a 100° flat head screw in corrosion-resistant steel. It has a No.8–32 (UNC) thread, has a cruciform recessed head and is $\frac{1}{2}$ in long.

(iii) An AN 509DD416–20 is a 100° flat head, structural screw in aluminium alloy. It has a $\frac{1}{4}$ in (UNF) thread, has a slotted head and is $1\frac{9}{32}$ in long.

3.3 **Early Series AN Nuts.** These nuts are made in a variety of different materials, and should normally be used with early series AN bolts and AN screws. Some nuts are designed specifically for use in engines, and should not be used in airframe locations; they are thicker than standard airframe nuts. Early series AN nuts are not marked for identification purposes, but can be recognized from their shape and surface finish. Table 3 gives a list of these nuts, and Fig. 3 illustrates the various types. As with the AN screws, some nuts may be obsolescent, and not available in the full range of sizes.

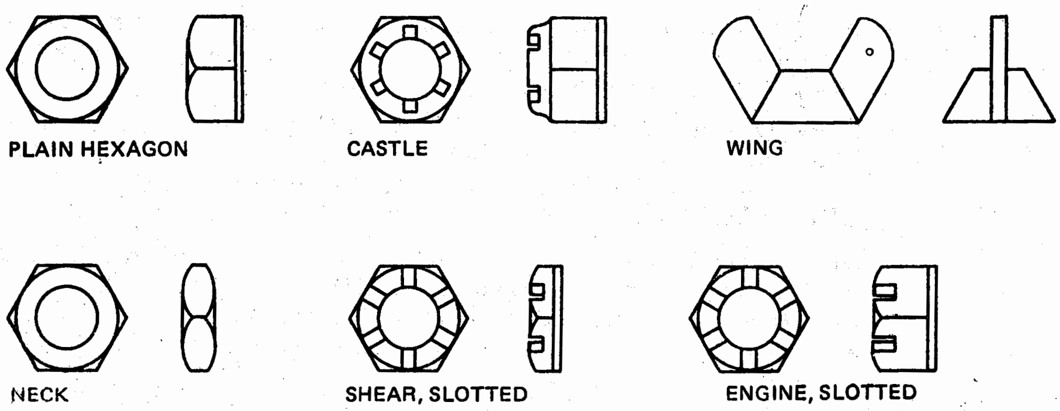


Figure 3 EARLY SERIES AN NUTS

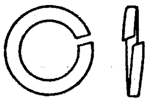
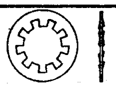
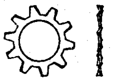
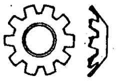
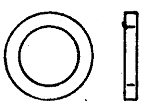
3.3.1 **Coding.** The nuts listed in Table 3 are coded according to the type and size of thread, by a dash number placed after the AN number. Those nuts which are intended for use with AN bolts have the same code as the bolts, i.e. a number indicating thread diameter in sixteenths of an inch, and No.6, No.8 and No.10 threads being —1, —2 and —3, respectively. Those nuts intended for use with machine screws (AN 340 and 345) are coded according to the code for screws. The code represents the thread number (—0 to —10) or the diameter in sixteenths of an inch (—416, —516, etc.) as detailed in paragraph 3.2.1 (a)(i). Wing nuts (AN 350) are coded by the thread designation (—640, —832, etc.) or thread diameter in the fraction sizes (—4 = ¼ in, —5 = $\frac{5}{16}$ in, etc.). Material is indicated by a letter placed in the code instead of the dash; C = corrosion-resistant steel, DD = aluminium alloy, machine-screw nuts, D = other aluminium alloy nuts, B = brass, and the absence of a letter indicates a non-corrosion-resistant steel nut. With AN 315 and 316 nuts, 'L' or 'R' is added after the code to indicate left- or right-hand threads. Examples of this coding are: AN 350B4 is a brass wing nut to fit a ¼ in bolt, and AN 316–6L is a steel check nut to fit a ⅜ in bolt with a left-hand thread.

TABLE 3 EARLY SERIES AN NUTS

AN Number	Type	Material	Process	Nominal Range of Thread Sizes	Thread
310	Nut, castle	Steel CRS Al. alloy	Cad. plated Nil Anodised	No.10 to 1¼ in	UNF
315	Nut, plain	Steel CRS Al. alloy	Cad. plated Nil Anodised	No.6 to 1¼ in (also left-hand thread)	UNF
316	Nut, check	Steel	Cad. plated	¼ to 1 in (also left-hand thread)	UNF
320	Nut, castle, shear	Steel CRS Al. alloy	Cad. plated Nil Anodised	No.6 to 1¼ in	UNF
340	Nut, machine screw, hexagon	Steel CRS Brass Al. alloy	Cad. plated Nil Nil Anodised	No.2 to ¼ in No.2 to ¼ in No.2 to No.6 No.6 to ⅜ in	UNC
345	Nut, machine screw, hexagon	Steel CRS Brass Al. alloy	Cad. plated Nil Nil Anodised	No.0 to ¼ in No.0 to ¼ in No.0 to No.10 No.10 to ¼ in	UNF
350	Nut, wing	Steel Brass	Cad. plated Nil	No.6 to ½ in	UNF
355	Nut, engine, slotted	Steel	Cad. plated	No.10 to ¾ in	UNF
360	Nut, engine, plain	Steel	Cad. plated	No.10 to ¾ in	UNF

3.4 **Early Series AN Washers.** AN Standards include three types of washers, and, although these have been replaced in later aircraft designs by MS washers, they may still be found on some older types of aircraft and are included for reference. These washers are listed and illustrated in Table 4.

TABLE 4 EARLY SERIES AN WASHERS

AN Number	Type	Shape	Material	Process	Material Code
935	Washer, lock, spring		Steel Bronze CRS	Cadmium plated Nil	Nil B C
936	Washer, shake-proof	A  B  C 	Steel Bronze	Cadmium plated Tinned	Nil B
960	Washer, plain		Steel CRS Brass Al. alloy Al. alloy	Cadmium plated Nil Nil Nil Anodised	Nil C B D PD

3.4.1 **Coding.** Washers are identified by the AN number, a dash number to indicate size, and letters to indicate material and finish.

(a) **Size.** The size of a washer is related to the size of bolt it is designed to fit, and the dash number is in accordance with the code outlined in paragraph 3.2.1 (a) (i).

(b) **Material.** Material is indicated in the code by adding the letters shown in Table 4.

(c) **Thickness.** AN 935 and 960 washers may be available in light or regular thickness, the light washer being indicated by an 'L' at the end of the code. Actual thicknesses should be obtained from the AN Standard.

(d) **Examples**

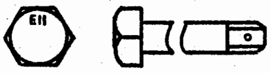
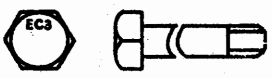
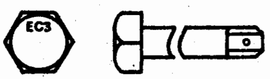
(i) AN 936A416B is a style A regular shakeproof washer designed to fit a $\frac{1}{4}$ in bolt and is made of bronze.

(ii) AN 960 C–616L is a light plain washer in corrosion-resistant steel, for a $\frac{3}{8}$ in bolt.

3.5 **Late Series AN Fasteners.** These fasteners are all marked to show the material from which they are made. When ordering a particular fastener, the part number should be taken from the tables in the appropriate specification, since the size cannot be determined from a standard coding. Tables 5, 6 and 7 list the various bolts, screws and nuts which are currently available in this series of specifications, and give the range of numbers allocated to each type.

3.5.1 Late series AN bolts are listed in Table 5 and are available in sizes 10–32, $\frac{1}{4}$–28, $\frac{5}{16}$–24, $\frac{3}{8}$–24, $\frac{7}{16}$–20, $\frac{1}{2}$–20, $\frac{9}{16}$–18, $\frac{5}{8}$–18 and $\frac{3}{4}$–16.

TABLE 5 LATE SERIES AN BOLTS

AN Number	Type	Material	Identification
101001–101900	Bolt, hexagon head	Alloy steel (AMS 6322) cadmium plated	
101901–102800	Bolt, hexagon head, drilled shank		
102801–103700	Bolt, hexagon head, drilled head (1 hole)		
103701–104600	Bolt, hexagon head, drilled head (6 holes)		
104601–105500	Bolt, hexagon head	Corrosion-resistant steel (AMS 7472)	
105501–106400	Bolt, hexagon head, drilled shank		
106401–107300	Bolt, hexagon head, drilled head (1 hole)		
107301–108200	Bolt, hexagon head, drilled head (6 holes)		

3.5.2 Late series AN screws are listed in Table 6, and are available in the sizes shown.

3.5.3 Late series AN nuts are listed in Table 7 and are available in the sizes shown.

3.5.4 A plain washer is also available in the late series AN specifications. This is a plain steel washer of cadmium plated steel (AMS 6350), made to fit bolts in sizes No.10 to 1 in, and given a number in the range 122576 to 122600. The washers are rubber stamped with the mark 'E 23'.

4 **MS FASTENERS** A wide variety of fasteners is available in the MS range. All of these fasteners are marked to show the material from which they are made or the MS specification to which they conform; in addition, most fasteners are marked with the manufacturer's identification. Bolts and screws are marked on their heads, and nuts are marked either on the flat (hexagon nuts) or on the top face (other types). To assist in identification, Fig. 4 illustrates the various types of bolt and screw heads in this series, and these are referred to in the appropriate Tables. Nuts are similar to those illustrated in Table 7.

TABLE 6 LATE SERIES AN SCREWS

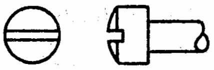
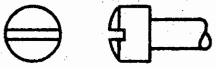
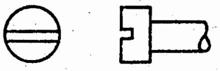
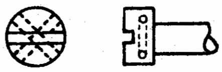
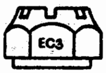
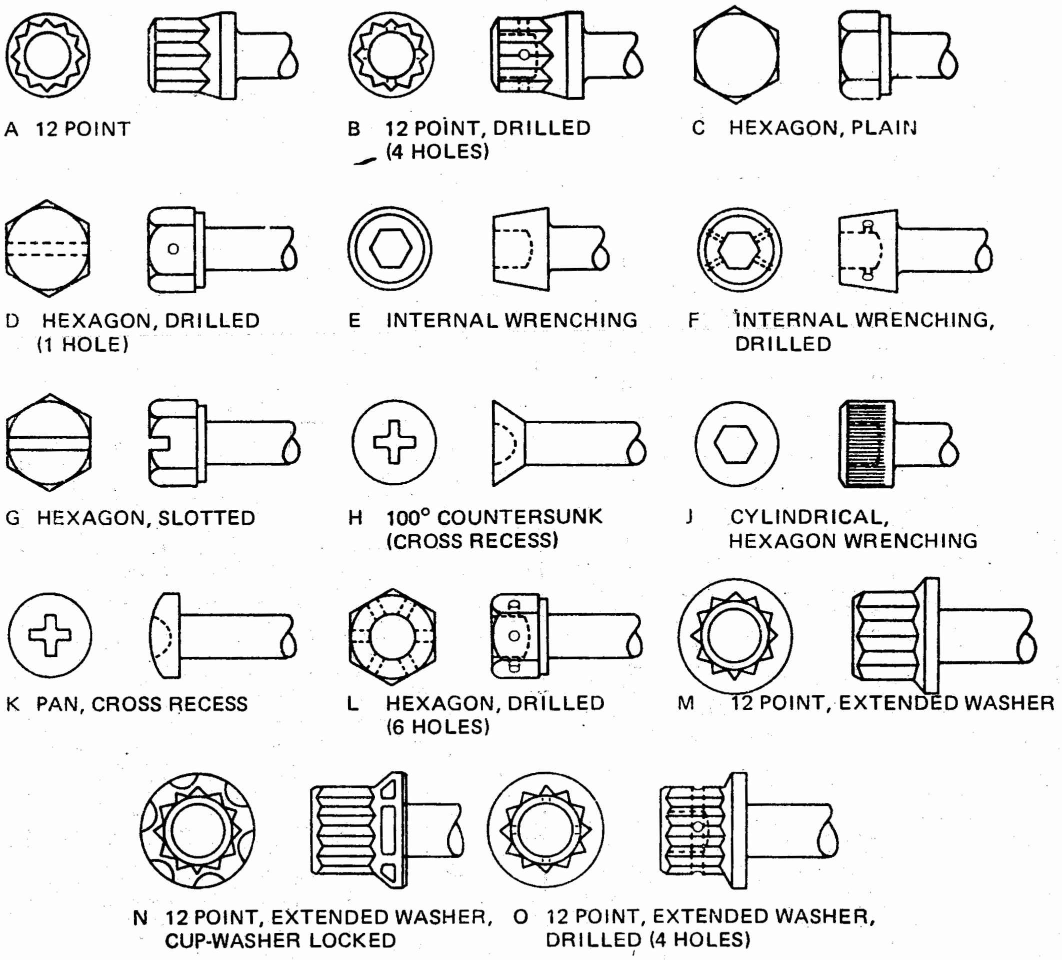
AN Number	Type	Material	Sizes	Identification
116901–116912	Screw, oval fillister	Carbon steel (AMS 5061) cadmium plated	4–40	
116913–116924	Screw, oval fillister, drilled		4–40	
116925–116960	Screw, oval fillister		6–32	
116961–117000	Screw, oval fillister, drilled		6–32	
117001–117040	Screw, oval fillister		8–32	
117041–117080	Screw, oval fillister, drilled		8–32	
115401–115600	Screw, flat fillister	Alloy steel (AMS 6322) cadmium plated	UNF No. 10 to $\frac{3}{8}$ in	
115601–115800	Screw, flat fillister, drilled shank			
115801–116150	Screw, flat fillister, drilled head		No. 10 UNF ¼ to $\frac{3}{8}$ in UNF ¼ to $\frac{3}{8}$ in UNC	

TABLE 7 LATE SERIES AN NUTS

AN Number	Type	Material	Sizes	Identification
121501–121525	Nut, hexagon, plain	Alloy steel (AMS 6322) cadmium plated	No. 10 to 1 in UNF	
121551–121575	Nut, hexagon, castle			
121526–121550	Nut, hexagon, plain	Corrosion-resistant steel (AMS 7472)		
121576–121600	Nut, hexagon, castle			
150401–150425	Nut, hexagon, check	Alloy steel (AMS 6320) cadmium plated	No. 10 to ¾ in UNF	
150426–150450	Nut, hexagon, shear, slotted			



A 12 POINT

B 12 POINT, DRILLED (4 HOLES)

C HEXAGON, PLAIN

D HEXAGON, DRILLED (1 HOLE)

E INTERNAL WRENCHING

F INTERNAL WRENCHING, DRILLED

G HEXAGON, SLOTTED

H 100° COUNTERSUNK (CROSS RECESS)

J CYLINDRICAL, HEXAGON WRENCHING

K PAN, CROSS RECESS

L HEXAGON, DRILLED (6 HOLES)

M 12 POINT, EXTENDED WASHER

N 12 POINT, EXTENDED WASHER, CUP-WASHER LOCKED

O 12 POINT, EXTENDED WASHER, DRILLED (4 HOLES)

Figure 4 MS BOLTS AND SCREWS

4.1 **MS Bolts.** Table 8 lists a wide range of bolts and screws in the MS series. It should be noted, however, that the term 'bolt' is applied to the whole range of sizes in which a particular item is supplied. In the specifications, an item with a No. 8 or smaller thread is generally termed a 'screw', regardless of the fact that it is identical in shape and material to a larger item, which is termed a 'bolt'. However, in some cases the term 'bolt' is also applied to an item with a No. 8 thread.

4.1.1 **Coding.** For most of the items listed in Table 8, the MS number relates to an item of a particular diameter, and a table provided in the specification details the range of lengths available in that size. Length is indicated by a dash number, but the length indicated by a particular dash number varies with the diameter, so that the complete part number of a particular item can only be determined by reference to the specifications.

TABLE 8 MS BOLTS AND SCREWS

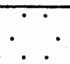
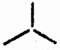
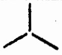
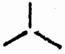
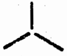
MS Number	Type	Head Shape (Fig. 4)	Head Marking	Thread	Thread Size Range	Material*	Plating
9033–9038	Bolt, 12 point, heat resistant	A	EH 19	UNF	No.10 – ½ in	AMS 5735	Nil
9060–9066	Bolt, 12 point, drilled, extended washer head	O	EH 19	UNF	No.10 – ½ in	AMS 5735	Nil
9088–9094	Bolt, 12 point, drilled head	B	E 11	UNF	No.10 – $\frac{9}{16}$ in	AMS 6322	Cad.
9110–9113	Bolt, 12 point, extended washer head	M	MS No.	UNF	No.10 – ⅜ in	AMS 5731	Nil
9146–9152	Bolt, 12 point	A	E 11	UNF	No.10 – $\frac{9}{16}$ in	AMS 6322	Cad.
9157–9163	Bolt, 12 point	A	E 11	UNF	No.10 – $\frac{9}{16}$ in	AMS 6322	Black oxide
9169–9175	Bolt, 12 point, drilled head	B	E 11	UNF	No.10 – $\frac{9}{16}$ in	AMS 6322	Black oxide
9177 and 9178	Screw, 12 point, extended washer head	N	EH 19	UNF	No.6 & No.8	AMS 5735	Nil
9183 and 9184	Screw, 12 point, drilled head	B	E 11	UNF	No.6 & No.8	AMS 6322	Cad.
9185 and 9186	Screw, 12 point	A	E 11	UNF	No.6 & No.8	AMS 6322	Cad.
9189 and 9190	Screw, 12 point	A	E 11	UNF	No.6 & No.8	AMS 6322	Black oxide
9191 and 9192	Screw, 12 point, drilled head	B	E 11	UNF	No.6 & No.8	AMS 6322	Black oxide
9206–9214	Bolt, 12 point, extended washer head	M	MS No.	UNJF	No.6 – $\frac{9}{16}$ in	AMS 6304	Diffused nickel cadmium
9215–9222	Bolt, 12 point, extended washer, drilled head	O	MS No.	UNJF	No.6 – ½ in	AMS 6304	Diffused nickel cadmium
9224	Bolt, 12 point, heat resistant	A	EH 19	UNF	$\frac{9}{16}$ in	AMS 5735	Nil
9281–9291	Bolt, hexagon head	C	MS No.	UNF	No.4 – ¾ in	AMS 6322	Black oxide
9292–9302	Bolt, hexagon head, drilled	D	MS No.	UNF	No.4 – ¾ in	AMS 6322	Black oxide
9438–9448	Bolt, hexagon head, drilled	D	MS No.	UNJF	No.6 – ¾ in	AMS 6304	Diffused nickel cadmium
9449–9459	Bolt, hexagon head	C	MS No.	UNJF	No.6 – ¾ in	AMS 6304	Diffused nickel cadmium
9487–9497	Bolt, hexagon head	C	MS No.	UNJF	No.8 – ¾ in	AMS 5731	Nil
9498–9508	Bolt, hexagon head, drilled	D	MS No.	UNJF	No.6 – ¾ in	AMS 5731	Nil
9516–9526	Screw, hexagon head	C	MS No.	UNJF	No.4 – ¾ in	AMS 6322	Cad.
9527–9537	Screw, hexagon head, drilled	D	MS No.	UNJF	No.4 – ¾ in	AMS 6322	Cad.
9554–9562	Bolt, 12 point, extended washer head, PD shank	M	MS No.	UNJF	No.6 – $\frac{9}{16}$ in	AMS 5731	Nil
9563–9571	Bolt, 12 point, ext. washer, drilled head, PD shank	O	MS No.	UNJF	No.6 – $\frac{9}{16}$ in	AMS 5731	Nil
9572–9580	Bolt, 12 point, extended washer head	M	MS No.	UNJF	No.6 – $\frac{9}{16}$ in	AMS 5731	Silver plated
9583–9591	Bolt, hexagon head, drilled	L	MS No.	UNJF	No.10 – ¾ in	AMS 5731	Nil

TABLE 8 (continued)

MS Number	Type	Head Shape (Fig. 4)	Head Marking	Thread	Thread Size Range	Material*	Plating
9676–9679	Bolt, 12 point, extended washer head, cupwasher locked	N	MS No.	UNJF	No.10 – $\frac{5}{8}$ in	AMS 5731	Nil
9680–9683	Bolt, 12 point, extended washer head, cupwasher locked	N	MS No.	UNJF	No.10 – $\frac{3}{8}$ in	AMS 6322	Cad.
9694–9702	Bolt, 12 point, extended washer head	M	MS No.	UNJF	No.4 – $\frac{9}{16}$ in	AMS 5708	Nil
9712–9720	Bolt, 12 point, extended washer, drilled	O	MS No.	UNJF	No.4 – $\frac{9}{16}$ in	AMS 5708	Silver plated
9730–9738	Bolt, 12 point, extended washer, PD shank	M	MS No.	UNJF	No.4 – $\frac{9}{16}$ in	AMS 5643	Nil
9739–9747	Bolt, 12 point, extended washer, drilled, PD shank	O	MS No.	UNJF	No.4 – $\frac{9}{16}$ in	AMS 5643	Nil
9748–9756	Bolt, 12 point, extended washer head, PD shank	M	MS No.	UNJF	No.4 – $\frac{9}{16}$ in	Titanium	Nil
9757–9765	Bolt, 12 point, extended washer, drilled head, PD shank	O	MS No.	UNJF	No.4 – $\frac{9}{16}$ in	Titanium	Nil
9883–9891	Bolt, 12 point, extended washer head	M	MS No.	UNJF	No.4 – $\frac{9}{16}$ in	AMS 5616	Nil
20004–20024	Bolt, internal wrenching	E or F	MS No.	UNF	¼ – 1½ in	Alloy steel	Cad.
20033–20046	Bolt, hexagon head, 1200°F	C	1200	UNF	No.10 – 1 in	Corrosion- and heat-resisting steel	Nil
20073 & 20074	Bolt, hexagon head, drilled	D	X	–73 = UNF –74 = UNC	No.10 – ¾ in	Alloy steel	Cad.
21095	Bolt, self-locking, 250°F, hexagon head	C	–	UNF	No.10 – 1¼ in	CRS	Nil
21096	Bolt, self-locking, 250°F, pan head + recess	K	Nil	4,6,8 = UNC, larger = UNF	No.4 – ½ in	Alloy steel	Cad.
21097	Bolt, self-locking, 250°F, pan head + recess	K	Nil	4,6,8 = UNC, larger = UNF	No.4 – ½ in	CRS	Nil
21250	Bolt, 12 point, 180 000 lbf/in², drilled or plain	A or B	MS No.	UNF	¼ – 1½ in	Alloy steel	Cad.
21277–21285	Bolt, 12 point, extended washer head	M	MS No.	MIL–S–8879	No.4 – $\frac{9}{16}$ in	AMS 5735	Nil
21286–21294	Bolt, 12 point, extended washer, drilled	O	MS No.	MIL–S–8879	No.4 – $\frac{9}{16}$ in	AMS 5735	Nil

* AMS 6304 and AMS 6322 are low alloy steels.
All other AMS specifications in the Table are corrosion- and heat-resisting alloys.

TABLE 9 MS SCREWS

MS Number	Type	Head Shape (Fig. 4)	Head Marking	Thread	Thread Size Range	Material	Plating
9122 and 9123	Screw, hex. head, slotted	G	E 11	UNF	No. 10 and $\frac{1}{4}$ in	AMS 6322	Cadmium
21262	Screw, cyl. head, 160 KSI int. wren. 250°F	J		4,6,8 = UNC Larger = UNF	No. 4 – $\frac{5}{8}$ in	Alloy steel	Cadmium
21295	Screw, cyl. head, 160 KSI int. wren. 250°F	J		4,6,8 = UNC Larger = UNF	No. 4 – $\frac{5}{8}$ in	CRS	Nil
24693	Screw, flat 100°, + recess	H	–	UNC 2A UNF 2A	No. 6 – $\frac{3}{8}$in	CRS	Nil
24694	Screw, flat 100°, + recess	H	–	UNC 3A UNF 3A	No. 6 – $\frac{9}{16}$ in	CRS	Nil
27039	Screw, pan head, + recess, structural	K	B C	8 = UNC Larger = UNF	No. 8 – $\frac{1}{2}$ in	Bronze Alloy steel CRS	Nil Cadmium Nil
35297	Screw, cap, hex. head	C		UNC 2A	$\frac{1}{4}$ – 1$\frac{1}{4}$ in	Carbon steel	Cad. or zinc
35299	Screw, cap, hex. head	C		UNC 2A	$\frac{1}{4}$ – 1$\frac{1}{4}$ in	Carbon steel	Phosphate
35307	Screw, cap, hex. head	C		UNC 2A	$\frac{1}{4}$ – 1$\frac{1}{4}$ in	CRS	Nil
35308	Screw, cap, hex. head	C		UNF 2A	$\frac{1}{4}$ – 1$\frac{1}{4}$ in	CRS	Nil
51095	Screw, cap, hex. head, drilled	D		UNC 2A	$\frac{1}{4}$ – 1 in	Carbon steel	Cadmium
51096	Screw, cap, hex. head, drilled	D		UNF 2A	$\frac{1}{4}$ – 1 in	Carbon steel	Cadmium
51099	Screw, cap, hex. head, drilled	D		UNC 2A	$\frac{1}{4}$ – 1 in	CRS	Nil
51100	Screw, cap, hex. head, drilled	D		UNF 2A	$\frac{1}{4}$ – 1 in	CRS	Nil
51105	Screw, cap, hex. head, drilled	D		UNC 2A	$\frac{1}{4}$ – 1 in	Carbon steel	Cadmium
51106	Screw, cap, hex. head, drilled	D		UNF 2A	$\frac{1}{4}$ – 1 in	Carbon steel	Cadmium
51107	Screw, cap, hex. head, drilled shank	C		UNC 2A	$\frac{1}{4}$ – 1 in	Alloy steel	Phosphate
51108	Screw, cap, hex. head, drilled shank	C		UNF 2A	$\frac{1}{4}$ – 1 in	Alloy steel	Phosphate
51109	Screw, cap, hex. head, drilled shank	C		UNC 2A	$\frac{1}{4}$ – 1 in	CRS	Nil
51110	Screw, cap, hex. head, drilled shank	C		UNF 2A	$\frac{1}{4}$ – 1 in	CRS	Nil
90726	Screw, cap, hex. head	C		UNF 2A	$\frac{1}{4}$ – 1$\frac{1}{2}$ in	Carbon steel	Cadmium
90727	Screw, cap, hex. head	C		UNF 2A	$\frac{1}{4}$ – 1$\frac{1}{2}$ in	Alloy steel	Cadmium
90728	Screw, cap, hex. head	C		UNC 2A	$\frac{1}{4}$ – 1$\frac{1}{2}$ in	Alloy steel	Cadmium

4.1.2 With bolts in the ranges MS 20004 to 20024 and MS 20033 to 20046, the thread size is indicated by the part number as outlined in paragraph 3.1.2 (a), and the length is indicated by a dash number, which represents grip length in sixteenths of an inch.

4.1.3 With bolts in the MS 21250 series, the dash number indicates both diameter and length. The first two figures indicate diameter in sixteenths of an inch, and the last two figures indicate grip length in sixteenths of an inch.

4.1.4 With the MS 20004 to 20024, and MS 21250, bolts, an H in place of the dash indicates a drilled-head bolt.

4.2 **MS Screws.** Table 9 lists a variety of the screws covered by MS specifications, and shows the features by which these screws may be partially identified.

4.2.1 Because the individual specifications vary, the screws listed in Table 9 should be fully identified by reference to the particular specification.

4.3 **MS Nuts.** The non-self-locking nuts to MS specifications are listed in Table 10. These nuts are similar in appearance to those shown in Table 7, but all are marked with the appropriate MS part number for identification purposes.

TABLE 10 MS NON-SELF-LOCKING NUTS

MS Number	Type	Thread	Size Range	Material	Plating
9356	Nut, plain, hexagon	No.4, 6 and 8 nuts have UNC thread. Larger size nuts have UNF thread.	No.4 – 1 in	AMS 5735	Nil
9357	Nut, plain, hexagon		No.4 – 1 in		Silver
9358	Nut, castle		No.10 – 1 in		Nil
9359	Nut, castle		No.10 – 1 in		Silver
9360	Nut, plain, hexagon, drilled		No.10 – 1 in		Silver
9361	Nut, plain, hexagon, check		No.10 – 1 in		Nil
9362	Nut, plain, hexagon, check		No.10 – 1 in		Silver
9363	Nut, hexagon, slotted, shear		No.10 – 1 in		Nil
9364	Nut, hexagon, slotted, shear		No.10 – 1 in		Silver

4.3.1 **Coding.** Nuts are coded by the MS number plus a dash number indicating thread size —04 is No. 4, —06 is No. 6, —08 is No. 8, —09 is No. 10, —10 is $\frac{1}{4}$ in, —11 is $\frac{5}{16}$ in, —12 is $\frac{3}{8}$ in, —13 is $\frac{7}{16}$ in, —14 is $\frac{1}{2}$ in, —15 is $\frac{9}{16}$ in, —16 is $\frac{5}{8}$ in, —17 is $\frac{3}{4}$ in, —18 is $\frac{7}{8}$ in and —19 is 1 in.

4.4 **MS Washers.** Two ranges of washers are covered in the MS series. MS 35338 is a cadmium-plated, steel, spring washer, and replaces the AN 935 regular spring washer. MS 35333 and 35335 are lock washers in cadmium-plated steel and bronze, which replace the AN 936 style A and style B shakeproof washers, respectively. All of these washers are ordered by the MS number, followed by a dash number indicating the size of bolt the washer is designed to fit. The dash number applicable to a particular washer should be obtained from the tables provided in the specification.

5 **NAS FASTENERS** NAS Specifications provide a wide range of fasteners, with a variety of head shapes and wrenching recesses (Fig. 5). The range of bolts and screws includes both self-locking and non-locking versions, and many varieties are also available with oversize shanks for repair work. A few washers and nuts are also included in the NAS specifications, but these items are generally supplied under manufacturers' specifications and are not included in this Leaflet.

5.1 All NAS bolts and screws are marked for identification purposes, but the extent of the marking depends on the size of the head and on the requirements of the particular specification. Many components are marked in accordance with NAS 1347, which provides for four types of identification. Type I is the material code and is the same as that shown in Fig. 1 for AN bolts; Type II is the basic part number, i.e. the NAS number; Type III is the basic part number and a material code letter; Type IV is the complete part number, including basic part number, material code, figures for diameter and length, and a letter for type of finish. These markings are shown in Table 11, and explained in paragraphs 5.2 and 5.3. It should be noted, however, that in the smaller sizes a shortened version of the code may be permitted by the specification. On fasteners with a Tri-Wing recess the marking also includes a figure, inside a circle, which indicates the size of the recess in accordance with NAS 4000. Oversize bolts are also marked with an 'X' or 'Y'.

NOTE: Provision is also made for including the manufacturer's identification mark on the head.

5.2 **Coding.** The bolts and screws listed in Table 11 are coded according to their type, diameter, length, type of plating and material. Where a component is made in more than one material, an alloy steel part is given the basic part number; similarly, where applicable, the basic part number implies that the part is not drilled for locking purposes.

5.2.1 **Diameter.** Most bolts and screws are coded according to thread size in a similar way to AN and MS parts; however, there are some exceptions.

(a) NAS 1261 to 1265 and NAS 1266 to 1270 are available in sizes $\frac{9}{16}$—18, $\frac{5}{8}$—18, $\frac{3}{4}$—16, $\frac{7}{8}$—14, and 1—12; they are coded in numerical order and indicated by an 'A' in Table 11.

(b) For bolts and screws which are given a range of numbers (except as detailed in (d)), the last figure or two figures indicates the size as follows:—

NAS xxx0 = 4—40, xxx1 = 6—32, xxx2 = 8—32, xxx3 = 10—32, xxx4 = $\frac{1}{4}$—28, xxx5 = $\frac{5}{16}$—24, xxx6 = $\frac{3}{8}$—24, xxx7 = $\frac{7}{16}$—20, xxx8 = $\frac{1}{2}$—20, xxx9 = $\frac{9}{16}$—18, xx10 = $\frac{5}{8}$—18, xx12 = $\frac{3}{4}$—16, xx14 = $\frac{7}{8}$—14, xx16 = 1—12, xx18 = 1$\frac{1}{8}$—12, and xx20 = 1$\frac{1}{4}$—12.

The threads are usually UNC, UNF, UNJC or UNJF, but some bolts and screws are also available with American National threads, and these are coded separately. Those parts which comply with the Unified standard are indicated by a 'B' in Table 11.

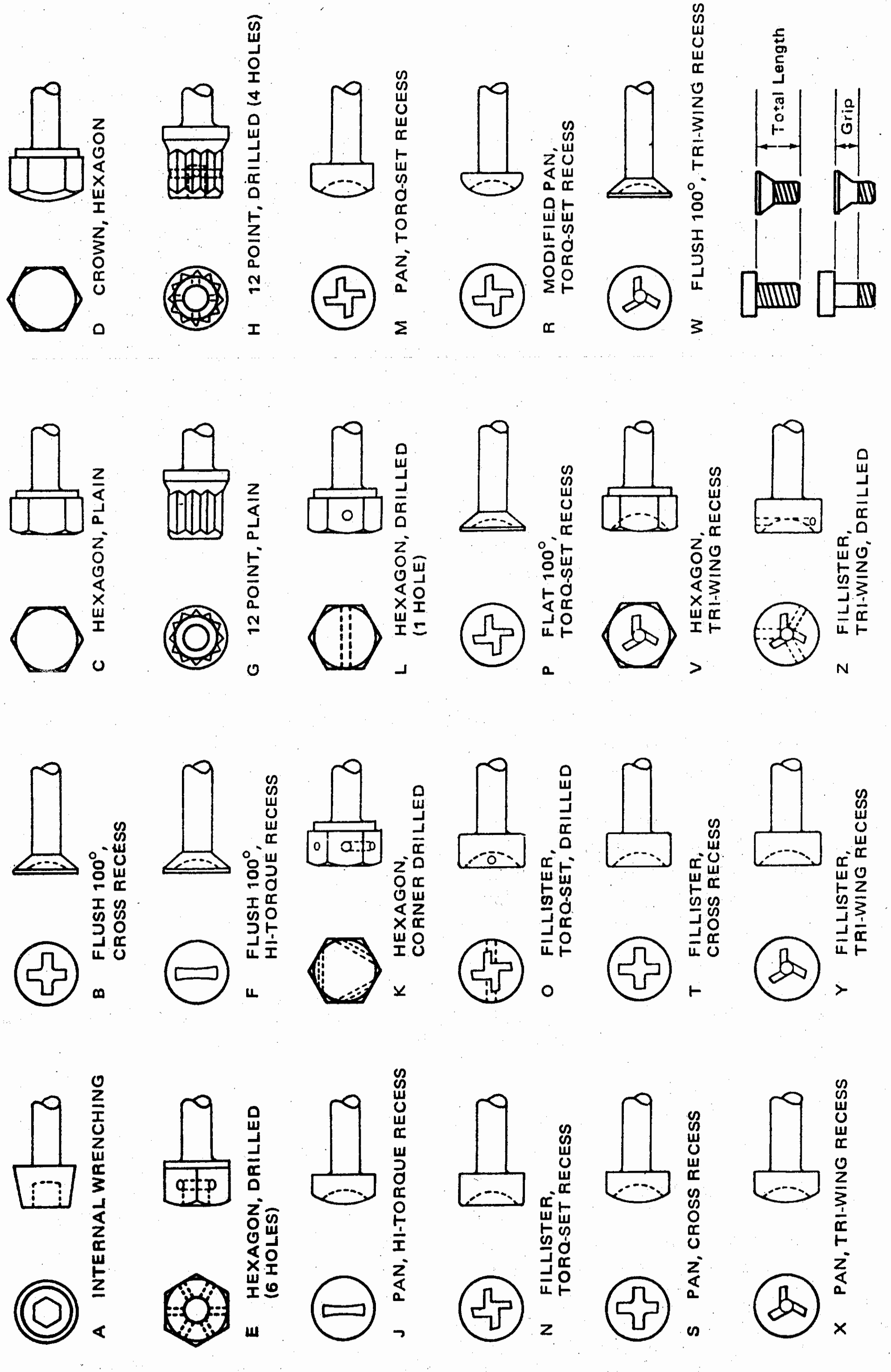


Figure 5. NAS BOLTS AND SCREWS

(c) For bolts and screws which are given a single NAS number, the diameter is given by the first dash number as follows:—

NAS xxxx—02 = 2—56, xxxx—04 = 4—40, xxxx—06 = 6—32, xxxx—08 = 8—32, xxxx—3 = 10—32, xxxx—4 = $\frac{1}{4}$—28, and so on, in steps of $\frac{1}{16}$ in, following the sizes given in (b). Parts following this code are marked 'C' in Table 11.

(d) NAS 1271 to 1280 are available in sizes from $\frac{1}{4}$ to 1 in, and are coded in numerical order.

5.2.2 **Length.** The length is indicated by the second dash number for parts with the 'C' diameter code, or the first dash number for all other parts. The length dash-number indicates the total length of a part with a full thread or the grip length of a part with a shorter thread (see Fig. 5), in sixteenths of an inch; exceptions are NAS 563 to 572, for which the length dash number represents thirty-seconds of an inch, and NAS 428, for which the dash number represents eighths of an inch as detailed in paragraph 3.1.2(b) for AN parts.

5.2.3 **Plating.** Alloy-steel bolts and screws are normally cadmium plated in accordance with QQ–P–416 Type II Class 3. If a different plating is used, or if CRS or titanium parts are plated, the following code may be used:—
W = QQ–P–416 Type I Class 3 plating.
B = Blackened Type II plating.
H = CRS with Type II plating.
P = CRS or titanium with Type II plating.
U = Unplated.
A = Aluminium coating to NAS 4006.

5.2.4 **Type of Locking.** Unless otherwise noted in Table 11, the type of locking is indicated as follows:—
D = Drilled shank.
H = Drilled head.
L = Nylon strip locking element.
N = Nylon button or pellet locking element.
LK = KEL–F strip locking element.
NK = KEL–F pellet locking element.
K = KEL–F locking element, type optional.

NOTE: The lack of a letter for a self-locking bolt indicates that the type of locking element is unimportant.

5.2.5 **Type of Recess.** Where a choice of wrenching recesses is available, the following code is used to indicate the type required:—
T = Torq–Set.
H = Hi–Torque.
P or R = Phillips (cruciform).

NOTE: The type of recess indicated by the lack of a code letter is shown in Table 11.

5.2.6 **Type of Material.** The NAS fasteners listed in Table 11 are manufactured from alloy steel, corrosion-resistant steel (CRS), corrosion-and heat-resistant (C and HR) steel, and titanium alloy. Except in the case of titanium alloy, which is sometimes indicated by a 'V' (see Table 11), the type of material is not specified unless the fastener is made in more than one material. The basic code applies to alloy steel, and the following code indicates other materials:—
CR = corrosion-resistant steel, 125,000 lbf/in^2.
C = corrosion-resistant steel, 140,000 lbf/in^2.
E = corrosion-resistant steel, 160,000 lbf/in^2.
V = titanium alloy.

TABLE 11 NAS BOLTS AND SCREWS

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
144–158	Bolt, internal wrenching	A	No.1 – 1¼ in	Alloy steel	B	A = drilled shank DH = drilled head Nil = undrilled			NAS No.
333–340	Bolt, flush 100°, close-tolerance	B	No.10 – ⅝ in	Alloy steel	B	A = undrilled shank P = Phillips recess Nil = hex. socket C = cad. plated shank	–	See Specification for Length Code	NAS No. + △
428	Bolt, crown hex. head	D	No.10 – ⅜ in	Alloy steel	C	H = drilled head K = slotted shank	–	–	NAS 1347 Type IV
464	Bolt, shear, close-tolerance	C	No.10 – 1 in	Alloy steel	C	P = cad. shank	A = undrilled shank		NAS No. + △
501	Bolt, hex. head, non-magnetic	C	No.10 – 1¼ in	CRS	C	A = undrilled shank H = drilled head	–	–	NAS No. + –
560	Screw, 100°, non-magnetic, structural	B	No.8 – $\frac{9}{16}$ in	CRS	C	C = low strength H = high temp. X = high strength	K = Phillips recess P = cad. plated	–	NAS No. + C, H or X
563–572	Bolt, full threaded, fully identified	E	No.10 – ¾ in	Alloy steel	B	–	–	–	NAS No. + dash no.
583–590	Bolt, 100°, close-tolerance, 160,000 lbf/in^2, Hi-Torque	F	No.10 – ⅝ in	Alloy steel	B	–	–	–	NAS 1347 Type IV
624–644	Bolt, 12 point, 180,000 lbf/in^2	G or H	¼ – 1½ in	Alloy steel	B	H = drilled head	–	–	NAS No.
653–658	Bolt, hex. head, short thread, close-tolerance	C	No.10 – ½ in	Titanium	B	V = titanium	–	D = drilled shank	NAS No. + dash no. + material
663–668	Bolt, 100°, close-tolerance, long thread	F	No.10 – ½ in	Titanium	B	V = titanium	–	HT = Hi-Torque	NAS 1347 Type IV
673–678	Bolt, hex. head, close-tolerance	C or K	No.10 – ½ in	Titanium	B	V = titanium	–	D = drilled shank H = drilled head	NAS No. + dash no. + material
1003–1020	Bolt, hex. head, non-magnetic, heat-resistant	C or L	No.10 – 1¼ in	CRS	B	–	–	A = undrilled H = drilled head Nil = drilled shank	NAS No. + dash no.
1083–1088	Bolt, 100°, close-tolerance, short thread	F	No.10 – ½ in	Titanium	B	V = 6AL–4V alloy T = 4AL–4MN alloy		Nil = Phillips HT = Hi-Torque	NAS 1347 Type IV

TABLE 11—*continued*

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
1100	Screw, pan head, full thread, Torq-Set	M	No.0 – ⅜ in	Alloy steel Titanium CRS	C	C = CRS 140 000 psi E = CRS 160 000 psi V = titanium	–	B = black plating P = type II plating W = type I plating	NAS No. + dash no. + material
1101	Screw, flat fillister, full thread, Torq-Set	N or O	No.0 – ⅜ in	As 1100	C	As 1100	H = drilled head	As 1100	NAS No. + dash no. + material
1102	Screw, 100°, full thread, Torq-Set	P	No.2 – ⅜ in	As 1100	C	As 1100	–	As 1100	NAS No. + dash no. + material
1103–1120	Bolt, shear, hex. head modified, short thread	C	No.10 – 1¼ in	Alloy steel	C	As 1100	–	As 1100 D = drilled	NAS No. + dash no. + material
1121–1128	Screw, flat fillister, close-tolerance, short thread	N or O	No.6 – ½ in	As 1100	B	As 1100	–	H = drilled head P and W as 1100	NAS No. + dash no. + material
1131–1138	Screw, pan head, close-tolerance, short thread	M	No.6 – ½ in	As 1100	B	C = CRS V and T as 1083	–	P and W as 1100	NAS No. + dash no. + material
1141–1148	Screw, pan head (mod), close-tolerance, short thread	R	No.6 – ½ in	As 1100	B	As 1100	–	P and W as 1100	NAS No. + dash no. + material
1151–1158	Screw, 100°, close-tolerance, short thread	P	No.6 – ½ in	As 1100	B	As 1131	–	D = Drilled shank P and W as 1100	NAS No. + dash no. + material
1161–1168	Screw, 100°, shear, self-locking	P	No.6 – ½ in	Alloy steel CRS	B	E as 1100	–	P and W as 1100 + locking code	NAS No. + dash no. + material + circle of dots
1171–1178	Screw, pan, shear, self-locking	M	No.6 – ½ in	Alloy steel CRS	B	E as 1100	–	P and W as 1100 + locking code	NAS No. + dash no. + material + circle of dots
1181–1188	Screw, flat fillister, shear, self-locking	N	No.6 – ½ in	Alloy steel CRS	B	C and E as 1100	–	P and W as 1100 + locking code	NAS No. + dash no. + material + circle of dots

TABLE 11—*continued*

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
1189	Screw, 100°, full thread, self-locking, 250°F	B or P	No.2 — $\frac{3}{8}$ in	Alloy steel CRS	C	C as 1100	P = Phillips recess T = Torq-Set recess	W as 1100 + locking code	NAS No. + dash no. + circle of dots
1190	Screw, pan head, full thread, self-locking	M or S	No.2 — $\frac{3}{8}$ in	Alloy steel CRS	C	C and E as 1100	P = Phillips recess T = Torq-Set recess	H = type II plating W = type I plating + locking code	NAS No. + dash no. + circle of dots
1191	Screw, flat fillister, full thread, self-locking, 250°F	N or T	No.2 — $\frac{3}{8}$ in	Alloy steel CRS	C	C and E as 1100	P = Phillips recess T = Torq-Set recess	H and W as 1190 + locking code	NAS No. + dash no. + circle of dots
1202—1210	Bolt, 100°, close-tolerance, 160,000 lbf/in^2, short thread	B	No.8 — $\frac{5}{8}$ in	Alloy steel	B		—	D = drilled shank W as 1190	NAS 1347 Type IV
1216	Bolt, pan head, full thread, Hi-Torque	J	No.4 — $\frac{3}{8}$ in	Alloy steel CRS	C	—	CR = CRS 125,000 lbf/in^2 C = CRS 140,000 lbf/in^2	B = black plating P = type II plating	NAS 1347 Type IV
1217	Bolt, pan head, short thread, Hi-Torque	J	No.8 — $\frac{3}{8}$ in	Alloy steel CRS	C	—	C and CR as 1216	B and P as 1216	NAS 1347 Type IV
1218	Bolt, pan head, long thread, Hi-Torque	J	No.4 — $\frac{3}{8}$ in	Alloy steel CRS	C	—	C and CR as 1216	B and P as 1216	NAS 1347 Type IV
1219	Bolt, 100°, full thread, Hi-Torque	F	No.4 — $\frac{3}{8}$ in	Alloy steel CRS	C	—	C and CR as 1216	B and P as 1216	NAS 1347 Type IV
1220	Bolt, 100°, short thread, Hi-Torque	F	No.8 — $\frac{3}{8}$ in	Alloy steel CRS	C	—	C and CR as 1216	B and P as 1216	NAS 1347 Type IV
1221	Bolt, 100°, long thread, Hi-Torque	F	No.4 — $\frac{3}{8}$ in	Alloy steel CRS	C	—	C and CR as 1216	B and P as 1216	NAS 1347 Type IV
1223—1235	Bolt, hex. head, close-tolerance, self-locking	C	No.10 — 1¼ in	Alloy steel CRS	B	C = CRS	—	W as 1190 + locking code	NAS 1347 Type IV + circle of dots
1243—1250	Bolt, 100°, close-tolerance, short thread, Hi-Torque, 0·0156 in oversize, 160,000 lbf/in^2 (a)	F	No.10 — $\frac{5}{8}$ in	Alloy steel	B	—	—	—	NAS 1347 Type IV
1253—1260	Bolt, 100°, close-tolerance, short thread, Hi-Torque, 0·0312 in oversize, 160,000 lbf/in^2 (a)	F	No.10 — $\frac{5}{8}$ in	Alloy steel	B	—	—	—	NAS 1347 Type IV

TABLE 11—*continued*

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
1261–1265	Bolt, hex. head, close-tolerance, short thread	C	$\frac{9}{16}$ – 1 in	Titanium	A	–	–	D = drilled shank	NAS 1347 Type IV
1266–1270	Bolt, hex. head, close-tolerance	C	$\frac{9}{16}$ – 1 in	Titanium	A	–	–	D = drilled shank	NAS 1347 Type IV
1271–1280	Bolt, 12 point	G or H	¼ – 1 in	Titanium	D	H = drilled head	–		NAS 1347 Type IV
1303–1320	Bolt, hex. head, close-tolerance, 160,000 lbf/in^2	C or K	No.10 – 1¼ in	Alloy steel	B	–	–	D = drilled shank H = drilled head W = type I plating	NAS No. + dash no.
1503–1510	Bolt, 100°, close-tolerance, short thread, Hi-Torque, 160,000 lbf/in^2	F	No.10 – $\frac{5}{8}$ in	Alloy steel	B	–	–	W = type I plating	NAS No. + dash no.
1578	Bolt, pan head, shear, 1200°F	J or M	No.10 – ½ in	C and HR steel (U–212)	C	–	T = Torq-Set recess H = Hi-Torque recess	–	NAS 1347 Type II
1579	Bolt, pan head, full thread, 1200°F	J or M	No.10 – $\frac{3}{8}$ in	C and HR steel (U–212)	C	–	T and H as 1578	–	NAS 1347 Type II
1580	Bolt, tension, 100°, 1200°F	F or P	No.10 – $\frac{5}{8}$ in	C and HR steel (U–212)	C	–	T and H as 1578	–	NAS 1347 Type II
1581	Bolt, shear, 100° reduced, 1200°F	F or P	No.10 – $\frac{5}{8}$ in	C and HR steel (U–212)	C	–	T and H as 1578	–	NAS 1347 Type II
1582	Bolt, 100°, full thread, 1200°F	F or P	No.10 – $\frac{3}{8}$ in	C and HR steel (U–212)	C	–	T and H as 1578	–	NAS 1347 Type II
1586	Bolt, tension, 12 point, 1200°F, external wrenching	G or H	¼ – 1¼ in	C and HR steel (U–212)	C	–	H = drilled head	–	NAS 1347 Type II
1588	Bolt, shear, hex. head, 1200°F	C	No.10 – 1 in	C and HR steel (U–212)	C	–	–	–	NAS 1347 Type II

TABLE 11—*continued*

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
1603—1610	Bolt, 100°, close-tolerance, 0·0312 in oversize, 160,000 lbf/in^2 (b)	F or P	No.10 — ⅝ in	Alloy steel	B	—	—	R = Phillips recess Nil = Hi-Torque	NAS 1347 Type IV
1620—1628	Screw, 100°, short thread, Torq-Set recess	P	No.4 — ½ in	Alloy steel CRS Titanium	B	C, E and V as 1100	—	D = drilled shank P = type II plating	NAS 1347 Type IV
1630—1634	Screw, pan head, short thread, Torq-Set	M	No.4 — ¼ in	Alloy steel CRS Titanium	B	C, E and V as 1100	—	D = drilled shank P = type II plating	NAS 1347 Type IV
1703—1710	Bolt, 100°, close-tolerance, 0·0156 in oversize, 160,000 lbf/in^2 (b)	B or F	No.10 — ⅝ in	Alloy steel	B	—	—	R = Phillips recess Nil = Hi-Torque	NAS 1347 Type IV
2803—2810	Bolt, 100°, close-tolerance, 180,000 lbf/in^2, Torq-Set	P	No.10 — ⅝ in	Alloy steel	B	—	—	—	NAS No. + dash no.
2903—2920	Bolt, shear, hex. head, 0·0156 in oversize (b)	C or K	No.10 — 1¼ in	Alloy steel	B	E = short thread	—	D = drilled shank H = drilled head W = type I plating	NAS No. + dash no.
3003—3020	Bolt, shear, hex. head, long or short thread, 0·0312 in oversize (b)	C or K	No.10 — 1¼ in	Alloy steel	B	E = short thread	—	D = drilled shank H = drilled head W = type I plating	NAS No. + dash no.
4104—4116	Bolt, 100°, close-tolerance, long thread, Tri-wing recess, self-locking and non-locking	W	¼ — 1 in	Alloy steel	B	B = black plating D, L or P see (g)	—	X = 0·0156 in oversize Y = 0·0312 in oversize	NAS No. + dash no. (e) (f) (g)
4204—4216	Bolt, 100°, close-tolerance, long thread, Tri-wing recess, self-locking and non-locking	W	¼ — 1 in	CRS (c)	B	U = unplated D, L or P see (g)	—	X and Y as 4104	NAS No. + dash no. (e) (f) (g)
4304—4316	Bolt, 100°, long thread, Tri-wing recess, self-locking and non-locking	W	¼ — 1 in	Titanium (d)	B	U = unplated D, L or P see (g)	—	X and Y as 4104	NAS No. + dash no. (e) (f) (g)
4400—4416	Bolt, 100°, short thread, Tri-wing recess, self-locking and non-locking	W	No.4 — 1 in	Alloy steel	B	B = black plating D, L or P see (g)	—	X and Y as 4104	NAS No. + dash no. (e) (f) (g)

TABLE 11—*continued*

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
4500–4516	Bolt, 100°, close-tolerance, short thread, Tri-wing recess, self locking or non-locking	W	No.4 – 1 in	CRS (c)	B	U = unplated D, L or P see (g)	—	X and Y as 4104	NAS No. + dash no. + C for CRS (e) (f) (g)
4600–4616	Bolt, 100°, close-tolerance, short thread, Tri-wing recess, self-locking and non-locking	W	No.4 – 1 in	Titanium (d)	B	U = unplated D, L or P see (g)	—	X and Y as 4104	NAS No. + dash no. + V for titanium (e) (f) (g)
4703–4716	Bolt, 100°, close-tolerance, short thread, reduced head, non-locking, Tri-wing recess	W	No.10 – 1 in	Alloy steel	B	D = drilled shank Nil = undrilled	—	X and Y as 4104	NAS No. + dash no. (e) (f)
4803–4816	Bolt, 100°, close-tolerance, short thread, reduced head, non-locking, Tri-wing recess	W	No.10 – 1 in	CRS (c)	B	D = drilled shank U = unplated	—	X and Y as 4104	NAS No. + dash no. + C for CRS (e) (f)
4903–4916	Bolt, 100°, close-tolerance, short thread, reduced head, non-locking, Tri-wing recess	W	No.10 – 1 in	Titanium (d)	B	D = drilled shank U = unplated	—	X and Y as 4104	NAS No. + dash no. + V for titanium (e) (f)
5000–5006	Bolt, pan head, close-tolerance, short thread, Tri-wing recess, self-locking and non-locking	X	No.4 – $\frac{3}{8}$ in	Alloy steel	B	B = black plating L or P see (g)	—	X and Y as 4104	NAS No. + dash no. (e) (f) (g)
5100–5106	Bolt, pan head, close-tolerance, short thread, Tri-wing recess, self-locking and non-locking	X	No.4 – $\frac{3}{8}$ in	CRS (c)	B	U = unplated L or P see (g)	—	X and Y as 4104	NAS No. + dash no. + C for CRS (e) (f) (g)
5200–5206	Bolt, pan head, close-tolerance, short thread, Tri-wing recess, self-locking and non-locking	X	No.4 – $\frac{3}{8}$ in	Titanium (d)	B	U = unplated L or P see (g)	—	X and Y as 4104	NAS No. + dash no. + V for titanium (e) (f) (g)
5300–5360	Screw, flat fillister head, full thread, Tri-wing recess, self-locking and non-locking	Y or Z	No.4 – $\frac{3}{8}$ in	Alloy steel	B	H = drilled head B = black plating L or P see (g)	—	—	NAS No. + dash no. (f) (g)

TABLE 11—*continued*

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
5400–5406	Screw, flat fillister head, full thread, Tri-wing recess, self-locking and non-locking	Y or Z	No.4 – ⅜ in	CRS (c)	B	H = drilled head U = unplated L or P see (g)	—	—	NAS No. + dash no. + C for CRS (f) (g)
5500–5506	Screw, flat fillister head, full thread, Tri-wing recess, self-locking and non-locking	Y or Z	No.4 – ⅜ in	Titanium (d)	B	H = drilled head U = unplated L or P see (g)	—	—	NAS No. + dash no. + V for titanium (f) (g)
5600–5606	Screw, 100°, full thread, Tri-wing recess, self-locking and non-locking	W	No.4 – ⅜ in	Alloy steel	B	B = black plating L or P see (g)	—	—	NAS No. + dash no. (f) (g)
5700–5706	Screw, 100°, full thread, Tri-wing recess, self-locking and non-locking	W	No.4 – ⅜ in	CRS (c)	B	B = black plating U = unplated L or P see (g)	—	—	NAS No. + dash no. + C for CRS (f) (g)
5800–5806	Screw, 100°, full thread, Tri-wing recess, self-locking and non-locking	W	No.4 – ⅜ in	Titanium (d)	B	U = unplated L or P see (g)	—	—	NAS No. + dash no. + V for titanium (f) (g)
6000–6003	Screw, hex. head, full thread, Tri-wing recess	V	No.4 to No.10	CRS (c)	B	U = unplated	—	—	NAS No. + dash no. + C for CRS (f)
6100–6103	Screw, hex. head, full thread, Tri-wing recess	V	No.4 to No.10	Titanium (d)	B	U = unplated	—	—	NAS No. + dash no. + V for titanium
6203–6220	Bolt, hex. head, short thread, close-tolerance, self-locking and non-locking	C or K	No.10 – 1¼ in	Alloy steel	B	D, L or P see (g)	—	X or Y as 4104 D = drilled shank H = drilled head	NAS No. + dash no. (e) (g)
6303–6320	Bolt, hex. head, short thread, close-tolerance, self-locking or non-locking	C or K	No.10 – 1¼ in	CRS (c)	B	U = unplated L or P see (g)	—	X or Y as 4104 D = drilled shank H = drilled head	NAS No. + dash no. (e) (g)
6403–6420	Bolt, hex. head, short thread, close-tolerance, self-locking and non-locking	C or K	No.10 – 1¼ in	Titanium (d)	B	U = unplated L or P see (g)	—	X or Y as 4104 D = drilled shank H = drilled head	NAS No. + dash no. (e) (g)

TABLE 11—*continued*

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
6604 6620	Bolt, hex. head, long thread, close-tolerance, self-locking and non-locking	C or K	¼ – 1¼ in	Alloy steel	B	D = drilled shank H = drilled head L or P see (g)	—	X or Y as 4104	NAS No. + dash no. (e) (g)
6704– 6720	Bolt, hex. head, long thread, close-tolerance, self-locking and non-locking	C or K	¼ – 1¼ in	CRS (c)	B	D = drilled shank H = drilled head U = unplated L or P see (g)	—	X or Y as 4104	NAS No. + dash no. (e) (g)
6804– 6820	Bolt, hex. head, long thread, close-tolerance, self-locking and non-locking	C or K	¼ – 1¼ in	Titanium (d)	B	D = drilled shank H = drilled head U = unplated L or P see (g)	—	X or Y as 4104	NAS No. + dash no. (e) (g)

NOTES:

(a) For repair work only, replacing NAS 1503 to 1510.

(b) For repair work only.

(c) Cadmium plated CRS bolts have green dye or paint on the end of the shank.

(d) Cadmium plated titanium bolts have red dye or paint on the end of the shank.

(e) Oversize bolts are marked with 'X' or 'Y' (see code).

(f) Heads are also marked with an encircled number, to indicate the size of the Tri-wing recess, in accordance with NAS 4000.

(g) Method of locking, included in code and marked on head, is as follows:
D = drilled shank. L = locking element is optional. P = patch type locking element.

5.3 Examples of Coding

(a) NAS 564–15 is a full-threaded bolt in cadmium-plated alloy steel, with ¼–28 thread, and length of $\frac{15}{32}$ in.

(b) NAS 1146E12P is a screw with a modified pan head, close-tolerance shank and Torq-Set recess, made from CRS (160,000 lbf/in^2), with Type II plating. It has a ⅜–24 thread and a ¾ in grip length.

(c) NAS 1189–3T8L is a self-locking screw with a 100° countersunk head and full thread. It has a 10–32 thread, is ½ in long, and is in alloy steel with Type II plating. It has a strip-type nylon locking element and a Torq-Set recess.

(d) NAS 6804D10X is a hexagon head, close-tolerance bolt in titanium alloy, with a long thread. It has a ¼–28 thread and ⅝ in grip length, and a drilled shank which is 0·0156 in oversize.

BL/3-1

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BASIC

METROLOGY

MEASUREMENT OF BRITISH ASSOCIATION AND WHITWORTH FORM SCREW THREADS

1 INTRODUCTION This leaflet gives guidance on the inspection of screw threads produced by recognised methods such as machining, dieing, tapping, rolling, etc. Where it is necessary to achieve the maximum resistance to fatigue, bolts produced by a rolling process are usually preferred.

1.1 The accuracy of screw threads should be verified by a system of gauging, and a suitable system, together with the ancillary checks considered necessary to ensure compliance with the specified drawing requirements, is defined in this leaflet.

1.2 Guidance on the measurement of Unified Screw Threads is given in Leaflet **BL/3-2.**

2 SCREW THREAD SPECIFICATIONS The specifications for screw threads of Whitworth form, i.e. British Standard Whitworth (B.S.W.), and British Standard Fine (B.S.F.), are defined in British Standard, No. 84: 1956, whilst those for British Association (B.A.) threads are given in British Standard, No. 93 : 1951. The specifications for British Standard Pipe (B.S.P.) parallel threads were given in B.S. 84 : 1940, but are not included in the latest issue of this specification since they are now covered in B.S. 2779 : 1956 entitled "Fastening Threads of B.S.P. Sizes".

2.1 The above specifications define the basic series of diameters and corresponding pitches, together with recommended tolerances and limits. In B.S. 84 : 1956 there are also included recommended tolerances for other threads of Whitworth form up to twenty inches diameter.

2.2 There is no specification in the B.S. range dealing with brass threads, which are of Whitworth form, 26 threads per inch.

3 SCREW THREAD TERMINOLOGY For the benefit of those not familiar with screw thread terminology, a glossary is given below. Reference should also be made to Figures 1 and 2.

3.1 **Angle of Thread.** The included angle between the flanks of a thread, measured in an axial plane section.

3.2 **Axis of Thread.** The longitudinal centre line through the threaded portion.

3.3 **Basic Size.** The nominal standard dimensions of the threads from which all variations are made.

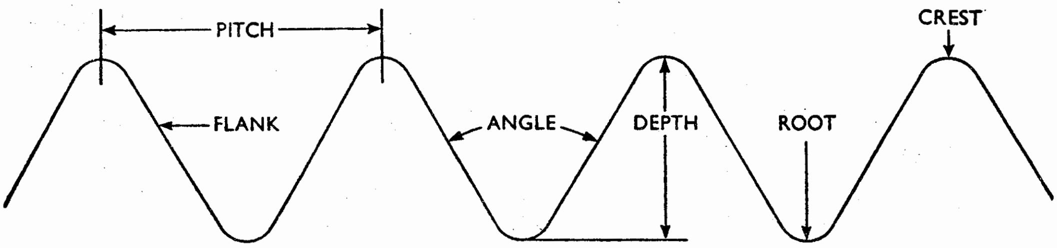

Figure 1 SCREW THREAD TERMINOLOGY

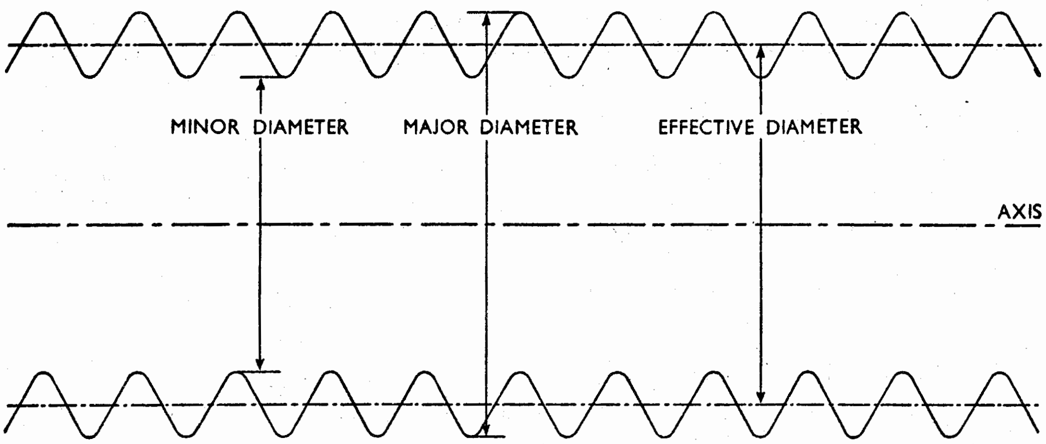

Figure 2 SCREW THREAD TERMINOLOGY

3.4 **British Association Threads.** A system of metric threads, confined to small sizes ranging from 6 mm. to 0·25 mm. in diameter and from 1 mm. to 0·070 mm. pitch. The diameters are designated in numbers ranging from 0 to 25. The thread is of a symmetrical "V" formation of 47½° included angle, having its crests and roots rounded with equal radii, such that the basic depth of the thread is 0·60 of the pitch.

3.5 **British Standard Fine.** A thread of Whitworth form, but of a finer pitch for a given diameter.

3.6 **British Standard Pipe.** A thread of Whitworth form, designated originally by the bore of the pipe on which it was formed and not by its major diameter, which is a decimal size, slightly smaller than the outside diameter of the pipe.

3.7 **British Standard Whitworth.** The standard British thread. It is a symmetrical "V" thread of 55° included angle, with a radius at root and crest of 0·1373 × pitch. The pitch of the thread is standardised for given diameters.

3.8 **Crest.** That part of the surface of a thread which connects adjacent flanks at the top of the ridge.

3.9 **Depth of Thread.** The distance between the root and crest, measured at right angles to the axis.

3.10 **Effective Diameter**

3.10.1 **Simple Effective Diameter.** The diameter of the pitch cylinder of the parallel thread or the pitch cone of a taper thread, in a specified plane normal to the axis. With Whitworth threads of nominal form, the simple effective diameter occurs half-way down the flanks and its nominal value may be obtained by subtracting one depth of thread from the nominal major diameter.

3.10.2 **Virtual Effective Diameter.** The effective diameter of an imaginary thread of perfect pitch and angle, having the full depth of flanks, but clear at the crests and roots, which would just assemble with the actual thread over the prescribed length of engagement. The virtual effective diameter exceeds the simple effective diameter with external threads, but is less than the simple effective diameter with internal threads, by an amount corresponding to the diametrical effects due to any errors in the pitch and/or flank angles of the thread.

3.11 **Flank.** The surface of the thread which connects the root and the crest.

3.12 **Flank Angle.** The angle between the flank of the thread and a line drawn perpendicular to the axis.

3.13 **Lead.** The distance a screw advances axially in one complete turn.

3.14 **Length of Engagement.** The axial distance over which two mating threads are designed to make contact.

3.15 **Major Diameter.** The largest diameter of the thread measured in a plane normal to the axis.

3.16 **Minor Diameter.** The smallest diameter of the thread measured in a plane normal to the axis.

3.17 **Pitch.** The distance from the centre of one crest to the centre of the next, measured parallel to the main axis.

3.18 **Root.** That part of the surface of the thread which connects adjacent flanks at the bottom of the groove.

3.19 **Truncation.** A truncated thread is one having flat crests, e.g. in the truncated Whitworth form thread, the basic rounded crests at the major diameter of an external thread and the minor diameter of an internal thread are removed at their junctions with the straight flanks of the basic thread form.

4 LIMITS AND TOLERANCES OF THREADS To permit control of screw thread dimensions during production, drawings should stipulate the nominal size, specification reference and class, whilst for screw threads of special diameter/pitch relationships, or for interference fits, the drawings should specify the toleranced sizes for the major, effective and minor diameters. If such information is not given, the guidance of the designer should be sought.

4.1 The major diameter of internal threads is controlled in practice by the major diameters or the taps of screwing tools used to cut the threads, thus a tolerance is not usually specified, but only a minimum size, which should be the same as the basic major diameter. However, a sharp root radius should be avoided, and the screwing tools used should be capable of producing a root radius equal at least to one-half of the standard radius for the pitch concerned.

4.2 The tolerances permitted for the major, effective and minor diameters of a screw thread provide, in effect, an envelope of limiting boundaries within which the thread form must lie. The accuracy of pitch, however, should be assessed over the specified length of engagement of the mating parts, since no separate tolerance is given. In a similar manner, no tolerance is usually quoted for the flank angle.

4.3 **Effect of Pitch and Flank Angle Errors.** Errors in the pitch and flank angles of a thread virtually increase the effective diameter of an external thread, and decrease that of an internal thread (see paragraph 3.10). For threads to be acceptable, therefore, it is necessary to ensure that any compounding of the effective diameter by pitch and flank angle errors does not cause the upper limit of the effective diameter of external threads, or the lower limit of that of internal threads, to be exceeded.

4.3.1 The size of the effective diameter, whether or not influenced by pitch or flank angle errors, is automatically safeguarded provided the thread is found to be acceptable by the gauging system detailed in paragraph 7. However, if the requisite gauges are not available, e.g. during experimental or pre-production conditions, and the accuracy of the threads is to be verified by direct measurement, it will be necessary to measure all elements of the threads, and to compute the effective diameter in relation to possible errors in the pitch and flank angles from the following formulae.

4.3.2 IF Z = maximum pitch error over specified length of engagement.
A_1 and A_2 = errors in opposite flank angles, regardless of sign, in degrees.
E = virtual change in effective diameter.
P = basic pitch of thread.

(i) For Whitworth threads:
Pitch error .. .. $E = 1{\cdot}921 \times Z.$
Flank angle error .. .. .. $E = 0{\cdot}0105 \times P(A_1 + A_2).$

(ii) For B.A. threads:
Pitch error .. .. $E = 2{\cdot}273 \times Z.$
Flank angle error .. .. .. $E = 0{\cdot}0091 \times P(A_1 + A_2).$

4.4 **Classes of Fit**

4.4.1 **Whitworth Form Threads.** Three classes of fit for external threads and two classes for internal threads are provided in B.S. 84 : 1956 and are as follows:

(i) **Close Class External Threads.** This class applies to threads where a good snug fit is required. It is obtainable consistently only by the use of the highest quality production equipment, supported by an accurate system of inspection and gauging. It is normally used for special work where refined accuracy of pitch and thread form is particularly required.

NOTE : An efficient system of inspection, including gauging, is necessary for all screw threaded work whether close class or not.

(ii) **Medium Class Internal and External Threads.** This class of fit applies to the better class ordinary interchangeable screw threads.

(iii) **Free Class External Threads.** This class applies to the majority of ordinary commercial quality bolts.

(iv) **Normal Class Internal Threads.** This class applies to the ordinary commercial quality nuts which are intended for use with medium or free class bolts.

4.4.2 **B.A. Threads.** Provision is made in B.S. 93 : 1951 for one class of fit for internal threads, sizes 0 B.A. to 16 B.A., and two classes for external threads, i.e. close class for sizes 0 B.A. to 10 B.A. and normal class for sizes 0 B.A. to 16 B.A. Close class fit are not given for external threads, sizes 11 B.A. to 16 B.A., since such bolts are not normally highly stressed.

(i) **Close Class External Threads.** The contents of paragraph 4.4.1 (i) are equally applicable in this instance.

(ii) **Normal Class External Threads.** This class applies to threads produced for general commercial use, and is suitable for general engineering purposes.

4.5 **Plated Threads.** In order to avoid any undue restriction of screwing tolerances, and also to prevent the removal of the plating during assembly, for threads which are plated with metals such as cadmium, nickel, etc., where the usual thickness of the plating is in the order of 0·0002 in., the following arrangements are permitted by B.S. 84 : 1956 and B.S. 93 : 1951.

4.5.1 For Whitworth external threads of either medium or free class, it is necessary to ensure that the threads prior to plating are not undersize, and that the maximum sizes are not exceeded after plating. For external threads to the close class, the tolerances may be displaced by an amount not exceeding 0·001 in. before plating.

4.5.2 For B.A. external threads of normal class, sizes 11 B.A. to 16 B.A. and all close class threads, the lower limits of the minor, effective and major diameters may be reduced by an amount not exceeding 0·001 in. before plating.

4.5.3 Due to the tendency of close fitting bolts and nuts manufactured of stainless steel to seize when tightened together, it is recommended that Whitworth form bolts manufactured in this material, in sizes up to and including ¾ in., should not be made to "close" class limits before plating, but rather to the "medium" or "free" class limits for unplated bolts, whilst B.A. bolts made of stainless steel should be made to the "normal" class limits for unplated bolts.

4.5.4 The recommended gauging system for checking plated threads is given in paragraph 7.3.

5 INSPECTION OF SCREW THREADS An inspection of the threads should be made to verify that the drawing requirements in respect of dimensional accuracy, thread form and standard of finish are met. Information on implementing these inspections is given in paragraph 7 to 11, whilst a description of the equipment to be used is given in the following paragraph.

6 THREAD GAUGES The system of "Workshop" and "Inspection" grade gauges recommended in B.S. 919 : 1940 has been superseded in B.S. 919 : 1952 by a system of gauges designated "General" and "Reference" grade gauges. General and Reference grades are provided for "Go" screw plug, ring and caliper gauges and their associated setting plugs, but for "Not Go" screw gauges and "Go" and "Not Go" major diameter gap gauges and minor diameter plug gauges, B.S. 919 : 1952 recommends the use of General grade gauges only.

6.1 **General Gauges.** These gauges are so dimensioned as to control the thread flanks within the specified work limits, i.e., the gauge tolerances lie within the work limits. The use of General gauges is recommended for medium and free fit class Whitworth form threads and for all classes of B.A. threads.

6.2 **Reference Gauges.** These gauges are designed around the nominal size of the thread with a minimum encroachment into or outside the work tolerance. The principal uses of Reference gauges are as referees in cases of doubt, thus serving as a check on the continued accuracy of General gauges, and for checking threads which have been manufactured to close class tolerances.

6.3 **"Go" Gauges.** These gauges are designed to control the maximum diameter and pitch of the external thread and the minimum diameter and pitch of the internal thread. The gauges are manufactured to the thread form and gauge length specified in B.S. 919 : 1952.

6.4 **"Not Go" Gauges.** "Not Go" effective diameter gauges are also designed to comply with the requirements of B.S. 919 : 1952, where it is specified that the threads should be cleared at the crests and roots in order to permit control of the effective diameter only. To minimise the possibility of pitch error affecting the result, the gauges embody not more than two or three turns of thread.

6.5 **Accuracy of Gauges.** It is important that all thread gauges should be checked periodically to ensure that they are not worn beyond permissible limits or are otherwise inaccurate. Checking is normally done by skilled inspectors, and if the gauges are in continuous use, a daily check is desirable. If the work is of an intermittent nature, a weekly check should suffice, but if the work is being handled in "short runs", a check before and after use is recommended.

6.5.1 Each gauge should bear a serial number, and records of all checks should be kept.

6.5.2 Where resetting is necessary in the instance of adjustable gauges, setting plugs of guaranteed accuracy should be used. (See paragraph 6.6).

6.6 **Setting Plugs.** Setting plugs are screw plug gauges to which adjustable screw ring and caliper gauges are set. They have truncated crests and are cleared at the roots to ensure contact only with the flanks of the threads of the gauge being set. General setting plugs should be used for General "Go" gauges and Reference setting plugs should be used for Reference "Go" gauges.

6.7 **General.** It is recommended that the handles of the various types of gauges, i.e. general, reference, pre-plating, etc., should be painted in different colours to reduce the risk of an incorrect gauge being used.

7 GAUGING SYSTEM

7.1 **Gauging of External Threads.** The following gauges should be used when checking external threads to ensure compliance with the drawing requirements.

7.1.1 A "Go" full form caliper or ring gauge to control the maximum diameter of the thread, and to ensure that the pitch is acceptable over the specified length of engagement.

7.1.2 A "Not Go" effective diameter thread caliper gauge to control the minimum effective diameter of the thread.

NOTE : The use of "Not Go" effective diameter ring gauges is not recommended for general applications.

7.1.3 A "Not Go" major diameter gap gauge to control the minimum major diameter of the thread.

7.1.4 When truncated threads are to be checked, "Go" and "Not Go" major diameter gap gauges, specially dimensioned for truncated threads, should be used to control the major diameter.

7.2 **Gauging Internal Threads.** The following gauges should be used when checking internal threads to ensure compliance with drawing requirements.

7.2.1 A "Go" full form screw plug gauge to control the minimum diameter of the thread, and to ensure that the pitch is acceptable over the specified length of engagement.

7.2.2 A "Not Go" effective diameter screw plug gauge to control the maximum effective diameter of the thread.

7.2.3 A "Not Go" minor diameter plug gauge to control the maximum minor diameter of the thread.

7.2.4 When truncated threads are to be checked, "Go" and "Not Go" minor diameter plug gauges, specially dimensioned for truncated threads, should be used.

7.2.5 Observation should be made to ensure that the axis of the thread through the nut is at right angles to the end faces. This is particularly important in larger nuts which may be used at predetermined torque loadings on ground-threaded high tensile bolts or studs (Leaflet **AL/7-8**).

7.3 **Gauging Plated Threads.** Reference was made in paragraph 4.5 to the special arrangements permitted in regard to manufacture when threads are to be metal plated. The gauging system recommended for checking such threads, both before and after plating, is given in the following paragraphs.

7.3.1 **External Threads.** Prior to plating, the threads should be checked with a "Not Go" effective diameter caliper gauge to control the minimum effective diameter specified prior to plating, and a "Not Go" major diameter gap gauge, made to control the minimum major diameter specified prior to plating.

(i) After plating, the threads should be checked with a "Go" full form thread caliper or ring gauge to control the maximum diameter of the thread.

(ii) When plated truncated threads are to be checked, a "Go" major diameter gap gauge, specially dimensioned for truncated threads, should be used to control the major diameter.

7.3.2 **Internal Threads.** Prior to coating, the threads should be checked with a "Not Go" effective diameter screw plug gauge to control the maximum effective diameter specified prior to plating, and a "Not Go" minor diameter plug gauge, made to control the maximum minor diameter specified prior to plating.

(i) After plating, the threads should be checked with a "Go" full form screw plug gauge to control the minimum diameter of the thread.

(ii) When plated truncated threads are to be checked, a "Go" minor diameter plug gauge, specially dimensioned for truncated threads, should be used to control the minor diameter.

7 4 **Relaxation of Gauging.** When a quantity of identical threads are to be produced, and it has been verified by inspection that a satisfactory production technique has been established, the gauging operations described above may be selectively applied at the discretion of the Chief Inspector. For rolled threads, evidence of identical conditions of manufacture would consist of ensuring that the machines producing the threads had been fed with blanks adequately controlled as to size and ductility, that the machines had been correctly set prior to each run, and that the threads produced by each machine had been checked periodically during each run to verify their continued dimensional accuracy.

8 THREAD FORM A standard gauging system is not in itself sufficient to verify completely the thread form, since the form at the crest and root is not controlled by the gauges. For this reason, and as a periodic check on the general quality of thread production, a supplementary inspection of the threads should be made, either by the use of optical instruments or by projecting the threads on to a screen at an appropriate magnification and comparing them with a standard line diagram representing the thread form, drawn to the same magnification. An optical examination or projection of the threads should be carried out on initial production to verify that a satisfactory screw production technique has been established. When checking external threads, this is a convenient point to confirm that the radius between the shank and the head is within permissible limits.

8.1 When internal threads are to be examined by a projection process, it will be necessary to take a cast of the threads, care being taken to ensure that the cast is a true reproduction of the thread form.

8.2 The form of the thread should be checked to ensure that it is regular and, where radiused roots and crests are specified, that these are correctly formed and blend uniformly with the flanks. When the threads have been truncated, it should be ascertained that the specified length of thread flank has been maintained. (See paragraph 3.19).

9 STANDARD OF FINISH The threads should be examined to ensure that the required standard of surface finish has been attained, and that there is no evidence of tearing or chatter; it is recommended that a magnifying glass of suitable magnification or some other suitable optical instrument is used for this purpose. The standard of finish is largely influenced by the type of material being threaded. One of the most difficult materials to thread is B.S.S. S80, but with a suitable combination of cutting speed, tool materials and angles, and cutting lubricants, a finish equal to the simpler materials can be achieved.

10 NOTES ON USING GAUGES Three types of gauges are in general use for checking external threads, i.e., roller type caliper gauges, anvil type caliper gauges, and ring gauges; of these, the two former types are usually preferred for general gauging.

10.1 Caliper gauges, which can be used for checking both left and right hand threads consist of two pairs of rollers or anvils, arranged as illustrated in Figure 3. The gauging elements can be adjusted to suit various diameters and are set by means of the special setting plugs described in paragraph 6.6. After setting, the adjusting mechanism of the gauge should be sealed to prevent unauthorised adjustments.

10.2 Caliper gauges, unlike ring gauges, permit the external threads to be checked for ovality and, to this end, threads should always be checked in two positions at right angles to each other.

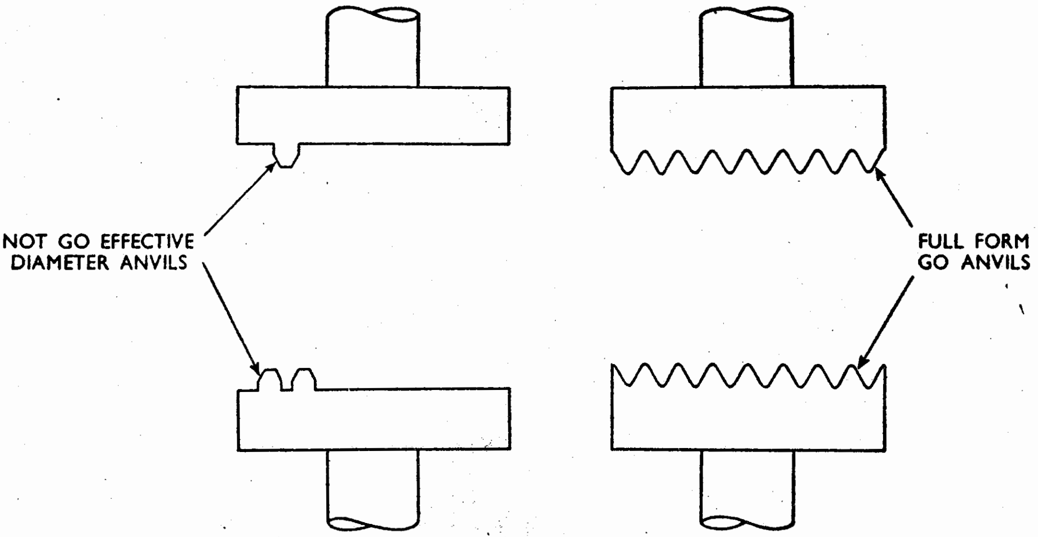

Figure 3 ARRANGEMENT OF CALIPER GAUGES

10.3 It is essential that the threads should be free of swarf and dirt before gauging is begun, and care should be taken to employ only a light pressure on the gauge to minimise the possibility of springing the frames. When anvil type gauges are used, the items to be checked should be applied from the front of the gauge, and should never be drawn through from the rear.

10.4 If the threads will not pass through the "Go" gauge, but will slip easily through the "Not Go" portion, this is indicative of an error in either the thread form or the pitch. The nature of the error can be established by trying the first thread only of the item into the "Go" gauge, and if the thread passes through, it can be assumed that the error is in the pitch, but if it fails to pass through then, assuming the major diameter to be correct, a serious error in flank angle, or malformation of the root or crest, will be indicated.

10.5 Ridging or flashes may occur on external threads which have been produced by a moulding or diecasting process, and it is recommended that threads produced by either of these methods should be checked for continuity with a ring gauge.

11 GENERAL INSPECTION In addition to gauging the threads, the parts should be inspected for general dimensional accuracy. The majority of thread drawings specify that a "lead", or chamfer, should be applied to the first half or full thread, and this also should be checked for accuracy.

11.1 Bolts, and in particular those having short plain shanks, which are produced on automatic machines using automatic die chucks, should be checked to ensure that the final thread is correctly formed, since, for various reasons, the thread form cutter may fail to cut a full final thread.

11.2 Rolled threads may be affected by chips in rolling dies, which will produce similar identically repeated bumps on each thread produced from the dies. A proportion of the threads should be examined visually for such defects, since they may not necessarily be revealed by gauging.

BL/3-2

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BASIC

METROLOGY

MEASUREMENT OF UNIFIED THREADS

1 INTRODUCTION This Leaflet gives guidance on the measurement and inspection of Unified screw threads produced by recognised methods such as grinding, machining, dieing, tapping or rolling. In modern practice the majority of external threads are produced by rolling and internal threads by tapping. It has been found by experience that these methods produce a thread with the greatest resistance to fatigue.

1.1 The Unified system of screw threads was introduced by Canada, the United States and the United Kingdom to provide a common standard between the three countries. The International Standards Organization (I.S.O.) has recommended the system as an international system of screw threads in inch units, in parallel with a similar system in metric units. Both systems use a similar form of thread profile and tolerance. Data relating to the inch series threads of ¼ inch diameter and over is contained in British Standard 1580 and for threads below ¼ inch diameter in British Standard 3155.

1.1.1 The range of threads included in BS 1580 is as follows:—

(i) UNC Unified coarse pitch thread with progressive pitch sizes (i.e. pitch varies with diameter).

(ii) UNF Unified fine pitch thread with progressive pitch sizes.

(iii) UNEF Unified extra fine pitch thread with progressive pitch sizes.

(iv) UN Unified thread with constant pitch (e.g. an 8UN thread has 8 threads per inch regardless of the diameter).

(v) UNS Unified thread of special pitch/diameter combination not included above, but for which the tolerances are derived from the standard formulae.

(vi) In addition to the above, modified profile threads may be used for special applications, e.g. 'Mod' after the designation, means that the major diameter is decreased for threads used in high temperature zones; effective diameter is the same as for the standard thread.

1.1.2 The range of threads included in BS 3155 and accepted for use in the aircraft industry are nominated as UNC or UNF and conform generally to the requirements of BS 1580 except that they are normally only manufactured in one class of fit (i.e. Class 2A and 2B, see paragraph 4).

1.1.3 **Abbreviation System.** The abbreviation system recommended for the indentification of Unified threads consists of a combination of the diameter, pitch, series and class of fit, e.g. ¼–28 UNF 2A (or 0·250–28 UNF 2A). For a left handed thread the suffix 'L' is added. The numbered threads are designated in a similar way, e.g. 10–32 UNF 2A (or 0·190–32 UNF 2A). For products manufactured to aircraft specifications the part number is prefixed by the specification number. In circumstances where the thread is to be coated, additional information may be added to a drawing for manufacturing purposes. This will include the major and effective diameters before and after coating and additional symbols may also be used to specify particular forms of thread or lengths of engagement.

1.1.4 Of the above threads UNF and UNC are those selected for general use within the aircraft industry and a single range of sizes has been chosen in which the majority of fasteners are manufactured. These are: 0–80 UNF, 2–64 UNF, 4–40 UNC, 6–32 UNC, 8–32 UNC, 10–32 UNF, ¼–28 UNF, 5/16–24 UNF, ⅜–24 UNF, 7/16–20 UNF, ½–20 UNF, 9/16–18 UNF, ⅝–18 UNF, ¾–16 UNF, ⅞–14 UNF and 1–12 UNF. Special threads (UNS and UNS Mod.) have some particular uses but in the main are being replaced by threads of UNJ form (see paragraph 1.2).

1.2 **UNJ Threads.** A recent addition to the Unified range of threads is the UNJ thread form, which is designed for increased fatigue strength where working stress levels are high. It features an enlarged root radius on the external thread (Figure 4) and is particularly suitable for aircraft applications. The requirements for high strength are further met by restricting the tolerances to those of a Class 3A (external) or 3B (internal) fit. Data relating to UNJ threads is contained in British Standard 4084 and is discussed in paragraph 5 of this Leaflet.

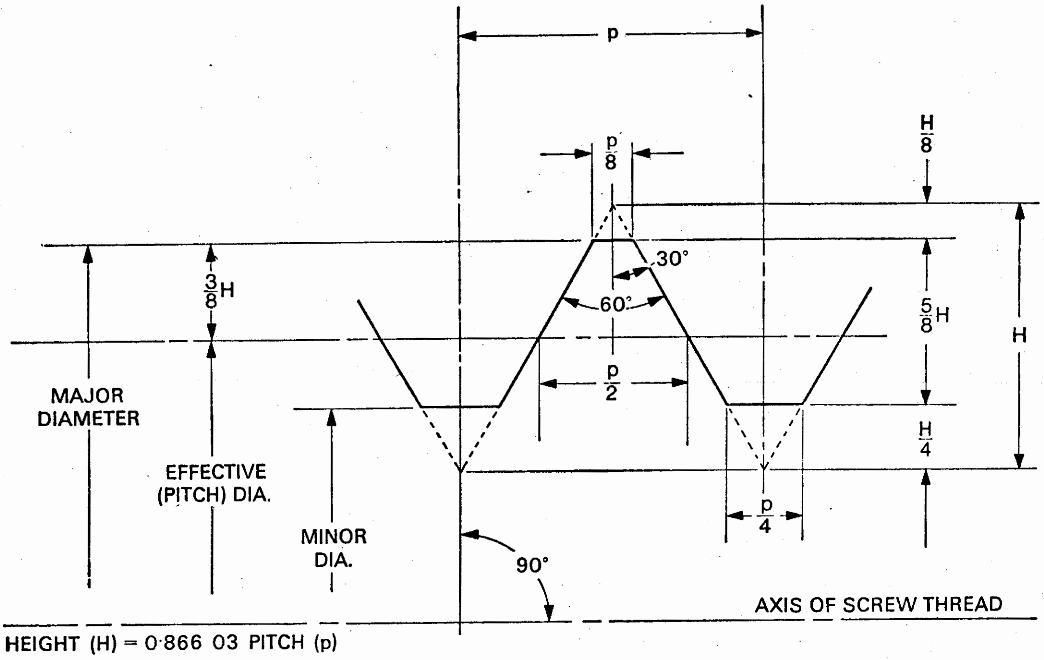
1.3 **General.** The accuracy of fastener threads should be verified, during manufacture, by a system of gauging and optical projection. A suitable system is defined in BS 919 Part 1, and explained in this Leaflet.

1.4 Specifications for aircraft fasteners having Unified threads are included in the British Standards 'A' series of specifications, in the Society of British Aerospace Companies 'AS' series and in the Aircraft General Standards series.

2 UNIFIED THREAD FORM The basic form of a Unified thread is illustrated in Figure 1 and is derived from an equilateral triangle with one side parallel to the axis of the thread. The triangle is truncated by an amount equal to ⅛ of its height at the major diameter and ¼ of its height at the minor diameter.

2.1 The design form of the thread (Figure 2), i.e. the thread in its maximum metal condition, varies from the basic form in that the root of the external thread is rounded to a specified radius below the flat. It will be seen from Figure 2 that contact between the design forms of the external and internal thread is confined to the flank over a radial depth of ⅝ the height of the basic triangle. In practice the root of the internal thread is rounded outside the major diameter to avoid sharp corners.

2.2 Modern mass production methods often result in partial or even complete rounding of the external thread crests, but this is not detrimental to the strength of the fastener and does not conflict with the checking methods used. It does render the thread less susceptible to damage and has the added advantage of minimising the plating faults which often occur at sharp corners.



HEIGHT (H) = 0·866 03 PITCH (p)

Figure 1 BASIC FORM OF UNIFIED THREAD

3 LIMITS AND TOLERANCES In order to provide for interchangeability and ensure the correct class of fit for a particular application, standard Unified threads are controlled by a system of tolerances which are defined in BS 1580. This Standard relates to threads of ¼ inch diameter and larger but the principles employed are also applicable to the numbered sizes (i.e. 0–80 to 10–32) the tolerances for which are listed in BS 3155.

3.1 The tolerances permitted for the major, effective and minor diameters of a screw thread provide, in effect, an envelope of limiting boundaries within which the thread surface must lie. The accuracy of pitch, however, should be assessed over the specified length of engagement of the mating parts, since no separate tolerance is given. In a similar manner no separate tolerance is normally quoted for the flank angle.

3.2 **Effective Diameter Tolerance.** This is derived from a three part formula which takes account of diameter, pitch and length of engagement. For UNC, UNF, UNJ, 4UN, 6UN and 8UN threads, a length of engagement equal to one diameter is used; for all other threads a length of engagement of 9 pitches is used.

3.3 **Major Diameter Tolerance.** With external threads the tolerance on major diameter is derived solely from a formula based on pitch. With internal threads no tolerance is quoted, it being considered that this dimension will be adequately controlled by the crests of the tap or cutting tool.

3.4 **Minor Diameter Tolerances.** The minor diameter tolerance on external threads is related directly to the effective diameter tolerance. The minor diameter of an internal thread is formed by an operation prior to threading and the tolerance is related to pitch and diameter.

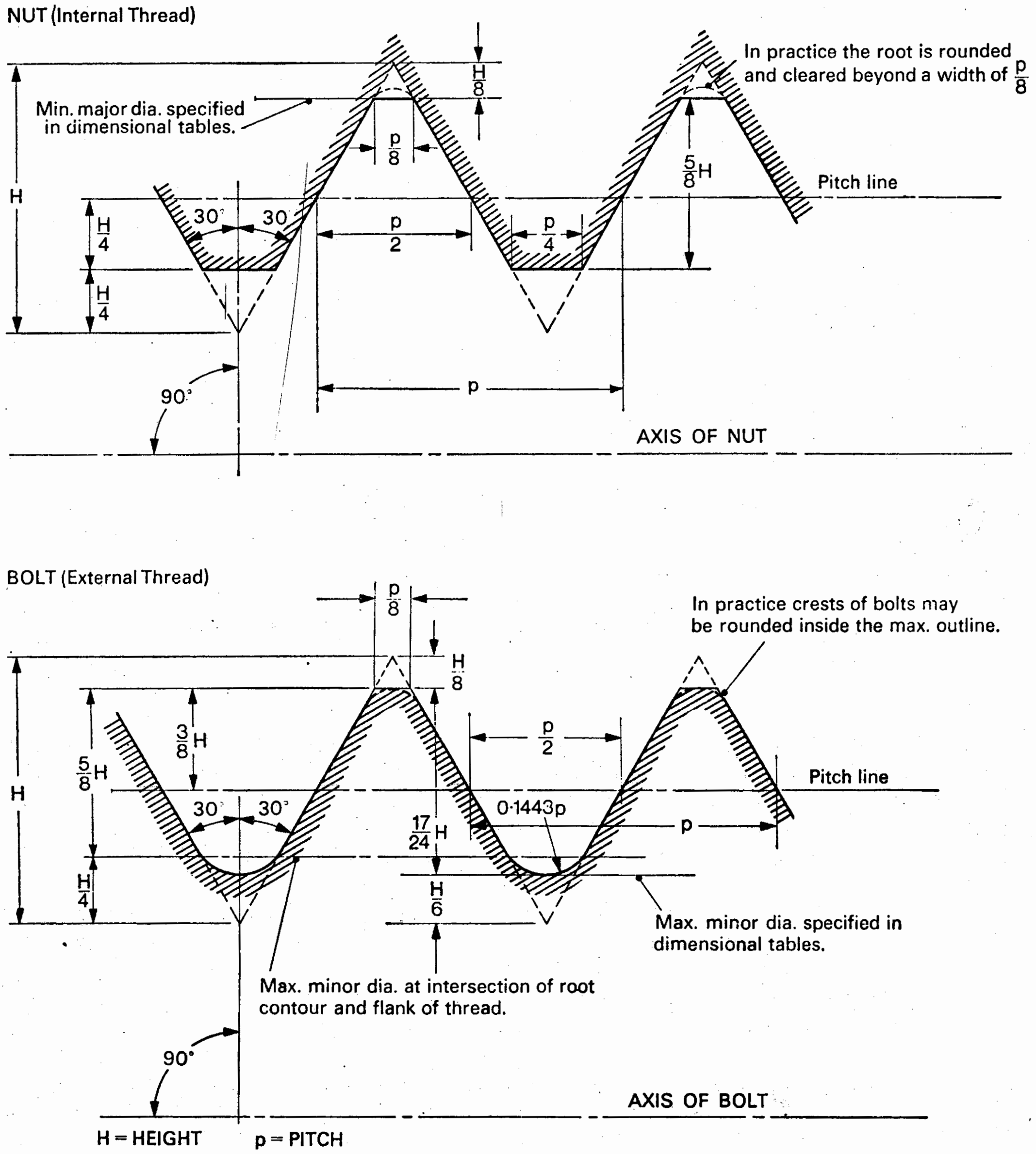


Figure 2 DESIGN FORM OF UNIFIED THREAD (MAXIMUM METAL CONDITION)

3.5 **Depth of Engagement.** The depth of engagement (i.e. radial amount of thread overlap) is 5H/8 for standard Unified threads and 9H/16 for UNJ threads when mating threads are in the maximum metal condition. This is reduced by the tolerances permitted on the major diameter of the external thread and the minor diameter of the internal thread.

3.6 **Allowance.** This is the design clearance permitted between mating threads and is deducted from the basic size of the external thread. The allowance for Class 1A and 2A threads is 30 per cent of the Class 2A effective diameter tolerance but there is no allowance permitted for Class 3A threads.

NOTE: Due to the tendency of close fitting fasteners of unplated stainless steel to seize when tightened it is recommended that stainless steel bolts should not be made to Class 3A limits.

3.7 **Provision for Coated Threads.** Where specified, a depth of coating (e.g., cadmium or tin) of 0·0002 inch is normally required on all threads and this coating would interfere with the thread tolerances if not taken into account during manufacture. The allowance for Class 2A threads is normally permitted to be absorbed by the coating (but see paragraph 4.4) and it is, therefore, unnecessary for the thread to be reduced in size before coating. For other external threads and all internal threads, diametral limits are laid down in the appropriate specification, to which the thread must conform before the coating is applied. The appropriate limits, as applicable to the effective diameter, are illustrated in Figure 3.

3.8 **Effect of Pitch and Flank Angle Errors.** Errors in pitch and flank angle have the effect of increasing the simple effective diameter of an external thread and decreasing that of an internal thread. No specific tolerances are given for these parameters, but they are adequately controlled by the effective diameter tolerance. For example, if a bolt has a simple effective diameter on the maximum size, no pitch or flank angle deviations will be accepted by the checking gauge, but if the simple effective diameter is of minimum size then some deviations in pitch and/or flank angle will be accepted.

3.8.1. Should the requisite gauges not be available, e.g. during experimental or pre-production conditions, and the accuracy of the threads is to be verified by direct measurement, it will be necessary to measure all elements of the threads and to compute the effective diameter in relation to possible errors in pitch or flank angle from the following formula:—

If Z=maximum pitch error over specified length of engagement, in inches,

A_1 and A_2=errors in opposite flank angles, regardless of sign, in degrees,

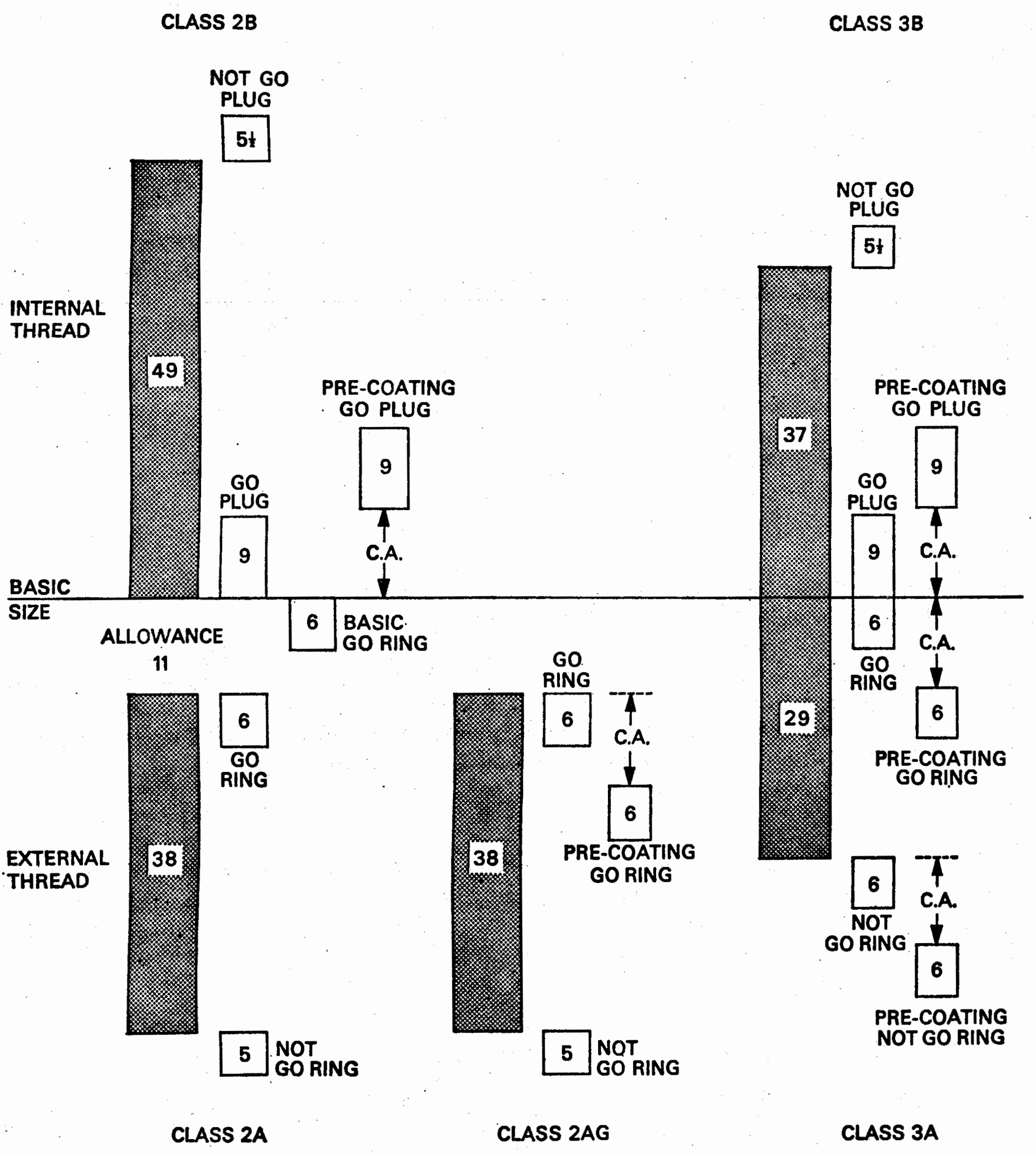
E=virtual change in effective diameter,

P=basic pitch of thread, then,

Pitch error .. .. $E = 1{\cdot}732 \times Z$

Flank angle error .. $E = 0{\cdot}01 \times P\,(A_1 + A_2)$

NOTE: In the basic form of the Unified screw thread, the lengths of straight flank above and below the pitch line are not equal For this reason the virtual change in effective diameter resulting from positive flank angle errors on the bolt and negative flank angle errors on the nut will be slightly less than that resulting from negative flank angle errors on the bolt and positive flank angle errors on the nut. The factor 0·01 in the expression above is the mean value of the corresponding factors applying to these two sets of conditions and is sufficiently accurate for practical purposes.



C.A. = Coating allowance = 0·001 inch in sizes of ¼ inch dia. and larger.

1 UNIT = 0·0001 inch.

▨ = PRODUCT TOLERANCE

□ = GAUGE TOLERANCE

Figure 3 EFFECTIVE DIAMETER TOLERANCES

4 CLASSES OF FIT Three ranges of tolerances are specified in BS 580 for Unified threads of ¼ inch diameter and larger, but threads in the numbered sizes are limited to Class 2 and UNJ threads to Class 3.

4.1 **Class 1A External Thread, Class 1B Internal Thread.** These classes apply to the majority of fasteners of ordinary commercial quality and correspond in general to the 'free' class fit of BS 84 (Screw threads of Whitworth Form).

4.2 **Class 2A External Thread, Class 2B Internal Thread.** These classes apply to the majority of fasteners used in the aircraft industry and correspond to the 'medium' class fit of BS 84.

4.3 **Class 3A External Thread, Class 3B Internal Thread.** These classes apply to threads which have a snug fit and correspond to the 'close' fit grade of BS 84. They are being used in increasing quantities in the aircraft industry, particularly in aircraft engine applications.

4.4 **Class 2AG External Threads.** This class of thread is used where a Class 2A fit is required and it is necessary to maintain the allowance after coating (i.e. for use in high temperature zones or where a lubricant is specified); it is applicable to the external thread before coating. The basic diametral limits are 0·001 inch less than those quoted for a Class 2A fit on threads ¼ inch diameter and larger, with corresponding smaller reductions for the numbered sizes.

4.5 **General.** Normally the same class of internal and external thread are used together, but different grades of fit may be obtained, if required, by using different classes. It should also be noted that nuts with UNJ threads may be used in place of those with standard Unified threads.

5 UNJ THREAD FORM The basic and design forms of Unified threads are shown in Figures 4 and 5 respectively. These threads are described in BS 4084 and comprise a coarse thread series (UNJC) and a fine thread series (UNJF) similar to those in the standard Unified range.

5.1 **Tolerances.** As mentioned in paragraph 1.2, UNJ threads are only manufactured to Class 3 tolerances and no provision is therefore made for an allowance on the internal thread. Tolerances on effective and major diameters are calculated in the same way as for standard Unified threads, the length of thread engagement used in the formula for calculating effective diameter tolerance being equal to the basic thread diameter. Minor diameter tolerances for internal threads are calculated in the same way as for standard Unified threads but the formula used gives a slightly larger diameter to allow for the increased root radius of the mating external thread.

5.2 **Gauging.** The general principles to be observed when inspecting UNJ threads are the same as those required for standard Unified threads. BS 4084 stipulates that the root of the external thread shall also be inspected by optical projection to check the root radius and the blending of the curve with the flanks.

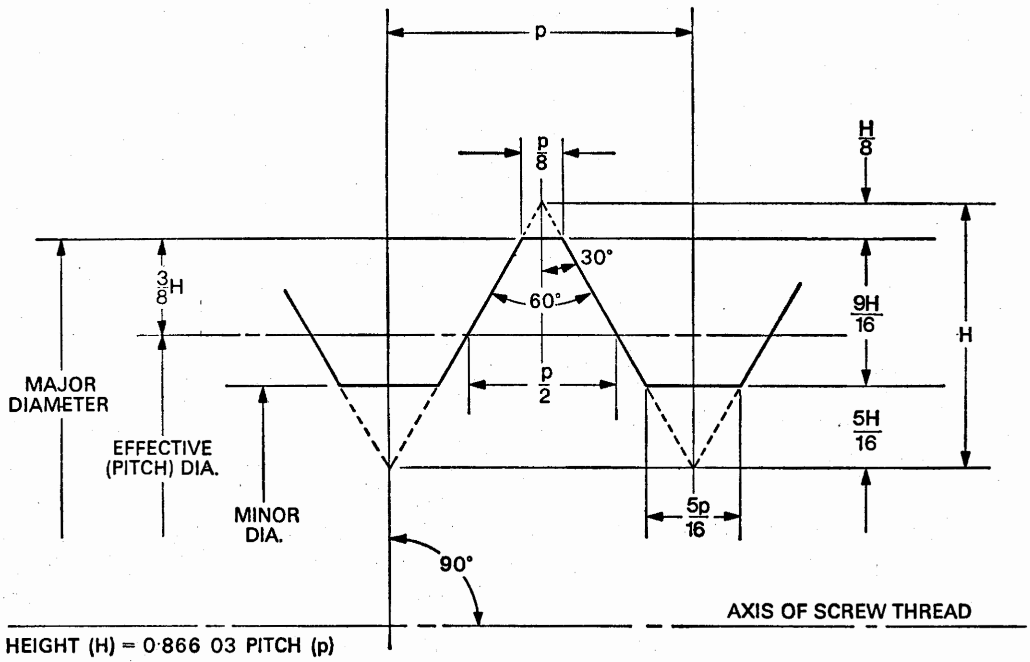


Figure 4 BASIC FORM OF UNJ THREAD

6 THREAD GAUGES BS 919 Part 1 gives full details of the types of gauges to be used when checking screw threads of Unified form and also lists the tolerances which are acceptable during manufacture. Following American practice only one series of gauges is specified for use during both manufacture and inspection. Typical gauges are illustrated in Figure 6.

6.1 **GO Gauges.** These gauges are designed to ensure that the product does not exceed the maximum metal condition specified in the appropriate Standard (BS 1580, BS 4084 or BS 3155) for the type and size of thread. A GO screw plug gauge will ensure that the major and effective diameters of an internal thread are not below the minimum size specified; it will not check the minor diameter however as the gauge thread roots are cleared beyond the minor diameter for practical reasons. The minor diameter of the internal thread is checked with a plain GO plug gauge. A GO screw ring or caliper gauge will ensure that the effective diameter of an external thread is not greater than the maximum size specified and that it will assemble with an internal thread of minimum size. It will not ensure that the major diameter is not too large; this is checked by a plain ring or caliper gauge. GO gauges are normally made to a length at least equal to the length of engagement of the product threads.

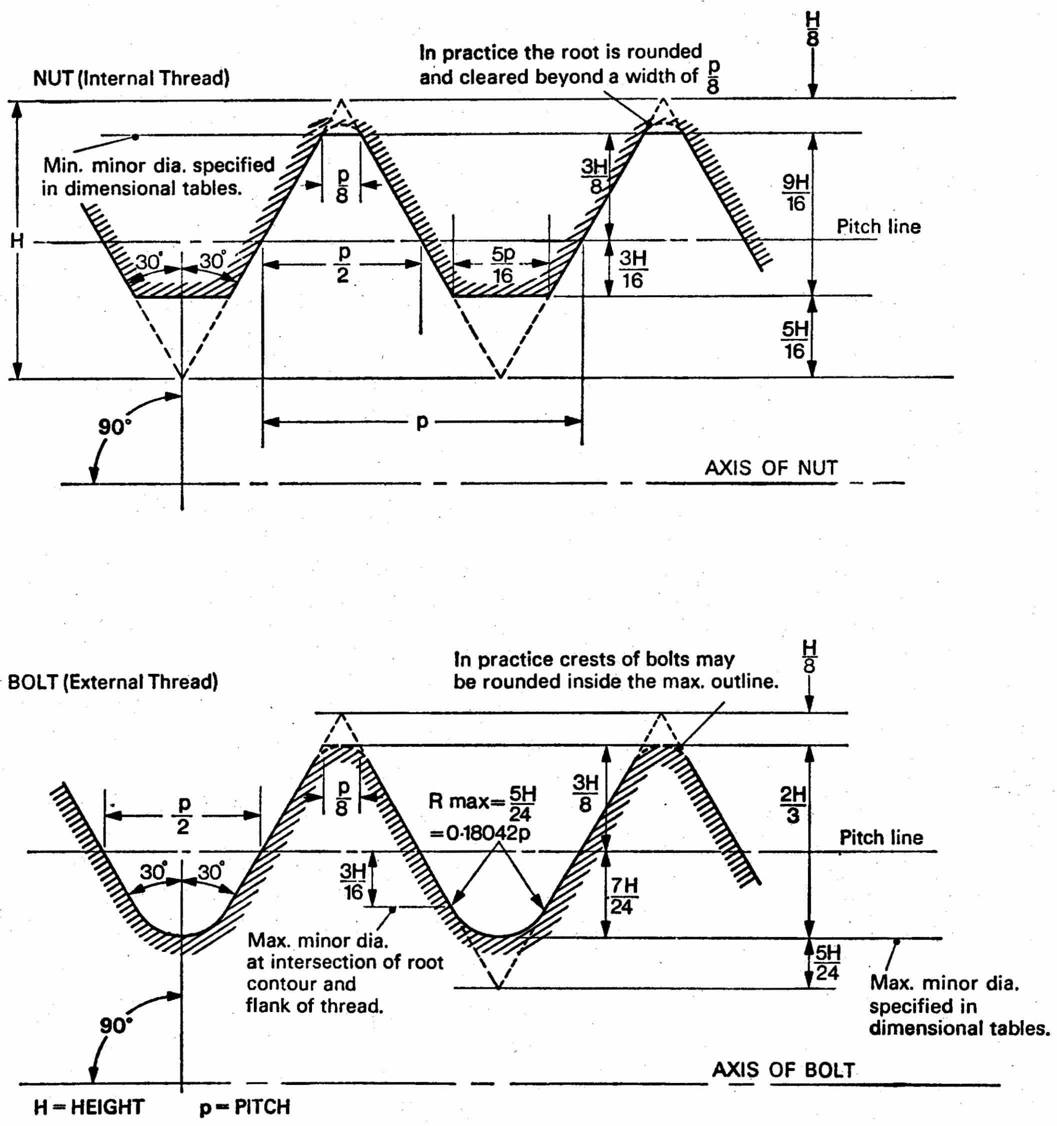


Figure 5 DESIGN FORMS OF UNJ THREAD (MAXIMUM METAL CONDITION)

6.2 **NOT GO Gauges.** These gauges are designed to ensure that the product meets the minimum metal limit specified in the appropriate Standard and are similar in appearance to GO gauges. NOT GO gauges for crest diameters are plain plug gauges for internal threads and plain ring or caliper gauges for external threads, made to the minimum metal limit of the product thread. NOT GO screw gauges for checking the minimum metal limit on effective diameters are of two types, namely, low addendum or high addendum. A low addendum gauge only contacts the thread over a short length of flank whereas the high addendum gauge has a much larger area of contact. The low addendum gauge is a better method of checking simple effective diameters where flank angle or other thread malformations are present, and is used widely in the United Kingdom. The high addendum gauge is, however, recommended for checking Unified threads in the numbered sizes. To minimise the effect of pitch errors, NOT GO screw gauges embody only 2 or 3 turns of thread.

6.3 **Gauge Tolerances.** The manufacturing tolerances for GO gauges are placed within the limits specified for the product thread to ensure that no work is accepted which is outside these limits and that mating threads will always assemble. The manufacturing tolerances for NOT GO gauges, however, are placed outside the product limits in British practice, but the tolerances are so small that acceptance of threads outside the limits is unlikely.

6.4 **Adjustable Gauges.** To permit their continued use after wear has taken place, ring and caliper gauges are often manufactured in an adjustable form. To set the size of an adjustable ring gauge a 'double-length' setting plug is used. The effective diameter of this setting plug remains constant over its whole length, but while the major diameter of one half is at the maximum size the other half is truncated to the minimum size. On GO gauges this form of setting plug enables the thread form to be checked and on NOT GO gauges it is possible to verify that both the effective diameter and major diameter are satisfactory. Adjustable caliper gauges are set with a 'single length' setting plug which has a length approximately equal to that of the gauge.

6.5 **Check Gauges.** GO and NOT GO check gauges are required for verifying the size of a new solid type ring gauge and are similar to the plug gauges used for checking product threads but are made to finer limits. NOT GO effective diameter check gauges are also required to ensure that solid ring gauges are not kept in use when worn beyond limits. Check gauges are an alternative to direct measurement and are indispensable in sizes below ¼ inch diameter.

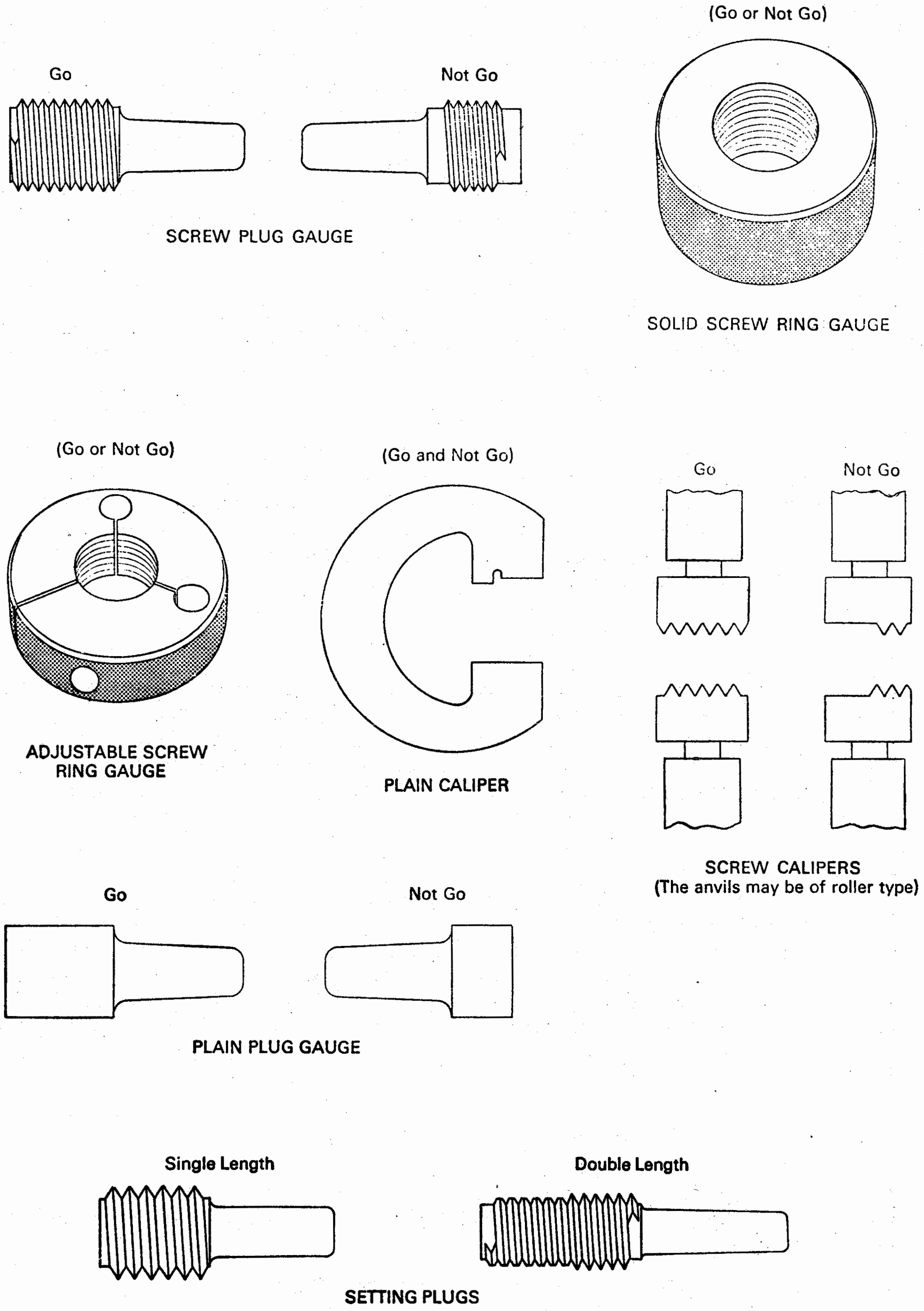
6.6 **Marking of Gauges.** Each gauge must be adequately marked to show the use for which it is intended and the size of the limits it is intended to control. Examples of typical markings are given below:—

(i) GO screw plug gauge (low addendum) : '¼-28 UNF 2B GO EFF 0·2268'

(ii) NOT GO screw caliper : '¼-28 UNF 2A NOT GO EFF 0·2258'

(iii) GO Pre-coating screw plug gauge : '¼-28 UNF 2B GO EFF 0·2278 BEF COAT'.

6.6.1 The letters 'LH' are also added if the thread is left hand, and a system of serial numbers is recommended for record and checking purposes.



SCREW PLUG GAUGE

SOLID SCREW RING GAUGE

ADJUSTABLE SCREW RING GAUGE

PLAIN CALIPER

SCREW CALIPERS
(The anvils may be of roller type)

PLAIN PLUG GAUGE

SETTING PLUGS

Figure 6 TYPICAL THREAD GAUGES

6.7 **Notes on the Use of Gauges.** The primary purpose of GO screw gauges is to prove that the whole of the surface of the product thread falls within the maximum metal limits specified. A solid plug gauge is used on internal threads and a solid ring gauge is most reliable for external threads. The ring gauge in particular is prone to wear, however, and adjustable ring gauges are often used although these too have limitations, mainly due to being slightly out of shape after adjustment. Caliper gauges, whether of the anvil or roller type may also have shortcomings due to the 'give' of the frame, Inspectors, therefore, have a choice of gauges for any particular purpose and should select the most appropriate for the product and method of manufacture.

6.7.1 Cleanliness of the product thread and gauges is most important. The presence of dirt and swarf in a thread, besides giving a false indication of fit, may also damage the gauge.

6.7.2 The position of the gauge tolerance zones in relation to the product limits is shown in Figure 3. Since all internal work is slightly bell-mouthed and external work often slightly tapered, it may be possible for a product on the minimum metal limit to be partly accepted by the NOT GO gauge. Provided not more than two threads are engaged this is acceptable at the discretion of the Chief Inspector.

6.7.3 Caliper gauges, unlike ring gauges, only check a small part of the thread circumference. This is advantageous in that, by checking at different radial positions on the thread, it is possible to detect ovality and some types of lobing. Unless used with extreme caution 'thread chaser' type anvils will accept threads which deviate from design and for this reason roller or semi-roller type calipers are often used.

6.7.4 **Setting Adjustable Gauges.** Adjustable ring gauges are initially ground to a size slightly larger than the setting plug. If this is not done, and the gauge has to be opened out to permit entry of the setting plug, the diameter of the ring gauge threads will be less than that of the plug and tend to touch at the corners of the ring slots, resulting in a tendency to shave the setting plug threads. It is not possible to obtain a perfect fit all round the ring but a satisfactory fit may be obtained in the following way:—

(i) Enlarge the ring until an easy fit is obtained on the plug.

(ii) Slightly tighten and lock the ring alternately until a firm fit is obtained. It will assist the closing of the threads if the gauge is lightly tapped during this operation.

(iii) Remove the plug, then re-insert it to check the fit.

(iv) When proper adjustment has been obtained the ring should be sealed.

7 INSPECTION OF SCREW THREADS Gauges of the types described in paragraph 6 are generally used to ensure that production threads conform to specification; they do not, however, ensure that a completely satisfactory thread is formed. The form and finish of the roots of both internal and external threads are not precisely controlled by gauges and reliance must be placed on the accuracy of the cutting or rolling tools used. Maintenance of a satisfactory product thread is achieved by careful inspection of these tools and by the use of optical projection to ensure a good thread profile. It will be necessary to make an accurate cast of an internal thread in order to apply projection methods.

7.1 **Gauging.** It will be evident from the foregoing paragraphs, and from Figure 3, that a number of gauges will be required to check a particular product during manufacture. It will also be seen that the tolerances applied to a particular type of gauge are the same regardless of thread class, and certain gauges may therefore be used for more than one purpose. Table 1 lists the effective diameter thread gauges and crest diameter plain gauges which will be necessary for inspecting product threads of any class.

7.1.1 The gauging of minimum metal limits after coating is not recommended. These limits must be controlled before the application of the coating by the use of appropriate GO and NOT GO gauges. Provided that the product is accepted by the GO gauge after plating the thread should be satisfactory.

7.1.2 As mentioned in paragraph 3.7 the coating of Class 3B threads is not recommended due to the fact that the coating allowance absorbs an unduly large proportion of the product tolerance. If a Class 2B nut is used instead, the effective diameter tolerance, after coating, will approximate to Class 3B limits. If required, a Class 3B internal thread may be coated, but the GO plug gauge used before coating should be of basic diameter plus 0·001 inch (for threads ¼ inch diameter and larger).

7.2 **Standard of Finish.** Product threads should be examined to ensure that the required standard of finish has been obtained and that there is no evidence of tearing or chatter; it is recommended that a magnifying glass of suitable magnification or some other optical instrument should be used for this purpose.

7.2.1 The standard of finish is affected by the speed and method of manufacture and also by the type of material being threaded. Suitable techniques should be selected for a particular material in order to achieve a satisfactory finish. Where cutting tools are used on stainless steel such as S80, frequent checks may be necessary to ensure that tool wear has not degraded the thread finish.

7.3 **Additional Inspections for Nuts.** In addition to the checks made to ensure that the thread form is satisfactory, additional checks are normally specified for nuts.

7.3.1 **Concentricity.** A nut thread is cut after the drilling of the hole which forms the minor diameter; the effective and minor diameters, therefore, are not necessarily coaxial. Concentricity may be checked by the use of a GO screw plug gauge having a plain extension equal in size to the plug gauge used for checking the minor diameter; eccentricity will result in non-acceptance of this type of gauge.

TABLE 1

GAUGES REQUIRED FOR CHECKING UNIFIED THREADS

(Screw Gauges for Effective Diameters and Plain Gauges for Crest Diameters)

Thread Class and Limit	*Gauges Required*		
	Uncoated	*Before Coating*	*After Coating*
1A Max. limit 2A Max. limit 2AG Max. limit 3A Max. limit	2A GO 2A GO — Basic	2A GO — ·0015 in 2A GO 2A GO — ·001 in Basic — ·001 in	2A GO Basic 2A GO Basic
1A Min. limit 2A Min. limit 2AG Min. limit 3A Min. limit	1A NOT GO 2A NOT GO — 3A NOT GO	1A NOT GO 2A NOT GO 2A NOT GO 3A NOT GO —·001 in	None recommended None recommended None recommended None recommended
1B Min. limit 2B Min. limit 3B Min. limit	Basic Basic Basic	Basic +·001 in Basic +·001 in Basic +·001 in	Basic Basic None recommended
1B Max. limit 2B Max. limit 3B Max. limit	1B NOT GO 2B NOT GO 3B NOT GO	1B NOT GO 2B NOT GO 3B NOT GO	None recommended None recommended None recommended

NOTE: A 'Basic' gauge is a GO gauge of nominal size.

7.3.2 **Squareness.** In order to check that the bearing face of a nut is at right angles to the thread axis, the nut is screwed onto a tapered screw gauge having a close fitting sleeve. Any error may be measured by means of a feeler gauge inserted between the nut face and the sleeve. The permitted squareness tolerances are quoted in BS A100.

7.4 **Direct Measurement.** Occasions are likely to occur when a threaded product is manufactured in quantities which render the provision of suitable gauges uneconomical. In these circumstances direct measurement of the diameters, pitch and flank angles of the threads is resorted to. Measurement of the crest diameter is a simple matter but measurement of the effective diameter presents difficulties. Thread measuring wires are normally used for checking the effective diameter of external threads, the virtual effective diameter being calculated by measurement of the pitch and flank angles and reference to the equivalence tables included in BS 919 Part 1. It is also essential that inspection by optical projection is carried out to determine that the thread roots and flanks are correctly formed. Measurement of the effective diameters of an internal thread is usually avoided by fitting it to a mating component of satisfactory size and form, and by careful inspection of the cutting tool.

7.5 **Selective Inspection.** When a large quantity of identical threads is to be produced and it has been verified by inspection that a satisfactory production technique has been established, the inspection described above may be selectively applied at the discretion of the Chief Inspector. For rolled threads, maintenance of identical conditions of manufacture would consist of ensuring that the machines producing the threads were fed with blanks adequately controlled for size and ductility, that the machines had been correctly set prior to each run, and that the threads produced by each machine had been checked periodically during each run to verify their continued dimensional accuracy.

7.6 **General Inspection.** In addition to gauging the threads, a product should be checked for general dimensional accuracy. The majority of specifications for threaded components require a 'lead' or chamfer to be applied to the thread and it is usually necessary to provide a 'run-out' at the shank end of the thread to minimise stress concentration. These details should be checked against the specification.

7.6.1 Bolts with plain shanks may also require checking for straightness, and bolt specifications normally include checks for concentricity of the thread with the shank and squareness of the head with the shank.

BL/3-3

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BASIC

METROLOGY

SURFACE TEXTURE MEASUREMENT

1 INTRODUCTION This Leaflet gives guidance on the assessment of material surfaces where the texture must be inspected to defined limits or to an agreed standard.

1.1 A controlled surface texture is necessary on many aircraft components, not only between mating surfaces, but also on exterior surfaces.

1.1.1 In general, sliding surfaces require a smooth finish, in order to minimize friction or to provide a positive seal area. A smooth finish is particularly important with highly stressed parts, to improve resistance to fatigue failure and corrosion. Structural parts made from notch-sensitive materials, such as very high tensile steel and high strength aluminium alloys, require the smoothest possible finish; the quality of the surface often being more important than minor dimensional inaccuracies.

1.1.2 Mating surfaces in an assembled joint generally require a smooth surface, in order to provide the maximum contact area. The surface texture of parts which are assembled with an interference fit is also important, particularly where the hardness of the parts differs, since an excessively rough surface on the harder part will result in abrasion of the softer material. The effect of this would be an impairment of the standard of fit, and the possibility of concealed corrosion.

1.1.3 A controlled amount of surface roughness may be essential in some cases, examples being the bore of an engine cylinder, where oil is retained on the wall to reduce friction and prolong cylinder life, and in seal grooves to prevent seal roll.

1.2 A particular degree of surface roughness is often specified for the surfaces of a component, therefore, and a manufacturing process is chosen which will produce the surface required.

1.3 Special care should be taken when handling items for which a particular surface texture is specified, since any physical damage may require re-working in order to obtain the texture required. Items should be protected from damage and corrosion whilst in storage, as outlined in Leaflet **BL/1-7.**

1.4 Detailed information on the assessment of surface texture is provided in British Standard (BS) 1134, and International Organization for Standardization ISO/R 468, and specifications for roughness comparison specimens are contained in BS 2634. A glossary of related terms is included in paragraph 8 of this Leaflet.

2 **FORMS OF SURFACE TEXTURE** Surface texture is defined (in BS 1134) as those irregularities, with regular or irregular spacing, which tend to form a pattern on the surface. The texture consists of roughness and waviness, which may be superimposed on any errors of form (i.e. departures from the required geometric form, which are within the manufacturing tolerances) which may be present. These irregularities are shown in Figure 1, in which, because of the small height of the irregularities compared with the spacing of their crests, the vertical scale is greatly expanded. Surface irregularities take the form of a series of peaks and valleys, which may vary both in height and spacing, and produce a texture which is generally characteristic of the production process. Cutting tools produce a regular, well-defined pattern, whilst grinding produces a less regular but equally directional pattern. Lapping, honing, and other abrasive processes, generally produce an irregular, multi-directional pattern, which may vary from point to point on the surface. Roughness is generally produced by the cutting tool or grinding wheel, and is inherent in the particular production process; it also depends on the cutting speeds and feeds used. Roughness is superimposed on waviness, which has a longer spacing, and results from machine or workpiece deflection, vibration, or chatter.

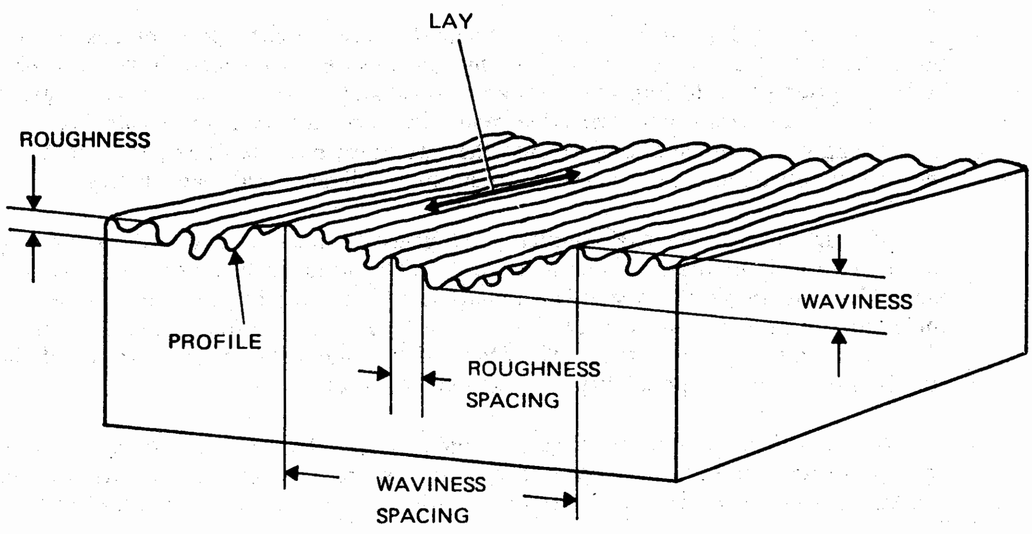
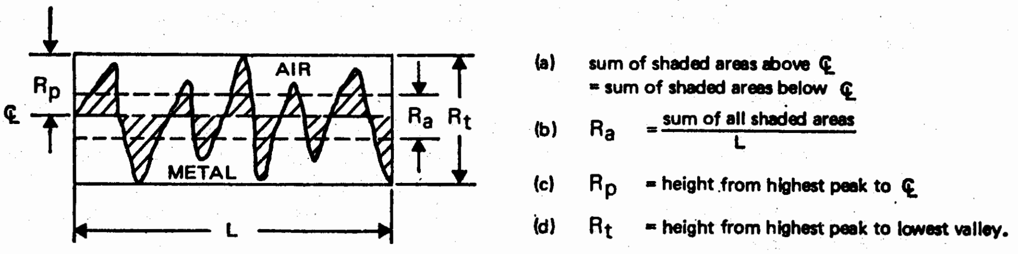


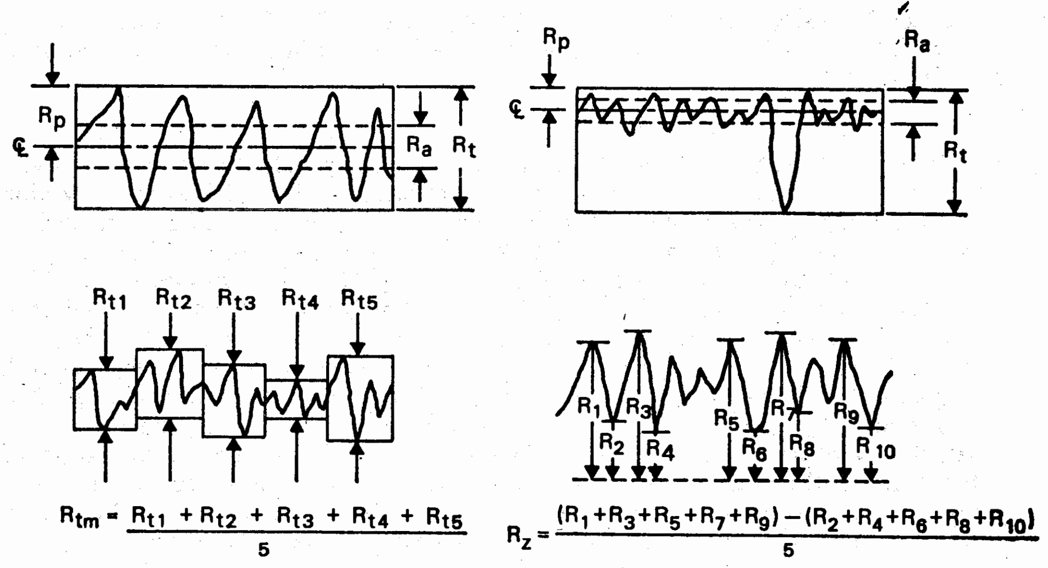
Figure 1 SURFACE IRREGULARITIES

2.1 In some instances the production processes (e.g. machining on numerically controlled machines) may produce a particular type of surface, with pronounced waviness and mismatching (i.e. a surface irregularity caused by successive cutter paths failing to produce a continuous surface). With this type of surface, waviness and mismatching are treated separately from surface roughness, and separate limitations on depth and spacing are imposed. When specified separately, waviness is measured from the graph produced by a profile recording machine, and mismatching is measured by normal metrological methods.

3 SURFACE MEASUREMENT PARAMETERS As may be seen from Figure 1, the shape of a surface is basically three-dimensional, but a simple and realistic means of assessing the surface texture is to measure the profile of a plane section taken through the surface, and thus reduce the problem to a two-dimensional one. On surfaces with a predominantly directional texture, the measurements must be taken at 90° to the lay, or misleading results will be obtained. On surfaces with a multi-directional texture the direction of measurement may be unimportant, but if necessary will be quoted on the appropriate drawing.



DEFINITIONS



$$R_{tm} = \frac{R_{t1} + R_{t2} + R_{t3} + R_{t4} + R_{t5}}{5}$$

$$R_z = \frac{(R_1+R_3+R_5+R_7+R_9) - (R_2+R_4+R_6+R_8+R_{10})}{5}$$

EXAMPLES

Figure 2 SURFACE MEASUREMENT PARAMETERS

3.1 **Grading of Surface Texture.** The method which has been adopted internationally as the standard means of grading surface texture, is known as the arithmetical mean deviation (formerly known as centre-line-average—CLA) and is termed the R_a parameter. R_a represents the average roughness of the surface. Other means of grading the surface are the measurement of total profile deviation (highest peak to lowest valley) and the smoothing depth (highest peak to reference line (see paragraph 8.15)); the former is known as R_t and the latter R_p. Where CLA values are quoted on drawings, the units will generally be μin (millionths of an inch or micro-inches), but where R values are quoted the units will generally be μm (millionths of a metre or microns). Definitions and parameters are shown in Figure 2.

3.1.1 The R_a value may be determined by electrical or other instruments which plot the surface contours and measure their average height, or by graphical assessment of a profile recording (paragraph 4.3).

3.1.2 In some cases the measurement of average peak-to-valley height is required. When this is measured by means of an electrical instrument, the mean R_t value over a number of sampling lengths is taken, and the parameter is known as R_{tm}. When the average peak-to-valley height is determined by graphical assessment of profile recordings, the five highest peaks and five lowest valleys are measured, and the parameter is known as R_z (paragraph 4.3.2).

3.1.3 A range of preferred R_a values, together with a list of equivalent Roughness Grade Numbers, is included in Table 1 (see page 13). The Roughness Grade Numbers may be used on drawings in order to avoid the misinterpretation of numerical values.

3.2 **Sampling Length.** A sampling length is the length of profile chosen for the purpose of making an individual measurement of surface texture. Figure 3 illustrates a section through a surface possessing roughness, waviness, and errors of form. The various sampling lengths (L) which could be used are shown on the illustration, and it can readily be seen that the value obtained for the total height (H) of the surface irregularities, will depend on the sampling length selected. If a short sampling length (L_1) is selected, surface roughness only will be recorded, but if a sampling length greater than the peak-to-peak distance of the waviness is selected (L_2), then both roughness and waviness will be recorded. To assess the whole surface, including errors of form, a sampling length of L_3 would be required. In practice, a sampling length of 0·8 mm has been found satisfactory where only roughness is to be considered, and this length is generally used for assessing the finer textures. Where waviness has to be included in the surface texture measurement, then a longer sampling length must be chosen; the actual length will depend on the class of work and the manufacturing process being used.

3.2.1 When measuring roughness only, and using a short sampling length, the texture of various parts of the surface may appear to vary considerably because of irregularities with a spacing longer than the sampling length. The effect of these irregularities may be reduced by taking a number of observations in a row, and measuring the mean height of each sampling length separately. By averaging out a number of consecutive sampling lengths a satisfactory result may be obtained.

3.2.2 A range of standard sampling lengths is listed in BS 1134, and meter cut-off wavelengths (paragraph 5.2.1) of the same value are used. When specifying the surface texture required for a particular surface, on a drawing, the meter cut-off to be used should normally be quoted in parenthesis following the surface texture value, e.g. 0·1 μm R_a (0·25), but may be omitted in the case of the standard 0·8 mm cut-off.

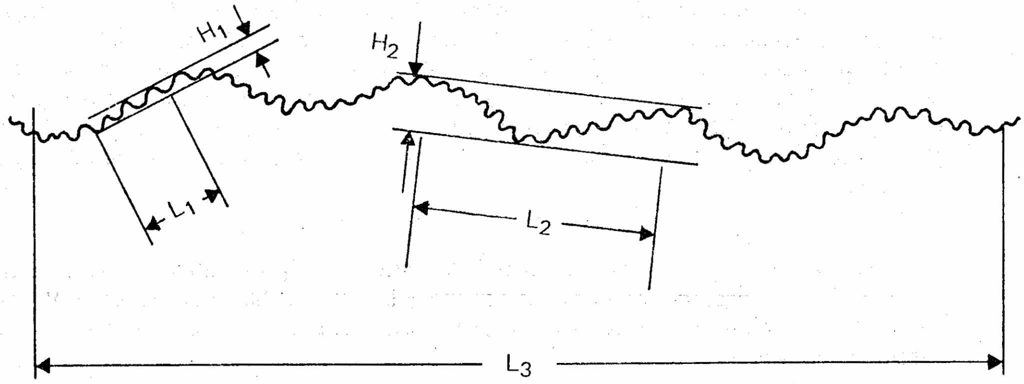


Figure 3 SAMPLING LENGTH

4 **ASSESSMENT OF SURFACE TEXTURE** The texture of a surface may be measured with instruments which operate on mechanical, electro-mechanical, pneumatic or optical principles, but for normal purposes the electro-mechanical instruments are the more versatile, and are used internationally (paragraph 5). These instruments measure the mean deviation of the surface relative to a defined centre line, the measurement taking no account of the form of the deviations, which may vary considerably. Figure 4 illustrates some of the forms which are likely to be found, and a surface could resemble any of these or a combination of any number of forms. The numerical measurement of R_a values is not, therefore, a complete expression of the shape of the surface, but when the production process is also known, a reasonable assessment of the surface can be made.

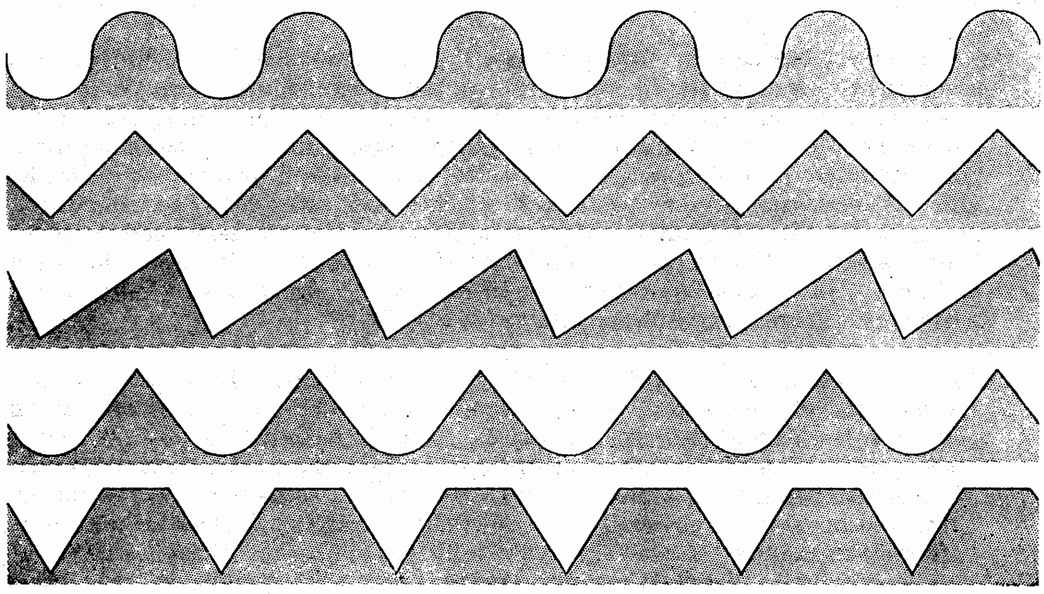


Figure 4 FORMS OF SURFACE TEXTURE

4.1 **Replicas.** When it is necessary to make an assessment of an internal surface, or a surface which is not easily accessible for examination, a replica of the surface can be made and tested. The surface of the replica will be an inverse profile of the actual surface, and, because of the different material, will both look and feel different. However, these differences, and any random faults such as shrinkage or bubbles in the material, can usually be ignored, and reasonably accurate results can generally be obtained. Before making a replica, the surface to be reproduced must be thoroughly cleaned, to remove all traces of oil, grease and moisture. A suitable solvent should be applied with a soft brush, and care should be taken not to scratch or otherwise damage the surface.

4.1.1 One method of producing a replica, is to soften a strip of cellulose acetate with a solvent such as acetone, and press it firmly against the surface until it sets. When removed, the cellulose acetate strip hardens sufficiently to permit testing with a lightly-loaded stylus.

4.1.2 A more accurate method of reproducing a surface is by the use of synthetic resins, which are marketed under a variety of trade names. These materials are usually supplied as a separate powder and liquid, which must be mixed in the correct proportions before use. After mixing, the material may be poured onto the surface which is to be reproduced, and allowed to set; it may be necessary to use a dam of modelling clay or putty to contain the mixture while it is setting. When set, the cast can be removed and its surface tested.

4.1.3 If doubt exists as to the accuracy of a replica, the process may be tested by making a replica of a sample part, which can be measured, and comparing the two surfaces. For finer surfaces a cast may also be taken of an "optical flat", so that differences between the optical flat and its replica will indicate errors resulting from the replica process. For the results to be valid, the comparisons must be made at exactly the same position on the original surface and on the replica.

4.2 **Roughness Comparison.** When a single R_a value is quoted for the surface on a particular part, this indicates the upper limit of roughness, and the production process should aim at producing a surface which is smoother than this limit. In such a case it is often sufficient for the machine operator to be provided with a roughness comparison specimen of the required R_a value (or preferably two specimens, one of the required R_a value and another of half that value), with which he may compare, by appearance and touch, the part he is producing. The specimen should be of the same material as the finished article, and should be produced by an identical process, using similar tools and feed rates. The methods of manufacture of roughness comparison specimens and the tolerances which are acceptable, are detailed in BS 2634.

4.2.1 In some instances a roughness comparator may be used for direct numerical comparison of the surfaces. This instrument is set to the roughness comparison specimen and indicates directly on a scale. Some instruments are provided with a stylus head which can be used while the work is still in the machine, and, by the use of various attachments, straight, convex and concave surfaces can be compared. These instruments are generally not sufficiently accurate to be used as measuring instruments, and their use should be confined to the comparison of surfaces against a known standard. It should be noted that the use of a comparator on a roughness comparison specimen will affect the surface of the specimen and greatly reduce its useful life.

4.3 **Graphical Determination of Roughness Values.** In order to make a graphical assessment of roughness values, a profile graph of the surface must be obtained from a recording instrument. These graphs usually have different values of magnification for the vertical and horizontal scales, in order to provide profiles similar to those shown in Figures 5 and 6. The vertical magnification is generally of the order of 10 to 500 times the horizontal magnification.

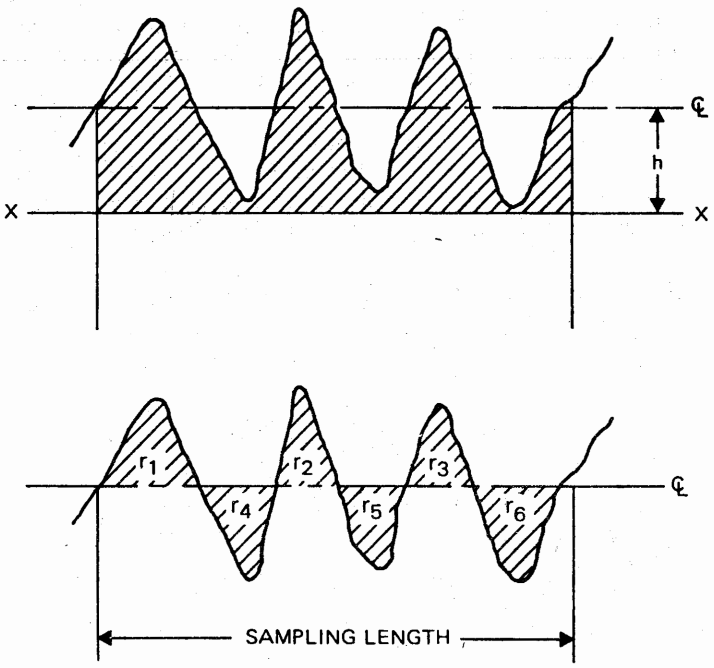


Figure 5 GRAPHICAL ASSESSMENT OF R_a VALUES

4.3.1 **R_a Values.** Figure 5 shows a graphical recording of a surface over one prescribed sampling length (L). If the profile has a distinguishable periodicity this sampling length must include a whole number of periods.

(a) To determine the R_a value of this surface, it is first necessary to find the centre line of each sampling length, and this is done by drawing a line (X–X) parallel to the general direction of the profile and including the lowest valley. The area of the section above this line is then calculated by measuring equally spaced co-ordinates, or by use of a planimeter; this area, divided by the sampling length gives the height (h) of the centreline above the line X–X.

(b) The arithmetic mean height of the surface deviations is then found from the formula:—

$$R_a(\mu m) = \frac{\text{sum of areas } r_1, r_2, r_3, r_4, r_5, r_6 \text{ (mm}^2\text{)}}{\text{sampling length (mm)}} \times \frac{1000}{V_v}$$

where V_v = the vertical magnification of the scale.

4.3.2 **R_z Values.** For some purposes an assessment of average peak-to-valley heights of surface irregularities is required. These values are numerically different from R_a values, and are generally 4 to 7 times the R_a values, depending on the shape of the profile. The profile graph used for measuring the R_z value of a surface is produced in the manner described in paragraph 4, but a different magnification and sampling length from those specified for R_a values may be chosen.

(a) An arbitrary line (X–X) is drawn on the profile graph (Figure 6), parallel to the general direction of the profile. The height of the five highest peaks (p) and the five lowest valleys (v) above this line are drawn in and measured (in millimetres). The R_z value (μm) is then determined from the formula:—

$$R_z = \frac{(p_1 + p_2 + p_3 + p_4 + p_5) - (v_1 + v_2 + v_3 + v_4 + v_5)}{5} \times \frac{1000}{V_v}$$

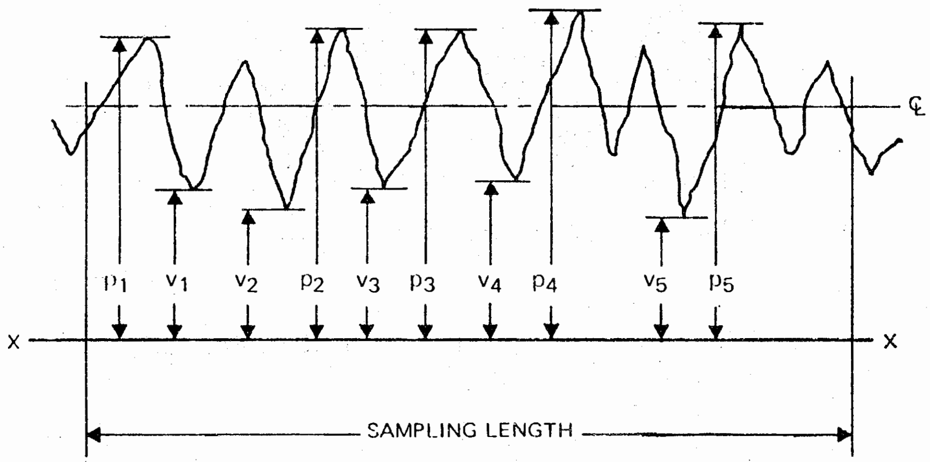


Figure 6 GRAPHICAL ASSESSMENT OF R_z VALUES

5 INSTRUMENTS The majority of instruments used for assessing surface texture use a stylus, which rests on the surface and is traversed across it. Vertical movements of the stylus are converted, by means of an electro-magnetic or piezo-crystal transducer into an electric current, which is amplified and indicated on a direct-reading meter or graph. Many instruments employ a skid as the datum for the stylus (Figure 9), and some are also capable of measuring a particular geometric form, e.g. straightness or roundness, by use of a suitable traverse datum.

5.1 **Stylus.** The accuracy with which an instrument is able to assess the profile of a surface, depends to a large extent on the shape of the stylus and on the method used for guiding the stylus over the surface.

5.1.1 The stylus should, ideally, have a geometrically sharp point, but since this is not possible it is finished with a rounded tip. A radius of 2 μm is used with profile recording instruments, while a radius of 10 μm is considered satisfactory for instruments giving average readings only; the cone angle of the point is generally between 60° and 90°. The effects of using a rounded stylus are shown in Figure 7. It can be seen that the path traced by the stylus does not follow the contour of the surface, but produces a rounded crest and shallow valley. The stylus would also be incapable of producing an accurate record of a vertical wall in the shape of the profile, and would miss any fine deep scratches or cracks. However, the irregularities on most surfaces tend to be quite shallow, and the errors resulting from the rounding of the tip are small. In addition, these errors are masked by the differences in the magnification of the vertical and horizontal scales on a profile graph, and the loss of depth and rounding of the crests tend to offset each other in an average reading instrument. Reproduction of the surface using a rounded stylus does not, therefore, result in serious defects, and the radii chosen for the tip has been shown to be satisfactory for normal uses.

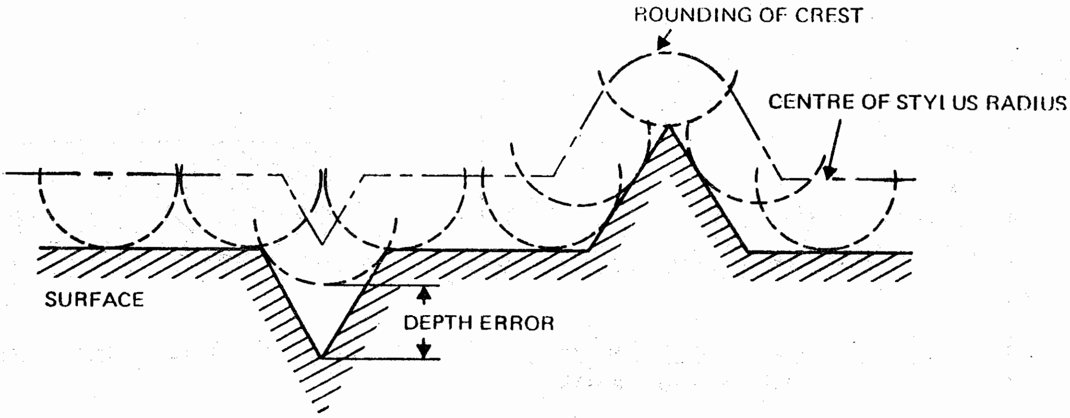


Figure 7 EFFECTS OF USING A ROUNDED STYLUS

5.1.2 The ideal datum for the stylus would be a mechanism which followed the nominal contour of the surface. A simpler method is normally used, however, and consists of a skid, with a large radius in the direction of traverse, which rests on the surface and follows its general contour. The stylus is connected to and follows the movement of the skid, and it is the vertical movement of the stylus about this datum which is measured and recorded by the instrument.

5.1.3 Figure 8 illustrates the errors which may be introduced by the skid on a surface with widely spaced ridges. The skid will rise over the ridges and fall in the valleys, and a large skid radius is required to minimize this effect. It is usually recommended that the radius of the skid should be at least 50 times the meter cut-off value (paragraph 5.2.1).

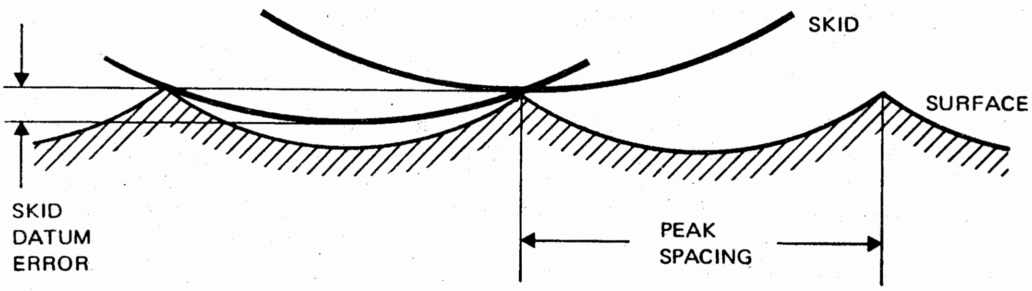


Figure 8 SKID ERROR

5.1.4 Further errors may be introduced by the position of the stylus relative to the skid. If the stylus is located behind the skid, and the spacing of ridges is, for example, twice the distance between the skid and the stylus, then the errors will be doubled. One method of minimizing errors of this type is to mount the stylus in a pick up with parallel skids (Figure 9). This method is often used, and the resulting errors in measuring closely spaced texture are usually ignored.

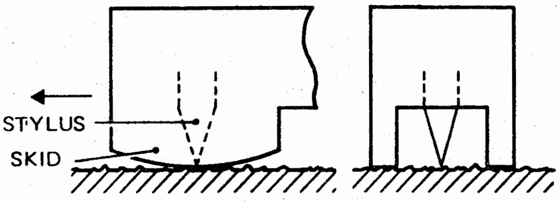


Figure 9 PICK-UP WITH PARALLEL SKIDS

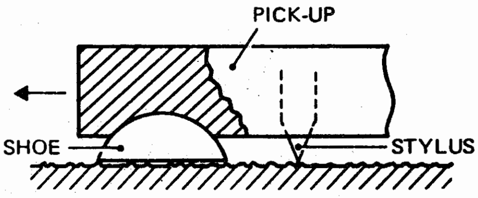


Figure 10 SWIVELLING SHOE

5.1.5 When the spacing of ridges on the surface is too wide for accurate measurement with a skid, a swivelling shoe may be used. This is illustrated in Figure 10, and consists of a shoe the contact face of which is shaped to the general contour of the surface, and is mounted in such a way that widely spaced ridges will swivel the shoe in its mounting, thus reducing their effect. This type of surface may also be measured using an independently mounted guide, which has the nominal shape of the surface, but no contact with it.

5.1.6 To ensure satisfactory contact with the surface but to prevent damage to it, BS 1134 prescribes a static measuring force on the stylus of up to 0·7 N for a stylus with a 2 μm radius, and up to 16 N for a stylus with a 10 μm radius. BS 1134 also prescribes that the surface roughness of the skid shall be not greater than 0·1 μm R_a, and that the force exerted by the skid on the surface, shall be not greater than 0·5 N.

5.2 **Electrical Measuring Instruments.** Electrical measuring instruments are mainly of two types; those which are used in workshops and provide meter readings only, and those which are used for inspection purposes and generally provide both profile recordings and meter readings. In either type the pick-up is traversed across the surface of the test piece at a set speed, and any vertical movement of the stylus is transmitted through the instrument's circuits, to drive the recording pen or meter needle. Some meter instruments indicate R_a values only, but others are available which will indicate R_t, R_{tm}, R_p and the average wavelength of the irregularities of a surface.

5.2.1 **Meter Cut-off.** When a generator type pick-up is traversed across a surface, the spacing of any ridges on the surface will give rise to a definite current frequency; the frequency depending on the speed of traverse and the spacing of the ridges. By the use of frequency-dependent electronic filters, only those spacings which are less than the sampling length are passed to the meter, and those spacings greater than this are attenuated. The wavelength separating the transmitted from the attenuated components in the profile, is known as the meter cut-off. Most meter instruments are provided with controls for altering the meter cut-off, so that the instrument may be used over a range of sampling lengths. Since the frequency of the signals derived from the stylus depends on its speed of traverse, the pick-up of a meter instrument must be motor driven at a speed suitable for the pick-up, and the instrument circuits must be designed accordingly.

(a) Instruments providing profile graphs only, need not be motor driven, since a complete record of the actual surface is produced. Most instruments of this type also provide meter readings, however, so that the majority of profile measuring instruments have motor-driven pick-ups.

5.2.2 **Traversing Length.** The traversing length (or stroke) of the pick-up, is its linear movement during the measurement of a surface. BS 1134 provides a table of traversing lengths to be used, depending on the value of the meter cut-off, but it may often be necessary to vary this movement.

(a) Electrical integrating instruments indicate the average roughness over a number of sampling lengths, and the pick-up must traverse at least this distance for a reading to be given.

(b) Use of a long traversing length may reveal unexpected irregularities in the surface, which would not have been revealed by a short traversing length.

(c) Examination of a ground surface will reveal patterns which appear several times across the surface, and are of approximately the same width. The traversing length must be at least equal to, or preferably slightly greater than, the width of these patterns, in order to obtain a representative reading for the whole surface.

(d) The traversing length may be limited by the size of the surface to be checked, or the physical limitations of the measuring equipment.

(e) Use of a long traversing length may be unnecessary when measuring very fine surfaces.

6 CARE AND USE OF MEASURING INSTRUMENTS The instruments used for the measurement of surface texture are generally robust, and are designed to withstand normal workshop use. These instruments are, nevertheless, precision instruments, and care is essential in their handling to ensure that they retain their accuracy. An instrument should normally be checked daily on a roughness comparison specimen, to ensure that the readings are within the prescribed limitations, and regular servicing should be carried out. Checks on the accuracy of an instrument should be made at regular intervals, using a master roughness standard which has evidence of traceability to National Physical Laboratory Standards. Many texture measuring instruments have a number of switches or controls, which must be correctly set before a measurement is taken, and operators should be aware of the effects of incorrect selection on the readings obtained. The manufacturer's instructions regarding the setting-up of a particular instrument should be carefully followed, and with the more sophisticated instruments, special training may be required. The pick-up, and the surface which is to be measured, must be clean and free from swarf and other debris, and care must be taken to ensure that the pick-up will not be obstructed throughout its traversing distance. This is particularly important when the instrument is being used on production machines, for checking work during manufacture.

6.1 When a surface texture measurement is required on a surface, the appropriate meter cut-off should be used for all normal checking and inspection. To ensure that no significant irregularities are overlooked, and in instances when, for example, it is necessary to check the production process, a number of methods may be used to select the most appropriate meter cut-off, depending on the equipment available.

6.1.1 When initially selecting a meter cut-off for use during production or inspection of a component, the use of a profile recording machine can be very helpful. If a number of tracings of the surface are taken, without applying any cut-off value, the tracings can be examined and the spacing between irregularities can be noted. Estimation of the size of the spacings can then be made, and a meter cut-off value which will take account of these spacings can be applied.

6.1.2 If a profile recording machine is not available, the surface should be visually examined, and the spacing of any dominant patterns in the texture should be measured. Three or more measurements of the surface texture should then be made, using a meter cut-off slightly longer than the dominant pattern spacing, and the average R_a value should be noted. A further series of measurements should then be taken using a longer meter cut-off; any significant irregularities beyond the range of the first meter cut-off will be indicated by a large increase in the average R_a value. Provided that the two series of R_a values are similar, the original meter cut-off may be used.

6.1.3 In some cases the meter cut-off value may be applied according to the R_a value of the surface. Again three or more readings should be taken, and the average R_a value should be noted. If this value is less than 0·1 µm a cut-off of 0·25 mm may be used, if it is between 0·1 and 2·0 µm a cut-off of 0·8 mm should be used, and if it is over 2·0 µm, then a cut-off of 2·5 mm should be used.

6.1.4 In instances where it is only required to study the roughness of a surface, the meter cut-off should be reduced so as not to record any waviness which may be present.

6.2 When inspecting a surface for compliance with a prescribed standard, the surface should first be examined visually to ensure that the texture of the surface is uniform and free from blemishes, and a sampling area should be chosen which is truly representative of the surface as a whole. With large areas, a number of readings should be taken to confirm the consistency of the texture.

7 DRAWING NOTATION When the surface texture of a component has to be controlled, all the necessary factors must be stated on the appropriate drawing.

7.1 **Surface Texture Values.** The surface texture values required, are expressed in µm (or µin on older drawings), and are applicable to the material surface before any protective treatments are applied. These are normally R_a values, but in some cases other parameters may be specified (e.g. R_z or R_t). On some drawings the instructions relating to the surface texture are written on the face of the drawing, but on others the required roughness values are quoted over the machining symbol for each surface. The R_a values may be quoted as a single figure (e.g. 0·8 µm R_a), representing the maximum acceptable roughness of the surface, or they may be quoted in the form of two figures (e.g. $\begin{matrix}0{\cdot}4\\0{\cdot}8\end{matrix}$ µm R_a, or 0·4 – 0·8 µm R_a), representing the range within which the roughness of the surface must fall. When a non-standard meter cut-off is to be used, this is also quoted (e.g. 0·8 µm R_a (2·5)).

7.1.1 Table 1 lists preferred roughness values, and Table 2 shows the range of roughness values which may be expected to result from various production processes.

TABLE 1

PREFERRED ROUGHNESS VALUES

Roughness Grade No.		N12	N11	N10	N9	N8	N7	N6	N5	N4	N3	N2	N1
Nominal R_a values	(µm)	50	25	12·5	6·3	3·2	1·6	0·8	0·4	0·2	0·1	0·05	0·025
	(µin)	2000	1000	500	250	125	63	32	16	8	4	2	1

TABLE 2

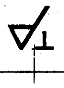
ROUGHNESS (R_a) VALUES PRODUCED BY VARIOUS PROCESSES

Process	Roughness (µm)
Sawing	25 — 3·2
Planing, Shaping	25 — 0·8
Drilling, Chemical Milling	6·3 — 1·6
Milling	6·3 — 0·8
Broaching, Reaming	3·2 — 0·8
Boring, Turning	6·3 — 0·4
Grinding	1·6 — 0·1
Honing	0·8 — 0·1
Polishing, Lapping	0·4 — 0·05
Sand Casting	25 — 12·6
Forging	12·5— 3·2
Extruding, Cold Rolling	3·2 — 0·8

7.2 **Direction of Lay.** When it is necessary to specify the direction of lay, a symbol may be placed after the machining symbol on the drawing. The symbols shown in Table 3 are in accordance with BS 1134, and will generally be found on manufacturers' drawings. If these are insufficient to clarify the direction of lay, a note is usually added to the drawing.

TABLE 3

SYMBOLS FOR DIRECTION OF LAY

Symbol	Meaning
	Parallel to the plane of projection of the view to which it is applied.
	Perpendicular to the plane of projection of the view to which it is applied.
	Crossed in two slant directions relative to the plane of projection of the view to which it is applied.
	Multi-directional.
	Circular relative to the centre of the surface to which it is applied.
	Radial relative to the centre of the surface to which it is applied.

8 GLOSSARY The following terms relate to surface texture measurement, and are, for the most part, taken from BS 1134.

8.1 **Centre Line.** A line representing the form of the Geometric Profile and parallel to the general direction of the profile throughout the sampling length, such that the sums of the areas contained between it and those parts of the profile which lie on each side of it are equal.

8.2 **Effective Profile.** The contour that results from the intersection of the Effective Surface by a plane conventionally defined with respect to the Geometrical Surface.

8.3 **Effective Surface.** The close representation of a Real Surface obtained by instrumental means.

8.4 **Electrical Mean Line.** In an electrical meter instrument, a Reference Line established by the circuits determining the meter cut-off, which line divides equally those parts of the modified profile lying above and below it.

8.5 **Geometrical Profile.** The profile that results from the intersection of the Geometrical Surface, by a plane conventionally defined with respect to this surface.

8.6 **Geometrical Surface.** The surface defined by the design, neglecting errors of form and surface roughness.

8.7 **Horizontal Magnification.** In a profile recording instrument, the ratio of the movement of the recorder chart to that of the stylus along the surface.

8.8 **Irregularities.** The peaks and valleys of a Real Surface.

8.9 **Lay.** The direction of the predominant surface pattern, ordinarily determined by the production method used.

8.10 **Measuring Traversing Length.** The length of the modified profile used for measurement of surface Roughness parameters.

8.11 **Meter Cut-off** (B_{max}). In a Profile Meter Instrument, the conventionally defined wavelength separating the transmitted from the attenuated components of the Effective Profile.

8.12 **Profile Meter Instrument.** An instrument used for the measurement of Surface Texture parameters.

8.13 **Profile Recording Instrument.** An instrument recording the co-ordinates of the profile of the surface.

8.14 **R_a.** Arithmetical mean deviation of the profile above and below the Reference Line, through the prescribed Sampling Length.

8.15 **R_p.** The distance from the highest peak to the Reference Line, over the prescribed Sampling Length. The "smoothing depth".

8.16 **R_t.** The maximum Roughness (highest peak to deepest valley) over the prescribed Sampling Length.

8.17 **R_{tm}.** The mean value of R_t over a number of Sampling Lengths.

8.18 **R_z.** Ten-point height of irregularities. The average distance between the five highest peaks and the five deepest valleys, measured from a line parallel to the Reference Line but not crossing the profile.

8.19 **Real Surface.** The surface limiting the body, separating it from surrounding space.

8.20 **Real Profile.** The contour that results from the intersection of the Real Surface by a plane conventionally defined with respect to the Geometrical Surface.

8.21 **Reference Line.** The line chosen by convention to serve for the quantitative evaluation of the Roughness of the effective profile.

8.22 **Roughness.** The irregularities in the Surface Texture which are inherent in the production process, but excluding Waviness and error of form.

8.23 **Sampling Length.** The length of profile selected for the purpose of making an individual measurement of Surface Texture.

8.24 **Spacing.** The average distance between the dominant peaks on the Effective Profile.

8.25 **Static Measuring Force.** The force which the stylus exerts along its axis on the examined surface, disregarding the dynamic components arising from its movement over the surface.

8.26 **Surface Texture.** Those irregularities, with regular or irregular spacing, which tend to form a pattern on the surface.

8.27 **Vertical Magnification.** In a Profile Recording Instrument, the ratio of the movement of the indicating device of the recorder to the displacement of the stylus in a direction normal to the surface.

8.28 **Waviness.** The component of Surface Texture upon which Roughness is superimposed.

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BASIC

METROLOGY

MEASURING INSTRUMENTS BASED ON THE VERNIER PRINCIPLE

1 INTRODUCTION This leaflet gives guidance on the use and maintenance of measuring instruments based on the vernier principle. In general the use of these instruments presents no difficulty but a certain degree of skill and care is required if accurate results are to be assured; in common with most measuring instruments, care is also necessary in handling and use to avoid damage which could result in inaccuracies.

1.1 Precision vernier instruments manufactured in the United Kingdom are produced in accordance with the requirements of British Standard 887, entitled "Vernier Callipers", British Standard 1643, entitled "Vernier Height Gauges" and British Standard 1685, entitled "Bevel Protractors (Mechanical and Optical)". It should be borne in mind when using vernier instruments that the accuracy cannot be assumed to be greater than the maximum errors permitted by the above standards. For example, the maximum permissible errors for vernier callipers and height gauges reading up to twelve inches, from twelve to twenty-four inches and from twenty-four to forty-eight inches, are ±0·001 in., ±0·0015 in. and ±0·002 in. respectively. For bevel protractors, B.S. 1685 states "Protractors with vernier scales shall be graduated to read direct to five minutes of arc, and the error of indication in any position of the blade, including the acute angle attachment if fitted, shall not exceed plus or minus five minutes of arc".

1.2 In addition to the more usual vernier callipers, height gauges and bevel protractors, vernier callipers adapted for gear tooth measurement and depth measurement, and as standard reference verniers are also available.

NOTE: It should be appreciated that these measuring instruments should be used only when the work and the instrument temperatures are equal.

2 THE VERNIER SYSTEM A brief description of the vernier system as a means of defining linear dimensions is as follows.

2.1 Assuming two lines of equal length, each divided separately so that the total number of divisions in one is greater by one division than the number of divisions in the other, the displacement or reading is equal to the linear difference between any two divisions. For example, one of the most commonly used scales is where the main scale is divided into 20ths (0·050) of an inch and the vernier scale comprises 50 divisions over a distance of 2·45 in., each division equalling 0·049 in. Thus the difference between any division on the main scale and any division on the vernier scale is 0·001 in. This principle is illustrated in Figure 1.

2.2 One other widely used scale is where the main scale is divided into 40ths (0·025) of an inch and the vernier scale is divided into 25 equal divisions over a distance of 1·225 in., each division equalling 0·049 in. The same principle as described in the previous paragraph applies but, with this type, the vernier scale is read on alternative lines of the main scale, the two divisions together equalling 0·050 in.

2.3 There are two other types of scales in use but these have largely been superseded due to the necessity of having to use some form of magnification to obtain a true reading. In one, the main scale is divided into 40ths (0·025) of an inch and the vernier scale is divided into 25 divisions over a distance of 0·60 in., each division equalling 0·024 in. In the other the main scale is divided into 50ths (0·020) of an inch and the vernier scale has 20 divisions over a distance of 0·380 in., each division equalling 0·019 in.

2.4 In addition to the decimal inch scaled instruments described above, vernier instruments graduated to the metric system are obtainable. Some of these are composite types with inch and metric scales on opposite sides, whilst others read inches or metric dimensions only.

2.5 **Reading the Inch-Unit Vernier.** To read the measurement registered by this vernier, the number of inches and sub-divisions of an inch that the zero line of the vernier scale has moved over the main scale should be noted, and to this reading should be added the thousandths of an inch, which is indicated where a line of the vernier scale is coincident with a line on the main scale. For example, in Figure 1, the scale registers the following settings. Main scale : inches=5, tenths=1 and the 43rd line of the vernier scale is coincident with a line on the main scale. The reading thus obtained is 5·000+0·100+0·043=5·143 in.

2.5.1 **Reading the Metric-Unit Vernier.** This instrument reads in a similar manner to the inch-unit vernier, has main scale graduation of centimetres, millimetres and half millimetres. The vernier scale (equal to 24 half millimetres) is divided into 25 equal divisions, producing a difference between main scale and vernier scale graduations of $0{\cdot}5 \times \frac{1}{25} = \frac{1}{50}$ mm. (0·02 mm.).

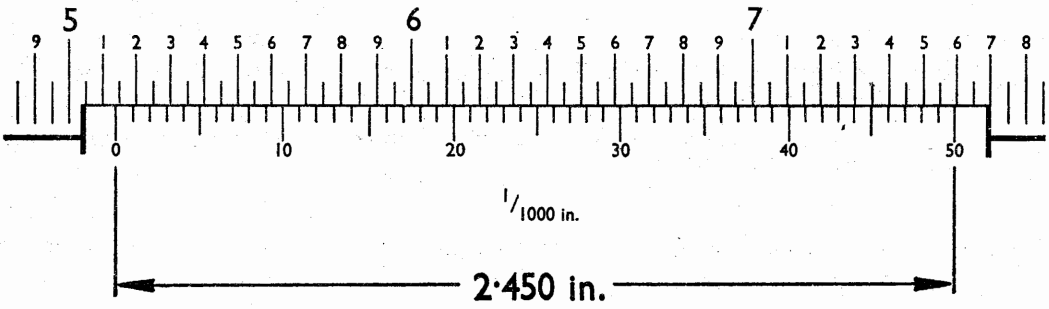


Figure 1 THE VERNIER SCALE

2.5.2 In some instances difficulty may be experienced in deciding which two lines are in fact coincident. In such cases a decision may be helped by the fact that the lines on either side of the most nearly coinciding lines appear to be equally stepped (see Figure 1). It should be borne in mind that it is a fundamental of the vernier system that not more than one line of the vernier scale can be truly coincident with a line on the main scale.

2.5.3 **Measuring Capacity.** The measuring capacity of a vernier instrument is its graduated length minus the length of the vernier scale. Thus an instrument having a scale such as that described in paragraph 2.1 may have, for example, a graduated scale of 14·450 in. minimum but would be supplied as having a measuring capacity of 12 in.

3 THE VERNIER CALLIPER GAUGE This instrument consists of a beam, on which is marked the main scale, and two jaws between which the item to be measured is placed. One jaw is integral with the beam whilst the other, upon which is mounted the vernier scale, slides along the beam (Figure 2). The measuring faces of the jaws are accurately machined to be straight and parallel.

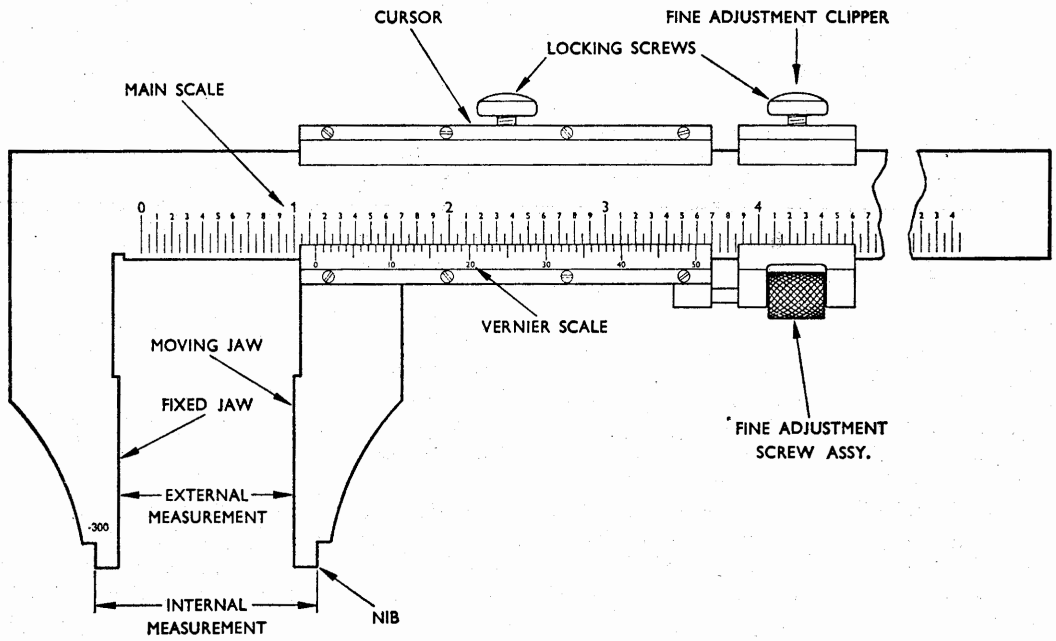


Figure 2 VERNIER CALLIPER

3.1 With precision calliper gauges the movable jaw is connected to a clamping device (termed the "fine adjustment clipper") by means of the fine adjustment screw assembly. The clipper can be locked on to the beam at any position by means of a locking screw, the accurate setting of the measurement being achieved by rotating the knurled wheel of the fine adjustment screw assembly in the required direction.

3.2 A vernier calliper is used where insufficient accuracy would be obtained with ordinary callipers. However, some degree of skill is necessary (unless the instrument is provided with a friction lock) to obtain the correct "feel", otherwise inaccurate readings will be obtained and, if overtightened, the instrument may be permanently damaged. Thus, the jaws should always be closed gently on to the workpiece, no attempt being made to alter the measurement by force.

3.3 When setting the callipers to a given measurement, the clipper should be securely locked at the approximate measurement and the final adjustment made by means of the fine adjustment screw. After setting the instrument, the jaw locking-screw should also be tightened before the calliper is used.

3.4 The parts to be measured should be perfectly clean, since foreign matter will not only affect the reading obtained but may damage the accurately finished faces of the jaws.

3.5 For the measurement of internal dimensions, some instruments are provided with a pair of "knife-edge" jaws mounted immediately above those used for external measurement. Other instruments have the outside lower portion of the external measuring jaws rounded (the "nibs" shown in Figure 2), the overall dimension of the nibs with the calliper closed usually being some convenient figure (e.g. 0·3 in.) which must be added to the indicated reading. The allowance to be made for the width of the nibs is usually indicated on the fixed jaw (see Figure 2). No attempt must be made to force a locked calliper between two surfaces, otherwise wear or out-of-parallelism may result.

3.6 Some makes of callipers are marked with two spots, or "targets", one on the fixed jaw and one on the movable jaw, from which dividers or trammels may be set after the calliper has been set.

3.7 Before use (in particular, before using a particular instrument for the first time) the calliper should be checked by closing the jaws and holding the instrument up to the light, checking for full contact of the measuring surfaces. Without disturbing the jaws, the reading of the calliper should then be checked to ensure that the zero lines of the main scale and the vernier scale are coincident. Guidance on the general maintenance and checking of vernier instruments is given in paragraph 7.

4 VERNIER HEIGHT GAUGE In principle the vernier height gauge is an adaptation of the vernier calliper gauge but instead of the measurement being based on the distance between fixed and movable jaws, it is calculated on the distance between a movable jaw and the surface on which the instrument stands (usually a surface table). See Figure 3.

4.1 The instrument is provided with a relatively heavy base having a lapped underface ; the upper surface of the movable jaw (termed the measuring jaw) is the surface from which measurements are taken and this surface is parallel with the underface of the base. The measuring jaw is provided with a detachable scriber to permit the accurate marking out of workpieces. The scriber itself is produced within fine tolerances, it being a requirement of B.S. 1643 that the measuring faces must be flat and parallel to within 0·0002 in.

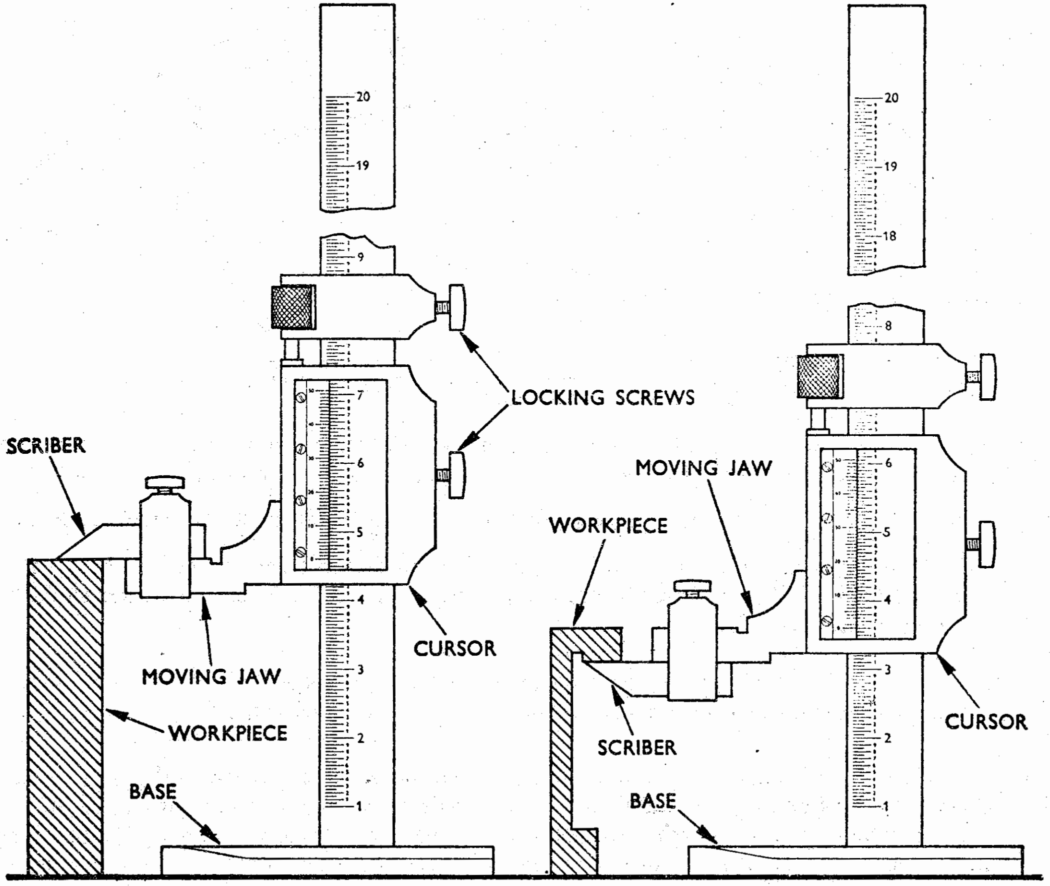
4.2 The main scale of the instrument does not commence at zero, since as the measurement is taken from a surface table, this surface is, in fact the zero (see Figure 3).

4.3 Since it is the top of the measuring jaw from which measurements are taken, it is necessary to fit the scriber for external measurements, but for internal measurements the scriber may be removed. However, in some instances the measuring jaw may not project sufficiently to permit an internal measurement to be taken, in which case the scriber may be fitted to the measuring jaw as shown in Figure 4. When so used the thickness of the measuring jaw (usually marked on it) must be subtracted from the indicated reading. If the scriber is fitted to the top of the measuring jaw for internal measurement (again in an upside down position), the thickness of the scriber (usually marked on it) must be added to the indicated reading.

4.4 When assessing external measurements it is advisable not to pre-set the height gauge, otherwise the scriber may ride over the workpiece, giving an incorrect reading. The scriber should be lowered gently on to the surface to be measured, care being taken to hold the base firmly on the surface table, and the setting locked. Conversely, when making internal measurements, the measuring jaw should be raised gently to the surface to be measured to avoid lifting the workpiece.

NOTE : It is particularly important to hold the base down firmly when using the fine adjustment screw.

4.5 When setting the instrument to an external flat surface the use of the lighting method described in paragraph 7.2 may be found useful in checking the final setting.



Figures 3 *and* 4 VERNIER HEIGHT GAUGE

4.6 It is essential that at all times the base of the instrument, the surface table, any ancillary measuring equipment used and the workpiece itself should be kept perfectly clean to ensure accuracy of measurement. If a height gauge is left on a surface table but is not in immediate use, steps should be taken to ensure that it is not knocked over and damaged.

5 **BEVEL PROTRACTORS** A typical bevel protractor consists of a solid base or "stock", one face of which is machined flat so that it can be laid accurately on a flat surface, e.g. a surface table. An adjustable straightedge attached to the instrument can be set to any angle relative to the base.

5.1 Angular movement of the straightedge rotates a disc on which is mounted a circular protractor scale (graduated in degrees) which, in conjunction with the vernier scale, permits the units (minutes) to be read in a similar manner to the vernier calliper. Thus, the number of whole degrees which have been passed by the vernier zero mark should be noted and then, continuing to read in the same direction (this is important as the scales are identical to the right and left of the zero lines), add the number of minutes indicated by the coincidence of a line on the vernier scale with a line on the main scale. In the example shown in Figure 5, the reading is 14° 20′.

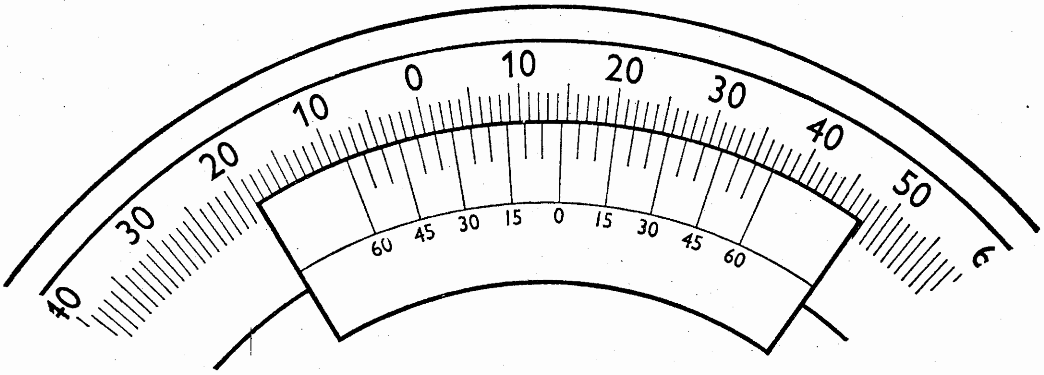


Figure 5 VERNIER PROTRACTOR SCALE

5.2 In the scale shown in Figure 5, a length of 23° of the main scale is divided into twelve equal parts to form the vernier scale. Thus one division of the vernier scale equals $\frac{23^\circ}{12}$, or 1° 55′, the difference between one division of the vernier scale and two divisions of the main scale being 5′. The instrument can, therefore, be read to an accuracy of 5′, but if greater accuracy is required, the angle should be measured by the sine bar method.

5.3 In order to facilitate the reading of the protractor, some manufacturers provide a magnifying glass or eyepiece which can be mounted on the instrument.

6 DEPTH GAUGES This instrument is again based on the vernier calliper principle, except that in this case the beam carrying the main scale passes at right-angles through a jaw on which is mounted the vernier scale. The jaw is placed over the depth to be measured (e.g. a blind hole) and the beam is lowered into the hole until contact is made with the bottom or some other predetermined point of contact, when the indicated measurement is read in the manner described for the vernier calliper.

7 MAINTENANCE OF VERNIER INSTRUMENTS At regular intervals (such periods being determined by the nature and conditions of the work involved) vernier instruments should be examined and check-calibrated in accordance with the manufacturers' instructions in a suitably equipped Standards Room. A record of all such checks should be kept. The general methods of maintenance and checks applicable are described in the following paragraphs.

7.1 **Indicated Dimension.** The dimensions indicated by the instrument should be checked by means of slip gauges or precision blocks of known accuracy. On larger instruments, length bars should be used for the longer dimensions. Where a calliper is provided with knife-edge jaws for internal measurement, the indicated measurement should be checked against a micrometer of known accuracy.

7.2 **Straightness of Measuring Faces.** The straightness of measuring faces should be checked by placing a knife-edge straightedge on each jaw in turn, holding the instrument before a source of diffused light. If the lighting is satisfactory an error of as little as 0·0001 in. should be readily visible.

7.3 **Parallelism.** The parallelism of the measuring faces may be checked by placing a precision parallel roller between the jaws of the instrument and gently closing them until contact is made, the movable jaw then being locked. Any error of parallelism of 0·0001 in. or more can be detected against a suitable source of diffused light.

7.3.1 An alternative method, or a method to be used when the error in parallelism appears excessive, is to check the variation of size between the measuring faces by means of slip gauges.

7.3.2 It is recommended that, where an excessive error in parallelism is detected, the instrument should be returned to the manufacturer for rectification.

7.4 Nib Dimension

7.4.1 The jaws of the vernier calliper should be brought together and the nibs checked for general wear or flats by the use of a micrometer at two or three positions around the nibs.

NOTE : Flats are most likely to occur in a plane parallel to the beam.

7.4.2 The original dimension across the nibs is usually indicated on the fixed jaw ; if any "truing-up" of the nibs is carried out which results in a change in this dimension, the new dimension (which has to be allowed for when making internal measurements) should be etched on the fixed jaw and the original dimension should be cancelled by an etch mark.

7.5 **Cleaning and Lubrication.** The instrument should be kept thoroughly clean and the moving parts lightly lubricated with acid-free machine oil.

7.5.1 Graduation and scale marks should be cleaned with a suitable solvent and a soft brush ; a pointed instrument or wire brush must never be used. The instrument should never be polished, especially near graduation markings since, apart from the possible detriment arising from the abrasive action, bright reflections from the instrument may make reading difficult.

NOTE : Reflection has been eliminated on most modern vernier instruments by the application of a hard satin-chrome finish on the scales.

7.5.2 To ensure against jerkiness in the moving parts (which could seriously affect the "feel" of the instrument) those moving parts which the manufacturer stipulates may be removed periodically, dismantled, cleaned in a suitable solvent, dried, lubricated and reassembled. A check calibration should always be made after reassembly.

7.6 **Repair.** In general it is recommended that all repairs to vernier instruments should be undertaken by the instrument manufacturer. When instruments are returned after repair, it should be ensured that the new dimensions of the nibs and, in the case of height gauges, the measuring jaw (if altered), have been appropriately etched on the instrument.

7.7 **Storage.** When not in use, vernier instruments should be kept in their appropriate cases and it is recommended that they should be stored in a warm cupboard. However, it is essential that the instruments should not be subjected to excessive heat otherwise, due to expansion, accuracy may be affected. Instruments should never be stored in the fully closed or locked positions.

BL/3-5

Issue 1.

30*th April*, 1966.

BASIC

METROLOGY

MEASURING INSTRUMENTS—MICROMETERS

1 INTRODUCTION This leaflet gives guidance on the construction, use and maintenance of the micrometer type of measuring instruments. In general, the use of these presents little difficulty, but a certain degree of skill and appreciation of their precision construction is required, if accurate measurement is to be attained. In common with all precision measuring instruments, considerable care is necessary in handling them to avoid unnecessary and costly depreciation.

1.1 Micrometer instruments manufactured in the United Kingdom should conform with the requirements of British Standard 870—"External Micrometers", British Standard 959—"Internal Micrometers (including stick micrometers)" and British Standard 1734—"Micrometer Heads". It should be appreciated that the degree of accuracy in using these instruments is governed by the permitted tolerances in the Standards. For example, the maximum permissible error ranges in the traverse of micrometer screws, is 0–0·0001 in. or 0·003 mm. for British and Metric reading micrometers measuring up to 12 inches or 300 mm., and 0–0·0002 in. or 0·005 mm. for instruments measuring 12 to 24 inches, or 300–600 mm.

1.2 In addition to the standard external and internal micrometers, there are other specially adapted instruments for various other tasks of measurement, and some of these are described in later paragraphs.

1.3 Information on measuring instruments of the vernier type is given in Leaflet **BL/3-4.**

2 THE STANDARD EXTERNAL MICROMETER

2.1 Figure 1 illustrates the typical standard type of micrometer for the measurement of external dimensions. The main components of the instrument are the frame, anvil, barrel, sleeve (or thimble) and the spindle. The jaws of the frame are suitably machined to receive the anvil (which is usually a press fit), and the barrel, which is frequently fitted into the frame with a fit which permits rotational adjustment by spanner or special key (see paragraph 8.2). The barrel is engraved with a graduated scale equal in length to the measuring range of the instrument (usually 1 in. or 25 mm.), and is bored and internally screwed with a fine and accurate right-hand thread. This thread accommodates the spindle which is machined with a matching male thread. An integral sleeve on the spindle surrounds the barrel when the spindle is inserted and screwed into the assembly, and this is usually knurled at the outer end to facilitate easy finger operation. The inner end of the sleeve is bevelled to prevent barrel scale shadows, and the bevelled portion is graduated into equal divisions around its periphery.

2.2 Some micrometers may have a fixed barrel and a removable or adjustable anvil which might be located by a grub screw or a pin. Others may be equipped with a spindle locking device (as illustrated) which, when used, ensures that the instrument remains set at any specific dimension or reading. The spindle attachment containing a spring loaded ratchet (also illustrated) is a common fitment, and this produces preset "feel" to the operation of the instrument. Many micrometers are provided with tungsten or carbide tipped anvils and spindles to reduce wear on the measuring faces.

NOTE: British Standard 870 prescribes that when a friction or ratchet attachment is fitted to the spindle, the force it exerts between the measuring faces shall be between 1½ to 2½ lb.

2.3 The details of micrometers for the measurement of British dimensions are given in paragraph 4.1, whilst those for measurement of Metric dimensions are covered in paragraph 4.2.

NOTE: Some instruments not to British Standard, although quite accurate, may not be provided with the general means of adjustment. Due allowance for "zero" error (see paragraph 8.2) must therefore be made, and the error must be added to all measurements made.

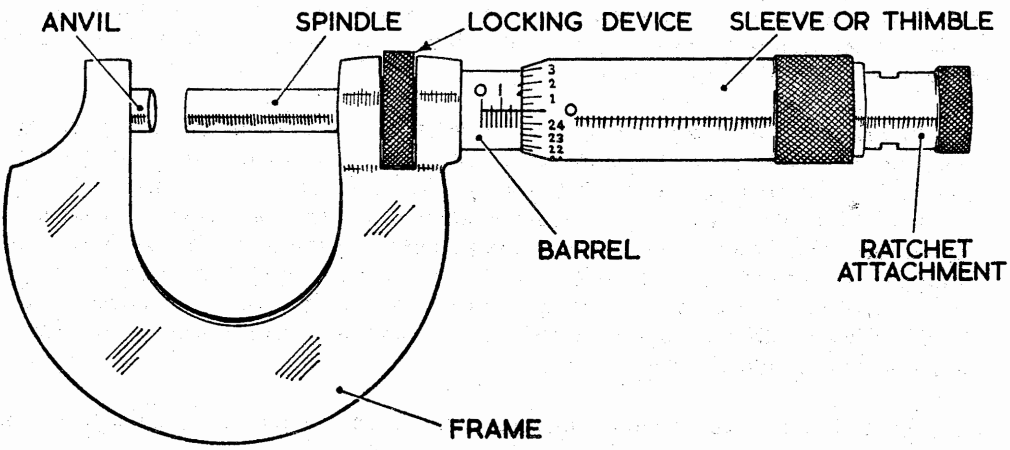


Figure 1. TYPICAL STANDARD EXTERNAL MICROMETER

NOTE: The British Standard prescribes that micrometer frames up to 4 in. shall be of a suitable quality of steel, those above 4 in. and up to 12 in. may be of a suitable quality of steel or malleable cast iron, and those above 12 in. may be of suitable steel, malleable cast iron or light alloy. The Standard recommends that suitable heat-insulating grips should be attached to the frame in convenient positions, and that frames should be heat-treated to avoid secular changes that might take place in the material.

3 THE INTERNAL MICROMETER

3.1 Internal micrometers are designed for internal measurement only. There are two common categories; the end-measuring or "stick" type and the "three-point" measuring type. Both of these measure internal dimensions with the same systems of graduation as the standard micrometer (paragraph 4.1 and 4.2).

3.2 **End-measuring or "Stick" Micrometers.** These instruments are usually available in combination-set form, and consist of a measuring head (similar to the standard type barrel and sleeve), and sets of extension rods which fit into the barrel to give various stages of measurement over the total range. Common sets are provided with three, five or nine extension rods, and in most of these it is usual for an auxiliary handle to be included, which can be screwed into the side of the barrel to enable check measurements to be made at the extreme ends of deep bores, etc.

NOTE: One manufacturing range consists of combination sets for measurements of 1-2 inches, 1-3 2-6, 2-8, 2-12, 8-32, 12-36, 12-48, 32-52, 36-60, and 52-72 inches.

3.3 An anvil is located in the head of the sleeve and in the outer end of each extension rod, and these are usually adjustable for wear on the anvil faces. (See paragraph 8.2.)

3.4 **Three-point Micrometers.** This type of internal micrometer incorporates three measuring anvils which are co-axially mounted in a measuring head at 120° to each other. The feature of three-point contact ensures greater accuracy in the measurement of internal dimensions. Generally, the larger type of micrometer head (paragraph 6) with 250 divisions, is embodied to enable the finer measurements to one ten-thousandth (0·0001) of an inch to be made, with the more convenient and simplest method of reading. The sleeve and spindle operation is similar to that of standard types, but the longitudinal spindle movement is transferred to axial anvil movement and, in operation, the barrel axis of the instrument will coincide with that of the hole or bore being measured.

NOTE: Some of these instruments may be provided with 50-division sleeves and barrels having a vernier scale (paragraph 4.3), whilst others may have 100-division sleeve scales only, with a measurement accuracy of two ten-thousands (0·0002) of an inch.

3.5 The anvils (Figure 2) are housed in a three-legged measuring head, with a central attachment lug on one side and a detachable screwed cap on the other, and the lug is internally threaded for attachment to the screwed barrel. The spindle incorporates a threaded propelling flange and conical measuring thread at the anvil end, and is threaded and locked into the head of the sleeve at the outer end. A spindle bearing is provided in the barrel at the sleeve end, and a ratchet attachment is embodied in the outer end of the sleeve. The inner ends of the anvils are angled and screw-cut to suit the conical measuring thread, and coil springs, fitted inside the cap, ensure constant contact between these components. Spindle movement is arranged through the engagement of the propelling flange with the internal threads of the measuring head lug.

NOTE: For better results in the measurement of ovality, some micrometers of this type have anvils set at unequal angles, and the manufacturer often defines the best operation method together with relevant formulae and calculations.

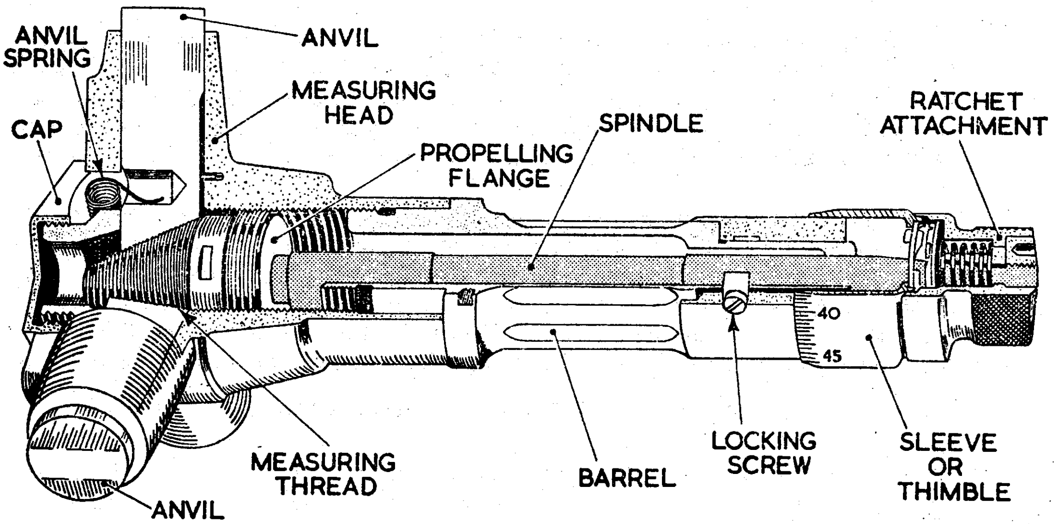


Figure 2. TYPICAL THREE-POINT INTERNAL MICROMETER

4 MICROMETER SYSTEMS

4.1 **The British System.** In the British micrometer, the spindle and barrel threads have a pitch of 0·025 in (40 T.P.I.). Thus, one complete turn of the spindle and sleeve will increase or decrease the distance between the anvil and spindle by 0·025 in. ($\frac{1}{40}$ in.), with left- and right-hand turning respectively. The barrel (or main) scale is graduated into tenths (0·10) and fortieths (0·025) of an inch, whilst the sleeve (or thimble) scale consists of 25 equal divisions. If the spindle is advanced or withdrawn by rotary movement equal to one sleeve graduation, then the distance between the measuring faces is decreased or increased by one thousandth (0·001) of an inch.

4.1.1 The micrometer measurement reading is equivalent to the total number of thousandths of an inch, indicated by that sleeve scale graduation which is coincident with the barrel scale line. (Datum or fiducial line).

4.1.2 To read the dimension recorded, the visible barrel scale graduation in tenths and fortieths are noted, and to this figure is added the number of thousandths shown on the sleeve scale at the intersection with the barrel scale line. Taking Figure 3 as an example, the barrel scale shows two tenths and three fortieths (0·200 + 0·075), and the sleeve scale shows the three thousandths line agreeing with the barrel scale line. Thus, 0·200 + 0·75 + 0·003 = 0·278 in., which is equivalent to the distance between the anvil and spindle end faces.

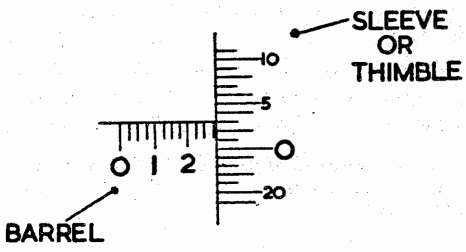


Figure 3. TYPICAL BRITISH MICROMETER READING

4.1.3 When a sleeve scale graduation is not exactly coincident, the relevant thousandth (0·001) graduation to be read is that immediately below the datum line. When a finer measurement is required, an estimation of a half (0·0005) or a quarter-thousandth (0·00025) of an inch can be made for the additional part-graduation visible below the datum line, and this can be added to the dimensional figure.

4.2 **The Metric System.** In the Metric micrometer, the spindle and barrel threads have a pitch of 0·5 mm. Thus, one complete turn of the spindle and sleeve will increase or decrease the distance between the anvil and the spindle by this amount. The barrel scale (Figure 4) is graduated into twenty-five divisions of 1 mm., and usually every fifth division is numbered in multiples of five. The millimetre divisions are sub-divided into half-millimetres (0·5 mm.), and the sleeve is graduated into fifty equal divisions. Thus, the movement of the sleeve, equal to one sleeve division, equals $\frac{0{\cdot}5}{50}$ or 0·01 mm.

4.2.1 To read the micrometer, the highest figure on the barrel scale is noted together with any additional visible half-millimetre division. To this is added the number of hundredths of a millimetre which are indicated by the coincident sleeve and datum lines. Thus, the reading of the metric micrometer scales, depicted in Figure 4, equals 5·00 mm. + 0·50 mm. + 0.14 mm., which equals 5.64 mm.

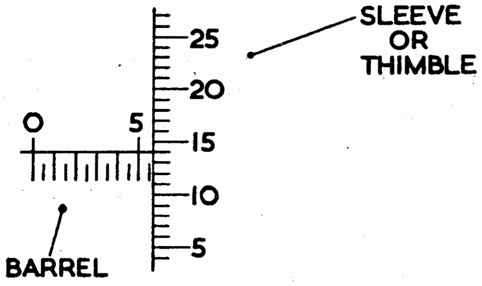


Figure 4. TYPICAL METRIC MICROMETER READING

4.3 **Vernier Scale Micrometers.** Micrometers with an additional scale based on the vernier principle are in common use, and these have a greater degree of measurement accuracy of one ten-thousandth (0·0001) part of an inch. Estimations (paragraph 4.1.3) are unnecessary; the standard thousandth reading is noted as in paragraph 4.1.2, and to this is added the coincident vernier scale reading in ten-thousandths (0·0001) of an inch (Figure 5).

4.3.1 Generally, vernier scale micrometer sleeves are graduated into 25 divisions and 25 half divisions. A convenient vernier scale length equal to 9 half-divisions of the sleeve scale is divided equally into 5 vernier scale divisions, and these are engraved on the barrel above and parallel to, and to the full extent of the datum line.

4.3.2 Thus, the vernier scale length is equal to 9 half-divisions on the sleeve (0·0045 in.). It follows that the difference in width between each sleeve division (two half-divisions) and each barrel division is one fith of a sleeve division. As each sleeve division is representative of 0·005 in., the difference is therefore 0·0001 in.

4.3.3 When a sleeve graduation line does not coincide with the datum line, it is necessary to note the vernier scale division which does coincide, and to add this number of ten-thousandths (0·0001) of an inch to the standard thousandths reading. In Figure 5, for example, the barrel scale shows four tenths and two forthieths (0·4000 + 0·0500), and the sleeve division below the datum line is 0·0190. There is a further half-division on the sleeve below the datum line (0·0005), and the coinciding vernier line is the fourth (0·0004). The micrometer reading is therefore 0·4000 + 0·0500 + 0·0190 + 0·0005 + 0·0004, which equals 0·4699 inches.

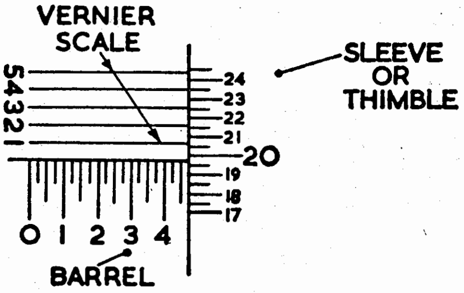


Figure 5. TYPICAL MICROMETER VERNIER SCALE

4.4 **Oblique Graduations.** Some micrometers may be manufactured with barrel scale graduations which are oblique to the datum line. These may be additional, in which case the normal parallel and the oblique graduations are engraved above and below the datum line, respectively. Oblique graduations prevent miscalculations in reading the instrument, for the following barrel scale graduation line is always visible, at least in part, in any position of the sleeve.

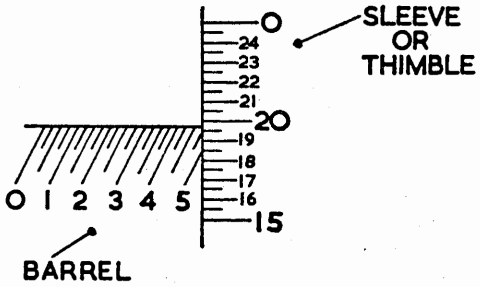


Figure 6. OBLIQUE GRADUATIONS

5 TYPES OF MICROMETER

5.1 Other than the standard type of micrometer (Figure 1) for measurement of external dimensions in British or Metric measurements, there are several other types of a special category for various manufacturing processes, curved profiles and for the measurement of soft materials, etc. Some of the more common of these and their particular applications are described in the following paragraphs.

5.2 **Variable-range Micrometers.** These instruments are made with large frames, and a set of detachable anvils is provided to cover each stage of measurement throughout the total range. Ranges are various, but common examples are 0–6 inches, 0–12 inches, 12–42 inches, 0–50 mm., 200–300 mm., and 900–1050 mm. Stages of measurement are generally of one inch or 25 mm. It will be appreciated that the shortest anvil will be fitted for the longest measurements and the longest anvil for the shortest. Various methods of anvil location are employed, but most anvils are provided with a flange or shoulder which abuts the frame face, and this ensures that the basic anvil setting is correct when the anvil is fitted.

5.3 **Recess Micrometers.** This type is similar to the standard instrument except that it is provided with a long anvil to facilitate the measurement of recessed dimensions. The anvil and spindle diameters are frequently of much smaller diameter, for use in connection with fine bores and drillings.

5.4 **Deep-frame Micrometers.** These micrometers are provided with deep "horseshoe" type frames, which enable measurements to be made of dimensions at some distance from the edges of larger components, sheets and plates, etc.

NOTE: In using this type, extreme care is required to avoid any distortion of the frame.

5.5 **Ball-end Micrometers.** In these instruments, the spindle or the anvil or both, are provided with rounded ends which permit the measurement of curved surfaces; they are particularly applicable to the "viewing" of ball bearing races. It is important to bear in mind, however, that the curved surface being measured must be of greater radius than the anvil/spindle ends, otherwise inaccurate measurements will be made.

5.6 **Hub Micrometers.** This type of micrometer has a very shallow frame, which enables it to be used inside bores, recesses, etc., having internal dimensions as small as 1 inch or less.

5.7 **Disc Micrometers.** The standard type of micrometer is not suited to the measurement of soft materials, since the spindle and anvil would tend to compress them, even during applications when the spindle ratchet attachment is used (Figure 1). This type, which is otherwise similar to the standard, is provided with anvils and spindles machined with integral face discs of various range diameters, e.g. $\frac{3}{8}$ in., $\frac{1}{2}$ in., $\frac{3}{4}$ in., etc.

5.8 **Depth Micrometers.** These instruments (Figure 7) have a similar application to the vernier depth gauge (Leaflet **BL/3-4**). They consist of the standard type barrel, sleeve and spindle, and the barrel is attached to, or is integral with, a base plate having hardened contact faces, which are ground and lapped square to the spindle axis. Some of these instruments are available in combination sets with detachable spindles, to cover various ranges of measurement and to widen the application, and others may be provided with detachable base plates of various dimensions and shapes.

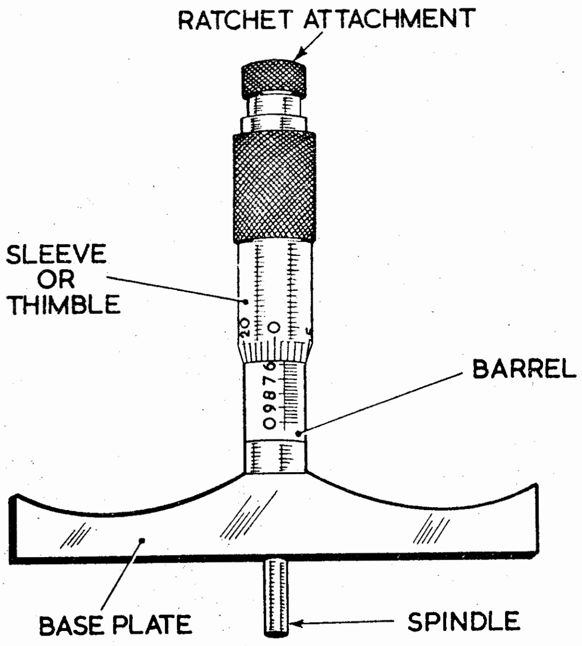


Figure 7. TYPICAL DEPTH MICROMETER

5.9 **Tube Micrometers.** These micrometers are similar to the standard type except for the frame and the anvil. The frame is usually of single jaw semi-"horseshoe" shape, and the anvil is a vertical shouldered and ground spindle-post, fitting into the frame at 90° to the spindle axis. Generally, these instruments are supplied with several anvils which differ in the diameter of the measuring tip, and this feature gives the instrument a wider range of tube thickness measurement.

5.10 **Calliper Micrometers.** This type of micrometer (Figure 8) is particularly suited to the measurement of small internal diameters. It consists of the standard barrel and spindle assembly, with an off-set pair of jaws located by a bracket attached to the inner end of the barrel. The stationary jaw is located on the outer end of a ground spindle, and this is recessed into the barrel bracket at its inner end. The moving jaw slides on the outer jaw spindle with a precision fit, and a split lug on the jaw clamps a split bush bearing in a recess machined in the end of the micrometer spindle. Some of these instruments are available with sets of removable jaws with differing nib widths, which stage and widen the measuring range of the calliper instrument.

NOTE: It should be borne in mind when taking internal measurements, that with instruments which give a zero reading with the jaws closed, the dimension over the nibs must be added to the micrometer readings.

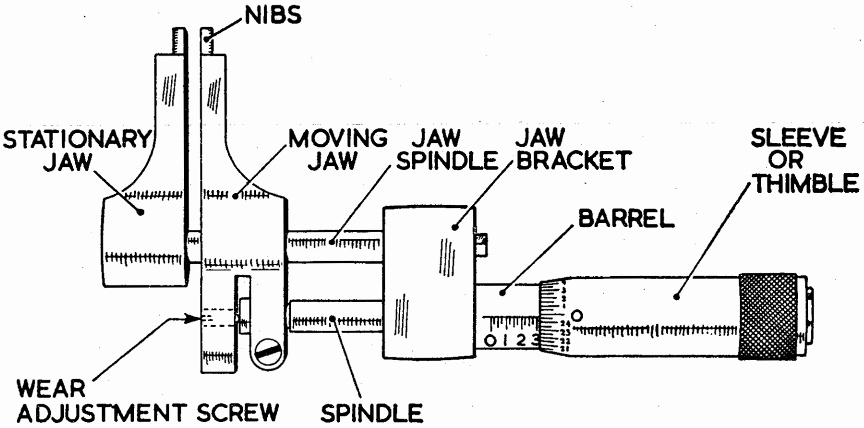


Figure 8. TYPICAL CALLIPER MICROMETER

5.11 **Vee-block Micrometers.** Drills, taps, reamers and certain cylindrical lapping tools, are manufactured with three, five or seven flutes, and these micrometers are necessary for the accurate measurement of the cutting or lapping dimensions of these tools. The micrometers are similar to the standard type, except that the anvil is integral with the frame, and, adjacent to the spindle, the anvil is vee-shaped to the appropriate angle to facilitate measurement of three, five or seven-fluted tools.

5.12 **Screw-thread Micrometers.** These instruments are similar to the standard type except that the spindle and anvil are provided with double and single points respectively (of the appropriate angle), for the measurement of thread dimensions of precision screw threads.

6 MICROMETER HEADS

6.1 As the term implies, these measuring devices are, in effect, the barrel, thimble and spindle of the orthodox micrometer. They are designed primarily for assembly into suitable bench brackets, and sets of matching extension pieces are supplied which fit over or into the micrometer head spindle to give various stages of measurement over the range. When mounted, the head with the appropriate extension piece is particularly suitable for tool-setting, checks for adjustable gauges and quick checkings of fixed points of measurement.

6.1.1 Some heads may be engraved with vernier scales (paragraph 4.3) for measurements to ten-thousandths (0·0001) of an inch. Others may be provided with large diameter thimbles, which are graduated into 250 divisions for direct scale readings, giving the same fine degree of measurement, or, with an additional vernier scale, a measuring accuracy of one hundred-thousandth (0·00001) of an inch.

6.1.2 To minimise wear at the measuring faces, some types of micrometer head are designed and manufactured with non-rotating spindles.

7 USING THE MICROMETER Apart from the correctness of the zero-reading of the instrument (paragraph 8.2), accuracy depends on the cleanliness of the measuring faces and the components undergoing measurement. Temperatures of instrument and component, and the correct method of manipulation, are also extremely important factors for consideration.

7.1 **Temperature conditions.** These have a significant effect on measurement results. Ideally, for very accurate work with small tolerances, the instrument and component temperatures should be equal (the Standard reference temperature is 68°F or 20°C); where this is not possible, then due allowances relevant to the co-efficients of expansion of the material being measured should be made.

7.1.1 Under certain conditions, an insulating lacquer might be applied to the instrument to reduce the temperature from hand operation, and precautions might be taken to avoid the handling of components with bare hands. (Some micrometers may be provided with a plastic covering in the appropriate places, to reduce the hand temperature effects.) Fine measurements should not be made during fluctuations in ambient temperature, in direct sunlight, or in the proximity of sources of heat.

7.1.2 When components are cleaned and afterwards dried with compressed air, chilling may result and cause temporary shrinkage. Therefore, sufficient time should be allowed to elapse, to enable components to regain ambient temperature.

7.1.3 Sometimes the micrometer is mounted in a suitable stand to reduce the amount of handling, and operators often wear gloves to minimise the handling of components undergoing measurement checks.

7.2 **Handling the Micrometer.** Ratchet attachments (when embodied) should always be used to ensure constant and co-related measurements. The sleeve should be turned gently at a constant rate towards the faces being measured; varying speeds of rotation will produce inaccurate readings. The average smaller size of micrometer will rest comfortably in one hand, the thimble or ratchet attachment can be manipulated by the thumb and forefinger, and the little finger can be extended to support the frame near to the anvil.

7.3 The instrument should not be set and forced over a measurement dimension; such a practice will strain the micrometer screw and wear the measuring faces. For similar reasons, the micrometer should never be drawn along parallel faces, particularly if these are rough or dirty.

8 MICROMETER MAINTENANCE Good maintenance of micrometers is attained by the appreciation that the instrument is a precision one, that correct handling is essential (paragraph 7), and that periodic dismantling, cleaning, adjustment and testing (paragraph 9), related to the conditions and extent of operational use, is carried out systematically. Micrometers should never be left lying on dusty benches, etc., but should be wiped clean after use, and replaced in the instrument case provided.

NOTE: Some manufacturers commendably number and colour-mark their instruments for identification, periods of issue and maintenance. Records of checks and maintenance are maintained in the Standards room of the Inspection Organisation. Classification is carried out for condition, and micrometers are allotted to various grades of work, e.g. rough turning, grinding, view room, etc. In some cases, dust-proof cupboards are provided for storage in the various workshops, and these are sometimes maintained at standard atmospheric temperature.

8.1 **Dismantling and Cleaning.** This should be done at regular intervals. No definite time cycle can be recommended, inasmuch that the frequency will vary with the extent of use, and the nature and conditions of operation. Component parts should be systematically laid out on clean surfaces (preferably under "view-room" conditions), washed in clean non-leaded petrol or naphtha, and then allowed to drain and dry. On assembly, the micrometer screw is to be lubricated with a light oil of instrument category, and all other surfaces should also be lightly smeared with oil.

8.2 **Micrometer Adjustments.** Adjustments consist of the setting of the "zero" reading of the instrument and, in instruments conforming to the Standards, the elimination of slackness in the micrometer screw.

8.2.1 **Setting the "Zero" Reading.** To facilitate accurate measurement, the "zero" reading should be checked and corrected before the instrument is used. In 0–1 inch instruments for external dimensions, the anvil and spindle faces are brought together, whilst in others for longer ranges, the measuring faces are closed upon round or cylindrical test pieces supplied with the instrument. When embodied, the ratchet attachment should always be used to ensure the correct "feel" in the setting.

8.2.2 With the instruments set in this manner, the barrel scale datum or fiducial line should be brought coincident with the zero division on the sleeve. Generally, micrometer barrels are movable within the frame by means of a special "C" spanner provided. Other types may be designed with adjustable anvils which either screw into the outer jaw of the frame, or the frame jaw is split and the anvil is locked in the correct position by a grub screw.

8.2.3 End measuring or "stick" micrometers (see paragraph 3.2) are usually equipped with adjustable anvils in the head of the sleeve, and at the outer end of each extension rod. Adjustments for these instruments are normally made (for the basic sleeve/anvil setting and each extension rod anvil setting) in the Standards room, against the measurement settings of a Micrometer Head (see paragraph 6).

8.2.4 Three-point internal micrometers are adjusted and corrected in the conventional way, except that setting rings are required. The anvils are inserted into the bore of the ring and are then set to the ring internal dimension by means of the ratchet attachment. A screw which locks the barrel-scale sleeve to the barrel is slackened, the sleeve is turned until the micrometer reading equals the bore dimensions, and the screw is then retightened. (See Figure 2.)

8.2.5 Depth micrometers are checked and set against the face of a surface table or plate, With the base plate and spindle faces in contact with the surface table, the micrometer reading should be "zero". Some of these instruments will be equipped with an adjustable barrel but others may be provided with adjustable spindles.

8.2.6 Calliper micrometers are usually adjustable at the end of the spindle where the jaw is split and fitted with clamping and adjusting screws. The clamping screw is slackened, the instrument jaws are closed, the adjusting screw is set to obtain "zero" reading, and the clamping screw is then relocked.

8.2.7 Vee-block and screw-thread instruments are provided with the appropriate setting gauges to suit the profiles of the measuring faces. With these in position between the anvil and spindle, orthodox adjustments will be made.

8.2.8 **Adjustment of the Micrometer Screw.** Micrometers manufactured to conform with British Standards are provided with adjustment for micrometer screw wear (Figure 9). The outer end of the barrel (inside the sleeve) is reduced in diameter and screw-cut with a very fine tapered thread. This extension is split in one, two or several equidistant positions, and a special internally-tapered ring nut is fitted. When the nut is turned clockwise with the spanner provided, it reduces the barrel screw diameter to suit the worn threaded diameter of the spindle screw. It should be borne in mind, however, that when this adjustment is made, the "feel" of the micrometer screw should be equal throughout the entire traverse of the spindle.

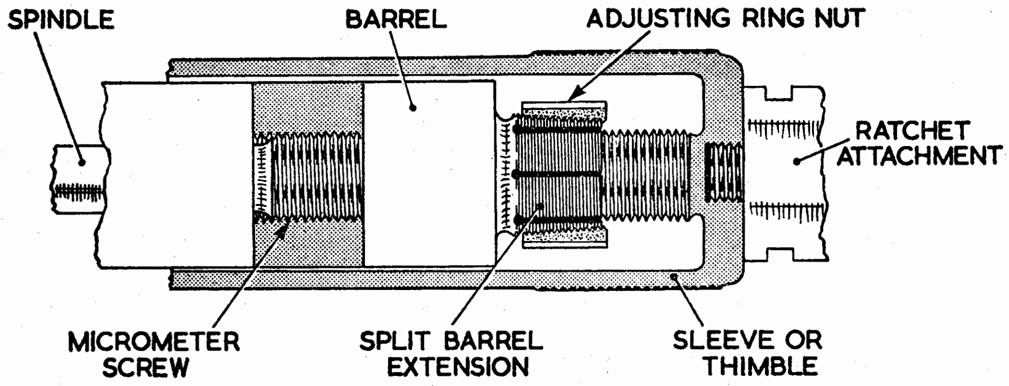


Figure 9. MICROMETER SCREW ADJUSTMENT

9 MICROMETER TESTING

9.1 **General Testing.** It will be appreciated that micrometers which have been adjusted (paragraph 8) and checked for measuring face flatness by slip gauge readings in various face positions, and for parallelism by concentricity checks between the anvil and the spindle, will be sufficiently accurate for most measurements and tolerances in the assembly and construction of aircraft.

9.2 **Finer Testing.** Micrometers which are to be used for small-tolerance, "Standard-room" or "View-room" work should be tested to a finer degree of accuracy. The following tests for flatness, parallelism and screw calibration are recommendations from British Standard 870.

9.2.1 **Flatness.** This is best tested by means of an optical flat brought into contact with each face in turn. Imperfections will be shown by a number of coloured interference bands on the surfaces, and the number and shape of these will indicate the degree of flatness present. The specified tolerance for flatness is 0.00005 in. and this is represented by a maximum number of five bands of similar colour on either of the faces.

NOTE: The bands are more distinct if the test is made in the light from a mercury vapour lamp, particularly if viewed through a green filter.

9.2.2 **Parallelism.** For 0–1 in. micrometers, this test may be made by utilising the same principle of optical interference. A number of optical flats of different thicknesses are used, the opposite faces being parallel as well as flat. These are positioned in turn between the measuring faces as if they were being measured and the number of interference bands on each face is noted. By careful manipulation between the measuring faces, the number of bands on one face is reduced to a minimum, and those on the opposite face are then counted. If this total number of bands of similar colour does not exceed ten, then the requirements of the Standard are satisfied.

9.2.3 In testing with optical flats of different thickness, the parallelism of the faces is checked in various angular positions. Generally, four flats are used with successive thickness variation of a quarter of 0·025 in., and the tests are made at four positions during a complete turn of the micrometer spindle.

9.2.4 Larger micrometers up to 4 in. may be tested by the same method. Two of the optical flats are wrung to the ends of a combination of slip gauges, and this combination is used as a parallel-ended test piece between the faces. The four-position check is made with changes in the length of gauge combination by 0·006 in. or 0·007 in. in succession.

9.2.5 For larger micrometers the optical test is too sensitive in relation to tolerances. It is usual for test pieces to be made up in suitable lengths for each size of instrument. Steel balls of $\frac{1}{8}$ in. or $\frac{3}{16}$ in. dia. are often soldered to the ends of a $\frac{1}{4}$ in. dia. steel rod, and the test pieces are inserted between the measuring faces in various positions around their periphery. Variations in these measurements should not exceed the tolerance prescribed.

NOTE: Adjustable test pieces of this kind are often used to cover several sizes of micrometer.

9.2.6 **Calibration of the Micrometer Screw.** Reading accuracy of 0–1 in. or 0–25 mm micrometers is usually checked by various readings on a series of slip gauges. These are chosen to test the micrometer, not only at complete spindle turns but also at intermediate positions, to cover inaccuracies in thimble graduations. The following series of gauges are suitable for progressive and periodic errors in the micrometer ranges.

0–1 in. Micrometer: 0·105, 0·210, 0·315, 0·420, 0·500, 0·605, 0·710, 0·815, 0·920 and 1·000 in.

0–25 mm. Micrometer: 2·5, 5·1, 7·7, 10·3, 12·9, 15·0, 17·6, 20·2, 22·8 and 25·0 mm.

These series give readings around the thimble twice over, and so provide a double check on any periodic error which might exist.

NOTE: For very accurate readings during such calibrations, the thimble may be viewed under a microscope of low magnification.

9.2.7 In larger micrometers, the errors in traverse can be checked, using slip gauges as in paragraph 9.2.6, by carefully clamping the instrument to a surface table or plate and fixing a temporary anvil with rounded face close to the face of the spindle. Alternatively, an indicator with sensitivity of at least 0·00005 in. can be used as a temporary anvil.

BL/4-1

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BASIC

MATERIALS

CORROSION—ITS NATURE AND CONTROL

1 INTRODUCTION

1.1 This Leaflet gives general guidance on the causes, appearance and prevention of corrosion which, if not detected in its early stages, can have disastrous consequences. Information on corrosion theory is included where it has bearing on the practical aspect of the inspection and maintenance of aircraft and aircraft parts. The Leaflet should be read in conjunction with Leaflets **BL/4-2** and **BL/4-3** which deal with the removal and rectification of corrosion and with methods of protecting aircraft against corrosion. For guidance on methods of inspecting the more intricate parts of aircraft structures and for additional information on areas liable to corrosion, reference should be made to Leaflet **AL/7-13.**

1.2 All metals are subject to chemical and electro-chemical attack which converts them into metallic compounds such as oxides, hydroxides, carbonates, sulphates or other salts. Some metals resist attack better than others but the resistance of most metals may vary with such factors as physical environment, applied or internal stress, heat treatment state or working temperature. Although many of the metals used in aircraft construction have reasonable resistance to corrosion, it is essential that all possible action is taken to prevent its occurrence and to detect and remedy any corrosive attack, even if it appears to be insignificant.

1.3 As corrosion may arise from many different causes and can affect all kinds of metallic structures and components, it is beyond the scope of this Leaflet to enumerate all the defects that may result from it. It is also impracticable to enumerate every remedy as the treatment of each affected part must be determined by its nature and its function in the particular aircraft. Guidance on the repair and re-protection of corroded parts should be obtained from the appropriate Manufacturer's Publications, but whenever doubt exists the Manufacturer should be consulted.

2 TYPES OF CORROSION Corrosion is largely an electro-chemical phenomenon and is liable to occur whenever a difference in potential exists between two metals or a metal and substances in its vicinity in the presence of an electrolyte (see Figure 1). It can also occur when a difference in potential exists between separate regions of a single piece of metal or between the different constituents of an alloy. The degree of corrosion experienced will depend on external conditions and in some environments will be negligible; serious attack usually takes place only if moisture is present to act as an electrolyte between the poles created by any difference in potential. Two changes then occur, the metal that is attacked suffers a chemical change, some of it being converted into a metallic compound, whilst the cathodic pole of the circuit may be reduced.

2.1 **Direct Chemical Attack.** When metals combine with atmospheric oxygen or are attacked by acids, the anodic and cathodic changes occur at the same point. Impurities in the atmosphere can be responsible for this type of corrosion. Thus, aircraft operating near the sea are affected by airborne salt particles, whilst the high sulphur content of industrial atmospheres has a markedly deleterious effect on some exposed metallic surfaces. There is also the possibility of accidental contact with harmful substances. Where this form of attack occurs, the attacked metal is converted into a chemical compound by the corrosive agent, e.g. aluminium may be converted to aluminium sulphate by battery acids.

NOTE: On aircraft used for crop spraying, special care must be given to the inspection of the structure owing to the corrosive nature of some of the chemicals used. Guidance on the CAA's recommendations and requirements applicable to these aircraft is given in Leaflet **AL/7-13.**

2.2 **Electro-chemical Attack.** The close proximity of dissimilar metals in aircraft, aided by the presence of conductive media such as water, encourages the establishment of circuits and results in the metal which is anodic to the other being attacked. In some cases, such as when aluminium alloy and magnesium alloy are in contact, both metals may be corroded. Electro-chemical attack will be encouraged by the existence of stray currents from electrical apparatus or electrostatically-charged bodies (see Leaflet **BL/4-3).**

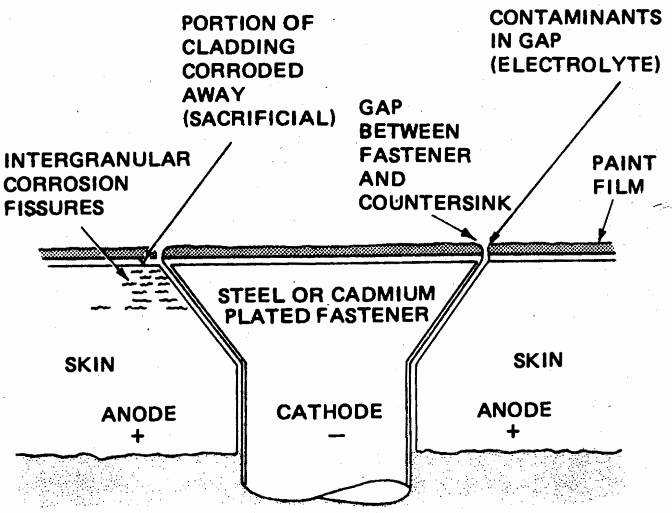

Figure 1 ELECTRICAL ASPECT OF CORROSION

2.3 **Evidence of Attack.** Both types of corrosive attack start on the surface of the metal but can work their way into the core if undetected. Evidence of corrosion will be indicated in the following manner:

(a) **Aluminium Alloy.** Corrosion of the aluminium surface is usually indicated by whitish powdery deposits with dulling of the surface on unpainted parts. The white powdery deposit also forms at discontinuities in protective coating and may spread beneath paint causing blistering or flaking. As the corrosion attack advances, the surface will appear mottled or etched with pitting. Swelling or bulging of skins, pulled or popped rivets are often visual indications of corrosion.

(b) **Alloy and Carbon Steels.** Corrosion is indicated by red rust deposits and pitting of the affected surfaces.

(c) **Corrosion Resistant Steels.** Corrosion is indicated by black pits or a uniform reddish-brown surface.

2.3.1 **Terminology.** The terminology used in describing corrosion is based on either the appearance of the corrosive attack or the mechanism associated with its formation. Frequently, several types of corrosion will occur simultaneously and it becomes difficult to determine the specific cause. The following types of corrosion are those most commonly experienced.

2.3.2 **Surface Corrosion.** This may take the form of a uniform etching of the surface, pitting or exfoliation of the surface grain boundaries. Light alloys are usually blotched by white or grey powdery deposits, whilst ferrous materials other than stainless steels become covered with reddish-brown rust, and a greenish powder forms on copper. Surface corrosion reduces the amount of sound material remaining and so weakens the structure but, since there is usually an indication of its existence, it is possible for it to be remedied by careful and systematic maintenance.

NOTE: In many instances the reduction in strength of a structure due to corrosion attack is out of all proportion to the reduction in thickness of the metal.

2.3.3 **Intergranular Corrosion.** The detection of this type of corrosion is difficult as the surface evidence may only be visible through a magnifying glass. Indications of the presence of corrosion can be obtained by anodising the part and examining for discoloration (black spots). Considerable experience is required for correct recognition, and often a metallurgical microsection examination will be necessary. The attack penetrates into the core of the material along the boundaries of the metal grains. As the material at the boundaries is usually anodic to the grain centres, the corrosion products often become concentrated at the boundaries, although sometimes the attack is transgranular and it is the material adjacent to the boundary which is attacked. The rate of attack is not limited by the lack of oxygen but is accelerated if applied or residual stress is present. Repeated tensile or fluctuating stresses encourage separation of the boundaries, so accelerating the spread of intergranular corrosion and giving rise to corrosion fatigue. As a result higher stress concentrations occur in the remaining sound material, cracks spread and complete failure follows. As there is no effective method of limiting or determining the loss of strength that occurs through this form of corrosion, material or parts showing any signs of it must be rejected immediately.

2.3.4 **Pitting.** Detected as a series of pits on the metal surface, usually in small, well defined local areas.

2.3.5 **Filiform and Exfoliation (or Laminar) Corrosion.** Filiform corrosion usually occurs under thin oil, grease or varnish films and is likely to be found on metal surfaces which have a protective film of any sort if there is evidence of a lack of adhesion of the protective film, and appears like 'worm-casts' on aluminium and magnesium alloys. Exfoliation appears as eruptions or flakiness on extruded alloys and can be a serious problem, although it is a relatively less harmful form of intergranular attack.

NOTE: Intergranular corrosion may occur without stress in the presence of acid chloride solutions or urine, etc., and the latter is often the cause of intergranular cracks which lead to component failure.

2.3.6 **Galvanic.** Galvanic corrosion is usually visible as pitting and is often referred to as dissimilar metal corrosion. However, it is not limited to just dissimilar metal couples. Various types of concentration cells, where electron flow occurs between areas or points of different electrical potential, are also examples of galvanic corrosion. Pitting results when, in the presence of a conducting solution, electron flow occurs between different metals or between different points or areas on a metal surface exhibiting different electrical potential.

2.3.7 **Microbial.** Microbial (microbiological) corrosion occurs in integral fuel tanks and is caused by the presence of bacteria and fungus in aviation kerosene. The fungus grows at the fuel/water interface, and the metabolic products formed corrode the metallic structure.

2.3.8 **Stress Corrosion.** This type of corrosion usually manifests itself as fine cracks. It occurs in alloys that are susceptible to cracking when exposed to a corrosive environment while under a tensile stress.

3 CONDITIONS CAUSING CORROSION Because of the stringent weight limitations of aircraft, structural parts and components cannot be designed so that they are heavier than is dictated by the requirements of mechanical strength. Thus, any loss of strength through corrosion damage is more critical than in other forms of transport. Aircraft parts should therefore be manufactured, protected and assembled so that corrosion is unlikely to occur and, after entering service, every precaution should be taken to preserve the original finish. Cleaning and inspection, and when necessary re-protection, are essential at frequent intervals throughout the working lives of all components and parts.

3.1 **Basic Factors of Material and Assembly.** The following factors are important as a guide to the prevention of corrosion:

3.1.1 **Selection of Materials.** As material specification used in initial construction or for subsequent repair are chosen by the Manufacturer, who should make resistance to corrosion a factor in selecting the appropriate specification, maintenance responsibility is normally limited to ensuring that all instructions for handling, storage, heat treatment, assembly and protection are correctly carried out and that a close watch is maintained for signs of incipient corrosion.

3.1.2 **Dissimilar Metals.** The contact of dissimilar metals, which occurs in many parts of aircraft structures and in most accessory components, is always likely to cause electro-chemical reaction, but in many instances such reaction can be prevented by maintaining protective or insulating layers between the metal surfaces. It should be remembered that parts to the same materials specification may have a relative difference in potential if their heat treatment states are different, and thus in some circumstances should be separated by jointing compound, etc., as though they were dissimilar metals. Some examples of dissimilar metal contacts are quoted:

(a) Steel bolts through aluminium alloy spars and structural members.

(b) Steel brake components secured to magnesium alloy wheels.

(c) Parts made of brass, steel, tungum, etc., such as clips or brackets, attached to aluminium alloy structural members.

(d) Aluminium alloy skin panels riveted to extruded stringers.

(e) Steel levers, shafts and gears housed in castings of light alloy.

3.1.3 **Heat Treatment.** Incorrect heat treatment may lower the corrosion resistance of the material treated, thus it is essential that all heat treatment should be applied strictly in accordance with approved specifications. The corrosion resistance of high-strength aluminium alloys is affected by their cooling rate; if this is rapid their susceptibility to intergranular corrosion is reduced, provided that locked-up quenching stresses are afterwards relieved.

NOTE: Heat is sometimes applied to structural parts for purposes other than the development of particular mechanical properties of the metal, e.g. when metal to metal joints are bonded by thermo-setting synthetic resins under the influence of heat and pressure. Since 'heat treatment' of this kind is not always covered by official specifications, close adherence to the aircraft Manufacturer's instructions is essential to ensure that the corrosion resistance and other properties of the metal are not impaired.

3.1.4 **Welding.** Welded joints are sometimes subject to corrosion because the heated strip has been rendered anodic to the surrounding metal but the danger can be greatly reduced by the exercise of skill and care. It should be remembered that the fluxes used in welding are often corrosive and hence all residues from fluxes should be thoroughly cleaned off immediately after welding. Some stainless steels are particularly susceptible to intergranular attack in the welded region (weld decay), although the likelihood of this can be reduced if the part is annealed after welding or if the steel contains stabilising elements such as titanium or niobium (Leaflet **BL/6-4**). Inert gas welding processes which do not require flux are sometimes used when the removal of flux would be difficult.

3.1.5 **Fretting.** This is a type of corrosion which can have serious consequences, as it reduces the fatigue strength of the structure; it occurs when parts are bolted tightly together and yet slip slightly on one another during flexing or other movements of aircraft parts. The heating caused by friction promotes oxidisation of steel parts and the oxide is then rubbed off to form dust frequently described as "cocoa". Fretting of aluminium alloys produces a black oxide. Structural assembly bolts should be inspected to ensure that the protective treatment plating is intact and should be assembled within the stipulated torque loading limits and in accordance with the Manufacturer's instructions.

3.1.6 **Stress.** Metals under stress generally corrode more rapidly than unstressed metals. The influence of stress on the development of intergranular corrosion is mentioned in paragraph 2.3.3. Corrosion that is continuing on parts under repeated stress is very much more harmful than corrosion for the same length of time without stress, and can lead to rapid failure of the part from fatigue. In many cases, stress corrosion cracks have resulted from initial pits in the surface.

3.1.7 **High Temperatures.** Parts which become heated in service, such as brake drums, combustion chambers and exhaust pipes, tend to oxidise more rapidly than unheated parts. This tendency is reduced if the parts are made from alloys containing nickel or chromium, although the corrosive effects of the sulphur present in exhaust gases may still do harm to heated engine parts.

3.1.8 **Electrical Equipment.** Faults in the insulation of electrical equipment which lead to current leakage can cause the equipment itself to corrode or can encourage electro-chemical attack in the surrounding structure. Insulation should therefore be carefully tested as outlined in Leaflet **EEL/1-6**. Sparking in confined spaces will produce nitric acid in the presence of moisture and this acid will then attack the surrounding material. Nitric acid attack can be prevented by ensuring that the vents of such equipment as magnetos are kept clean so as to permit the escape of the oxides of nitrogen evolved. Certain insulating materials give off vapours which are corrosive, e.g. phenolic resin-bonded insulating materials give off vapours which corrode cadmium plate.

3.2 **Factors Due to Environment and Operation.** Corrosion can arise from many circumstances, some of which are unavoidable but many of which can be anticipated and controlled. When conditions that create corrosion are an inevitable accompaniment of storage or operation, the only safeguard is adequate maintenance.

3.2.1 **Damage to Protective Coatings.** Metallic surfaces protected by chemical films, metal plating or organic coatings, may suffer severe attack if the protective coat is physically damaged. Some protective coatings are susceptible to attack from certain types of lubricants, de-icing fluids or hydraulic fluids, but this danger can be reduced by selecting protectives that are specially resistant for the items that are likely to be in contact with these fluids. Scratches caused by careless handling and abrasion from grit or water striking the aircraft at high speed can provide starting points for corrosion, but the seriousness of such defects depends on the materials affected. Thus aluminium alloy sheet clad with pure aluminium is not much harmed by minor scratches since the aluminium cladding provides 'sacrificial protection' (Leaflet **BL/4-3**). On the other hand, chromium plated steel will rust readily if the chromium is damaged.

3.2.2 **Surface Defects.** Corrosion may arise from particles of foreign matter, such as rolling-mill scale or emery particles, which are embedded in the surface. Particular care is necessary after such operation as filing, grinding or abrasive grit blasting to ensure that all particles are completely removed. A high polish is given to some components to enable them to resist attack, and this resistance will be lowered if polished surfaces are roughened or scored.

3.2.3 **Crevice Corrosion.** Intense corrosion is often found where non-conducting materials, such as plastics, glass-wool or upholstery, are in contact with metal. A similar effect may occur in inaccessible corners formed in metal parts. In such places, oxygen is replenished less quickly than elsewhere with the result that the crevice is rendered anodic to the surface outside and is therefore subject to electro-chemical attack. It follows that the contact of metals and non-conductors should be treated like the contact of dissimilar metals, and that all enclosed regions in aircraft structures should be vented and drained as adequately as possible. Ventilation also helps to prevent the accumulation of condensed moisture and discourages the growth of moulds and bacteria which can also promote corrosion.

3.2.4 **Marine Corrosion.** The salt present in sea water will attack many metals directly. Landplanes may be affected by airborne particles or spray droplets, whilst amphibians require constant attention to keep them free from the salt deposited by evaporated spray. If trapped in the aircraft structure, sea water will provide a particularly active electrolyte for electro-chemical action. Hulls are sometimes damaged because of the voluminous character of the corrosion products precipitated in crevices; as the material accumulates, plates may be bulged and rivets fractured. The inside of the chine members where the side sheeting joins the planing bottom is particularly vulnerable to corrosion because of its moisture trapping shape.

3.2.5 **Fuels, Oils and other Liquids.** Although petroleum products contain sulphur compounds and organic acids, they do not usually corrode fuel tanks, pipe-lines, etc., because of the resistant nature of the materials from which these items are made. The danger of corrosion chiefly arises from the water content of oils and fuels; the water acts as an electrolyte to promote combination with oxygen dissolved in the oil or fuel. This effect is most pronounced with leaded petrol, and light alloy tanks containing such fuels should be protected with inhibitor cartridges (Leaflet **BL/4-2**). Careful inspection of the external surfaces as well as the internal structure of the keel areas, particularly of pressurised aircraft, is necessary due to condensation and spillage from toilet and galley installations. Battery acids, de-icing fluids, disinfectants, water methanol spillage and urine can also cause extensive attack on structural parts and care should always be taken to wash off any of these fluids which may be spilt. Integral fuel tanks should be designed to give good water collection and drainage.

3.2.6 Water in aviation kerosene may cause serious corrosion within the fuel system. It may be saline or brackish, which with other contaminants such as iron oxide, micro-biological organisms, etc., may have very serious effects (see Leaflets **AL/3-15** and **AL/3-17**).

NOTE: All aviation fuels absorb moisture from the air and the amount of dissolved water contained varies with the temperature of the fuel. When the temperature of the fuel decreases, some of the dissolved water comes out of solution and falls to the bottom of the tank. When the temperature of the fuel increases, water is drawn from the atmosphere to maintain a saturation solution. Changes in temperature, therefore, result in a continuous accumulation of water.

4 THE CONTROL OF CORROSION Details of corrosion control during design and production are outside the scope of this Leaflet; the following paragraphs relate to care and maintenance under operating conditions.

4.1 **Cleaning.** It cannot be too strongly emphasised that frequent cleaning is essential for the prevention of corrosion. During take-off and landing, aircraft are splashed with mud and water; during flight, engine oil and exhaust products are deposited on parts of the structure, and at all times contamination by atmospheric dirt is likely to occur.

4.1.1 Metal-skinned structures should be washed down thoroughly using solutions, materials and equipment which are recommended by the aircraft Manufacturer. Non-flammable degreasing cleaners for aluminium alloys are available in powder form; they should be applied with a bristle brush, care being taken to remove all dirt from odd corners, panel edges, screw and rivet heads, etc. If deterioration of protective treatments or signs of corrosion are revealed by cleaning, the affected parts should be treated as described in Leaflets **BL/4-2** and **BL/4-3.** Cleaning preparations should be washed off with cold water after they have loosened the dirt, and the parts should be dried thoroughly before restoring any protective treatments.

NOTE: There are certain proprietary cleaners which, although harmless to metals, are inclined to rot fabric and other textile materials. It follows that care should be taken to prevent them from wetting fabric or upholstery. Transparent plastics can also be damaged by cleaning chemicals and should therefore be suitably protected. (For guidance in cleaning and maintenance of transparent plastics panels, see Leaflet **AL/7-4**).

4.1.2 At the intervals specified in the Approved Maintenance Schedule, marine aircraft should be beached and hosed down with fresh water. The bilges should be drained and flushed through with fresh water at the same time. Care should be taken that all deposits of salt and marine growths are removed from both the inside and outside of the aircraft and that all damage to protective coatings is made good. All submerged parts of the hull and floats should then be sprayed with liquid lanolin, pigmented lanolin or seaplane varnish, the spraying being continued to approximately 0·6 m (2 ft) above the water line.

4.1.3 Where battery or other acids have been spilled, the surrounding area should be rinsed with generous quantities of clean water to dilute and remove the acid. The affected parts should then be brushed with a dilute solution of sodium bicarbonate for lead acid batteries, and diluted acetic acid for nickel cadmium batteries, to neutralise any remaining electrolyte. After this has remained on the surface for a few minutes, the area should again be washed with water, finally wiped dry, and the protective treatments restored.

NOTE: In cases where spillage of acid or heavy concentrations of battery fumes (e.g. due to a runaway battery) have occurred which are not contained within a known area, it may be necessary to dismantle parts of all the surrounding structure to ensure the effective removal of all traces of electrolyte.

4.1.4 High octane fuels, which are doped with tetra-ethyl-lead and ethylene dibromide, produce lead bromide when burnt. This is ejected in the exhaust gases and can do considerable harm if deposited on aluminium alloys. Such deposits should be removed by using detergents or emulsifiable cleaners which will not soften the underlying paint coat. Where possible all apertures at wing root joints, etc., should be sealed to exclude exhaust gases from the inside of the structure, but if the gases do penetrate, internal cleaning will also be necessary. If the deposits are so hardened that they will not yield to normal cleaning, a paint stripper should be applied. Using a high pressure jet of water or rubbing with a damp rag, the stripper and paint can then be removed together. Afterwards the cleaned area must be re-protected (see Leaflets **BL/4-2** and **BL/4-3).**

NOTE: Paint strippers containing methylene dichloride or ethylene dichloride can seriously reduce the strength of resin-bonded joints, and hence aircraft on which processes such as "Redux" bonding have been used should only be cleaned with strippers which are recommended for the purpose by the aircraft Manufacturer. Information on acceptable materials, if not in the appropriate Manual, is normally available in Service Bulletins published by the Manufacturer's Service Department.

4.1.5 Although accumulation of oil and grease may not in themselves be corrosive, they tend to retain dirt and metal particles, to damage surface finishes and prevent inspection for cracks, etc. They should be removed from such parts as the landing gear and engine nacelles by means of solvents or emulsifiable cleaners. The cleaning agents recommended by the aircraft Manufacturer should always be used.

NOTE: It is important that the cleaning fluids specified by the Manufacturer are used in the strengths recommended and in applications where their use has been specified. Cases have arisen where cleaning fluids in combination with kerosene have had a deleterious effect on aircraft structures, the penetrating qualities of kerosene promoting seepage into skin joints. Such cases are particularly troublesome and it becomes difficult to diagnose the cause of corrosion. Also, unspecified cleaning fluids might contaminate or destroy jointing compounds, bonding adhesives or sealing mediums.

4.1.6 Wrong methods of cleaning can do more harm than good. The following points should be noted:

(a) Steel wool should not be used on aluminium alloy or magnesium alloy surfaces as particles may be lodged in crevices or embedded on organic coatings and so provide starting points for electro-chemical attack.

(b) Aluminium-clad light alloy sheet should not normally be polished with mechanical buffing wheels, except under a carefully controlled technique, as this will remove the coating of pure aluminium and the unprotected alloy core will be subject to corrosion.

(c) Dirt and swarf should not be washed or brushed inside the structure where particles may be trapped behind stringers, frames, etc. (Trapped water can do more damage than the dirt.) Interior cleaning should be done with an efficient vacuum cleaner.

(d) Pressure cleaning should be used with caution, particularly where bearings are in use. Steam cleaning should only be used when specified, for it can penetrate joints and leave water residues.

4.2 **Inspection.** Every precaution must be taken to ensure that all corrosion is detected in its early stages. Corrosion cannot always be found by visual examination alone, and one of the methods of non-destructive examination such as radiological examination (Leaflet **BL/8-4**) may be of assistance. However, corrosion tends to blister paint and its presence can be suspected if the paint flakes off when pressed.

NOTE: Because of the rapid improvements that have been made in radiological techniques, the latest information on this subject should be sought from the aircraft Manufacturer.

4.2.1 At the time specified in the Approved Maintenance Schedule and whenever the aircraft has been subjected to especially corrosive conditions, the inside and outside of the structure should be thoroughly examined. The upholstery and floor coverings should be removed and all access panels should be opened to facilitate inspection. With a strong light, a detailed examination (see also Leaflet **AL/7-13**) should be made of the spars, ribs, frames, bulkheads, stringers, etc. Particular attention should be given to poorly vented regions and to places where dampness and condensation are apparent or suspected. Strontium chromate inhibitor pellets are sometimes used in areas where water accumulates and the condition of such inhibitors should be assessed. The satisfactory adhesion of sealant fillets and paintwork should also be verified.

(a) Special attention should be given to parts of the fuselage where condensation may tend to collect. Considerable condensation will occur on the inner surfaces of pressure cabin structures. Water will run down the cabin wall structure and this will tend to start corrosion in the lower parts of the structure.

(b) Inspection should give special attention to such areas and particularly to the faying surfaces between stringers and skin, where moisture may remain trapped and promote corrosion. In some cases it may be necessary to dismantle parts of the structure to ensure adequate inspection.

NOTE: On some types of aircraft operating under widely different conditions, recent investigations have revealed the presence of serious corrosion which had remained undetected in parts of the structure. In some instances it has been shown that normal methods of inspection and radiological examination were inadequate, and dismantling, particularly of pressurised skin structures, was therefore necessary.

4.2.2 Where evidence of surface corrosion exists, the extent of pitting or exfoliation should be tested by probing with a fine needle. Whenever possible, the strength of all suspect rivets should be tested by applying a moderate shear load to the rivet head. The remedial action to be taken will depend on the depth and extent of the attack and the thickness and function of the affected parts, but any areas where rivets fail must obviously be repaired in accordance with the appropriate Repair Manual. Elsewhere, if the attack is not serious, the corrosion can be cleaned off and the part re-protected (Leaflets **BL/4-2** and **BL/4-3**), but any intergranular or widespread surface corrosion will also necessitate repair by renewal of the damaged areas.

4.2.3 Assessment of the condition of parts subjected to high temperatures is not easy but, as a general rule, discoloration and light scaling are normally acceptable (light scale sometimes protects the metal from further attack) whilst heavy scale is an indication that the strength of the metal has been reduced. However, the majority of exhaust systems fitted to aero engines are manufactured from stainless steel or inconel and visual examination of these components is often misleading. This is because those parts of the system which are subjected to the highest temperatures will, after extensive periods in service, suffer from intergranular corrosion. If undetected this is obviously dangerous and may constitute a fire hazard, but detection is possible by measurement of magnetic permeability. A rough check for this condition can be made with a small horseshoe magnet, the component under examination being rejected if the magnet shows any tendency to adhere to it, but sensitive instruments which measure the relative magnetic permeability should be used whenever possible. The guidance of the Manufacturer should be followed when assessing the condition of particular exhaust systems.

4.2.4 It is a wise precaution to remove a sample number of key assembly bolts during major inspections, care being taken to ensure that different bolts are removed at each inspection. Bolts securing engine mountings, wing and empennage attachment bolts, and undercarriage assembly bolts should be examined for signs of fretting corrosion. The bolt holes and surrounding material should be inspected for intergranular penetration and fatigue cracks by the methods given in Leaflet **BL/4-2.**

NOTE: This should only be done by skilled personnel with the appropriate jigs and assembly equipment.

4.2.5 It should be remembered that metal tubes may corrode internally as well as externally. Sealed tubes, which have been protected internally before assembly should not cause concern, but open-ended tubes can accumulate moisture. Guidance on the inspection and protection of tubes is given in Leaflet **BL/4-2.**

4.2.6 Visual examination for corrosion is one of the most essential aspects of inspection and is necessary on all components, pipelines, control cables, electrical equipment, instruments, etc. For further information on the inspection of particular systems and components, reference should be made to the appropriate Manual and to other CAIP Leaflets dealing with the systems concerned.

4.3 **Storage.** Aircraft, engines and components will deteriorate rapidly when stored unless adequate precautions are taken to protect them from climatic conditions, damp, condensation and accumulations of dust. It should be remembered that conditions suitable for some materials may not suit others. The following information stresses some important factors of good storage.

4.3.1 The most suitable environment for storing complete aircraft is a cool, dry hangar with a relative humidity of less than 60% where the structure is protected from strong sunlight, rapid changes of temperature, atmospheric impurities of marine or industrial origin, and the erosive effect of blown dust. Before prolonged storage is contemplated it is advisable, where possible, to remove all sound insulating and textile materials of a hygroscopic nature. After storage, special attention should be given to parts of the structure which have remained in contact with material of a hygroscopic nature. It should also be noted that damp wood will evolve acids that can be harmful to adjacent metal even though the wood may not be in direct contact with it.

4.3.2 Aircraft should be stored in a dry, clean condition, all drains and vents should be clear and unobstructed, and blanks should be fitted to intakes and apertures in which condensation might occur. Colour indicator type of silica-gel may be used in enclosed spaces to absorb atmospheric moisture.

4.3.3 Temporary protectives such as rust inhibitors and lanolin should be applied to exposed metal surfaces which are likely to corrode. Guidance on the protection of particular aircraft should be obtained from the Manufacturer concerned.

4.3.4 If aircraft have to be stored for long periods in the open or under detrimental climatic conditions, they should be adequately covered and protected by a special process. Packaging by the spray application of a plastics film is a satisfactory method, provided every precaution is taken to control the humidity of air inside the protective covering and an externally visible moisture absorption indicator is used.

4.3.5 Some of the special precautions necessary to protect engines from corrosion are covered in Leaflet **EL/3-14.** There are numerous precautions, with variations in materials, equipment and methods of application, which are specific for various engine types and installations; these must be applied strictly in accordance with the appropriate Manual and related technical documents.

4.3.6 Metals held in stores should not only be stored under controlled conditions but should be protected by a method suitable to the specification and shape of the material. Thus a coating of lanolin is usually applied to light alloy castings, whilst sheet and strip light alloy are most effectively safeguarded by spraying them with an approved plastics film on to a pre-oiled surface. Plastics films, which can be peeled off before fabrication, have the added advantage of protecting them against mechanical damage.

4.3.7 Components such as instruments, hydraulic valves and electrical equipment are usually packaged by their Manufacturers and given a guaranteed shelf life. However, it should be remembered that the shelf life is only valid if the storage conditions are suitable; in humid conditions corrosion may occur even if the packaging appears to be undamaged. The only remedy is periodic inspection, cleaning and re-protection throughout the shelf life of the component.

4.3.8 Aircraft, engines and components which have been stored for any considerable period should be carefully examined and tested before being put into service. Temporary methods of protection should be removed, and all permanent protection should be inspected and rectified as necessary.

NOTE: For further information on storage conditions for aeronautical supplies see Leaflet **BL/1-7.**

BL/4-2

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BASIC

MATERIALS

CORROSION—REMOVAL AND RECTIFICATION

1 INTRODUCTION

1.1 This Leaflet gives general guidance on the removal of corrosion products and on the cleaning and pre-treatment of the metal parts of aircraft. It should be read in conjunction with Leaflets **BL/4-1** and **BL/4-3** and the appropriate Manufacturer's publications for the aircraft concerned.

1.2 Many of the processes recommended in this Leaflet are covered by specifications issued by the Ministry of Defence or the British Standards Institution. Since these specifications are frequently re-issued, the alphabetical suffix of each DTD Specification has been omitted, but the application of any particular process should always conform to the latest issue of the relevant specification. All processes should be approved by the aircraft Manufacturer.

2 TREATMENT OF STRUCTURAL PARTS Wherever corrosion is found in aircraft it is essential that the corrosion products should be completely removed. This is necessary for two reasons, firstly to permit the extent of the damage to be assessed and secondly because the presence of corrosion products assists in the continuation of the attack. The full value of protective treatments will only be achieved if the surfaces are thoroughly cleaned and the treatments are applied immediately after cleaning.

2.1 **Preliminary Cleaning of Corroded Areas.** Parts which cannot be removed for cleaning should have all oil, grease, moisture and surface dirt cleaned off before the application of corrosion-removing chemicals. Oil and grease should be wiped off with rags soaked in organic solvents such as trichloroethylene fluid (BS 580) (Type 2 or other suitable grade), or a mixture of equal volumes of white spirit (BS 245) and either (a) solvent naptha (BS 479) or (b) 3°xylon (BS 458), used at room temperature as recommended in DEF STAN 03-2. (Degreasing procedures are detailed in specification DEF 1234.) Surface dirt should be removed with detergent solutions, using hand brushes with non-metallic bristles such as nylon.

NOTE: Trichloroethylene degreasing processes and the precautions necessary when used with certain metals are described in Leaflet **BL/6-8.**

2.2 **Removal of Old Protective Coatings.** To facilitate the inspection and re-protection of corroded surfaces, the protective coatings in the vicinity of the damage should be removed. Whenever possible this should be done chemically, as mechanical methods such as wire brushing, grinding or rubbing with emery, may overheat the surface or remove an undesirable amount of material. There is also the danger that abrasive methods may drag surface metal over the corroded area or cause particles to become embedded which will cause further corrosion later.

2.3 Air-blast abrasive equipment has been proved satisfactory, particularly for relatively large areas of surface corrosion removal. The abrasive must in all cases be aluminium oxide or glass beads, never silicon carbide; for coarse and rapid removal the particle size should not exceed 180 mesh (0·08 mm) and for fine control the size should be 400-600 mesh (0·038-0·025 mm). Due to the possibility of cladding removal from aluminium skins and cadmium plating from steel fasteners, etc., abrasive blasting should only be considered if a complete organic finish is to be applied.

2.3.1 **Removing Organic Coatings.** Non-flammable paint strippers should be used to remove paints, varnishes, synthetic enamels, cellulose, etc., (see DEF STAN 80-16 and Manufacturer's recommendations). A number of proprietary solutions are available which are satisfactory for the majority of organic coatings; they are neutral and will not attack the underlying metal provided they are rinsed off after the paint has been removed. The strippers should be brushed over the paint, left on the surface for a few minutes and the loosened paint then wiped off with a cloth, aluminium wool or non-metallic material, e.g. wood, Tufnol or suitable plastics materials. Steel wool should not be used.

2.3.2 Where a paint coating is required to be repaired or renewed in localised areas only, surrounding areas should be masked by means of suitable tapes, and these should be removed at suitable stages during the painting process to prevent subsequent contamination of later stages, and as soon as practicable after completion of the painting operation.

2.3.3 Where damage or removal of pressure cabin sealants or other sealing or stopping materials has occurred, these should be renewed either before or at some convenient point during repainting operations. Where stoving materials have been used originally, these may be replaced with an approved air drying scheme compatible with the original.

NOTE: The effects of certain strippers on adhesive-bonded joints, plastics parts and windows should be borne in mind (see Leaflet **BL/4-1**), and care should be taken to avoid caustic strippers on aluminium alloys. Rubber gloves and goggles should be worn to prevent any contact between the stripper and the skin.

2.3.4 When the paint has been removed, all traces of the stripper and residue should be removed by one of the following methods (DEF STAN 03-7).

(a) **Water-miscible paint remover:** Washing with clean water and drying, followed by solvent cleaning.

(b) **Solvent-miscible paint remover:** Washing with the appropriate solvent only.

2.3.5 **Removing Chemical Coatings.** It is not always essential to remove chemical coatings such as anodic films from aluminium alloys or phosphate coats from steels. As it is generally impossible to restore chemical coatings without removing the part and immersing it in a suitable bath, it is sometimes advisable to retain as much as possible of the original coating and, after local cleaning of the corroded areas, to apply one of the brush-on processes mentioned in paragraph 3.2.1, followed by organic coatings for subsequent protection. If the affected parts can be removed it is preferable to clean them completely and then re-protect by the original method.

(a) **Anodic Film.** Anodic films may be removed from aluminium alloys by the application of a solution of 10% sulphuric acid by volume in water plus 4% by weight of potassium fluoride (Leaflet **BL/7-1**).

(b) **Chromate Films.** Magnesium alloy parts which can be immersed should be cleaned as recommended in Leaflet **BL/7-3.** Local cleaning where immersion is not justified can be effected by swabbing with a solution of 100 g of chromic anhydride in 1 litre of water, with 14 drops of concentrated sulphuric acid added (2 oz of chromic anhydride in 1 pint of water, with 8 drops of concentrated sulphuric acid added). Where parts are not machined to fine tolerances, abrasion with fine 'wet' glass paper is permissible. The glass paper should be well wetted before use and care should be taken to prevent abrasive particles from remaining embedded in the surface. After rubbing down, the chromic-sulphuric acid solution should be applied and left on the surface for 2 or 3 minutes. The surface should finally be washed off with generous quantities of water and thoroughly dried.

(c) **Phosphate Films.** Phosphate films on steel are generally tenacious and are not easy to remove without immersion in acid solutions. To clean a small area of a part in situ, mechanical cleaning is usually most satisfactory, but when complete stripping is required a dip in dilute hydrochloric acid is recommended (see paragraph 3.2.2 (a)).

2.3.6 **Removing Metallic Coatings.** Coatings of cadmium, zinc, nickel, copper and tin are frequently used to protect steel aircraft parts; light alloys are usually protected by other methods. Immersion in an acid solution is usually the most effective method of removing a metallic coating, but it should be remembered that the removal of original deposits before replating is necessary only if the thickness of the deposit is critical. Mechanical cleaning is also used on occasions, particularly if the old deposit is flaking or peeling, but whichever method is used care should always be taken to avoid removing too much material, especially on parts to close dimensional tolerances.

2.4 **Removal of Corrosion Products.** Although the cleaning methods outlined in paragraphs 2.1 and 2.2 will remove superficial corrosion, surfaces which have been seriously attacked may still retain powdered oxides, salt crystals, etc., in pits and surface cavities. Chemicals suitable for cleaning each of the principal materials used in aircraft construction are available, but in some cases the chemicals will themselves cause corrosion if they penetrate faying surfaces. There is also evidence that some pickling and electro-chemical polishing techniques have an adverse effect on fatigue life and this aspect should receive serious consideration when selecting cleaning processes for parts which are subjected to fluctuating stresses in service. When doubt exists regarding the corrosive nature of certain chemicals, they should be tested as recommended in the following paragraph.

2.4.1 **Test for Cleaning Chemicals:**

(a) Prepare two panels of approximately 900 cm^2 (1 ft^2) area from material of the same specification as that to be treated.

(b) Apply the chemical to be tested to one face of each test piece and clamp the treated faces together.

(c) Expose the sandwiched test panels to alternate humid and dry atmospheric conditions in temperature conditions of 38°C (100°F). About 16 hours a day in humid conditions and 8 hours a day in dry conditions is recommended.

(d) After approximately 10 days the panels should be separated, rinsed and scrubbed, and examined for corrosion.

(e) The chemical will be acceptable if the metal is only lightly etched, but should not be used on the aircraft if it has caused deep pitting or intergranular corrosion of the test panels.

2.4.2 **Chemical Cleaning of Steel.** The removal of rust from steel by pickling in acid is often recommended, but it is not a practical method for in situ parts or welded steel tubular structures. A variety of proprietary rust removing solutions is available; most of them are solutions containing phosphoric acid, which, in addition to dissolving oxide film, partly inhibit the steel surface from further rusting. These solutions should always be applied as directed by their Manufacturers and in accordance with DEF STAN 03-2.

NOTE: Where parts are removable, the use of alkaline de-rusting solutions (with chelating reagents) is recommended.

2.4.3 **Chemical Cleaning of Aluminium Alloys.** Cleaning methods will vary according to the extent and location of the corrosion and the specification of the alloy concerned. General guidance on some recommended methods of cleaning are given below:

(a) Light corrosion deposits on aluminium alloys can often be wiped off with solvents or detergents which will leave a clean surface ready for pre-treatment and re-protection. The use of non-flammable preparations which are free of caustic substances is recommended. Swabbing with trichloroethylene is not advised because concentration of the fumes can be harmful and, in any case, the function of this chemical is to remove grease and not corrosion products. When solid particles are held in suspension in surface grease, they will be removed if the parts can be immersed in boiling trichloroethylene liquor but this is seldom a practical method of cleaning aircraft structural parts during maintenance. The use of an inhibited phosphate chemical brightener is also recommended.

(b) Heavy deposits on clad aluminium alloys should be removed chemically because mechanical cleaning will take off the protective cladding and expose a greater area of the core to subsequent corrosion. Preparations of thickened phosphoric acid are recommended for this purpose. All other material, including non-clad aluminium alloys, should be masked to prevent them being attacked by the acid. The corroded surface should then be brushed with the acid and, after an interval of not more than 3 minutes, scrubbed with a stiff non-metallic brush until all corrosion products are removed from pits, rivet heads, etc. The surface should then be rinsed off with generous quantities of water to remove all traces of remaining acid, and should then be thoroughly dried.

(c) Heavy deposits on non-clad aluminium alloys can be removed mechanically, i.e. by scraping, wet sanding with fine sandpaper or by light abrasion with aluminium wool (steel wool should not be used), provided dimensional tolerances are not exceeded. A general purpose surface wash which will also form a base for painting can be made up as follows:

Butyl alcohol	40%	By volume
Isopropyl alcohol	30%	
Phosphoric acid (85% solution)	10%	
Water	20%	

The alcoholic-phosphate wash should not be used on high strength wrought aluminium alloys such as DTD 5024, 5044, 5114 and 5124. On other alloys it should not be allowed to remain on the surface for longer than 15 minutes; in fact shorter times are desirable, particularly if the temperature is high. It should be applied with a soft cloth or bristle brush, washed off with water and the surface dried. As an alternative the proprietary 'brush on' solutions mentioned in paragraph 3.2.1 (b) may be used.

(d) The use of phosphoric acid corrosion removers is usually followed by the application of a chromate bearing conversion coating treatment such as the Alocrom series. These remove the final traces of corrosion and provide an improved surface condition for painting. The application of a 10% chromic anhydride solution for a few minutes is also efficacious, particularly on polished skins.

2.4.4 **Chemical Cleaning of Magnesium Alloys.** A solution of 10% by weight of chromic acid in distilled water with 0·1% sulphuric acid added is a satisfactory chemical for removing corrosion products from magnesium alloys. The solution should be brushed over the corroded area, working it well into pits and crevices, and should be left for about 5 minutes. It should then be rinsed off with clean water. Reference should be made to the requirements of specification DTD 911. (See paragraph 2.4.5 (b).)

2.4.5 **Note on Mechanical Cleaning.** Although mechanical cleaning is often necessary when preparing fabricated parts for anticorrosive treatments, its use should be restricted during maintenance work on complete aircraft.

(a) Steel and non-clad aluminium parts should be rubbed down with fine 'wet' glass paper in preference to emery papers. Wet sanding methods are more efficient, as water acts as a lubricant and permits a finer grain to be used; the rubbing should be in the direction of the working stress.

(b) Castings, forgings and extruded members can be hand scraped to blend out corrosion pits. Steel carbide tipped scrapers are recommended and should be used so that pits are transformed into saucer-shaped depressions which relieve stress concentration. Afterwards the depth and area of the depressions, and the total number per unit area of surface, should be assessed to ensure that the material has not been unduly weakened.

(c) Light abrasion is sometimes helpful in removing heavy deposits from skin panels. Pumice powder applied with a solvent-moistened cloth is generally satisfactory. If clad aluminium alloy sheet is cleaned by this method, a simple test with caustic soda should be made afterwards to determine whether sufficient aluminium remains to protect the alloy core. If the surface layer of pure aluminium has been rubbed off, a spot of dilute caustic soda solution will turn the surface black. After making the test the caustic soda should be thoroughly washed off.

NOTE: After testing and washing, a 10% solution of chromic anhydride is recommended to neutralise any caustic soda and passivate the etched surface.

3 TREATMENT OF COMPONENTS

The information in this paragraph relates to component parts which can be removed for immersion treatments.

3.1 **Degreasing.** The trichloroethylene vapour method (Leaflet **BL/6–8**) is satisfactory for most aircraft materials, but in cases of heavy contamination the following alternatives may be used:

3.1.1 **Aluminium Alloys.** Mild alkaline baths effectively remove grease from aluminium but the baths should be inhibited to limit attack on the metal. A satisfactory bath can be prepared from a 4-5% w/v (36 to 48g/litre (6 to 8oz/gal)) of a mixture of crystalline trisodium phosphate and sodium metasilicate in proportion between 2: 1 and 1 : 2 w/w (if anhydrous trisodium phosphate is used, the proportion will lie between 1 : 1 and 1 : 4) with or without a suitable wetting agent.

3.1.2 **Steels.** The immersion pickling processes described in paragraph 3.2 will remove residual grease as well as rust, scale and other surface dirt. However, cleaning with trichloroethylene or other solvents is necessary prior to pickling.

3.1.3 **Magnesium Alloys.** Instructions for cleaning by immersion in caustic soda or chromic acid are given in Leaflet **BL/7—3.** Sometimes pickling in a 5 to 10% solution of concentrated nitric acid in water is recommended for castings and parts which are not machined to close tolerances. The electrolytic-fluoride process mentioned in Leaflet **BL/4—3** will also remove corrosion products and has the further advantage that the fluoride film created on the surface is to a certain degree corrosion-resistant.

3.2 **Pickling Processes.** The following immersion processes are of value in preparing metal parts for subsequent protection treatment. Their action is generally twofold; they remove corrosion products and the residue of original treatments, and to some degree they etch the treated surfaces to provide a better key for organic protectives.

3.2.1 **Aluminium Alloys.** Treatments should be selected to suit the nature of the parts and to prepare them for the finish specified in the drawings or repair scheme. Some suitable processes for the preparation of clad sheet for painting are described in DEF STAN 03-2; they are for use as an alternative to etch primers. When proprietary processes are used the Manufacturer's instructions should be carefully followed to ensure that the fatigue resistance of the metal will not be lowered.

(a) **Chromic-sulphuric Acid Process.** After degreasing and rinsing the parts, they should be immersed for approximately 20 minutes in one of the alternative solutions given below. The temperature of the solutions should be maintained between 43 to 65°C (110 to 150°F). This process should not be used for spotwelded or riveted assemblies but is satisfactory for castings, forgings, extrusions, etc., provided they are thoroughly rinsed and dried afterwards.

Solution 1.	Sulphuric acid (Sp. Gr. 1·84)	15% by volume
	Chromic acid (CrO_3)	5% by weight
	Water	Remainder
Solution 2.	Sulphuric acid (Sp. Gr. 1·84)	15% by volume
	Sodium bichromate	7½% by weight
	Water	Remainder

(b) **Phosphoric Acid Processes.** The constituents of an alcoholic-phosphate wash are given in paragraph 2.4.3 (c); this solution can be used in a mild steel tank to pickle aluminium alloy components. A variety of proprietary solutions containing phosphoric acid are also available; some of these build up a thin phosphate film which provides a good base for painting. However, a distinction should be made between phosphoric acid processes which create phosphate films and those which only clean and etch. The proprietary cleaning processes listed in DTD 900 include Titanine metal degreasing paste, Jenolite AKSI etching compound and the ICI Deoxidine process 202. These are materials which can be brushed over aluminium assemblies including parts which are riveted together, but care must be taken to wash all surfaces thoroughly after treatment, drying carefully after washing. Deoxidine 170 is a hot dip process which is suitable for both steel and aluminium alloy; another treatment not covered by the specification is Deoxidine 125 which can be applied to both these metals by fold dipping or by brushing. If any of these treatments are applied by brush, all crevices and seams should be blown out with compressed air before proceeding to paint the treated area. Painting should follow promptly since none of these treatments builds a resistant film.

(c) **Chromic-phosphoric Acid Process.** After degreasing and rinsing the parts, if specified in the Maintenance Manual or other appropriate instructions, they should be immersed in a near-boiling aqueous solution as follows, for 20 minutes, if of sheet material, or up to 1 hour if cast.

Chromic acid (CrO_3)	0·75-1·0% w/v (7·4-9·9 g/ litre (1·2-1·6 oz/gal))
Phosphoric acid (Sp. Gr. 1·75)	0·5-0·75% v/v (5-7·4 cm^3/ litre (0·8-1·2 fl.oz/gal))

NOTE: The use of Deoxidine 624 followed by Alocrom 1200 is recommended. Alocrom 1200 or other similar conversion coating treatment should be used after pickling processes (particularly phosphoric acid) prior to painting, except when etch or wash primers are to be used.

3.2.2 **Steels.** The chemical treatments for steel can be divided into two main groups. Pickling is a process in which acids are used to remove rust and scale so that a chemically clean surface is produced which requires immediate protection to safeguard it from further corrosion. In contrast, phosphoric acid processes, in addition to de-rusting, coat steel surfaces with insoluble phosphate films which confer a measure of corrosion protection and form a good base for paint.

NOTE: Phosphating processes should only be used on aircraft parts if cadmium plating is impracticable.

(a) **Pickling Solutions.** Information on the pickling of steels is given in DEF STAN 03-2, which specifies solutions of 10% hydrochloric acid in water or 10% sulphuric acid in water. Since immersion in these solutions causes hydrogen absorption, heat-treated steels of more than 1004 MN/m^2 (65 tonf/in^2) ultimate tensile stress (UTS) should only be pickled by the electrolytic method given in paragraph (b) below. The danger of blistering and embrittlement of other steels due to hydrogen entering the metal can be reduced by adding inhibitors (such as quinoline ethiodide) to the acid, but if inhibitors or wetting agents are used the parts should have a final dip for not more than 2 minutes in an acid solution free of such substances. After immersing parts in dilute acid solutions they should be rinsed in clean water and dried. Limited brittleness can be reduced by heat treating the steel at 150 to 200°C.

(b) **Electrolytic Pickling.** The advantages of this method are twofold. Chemical cleaning is assisted by the evolution of oxygen on the surface of the metal and, as hydrogen is only produced on the cathode, no embrittlement occurs. An electrical bath is required containing a solution of 30% by volume of concentrated sulphuric acid in water, to each litre of which can be added 18 g of potassium dichromate (3 oz/gal). With the part as the anode, a current density of 1000 amps/m^2 (100 amps/ft^2) should be applied for approximately 5 minutes, after which the part should be rinsed in clean water and thoroughly dried.

(c) **Phosphating Processes.** Certain commercial phosphoric acid treatments, such as Waterisation, Jenolising and Bonderising, are approved for aircraft use by the provisions of DTD 900. These processes should be considered as foundation treatments for painting and not as reliable anti-corrosive measures in themselves. To obtain satisfactory phosphate films they should be applied in accordance with the instructions issued by their Manufacturers.

NOTE: Some laboratories state that electrolytic pickling of steels does produce embrittlement in high tensile steels, and that heat treatment is necessary afterwards for steels above 1004 MN/m^2 65 tonf/in^2) UTS. If plating is to be carried out, the heat treatment should follow that process as soon as possible and, in any event, within 2 hours.

4 ASSESSMENT OF CORROSION DAMAGE After removing paint, grease and corrosion products, the affected parts should be examined to determine whether their strength has been lessened beyond permissible limits. Pitting may cause local stress concentrations which may seriously impair both the static and the dynamic strength of thin sections whilst surface corrosion, without causing pitting, can lower the fatigue strength of load-bearing members. Cleaning operations often cause an appreciable reduction in cross-sectional area which must also be considered when evaluating the decrease of strength.

NOTE: A corrosive attack on a structural member will cause a reduction in strength out of all proportion to the reduction in thickness of the member; this should be borne in mind at all times when assessing corrosion damage and particularly when light gauge construction is involved such as a pressurised skin structure.

4.1 **Skin Panels.** Corrosion damage to aircraft skins should be classified as negligible or repairable according to the extent, depth, loading and location of the damage. It is not possible to give a general rule for classification based on the percentage reduction of skin gauge or the number of pits per unit area, as the load distribution through the affected panels must be considered. It is therefore essential to consult the approved repair scheme for the aircraft concerned. Some general guidance on the assessment and rectification of damage is given in the following paragraphs. It must be appreciated, however, that all previous corrosion rectifications must be taken into consideration.

4.1.1 If no pronounced pitting or roughening of the skin is evident after the removal of corrosion products, it is usually satisfactory to re-protect the part by applying the appropriate finishing scheme (see Leaflet **BL/4-3**).

4.1.2 Skin panels which have a rough and pitted surface after the corrosion products have been removed should be smoothed down with fine grade wetted sandpaper. The minimum reduction of cross-sectional area consistent with the blending out of jagged pits should be the aim. After smoothing, the minimum skin thickness in the affected region should be computed by measuring the depths of the deepest depressions; a method of mounting a dial test indicator for use as a depth gauge is illustrated in Figure 1.

NOTE: Where access is difficult, radiological and/or ultrasonic examination techniques (see Leaflets **BL/8-3** and **BL/8-4**) are often prescribed to determine the presence or extent of a corrosive attack. In some instances, however, such as at faying surfaces of stringers to skin panels, dismantling of specified parts of the structure has been found necessary as the only means of ensuring adequate inspection.

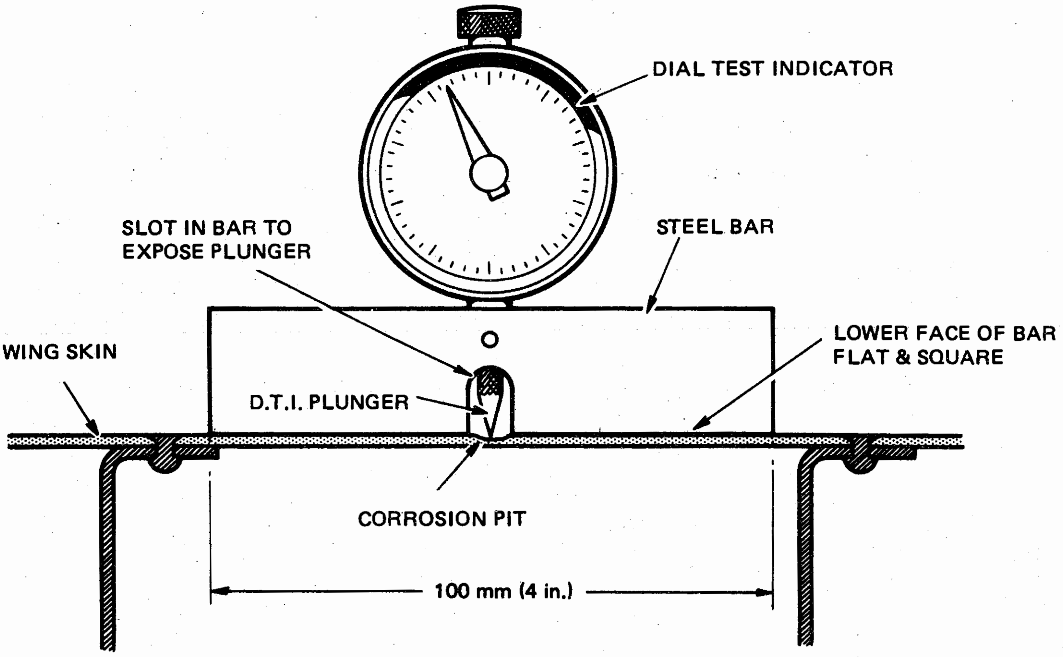

Figure 1 ASSESSMENT OF SKIN PANEL CORROSION

4.1.3 If the damage exceeds the general limits specified by the Manufacturer as negligible but is not thought to be of such a severe nature as to warrant renewal of the whole panel affected, the Manufacturer may, in some instances, issue a repair scheme whereby the original strength of the panel can be restored by the addition of local reinforcements.

4.1.4 If the smoothing down of corrosion damage would reduce the thickness of skin panels or similar components beyond permissible limits, they should be renewed. During removal the condition of rivets and faying surfaces should be examined. If these show signs of corrosion, repairs will be necessary over a wider area than that indicated by the extent of the surface damage.

NOTE: For guidance on repairs to metal aircraft structures reference should be made to Leaflet **AL/7-14.**

4.2 **Load-bearing Members.** The effects of corrosion on the strength of main load-bearing members can be serious. It has been clearly established that the fatigue life of wing spars can be drastically shortened by corrosive attack and these members should therefore receive the most careful attention during periodic inspections.

4.2.1 The inspection of spars is often rendered difficult because of limited access to the interior of the wing structure and because portions of the spar are obscured by electrical cable installations, fuel pipes, control mechanisms, etc. Special optical aids to facilitate inspection such as those outlined in Leaflet **AL/7-13** should be used to detect corrosion and, after its removal, to assess the damage it has caused. Areas affected by pitting should be checked for cracks by the penetrant dye method described in Leaflet **BL/8-2.**

4.2.2 Serious cases of spar corrosion should be reported to the Manufacturer of the aircraft. If minor corrosion is discovered, rectification should be possible in accordance with the approved repair manual for the aircraft.

4.2.3 When specified in the appropriate publication or at other times at the discretion of the inspector, a selection of the main assembly bolts should be removed and examined for signs of corrosion. The aircraft structure must be adequately supported to prevent strain and distortion before the bolts are removed. Before replacing assembly bolts they should be magna-flux tested (Leaflet **BL/8-5**) and the bolt holes should be carefully inspected for evidence of attack on the surrounding material. If cadmium has been removed from the bolts, they should be replated before replacement (Leaflet **BL/7-2**), and at all times jointing compound should be applied immediately before insertion, in accordance with the appropriate instructions (see also Leaflet **AL/7-8**).

NOTE: The inspection of bolt holes is a matter of great importance but often of unusual difficulty. Pits and cracks tend to be concealed by corrosion products, which are forced into them as the bolt is extracted. If the hole is reamed before inspection, the reaming action tends to close the edges of cracks; the hole should therefore be inspected both before and after reaming. In some cases satisfactory results may be obtained by cleaning the hole with a round bristle brush using the mixture of white spirit and naphtha recommended in paragraph 2.1. After cleaning it may be possible to adapt the penetrant dye or fluorescent method of detection (Leaflets **BL/8-2** and **BL/8-7**) to the particular job, using an endoscope or a light probe (Leaflet **AL/7-13**) in the bore of the hole. The eddy current method of examining bolt holes is effective and is often used where inspection by optical means is impracticable.

4.3 **Tubular Members.** Welded steel or aluminium alloy tubes used in aircraft construction are usually thin-walled and can therefore be seriously weakened by corrosion. Although external corrosion can be seen during inspection, internal corrosion may remain undetected until the tube is so weakened that failure occurs. For this reason it is essential that tubes are protected internally during assembly and sealed to prevent accumulation of moisture. Open-ended tubes should be protected internally and externally by the same method.

4.3.1 There is no completely reliable method of determining whether a sealed tube is corroded internally, short of cutting it open, but ultrasonic and radiological methods of examination will give an indication of reduction of thickness.

4.3.2 During assembly or after repair the interior of sealed tubes should be flushed with a protective material and reference should be made to the Manufacturer for the appropriate one to be used. Some such corrosion inhibitors are hot linseed oil, lanolin or zinc chromate pigmented lanolin to specification DTD 279 being particularly suitable. The flushing liquid is normally introduced through small holes, for which the appropriate design approval should first be obtained, drilled in the tubing. Surplus liquid should be drained off through suitable drain holes. It may be possible as an alternative, to remove an existing bolt or rivet ensuring that the hole is not enlarged. When sufficient liquid has been introduced to give a good coating, the holes should be plugged to exclude air or moisture.

NOTES: (1) If, for any reason, the above procedure cannot be carried out, the danger of corrosion will be greatly reduced if the enclosed air is dry and the tube is effectively sealed against the ingress of moisture. The interiors of steel tubes can be further safeguarded by the introduction of a Vapour Phase Inhibitor. Marketed in powder form, vapour inhibitors consist of stable organic nitric compounds which release corrosion-inhibiting vapour at a slow rate. The vapour will prevent corrosion even when oxygen and moisture are both present.

(2) During maintenance and overhaul, radiological methods of examination (Leaflet **BL/8-4**) are sometimes used for the detection of damage in tubes of relatively thin cross section. This method will show changes in sectional thickness when corrosion is present and, with the correct technique, some idea of the depth of the corrosive attack can be obtained. Similarly, in some instances where tubular members are made of heavy gauge, ultrasonic methods of examination will give an indication of local reductions in thickness (Leaflet **BL/8-3**).

4.4 **General.** Components which are not part of the structure can usually be removed for anti-corrosive treatment. If items such as pumps, valves and electrical equipment are found to be corroded, rectification appropriate to the particular material and its duty should be made. Reference to the relevant Manufacturer's publications for the aircraft concerned should be made at all times. Some points of special interest are listed below.

4.4.1 Doped fabrics in contact with painted metal surfaces sometimes cause the paint to deteriorate with the result that the metal is attacked. The metal should be protected by the application of a dope-resisting paint on top of the normal finish.

4.4.2 A method of protecting seaplane floats is to tie bags of potassium or sodium dichromate to the keelson so that the dichromate permeates the bilge water.

4.4.3 Light alloy tanks containing leaded fuels should normally be protected by corrosion inhibitor cartridges. 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.

4.4.4 When locking wire is used, it should be of a material which will not cause electro-chemical reaction with the part locked.

4.4.5 Control cables should be protected after installation, and at intervals, by applications of rust-preventing compounds. Lanolin-resin compounds or preparations containing zinc chromates are sometimes recommended; these should be diluted and applied so as to ensure penetration of the compound between the strands of the cable whilst avoiding an excess accumulation which would cause stickiness of controls in fairleads and pulleys.

NOTE: British Standards W9 and W11 call for a lubricant to be applied during the spinning of cables. It is therefore important, when cleaning these cables, not to wash out the lubricant by saturating the cables with a grease solvent.

4.4.6 During assembly and repair, dissimilar metals should be insulated from each other unless there are overriding structural and functional considerations. Corrosion-inhibiting sealing compounds should be applied wet between all faying surfaces immediately prior to assembly: solutions containing zinc or barium chromate are generally used. Most of the proprietary materials and processes are to be found in specification DTD 900. The compound should be applied in sufficient quantities to cover all contacting faces and to cause a small quantity to be squeezed out at the boundaries to form sealing fillets. Where special compounds are used for particular purposes. e.g. to seal pressure cabins or integral fuel tanks, they should be used to insulate dissimilar metals in addition to forming a seal.

NOTE: Unsatisfactory results will be obtained if inhibiting jointing compounds are kept in open containers which allow the compound to become semi-dry before application. This trouble can be avoided if the compound is supplied in squeeze-tubes, from which it can be directly applied to the joint.

4.4.7 Metal parts in contact with wood should be treated with the prescribed compound before assembly, in order to prevent corrosion due to moisture in the wood.

4.5 **Protective Treatments.** Metal surfaces (on other than stainless steels and un-alloyed titanium) should never be left unprotected after cleaning or repair. Where practicable the original protective treatment should be restored. In other cases alternative treatments suitable for application during maintenance work may be authorised. General information on the corrosion-proofing and finishing of aircraft is given in Leaflet **BL/4-3**, whilst details of some of the particular protective treatments are given in the BL/7 series of Leaflets, and specifications DTD 900, 903, 904, 905, 909 and 911, DEF STAN 03-2 and 03-7, BS 2569 Part 1 and 2, BS 4921 and Specification DEF 151.

BL/4-3

Issue 3.

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BASIC

MATERIALS

CORROSION—METHODS OF PROTECTION

1 INTRODUCTION

1.1 This Leaflet gives guidance on the selection and application of protective treatments to safeguard aircraft from corrosion. It should be read in conjunction with Leaflets **BL/4-1** and **BL/4-2,** which give general information on the control and rectification of corrosion, and with the relevant leaflets of Section BL/7, which give details of some of the treatments mentioned in this Leaflet.

1.2 When re-protecting aircraft, reference must be made to the appropriate Manufacturer's publications for guidance on the anti-corrosive treatments specified for the aircraft concerned. Reference should also be made to the latest issues of the relevant British Standards and Ministry of Defence DTD Specifications when these are quoted.

2 PREVENTION OF CORROSION Protection against corrosion can be provided in a number of ways. Some of the principles involved are briefly summarised in the following paragraphs.

2.1 **Choice of Metal.** Certain metals and alloys have a high natural resistance to corrosion. This applies to the noble metals because they have a low affinity for oxygen and other non-metallic elements, but the resistant materials which are used in aircraft construction, e.g. stainless steel and aluminium, owe their properties to thin films of oxides which protect the metal from further attack. However, because of strength or weight considerations, many aircraft parts cannot be made of 'self-protecting' material and hence require anti-corrosive treatment.

2.2 **Passivity.** In certain conditions metals and alloys commence to corrode and the initial products of corrosion form protective films which limit further attack. Natural passivity is sufficient protection for pure aluminium and the stainless steels, but passivity has to be produced under controlled conditions to be of value for aluminium alloys. The anodic treatment described in Leaflet **BL/7-1** is a form of artificial passivation.

2.3 **Surface Finish.** The oxide films on non-stainless steels do not become passive but corrosion-resistance can often be greatly increased by careful attention to mechanical finish. Thus some internal engine parts are highly polished but otherwise are only protected by a coat of clear varnish.

2.4 **Chemical Inhibition.** One of the most widely used methods of protection is to treat the metal with chemicals which inhibit or stifle corrosion and so artificially induce a form of passivity. The phosphate process for steels and the chromate and fluoride treatment for magnesium alloys are inhibiting treatments. Paints and primers usually contain inhibiting substances to increase the effectiveness of the protection they offer. It should be appreciated, however, that the inhibiting treatments are temporary and that the full treatment will include oil or paint films (paragraph 2.6).

2.5 **Sacrificial Protection.** When two metals of different electric potential are in close contact, the elements of a voltaic cell are established and the metal which is anodic to the other may be preferentially attacked. This principle is often deliberately applied to protect constructional materials. For example, cadmium and aluminium coatings protect steel because these metals are anodic to steel; at the same time the protection they render is long-lasting because they corrode at a much slower rate than steel. Similar protection is extended to aluminium-alloy sheet when it is clad by surface coats of pure aluminium; this protection is effective even at the sheared edges and where holes are drilled.

2.6 **Mechanical Protection.** Corrosion can be prevented by excluding water, oxygen and corrosive chemicals from the surface of the metal. This form of protection is the basis of most organic coatings, such as varnishes, paints and enamels, which are applied on top of inhibitive priming coats. To be effective the coats should be as watertight as possible, but, since even the best paint coats only delay rather than prevent the ingress of water, periodic re-protection is essential. Metallic coatings applied by spraying, dipping or electro-deposition may also give satisfactory mechanical protection.

3 TREATMENT OF AIRCRAFT PARTS It is the responsibility of Approved Design Organisations to specify the forms of protection to be used during the manufacture of each particular type of aircraft. During the operational life of the aircraft the original treatment should be renewed when necessary, but where this is impracticable a suitable alternative method should be specified.

3.1 **Chemical and Electro-chemical Treatments.** Treatments in this category are those which strengthen the natural oxide film of the base material or which convert the metal surface chemically to a protective coating of phosphate, chromate, etc. The most satisfactory results are usually obtained by immersion treatments but where these are impracticable brush-on applications can often be used. In the following paragraphs the standard immersion treatments for the principal aircraft constructional materials are given, together with brush-on substitutes which can be used for repair or in emergencies.

3.1.1 **Steel.** The majority of chemical treatments for steel involve the formation of phosphate films and to a certain degree are covered in Leaflet **BL/4-2.** Proprietary immersion and brush-on applications, if approved under the provision of the latest issue of DTD 900, can be used to inhibit corrosion and to form a base for painting steel parts which cannot be protected by metallic coatings. Certain processes can be followed by immersion in mineral oil to render them suitable for moving parts; the phosphate coating absorbs the oil and provides a wear-resisting surface. Chemical treatments do not provide adequate protection for steel if used alone; further corrosion-proofing, e.g. painting, is usually specified.

3.1.2 **Aluminium and Aluminium Alloys.** The most satisfactory chemical treatment for these materials is anodic oxidation (Leaflet **BL/7-1**). Unless clad with pure aluminium, the majority of aluminium alloy parts are anodised. Anodised structural components usually receive further protection from priming and paint coats.

(a) There are a number of proprietary processes which increase corrosion resistance and improve the adhesion of paint to aluminium and aluminium alloys. They are mostly simple chemical processes in which the parts are immersed in hot solutions of salts for periods of up to 10 minutes. It is not essential to apply paint immediately after the application of such processes as Alocrom or Walterisation L, as these render the surface passive; on the other hand it is undesirable to leave the treated surfaces so long that they become dirty before being painted.

NOTE: Processes which merely pickle the surface of aluminium-alloys, such as the Chromic-Sulphuric acid treatment of Specification DEF 130 and the Deoxidine treatments, do not protect against corrosion and should be followed immediately by priming and painting.

(b) Films can be produced by the application of pastes to parts in situ, e.g. Alocrom 1200; they are not as satisfactory as films produced by immersion treatments but are useful for items not exposed to weathering or abrasion.

3.1.3 **Magnesium Alloys.** Some chemical treatments for magnesium alloys are covered in Leaflet **BL/7-3**. The immersion processes given in that leaflet are all chromating processes but local repairs to protective films can be effected by the Alocrom 1200 chromate conversion by swab method. Another method of protecting these alloys is by the electrolytic fluoride method known as "Fluoridising". This involves anodising the components in a solution of ammonium fluoride. It is a particularly effective method for the removal of moulding contaminants and for restoring corrosion resistance which may have been reduced by processes such as shot or grit blasting. The process consists of applying a.c. current when the items are immersed in the solution, the voltage being gradually increased to a value of 100 volts. The current falls proportionately as impurities are removed from the surface of the magnesium alloy and a thin coating of magnesium fluoride is formed. This coating has a protective value about equal to that of a chromate film and forms a good paint base. To obtain satisfactory results, full details of the process should be obtained from the Manufacturer.

3.1.4 **Zinc Coated Components.** Metallic coatings of zinc are sometimes used to protect steel parts, but zinc coatings tend to corrode rapidly unless rendered passive. After plating with zinc, the chromate passivation process described in DTD 923 should be employed.

3.2 **Metallic Coatings.** The protection of one metal by the application of a surface coating of another of greater corrosion resistance is common practice. Thus, aluminium-alloy sheet used in aircraft construction is usually clad on both faces with thin layers of pure aluminium rolled on during manufacture. Steel is protected by a greater variety of methods, the more important of which are summarised below.

3.2.1 **Cadmium Plating.** The electro-deposition of cadmium (Leaflet **BL/7-2**) provides the most satisfactory form of protection for AGS and other parts of non-stainless steel. It is the standard anti-corrosive treatment for streamline wires, tie-rods and similar parts which are not usually painted. Where steel bolts and other parts are in close contact with light alloys, cadmium plating greatly reduces the danger of corrosion resulting from the proximity of dissimilar metals; it has been found that this is so even when the cadmium coat is scored or partially rubbed off. Cadmium plating can be applied to close dimensional limits and is suitable for the protection of closely fitting attachment bolts. The relevant British Standards for cadmium plated bolts with close tolerance shanks are A59 and A111, and for shear bolts A60 and A112.

NOTES: (1) It should not be assumed that stainless steels in contact with aluminium alloys are unlikely to promote intergranular corrosion or corrosion fatigue. For this reason it is advisable that they too should be cadmium plated, but a special technique is essential to ensure good adhesion of the cadmium. A plating technique that is suitable for some specifications of stainless steel involves degreasing, anodic pickling in dilute sulphuric acid (Leaflet **BL/4-2**), the deposition of a preliminary coating of nickel and, finally, cadmium plating by the usual method.

(2) Further protection by painting is not usually necessary on interior cadmium plated parts but, if it is specified, the cadmium coating should first be passivated by the process given in Specification DEF 130 or an etch primer should be used.

3.2.2 **Nickel and Chromium Plating.** These two metals are electrically deposited in a similar manner to cadmium; nickel-plating is cathodic to steel but will give good corrosion resistance if the coating is uniform and free from discontinuities. It is used for some turbine parts which are subjected to fairly high temperatures, and for the protection of many springs. Chromium is sometimes applied directly to the steel parts of aircraft as an anti-corrosive treatment and sometimes is deposited on top of nickel plating to improve appearance. Chromium plating is also used to resist wear in some engine cylinders, landing-gear shock-struts, jack rods, etc.

3.2.3 **Metallising.** Aluminium, zinc, cadmium and certain other metals can be sprayed directly on to steel from special pistols. The metal is fed into the pistol as a wire or a powder and is melted by an oxy-acetylene flame. Compressed air then blows it in the form of tiny molten globules on to the surface to be coated, where it solidifies. Spray coats of aluminium are applied to engine bearers, steel tube assemblies, combustion chambers, etc. Some of these items are afterwards painted but this is not always necessary.

3.2.4 **Flame Plating.** This process, similar to some metallising, is carried out on many aircraft parts which are subject to wear by fretting, particularly engine components such as compressor and impeller blades, combustion chamber parts and seals. It is sometimes applied to hydraulic pumps and motors. Briefly, the process consists of a charge of powdered tungsten carbide, chromium carbide or similar hard material, suspended in an oxygen/acetylene mixture in the breech of a special gun. The mixture is detonated and the particles become plastic; they are then blasted on to the areas being coated. This is repeated until the entire surface is coated to the required depth. Stripping of worn coatings can be carried out and new coatings applied, and thus the life of expensive components is considerably extended.

3.2.5 **Powder Processes.** Metal coatings of zinc and aluminium can be produced by packing steel parts, after sand blasting, in suitable mixtures containing the appropriate metal and heating them in sealed containers to specified temperatures. The application of aluminium by this method is known as Calorising. Sheradising, covered by BS 4921, creates a coat of zinc-iron alloy on steel parts.

3.2.6 **Replating Local Areas.** Local repairs to damaged metallic plating, and the deposition of metals in places where accessibility is limited, can be accomplished by certain plating processes without immersion in a plating bath. The part to be plated should be made the cathode by connecting it to a d.c. power unit. The electrolyte is brushed over the metal surface by an absorbent pad attached to the end of a graphite anode; the anode, which is called a "tampon", is air or water-cooled according to size. Plating solutions and current densities should be selected according to the Manufacturer's recommendations. Cadmium, copper, zinc, tin, etc., can be deposited very rapidly by this method.

3.3 **Organic Coatings.** Paints, varnishes and enamels protect metals by inhibition, by mechanical exclusion of corrosion influence, or by a combination of both these methods. Before application, the metal surfaces should be cleaned and pre-treated to provide a good key for the paint. General guidance on pre-treatment is given in Leaflet **BL/4-2**; mechanical roughening, chemical etching, chemical film formation or preliminary deposition of metal coating should be in accordance with approved practice for the materials concerned. Reference should always be made to the relevant aircraft Manufacturer for details of the organic coating scheme to be applied to a particular aircraft.

3.3.1 **Priming Coats.** Most aircraft painting schemes commence with the application of a primer containing an inhibiting chemical such as zinc chromate. The majority of primers are air drying, but when a stove enamel finish is specified the priming coat is also stoved (BS X31). Primers can be directly applied by brush or spray to aircraft parts in situ, but dipping is sometimes preferred for detachable items. Primers to suit the wide range of finishing schemes covered by the Ministry of Defence Process Specifications are supplied as proprietary products; care should be taken to ensure that the Specification selected is appropriate to the particular job. When painting certain aluminium alloy structures it is sometimes advantageous to use etching primers which obviate the need for preliminary etching by Deoxidine and similar chemicals. General guidance on finishing schemes is given in paragraphs 5 and 6.

3.3.2 **Cellulose Finishes.** Cellulose finishes are specified for many individual components of civil aircraft as well as for the exterior finishing of metal-skinned aircraft, as they give finishes which have good adhesion and resistance to weathering. Although the best results are obtained by spraying on top of a suitable primer, one-coat applications direct to pre-treated aluminium or aluminium-clad alloys have sometimes been used.

3.3.3 **Synthetic Finishes.** A number of external finishing schemes for the metal surfaces of aircraft are based on the use of pigmented oil varnishes or pigmented synthetic resin finishes. The relevant British Standard is BS X28 and the Ministry of Defence Specification is DEF 1044. The majority of finishing schemes are two-coat treatments; the pre-treated metal surface is given a brush or spray coat of the primer applicable to the scheme and, after the primer has dried, the finishing coat is applied by spray. Synthetic finishes should only be thinned with approved thinners (DTD 96); thinners for cellulose paints and dopes are generally unsuitable. As a general rule priming coats require a longer drying period for synthetic finishes than for cellulose finishes.

3.3.4 **Lanolin-resin Finishes.** Lanolin-resin preparations to Specifications DTD 279 and 633 are brush, spray or dip treatments which remain soft for considerable periods and are only occasionally applied to parts of aircraft in service. They have a limited application for the protection of marine aircraft.

DTD 420 covers a range of matt pigmented lanolin-resin finishes suitable for use on metal surfaces exposed to sea water. Generally, two-coat finishes applied by brush or spray are recommended.

3.3.5 **Stoving Finishes.** Stoving enamels generally have a much higher degree of resistance to abrasion than air-drying finishes and are therefore used for some power-plant components and certain airframe parts which are not adversely affected by stoving temperatures. For maximum durability, two-coat schemes are recommended. High temperature stoving finishes, such as those covered by DTD 56, generally consist of two coats of enamel, each of which is baked separately; low temperature finishes, whether proprietary or to BS X31, usually consist of a preliminary priming coat which is baked first, followed by application of the enamel and further stoving.

NOTE: There are some kinds of enamel, e.g. the synthetic glossy black enamel specified in DEF 1044, which can be either air dried or stoved. The principal advantage of stoving is that it shortens the drying time.

3.3.6 **Epoxide Finishes.** Interior and exterior protective finishing schemes of the cold curing epoxide type are now frequently used. There are three schemes: Scheme 1 consists of etch primer and finish; Scheme 2 consists of etch primer, filler and finish or epoxy primer, filler and finish; Scheme 3 consists of etch primer, epoxy primer and finish. Details of the schemes are covered in Specification DTD 5555 whilst the requirements for the materials are detailed in Specification DTD 5567.

3.4 **Special Fuel Tank Treatments.** Special sealing and anti-corrosion treatments are often given to fuel tanks and integral fuel tank structures. In certain instances where there are undrainable areas, these are filled with a light 'void' filler, to prevent the formation of stagnant water pockets in which micro-biological growths can form. Basic structural components are chemically treated, e.g. Alocrom 1200, etc., and in assembly all joints are inter-layed with a sealant such as Thiokol PR 1422. After assembly, all joints are brush-treated with rubber sealant compound such as Buna-N (EC 776) and PR 1005L, and some tanks are then given a final 'slushing' treatment with Buna-N in the tank, to impart a uniform protective film on all inner surfaces. The tank (or structural assembly) is slowly rotated in a special rig, and this ensures that the protective film is free from pinholes. Reference should always be made to the relevant aircraft Manufacturer for the appropriate treatment for any particular aircraft.

4 TESTING PROTECTIVE TREATMENTS The efficacy of a protective treatment depends on its nature, its adhesion to the surface of the basis metal, its thickness, its uniformity and its chemical stability. In many cases the only guarantee of satisfactory protection lies in close control of pre-treatment and application of finish plus the general appearance of the completed treatment, but sometimes it is necessary to test the treated part, or an equivalent test piece, to ensure that the specified properties have been obtained. It is, therefore, advisable to consult the relevant aircraft Manufacturer for the preferred methods.

4.1 **Chemical Treatments.** There is no simple and reliable test for chemically produced films, since they are usually too thin to permit measurement of the thickness of deposits by checking the gauge. Parts on which phosphate films have been produced should be inspected for colour; a finely crystalline grey surface is required, as coarse or sparkling films indicate inadequate cleaning or wrong bath composition. Chromate films on magnesium alloys are judged by their colour, as explained in Leaflet **BL/7-3**.

4.2 **Anodic Treatment for Aluminium Alloys.** Leaflet **BL/7-1** gives two practical methods of testing anodic films, i.e. the methyl violet test for sealing and the electrical potential test. The average thickness of anodic films can be checked by the method given in British Standard 1615, in which a test piece with a surface area of not less than 32 cm² (5 in²) is anodised and then stripped in a boiling solution of phosphoric acid and chromic acid in distilled water. The test piece should be immersed until constant weight is obtained, the loss of weight being taken as the weight of the anodic film.

NOTE: Eddy current instruments are available and can be utilised to gauge anodic films.

4.3 **Coating Thickness Measurement.** The thickness of conducting or non-conducting coating on ferrous or non-ferrous bases can be measured using basic eddy current methods (see Leaflet **BL/8-8**), although measurement becomes difficult where the conductivity of the coating and base metal are similar. When measuring thin coatings it is recommended that equipment designed specially for coating thickness measurement should be used.

4.4 **Electro-plated Coatings.** The British Non-Ferrous Metal Research Association has devised a standard test for the inspection of electro-deposited metallic coatings; the BNF Jet Test is for local thickness measurements and has the advantage over other chemical methods in that it gives the thickness at any desired point. An adhesion test for the detection of local non-adherence of metallic coatings is given in BS 1224, Appendix C, and is summarised in paragraph 4.4.2.

4.4.1 **The BNF Jet Test.** The apparatus for conducting this test is illustrated in Figure 1. The separating funnel should be filled with a reagent solution appropriate to the nature of the metal; suitable solutions for testing cadmium and zinc coatings are given below. The test should be made as follows:

(a) The article to be tested should be clamped so that the surface under test is at an angle of about 45° to the horizontal and about 6 mm (¼ in) below the tip of the jet.

(b) Jet Test solutions for cadmium and zinc coatings are:

	Cadmium	**Zinc**
Ammonium nitrate	17·5 g	70 g
N/1 Hydrochloric acid..	17·5 ml	70 ml
Distilled water to produce	1 litre	1 litre

(c) The tap should be opened and, simultaneously, a stop-clock should be started. At the end of 5 to 10 seconds, the tap should be closed and the clock stopped simultaneously and, without moving the specimen, the test piece should be examined for penetration.

(d) The process in (c) should be repeated until the first sign of penetration is seen below the jet. The total time of impingement is taken as a guide for a further test in which the reagent is allowed to run continuously until the end-point is nearly reached.

(e) The temperature of the solution and the total time for penetration are the data from which the thickness is calculated. The time required for a particular penetration at the temperature of the test should be obtained from curves supplied by the Manufacturer of the test apparatus and the total time of penetration should be divided by this time.

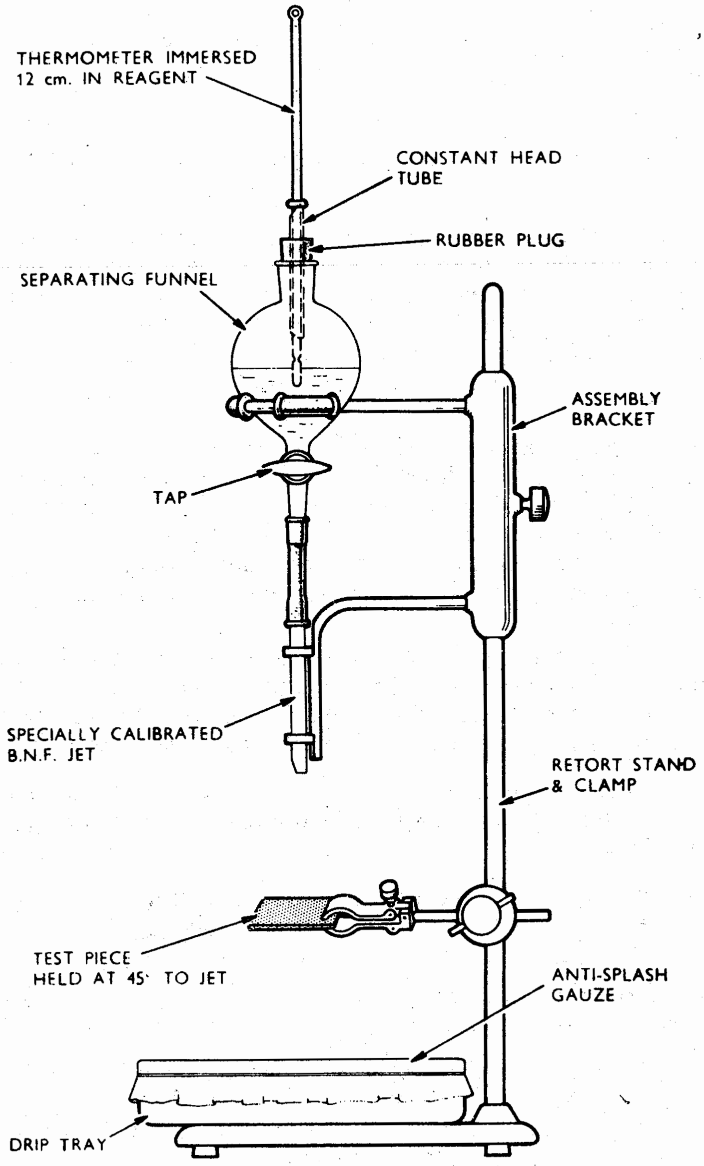

Figure 1 APPARATUS FOR BNF JET TEST

4.4.2 **Test for Determination of Adhesion.** An area of 6 cm^2 (1 in^2) of the plated surface should be rapidly and firmly rubbed for 15 seconds with the smooth edge of a metal implement such as a copper coin, the pressure being sufficient to burnish the film at every stroke without cutting into it. If inspection then shows no detachment of the deposit, the adhesion is satisfactory. A blister which grows with the rubbing indicates poor adhesion; splitting and peeling of the deposit shows it to be of inferior quality.

4.5 **Organic Finishes.** The standard method of testing the corrosion-resistant properties of paint, varnish, lacquer and related products is by means of the salt spray test specified in Method No. 24 of Ministry of Defence Specification DEF 1053. The apparatus for making this test is shown in Figure 2. It consists of a glass tank with a close fitting lid in which a salt mist is produced by spraying the test solution through an atomiser. Test panels, the preparation of which is given in detail in Method No. 2 of the Specification, are painted with the finish under test and are then supported on non-metallic supports with their test faces upwards. They should be at approximately 15° to the vertical in the tank so that they will be evenly coated with droplets of solution, but the spray must be prevented by a baffle from impinging directly on to the test faces. The salt solution drained from the panels should not be recirculated. The composition of the solution should be as follows:

Calcium sulphate ($CaSO_4$)	1·3 g
Magnesium chloride ($MgCl_2$)	2·6 g
Magnesium sulphate ($MgSO_4$)	1·7 g
Sodium chloride ($NaCl$)	21·4 g
Water (distilled)	to 1000 ml

Test panels are normally exposed for periods of 10 days, at the end of which period they should be removed, washed in running water and dried with absorbent paper. Any deterioration in the paint film should then be noted, after which a strip 150 mm x 50 mm (6 in by 2 in) should be cleaned off with a suitable paint remover to permit inspection of the underlying metal for corrosion.

NOTE: When required, the thickness of paint coats can be gauged by using the electrodes of a capacitance-type proximity meter. This method is applicable whether the base is ferrous or non-ferrous. Eddy current (for non-ferrous bases) and magnetic (for ferrous bases) thickness meters are now in use. They are not greatly affected by permeability or curvature of the base material and may be used on organic or metallic coatings.

5 EXTERNAL FINISHING OF AIRCRAFT Finishing schemes for metal-skinned aircraft are selected to provide the maximum of corrosion protection with the minimum weight of paint. Adherence of finish, effect on aircraft performance and appearance are also important; therefore, verification of the scheme used should be obtained from the relevant aircraft Manufacturer.

5.1 **Surface Finishes.** Cellulose or synthetic finishes give satisfactory protection if applied on top of suitable primers. After pre-treatment the metal surface should be finished in accordance with a recognised scheme; for the best results it is advisable to use compatible primers, undercoats and finishing coats from the same Manufacturer. Polyurethane and acrylic finishes are now widely used in some modern aircraft, whilst others utilise epoxy paint and epoxide primers.

5.2 **Retouching Local Areas.** It is not always necessary to clean down to the bare metal before touching up a damaged finish but this is advisable if there is any evidence of flaking or blistering. The area should be flattened down with 'wet' sandpaper or with pumice powder applied with a damp cloth. The edges of the area should be feather-edged. If stopping is required, the stoppers should be applied with a knife. The priming coat should then be sprayed on using a round instead of a fan spray and spraying from the feather-edge inwards. The same technique should be used for the finishing coat, for which it is advisable to adjust the spray gun to give a finer spray than usual.

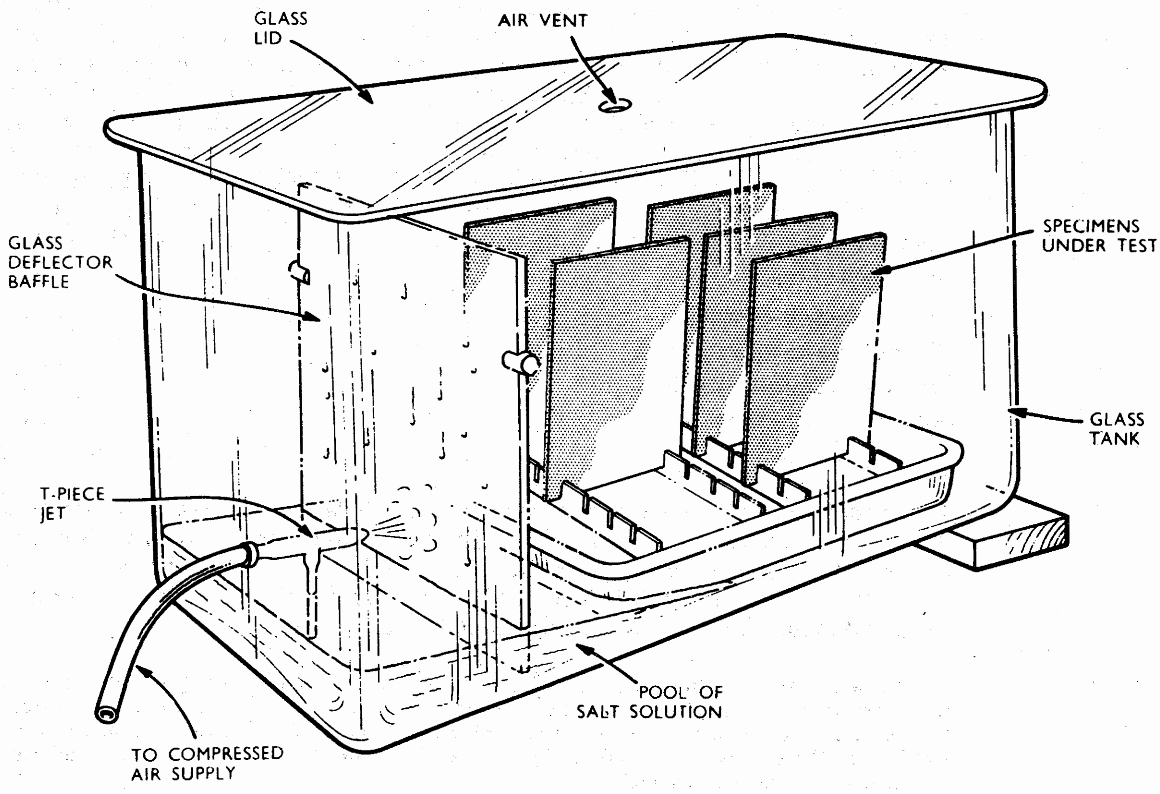

Figure 2 APPARATUS FOR SALT SPRAY TEST

5.3 Experience has shown that external paint schemes reduce maintenance labour and enhance the appearance of an aircraft. Stoving is carried out where practicable, but the paint materials used, including the latest epoxy/polyamide, will be suited to air-drying touch-up operations which might be necessary from time to time. Most paint materials are described in Ministry of Defence Specifications DTD 827, 5555, 5567, 5580 and 5599.

6 **INTERNAL FINISHING OF AIRCRAFT** The interiors of wings, fuselage, etc., are usually protected by at least one coat of zinc-chromate or general purpose primer. This should be applied by spray, care being taken to ensure that all corners and enclosed spaces are adequately covered. Where greater resistance to abrasion is required, a cellulose or synthetic finish is applied on top of the primer. Special additional treatments are given to areas subject to excessive contamination.

6.1 Some aircraft Manufacturers ensure that every component receives a full protective treatment, including painting, at the detail stage. Paint is applied to clean pre-treated metal surfaces and stoved to ensure the best adhesion and durability. This finish has good resistance to knocks and abrasives, and the parts are thus protected from damage during assembly. In assembly, paint and interfaying compound is present in all joints, giving enhanced protection from corrosion and fretting.

6.2 Aluminium-alloy parts are often protected by the Alocrom 1200 process which has no deleterious effect on the fatigue properties of the metal, and gives a good bond for paint adhesion. Steel components are cadmium plated and then given chromate passivation, which improves the paint adhesion and provides increased corrosion resistance. The paint treatment is often an epoxy/polyamide system using a chromate pigmented primer and a gloss finish which is suited to air-drying touch-up operations. Areas subject to slight contamination may receive chemical cleaning, chemical protection and primer painting only, whilst areas contaminated by water, oil, etc., may receive an additional process of hard gloss finishing paint. Those areas subject to attack from acid or corrosive fluids are given a further treatment of epoxy nylon lacquer.

6.3 Some Manufacturers apply a water displacing corrosion inhibitor to supplement the finishing scheme, and similar material may also be used, where permitted, in cases where interior paintwork has been damaged. These inhibitors are volatile liquids which are sprayed or brushed on the surfaces to be treated; the liquid carrier then evaporates leaving a waxy film on the surface. The inhibitor penetrates small cavities and between faying surfaces and thus prevents the ingress of moisture.

6.3.1 These inhibitors are usually slightly toxic and the appropriate precautions should be observed during their application. In addition, corrosion inhibitors may contain flammable components and may present a fire hazard when mixed with oxygen or subjected to high temperatures. All safety precautions recommended by the Manufacturer should therefore be observed.

BL/4-10

Issue 1.

15*th November*, 1974.

BASIC

MATERIALS

MERCURY CONTAMINATION OF AIRCRAFT STRUCTURES

1 INTRODUCTION This Leaflet describes the possible effects of the spillage of metallic or mercury salts and solutions on aircraft structures, and the methods by which these substances may be removed.

1.1 Contact between mercury and aircraft structures is, fortunately, infrequent, but on those occasions when it does occur, immediate action is necessary to prevent serious loss of strength in the contaminated components, since the effects of spilt mercury are potentially more dangerous than those of spilt battery acid. The aircraft must not be moved, and no action must be taken which might disturb the mercury and increase the area of contamination. The area must be isolated, and decontamination must be carried out as quickly as possible. Metallic structural members, exposed wires, electrical cables, terminal blocks, and other metallic parts susceptible to mercury attack, must be carefully examined, and replaced or repaired if evidence of corrosion is found.

2 GENERAL If mercury is spilled (by breakage of a container, mercury vapour lamp, thermometer or similar instrument) the mercury will split into small globules, which will quickly disperse over a wide area, and attack many of the metals with which they come into contact. If the spillage occurs in the passenger or freight compartments of an aircraft, some of these globules are likely to find their way through joins in the floor panels and insulation blankets, and come to rest on the aircraft skin and structure, where corrosion and embrittlement of the aluminium may start. A film of oxide, paint, grease or oil, will delay the onset of mercury attack, but where the mercury is in contact with bare metal, and moisture is present, the attack will progress rapidly and cannot be arrested by any normal cleaning process.

2.1 **Amalgamation.** If metallic mercury, or mercury salts or solutions come into contact with any of a number of materials, they combine with the basic material, and form an amalgam which has no appreciable structural strength. This process is very rapid, particularly in moist conditions, and the affected component may be completely destroyed.

2.2 **Embrittlement.** Intergranular penetration by the mercury results in embrittlement, which will initiate cracks, and accelerate crack propagation. Degradation of the structural strength of the material may be complete, and will be accelerated if the material is under stress.

2.3 **Recognition of Mercury Attack.** Evidence that corrosion and embrittlement have commenced, may be recognised visually, as follows:—

(i) On aluminium or aluminium alloys; a greyish powder, fuzzy deposit, or whiskery growth.

(ii) On copper, brass or gold; a silvery stain or coating.

(iii) On silver, cadmium or zinc; the surface of the affected area will appear slightly brighter than that of the surrounding metal. This may be very difficult to see.

2.3.1 In all cases where visual signs of mercury attack are found or suspected, the affected part must be replaced, or repaired by the insertion of new material.

3 HEALTH HAZARDS Both mercury and its vapour are toxic, and at normal room temperatures a toxic concentration will be present in the air above spilled mercury. Care must be taken to prevent mercury and its vapour from being inhaled or swallowed, or from coming into contact with the skin or eyes. If a person finds that his hands have come into contact with mercury, he should not eat, smoke or blow his nose without first washing carefully with soap and hot water. Protective clothing and rubber gloves must be worn by personnel engaged in decontamination, and adequate ventilation must be provided in the working area. After decontamination has been carried out, the protective clothing should be discarded, and the hands, and any tools used, thoroughly washed with soap and hot water.

4 DETECTION Large globules or pools of mercury are normally easily visible, but small particles may be difficult to locate. Fortunately, even minute particles of mercury show up well on an X-ray radiograph, appearing as white dots, while corrosion and embrittlement appear as tree-like forms in the aluminium structure.

4.1 An electronic device known as a 'sniffer' is commercially available, which can be used to detect mercury vapour. This device will also indicate the presence of liquid mercury which is not visible to the naked eye.

5 CLEANING METHODS There is no satisfactory method of removing mercury corrosion, but a number of methods have been developed for picking-up spilled mercury, and these may be broadly classified as mechanical or chemical. On no account should normal methods of cleaning such as washing, wiping with a cloth, or using an air-jet, be employed, as these will merely increase the area of contamination. When collecting loose mercury, care must be taken not to scratch the metal surface, as this could result in mercury attack on a previously unaffected area.

NOTE: Jars containing mercury or other corrosive fluids should always be contained within an unbreakable case, so that accidental demage to, or spillage from, the jar will not introduce additional problems.

5.1 **Mechanical Methods**

5.1.1 **Suction.** A powerful vacuum-cleaner, or vacuum pump, may be used to pick up pools or large globules of mercury. However, since mercury or mercury vapour may have an adverse effect upon their mechanisms, a glass trap should be used to collect the spilled mercury, and should be located near to the free end of the suction pipe. By using suction, rubber pipes of small bore may be adapted to remove mercury from otherwise inaccessible corners. A medicine dropper, or a rubber battery-water syringe, may be used for picking up large globules if no mechanical suction device is available.

5.1.2 **Brush.** A tool developed specifically for picking up spilled mercury, consists of a brush with nickel-plated carbon fibre bristles. When the brush is drawn lightly over the contaminated surface, mercury is picked up by capillary action. The brush should be carefully shaken into a suitable container after each stroke.

5.1.3 **Foam Pad.** A commercially made plastic foam collector may be used on flat surfaces to pick up small globules of mercury. The pad should be pressed onto the mercury, and, when pressure is released the globules will be drawn into the pad. Mercury may then be expelled into a suitable container by squeezing the pad in a special holder.

5.1.4 **Adhesive Tape.** Small globules of mercury may be picked up by pressing adhesive tape or medical plaster onto them, but care is necessary to prevent spreading the contamination during removal of the tape.

5.2 **Chemical Methods.** If calcium polysulphide is brought into contact with mercury, an inert solid (mercuric sulphide) is formed, and this can be easily removed. The normal method of application is to make a thin slurry of calcium polysulphide in water, and to brush this onto the contaminated area. When the mixture is thoroughly dry (after approximately two hours), it may be removed by brushing and vacuum cleaning. An alternative, but less effective method, is outlined in paragraph 5.2.1.

5.2.1 **Chemical Recovery.** In this method a length of flexible electrical cable, comprising fine strands of bare copper wire, is used, together with glass jars or test tubes containing separately, dilute nitric acid (5% by volume in water), distilled water, methylated spirits, and a small quantity of mercury. The recovery process is as follows:—

(i) Bare the cable for 2·5 cm (1 inch) approximately, untwist the wire to form a brush, and immerse the bared wires in the nitric acid for a few seconds to remove any staining.

(ii) Wash the brush quickly in the distilled water to remove the acid, and then in the methylated spirits.

(iii) After shaking off excess liquid, dip the brush in the jar of mercury. An amalgam should form on the bared wires.

(iv) Insert the brush into the spilled mercury to pick up a small quantity, then shake off this mercury into the mercury jar. Repeat this step until all spilled mercury is recovered.

NOTES: (1) Over exposure to air between steps (iii) and (iv), may result in oxidation of the copper wire and failure to form an amalgam.

(2) The active life of the brush after step (iii) may be a few minutes only, and the process will have to be repeated as necessary.

(3) The brush must be discarded if the copper strands show signs of breaking away as a result of amalgamation with the mercury.

6 DECONTAMINATION PROCEDURE Whenever spillage of mercury has been reported or discovered, the area should immediately be isolated to prevent the spread of contamination through transfer by footwear and clothing. If radiographic facilities are available, the following actions should be taken:—

(i) Locate and remove the source of contamination, taking care to prevent further spillage.

(ii) Carry out a radiographic examination to ascertain the extent of contamination at floor level.

(iii) Remove all mercury from the floor panels, paying particular attention to the joins, and using an appropriate cleaning method (paragraph 5).

(iv) Remove the floor panels, and carry out a further radiographic examination of the underfloor skin and structure, including electrical cables and terminals, and any components of a material which is likely to be affected by mercury attack.

(v) Remove any mercury indicated on the radiographs.

NOTE: If mercury has penetrated between riveted or bolted joints, it will be necessary either to separate the joints, or to completely remove the panels or structure concerned, in order to clean the contaminated surfaces. Drill bits used on contaminated structure should be discarded.

(vi) Carry out a careful visual examination of the area, using a lens of 10× magnification, and renew or repair any components which show signs of mercury attack.

(vii) Carry out a final radiographic inspection to ensure that all traces of mercury have been removed, and re-assemble the skin and structure, using approved repair schemes where necessary.

(viii) Apply a film of oil to the area so as to prevent any minute particles of mercury, which may have been overlooked, from causing future corrosion.

6.1 If contamination is discovered at an airfield without radiographic facilities, the source should be carefully removed and the affected area progressively stripped to the metallic structure. A thorough examination for mercury should be carried out before removing any item, and any mercury found should be removed by a suitable method before proceeding with the stripping. Material exhibiting signs of mercury attack must be renewed or repaired, and the suspect area should be marked with chalk or grease crayon. The aircraft must be routed to a base with radiographic facilities, for complete decontamination and inspection as outlined in paragraph 6.

6.2 Details of the occurrence, including the exact area affected and the action taken, should be entered in the appropriate records.

6.3 After the aircraft has been in service for a short time, a further inspection of the previously contaminated area should be carried out, to ensure that no further corrosion or embrittlement cracking has occurred.

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BASIC
ENGINEERING PRACTICES AND PROCESSES
SOFT SOLDERING

1 INTRODUCTION This Leaflet gives guidance on the manufacturing processes involving the use of soft solders. Soft soldering is a method of joining metals without intentional fusion of the basis metal, the solders having a lower melting point than the metals being joined. The term "soft soldering" is used to distinguish the process from brazing, which is performed at higher temperatures.

1.1 Information on brazing is contained in Leaflet **BL/6-2,** on oxy-acetylene welding in Leaflet **BL/6-4,** on arc-welding in Leaflet **BL/6-5,** and on spot welding in Leaflet **BL/6-12.**

2 STRENGTH OF SOLDERED JOINTS The strength of a soldered joint is dependent on the continuity and adhesion of the solder film and the mechanical properties of the solder, and can only be verified by the destruction of the joint. In order to ensure satisfactory joints it is essential that adequate inspection is carried out at various stages throughout the process. In addition, where a large number of similar articles are being soldered, periodic tests can be made by sectioning, or by pulling surfaces apart. In the majority of applications, the solders used are considerably weaker than the materials they join; where the film of solder is too thin the joint will be brittle; conversely, if the film is too thick, the shear strength of the joint will be low. (See paragraph 7.5.)

3 SCOPE OF PROCESS Most metals, with the exception of some aluminium alloys, magnesium alloys and zinc-base die-castings, can be soldered, but before applying the process it should be verified that the relevant specifications permit its use. For example, because of the danger of intercrystalline penetration by the molten solder, the soldering of high tensile steel tubes, complying with specifications such as British Standards T57, T58, T59 and T60, is prohibited, both for jointing and for the attachment of identification labels. The soldering of aluminium with aluminium solder and a suitable flux is possible and is sometimes used for radio and instrument assemblies, but is not normally permitted for other aircraft purposes.

4 MATERIALS The solders and fluxes used for aircraft purposes must comply with British Standards or DTD specifications. Relevant specifications are given in Table 1.

TABLE 1
SOLDERING SPECIFICATIONS

Specification	Description
BS 219	Soft Solders.
BS 441	Rosin-Cored Solder Wire.
DTD 599	Non-corrosive Flux for Soft-Soldering (except high-pressure oxygen equipment).
DEF 34/1	Tinning and Soldering Solution.

4.1 **Solders.** Solder is available in two forms, i.e. stick solder with which a separate flux is used, and solder in wire from having a rosin flux core. BS 219 covers a range of antimonial and non-antimonial stick solders, whilst BS 441 is concerned with wire solders having non-corrosive, activated and non-activated flux cores. (See paragraphs 4.2.2 and 4.2.3.)

4.1.1 **General Purpose Solders.** The solders which may be used for general soldering work are designated in BS 219 and listed in order of tin content in Table 2. Solder manufactured to other specifications may be recommended for particular applications, and an approved proprietary brand of tin/lead solder containing a small percentage of copper is also available for electrical circuit bit-soldering. It is claimed that the copper content reduces bit erosion without impairing the efficiency of the solder.

TABLE 2

GENERAL PURPOSE SOLDERS

Grade	Alloy (%)			Melting Range (°C)	Typical Uses
	Tin	Antimony	Lead		
A	64 to 65	max. 0·6	remainder	183 to 185	Components liable to damage by heat, e.g. electrical and instrument assemblies. Nickel and high nickel alloys.
K	59 to 60	max. 0·5	remainder	183 to 188	
B*	49 to 50	2·5 to 3·0	remainder	185 to 204	General coppersmiths and tinsmiths bit-soldering and machine work.
F	49 to 50	max. 0·5	remainder	183 to 212	
M*	44 to 45	2·2 to 2·7	remainder	185 to 215	
R	44 to 45	max. 0·4	remainder	183 to 224	
C*	39 to 40	2·0 to 2·4	remainder	185 to 227	Blowpipe soldering and general fine work.
G	39 to 40	max. 0·4	remainder	183 to 234	
H	34 to 35	max. 0·3	remainder	183 to 244	Dipping baths. General plumbers' work.
L*	31 to 32	1·6 to 1·9	remainder	185 to 243	
D*	29 to 30	1·5 to 1·8	remainder	185 to 248	
J	29 to 30	max. 0·3	remainder	183 to 255	
V	19 to 20	max. 0·2	remainder	183 to 276	Electric lamps, dipping solder.
N*	18 to 18·5	0·9 to 1·1	remainder	185 to 275	

NOTES: (1) Grades marked with an asterisk are known as antimonial solders, the antimony being added to increase strength. They should not be used on zinc or galvanised work.
(2) The two figures quoted in the melting range column represent the completely solid and completely liquid states.

4.1.2 **High Temperature Solders.** Three types of solders which may be used in high temperature applications are also specified in BS 219. They are used in the manufacture of oil coolers, radiators, etc., where operating temperatures would adversely affect solders with lower melting temperatures. High temperature solders may be applied by soldering iron or torch flame.

TABLE 3

HIGH TEMPERATURE SOLDERS

Grade	Alloy (%)				Melting Range (°C)
	Tin	Antimony	Lead	Silver	
95A	94·5 to 95·5	4·75 to 5·25	max. 0·7	—	236 to 243
5S	4·75 to 5·25	max. 0·1	remainder	1·4 to 1·6	296 to 301
1S	1·0 to 1·5	max. 0·1	remainder	1·4 to 1·6	309 to 310

4.1.3 **Wire Solder.** Solders of this type, complying with the requirements of BS 441, are of circular cross-section, having one or more continuous cores of activated or non-activated flux. Because wire solders release flux and solder simultaneously when the appropriate temperature is applied, they are generally considered to be more efficient than stick solders. These solders are available in five grades. Information on their properties and uses is given in Table 4.

TABLE 4

WIRE SOLDERS

Alloy (%)		Melting Range (°C)	Typical Uses
Tin	Lead		
65 max. 60 max.	remainder remainder	183 to 185 183 to 188	Electrical, radio and instrument assemblies liable to damage by heat or requiring free running solder.
50 max.	remainder	183 to 212	Electrical, radio and instrument work where slightly higher temperature and some slight loss of penetrating power are permissible. General hand soldering and medium coppersmiths' work.
40 max.	remainder	183 to 234	Tagging components less liable to damage by heat. Tinsmiths' and coppersmiths' light gauge handwork.
20 max.	remainder	183 to 276	Blobbing electric lamp contacts.

4.1.4 **General.** Care must be taken to ensure that the solder used is of the type specified on the drawing and is the correct type for the work in hand. Apart from the effect on the strength of the joint, the use of incorrect solder may result in other damage, e.g. if solder with too high a melting point is used, damage may result to the surrounding structure from the heat required to melt the solder.

4.2 **Fluxes.** Since solder will only adhere to clean metal, all surfaces to be soldered must be thoroughly cleaned (paragraph 5). However, even after cleaning, the oxidation occasioned by heating will prevent the satisfactory adhesion of solder. The use of flux reduces the effect of oxidation, removes oxides and other impurities, helps the molten solder to run freely and results in the production of a stronger joint.

4.2.1 Fluxes complying with Specification DTD 599 are available in rosin, liquid and paste forms, are non-corrosive, and either activated or non-activated. Rosin to this specification is used for the flux in wire solders.

4.2.2 **Activated Fluxes.** Activated fluxes consist of wood or gum rosin, and contain a small proportion of an agent intended to facilitate the soldering process; such fluxes are usually selected when a more active cleaning agent is required.

4.2.3 **Non-Activated Fluxes.** These fluxes consist of wood or gum rosin only and are usually selected for the soldering of surfaces where active cleaning is unnecessary.

4.2.4 **Test to Distinguish Activated from Non-Activated Flux in Wire Solder.** The method of conducting this test is described in BS 441. The principle of the test is that a specimen of the solder is melted on a prepared nickel plate. It is essential that the solder should be melted within a period of from two to six seconds, and if the solder on melting wets the nickel and spreads upon its surface, the flux is judged to be activated.

4.2.5 **Fluxes for Stainless Steel Soldering.** Suitable fluxes, which are all corrosive, are as follows:—

(i) A liquid flux made by dissolving zinc chloride in a solution of equal volumes of hydrochloric acid and water. The solution may be applied with a brush or, if more convenient, the parts may be dipped into the solution.

(ii) Ortho-phosphoric acid, in its commercial form, which should be applied undiluted.

(iii) Phosphate-base flux pastes.

4.2.6 **Oxygen Equipment.** Rosinous fluxes, such as those complying with Specification DTD 599, must not be used for soldering oxygen equipment. A flux complying with DEF 34/1 is suitable.

4.2.7 **Miscellaneous Applications**

(i) For Monel and nickel the rosin types of fluxes are suitable, but for Inconel and the Nimonic alloys, a more vigorous flux, such as killed spirits of salts or lactic acid, is necessary.

(ii) Parts which cannot be washed after soldering, e.g. radio, electrical and instrument equipment, should be soldered in conjunction with a flux complying with DTD 599.

(iii) Zinc-plated steel parts, including galvanised wire ropes, should be soldered in conjunction with a flux complying with DTD 599 or with a triethanolamine oleate flux.

(iv) Where such action is permissible (see paragraph 3) the soldering of identification labels to steel tubes should be in conjunction with a flux complying with DTD 599.

4.2.8 **General.** Care must be taken to ensure that the flux used is of the type specified on the drawing and is of the correct type for the work in hand. The use of the wrong type of flux may not prevent oxidation of the surfaces to be joined, nor act as an efficient cleaning agent. In addition, it is imperative that a corrosive flux such as that complying with DEF 34/1 is only used on work from which its residues can be readily removed. (See paragraph 8.6.)

4.3 **Flux Baths.** Where a flux bath is used, the bath should be kept in a clean condition, and the contents checked at regular intervals. The acidity of fluxes of the DEF 34/1 type must be carefully controlled.

5 SURFACE CLEANING The following methods of cleaning surfaces should be adapted to the material and type of joint.

5.1 A high polish is not desirable, since a slightly roughened surface provides the best base for a good joint. Best results will be obtained by mechanical cleaning of the surface with a suitable abrasive, such as a file, sandpaper, or emery cloth; this, however, does not apply to stainless steel (see paragraph 5.3). Care should be taken to remove only the surface film and not to reduce the thickness of the material. After such preparation it is necessary to degrease the surface using one of the solvents described in paragraph 5.2.

5.2 Trichloroethane and trichloroethylene are good liquid cleaners and the latter may also be used in a vapour degreasing bath (Leaflet **BL/6-8**). Neither petrol nor paraffin should be used, since both will leave a film on the metal surface.

5.3 **Cleaning Stainless Steel.** After degreasing, stainless steel may be cleaned by a pickling process followed by washing; suitable processes are given in the following paragraphs.

5.3.1 Anodic treatment in an aqueous solution containing one-third (by volume) of concentrated sulphuric acid and 2·5 per cent (by weight) of potassium dichromate. Current density should be at least 1100 amps per square metre of surface area, and the treatment should be continued until the surface has acquired a light grey colour.

5.3.2 Immersion for not more than five minutes in an aqueous solution containing 50 per cent (by volume) of concentrated hydrochloric acid.

5.3.3 After pickling, the parts should be washed in clean water.

5.4 **General.** In order to minimise the detrimental effects of the oxide film which forms rapidly on the surfaces of the parts after cleaning, the interval between the cleaning and soldering operations should be kept to a minimum.

6 SOLDERING EQUIPMENT

For normal small soldering operations, such as fixing a tag to an electrical cable, a hand soldering iron is the most convenient method of melting the solder. In cases such as fixing identification tags to pipes, where dissipation of heat may prevent the solder from flowing properly, the use of a large iron or blow-lamp may be necessary. Some soldering operations require much more sophisticated heating equipment, however, and in these cases dipping baths (paragraph 9), ovens, pre-heating equipment and automated handling methods are often used.

6.1 **Hand Soldering Irons.** A soldering iron consists of a copper 'bit' attached to a suitable handle, and may be heated either by a self-contained device (electrical elements or gas flame), or by an external source such as a fire or blow-lamp. Irons should be used at a temperature of approximately 60°C above the melting point of the solder, and should not reach a temperature which will result in rapid oxidation. Electric irons are often fitted with a thermostat to maintain ideal working conditions.

6.1.1 **Tinning.** Before an iron can be used for soldering the bit must be tinned, i.e. a coating of tin or solder applied to all faces. A suitable method of tinning an iron is described below.

(i) The faces at the tip of the bit should be filed to remove dirt and rough edges, after which the bit should be heated to a temperature sufficient to melt solder. One face of the bit should then be coated with flux and rubbed against a stick of solder until a thin film of solder adheres to it. The operation should be repeated until all faces are suitably tinned.

6.2 **Resistance Tools.** With these tools a low voltage electric current is passed into the work to be soldered, by means of a metal or carbon electrode. The resistance between the electrode and the work area causes a rapid local increase in heat which is used to perform soldering functions. The main advantages of this method are that electrical power is only used during the soldering operation and that the electrodes are nearly cold during approach to, and removal from, the work area.

6.3 **Induction Heating.** If a high frequency current is passed through a coil which is held adjacent to a workpiece, the workpiece will be heated by induction. This method is often used for soldering on a production line basis, but, since a large high frequency generation is required, is not suitable for occasional use.

6.4 **Ultrasonic Soldering Equipment.** Ultrasonic soldering equipment can be used for the jointing of aluminium. Further information on the process and equipment is given in paragraph 14.

7 PREPARATION FOR SOLDERING

Before the actual soldering operation is begun, preparations should be made taking into account the factors given in the following paragraphs.

7.1 The size of a soldering iron should be adequate for the job in hand, and should provide sufficient heat to prevent the solder from solidifying before it has completely melted in a joint. If a large soldering operation is contemplated using a common hand iron, two irons should be available, and used alternately, so that the materials being soldered will not lose heat while one iron is being re-heated.

7.2 The parts to be soldered should not be in contact with a material which will cause rapid dissipation of heat, e.g. if the parts are held in a vice, wood should be used for insulation purposes.

7.3 When pins are used with soldered joints, the holes should be drilled and the pins inserted before the joint is soldered. Oil must not be used when drilling unless the articles can be degreased before soldering.

7.4 Aircraft batteries should be disconnected, as a precaution against fire, when soldering is carried out adjacent to wiring looms or cables.

7.5 The clearance between the parts should be in accordance with drawing requirements, a gap of between 0·08 mm to 0·25 mm (0·003 inch to 0·010 inch) before tinning usually being specified for all materials except aluminium (paragraph 14.1.1).

8 GENERAL APPLICATION OF SOLDER After the surfaces have been cleaned, an adequate, but not excessive, amount of the appropriate flux should be applied; the surfaces should then be tinned by hot tinning, dipping in molten solder, or by electrolytic deposition. When a dipping process is used, surplus solder should be removed from the surface by wiping or other convenient means before assembly and final soldering.

NOTE: Electro-tinned surfaces, if allowed to age, may present difficulty in soldering unless the tinning is at least 0·008 mm (0·0003 inch) thick.

8.1 Where a common soldering iron is used, the bit should be heated in a blue flame. The use of a red or luminous flame is not recommended, since this would result in a deposit of soot on the bit. The bit should not be heated to such an extent that it displays a "rainbow" effect, as this will cause rapid oxidation necessitating re-tinning. In addition, overheating the bit may cause the solder to sputter and detrimentally affect adjacent parts.

8.2 Irrespective of the nature of the flame used for heating, some oxides will form on the bit; these should be removed by dipping the tip into a cleaning solution each time it is removed from the flame. A suitable cleaning solution can be made by mixing one pound of melted sal ammoniac with one pint of distilled water.

8.3 A mass of material tends to dissipate the heat from the surfaces to be joined, and to obviate this effect it is usually necessary to pre-heat the metal. Care must be taken to prevent the overheating or burning of the parts, since, apart from possible detrimental effects on the material, this will cause the solder to run out of the joint. However, if insufficient heat is applied, the solder will not run evenly into and fill the small space between the faces of the joint, and lack of strength will result.

8.4 The use of an excessive amount of solder is undesirable; if the process is correctly applied, a little solder, thoroughly melted, will cover a considerable surface.

8.5 When the solder is solidifying, any movement will produce internal fractures in the solder; such fractures are not readily discernible and will considerably weaken the joint. To prevent any such movement, the parts should be firmly clamped during the soldering process.

8.6 After soldering, the joints should be wiped clean and thoroughly washed in hot water. Joints soldered with the aid of paste fluxes should, before washing, be cleaned with a spirit solvent such as petrol or industrial methylated spirit. Joints soldered with the aid of zinc-chloride fluxes (e.g. DEF 34/1) should, before washing, be cleaned with a 1 to 2 per cent (by volume) hydrochloric acid solution, preferably with a suitable wetting agent additive.

NOTE: A wetting agent is a substance added to a liquid in order to reduce its surface tension.

8.7 Unless otherwise specified, joints which cannot be examined visually, e.g. such as may occur inside containers, etc., should be thoroughly washed with a 2 per cent (by volume) solution of hydrochloric acid, and subsequently swilled for at least two minutes with water. Where paste fluxes are used for such applications, a thorough washing in spirit solvent should precede the acid wash.

9 BATH SOLDERING There are a number of methods by which parts may be joined by dipping in molten solder. The simplest method is to dip items into a heated container after fluxing; this method may be suitable for occasional use where attention can be given to the removal of scum or dross immediately before dipping. The presence of dross is a serious matter in production line soldering and the two methods described below have been adopted to overcome this problem.

9.1 **Rotary Baths.** In this method the solder bath is rotated slowly, and dross flows under centrifugal force to the periphery, where it may be easily skimmed off. By this means soldering may be carried out at temperatures of up to 500°C, at which temperature normal bath operation would not be practical.

9.2 **Standing Wave Baths.** In this method a pump is used to pump molten solder from the bottom of the bath through a slot-shaped hole so that a standing wave of solder appears across the surface. Dross forming on the surface is swept to a catchment area where it can be periodically removed. This method is frequently used in the manufacture of printed circuit boards, which are pre-fluxed and drawn across the standing wave. One advantage of this method is that the size of the work is limited only by the width of the bath and not by its length.

9.3 **General Recommendations**

9.3.1 The composition of a bath should be checked at frequent intervals. Particular attention should be given to the copper pick-up, which should not be allowed to exceed 0·4 per cent.

9.3.2 The temperature of the bath should not be allowed to rise too high, as the solubility of copper in the solder increases rapidly with temperature. The formation of a blue film on solder with a high tin content is indicative of an excessive temperature, but this indication will not be found in solders containing less than approximately 40 per cent tin. Pyrometric control of solder baths is strongly recommended.

9.3.3 The bath used should be of adequate size for the work in hand, so that placing a large item in the bath does not result in undue cooling of the solder.

10 SOLDERING SHEET METAL The following method of soldering seams in sheet metal is usually employed, to comply with the tinning process referred to in paragraph 8.

10.1 The surface should be cleaned and a suitable flux applied. A heated bit should then be held on the surface until the material reaches the melting point of the solder. Solder should then be applied to the bit so that it will flow from the bit to the surface of the material and spread evenly. The solder may also be applied by dipping or by electrolytic deposition.

10.2 The tinned surfaces to be joined should be fluxed, placed together and heated by a bit held on the outside of the joint. The heat transference will be quicker if the bit is applied to the material with a firm steady pressure and moved along the seam slowly. When the materials become sufficiently hot, the solder on the tinned surfaces will melt and flow together to make the joint. Wherever possible, the seams should be soldered in the horizontal position.

10.3 The above process is sometimes known as "sweating" and other methods include the use of solder creams, and solder paints, which contain flux and solder, and which are applied to the surfaces of the joint either with a brush, or by dipping, before assembly. The parts are made a close fit, and are manufactured so that they remain in position during heating, or may be held together by a jig.

NOTE: When proprietary types of solder creams or solder paints are used, it is essential that they should be of a type approved for use on aircraft.

11 SOLDERED ASSEMBLIES MADE OF TINNED STRIP The methods of soldering described in the following paragraphs are used mainly for the manufacture of heat exchange equipment. Repairs must be strictly in accordance with the manufacturers' instructions.

11.1 **Honeycomb Structures.** The assembly is made up of strip material previously coated with solder, and the component parts are tacked by local heating to hold them in position, after which the completed assembly is placed in a jig. The assembly is then degreased, preferably by trichloroethylene, and allowed to drain, after which it is dipped into a flux bath and again allowed to drain.

11.1.1 Hot air is then blown through the assembly so that the coating melts and forms a soldered joint where the parts are in contact. After soldering, the flow of heated air is replaced by a flow of cold air, which is maintained until the temperature of the assembly drops to room temperature, when the assembly is removed from the jig and washed thoroughly.

11.1.2 As it is not possible visually to check assemblies produced by this method, it is essential that a schedule of operations should be compiled for each type of assembly, the suitability of which has been proved by sectioning and examination of trial assemblies.

11.1.3 A suitable schedule, subject to necessary variations, should include the following:—

(i) Each component should be thoroughly degreased.

(ii) After degreasing the assembly should be drained in such a manner as to preclude the formation of pockets of condensate.

(iii) The assembly should be adequately fluxed and thoroughly drained.

(iv) The assembly should be positioned in its jig so as to ensure that it is evenly heated or cooled.

(v) The temperature of the air and the time of blowing should be in accordance with drawing or schedule requirements.

(vi) After cooling, the assembly should be washed as detailed in paragraph 8.7, then thoroughly dried.

11.2 **Fin and Tube Structures.** In the production of fin and tube type heat exchangers, thin brass strip is formed into rectangular tubes with a rigid locked seam along one edge. The strip can be pre-tinned with solder, or the tube can be continuously tinned after forming by fluxing and dipping in a solder bath, after which it is cut to the required length.

11.2.1 The tubes are assembled into copper gill-plates punched with rectangular holes to space the tubes evenly apart. The assembly is placed in a jig and is dipped into a bath of flux, usually of the hydrazine type.

11.2.2 After draining, the assembly is baked in an oven, and during this process the solder on the tubes melts and joins the tubes to the gill-plates at their points of contact; at the same time the seam along the edge of each tube is permanently sealed with solder.

11.2.3 Oven temperature must be carefully controlled during the soldering process, and the assembly should be tested with compressed air at the test pressure stated on the drawing to ensure that the solder has effected a perfect seal. A flow test is also essential to ensure that the tubes are not blocked.

12 CABLE NIPPLES Nipples and other types of end fittings are normally swaged on to stranded cables, but on some types of aircraft soldered nipples may be used in systems where safety considerations are not of prime importance. To ensure satisfactory attachment of a soldered nipple the following procedure should be adopted (see Figure 1).

(i) Thread the cable through the nipple sufficiently to enable the strands to be splayed apart; the strands should be evenly spaced around the countersink in the nipple and project beyond it.

(ii) Clean the cable strands and the nipple (paragraph 5).

(iii) After cleaning, pull the cable back so that the splayed strands lie on the countersink.

(iv) Hold the nipple securely in a vice and ensure that the cable is straight and concentric with the hole in the nipple.

(v) Heat the joint with the soldering bit.

(vi) Apply a suitable flux and solder; the solder should fill the hole in the nipple and envelop the cable and splayed ends. When the solder is set, any projecting ends should be clipped off and filed flush with the surface of the nipple.

(vii) Examine the cable at the point where it enters the nipple, to ensure that there is a clean run of solder on and between the strands.

(viii) Remove all traces of flux from the nipple and cable (paragraph 8.6) and apply a coating of rust preventative. When required by the drawing, the assembly should be proof loaded.

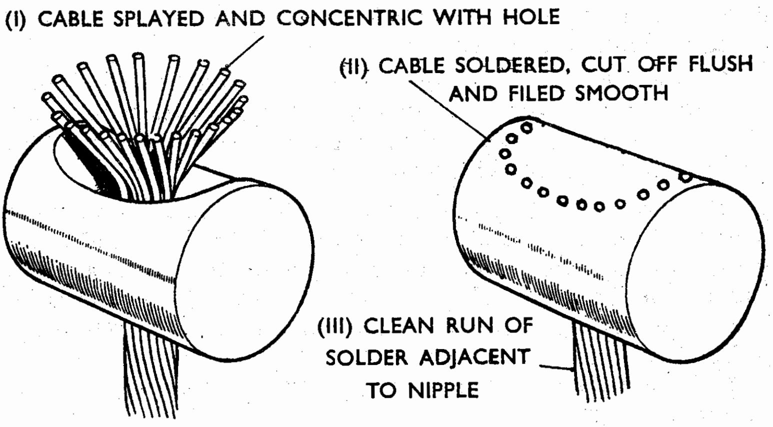

Figure 1 SOLDERING NIPPLES TO STRANDED CABLES

13 SOLDERED ELECTRICAL CONNECTIONS Electrical cables are usually attached to a terminal or plug by means of a crimped end connector, but, on some aircraft, connections may be made by soldering. Crimped end connectors are considered essential in some circuits, e.g. fire detectors, and in locations where high ambient temperatures may be expected; these connections should not be replaced by soldered connections.

13.1 **General Considerations**

13.1.1 Cored wire solder complying with BS 441 is generally used for making electrical connections for use in temperatures up to 100°C, but BS 219 Grade A or K solder and flux complying with DTD 599 are often recommended as an alternative. Grade 5S solder may be used for working temperatures up to 200°C. Corrosive fluxes are not generally permitted for use on electrical equipment because of the difficulty of removing the residue, and activated fluxes are not recommended for use on very thin wire (i.e. less than 43 s.w.g.) because of the relatively high erosion by the hot flux.

13.1.2 Heat applied by a soldering iron may be conducted along the wire and cause damage to cable insulation or to heat-sensitive components such as transistors. Damage may be prevented by using a "heat sink", which usually takes the form of close fitting pliers attached to the wire, to conduct heat away from the insulation or component. A heat sink may also be used to minimise "wicking" (i.e. the run of solder along the strands by capillary action), when soldering stranded or braided wire.

13.1.3 When soldering a number of connections in close proximity, a heat shield should be placed between the joint being soldered and adjacent connections. In similar locations the use of neoprene sleeves over completed joints is often specified to prevent short-circuiting.

13.2 **Soldering Process.** A soldered electrical connection must be strong enough to withstand normal handling and vibration, and must also provide the minimum resistance to the flow of electric current. The following procedure should ensure a satisfactory connection.

13.2.1 The cable should be cut to length and the insulation cut back sufficiently to make the connection, care being taken not to nick or damage the wire and to ensure that the remaining insulation does not touch the soldered joint. It is recommended that properly adjusted mechanical strippers or thermal strippers are used for removing unwanted insulation. If the cable is stranded it should be lightly twisted in the direction of lay to eliminate sharp projections.

13.2.2 The end fitting and exposed wire should be cleaned over their contact areas, using a light abrasive paper, then washed in a suitable solvent. The solvent must be compatible with the insulation material, so that any contact between the two will not cause the insulation to deteriorate.

13.2.3 Parts which are not pre-tinned or plated should be tinned by applying flux and solder with a heated iron. The tinning of flexible wires should be restricted to the minimum necessary for making the connection; over-tinning will reduce the flexibility of the wire and may lead to fracture in service.

13.2.4 The wire should be positioned in the end fitting and heat applied by means of a soldering iron until the solder flows through the joint, additional solder or flux being added as necessary. The connection should be made quickly, and held securely in place while the solder solidifies. The wire should be attached in such a way as to provide additional security to the joint, but must not prevent removal if the solder is melted in a future disconnection; if the tag has a hole the wire may be bent 90° through the hole, but if the tag does not have a hole the wire should be bent 180° to hook round the tag.

13.2.5 After soldering, the soldered parts should be cleaned with an approved solvent.

13.3 **Inspection.** Inspection of completed soldered connections should include the following:—

(i) Joints should be clean, smooth, bright and free from sharp projections, and the wire easily discernible through the solder.

(ii) As far as can be detected visually, the joint should be filled with adhering solder.

(iii) Insulation should be undamaged (i.e. not burned or affected by solvent).

(iv) There should be no pitting, corrosion, scale or other evidence of poor workmanship.

(v) Where electrical tests are specified, the results obtained should be within the prescribed limits.

14 SOLDERING OF ALUMINIUM Proprietary brands of cored wire solder are available, which may be used for soldering aluminium and many aluminium alloys, and a method of ultrasonic soldering may also be used.

14.1 The normal soldering technique is similar to that used with other materials but, because of the material's high specific heat and thermal conductivity, a greater heat input is required. An advantage of these properties is that uneven expansion and contraction are avoided, and heating of complex structures is simpler than with other materials. A soldering temperature of 280°C to 370°C is required, and may be obtained using a hand iron, gas torch, furnace or induction coil. Solder should be pre-positioned or hand-fed to the edge of the joint, and heat applied adjacent to the joint to bring it quickly to the soldering temperature, so that the solder melts by indirect heating.

14.1.1 As aluminium expands more than most materials, light jigging, which will allow the parts to expand and contract, should be used when necessary. A joint clearance of 0·05 mm to 0·1 mm (0·002 inch to 0·004 inch) will allow the solder to fill the gap by capillary action, and give maximum strength.

14.1.2 Pungent fumes are given off by the flux, and soldering should be carried out in a well-ventilated working area.

14.2 Ultrasonic soldering equipment is available in the form of an iron, for normal joints, or a bath, for the quick dip-turning of aluminium wire and small parts.

14.2.1 The working principle of the equipment is that ultrasonic vibrations are imparted to the bit of the iron or, where baths are used, to the vessel containing the solder. When the vibrations are applied to the molten solder on the surface of the material, the effect of the ultrasonic energy is to produce imploding cavitation bubbles in the solder, which remove the oxide film and permit a wetting action by the solder to take place. No flux is required for the process and the solder used should contain 90 per cent tin and 10 per cent zinc.

BL/6-2

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BASIC

ENGINEERING PRACTICES AND PROCESSES

BRAZING

1 INTRODUCTION This Leaflet gives guidance on the brazing processes applicable to ferrous and non-ferrous metals. For the purpose of this Leaflet 'brazing' means the joining of materials by a process in which a molten filler alloy is drawn by capillary attraction into the space between the adjacent surfaces of the parts to be joined. The parts to be joined are known as the basis, or parent, metals.

1.1 Low temperature brazing, also known as silver soldering or hard soldering, is a brazing process which uses filler alloys based mainly on the metals silver and copper, with a melting temperature within the range 600°C to 850°C. The strength of a joint brazed with silver brazing alloy, if properly designed, is often equal to the strength of the materials joined.

1.2 When brazing is carried out with filler alloys of high melting temperature, grain growth and softening of the parent metal often occur, thus necessitating further heat treatment to restore the required properties.

1.3 Where special techniques of brazing are applicable to certain materials, these are described under the heading of the material concerned.

1.4 Information on soft soldering processes is given in Leaflet **BL/6-1,** on oxy-acetylene welding in Leaflet **BL/6-4,** on arc-welding in Leaflet **BL/6-5,** and on spot welding in Leaflet **BL/6-12.**

2 STRENGTH OF JOINTS The strength and efficiency of brazed joints depend on a number of factors, including the design of the joint, cleanliness of the surfaces to be joined, the method of applying the process, the composition of the materials to be brazed, use of the brazing method and materials specified on the drawing or manual, and the competency of the operator. Primarily the strength of the joint depends on the area of the film which unites the surfaces of the parts forming the joint and, to a lesser extent, on the thickness of the film, a thin film usually producing the strongest joint.

2.1 Specific values for the strength of joints can be misleading, since so many factors are involved. For example, most joints made in normal workshop or mass-production conditions contain voids resulting from gas or flux entrapment, or from the formation of shrinkage cavities in the filler alloy during its transition from the liquid to the solid state. Although it is seldom possible to eliminate such faults completely, they can be minimised by careful attention to cleanliness, joint gaps, heating methods and the method of feeding the filler alloy into the joint.

2.2 Overheating during brazing can have a serious adverse effect on the strength of a joint. Care is necessary, when using a hand torch, to ensure that the flame is suitable for the work in hand, otherwise grain growth, burning, distortion or melting of the parent metal may result. Particular care is necessary when using oxy-acetylene gas, which has a flame temperature in excess of 3000°C. Overheating of the parent metal may also result from the use of incorrect brazing alloys.

2.3 Strength at elevated temperatures depends largely on the type of filler alloy used, and in general terms the silver brazing alloys having the lowest melting temperature are suitable for continuous service at temperatures up to about 250°C.

2.4 When dissimilar metals having different rates of thermal expansion are brazed, the possibility of stresses resulting from differential contraction during cooling is reduced by the use of low temperature filler alloys.

2.5 Flux should be removed from parts by washing in hot water but, with assemblies consisting of parts of dissimilar metals or with sudden changes in section, washing should not be carried out while the parts are still hot from brazing. This practice could result in stress cracking or the production of high residual stresses in the component.

3 SCOPE OF PROCESS All brazing operations should be performed strictly in accordance with the requirements of the relevant drawings. Materials suitable for brazing are listed in BS 1723, and various combinations of these materials may also be joined provided that a suitable technique has been established.

4 COMPETENCY OF OPERATORS As stated in paragraph 2, the strength and efficiency of brazed joints depend, amongst other factors, on the competency of the operators. It is recommended that the competency of operators responsible for the hand torch brazing of important parts, should be checked regularly by a testing programme such as that described below.

4.1 A sample should be selected for testing from the operator's production work wherever possible, but where this is not practicable, a butt, fillet, tube-to-tube, or sheet-to-sheet test piece, as appropriate to the type of work in hand, should be prepared.

4.2 The test piece should be submitted for microscopical examination to a laboratory approved for the examination of welded joints, and should show satisfactory penetration into the joint, adhesion and freedom from porosity, freedom from overheating of the parent metal, absence of coarse grain, etc. Further test pieces, to ensure continued competency, should be submitted at intervals not exceeding six months. When an operator fails a competency test he should undergo further practice and/or training before resubmitting a test piece.

4.3 An additional competency test should be submitted whenever there is a marked change in the material or types of joints being brazed.

5 MATERIALS FOR BRAZING The filler alloys and fluxes used for brazing aircraft parts must conform to the appropriate British Standards or to DTD 900.

5.1 **Filler Alloys.** Details of the composition and melting range of filler alloys or metals which may be used for brazing are contained in BS 1845 in a series of Tables. The basic alloying elements listed in each of Tables 1 to 8 in BS 1845, provide the prefix for the filler type (i.e. AL, aluminium; AG, silver; CP, copper-phosphorous; CU, copper; CZ, brass; NI, nickel; PD, silver-copper-palladium; AU, gold) and a numerical suffix signifies the particular alloy within a group; Table 9 lists the maximum permissible content of impurities in the alloys specified for vacuum brazing.

5.1.1 Filler alloys are generally available in rod, wire and strip, and in some instances in granular form, the choice depending on the brazing method used. Whilst the majority of hand torch operations require the filler alloy to be fed by hand from a rod, wire or strip, better results can sometimes be obtained by placing the brazing alloy in a predetermined position in the joint, and heating the assembly by means of a fixed torch, furnace, or electrical induction or resistance methods. Filler alloy inserts for this purpose usually take the form of wire rings, but, in some cases, foil, washers, or pressings of special shape are used.

5.1.2 A silver brazing alloy in the form of a paste or paint is also available, and consists of finely divided filler alloy, flux and a volatile liquid medium. The proportions of the constituents are so arranged that the paste can be used with any of the various heating methods described in this Leaflet.

5.2 **Fluxes.** The function of a flux is to dissolve oxides; it also has the effect of reducing the surface tension of the molten filler alloy, thus assisting the alloy to flow readily between the surfaces of a joint.

5.2.1 It is recommended that the flux used in any brazing operations should be agreed with the supplier of the filler alloy, since in certain instances a flux suitable for one filler alloy may not be suitable for another of similar composition, for example, because of the melting range of the alloy. An example of this is borax, which has a higher melting temperature than some of the filler alloys, and, in this case, its use may result in flux entrapment.

5.2.2 Fluxes are normally supplied in powder form, and should be made up in accordance with the manufacturers' instructions. The application of the flux for the various processes is described in the appropriate paragraphs.

6 BRAZING JIGS Components which are to be joined by a brazing process are normally specially designed to ensure correct location and filler penetration. In the majority of cases the parts fit naturally together or may be lightly supported in such a way as to permit natural expansion and contraction to take place, but in some instances the use of locating jigs is unavoidable.

6.1 Jigs should be so constructed that contact with the parts to be joined is as light as possible, and should be shaped to avoid contact with areas where brazing alloy is required to flow. Jigs should also be designed so that, whenever possible, the capillary flow of filler metal is assisted by gravity.

6.2 Where large jigs are necessary, because of the weight of the component, for instance, care should be taken to prevent the absorption of heat from the brazing area. This may be largely avoided by facing the jig with asbestos, fireclay or other ceramic material, and by limiting the size of the areas in contact with the component.

7 PREPARATION OF JOINTS FOR BRAZING All scale, grease, dirt, paint, moisture and other foreign matter must be removed from the area to be brazed. Components should first be degreased with trichloroethylene or similar solvent, then cleaned by one of the processes described in the following paragraphs, immediately prior to brazing.

7.1 **Steels.** The methods of cleaning steels vary with the chemical composition of the steel. In general, however, steels may be divided into two main groups, i.e. low alloy steels having a carbon content not in excess of 0·2 per cent, and non-corrodible steels or heat-resisting austenitic stainless steels.

7.1.1 **Low Alloy Steels.** The area to be brazed may be prepared by sand, shot or alumina-blasting or by brushing with a wire brush. When a blasting process is used, the materials should be brazed as soon as possible after blasting. If a pickling process is required, a solution of 7·5 per cent (by volume) Sulphuric Acid (S.G. 1·84), maintained at a temperature of 70°C in a lead or rubber-lined tank, is suitable. An inhibitor should be added to the solution at the rate of 1 oz. per gallon of concentrated acid.

7.1.2 **Non-Corrodible and Heat-Resisting Austenitic Stainless Steels.** The area to be brazed may be prepared by an alumina-blasting process or by brushing with a brush having stainless steel bristles. The materials should not be prepared for brazing by blasting with crushed steel shot. If a pickling process is required, a solution of the following composition is suitable:–

Hydrofluoric Acid	3·4 to 4·0 per cent (by weight)
Ferric Sulphate	10 to 15 per cent (by weight)
Water	Remainder

The solution should be contained in a lead-lined tank and should be maintained at a temperature of 60°C.

7.2 **Nickel Base Materials.** The areas to be brazed may be prepared by an alumina-blasting process or by brushing with a brush having stainless steel bristles. After mechanical cleaning, the edges to be brazed should be wiped with a suitable solvent. These materials should not be prepared by blasting with crushed steel shot. If pickling is necessary, it must be ascertained that the process used is satisfactory for the material in question, since an intercrystalline attack may result from the use of an incorrect solution.

7.3 **Aluminium and Aluminium Alloys.** The surfaces to be brazed should be prepared either by abrasive blasting with alumina grit or by brushing with a brush having nylon bristles. The use of brushes having copper alloy bristles should be avoided, since, should pieces of bristle become embedded in the surface, there is a danger of bi-metallic corrosion.

7.3.1 If an etching process is required, a solution of the following composition is recommended:—

Sulphuric acid (d = 1·84)	150 ml/l
Chromic acid	50 g/l
De-mineralised water	Remainder

The solution should be maintained at 60°C. Components should be immersed in the solution for 30 minutes, then thoroughly washed in cold water and dried.

7.4 **Copper and Copper-Based Alloys.** The surface may be cleaned by mechanical means such as alumina abrasive blasting or the application of abrasive cloths. Care should be taken to remove only the surface film and not to reduce the thickness of the material when cleaning is effected with abrasive cloth, final cleaning with a solvent being recommended in either case. The parts may also be etched by immersion for two minutes in an aqueous solution containing sulphuric acid (40 ml/l) and sodium dichromate (200 g/l).

8 BRAZING METHODS Capillary attraction is the major factor in making a brazed joint, and although, in theory, there is no limit to the extent of penetration by capillary attraction, in practice this is dependent on the dimensions of the joint. The best results are obtained where a joint gap of 0·05 mm to 0·1 mm (0·002 inch to 0·004 inch) is used.

8.1 If the optimum joint gap is to be maintained during the heating operation, allowance must be made for the different expansion coefficients of the component metal used in the assembly. However, if the joint gap varies from the ideal, and is, for example, up to 0·2 mm (0·008 inch), an alloy which remains plastic over a greater temperature range should be used, but such an alloy will not have the penetrating power of those normally used for standard gaps.

8.2 **Heat Application.** The methods of applying heat most commonly used in brazing may be classified into four categories, i.e. induction, resistance, furnace and torch, and are described in paragraphs 9 to 12 respectively; flux dip brazing is described in paragraph 15.4.3.

9 INDUCTION BRAZING In this type of heating the parts to be brazed are placed within the influence of the magnetic field of a coil which carries high frequency alternating current. The heating effect is rapid and, by careful design of the induction coil, the heat can be closely localised to minimise distortion, grain growth and oxidation. Since the heating effect is influenced by the thermal conductivity and electrical resistance of the component, copper and similar materials will take longer to heat up than materials such as iron or nickel. This method is particularly suitable for high speed brazing of ferrous materials in production line quantities but, because of the high cost of the equipment and the need to design special coils for each particular job, it is not often used for small quantity work.

9.1 Induction machines often employ a valve type generator with outputs of up to 15 kVA at frequencies ranging from 100 kHz to 3 MHz, and are usually fitted with timing mechanisms to control the actual heating time. The coils are usually made from copper tube through which water is passed for cooling purposes but solid copper coils may also be used.

9.2 In order to take advantage of the speed of induction brazing, paste flux and pre-placed filler alloy are often used, but, in some instances, e.g. when brazing titanium pipe fittings, brazing may be carried out in an argon atmosphere, and no flux is required.

10 RESISTANCE BRAZING Resistance brazing is often used where precisely localised heating is required to prevent loss of mechanical properties throughout the parent metal. A high electrical current of low voltage is passed through a resistive circuit so that the heat developed in the circuit raises the temperature in the joint area to the brazing temperature. There are two main methods in use, carbon resistance heating and interface heating.

10.1 In carbon resistance heating the electrodes are made from carbon, which has very high resistivity and heats up quickly. The electrodes are in direct contact with the area to be brazed and heat is conducted into the workpiece where the temperature is raised sufficiently to melt the brazing alloy and form the joint. Since the temperature of the electrodes is very high, some marking of the surface of the workpiece may result, but this can often be alleviated by the use of pulsed current.

10.2 In interface resistance heating the electrodes are made from, or faced with, a material of relatively low resistivity. Most of the heat is developed through the resistance to the passage of current at the electrode/work interface, and some is also developed in the work itself because of its resistivity. The amount of heat in the workpiece itself is substantially higher than in the carbon electrode method.

10.3 With resistance brazing direct heating is often used, the workpiece being gripped between the electrodes at the position where heating is required. In some cases, however, indirect heating may be used, both electrodes being located on one side of the largest component and the smallest component being heated by conduction.

11 FURNACE BRAZING The main advantages of using a furnace for brazing are that high rates of output can be achieved, uniform results obtained and an inert or reducing atmosphere used to prevent oxidation. This method is particularly suitable for large batches of small articles which are self-locating or easily jigged, or for parts likely to distort through uneven heating.

11.1 Steel or nickel alloys can be successfully furnace brazed using a copper or bronze filler alloy. Brazing is usually carried out in a controlled atmosphere of cracked ammonia, town gas or hydrogen, and flux is not normally required although it may be recommended in some cases.

11.2 Furnace brazing of aluminium and aluminium alloys is widely used. Brazed joints may be made between aluminium and aluminium alloy parts either by the use of inserts of aluminium brazing alloy, or by using sheets with an integral coating of brazing alloy. The use of a suitable flux is essential. Since the difference in melting temperature between the filler and the basis metal is very small, close control of the furnace temperature is most important.

12 TORCH BRAZING The brazing methods previously mentioned all require a high initial outlay or are only suitable for specialised tasks; they are, therefore, mainly used for large quantity brazing. Brazing by means of a hand torch, although requiring a skilled operator, is inexpensive and is widely used for all types of work.

12.1 A wide variety of gas mixtures is suitable for torch brazing. Oxygen may be combined with acetylene, hydrogen, propane or coal gas; air with propane, butane or methane; or compressed air with coal gas. Of these the most commonly used are oxygen/acetylene and compressed air/coal gas.

12.1.1 The selection of a gas for a particular job depends on the size of the component, the temperature required and the rate of heating required, but account must also be taken of the likelihood of overheating, with consequent excessive oxidation and the possible loss of physical properties in the component.

12.1.2 A mixture of compressed air and coal gas burns at approximately 1000°C and is especially suitable for preheating components and for brazing components of light construction, while an oxygen/acetylene mixture burns at temperatures up to 3000°C, and is used where high rates of heating are required.

12.2 **Brazing Process.** It is recommended that before heating is commenced, flux should be applied in the form of an aqueous paste, both to the joint area of the assembly and to the filler alloy. Where the duration of heating or the size of the joint makes it necessary to add flux during the brazing operation, such additions are best made by dipping the hot end of the filler rod or strip into dry flux. If the overlap of a joint exceeds $4\frac{3}{4}$ mm ($\frac{3}{16}$ inch) the surfaces should be coated with flux prior to assembly.

12.2.1 In all cases rapid heating of the joint is essential, and the flame must be adequate for this purpose, but care must be taken to avoid overheating. When an oxy-acetylene flame is used, a larger jet should be employed than that used for the welding of similar material of similar thicknesses. The envelope of the flame should be kept constantly on the move over as large a portion of the joint as possible, since a static flame is likely to cause local overheating and loss of heat control.

12.2.2 Heating should be started with the torch held several inches from the work so that the outer flame envelope spreads over a large area of the joint. Where parts of unequal thickness are brazed, the flame should be concentrated on the heavier part to ensure uniform heating.

(i) As heating is continued, the flux first bubbles then settles down to a thin clear liquid. When this stage is reached, the work is approaching the correct temperature for application of the brazing alloy.

(ii) The brazing filler strip or rod should then be placed in contact with the joint, but if the filler does not melt on contact with the work, it should be removed and the heating continued until the correct temperature is reached. The filler must not be melted by the flame and so allowed to drop on the work; heat should be applied to the work, and the heat from the work used to melt the filler.

12.2.3 When the brazing alloy melts in contact with the assembly, the feeding in of the strip should be continued until the joint is slightly overfilled to allow for shrinkage on solidification. When this stage is reached and the molten filler has had time to penetrate the joint fully, heating should be discontinued. Unless the work has sudden changes of section, or is an assembly of metals of widely different expansion characteristics, and if there is no specific instruction on the drawing, it is usual to quench in water after the filler has set. (See paragraph 2.4).

12.2.4 **Oxy-acetylene Flame.** A neutral flame should be used in all instances, except when copper-zinc, copper-zinc-silicon or copper-zinc-nickel-silicon filler alloys are employed, when a slightly oxidising flame is necessary.

(i) An oxidising flame is produced by excess oxygen giving a considerably smaller inner flame than that obtained in the neutral condition.

(ii) A neutral flame is composed of an equal amount of both oxygen and acetylene, giving a clearly-defined inner flame.

(iii) A reducing, or carburizing, flame is produced by an excess of acetylene in proportion to oxygen, giving a furry edge to the inner flame.

12.2.5 The appearance of the various flames is shown in Figure 1.

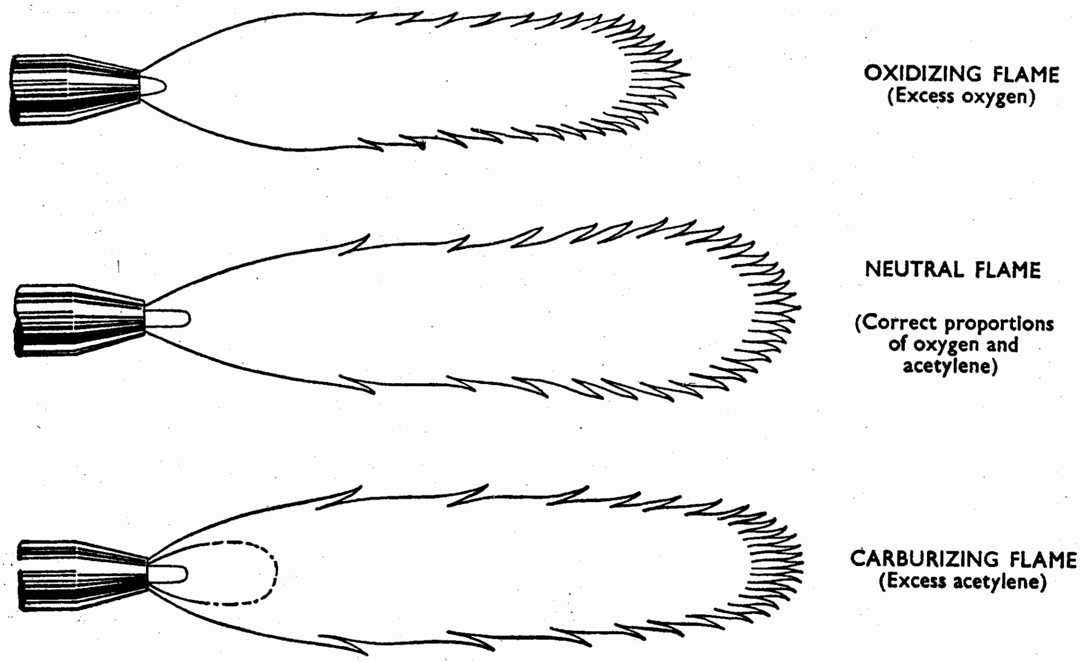

Figure 1 FLAME ADJUSTMENT

12.3 **Torches.** Brazing torches vary in design according to the gas used. When oxy-acetylene is employed, a welding torch, together with the normal welding equipment, is used, the flame being adjusted to suit the brazing work in hand. Information on this equipment will be found in Leaflet **BL/6-4,** Oxy-acetylene Welding.

12.3.1 There are several types of torches available for brazing with coal gas and air. Brazing torches are designed for lightness and balance to avoid physical strain on the operator. Flame control is obtained by various means, such as two adjustable levers, knurled knobs or, in some instances, a spring-loaded trigger-type of lever.

12.3.2 A typical brazing or braze welding hand torch embodies the following features: (a) quick action valves with conveniently placed thumb control for the gas and air supplies; (b) a built-in economiser that cuts off the gas and air supply when the operator's grip is relaxed, and restores the flame when the torch is again grasped; this same control enables a soft warming-up flame to be obtained by partial operation of the lever; (c) a pilot flame adjustable to suit different gas pressures; (d) several interchangeable flame units to provide various flame characteristics to suit a wide range of work and gas combinations.

12.3.3 Air is supplied by an electric blower, a foot operated bellows, a compressed air bottle, or the normal factory supply suitably regulated to the required pressure.

12.3.4 **Fixed Torches.** A logical development of the hand torch is to use fixed burners stationed around a turntable, conveyor belt or similar equipment. Conventional torches are used, but special burners have been developed for this purpose. Compressed air and coal gas are fed to the burner, which comprises a series of fine jets. This produces a flame which does not 'bounce' and has a good depth of heating. These arrangements are commonly fitted with electric timers.

13 BRAZE WELDING Braze welding, also known as bronze welding, is a process suitable for use with metals of high melting temperature, in which the main strength of the joint is obtained by building up a fillet of filler alloy. No fusion of the basis metal takes place, but some penetration of the filler alloy into the joint gaps may occur through capillary action.

13.1 Filler rods for braze welding are specified in BS 1724, and are basically a copper/zinc alloy, but may contain quantities of nickel, manganese, silicon or tin, depending on the metals being joined.

13.2 **Fluxes.** Proprietary types of fluxes are used, usually on the recommendation of the manufacturer of the braze welding rod. Fluxes should only be applied after the joint has been suitably prepared as detailed in paragraph 7.

13.3 **Torches.** Because of the high temperatures required for braze welding, an oxy-acetylene torch is normally used.

14 FLUX REMOVAL Flux residue is likely to promote corrosion when exposed to atmospheric moisture. The residue cannot be neutralised and should be removed from brazed joints by either chemical or mechanical means, removal being facilitated by the use of adequate amounts of flux and by the avoidance of overheating or prolonged heating during the brazing operation.

14.1 **Aluminium and Aluminium Alloys.** The following procedure may be used for removing flux residue from joints in aluminium or aluminium alloy assemblies:—

(i) Wash in boiling water for 10 to 60 minutes according to the complexity of the assembly, preferably in a bath through which there is a continuous flow of water.
(ii) Rinse in clean hot water.
(iii) Wash in a solution of 10 per cent nitric acid in water at a temperature of 65°C for 20 minutes.
(iv) Rinse in water and inspect visually for signs of flux residue.

If flux residue is still present, continue as follows:—

(v) Immerse for up to 30 minutes in a second nitric acid bath to which 1 to 5 per cent sodium dichromate may be added.
(vi) Rinse in clean hot water, drain and dry.
(vii) Inspect for flux residue and, if necessary, repeat operations (v) and (vi).

14.2 **Materials Other than Aluminium.** Where no harmful effects can occur, flux removal is assisted by quenching the work in water as soon as the filler has solidified, but where the component parts of an assembly are of dissimilar materials or have sudden changes in section, they should be allowed to cool before washing. (See paragraph 2.4). The parts should then be thoroughly dried to avoid the possibility of corrosion.

14.2.1 **Fluoride Fluxes.** Washing in water, followed by brushing with a wire brush, will generally remove the residue of fluoride fluxes, especially if hot or boiling water is used. In difficult cases, soaking in a cold solution of 5 per cent (by volume) of sulphuric acid (SG 1·84) in water, followed by a thorough washing in water and subsequent brushing, will facilitate flux removal, but it will be necessary first to ensure that such an operation will not prove harmful to the finished work, e.g. by entrapment of the solution.

14.2.2 **Borax Fluxes.** Residues of these fluxes are only slowly soluble in water; they may be removable by the methods specified in paragraph 14.2.1 but mechanical methods such as shot or grit blasting are sometimes necessary. In instances where mechanical methods are impractical the manufacturer may recommend that residues be dissolved in a hot caustic soda solution.

15 BRAZING ALUMINIUM AND ITS ALLOYS

There is a distinction between brazing aluminium and brazing of other metals. For aluminium and its alloys, the filler metal is of the aluminium-silicon type with a melting point only slightly lower than that of the basis metal. Consequently there is a much smaller margin (compared with the brazing of other materials) between the melting point of the filler and the temperature at which overheating and collapse of the basis metal can occur; accurate control of temperature is therefore most important.

15.1 BS 1845 gives a list of the filler materials which are suitable for brazing aluminium and its alloys. Some of the basis metals which can be brazed easily are the various grades of pure aluminium, and some of the alloys of aluminium and magnesium or aluminium, magnesium and silicon. The brazing of alloys containing more than 2 per cent magnesium is not recommended because of the difficulty of removing the oxide film.

15.2 Many types of proprietary fluxes are available for brazing aluminium and its alloys; these are generally of the alkali halide type, and the recommendations of the manufacturer of the filler material, regarding their use, should be observed. A standard aluminium brazing flux containing chlorides of sodium, potassium and lithium gives satisfactory results when used with aluminium which has been chemically cleaned. (See paragraph 7.3).

15.3 Most fluxes for aluminium and its alloys absorb moisture very rapidly, and their efficiency is reduced accordingly. It is essential, therefore, that fluxes should be stored in airtight containers. Containers manufactured from aluminium or glass are suitable for this purpose, but steel or brass should not be used, since these materials cause contamination.

15.4 **Brazing Process.** The three main methods of brazing aluminium and aluminium alloys are: torch or flame brazing, furnace brazing and flux dip brazing.

15.4.1 **Torch Brazing.** In torch brazing, acetylene and hydrogen are the preferred fuel gases, although other gases, e.g. coal gas, are used; all these gases are often used with oxygen.

(i) A brazing torch, which is often a standard welding torch, is suitable for most aluminium brazing work. The flame must be maintained in a neutral condition, but should this prove difficult, a slightly reducing flame is preferable to an oxidising flame (see Figure 1).

(ii) When using oxy-acetylene the possibility of overheating must be kept in mind. The melting point of the filler alloy must occur before the temperature of the joint causes sagging or plasticity of the basis metal.

15.4.2 **Furnace Brazing.** Furnace brazing requires a temperature control of $^{+5°C.}_{-0°C,}$ over a range of 540°C to 650°C, according to the material being brazed. The general requirements for brazing aluminium are, a rapid rise in temperature, a short period at the brazing temperature, and a rapid cooling to below the solidifying temperature of the brazing alloy. Any heat-treatment furnace giving such conditions, and having its linings protected from attack by flux, is suitable.

(i) A high rate of heat input ensures that the work is raised to the brazing temperature rapidly and so prevents excessive alloying between the filler metal and the basis metal. An even distribution of the heat throughout the chamber is a definite advantage. No useful purpose is served by having an inert or reducing atmosphere in the furnace.

(ii) As a general guide to timing, light gauge sheets take 2 to 6 minutes from the time the brazing temperature is reached until the filler metal has filled the joint area, and 4 to 15 minutes for complete furnace treatment; heavier sections may take up to half-an-hour for the complete furnace treatment.

(iii) Heat-treatable alloys must be reheated and quenched at the appropriate temperature to restore their properties, although quenching from the brazing temperature results in partial restoration. Quenching also loosens and partly removes the residual flux, thereby simplifying the final cleaning process. Thin gauge materials may become distorted if quenched by immersion, and water sprays may be used to minimise this by ensuring that all parts are cooled simultaneously.

15.4.3 **Flux Dip Brazing.** Flux dip brazing is used largely in the quantity production of assemblies having a large area of jointing in relation to their size, for example, heat exchangers or radiators, and is useful for the brazing of parts in an inaccessible position which cannot be brazed by other methods. This process is suitable for any aluminium alloy that is suitable for furnace brazing.

(i) Components should be cleaned, assembled with pre-placed filler material and heated in a furnace to a temperature just below the melting point of the filler alloy.

(ii) Assemblies should then be transferred to a bath containing molten flux at a temperature high enough to melt the filler, but not the parent metal; they should be removed as soon as the filler has had time to flow freely through the joints. Overlong immersion may result in flux attack and allow excessive diffusion between the filler and parent metal.

(iii) Heat-treatable assemblies should then be quenched or re-heated as described in paragraph 15.4.2 (iii).

15.5 **Flux Removal.** The quick removal of flux after brazing is essential; immediately the assembly can be handled, it should be treated as described in paragraph 14.

15.6 **Properties of Brazed Aluminium Joints.** As the brazing temperature is higher than the recrystallisation temperature of aluminium and aluminium alloys, annealing takes place during brazing.

15.6.1 Brazed assemblies made of non heat-treatable alloy have their design strength based on the strength of the annealed material.

15.6.2 Suitable assemblies made of heat-treated alloy of the aluminium-magnesium-silicon type may be strengthened after brazing by quenching, followed by natural or artificial ageing according to the requirements of the specification. Alternatively, assemblies may be re-heat-treated to restore the full strength of the basis material.

15.6.3 Aluminium filler alloy does not show a significant increase in strength after heat-treatment and limits the design strength of a brazed assembly.

16 HIGH NICKEL ALLOYS These alloys are usually specified for their heat and corrosion resistant properties.

16.1 Most of the high nickel alloys can be readily joined by silver brazing, but may be subject to intercrystalline penetration by the filler alloy if brazed in a state of stress. When high melting point filler alloys are used all stresses are relieved during the brazing process but, if low melting point filler alloys are used on heavily worked components, stress cracking may result if the components are not stress-relieved prior to brazing. Nickel alloys should normally be brazed in the annealed condition.

16.2 **Cleanliness.** Cleanliness is essential, and it is particularly important that all foreign matter which might contain sulphur or lead is removed before any heating takes place, as all nickel alloys are subject to some degree of attack by intercrystalline penetration by these elements, resulting in embrittlement. Possible sources of such contamination are: oil, grease, paint, marking pencils and cutting lubricants. Cleaning should be carried out just before the actual brazing operation. The tenacious oxide film requires vigorous treatment for its removal, particularly on the chromium-containing alloys, and especially after long storage. Mechanical methods, such as grinding, buffing, etc., are generally used, but chemical cleaning may also be employed. (See paragraph 7.2).

16.3 **Brazing Materials.** Silver brazing alloys complying with the AG series of filler alloys in BS 1845 are readily available and are recommended for use with nickel alloys. The flux should be of a type recommended by the manufacturer of the filler alloy; borax is not a satisfactory flux for this material. The flux is generally mixed with water and applied with a brush but, alternatively, the parts may be coated with flux and assembled whilst wet. Flux residue must be removed as described in paragraph 14.2.

16.4 **Heating.** Any of the methods of heating previously described may be used with nickel alloys. The hand torch method may be applied to most work, but particular care is necessary when using an oxy-acetylene torch, as the flame can easily produce temperatures well above those required for silver soldering and may overheat the basis metal.

17 HIGH TEMPERATURE BRAZING Where joints are required to retain their strength and corrosion resistance at elevated temperatures, high temperature brazing may be used.

17.1 Brazing alloys containing palladium or nickel are widely used for joining the Nimonic and Inconel types of alloys; these brazing alloys make joints which combine good mechanical properties at high temperatures with a high resistance to oxidation.

17.2 **Brazing Methods.** Brazing is usually carried out in a vacuum furnace or in a furnace containing an atmosphere of cracked ammonia or hydrogen, but salt bath or induction heating may also be used. Except when vacuum brazing, a flux should normally be used, but if, because of the difficulty of removing the residue, the use of a flux is undesirable, components are sometimes electro-plated with nickel before being brazed.

18 BRAZING STAINLESS STEEL Stainless steel parts are often joined by brazing. The method is adaptable to repetitive techniques and provides a simple means of making joints which are often as strong as the parent metal.

18.1 The success of the brazing operation depends on the use of a suitable stainless steel alloy and on the selection of a suitable filler and flux.

18.1.1 When stainless steels are heated, the formation of chromium carbide within the metal reduces the amount of chromium available and may decrease its resistance to corrosion. This effect is known as weld decay and has been largely overcome by the use of 'stabilised' steels containing titanium or niobium. If it becomes necessary to braze unstabilised stainless steels the effects of carbide precipitation may be minimised by keeping the brazing temperature and heating time to a minimum.

18.1.2 Joints in nickel-free stainless steel often suffer from a defect known as crevice corrosion when subjected to conditions of high humidity. Silver brazing alloys are generally employed where this type of corrosion is likely.

18.1.3 Nickel brazing alloys and alloys containing palladium and gold have been found particularly suitable for furnace brazing in a protective atmosphere, the resulting joints being resistant to chemical attack and crevice corrosion. Bronze filler alloys may also be used but are less resistant to chemical attack.

18.1.4 Fluoride fluxes are normally used when brazing with silver brazing alloys, but special fluxes with improved wetting properties are often recommended for use with stainless steel because of the formation, during brazing, of a thin film of residue which is insoluble in normal flux.

18.1.5 Flux residues should be removed as described in paragraph 14.2.

19 SAFETY PRECAUTIONS All brazing operations involve the use of flame or heat and the handling of metals at high temperatures; it is necessary, therefore, that certain simple safety precautions are observed. Additional precautions are necessary because of the use of alloys or fluxes, which may have toxic properties under certain conditions.

19.1 **General Precautions.** Components may retain their heat for a considerable period after brazing and should always be handled with care. Unless asbestos gloves are worn, unquenched parts should always be handled with pliers or tongs.

19.1.1 Torches should always be pointed away from the operator when being lit and should be lit either from the side or from below. If possible, hand torches should be fitted with a switch hook, in which a pilot jet and hook are connected to a valve in the gas supply. When the torch is hung from the hook, its weight cuts off the main gas supply but when it is picked up the flame relights.

19.1.2 Controlled atmosphere furnaces often have a curtain of burning gases at the entry and exit doors. These flames are often nearly invisible under certain light conditions and particular care may be necessary when inserting or removing components.

19.1.3 Hand torch brazing should always be carried out in a location shielded from flammable materials by refractory bricks or asbestos.

19.2 **Induction Brazing.** Metal articles heat up very quickly when placed within an induction coil. For this reason the hands should not be placed in a coil if a ring, watch or bracelet is worn, as severe burns could result.

19.3 **Salt Baths.** Molten salts splashed from a salt bath may cause very severe burns; protective clothing, including overall, gloves and goggles, should always be worn when working with a salt bath. Components must be completely dry before being immersed in the bath and must be lowered very slowly into the salts to prevent splashing. Salt residue should always be scrubbed from the hands before handling food.

19.4 **Brazing Alloys.** Most silver brazing alloys contain zinc or cadmium which, if overheated, give off fumes which may be irritating and injurious to health. Adequate ventilation must be provided when brazing with these alloys and overheating must be avoided.

19.5 **Fluxes.** Most brazing fluxes cause skin irritation, and physical contact should be avoided whenever possible. The hands should be washed frequently and a barrier cream used. In the event of flux being swallowed, medical attention should be sought immediately.

20 INSPECTION In order to obtain the most successful brazed joints, close control of all operations is essential. The design, manufacture and cleaning of the component parts of the joint, the brazing alloy and flux used, the heating process selected, the method of removing flux residues and the application of any necessary heat treatment, should all be in accordance with proven methods and substantiated by the manufacture and testing of sample joints.

20.1 Adequate control of the heating method is essential, particularly for induction heating, resistance heating and furnace heating, and staff should be competent to ensure that consistent results are obtained. Hand torch operators should have their work checked at frequent intervals. (See paragraph 4).

20.2 At specified intervals a completed assembly should be selected and subjected to strength tests and sectioning to ensure that the complete brazing operation remains satisfactory.

20.3 The following points should be checked when visually inspecting a finished joint:—

(i) The joint and surrounding surfaces should be free from pitting, corrosion, scale, flux residue and other evidence of bad workmanship.

(ii) The filler alloy must have penetrated throughout the joint. In the case of pipe joints an examination should be made for excessive penetration which may partially obstruct the pipe bore.

(iii) Fillets of filler alloy should be smooth and continuous.

(iv) The dimensions of the assembly should be in accordance with the appropriate drawing.

20.4 A visual examination may sometimes be insufficient to establish that the filler alloy has penetrated through the joint. In these cases, X-ray, ultrasonic or eddy current inspections may be required.

20.5 In some instances, brazed joints which have been found unsatisfactory, may be re-brazed under suitably controlled conditions. Care is necessary to prevent the build up of an excessive amount of filler alloys, particularly in the case of pipe joints (paragraph 20.3 (ii)).

BL/6-4

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BASIC

ENGINEERING PRACTICES AND PROCESSES

OXY-ACETYLENE WELDING

1 INTRODUCTION This Leaflet gives general guidance on the welding of ferrous and non-ferrous metals by the oxy-acetylene process. It should be read in conjunction with the approved drawings and any related instructions for the welding operation(s) concerned.

NOTE: The term 'welding' is used to describe the joining of metals in which local fusing of the metals is a basic process.

1.1 Information on other welding processes will be found in the following Leaflets:—

BL/6-5 Arc Welding
BL/6-12 Resistance Welding—Spot Welding
BL/6-16 Resistance Welding—Seam Welding
BL/6-17 Resistance Butt and Flash Welding

NOTE: Information on Bronze Welding (sometimes known as Braze Welding) will be found in Leaflet **BL/6-2.**

1.2 The CAA requirements for the approval of welders are prescribed in Section A of British Civil Airworthiness Requirements.

2 THE WELDING PROCESS In the oxy-acetylene welding process, oxygen and acetylene gases are fed through a welding 'blowpipe', the pressures and quantities of each being separately adjustable. The jet of mixed gas is ignited, and produces a flame with a temperature of approximately 3100°C (5600°F), which is used to melt the adjacent material of the parts to be joined. Filler rods are normally used for materials of 0·9 mm (20 s.w.g.) and thicker, and a flux is generally used to remove oxides from the surface of the metals and to ensure a sound weld; different materials require different filler rods and/or fluxes.

2.1 The oxy-acetylene welding process should not normally be used for welding magnesium or high-nickel alloys, and is not recommended for stainless steel; inert gas or plasma arc welding are more suitable for these materials.

2.1.1 The relevant approved drawings and any related instructions on the welding operations should be closely followed. The following details are generally provided on the drawing(s):—

(a) Specification of the material(s) to be welded.
(b) Specification of filler rod.
(c) Type of flux.
(d) Details of joint preparation and cleaning procedure.
(e) Welding instructions (e.g. tack weld, clamp, starting position).
(f) Heat treatment and removal of flux.
(g) Inspection and any related tests.

3 WELDING EQUIPMENT Paragraphs 3.1 to 3.6 contain information of a general nature on the control, use and care of welding equipment.

3.1 **Gas Cylinders.** Special precautions are taken with oxygen and acetylene cylinders to ensure that confusion of identity cannot occur. Oxygen cylinders are painted black and have a right-handed valve thread, whilst acetylene cylinders are maroon in colour and have a left-handed valve thread. In addition, the cylinders are produced in distinctive shapes as shown in Figure 1.

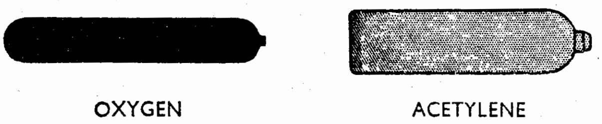


Figure 1 CYLINDER IDENTIFICATION

3.1.1 Gas cylinders should be stored in the upright position in well ventilated rooms. Those standing in the open should be protected from extremes of temperature and should not be placed on wet soil.

3.1.2 Oxygen cylinders, valves, etc., should not be handled with greasy hands or greasy gloves, neither should any part of the welding equipment be lubricated with oil or grease, since these materials ignite spontaneously when in contact with oxygen under pressure.

3.1.3 Acetylene can form explosive compounds when in contact with certain metals and alloys (e.g. copper and silver), it is, therefore, important that all fittings through which acetylene is to flow have been designed specially for that purpose.

3.2 **Gas Generators.** Where acetylene gas generators are in use, a daily check for gas purity is necessary. Blotting paper soaked in a 10% aqueous solution of silver nitrate should show no darkening when placed in the gas stream.

3.3 **Gas Feeding System**

3.3.1 Oxygen vigorously supports combustion, but since it has no smell it is difficult to detect. Conversely, acetylene has an unmistakable smell and will ignite and burn instantly from a spark or even a piece of heated metal. It is clear that a dangerous condition could arise as a result of leakage in equipment, particularly in confined spaces, and the feed system should be checked periodically to ensure freedom from leaks. Tests for leaks should be made with soapy water and a brush, and not with a naked flame.

3.3.2 Pressure gauges should be checked periodically against a master instrument to ensure accuracy, and a record should be kept of these checks.

3.3.3 To avoid any possibility of confusion, it is usual for black hoses fitted with right-hand threaded connections to be used with oxygen equipment and red hoses fitted with left-hand threaded connections to be used with acetylene equipment.

3.4 **Blowpipes.** The selection of the proper blowpipe nozzle for the work in hand is largely a matter of experience. The various factors which govern the size of the nozzle include the nature of the work, the thickness and type of material and the skill of the welder. The instructions issued by the manufacturer of the equipment give the best guidance in this respect, but it is recommended that nozzles be checked periodically to ensure that they continue to conform to nominal dimensions.

3.5 **Lighting the Blowpipe.** Before lighting the blowpipe the regulators must be set to the correct pressures and the light must be applied only when a flow of gas is properly established, otherwise a flash-back may occur. The use of a spark lighter is recommended.

3.5.1 It is important that the instructions given by the manufacturer regarding the correct procedure for lighting up and operating the equipment, and the safety precautions to be taken in the event of a cylinder becoming heated due to a flash-back or other incident, should be followed. Failure to comply with such instructions and precautions may cause the cylinder to heat up and burst.

3.5.2 If the flame goes out when the blowpipe is in use, it may be caused by the regulator pressure and/or the gas flow being incorrect, obstruction of the nozzle, the nozzle being held too close to the work or to overheating of the nozzle. When this occurs both blowpipe valves should be closed. Only when the condition has been rectified should the blowpipe be re-lit. However, if the blowpipe nozzle has become overheated it should be plunged into cold water with the oxygen valve slightly open prior to re-lighting.

3.6 **Manipulation of the Blowpipe.** The essential factors in the manipulation of the blowpipe are careful adjustment to give the required types of flame and holding the blowpipe and welding rod at the most suitable angles for the work in hand. Other factors to be observed are the control of the heating period to obtain a neat and uniform weld bead, adequate penetration without excess heating or burning (especially with thin sheets of non-ferrous metals) and good fusion of the materials being joined.

4 MATERIALS Because of the wide choice of available materials it is impracticable within the scope of this leaflet to give a list of weldable metals. It is always essential to ensure that the material to be welded and the welding procedure used are those specified on the drawing.

4.1 **Filler Rods.** In general, filler rods are made of the same material composition as the metal to be welded but there are exceptions, thus the welding of aluminium alloys complying with different specifications with filler rods of the same composition could lead to cracking. Unless otherwise stated filler rods should comply with BS 1453 entitled 'Filler Materials for Gas Welding'.

4.1.1 Filler rods should be stored in a warm, dry atmosphere, to prevent the pick-up of moisture which can cause porosity in welds.

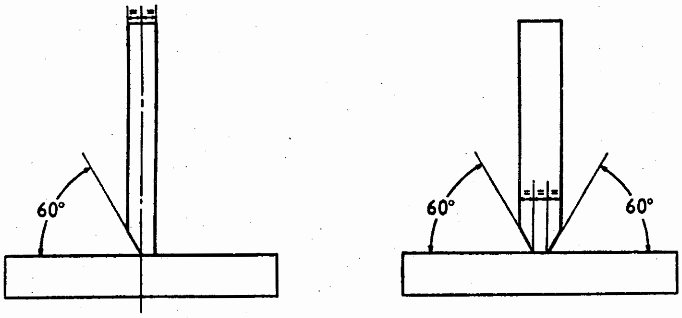
4.2 **Fluxes.** With most metals, except steel, the melting temperature of the metal is much below the melting point of the oxides formed by heating and therefore the oxides remain as solid particles. Flux reduces the effects of oxidation, floats oxides and other impurities to the surface of the weld where they do no harm, and produces a stronger weld. Fluxes are not used for the welding of carbon steels because the oxides of the various elements unite and form a slag at a temperature lower than that of the molten metal, the slag floating to the surface of the weld.

4.2.1 The oxides of different materials vary considerably in physical and chemical properties and no one type of flux is suitable for use with all materials. Unless otherwise specified, it is usual to use the flux recommended by the filler rod manufacturer.

4.2.2 Most welding fluxes absorb moisture readily and their efficiency is reduced accordingly; damp flux will also cause porosity in the weld. It is essential therefore that fluxes are kept in airtight containers. Containers made of aluminium or glass are suitable but steel or brass should not be used as these materials cause contamination of the flux.

5 JOINT PREPARATION It is usual for joints to be designed as simply as possible. Applications requiring the joining of metals of vastly dissimilar thickness are seldom specified since the heat required to bring the thicker material to the molten state may burn or melt away the thinner material.

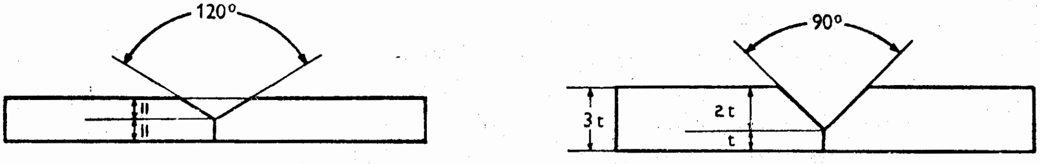
5.1 **Fillet Welds.** To ensure adequate strength and weld penetration, chamfered edges, prepared as shown in Figure 2, are usually required for materials of 1·6 mm (16 s.w.g.) and thicker. For materials in the thickness range of 1·6 to 2·5 mm (16 to 12 s.w.g.) a single chamfer, as shown in Figure 2(A), can be used to ensure satisfactory penetration in instances where welding from both sides is not possible, but for materials thicker than 2·5 mm (12 s.w.g.) a double chamfer, as shown in Figure 2(B), is usually required to provide the necessary strength. Materials thinner than 1·6 mm (16 s.w.g.) should be welded from one side only to avoid burning and weakening the material. Fillet welding of aluminium and aluminium alloys is not normally recommended because of the danger of flux entrapment which could lead to serious corrosion. However, if fillet welding of these materials is essential then the joint should be completely sealed.



(A) SINGLE FILLET WELD (B) DOUBLE FILLET WELD

Figure 2 PREPARATION FOR FILLET WELDS

5.2 **Butt Welds in Materials other than Aluminium Alloys.** Prepared edges are not usually required for materials thinner than 1·6 mm (16 s.w.g.) but to ensure weld penetration and adequate strength in thicknesses up to 3·2 mm (10 s.w.g.) it is usual to chamfer the two adjacent edges thus forming a 'V' with an included angle of say 120°, as shown in Figure 3(A). For thicker materials the edge preparation is usually as shown in Figure 3(B).



(A) (B)

Figure 3 BUTT WELDS

5.2.1 In butt welding flat sheet due allowance should be made for distortion. If the edges are placed together for their entire length, as welding proceeds they will first diverge then gradually pull together again until one edge will tend to ride over the other and make welding impossible; this can be avoided by tack welding at suitable intervals before starting the welding run.

5.3 **Butt Welds in Aluminium Alloys.** For materials thinner than 2·0 mm (14 s.w.g.) no edge preparation is necessary but it is usual to leave a gap equal to the thickness of the material between the edges of the two sheets. For materials thicker than 2·0 mm (14 s.w.g.) the edges are usually prepared as shown in Figure 3(B), except that the angle is smaller (say 60 to 70°) and a gap not exceeding one-third the thickness of the material should be left between the sheets.

5.4 **Welds in Tubular Sections.** The preparation of tube ends for welding will depend mainly on the gauge of the material and the design of the joint. Where tubes intersect, special instructions will be given on the drawings regarding the fit of the tubes.

5.4.1 The clustering of several tubes at a given point is normally avoided, as the large amount of welding and the resultant heat in a restricted space may cause cracks in the welds and may weaken the basic metal. Where weld concentrations of this kind are unavoidable the instructions often stipulate a stress relieving treatment.

5.4.2 Where a tube or a tubular structure is completely sealed (e.g. to prevent internal corrosion), a hole should be drilled in a specified position to allow the expanded hot air to escape. When welding has been completed and the work has cooled down, the hole should be plugged (e.g. by welding) to avoid ingress of moisture.

NOTE: Some tubular structures, such as engine bearers, are protected internally by the introduction of a corrosion inhibiting fluid after welding has been completed.

5.5 **Cleaning Surfaces for Welding.** All scale, grease, dirt, paint or other extraneous matter should be removed for a minimum distance of 25 mm (1 in) each side of the edges to be welded. The methods of cleaning will vary with the material concerned. Some typical cleaning methods are given in paragraphs 5.5.1 and 5.5.2.

NOTES: (1) When a pickling process is required for cleaning purposes, it is essential that the process to be used is approved by the Design Organisation concerned.

(2) It is imperative that suitable safety precautions are observed when handling the types of acid used in the pickling processes described in 5.5.1 and 5.5.2.

5.5.1 **Aluminium and Aluminium Alloys.** The edges to be welded should be prepared either by vacuum blasting or by brushing with a brush with stainless steel or nickel bristles. The use of brushes with copper alloy bristles should be avoided because of the corrosion hazard which could result from pieces of bristle becoming enbedded in the surface. Chemical cleaning methods may also be used as follows:—

(a) **Brush Application.** A typical solution for brush application would consist of de-mineralised water containing:—

Sulphuric Acid (d = 1·84)	5% (V/V)
Hydrofluosilicic Acid	2·5% (V/V)
Aluminium Sulphate	3 g/litre

(i) This solution must be kept in a rubber lined tank.

(ii) The pickling solution should be removed by thoroughly rinsing the part in cold water, and it is recommended that a jet of water is used for this purpose. The part should then be dipped in hot water to assist drying.

(b) **Bath Treatment.** To remove an anodic film the treatment specified in DEF 03-2/1 should be used as follows:—

(i) The parts should be immersed in a solution consisting of de-mineralised water containing:—

Sulphuric Acid (d = 1·84)	150 ml/litre
Chromic Acid (CrO_3)	50 g/litre

(ii) The solution, which should be kept in a lead-lined tank, should be maintained at approximately 60°C.

(iii) The etched parts should be washed as quickly as possible in cold water, and thoroughly dried.

5.5.2 **Steels.** The methods of cleaning steels vary with the type of steel concerned. In general, steels may be divided into two main groups: (a) low carbon and alloy steels, (b) corrosion-resisting or heat-resisting austenitic steels.

(a) **Low Carbon and Alloy Steels.** The edges to be welded may be prepared by sand, shot or alumina blasting or by brushing with a wire brush. Where a blasting process is used, the material should be welded as soon as possible to prevent corrosion.

(b) **Corrosion-Resisting and Heat-Resisting Austenitic Stainless Steels.** The edges to be welded can be prepared by an alumina blasting process or by brushing with a brush with stainless steel bristles. Blasting with crushed steel shot should not be used. A typical pickling solution for brush application would consist of:—

Hydrofluoric Acid	3·0 to 4·2% (W/V)
Ferric Sulphate	10 to 15% (W/V)
Water	Remainder

(i) The solution should be contained in a lead-lined tank and maintained at a temperature of 60°C.

(ii) The pickling solution should be removed by thoroughly rinsing the part in cold water, and it is recommended that a jet of water is used for this purpose. The part should then be dipped in hot water to assist drying.

6 WELDING JIGS The accurate assembly of welded parts may necessitate the use of special jigs which will be unaffected by changes in temperature.

6.1 The type of joint, the nature of metal to be welded, and accessibility are factors which influence the design of jigs. The jigs should permit free access to the area to be welded. The jig assembly should be fairly rigid, but not so rigid that the parts become stressed during cooling, and clearance should, therefore, be allowed for the expansion and contraction of the parts.

6.2 Where clamping or locking devices are incorporated in the jigs to control distortion, they should align the components to a degree of accuracy which does not permit the overall distortion to exceed the following:—

(a) 0·075 mm (0·003 in) in material thinner than 0·7 mm (22 s.w.g.).

(b) 0·125 mm (0·005 in) in material of thickness 0·7 to 1·2 mm (22 to 18 s.w.g.).

(c) 0·25 mm (0·010 in) in materials thicker than 1·2 mm (18 s.w.g.).

6.3 When tubular sections are to be welded, the parts should be correctly fitted into the jig in relation to one another. The jig should be so constructed that there is no possibility of misplacing the tubes from the intended position, otherwise uneven joints and unequal distribution of stresses may result.

7 STRESS AND DISTORTION During welding operations the parts are in varying conditions of expansion and contraction, and the adaptation of the sequence of welding operations to each particular application is important if stress concentrations are to be kept to a minimum.

7.1 The heat necessary to perform the welding operation can be reduced if the weld metal is run in thin layers and the welding speed is reduced by using the smallest flame consistent with correct penetration and fusion. (For aluminium welding see paragraph 8.3.6).

7.2 Reduction of localised heat can also be effected by welding in short lengths, either with each length ending where the previous one began, or with each length as far apart from the previous one as possible. With fillet welding, when welding is to be done on both sides, the metal may be deposited in short lengths on alternate sides.

7.3 When butt welding sheets, particularly when jigs are not available, distortion can be considerably reduced if the joint is 'tack' welded at suitable intervals prior to commencing the finishing weld.

8 WELDING ALUMINIUM ALLOYS The oxy-acetylene welding process is used mainly for aluminium alloy sheet which is less than approximately 2·0 mm (14 s.w.g.) thick; sheets of greater thickness are normally welded by the inert gas arc welding process (Leaflet **BL/6-5**).

8.1 The melting point of aluminium is low and heat is conducted rapidly through the material. There is very little indication, by physical or colour change, that the material is approaching the melting point and when this stage is reached the material suddenly collapses. The material is very weak at temperatures near the melting point and adequate support should be provided. However, rigid clamping should be avoided whenever possible, to reduce the risk of cracking due to contraction on cooling. Where rigid clamping cannot be avoided, a welding technique must be employed which will keep the stresses to a minimum.

8.2 **Application of Flux.** The flux may be prepared for application by mixing it with methylated spirit to a free-flowing consistency, and then applying it with a brush or dipping the filler rod into the mixture. The methylated spirit will dry off rapidly and will have no deleterious effects.

8.2.1 When it is necessary to apply dry flux to the filler rod, the end of the rod should be heated and dipped into the powder. The deposit of powder adhering to the rod should be melted and allowed to run over the rod surface for about 150 mm (6 in) of its length.

8.2.2 When welding alloys containing magnesium, it is recommended that, in addition to applying flux to the rod, a layer of flux paste should be applied to the edges of the work before welding is commenced. If possible, the flux should be applied to the underside also to ensure a smooth, oxide-free, penetrating bead.

8.3 **The Welding Process.** A slightly carbonising flame should be used since an excess of oxygen will cause the rapid formation of aluminium oxide. However, the excess of acetylene should not be too great as it will be absorbed into the molten metal and result in a weakening of the joint. A low gas velocity giving off a quiet hissing sound should be used. Frequent checks should be made to ensure that the correct type of flame is maintained.

8.3.1 The blowpipe nozzle is usually comparable to that used for steel of similar thickness, any increase or decrease in nozzle size being determined by the gauge and bulk of material involved.

8.3.2 To minimise the possibility of cracking and to reduce the effects of expansion, sheet material should be pre-heated by playing the flame over the joint area before welding. With thin sheets it is advisable to start the weld inside one edge of the work and to weld the short unwelded portion in the opposite direction later.

8.3.3 When starting to weld, the two joint edges should begin to melt before the filler rod is added. The work must be watched carefully for signs of melting, experience determining the proper time for adding the filler metal. The filler rod should be held in a direct line with the weld, with the flame near the material being welded. Both edges of the weld should receive an equal amount of heat, and the metal from the filler rod should fuse with the parent metal.

8.3.4 The blowpipe should be held at an angle of about 30° to the plane of the weld, the angle being decreased as the end of the weld is approached. The tip of the inner cone of the flame should be held closely over the weld and should not be moved up and down. This practice results in heating a smaller area of the joint and minimises the possibility of 'blowing' through, especially when welding thin sheets.

8.3.5 Any tendency to partial collapse or excessive penetration should be rectified by instantly lifting the flame well clear of the material and not by a gradual withdrawal, since this will only worsen the condition.

8.3.6 One of the main differences between aluminium welding and steel welding is in the speed of working. With aluminium welding, as the weld progresses and the metal becomes hotter, the rate of welding should be increased, but in any case the welding speed should be as fast as possible. Where practicable it is better to complete the weld in one operation.

8.3.7 When welding long seams, the material should be tack welded at frequent intervals, e.g. for material of 1·6 mm (16 s.w.g.) and thinner at 25 to 38 mm (1 to 1·5 in) intervals, and for materials between 1·6 and 2·5 mm (16 and 12 s.w.g.) at 75 mm (3 in) intervals. Tack welds should fully fuse the metal.

9 WELDING PLAIN CARBON AND LOW ALLOY STEELS

9.1 A neutral flame should be used (see Figure 4) and the inner cone should be held close to the material being welded. The blowpipe and welding rod should be held at angles of about 60° and 30°, respectively, to the plane of the weld.

NOTE: A completely neutral flame is difficult to recognise, and in order to avoid the detrimental effects of an oxidising flame, a flame carrying the slightest trace of excess acetylene should be used. This condition is obtained when the blue cone nearest the jet has a slight fringe or 'haze' of white flame.

9.2 Good fusion should be obtained evenly on each side of the weld; the rod should be fed into the molten metal and not melted off by the flame itself, otherwise too much material may be run and this will result in a reduction of temperature in the weld with consequent unsatisfactory fusion.

9.3 The welding rod should be of the correct size for the work in hand; if too large it will melt too slowly and produce excessive build up and poor penetration; if too small the rod will melt too quickly and cause difficulty in building up the weld.

10 WELDING CORROSION-RESISTING AND HEAT-RESISTING STEELS

10.1 The heat conductivity of corrosion-resisting steel is approximately 50% less than that of mild steel, whilst its coefficient of expansion is approximately 50% greater. Therefore, correspondingly greater allowance should be made during welding to prevent distortion.

10.2 A welding flame showing a faint haze of excess acetylene around the cone should be used to ensure non-oxidising conditions (see Figure 4) and frequent checks should be made to ensure that this condition is maintained. Excessive oxygen will produce a porous weld, while excessive acetylene will produce a brittle weld. A blowpipe nozzle comparable to that used for mild steel is recommended for light gauge sheet, and up to two sizes smaller than that used for comparable mild steel when welding thicker sections.

10.3 As the rate of heat conduction through the material is less than that of mild steel, the heat is localised and, to minimise the possibility of burning the material, the flame should be played over a larger area than usual. The tip of the inner cone of the flame should be kept very close to the surface but 'puddling' should be avoided. Care is necessary to prevent the flame penetrating thin gauge sheets. The welding rod should be kept in the flame throughout the welding operation, and on completion of the weld the flame should be withdrawn slowly to avoid cracking of the material.

11 REMOVAL OF FLUX Unless the flux is specifically approved as being non-corrosive, it is essential that all traces should be removed.

11.1 **Ferrous Metals.** Where size permits, flux can be removed from ferrous parts by immersing them in boiling water for a period of not less than 30 minutes, the water being changed frequently to avoid contamination. Where immersion is not practical, the parts should be washed until all traces of flux are removed. If the flux residue is brittle its removal is sometimes made possible by lightly tapping it with a hammer.

11.2 **Aluminium Alloys.** The fluxes used in welding aluminium alloys are highly corrosive, and the products of corrosion are also actively corrosive. The action is therefore progressive, and any trapped flux will continue to act until the material is penetrated.

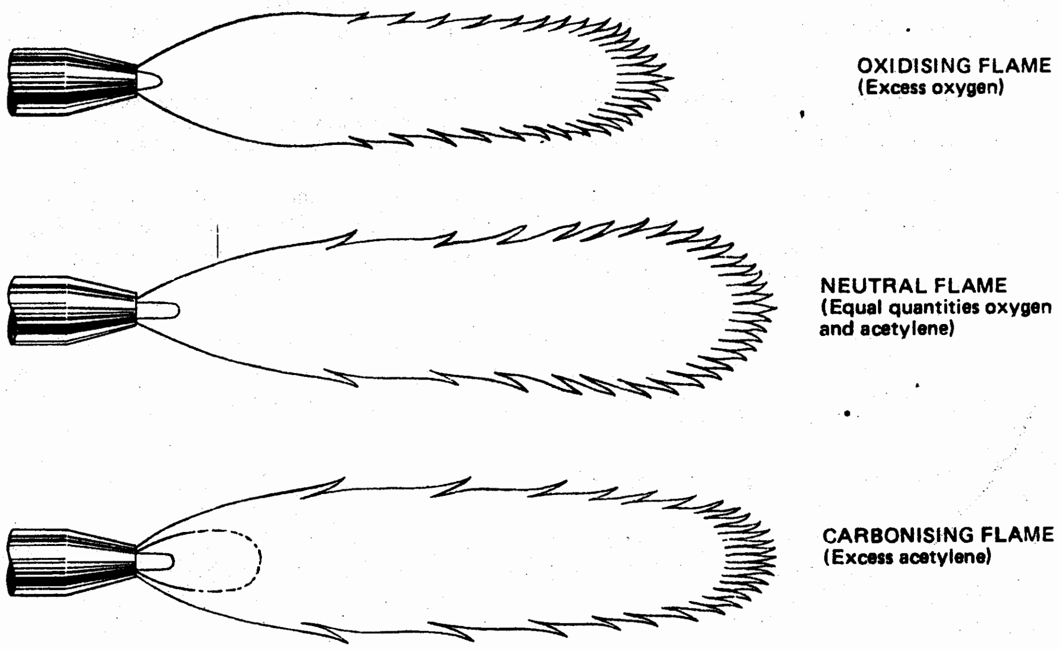


Figure 4 FLAME ADJUSTMENT

11.2.1 The flux should be removed by washing the parts in boiling water for a minimum of 30 minutes, changing the water frequently or using a continuous flow. The washing should be repeated until all traces of flux are removed. The parts should be finally rinsed in hot water and then dried.

11.2.2 Alternatively, flux may be removed by immersing the parts for 20 minutes in a solution of 10% nitric acid in water, maintained at a temperature of 65°C, after which they should be rinsed. The parts should be immersed in a second 10% nitric acid bath for up to 30 minutes, the time depending upon the amount of residual flux, after which the parts should be washed in hot water, drained, dried and inspected. If flux residue still remains, this treatment should be repeated.

NOTE: It may be an advantage to add a small proportion (1 to 5%) of sodium bichromate to the second nitric acid bath.

11.2.3 The efficiency of the final washing operation (whether or not acid treatment has been used) can be checked by adding a small quantity of silver nitrate test solution to a sample of the water in which the joint was washed. If a white precipitate appears it indicates that flux residues are still present and that further cleaning is necessary.

12 HEAT TREATMENT In general, steels having a carbon content in excess of 0·26% are liable to crack after welding unless suitable pre-welding and post-welding heat treatment procedures are employed. It is essential that when such steels are welded the heat treatment prescribed in the relevant specification or drawing is followed.

12.1 Where heat treatment of a welded part is necessary, the part, or a control sample heat treated with the part, should be mechanically tested to ensure that the physical properties of the material still comply with the requirements of the material specification or the drawing.

12.2 The local application of heat for the purpose of final heat treatment is not permitted, neither should attempts be made to correct distortion by the application of local heat without the agreement of the Design Organisation.

12.3 Parts made from carbon and low alloy steels, which can be used in the 'as welded' condition, are sometimes normalised, i.e. heat treated after welding with the object of refining the coarse grain structure in the weld and heat-affected areas.

13 INSPECTION The production of satisfactory welded joints depends on close supervision of the welding process and careful inspection of the completed weld. The depth of inspection of a particular weld will depend to a large extent on the use for which the part is required, and may include visual inspection, pressure tests, radiography, fluorescent or dye penetrant, or magnetic flaw detection. The types of inspection or tests to be carried out should be as stated on the appropriate drawings or manufacturer's instructions.

13.1 **Visual Inspection.** All welds should be subjected to a visual inspection, and this may be all that is required on structures which are neither highly stressed nor critical from fatigue considerations. A visual inspection should ascertain the following:—

(a) That fusion is satisfactory. Adhesion (i.e. as a result of the weld metal flowing on to the unfused parent metal outside the weld bead) may be caused by the use of too large a flame or careless manipulation of the blowpipe.

(b) There should be no undercutting where the weld metal joins the parent metal. The welded part must not be reduced in thickness by the welding operation.

(c) With butt welds, penetration should be obtained right through the joint; an under bead should appear through the full length of the weld.

(d) The build up of the weld should be satisfactory; a concave surface on the face of the weld will indicate lack of metal with consequent weakness.

(e) The weld should show regular surface ripples of close texture; it should be free from indentations, porosity, scale, slag or burn marks.

(f) The dimensions of fillet welds should be correct, especially the leg length (spread of the weld on each side of the joint) and the throat thickness (depth of the weld at the angled joint). Lack of corner fusion or 'bridging' is a common fault in fillet welds and can result in a weak joint; penetration of the weld through both sheets is also considered undesirable.

(g) A weld which has been inspected and subsequently dressed by filing, grinding or machining, as specified on the drawing, should be re-inspected on completion of these operations.

NOTES: (1) Welds in certain alloys are improved by hammering during cooling, but this should only be done if specified on the drawing or in the process specification.
(2) A visual examination may be carried out using a lens of low magnification.

13.2 **Additional Tests.** The type of examination applied to a weld subsequent to the visual inspection depends on the effect a failure would have, and whether the part is highly stressed or subject to fatigue. Any of the following examinations may be prescribed:—

(a) Fluorescent dye (Leaflet **BL/8-7**) or penetrant dye (Leaflet **BL/8-2**) are used to reveal surface defects and are an amplification of the visual examination.

(b) Magnetic flaw detection (Leaflet **BL/8-5**) is used on magnetic materials in preference to dye penetrants as it is more selective and will reveal defects not reaching the surface.

(c) Radiography, using X-rays or gamma rays (Leaflet **BL/8-4**), is used to reveal defects which are contained within the material and do not break the surface.

(d) Alternative methods of detecting hidden defects, including ultrasonic (Leaflet **BL/8-3**) and eddy current (Leaflet **BL/8-8**), may also be specified.

NOTE: In each case a technique suitable for the weld and the defects normally expected will have been decided upon, and should be carefully followed when carrying out an examination.

13.2.1 **Pressure Tests.** Pressure tests should be used on all welded pressure vessels, ducts and similar parts. The pressure to be used in a particular case should be as stated on the appropriate drawing.

14 SAFETY PRECAUTIONS Because of the intensity of the flame used in welding and the fumes given off by certain alloys at high temperatures, special precautions are necessary to safeguard operators. These precautions include the following:—

(a) All operators should wear protective clothing as a safeguard against burns from splashes of molten metal.

(b) All operators should wear protective face masks or goggles and should ensure that they are kept in a satisfactory condition.

(c) The precautions outlined in H.M. Factory Inspectorate Code of Practice for Health Precautions with regard to the welding of leaded steels, should be observed, as necessary.

(d) The heating of steels containing certain alloying elements can result in potentially dangerous fumes, and Department of Employment Technical Data Note 2/73 should be taken into account when welding these materials.

14.1 In addition to the precautions necessary during welding, the use of X-ray or gamma ray inspection methods also calls for the careful attention to safety precautions. These precautions are outlined in the Radioactive Substances Act and in the Ionising Radiations (Sealed Sources) Regulations. Radiographic inspections should be carried out by, or under the supervision of, a person who has satisfactorily completed a course of instruction in radiography and is acceptable to the CAA in accordance with BCAR.

BL/6-5

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BASIC

ENGINEERING PRACTICES AND PROCESSES

ARC WELDING

1 INTRODUCTION This Leaflet gives guidance on metallic arc welding and inert gas arc welding. Carbon arc and atomic hydrogen arc welding are also briefly described, but since these methods now have little application for aircraft purposes brief details only are given. Inert gas metal arc welding is used mainly for medium and heavy gauge materials, and its use is limited in aircraft engineering.

1.1 Guidance on oxy-acetylene welding is given in Leaflet **BL/6–4,** on spot welding in Leaflet **BL/6–12,** on seam welding in Leaflet **BL/6–16** and on butt and flash welding in Leaflet **BL/6–17.**

1.2 The CAA requirements for the approval of welders are prescribed in British Civil Airworthiness Requirements (BCAR).

2 GENERAL The ease with which materials can be welded varies considerably; some materials are easy to weld, whilst others require particular care and additional heat treatment before or after welding to achieve full strength. To ensure that the parts are welded by the correct method and regain strength after welding, adequate information should be provided on the associated drawing or documents relating to the drawing. The following information should normally be quoted:—

(a) The welding process to be used.

(b) Details of any pre-cleaning treatment.

(c) Details of any pre-welding heat treatment required, including temperature and method of application.

(d) Details of current, electrodes and, where applicable, gas flow rates to be used.

(e) Details of joint preparation, location and dimensions of weld.

(f) Cleaning process for the removal of flux residue.

(g) Details of any post-welding heat treatment.

(h) Details of any additional treatment such as hammering the weld during cooling, or grinding of the finished weld.

(j) Details of any routine production tests.

(k) Any special requirements for non-destructive examination.

2.1 **Examination of Welds.** Apart from the usual visual examination of welded joints (see paragraph 8) there are a number of non-destructive examination methods available for ascertaining the quality of a weld.

These are as follows:—

(a) Oil and Chalk Process (Leaflet **BL/8–1**).

(b) Penetrant Dye Process (Leaflet **BL/8–2**).

(c) Ultrasonic Examination (Leaflet **BL/8-3**).
(d) Radiological Examination (Leaflet **BL/8-4**).
(e) Magnetic Flaw Detection (Leaflet **BL/8-5**).
(f) Fluorescent Penetrant Process (Leaflet **BL/8-7**).

2.2 **Arc Welding Processes.** The basic principles of the various arc welding processes are given in paragraphs 2.2.1 to 2.2.5 and the processes are described in detail in paragraphs 3 to 7. The electrical power required for the various arc welding processes is outlined in the relevant paragraphs, but the equipment obtainable from some manufacturers provides alternative power outputs to enable several different processes to be carried out using the same equipment.

2.2.1 **Metallic Arc Welding.** The heat is supplied by an electric arc struck between the workpiece and a consumable flux-coated electrode (see paragraph 3), the workpiece and electrode being connected in series between the output terminals of an electrical power source.

2.2.2 **Tungsten Inert Gas Arc Welding.** This process is commonly referred to as TIG welding. The arc, which is shrouded in an inert gas (usually argon), is struck between a non-consumable tungsten electrode and the parts to be welded (see paragraph 4).

NOTE: A filler rod may be used.

2.2.3 **Atomic Hydrogen Arc Welding.** The arc is struck between two non-consumable electrodes in a flow of hydrogen (see paragraph 5).

NOTE: A filler rod may be used.

2.2.4 **Carbon Arc Welding.** The arc is struck between a carbon electrode and the workpiece (see paragraph 6).

NOTE: A filler rod may be used.

2.2.5 **Metal Inert Gas Arc Welding.** This process is commonly known as MIG welding, and differs from TIG welding in that a consumable electrode, usually similar in composition to the basic metal, is used instead of a tungsten electrode (see paragraph 7).

2.3 **Distortion.** Due to the very high rate of heat generation obtained with electric arc welding where the welding arc temperatures are in the region of 6000°C (compared with 3000 to 3500°C for oxy-acetylene welding), it is possible to confine the heat to a small area, thus reducing considerably any tendency of the workpiece to distort. However, the high local heat input associated with this process usually results in an increased tendency of the workpiece material to crack compared with the oxy-acetylene process.

2.4 **Weldable Materials.** A wide range of materials may be joined by one or other of the arc welding processes and, although all their individual characteristics cannot be fully described in this Leaflet, some guidance is given in paragraphs 2.4.1 to 2.4.9. In addition, Table 1 lists some of the materials in the BS and DTD series which are suitable for welding, but the process for a particular material will usually be chosen by the design office and may have resulted from experimentation and experience with that material.

2.4.1 **Low Carbon Steels.** Mild steel has a carbon content in the range of 0·01 to 0·26% and a manganese content below 0·7%. The advantage of this material is that its properties are not affected by heat and it is therefore very suitable for welding.

TABLE 1

MATERIALS SUITABLE FOR WELDING

Material	Bars	Tubes	Sheets
Low carbon and low alloy steels	S14, S21, S91, S92	T45, T53, T62, T63, T64	S510, S511, S514
Aluminium alloys	L34	L54, L56	L16, L17, L59, L60, L80, L81, L113
Corrosion and heat resisting steels	S125, S126, S127, S128, S129, S130	T65, T66, T67, T68, T69, T70, T71	S524, S525, S526, S527, S528, S529, S530, S531
Magnesium alloys	DTD 142	DTD 737, L503	DTD 118
Copper alloys			BS 2780 DTD 283

2.4.2 **Low Alloy Steel.*** The carbon content of low alloy steel is such that hardening is more easily effected than in straight carbon steel, and although easily weldable, it will, in many cases, need heat treatment after welding to restore its properties.

2.4.3 **Medium Carbon Steels.*** These steels are employed where higher tensile strengths are required; they have a carbon content within the range of 0·3 to 0·6%. The weldability at the lower end of the carbon range is reasonably good, but heat treatment is necessary after welding to restore the original properties.

2.4.4 **Nickel and Nickel Alloys.** Nickel alloys should be annealed prior to welding in order to avoid buckling. These materials are readily weldable and the procedures used for welding low carbon steel are generally suitable.

(a) Some nickel alloys are not sensitive to heat treatment and are easily weldable by the TIG process. Others depend upon heat treatment for development of their optimum properties and the effect of welding must, therefore, be considered in relation to such heat treatment.

(b) Welding of the fully heat-treated material introduces a risk of stress cracking at the joint and inevitably leads to thermally affected zones, where the basic properties of the parent metal will be impaired.

(c) With heat treatable alloys of this kind, strict adherence to the drawing requirements regarding heat treatment is essential. As an example, one method used is to weld these alloys in the solution treated condition and to apply the age hardening treatment after welding.

2.4.5 **Aluminium and Aluminium Alloys.** The arc welding of aluminium and its alloys presents no particular difficulty, but the welding technique differs widely from that used for other materials. The pre-weld and post-weld heat treatment, as well as the equipment used and the method of manipulation, need special attention and care.

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*With both low alloy steels and medium carbon steels, cracking in the weld area can be serious, especially with steels at the higher end of the carbon range (see paragraph 3.7).

2.4.6 **Magnesium and Magnesium Alloys.** A number of magnesium alloys are difficult to weld by an arc welding process. Unsatisfactory results may be obtained with metallic arc welding; therefore, no attempt should be made to weld these materials by this process unless it is specified by the drawing, and previous experience of the weldability of the material is available.

2.4.7 **Titanium and Titanium Alloys.** Commercially pure titanium and several of the titanium alloys can be satisfactorily welded by the TIG process, provided that the process is closely controlled.

2.4.8 **Zirconium and Zirconium Alloys.** These materials are easily welded by the TIG process. The mechanical properties and corrosion resistance of the weld are generally good.

2.4.9 **Corrosion and Heat Resisting Steels**

(a) Ferritic steels which contain between 16 and 30% of chromium are normally used, because of their high resistance to heat and corrosion. A variety of these steels can be welded by the TIG process, but pre-weld heat treatment is generally required. Austenitic stainless steel filler wires are often used.

(b) Austenitic steels (corrosion resisting) normally contain approximately 18% chromium and 8% nickel, they also contain small quantities of titanium and niobium as stabilising elements to render the steel resistant to weld decay. They are easily welded but greater allowance must be made for distortion than with low carbon steel.

2.5 **Preparation of Surfaces.** Accurate fitting of the abutting edges is essential to good welding, but the metallurgical quality of the weld depends to a marked extent on the surface condition of the workpiece and filler rod. Dirt, oil, grease, paint and protective finishes must be removed from the weld area immediately before welding, as also (where aluminium alloys and non-corrodible steels are concerned) must the oxide films.

2.5.1 Tricholorethylene (Leaflet **BL/6–8**), acetone and other similar solvents are often employed as degreasing agents. All are very effective in removing extraneous surface deposits, but care is necessary to ensure that no traces of the degreasing agent are left when welding commences. The parts should be degreased, washed and thoroughly dried, otherwise vapours may be produced by the arc on any residual degreasing agents, and these may be toxic to the operator (see paragraph 2.6.5) as well as being a likely cause of gas porosity in the weld.

2.5.2 The tenacious surface oxide films on aluminium and magnesium alloys are best removed by brushing with a stainless steel wire brush or, for magnesium alloys, treatment to DTD 911 requirements. Manual scratch brushing may not be very effective unless carried out vigorously, and the use of a high-speed rotary wire brush is recommended. A number of proprietary brands of pickling solutions are also suitable for cleaning and removing surface films, but when such solutions are used, it is essential, to prevent corrosion, to ensure that all traces of the solution are subsequently removed by thorough washing. All these operations should be done as soon as possible prior to welding, as the effect of the pickle will be lost if delayed too long.

2.5.3 Filler rods (if not flux coated) must not be omitted from the cleaning operations. All filler rods are specially cleaned before despatch, but if left for any time, especially in damp conditions, they may be affected by oxidisation.

2.5.4 Further details on methods of joint preparation are given in Leaflet **BL/6–4**.

2.6 **Safety Precautions.** Safety equipment is necessary, and a helmet, or face shield, in which renewable protective glasses of appropriate tint can be inserted, is essential, as are gauntlets and suitable well-ventilated flameproof clothing.

2.6.1 Both ultra-violet and infra-red rays are emitted during electric arc welding, the effects being greater with the higher currents.

2.6.2 With arc welding the eyes should be protected using a special filter in addition to the normal lens (BS 679).

2.6.3 Welding leathers or overalls with high ultra-violet absorption characteristics, and head shields and gauntlets should always be worn during the welding operation, especially when welding with an inert gas and consumable electrode.

2.6.4 When operators' assistants are within two or three metres of the arc, it is advisable that they should wear anti-flash goggles with opaque sides to protect the eyes from radiation. When welding is being done in an erecting or assembly shop, portable screens should be placed around the welding area to avoid flash injuries to workshop personnel.

2.6.5 One source of danger is the formation of poisonous or objectionable gases as a result of the breakdown of solvent vapours in the welding arc. For example, phosgene gas (which is dangerous in minute concentrations) is produced when trichloroethylene is subjected to high temperatures, and, since the vapour of this particular solvent cannot always be detected by smell, a dangerous situation could exist if it were not completely removed before welding commenced. All solvent degreasing, washing and drying operations should, therefore, be conducted outside the welding shop.

2.6.6 With all electrical welding units, the manufacturer's instructions regarding precautions to be taken should be carefully observed. When the normal open-circuit voltage is likely to be dangerous, an automatic safety device, which reduces the voltage at the electrode holder to a safe value when the welding arc is broken, should be fitted.

2.6.7 **Hydrogen Gas.** When welding with the atomic hydrogen process, it should be noted that the presence of hydrogen in a confined space may represent an explosion hazard, unless sufficient ventilation is provided to prevent the hydrogen forming a dangerous mixture with the oxygen in the atmosphere.

3 METALLIC ARC WELDING

3.1 **Introduction.** In metallic arc welding, the electrode, which is also the filler rod, is coated with flux and is consumed during the welding operation. The electrode melts and supplies the filler metal required to make the joint, the arc being maintained by feeding the electrode at uniform rate and maintaining a constant distance between it and the workpiece.

3.2 **Materials.** No attempt should be made to weld materials which are not designated as suitable for metallic arc welding but, with the exception of aluminium and magnesium alloys, many materials may be welded by this process.

3.2.1 **Scope.** Metallic arc welding is used mainly for the welding of plain carbon and low alloy steels, but many non-ferrous materials, such as nickel alloys and heat-resisting and non-corrodible steels, can be successfully welded by this method. Materials thinner than 1.6 mm (16 s.w.g.) must not be welded by this process.

3.2.2 **Electrodes.** The electrodes are supplied as proprietary items and are coated with flux. The flux covers and adheres firmly to the core or rod of the electrode in a semi-flexible sheath. As the flux melts under the heat of the arc it produces a thick slag covering for the molten weld and an envelope of non-oxidising gas, which together protect the molten metal from the oxidising and nitriding effects of the surrounding air. Only electrodes specified on the drawing should be used; they should be stored in clean dry conditions, and should be heated to a temperature, and for a period, recommended by the manufacturer immediately before use. In the case of low hydrogen electrodes, it is essential that they should be stored in specially heated ovens which keep the moisture content of the coating at a low value.

3.2.3 The flux on the electrodes may also be used to introduce alloy additions into the weld deposit.

3.3 **Welding Process.** To strike an arc between the electrode and the work, the electrode, which is fixed in a special insulated holder, is applied to the work and immediately withdrawn a short distance, thus initiating an arc of intense heat. The tip of the electrode melts and vaporises, and the molten metal is transferred across the arc from the electrode to the joint. Simultaneously, the heat generated melts the workpiece at the joint, and fusion with the electrode material is effected; the arc is maintained by feeding the electrode, at a uniform rate, towards the workpiece. During welding there must be a balance between arc length, current and welding speed, and these factors are dependent upon one another to achieve a satisfactory weld.

3.3.1 **Arc Gap.** The distance between the electrode and the joint is determined by experience, but several variables, such as the voltage used, the type of electrode and the size and type of the materials to be joined, have to be considered. Skill is also required in the manipulation of the electrode, especially in striking and maintaining the correct arc, since if the electrode is allowed to remain in contact with the work it will become welded to the work; sometimes, in such cases, the electrode may be broken loose by a quick thrust of the holder, otherwise it will have to be cut away. However, should the electrode be withdrawn too far, the arc will be lost and the process of striking the arc will have to be repeated. One suggested procedure to facilitate re-striking is that the cup of flux at the end of the electrode should be squeezed between the thumb and forefinger of the welder's glove; this will break away the cup and, at the same time, will not damage the coating of the electrode.

3.3.2 **Positional Welding.** This term defines the position of the workpiece in relation to the operator, and is illustrated in Figure 1. For downhand butt welds, the best angle for the electrode is between 20 and 30° from the vertical to minimise the risk of slag entrapment. However, when low hydrogen or alloy rods are used in the downhand position, the angle of the electrode should be about 10°; in this way the arc is kept as short as possible and loss of the alloying element is avoided. For overhead welds, the arc must be kept very short and the current reduced by about 10% of the usual downhand figure. In vertical welding, the electrode is best held more or less at right-angles to the work and the current should be kept to about 80 to 85% of the usual downhand figure.

3.3.3 **Low Current Welding.** As low a current as possible should be used, consistent with avoiding a 'sticky' arc; this is the tendency of the workpiece or filler rod not to flow, and is caused by the temperature drop during fusion.

3.3.4 **Fillet Welds.** For fillet welds, where the thickness of the parts to be joined is the same, a 45° electrode position, bisecting the fillet, is recommended. Where parts of dissimilar thickness are to be joined, the electrode should be positioned so that the arc tends to play more on the thicker of the two materials.

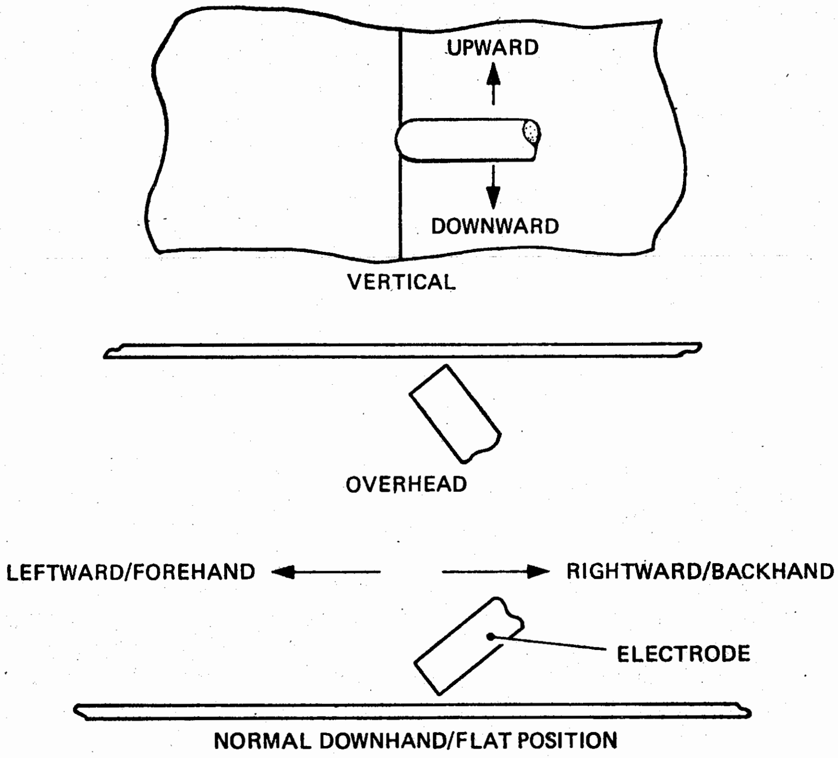

Figure 1 POSITIONAL WELDING TERMS

3.3.5 **Arc Breaking.** When breaking the arc, or when the electrode has been consumed, the arc should be made as short as possible and a circular motion should be made in the welding pool, terminating at the centre of the weld. At this stage, the arc should be broken suddenly to avoid the formation of craters or porosity. To recommence welding, the arc should be struck at the end of the previous run, going back over the 'tail' rather quickly and then welding in the usual way.

3.3.6 **Arc Blow.** When direct current is used, the arc may tend to wander and become uncontrollable. This is known as 'arc blow' and is caused by the magnetic field of the arc stream creating a magnetic field in the material being welded, with a resulting interaction between the fields. The usual methods of counteracting arc blow are to weld in a direction moving away from the earth connection, to change the position of the earth connection, or to change the position of the work on the welding table. With alternating current arc blow does not occur, but a.c. tends to produce an unstable arc, unless a high-frequency oscillator, which stabilises the arc by injecting a high-voltage, high-frequency current, is fitted.

3.3.7 **Spatter.** If small particles of metal are found scattered around a finished weld, this is known as 'spatter' and may be caused by excessive current, arc blow or too high a voltage.

3.4 **Distortion.** The correct sequence of welding operations must be followed in order to reduce distortion and stress concentrations to a minimum. Although there is less distortion with metallic-arc welding than with oxy-acetylene welding, because of the more intense heat which can be confined to a smaller area, it is, however, important to ensure that any jigs used are so designed to allow for expansion and contraction of the work. During welding, the areas surrounding the weld will be in varying conditions of expansion and contraction and stresses will be set up in the material; some of these stresses will disappear on cooling, but others may remain. These stress effects may be reduced, where applicable, by subsequent heat treatment.

3.4.1 The amount of localised heat can be reduced by decreasing the speed of welding. If the largest electrode consistent with the size of joint and the highest welding current is used, then the heat input per unit length of weld is greater, so that a larger area is heated and the rate of cooling is slower.

3.4.2 Reduction of localised heat can also be effected if the weld metal is deposited in short lengths, either with each length ending where the previous one began, or with each length as far apart from the previous one as possible.

3.4.3 When butt welding long joints, such as metal plates where the joints have been set slightly apart, the edges will tend to come together, as the weld proceeds. This may be prevented by first tack welding the joint at regular intervals.

3.4.4 **Design of Joints.** For butt welds on materials less than 3·2 mm (0·125 in) thick, bevelling of the edges is not necessary; the plates can be set as an open square butt with a gap equal to half the thickness of the metal. For thicker materials the edges should be bevelled to form a 'V' butt joint with an included angle of 120°. However, when high alloy steels are welded, a greater heat input is necessary to retard the cooling rate and an angle of 140° is recommended.

NOTE: Removable backing bars should be used whenever possible (see paragraph 4.7).

3.5 **Current and Voltage.** The details of the current range are usually recommended by the manufacturers of the electrodes, but Table 2 lists approximate values. However, it should be noted that the value of the current used will depend to a great extent upon the nature of the work; in general, the higher the current in the range given for one electrode size, the deeper the penetration and the faster the rate of deposit. Table 2 refers to a general purpose steel electrode which may be used as the positive or negative electrode according to the instructions given on the drawing. The voltage varies from 20 to 25, according to electrode size. Alternating current is usually supplied from a simple step-down transformer which reduces the mains voltage to that required for welding. Direct current is obtained either from a mains supply through a suitable rectifier or from a generator driven by external means.

3.5.1 Should the current be too high, the crater and the penetration will be too deep and the deposited layer will be too flat. The arc will be fierce, giving a loud crackling sound, and the electrode will become overheated and burn away quickly; spatter will also be excessive.

3.5.2 When the current and the welding speed are correct, the arc will give a steady crackle and it will be stable and easily controlled, the crater will be of medium size and the penetration good; the deposited metal will present a smooth and even surface.

TABLE 2

ELECTRODE/CURRENT VALUES

Diameter of Electrode	Approximate Current in Amperes		
	Minimum	Maximum	Normal
2·4 mm (0·1 in)	50	90	80
3·2 mm (0·125 in)	60	130	115
4 mm (0·156 in)	100	180	165/175
6 mm (0·25 in)	150	250	220/230

3.5.3 When using direct current, the voltage must not be too low or the electrode will stick to the work. The arc will be difficult to maintain and it will go in and out with a spluttering sound causing the weld metal to be deposited in blobs and with no depth of penetration. Should the voltage be too high, the arc will be fierce, giving a noisy hissing sound and will tend to wander; the deposited metal will be porous and flat, and spatter will be excessive.

3.5.4 Alternating current machines often have a high frequency current superimposed on to the welding current to initiate and stabilise the arc when welding certain materials.

3.6 **Removal of Flux.** Unless a flux is specifically approved as being non-corrosive, it is essential that all traces of flux residue should be removed.

3.6.1 **Ferrous Parts.** Flux can be removed from welded ferrous parts by immersing them in boiling water for not less than 30 minutes. The water in the cleaning bath should be changed at suitable intervals to avoid the risk of contamination. If the flux residue is brittle, it can sometimes be removed by tapping with a light hammer.

3.6.2 **Nickel and High Nickel Alloy Parts.** After welding, the flux residue should be removed by mechanical means, e.g. wire brushing, as the fused flux is not soluble in water. Removal by chemical means is not recommended, as the necessary solution will attack the base metal. For welds intended for service at high temperature, complete removal of the flux is essential, because of the possibility of reaction with the parent metal when subjected to long periods at high temperature.

3.7 **Heat Treatment.** In general, steels with a carbon content in excess of 0·26% are liable to crack after welding unless the pre-and post-welding heat treatment prescribed in the relevant specification or drawing is adhered to.

3.7.1 Where hardening and tempering of the welded parts is prescribed, tests should be carried out in accordance with the requirements of BS S100, S500 or T100, as appropriate. If the drawing specifies stress relieving, the stated temperatures should not be exceeded.

3.7.2 The local application of heat for the purpose of final heat treatment is not permitted, neither should attempts be made to correct distortion by the application of local heat, without the concurrence of the Design Office.

3.7.3 Parts made from carbon and low alloy steels, which can be used in the 'as welded' condition, are sometimes normalised, i.e. heat treated after welding with the object of refining the coarse grain structure in the weld and heat-affected areas.

3.8 **Inspection.** See paragraph 8.

4 TUNGSTEN INERT GAS (TIG) ARC WELDING

In this process the heat for welding is supplied by an arc struck between a tungsten electrode and the material to be welded. The weld area and the arc are surrounded by an inert gas (usually argon gas) which prevents contamination of the weld zone by atmospheric oxygen and nitrogen. Welding may be carried out in a welding chamber containing inert gas, or in the open with gas being supplied through a shield around the electrode; in the latter case an inert gas or a flux may need to be provided on the underside of the work.

4.1 This process gives neat welds of excellent metallurgical qualities. Compared with gas welding, the welding speed is high and distortion is reduced to a minimum. Finishing operations are considerably reduced as there is no flux residue; smooth welds are usual, so that no dressing or grinding is required.

NOTE: Discoloration of the weld or base metal, such as the presence of dark or light deposits along or near the weld, should not be taken as an indication that the weld is unsatisfactory without further investigation.

4.2 **Materials.** All welding operations should be performed strictly in accordance with the relevant drawings. No attempt should be made to weld materials which are not designated in the appropriate specification as being suitable for tungsten inert gas arc welding. All the materials weldable by the oxy-acetylene process are suitable for welding by this process.

4.2.1 **Application.** Although suitable for welding any material which can be fusion welded, TIG welding has brought notable improvements in fabrication techniques and also enables satisfactory welding of materials previously considered unsuitable for fusion welding. It is particularly useful for welding aluminium and aluminium alloys, the Nimonic alloys and non-corrodible and heat-resisting steels.

4.2.2 **Material Thickness.** Due to the deep penetrative qualities of TIG welding, a very wide range of metal thickness can be successfully welded; for example, non-corrodible steel sheet of 0·25 mm (0·01 in) thickness and aluminium alloy plate 12·5 mm (0·5 in) thick can be readily welded by hand torch. However, it is usually considered to be uneconomic to use this process on thicker gauge material which could be welded by the metallic-arc process. As the distortion which occurs with gas welding generally restricts the gauge of the metal to be welded, it will be appreciated that with the localised nature of the heat application used in TIG welding, this restriction is considerably eased.

4.3 **Equipment.** The equipment required consists of a welding 'torch' (air or water cooled) and a current regulator, together with a source of current and a supply of inert gas (usually argon). The filler rods to be used for all types of welding are specified in BS 2901.

4.3.1 **Argon Supply.** Argon is present in the atmosphere in concentrations of approximately 0·94% by volume. It is extracted by fractional distillation and is stored in cylinders at a pressure of about 132 atmospheres. It is chemically inert, odourless and non-toxic. Cylinders containing argon are painted blue in accordance with BS 349. It is important that argon lines should be checked periodically for leaks, since serious contamination by oxygen and nitrogen can sometimes arise from this cause.

(a) The rate of gas flow is important and must be suitably regulated (see Tables 3 and 4). When welding thin materials at low current, a small flow of gas gives adequate protection to the small area of molten metal, but a larger flow is required when welding heavier gauge materials. Where higher welding currents are needed, bigger gas nozzles, designed to shroud a wider area, are also required.

(b) Arc stability is also important, less current being required for the more stable type of arc. It is essential to use a flow regulator and meter in the argon line, so that the supply of gas can be controlled for the particular job in hand. The use of a gas economiser is recommended to reduce wastage.

(c) To ensure that the purity of the gas will be satisfactory, it is essential to stress, when ordering, that it is required for the purpose of welding.

4.3.2 **Nature of Current.** The tungsten inert gas arc process is used with both direct and alternating current, the choice of current being determined by the material to be welded. Metals with refractory surface oxide films, e.g. magnesium alloys and aluminium and its alloys, are generally welded with a.c., while d.c. is used for carbon, low alloy, non-corrodible and heat resisting steels, nickel alloys, Nimonic alloys and copper. The maintenance of a stable arc is essential in reducing the current required.

4.3.3 **Alternating Current.** The use of a.c. with a tungsten electrode combines the advantages of reasonable penetration with only moderate heating of the electrode and adequate dispersal of the oxide film from the weld surface. The reversal of current in the a.c. cycle, however, raises a particular difficulty in conjunction with the difference in arc characteristics in the respective half cycles. Twice in each cycle, as the arc current changes in direction, it passes through zero and at these times the arc is extinguished and must be re-ignited for welding to continue. Re-ignition, however, is opposed by the arc gap and, to an added extent, when the polarity of the work is negative; in fact, the resistance during the change of direction may become sufficient to prevent arc re-ignition. This is overcome by the insertion of a series of high-voltage, high-frequency oscillatory sparks across the arc gap at the instants of zero arc current, to prevent the arc gap becoming non-conducting, or by means of a surge injector which provides a surge when the arc voltage is at zero.

4.3.4 **Equipment.** The a.c. equipment consists of the welding transformer, d.c. suppressor, HF unit with or without surge injection, and a power-factor correction condenser. A pedal operated control switch for the HF unit must be incorporated, otherwise unsatisfactory welds may result. The switch may be one which controls the HF unit alone, or may be of a type which incorporates a toe-action switch for switching on the current and a heel-action switch for controlling the HF unit.

4.3.5 **Direct Current.** With TIG welding, the choice of polarity depends only on the type of material being welded, since a tungsten electrode is used throughout and is virtually non-consumable. In a d.c. arc, approximately two-thirds of the heat is concentrated on the positive end of the arc and one-third on the negative end. If the tungsten electrode is made positive and the workpiece negative the relatively smaller mass of the tungsten electrode is subjected to the larger proportion of arc heat and the

TABLE 3

ALUMINIUM AND ITS ALLOYS (A.C. ONLY)

Material Thickness mm (s.w.g.)	Current (amperes)	Electrode Diameter mm (in)	Filler Rod Diameter mm (in)	Argon Consumption 1/h(ft^3/h)
0·90 (20)	45 to 60	1·6 (0·0625)	None or 1·6 (0·0625)	336 (12)
1·20 (18)	60 to 70	2·4 (0·0938)	2·4 (0·0938)	336 (12)
1·60 (16)	75 to 90	2·4 (0·0938)	2·4 (0·0938)	336 (12)
2·00 (14)	90 to 110	3·2 (0·125)	2·4 or 3·2 (0·0938 or 0·125)	354 (13)
2·50 (12)	110 to 130	3·2 (0·125)	3·2 (0·125)	354 (13)
3·20 (10)	130 to 150	4·0 (0·125 to 0·1875)	3·2 (0·125)	354 (13)

NOTE: The tungsten inert gas arc welding of aluminium and its alloys less than 1·6 mm (16 s.w.g.) thick is not generally recommended because the arc is too severe to permit proper control; oxy-acetylene welding is to be preferred.

TABLE 4

NON-CORRODIBLE AND HEAT RESISTING STEELS (A.C. AND D.C.)

Material Thickness mm (s.w.g.)	Current (amperes)	Power	Electrode Diameter mm (in)	Filler Rod Diameter mm (in)	Argon Consumption 1/h(ft^3/h)
0·55 (24)	15 to 30	d.c. a.c.	1·0 (0·047)	None or 1·0 (0·047)	84 to 112 (3 to 4)
0·70 (22)	20 to 40	d.c. a.c.	1·2 (0·047) 2·4 (0·0938)	None or 1·2 (0·0625)	84 to 112 (3 to 4)
0·90 (20)	30 to 50	d.c. a.c.	1·2 (0·0625) 2·0 (0·0938)	None or 1·2 (0·0625)	84 to 112 (3 to 4)
1·20 (18)	40 to 60	d.c. a.c.	1·6 (0·0625) 2·0 (0·0938)	1·6 or 2·0 (0·0625 or 0·0938)	112 to 140 (4 to 5)
1·60 (16)	60 to 80	d.c.	1·6 (0·0625) 2·4 (0·0938)	2·0 or 2·4 (0·0625 or 0·0938)	140 to 168 (5 to 6)
2·00 (14)	70 to 90	d.c.	2·4 (0·0938)	2·4 (0·0938)	168 to 200 (6 to 7)
2·50 (12)	90 to 110	d.c.	2·4 or 3·2 (0·0938 or 0·125)	2·4 (0·0938)	168 to 200 (6 to 7)
3·20 (10)	110 to 130	d.c.	3·2 (0·125)	3·2 (0·125)	168 to 200 (6 to 7)

relatively larger mass of the joint assembly absorbs the lesser proportion of heat. If, therefore, the tungsten electrode is connected to the negative pole of the generator and the work to the positive pole, the electrode remains comparatively cool, thus negative pole d.c. is widely used for all tungsten inert gas arc welding of steels and high nickel alloys.

4.3.6 **Equipment.** D.C. power may be drawn from a motor-generator plant or a metal-rectifier set.

4.3.7 **Arc Initiation.** Arc initiation and stability can be improved by superimposing a high-frequency current at low power upon the welding current; this also helps to maintain electrode shape and reduce tungsten inclusion in the weld deposit. Suitable units for generating this HF current are available and can be used just for arc initiation, or throughout the welding operation, according to choice.

4.3.8 **Torches.** Torches ranging from 50 to 600 amperes are available for manual welding. For welding currents up to 150 amperes, air-cooled torches are normally used, but for higher currents water cooling is desirable. In either case the argon gas is supplied through a combined power cable and gas hose, and emerges from the refractory (ceramic) shield designed to direct an even flow of argon around the electrode and weld area.

(a) Most torches are designed to take a selection of various sizes of electrodes and gas shields, so that a wide range of material thicknesses can be welded with the same torch.

(b) Should difficulty arise in manipulating a standard torch in awkward positions, a variety of special designs are available. A typical example of a lightweight torch used for welding thin gauge metals is the 'pencil' torch; it has a wide range of application in the aircraft industry. A similar type is also available with a swivel head for welding at different angles.

4.3.9 **Electrodes.** The tungsten electrode, with a melting point of over 3350°C, is virtually non-consumable. The addition of small percentages of other elements is often made to improve arc striking qualities and stability at low welding currents. The electrode extension beyond the shield is important and should be about 3·2 mm (0·125 in) for butt welding and slightly more for fillet welding.

4.4 Welding Technique

4.4.1 **Joint Preparation.** For the butt welding of high nickel alloys, aluminium and aluminium alloys, less joint preparation is required than with gas welding. No special joint preparation is required for any material up to 3·2 mm (0·125 in) thick, and in the case of aluminium alloys, parts up to 6 mm (0·25 in) thick can be welded without bevelling. When the joint edges are not bevelled (square) a gap of half the thickness of the plate should be left between the edges. In general, however, for materials thicker than 3·2 mm (0·125 in), the edges to be welded should be bevelled, so that when the plates are joined a 70° 'V' is formed leaving a thickness of about 0·8 mm (0·03 in) at the bottom of the plates. Backing bars (see paragraph 4.7.1) should be used whenever possible.

4.4.2 **Cleaning.** Argon has no fluxing action and the joint to be welded must, therefore, be absolutely clean; any oxide, grease or dirt will lead to welds of poor quality. Storage of clean materials leads to the formation of a surface oxide film which requires mechanical removal; degreasing alone is not effective. Care should be taken to ensure that the edges to be joined, as well as their top and bottom surfaces, are clean. Materials oxidised during previous heat treatment should first be pickled, and all materials should be cleaned by mechanical means (such as wire brushing) and degreased before welding; any filler rod must be treated in the same way. If more than one pass is used, the previous weld must be thoroughly cleaned before the next run. For details of surface preparation for all materials weldable by the TIG process see paragraph 2·5.

4.4.3 **Butt Welding.** The angles of the torch and the filler rod should be 80 to 90° and 10 to 20°, respectively, from the surface of the horizontal plate (see Figure 2). The arc length (defined as the distance between the tip of the electrode and the surface of the weld crater) varies between 3 mm (0·125 in) and 6 mm (0·25 in) depending on the type of material and the current used.

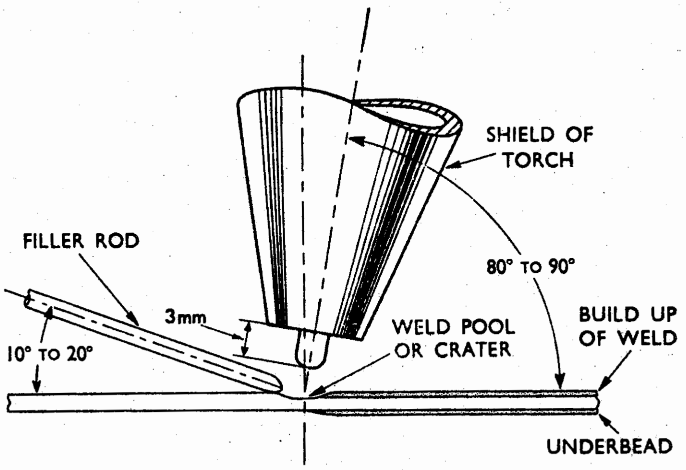

Figure 2 RECOMMENDED ANGLES FOR TORCH AND FILLER ROD

(a) The filler rod is fed into the edge of the molten pool and not directly into the arc; it should be fed in with a slightly transverse scraping motion, with the tip of the filler rod making contact with the weld metal. This ensures that the rod is at the same electrical potential as the plate during transfer of metal to the weld and avoids any tendency of the rod to spatter (see paragraph 3.3.7).

(b) The hot end of the filler rod should always be kept within the influence of the argon gas to prevent oxidation.

(c) Butt welds in thin gauge materials are best made with a progressive forward motion without weaving, but a slightly different technique is required when welding medium or heavy gauge plate. As the filler rod diameter increases with increase in plate gauge, there is a tendency for the filler rod to foul the electrode. Contamination of the tungsten electrode by particles of molten metal causes immediate 'sputtering' of the electrode and particles of tungsten may become embedded in the weld. If this occurs it is essential to change the electrode and, to avoid repetition, the arc length should be increased slightly to accommodate the filler rod. This procedure is limited, however, as there is a maximum arc length beyond which good welding becomes impossible.

(d) To avoid contact between the electrode and the filler rod when welding heavier section plate, it is essential that a filler rod of the correct diameter for the thickness of material being welded is used (see Tables 3 and 4). The weld area is melted under the arc, the torch is withdrawn backwards for a short distance from 6 to 12 mm (0·25 to 0·5 in) along the line of the seam, and the filler rod is inserted in the molten pool. The torch is moved forward and the filler rod is withdrawn from the pool simultaneously. This movement of both torch and filler rod, backwards and forwards in a progressive forward motion, melts down filler rod and plate without the filler rod entering the core of the arc.

4.4.4 **Fillet Welding.** The axis of the tungsten electrode should bisect the angle between the horizontal and vertical members of the joint, whilst the angle of the electrode with respect to the longitudinal axis of the joint should approach as closely as possible to 90°. This prevents, as far as possible, fouling of the argon shield on the plate surface and provides the best shrouding of the molten metal. The filler rod should be fed into the molten weld pool at a very acute angle and with the same technique as used for butt welding. On sections thicker than 1·6 mm (0·0625 in) the forward and backward motion of the torch should be employed to obtain full root penetration (see paragraph 4.4.3 (d)).

(a) **Electrode Length.** In awkward corners it may be desirable to extend the electrode tip beyond the normal 6 mm (0·25 in) or so from the argon shield in order to obtain better visibility. Provided this procedure is not carried to extremes and that the argon flow is increased slightly, no detrimental results in the quality of the weld should occur.

4.5 **Positional Welding.** The downhand technique (see paragraph 3.3.2) should be used where possible, since other techniques reduce the welding speed without decreasing heat input and may induce distortion. The downward vertical technique can be used on sections thicker than 2·4 mm (0·09 in). Some side-to-side motion may be necessary with upward vertical welding to avoid excessive droplet formation, and the filler rod should be inserted in fairly rapid, short bursts, depositing a small quantity of metal with each movement.

4.6 **Completing the Weld.** Until experience is gained with a particular material, operators are likely to have some difficulty in preventing crater formation at the end of a run. To assist in overcoming this difficulty, devices are available which reduce the welding current gradually; alternatively, extension tabs may be left on the component, on which the weld can be run out and the tab then discarded. To assist in preventing oxidation, the argon should not be cut off too soon after the completion of welding.

4.7 **Jigs and Fixtures.** Accurate alignment and careful preparation of joints are essential for tungsten inert gas arc welding, and use should be made of jigs and fixtures whenever possible. Tack welds may be used, but these should be small and short, and must be thoroughly wire brushed before they are incorporated in the main weld.

4.7.1 **Backing Bars.** Backing bars are widely used with automatic TIG welding and serve to minimise distortion and to control penetration. They usually form part of a fixture which also serves to ensure accurate alignment of the welded joint. Good contact between the backing bars and the sheet material is necessary. The bars can be grooved to suit the type of underbead required, and argon is often supplied separately to the underside of the joint, via such a groove. Various materials may be used for backing bars, but where an insert is used chromium plated copper is the usual choice and water cooling is sometimes applied. Care must be taken to ensure that the backing bars are clean and that condensation does not contaminate the argon supply. Figure 3 shows a typical arrangement of backing bar.

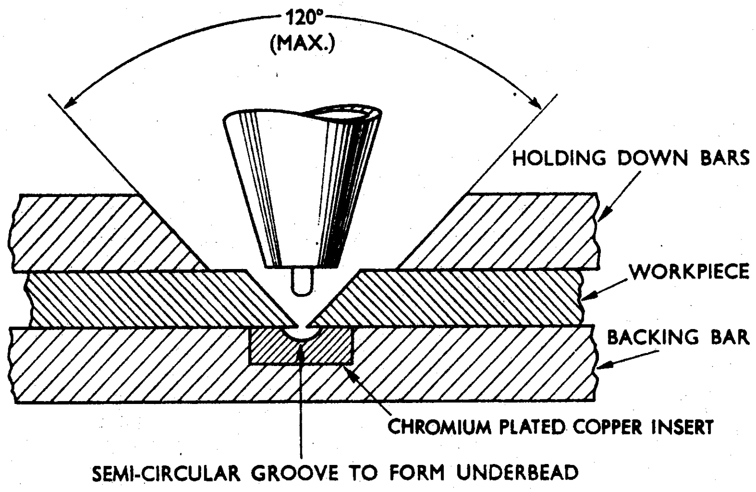

Figure 3 TYPICAL GROOVED BACKING BAR

4.7.2 **Other Backing Methods.** For some components it may be impossible to fit a backing bar. In these circumstances other backing methods may be tried. Refractory materials or appropriate welding fluxes may be applied to the underside of the joint. Fluxes so applied should be thoroughly dry before welding is begun, and procedures to guard against undesirable flux reactions and for the final removal of flux residue from the weld area should be in force.

4.7.3 **Underbead.** An argon atmosphere maintained at the underside of a weld may improve penetration and help to control the form of underbead, but in some components, such as those of small tubular type, a jig may be unnecessary and it may be possible to contain the argon within the component.

4.7.4 **Magnetic Holders.** Magnetic devices for holding components together are widely used. Permanent magnets are available to give pulls of up to 225 N (50 lbf) and electro-magnets can be obtained with considerably greater strength.

4.8 **Flux Removal.** In instances where a flux has been used on the underside of a weld, any flux residues should be removed as soon as possible after welding. Steel and nickel parts should be treated as described in paragraph 3.6, and aluminium and magnesium parts should be treated as described in paragraphs 4.8.1 and 4.8.2 respectively.

4.8.1 **Aluminium Parts.** Flux should be removed by washing the parts in boiling water or in a solution of 5% nitric acid in water at 60°C for at least 15 minutes, then thoroughly rinsing in running water and drying. The process should be repeated until no flux remains.

(a) The efficiency of the final washing operation, whether or not acid treatment has been used, can be checked by adding a small portion of silver nitrate test solution to a sample of the water in which the joint was washed. If a white precipitate appears, it indicates that the flux residues are still present and further cleaning is necessary.

NOTE: The fluxes used in welding aluminium alloys are highly corrosive and the products of the corrosion are also actively corrosive, corrosive action is, therefore, progressive and any trapped flux will continue to act until the material is penetrated.

4.8.2 **Magnesium Parts.** Flux should be removed by vacuum blasting or washing in boiling water. This cleaning should be carried out in conjunction with the preparations for the application of the chromate treatment to DTD 911.

4.9 **Heat Treatment.** Some form of heat treatment may be required on many parts, and precise details will be specified on the relevant drawing.

4.9.1 Stress relieving heat treatment may be prescribed prior to the welding of some stainless steel or chromium-nickel alloys to relieve residual stresses, and after welding of complex structures in non-heat-treatable alloys.

4.9.2 Heat treatable alloys may require a full heat treatment to restore their properties after welding. The times and temperatures of the heat treatment will vary according to the type of alloy, and some compromise may have been made when joining parts made from different alloys. There may also be a restriction on the number of heat treatments given to a particular alloy (for example, magnesium alloys should not be heat treated more than three times).

4.10 **Inspection.** See paragraph 8.

5 ATOMIC HYDROGEN ARC WELDING

Heat is produced by an arc struck between two inclined tungsten electrodes. A stream of hydrogen passed through the arc is dissociated (temporarily broken down into atoms) with a corresponding increase in energy content, the extra energy being released as heat when the atoms re-combine to form molecular hydrogen at the relatively cool surface of the weld joint.

5.1 The process is used mainly for the welding of steels and is particularly applicable to automatic production welding. Filler rods should be those recommended for gas welding.

5.2 Although remaining useful for specialised and quantity production work, this method is not now widely employed and has been mainly superseded for aircraft work by the TIG process.

5.3 **Inspection.** See paragraph 8.

6 CARBON ARC WELDING In this process, which has been largely superseded by TIG welding, the characteristic principle is that an arc is drawn between the parts to be welded and the carbon electrode which is manipulated by the welder. The filler wire (or rod) and the flux are the same as used in oxy-acetylene welding, and welding is usually done by the leftward procedure.

6.1 The process is not normally used for welding materials thinner than 1·2 mm (18 s.w.g.) and is usually restricted to straight butt joints.

6.2 Direct current is used, the carbon electrode being positive and the workpiece negative.

6.3 Electrode loss by disintegration is very high and care must be taken to ensure that the weld is free from carbonising, which causes the weld to harden with a tendency to surface cracking. This process is not recommended for high quality work owing to the risk of carbon pick up.

6.4 **Inspection.** See paragraph 8.

7 METAL INERT GAS (MIG) ARC WELDING In this process, a consumable electrode in the form of a filler wire is fed automatically into the arc at a controlled rate, the wire and weld area being shrouded with an inert gas.

7.1 **Scope.** The MIG arc welding process is used on the heavier gauge materials and requires a certain continuity of production for it to be a practical proposition; at present, plates thinner than 3·2 mm (0·125 in) cannot be satisfactorily welded by the process and, because of this limitation, it is not usually used in the aircraft industry.

7.2 **Equipment.** The equipment comprises the following essential parts — a gun or torch to which the filler wire and current are fed, a carriage unit which houses the reel of filler wire and the control circuits, a d.c. power unit (which may be a standard d.c. welding generator) and an inert gas supply with a suitable regulator.

8 INSPECTION Close supervision of a welding operation is not generally possible and the production of a satisfactory weld depends mainly on the skill of the welder. During the welding operation, careful attention to the following points will help to ensure the production of a satisfactory weld:—

(a) The welding process used is in accordance with the drawings.
(b) Evidence is available that the welder is authorised to weld the particular work concerned.
(c) The materials being welded are those stipulated on the drawing.
(d) The type and size of electrode, current characteristics and any flux used are as specified on the drawing.
(e) Where filler rod or wire is used it is of the type specified on the drawing.
(f) The specified number of runs per weld and rate of deposition are observed.
(g) Heat treatment, if required, is effected as specified on the drawing.
(h) The identity of the welder is established for any weld submitted to inspection.
(j) The rate of burning of the electrode and the progress of the weld.
(k) The amount of penetration and fusion.
(l) The manner in which the weld metal is flowing.
(m) The sound of the arc (see paragraph 3.5) indicating correct current and voltage for the particular work in hand.

8.1 **Carbon Arc Process.** The weld must be free from carbonisation, which would be indicated by the smooth hard appearance of the weld.

8.2 **Atomic Hydrogen Process.** The flow of hydrogen must be according to drawing requirements.

8.3 **Cylinders.** Argon cylinders should not be used at pressures less than 140 N/m^2 (20 lbf/in^2) as the reduction in argon flow beyond this limit will increase the danger of contamination of the weld by air, and the subsequent purging of a cylinder empty of argon is a serious problem for the manufacturer.

8.4 **Final Inspection.** After cleaning, the completed weld should be examined for the following points:—

(a) Fusion should be satisfactory between the weld and the parent metal on both edges.

(b) There should be no undercutting where the weld metal joins the base metal, and the welded parts should not be reduced in thickness by the welding operation.

(c) Good penetration should be apparent, and an underbead should show throughout the whole length of the weld.

(d) The build-up of the weld should be satisfactory (a concave surface on the face of the weld indicates lack of weld metal with consequent weakness).

(e) The weld should show a regular surface, and should be free from porosity, scale, slag or burn marks.

(f) The area surrounding the weld should be free from spatter.

(g) The dimensions of the weld should be correct, especially the leg lengths and throat depth in fillet welds.

(h) All welds should be carefully examined for cracks, particular care being taken with magnesium alloys.

8.4.1 It must be ascertained that any method of non-destructive examination called for on the drawing has been applied (see paragraph 2.1).

8.4.2 All welds, except those which are required by the drawing to be hammered during cooling, must be examined in the 'as welded' condition. If, after inspection, the weld is dressed by filing, grinding or machining, it is again to be inspected. Light tapping with a hammer to break off flux residue resulting from the use of flux-covered electrodes is necessary as an aid to inspection and should not be regarded as a dressing operation.

8.4.3 Welds in certain alloys are improved by hammering during cooling. This treatment is only done when required by the drawing. Attention is drawn to the danger that cracks may develop in magnesium alloys which are hammered cold; it is a general practice to hammer such welds within a temperature range of 300 to 400°C, and in no circumstances should hammering take place below 250°C.

9 **ARC 'SPOT' WELDING** In certain circumstances an arc 'spot' welding process can be employed as an alternative to resistance spot welding (Leaflet **BL/6-12**). It is of particular value if only one side of the workpiece is accessible.

9.1 The process is suitable for the joining of non-corrodible steels, some alloy steels and titanium, but should not be used in conjunction with aluminium or magnesium alloys. The welding of some plain carbon steels and heat resisting steels may give rise to some difficulties.

9.2 The thickness of the top sheet of the weld may be between 0·037 and 1·6 mm (28 and 16 s.w.g.) and it can be welded to an under sheet of like thickness or greater thickness, but for sheets in excess of 1·6 mm (16 s.w.g.) the penetration of the weld becomes progressively shallower.

9.3 The weld is made by the TIG process and is effected by holding the torch firmly against the exposed face of the joint and pressing the torch switch. The welding process is then automatically controlled by the welding machine.

9.4 The controlled current causing the arc flows for a pre-set period of up to a few seconds, resulting in the melting of the area of the top sheet which is under the torch head. The molten metal crosses the interface of the joint, becomes common to both components, and solidifies into a solid 'U' or 'V' shaped nugget, joining the sheets together at this spot.

9.5 A backing bar may be necessary to achieve the necessary contact between sheets and, in some instances, e.g. when welding titanium, it may be necessary to carry a stream of argon to the underside of the weld through a groove or duct in the backing bar.

9.6 The welding current must not be cut off abruptly after the welding operation, otherwise a crater will form in the top surface of the weld nugget. The usual method of cut off is to reduce the current to zero in several stages. This is usually known as 'current decay'.

9.7 The essential factors for successful welding with this process are to ensure that current values and times, arc length and current decay control are in accordance with drawing requirements.

9.8 **Joint Preparation.** Prior to welding, the surface of the joint should be prepared either by a pickle or abrasive process, but if the surface is free from scale, degreasing alone may be sufficient. Unless otherwise stated on the drawing, the gap between the two mating parts should not exceed 0·025 mm (0·001 in).

9.9 **Inspection.** Procedures should be instituted to ensure that:—

(a) The position and pitch of the welds are in accordance with drawing requirements and, if stipulated on the drawing, the underside of the weld is free from excessive penetration.

(b) Both sides of the weld are free from excessive concavity, craters, cracks, holes or fissures. A satisfactory weld usually has a convex top surface upon which often appears a small 'pip' resulting from controlled current decay.

(c) If the drawing stipulates light hammering, the blows are to be applied only to the centre of the weld surface (but see paragraph 8.4.3). After hammering, the welds should again be examined for freedom from defects.

(d) A weldability test is carried out on each cast of steel to verify its satisfactory response to this process.

(e) The process should be controlled by a system of test samples subjected to the appropriate prising tests and micro-examinations. Details of suitable test pieces are given in Leaflet **BL/6-12,** but as the welding characteristics for a given single weld are not influenced by its neighbours, a two spot sample may be employed instead of the three spot test piece shown in Leaflet **BL/6-12.** The test piece prepared from the sample must, however, contain both welds.

(f) Every effort should be made to check the welds by a radiological method, since this is a valuable aid to visual inspection.

BL/6-6

Issue 1.

1*st August*, 1950.

BASIC

GENERAL WORKSHOP PROCESSES

TIMBER CONVERSION — SPRUCE

1 INTRODUCTION

1.1 A good basic knowledge combined with many years' experience in the handling of timber is essential for the accurate assessment of the characteristics and defects which make it either suitable or unsuitable for aircraft parts.

1.2 This leaflet is not intended to give guidance on how to select timber ; it outlines the Board's recommended method of converting it into aircraft parts and mentions common defects which may be encountered during conversion.

2 SEASONING

2.1 Timber which has been cut from selected trees is stacked, prior to shipment, for approximately 60 days. During this time the timber loses much of its free moisture and it is in this condition that it should be transported.

2.2 Timber is usually seasoned in air-drying sheds for periods ranging from one to three years, or longer ; if it is required for immediate use it may be artificially seasoned (*i.e.*, kiln-dried).

2.3 The process of seasoning reduces the moisture content of timber to a point where it is in equilibrium with the surrounding atmosphere, and enables protective treatments to be applied more effectively.

3 CHARACTERISTICS After the timber has been properly seasoned, samples should be cut and tested to determine its suitability for use on aircraft. Before taking the samples from a plank of timber, approximately six inches should be cut from the end and discarded as this piece may be drier than the remainder.

3.1 **Moisture-Content.** The moisture-content of the sample should be determined by weighing it and then drying it in an oven at a temperature of 100° to 105°C. until two successive weighings yield the same result. Care should be taken to ensure that when the sample is split up, no material is lost and that the weighing is done promptly so as to avoid false results. The moisture-content should be calculated from the following formula :

$$\frac{W_1 - W_2}{W_2} \times 100$$

where W_1=the weight of the sample prior to drying
and W_2=the weight of the sample after drying.

3.2 A quicker method of determining the moisture-content of timber is by the use of the Marconi Moisture Meter. This instrument will record the moisture-content in a few seconds, whereas the method of weighing, drying and calculating takes much longer. The meter should, however, be checked periodically to ascertain that it remains accurate. For general guidance, the correct moisture-content should be 15% with a tolerance of ±2%.

3.3 **Density.** The density should be determined by weighing and measuring the volume of a sample cut from the plank. A practical method of doing this is to cut the sample 3·8 inches long, by 1 inch square, and determine its weight in grammes. The figure for the weight of the sample in grammes is equal to the figure for the density in pounds per cubic foot. The weight of spruce generally varies between 20 lb. and 36 lb. per cubic foot. For grade A spruce the density should not be less than 24 lb. when the moisture-content is 15%.

3.4 **Brittleness**

3.4.1 A notched test piece, the sides of which are cut radially and tangentially, of the dimensions 5¼ inches long by ⅞ inch square, should be broken in an impact test machine of the Izod type, the blow being applied tangentially ; the test piece should absorb not less than 5 foot-pounds. Care should be taken that the blow is applied in the right direction, for if broken the opposite way a false reading will be obtained. A tolerance of 0·5 foot-pounds is generally allowed, provided the fracture shows a satisfactory amount of fibre.

3.4.2 The weight-dropping machine provides an alternative method of testing timber for brittleness. A plain test piece, 12 inches long by 1 inch square, should be cut radially and tangentially, and parallel to the grain. When placed in the testing machine, the test piece should withstand one blow of 13 foot-pounds without showing signs of tension failure on the vertical sides. Where doubt exists, a further blow of 6·5 foot-pounds may be applied and there should be no sign of failure. The opening out of a few fibres should not be interpreted as a failure.

3.5 **Splitting Test.** The object of this test is to determine the inclination of the grain. The sample should be split with a very blunt chisel so that the wood will be split and not cut. The split surfaces give the true direction of the grain. The split should be made some distance from the edge of the sample, otherwise a misleading result may be obtained.

3.6 **Rate of Growth.** The number of annular rings per inch varies to some extent. Timber with a rate of growth of less than six rings per inch should be rejected.

3.7 **Recording of Tests.** The results of the above-mentioned tests should be recorded and related to the plank of timber to which they refer. The actual test pieces should also be kept for a period of not less than two years.

4 CONVERSION After the bulk timber has been tested and graded, it may be converted into structural members for use on aircraft. This conversion should be done with every possible care, for much depends on the way in which timber is sawn.

4.1 **Rift-Sawing.** The process of cutting timber along the radius of the annular rings is known as rift-sawing. An illustration of this is given in Figure 1. Rift-sawing and near-quarter-sawing are very much the same.

4.2 **Tangential-Sawing.** The process of cutting at a tangent to the annular rings is known as tangential-sawing. An illustration of this is given in Figure 2. Tangential sawing (slashing) produces what is commonly known as a "flower-face."

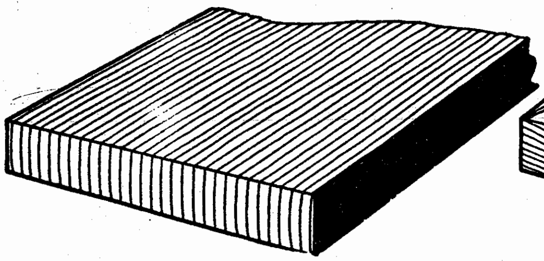

Figure 1

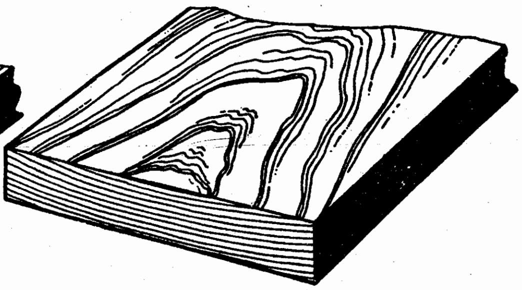

Figure 2

4.3 **General**

4.3.1 Before a piece of bulk timber is converted, the end section of the plank should be noted, particularly the direction of the annular rings. It will be seen from this whether the plank is tangential-sawn, rift-sawn or quarter-sawn.

4.3.2 The actual method of converting timber is best described by the use of an example as follows. Assuming that spar members of a rough finished size of 4 inches by 2 inches are required and a 4 inch rift-sawn plank of timber is available, it should be cut tangentially to give a size of 4 inches by 4 inches, after which a radial cut will give rift-sawn pieces 4 inches by 2 inches (allowance should, of course, be made for the saw-cut). The main advantage of rift-sawn timber is that it shrinks chiefly in one direction only, and does not warp very much.

5 DEFECTS After timber has been converted it should be examined for defects. Some of the more common defects are outlined in the following paragraphs.

5.1 **Dote Disease.** This is the worst of all defects and does much damage to the wood. It is an inherent disease which only occurs at the base of the living tree. When the tree is felled it is cut at a point ten feet or more above the ground as a precaution against the possibility of dote. Converted pieces of timber should be examined not only on the sides but also on the ends ; dote will be recognised by the presence of brownish yellow patches, somewhat similar to thin mineral oil spots. Dote is contagious and any infected wood should be burnt

5.2 **Decay or Rot.** A defect similar to dote disease can develop after a tree has been felled if the timber is exposed to excessive soaking and partial drying. Dry-rot fungus requires a certain amount of moisture to thrive on but once the disease is established it thrives on the moisture already in the wood. The decayed wood is brown in colour and appears as though it had been charred ; the timber is rendered soft and dry, and will flake off easily.

5.3 **Incorrect Grain Inclination.** The limit of grain inclination for spruce is 1 in 15 for grade A, and 1 in 12 for grade B. The inclination should be checked to ensure that the above limits are not exceeded. The most usual method of determining the inclination of the grain is by examining the flower-face of the timber to find the resin ducts. It will readily be seen whether they are straight or inclined. If the inclination exceeds the limits specified, the timber should be classified in a lower grade.

5.4 **Heart-Shake.** This defect usually follows the course of a sap duct longitudinally, and is usually visible on the tangential surface. The use of a small size feeler gauge will assist in finding the depth of the shake. The defect should be cut out of the timber.

5.5 **Ring-Shake.** This defect is indicated by a parting of the annular rings. Ring-shakes are usually caused by frost, particularly after a heavy rainfall. The defect should also be cut out of the timber.

5.6 **Compression-Shake.** This defect appears on a cross-section and usually takes the form of a thin wavy line. Compression-shakes are most dangerous as they are a partial fracture of the timber and any future loads may cause the fracture to be completed.

5.7 **Knots.** There are several kinds of knots which may be encountered when examining converted timber ; these are the dead-knot, the bud-knot and the pin-knot. The presence of any of these knots can have a detrimental effect. Generally they should not be more than a quarter of an inch in diameter but no hard and fast rules can be specified ; each case must be decided on its merits. Timber with "clusters" of pin-knots in it should be rejected.

5.8 **Pitch Holes.** There are two kinds of pitch holes, one being the horizontal type which usually appears at the base of a knot, and the other the vertical type which is sometimes referred to as a gum pocket. Gum pockets may either be "alive" (the gum-seam has not dried out) or "dead", and in the case of the latter, the timber should be rejected. Tests on "live" gum pockets have shown that the timber in the region of the gum pocket usually gives better result than the remainder of the timber.

5.9 **Blue Stain.** This defect only occurs in sapwood which should not be used in aircraft parts.

BL/6-7

Issue 3.

December, 1979.

BASIC

ENGINEERING PRACTICES AND PROCESSES

SYNTHETIC RESIN ADHESIVES

1 INTRODUCTION This Leaflet gives guidance on the gluing of wooden structures and on the adhesives which can be used for this purpose.

1.1 Synthetic resin adhesives are used extensively for joints in wooden structures to avoid the localised stresses and strains which may be set up by the use of mechanical methods of attachment; the strength of such structures depends largely on the effectiveness of the glued joints, and cannot be verified by means other than the destruction of the joints. Acceptance has, therefore, to be governed by adequate inspection at various stages throughout the gluing process and by assessment of the results obtained from representative test pieces (see paragraph 9).

1.2 Synthetic resin adhesives used for gluing aircraft structural assemblies must comply with the requirements prescribed in an acceptable Specification, usually British Standard 1204 Part I, for Weather and Boil Proof (WBP) or Moisture Resistant (MR) adhesives.

1.3 Information on the inspection of glued joints for evidence of deterioration under service conditions is given in Leaflet **AL/7-9.**

1.4 The terminology used in this Leaflet is that given in BS 1204, entitled "Synthetic Resin (Phenolic and Aminoplastic) Adhesives for Constructional Work in Wood". For those not familiar with the terminology, a glossary of terms not explained in the text, is given in paragraph 13.

2 GENERAL Synthetic resin adhesives (see paragraph 13.12) usually consist of two separate parts, i.e. the resin and the hardener. The resin develops its adhesive properties only as a result of a chemical reaction between it and the hardener, and will not harden without it. With some adhesives, an inert filler may be added to increase viscosity and to improve gap-filling properties.

3 PREPARATION OF ADHESIVES Synthetic resins (see paragraph 13.11) can be obtained in either liquid or powder form. In general, powder resins have the longer storage life, since they are less susceptible to deterioration which can result from high ambient temperatures.

3.1 **Powder Resins.** Powder resins should be mixed with water in accordance with the manufacturer's instructions before they can be used in conjunction with a hardener, and to obtain satisfactory results it is essential that they should be properly mixed. Once mixed, the resin should not be diluted unless this is specifically permitted by the manufacturer.

3.2 **Liquid Resins.** When resins are supplied in liquid form, they are ready for immediate use in conjunction with the hardener. Liquid resin should not be diluted unless this is permitted by the manufacturer.

3.3 **Hardeners.** When mixing the hardener (paragraph 13.7) with the resin, the proportions should be in accordance with the manufacturer's instructions. Hardeners should not be permitted to come into contact with the resin except when the adhesive is mixed just prior to use, or, as is necessary with some adhesives, when the joint is assembled by coating one face with resin and the other with hardener. When the latter method is employed, the surface to which each is applied should be in accordance with drawing requirements (see paragraph 6).

3.4 **Mixed Adhesives.** In many instances, manufacturers specify a definite period of time which must elapse between the mixing and the application of the adhesive and during this period the adhesive should be kept covered to prevent contamination.

3.5 **Utensils.** The utensils used for hardener should not subsequently be used for resin, and vice versa. These utensils and those used for the mixed adhesive should be acid-proof and should be kept scrupulously clean. After use, and before the adhesive has had time to set, they should be cleaned with warm water containing 5% sodium carbonate (washing soda).

4 PREPARATION OF SURFACES

4.1 **Plywood Surfaces.** All areas of plywood surfaces to be glued should first be 'sanded' in order to remove surface glazing and loose fibres. Sanding should be done lightly and uniformly either in the direction of the grain or diagonally across it, using a medium grade of glasspaper; local scratching or roughening, use of too coarse a paper and undue pressure, should be avoided. The sanding should not be excessive otherwise the fit of the joint may be affected.

4.2 **Timber Surfaces.** Timber surfaces should be suitably roughened so as to form a firm key for the adhesive, and a medium grade of glasspaper or a wood scraper is suitable for this purpose. To form a strong, efficient joint, it is essential that the mating surfaces should be a good fit. This is particularly important in the case of blind joints, the members of which may be chalked on their gluing surfaces before being assembled dry as a check on the fit; the chalk should be completely removed before application of the adhesive.

4.3 **Moisture Content.** It is important that the parts to be joined should have approximately the same moisture content, since variations may cause stresses to be set up as a result of swelling or shrinkage and thus lead to the failure of the joint. The moisture content should, additionally, be within the Specification limits for the particular timber. A safe range would be 8 to 16%, but with resorcinols this could be extended to 20% from a gluing viewpoint; however, this would not be satisfactory for aircraft components as joints would be likely to shrink after manufacture.

4.3.1 The moisture content of timber can be determined by taking a sample of the timber to be glued, weighing it, and then drying it in an oven at a temperature of 100 to 105°C (212 to 221°F) until two successive weighings yield the same result. The moisture content can be determined by the formula:—

$$\frac{W_1 - W_2}{W_2} \times 100,$$

where W_1 = the weight of the sample prior to drying, and
W_2 = the weight of the sample after drying.

4.3.2 A method of determining the approximate moisture content is by the use of an electrical meter working on either the resistance or the capacitance principle. When this instrument is used, its accuracy should be checked periodically against a sample, the moisture content of which is determined by the weighing method described in paragraph 4.3.1.

4.4 **General.** The surfaces to be joined should be clean and free from grease, oil, wax, crayon, paint and varnish; it is advisable not to handle the joint faces once they have been prepared. Where old timber is to be re-used, all traces of the previous adhesive should be removed, and the timber beneath should be cleaned; local staining of the wood by previous hardener or casein cement may be disregarded. Where any painting operations are to be carried out, all surfaces which are to be glued should be adequately masked.

5 CONDITIONS FOR GLUING Synthetic resin adhesives are very sensitive to variations in temperature, and the usable (pot) life of the adhesive, choice and proportion of hardener and clamping times, all depend largely on the ambient temperature at the time of gluing: it is, therefore, important to ensure that the manufacturer's instructions regarding these factors are followed.

5.1 The timber to be glued should be allowed sufficient time to attain the temperature of the room in which the gluing is to take place; it should not be overheated or raised too quickly from a low temperature, since this affects the surfaces of the timber and reduces the efficiency of most synthetic resin adhesives. It is important, therefore, that timber should be kept clear of radiators and other sources of heat prior to gluing.

6 APPLICATION OF ADHESIVE With certain exceptions, adhesives are used in the mixed form and the recommendations given in this paragraph apply only to the use of such adhesives.

6.1 It is generally desirable to apply adhesive to both surfaces of a joint. This applies particularly where plywood is to be glued to a fairly robust member, where the glue line (see paragraph 13.6) is likely to be variable or when it is not possible to apply uniform pressure to the joint after gluing.

6.2 Ordinary glue spreaders are satisfactory for the application of synthetic resin adhesives, but those having slightly grooved rubber rollers give the best results. Brushes may also be used provided they are perfectly clean.

6.3 The amount of adhesive required depends largely on the type of timber and the accuracy of machining; dense timbers require less adhesive than soft or porous types. Side-grained surfaces may be satisfactorily glued with thin spreads, and while end-grain joints have virtually no structural value, generous spreads may be applied for gap filling and sealing purposes. The general rule is that the adhesive should completely cover the surfaces to be glued and should be tacky when pressure is applied to the joint.

6.4 Difficult gluing conditions may sometimes occur when a soft timber is to be glued to one which is much denser, because the adhesive tends to flow into the more porous timber. In such instances, unless otherwise specified by the manufacturer of the adhesive, pre-coating and partial drying of the softer surface, prior to normal spreading, is recommended.

7 ASSEMBLY Care should be taken before the adhesive is applied to ensure that the surfaces make good contact and that the joint will be correctly positioned, since once contact is made after the adhesive is applied, the joint will be below strength if further movement is necessary. The interval between the application of the adhesive and assembly of the joint under pressure should, unless otherwise permitted, be kept as short as possible. Pressure should be applied quickly and should be even. All devices used to bring the glued surfaces together should be checked (this applies particularly to clamps) to ensure that the pressure is uniformly applied over the entire area; uneven pressure may cause uneven contact and a gaping joint.

NOTE: Some adhesives contain solvents which should be allowed to evaporate before the joint is made. If this is not done, bubbles may be created and a weakness caused. For adhesives of this type the manufacturer will specify a time interval which should elapse before the joint is closed.

7.1 High clamping pressures are neither essential nor desirable provided that good contact between surfaces being joined is obtained. For parts which are flat and unstressed it is not always necessary to maintain the pressure until the full joint strength is developed, but for work which is shaped by pressure, longer times may be required to guard against opening stresses. The tightness of clamps should be checked approximately 10 minutes after assembly.

7.2 If the parts are thin and the pressure is uniformly distributed, only a slight pressure is required and small pins or screws will generally provide this; care should be taken not to pump the adhesive out of the joint when hammering pins through closing strips.

7.3 When pressure is applied, a small even quantity of glue should be expressed from the joint and this should be wiped off before it dries. The pressure should be maintained, and the joint should not be disturbed during the full setting time; this is important as the adhesive will not re-unite if disturbed before it is fully set.

7.4 When large 'glue-face' areas are to be joined, e.g. when joining two ply surfaces, the drawing usually specifies the drilling of small vent holes at regular intervals to prevent air being trapped between the two surfaces. After the joint has been made, these holes should be checked to ensure that adhesive has exuded from them.

8 **SETTING TIMES AND TEMPERATURES** The setting time depends on the temperature at which the jointing operation is carried out; an increase in temperature results in a decrease in the setting time. Conversely, a decrease in temperature causes a considerable increase in the setting time, and with some adhesives a temperature below 15°C (60°F) is not recommended. It is, therefore, generally advantageous to apply heat during pressing whenever possible so as to effect reasonably quick and strong adhesion. Heat may be applied by means of an electrically or steam heated platen such as would be used for special presswork. Local warmth may be applied with electrically heated blankets, electric fires, a battery of electric bulbs, or drying kilns. The temperature may generally be raised to approximately 80°C (176°F) for very rapid setting; intense surface heating should be avoided as this may scorch the timber and cause the glue to bubble, the latter resulting in the production of a very weak joint. It must be remembered that it is the temperature of the glue line which determines cure rate and not the surface or ambient temperature. The warming of a cold assembly may cause the exuded glue to harden quickly, giving a false impression that the complete joint has cured (see also paragraph 5.1).

8.1 Full joint strength and resistance to moisture will only develop after conditioning for a period of at least two days, depending on the temperature and the type of hardener used. However, when repairs are made on aircraft, the joint should be of sufficient strength after one day. When it is necessary to ensure maximum resistance to moisture it is generally recommended that the assembled structures should be kept at room temperature of 21 to 24°C (70 to 75°F) for two to three weeks so that complete chemical reaction can take place.

8.2 Further assembly work can be carried out immediately the clamps have been removed provided the joint is not subjected to additional stress, otherwise the conditioning period recommended by the manufacturer is necessary. The degree of setting of the adhesive which has squeezed from the glue line is not necessarily an indication of the strength of the joint, and precautions should be taken to ensure that the joints are handled with due care until they have attained full strength.

8.3 After the joint has been conditioned and all work completed, all unprotected parts should be treated in acccordance with drawing requirements.

9 **TESTING** Frequent tests should be made to ensure that joining techniques are satisfactory. Wherever possible, tests should be carried out on off-cuts of actual components from each batch. Where off-cuts are not available tests should be carried out on representative test pieces glued up with each batch of mixed adhesive. In addition, the glue strength of components rejected for faults other than gluing should be checked periodically.

9.1 **Test Samples.** The test samples should be cut from the timber used for the component and should not be less than 50 mm (2 in) long and 25 mm (1 in) wide with one member over-hanging the other by 12 to 18 mm (½ to ¾ in). The glued test sample should, when conditioned, be put in a vice and the joint should be broken by leverage exerted on the overhanging member. The fractured glue faces should show at least 75% of wood fibres, evenly distributed over the fractured glue surfaces. A typical broken test piece is shown in Figure 1.

9.2 **Wet Tests.** When specified, wet tests should be made for the purpose of testing the efficiency of the adhesive after immersing the test samples in water at different temperatures and for different times. Such tests are prescribed in British Standard 1204, but the results are only valid if BS 1204 test pieces are used. However, testing joints, in a manner similar to that outlined in paragraph 9.1, after immersion in cold water (15 to 25°C (60 to 77°F)) for 24 hours, will give a good indication of whether they are cured. Such tests should only be carried out on joints which have been conditioned for two to three weeks as in paragraph 8.1.

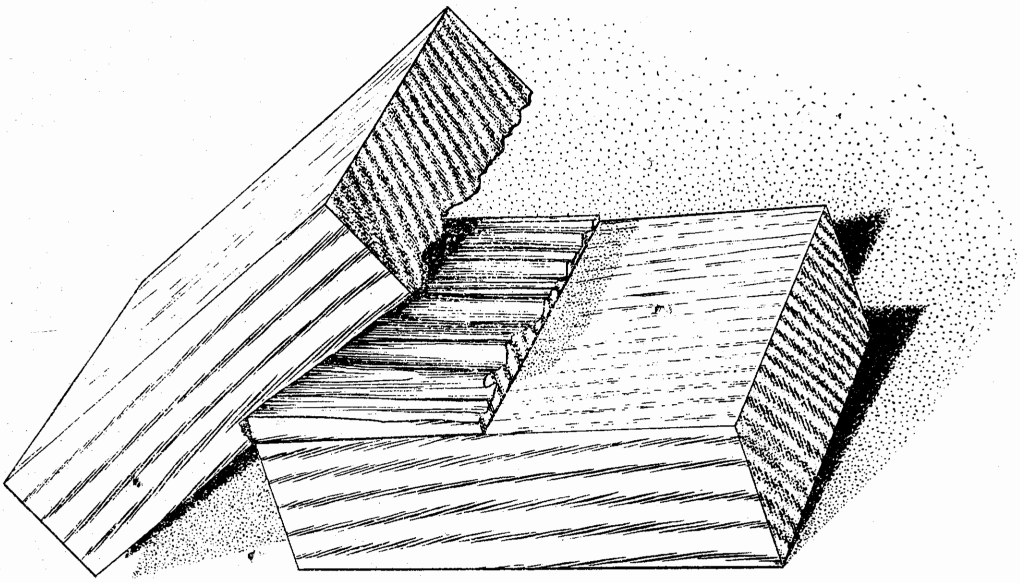

Figure 1 BROKEN TEST PIECE

10 FAILURE OF GLUED JOINTS Glued joints are designed to provide their maximum strength under shear loading. If a glued joint is known to have failed in tension it is difficult to assess the quality of the joint, as these joints may often show an apparent lack of adhesion. Tension failures often appear to strip the glue from one surface leaving the bare wood; in such cases, the glue should be examined with a magnifying glass, which should reveal a fine layer of wood fibres on the glued surface, the presence of which will indicate that the joint itself was not at fault. If examination of the glue under magnification does not reveal any wood fibres but shows an imprint of the wood grain, this could be the result of either pre-cure of the glue prior to the application of pressure during the manufacture of the joint, or the use of surface-hardened timber. This latter condition is particularly common with plywood and with other timbers which have been worked by high speed machinery and have not been correctly prepared in accordance with paragraph 4.1. If the glue exhibits an irregular appearance with star-shaped patterns, this may be an indication that the pot-life of the glue had expired before the joint was made or that pressure had been incorrectly applied or maintained. In all such instances other joints in the aircraft known to have been made at the same time should be considered to be suspect.

11 AIRCRAFT REPAIRS Where repairs are to be carried out on old aircraft in which the wooden structure is joined with a casein glue, all traces of the casein should be removed from the joint, since this material is alkaline and is liable to affect the setting of a synthetic resin adhesive; local staining of the wood by the casein can, however, be disregarded. Where formaldehyde based glues are to be used the surface should be wiped with a solution of 10% w/w acetic acid in water and allowed to dry before applying the glue.

12 STORAGE Apart from the very limited pot life of the mixed adhesive, the resin itself will not keep indefinitely, even under ideal storage conditions, and in no circumstances should the shelf life specified by the manufacturer be exceeded. Furthermore, resins in powder form which show signs of caking or corrosion of the container, and liquid resins which show signs of 'gelling' or have become excessively viscous, should be rejected even if the shelf life has not been exceeded. During storage, a temperature of 21°C (70°F) should not be exceeded.

13 GLOSSARY OF TERMS For the benefit of those not familiar with the terms used in relation to synthetic resin adhesives and their application, a glossary is given below.

13.1 **Cold Setting Adhesive.** An adhesive which sets and hardens satisfactorily at ordinary room temperature, i.e. 10 to 32°C (50 to 86°F), within a reasonable period.

13.2 **Close Contact Adhesive.** A non-gap-filling adhesive suitable for use only in those joints where the surfaces to be joined can be brought into close contact by means of adequate pressure and where glue lines (see paragraph 13.6) exceeding 0·125 mm (0·005 in) in thickness can be avoided with certainty.

13.3 **Closed Assembly Time.** The time elapsing between the assembly of the joints and the application of pressure.

13.4 **Double Spread.** The spread of adhesive equally divided between the two surfaces to be joined.

13.5 **Gap Filling Adhesive.** An adhesive suitable for use in those joints where the surfaces to be joined may or may not be in close or continuous contact, owing either to the impossibility of applying adequate pressure or to slight inaccuracies of machining. Unless otherwise stated by the manufacturer, such adhesives are not suitable for use where the glue line (see paragraph 13.6) exceeds 1·25 mm (0·05 in) in thickness.

13.6 **Glue Line.** The resultant layer of adhesive effecting union between any two adjacent wood layers in the assembly.

13.7 **Hardener.** A material used to promote the setting of the glue. It may be supplied separately in either liquid or powder form, or it may have been incorporated with the resin by the manufacturer. It is an essential part of the adhesive, the properties of which depend upon using the resin and hardener as directed.

13.8 **Open Assembly Time.** The time elapsing between the application of the adhesive and the assembly of the joint components.

13.9 **Single Spread.** The spread of adhesive to one surface only.

13.10 **Spread of Adhesive.** The amount of adhesive applied in order to join two surfaces, usually expressed in g/m^2 or $lb/100\ ft^2$.

13.11 **Synthetic Resin.** A synthetic resin (phenolic) is derived from the reaction of a phenol with an aldehyde. A synthetic resin (aminoplastic) is derived from the reaction of urea, thiourea, melamine or allied compounds with formaldehyde.

13.12 **Synthetic Resin Adhesive.** A composition substantially consisting of a synthetic resin of either the phenolic or amino-plastic type, but including any hardening agent or modifier which may have been added by the manufacturer or which may be required to be added before use, according to manufacturer's instructions.

BL/6-8

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BASIC

ENGINEERING PRACTICES AND PROCESSES

DEGREASING—TRICHLOROETHYLENE

1 INTRODUCTION This Leaflet gives guidance on the removal of oil and grease from metal surfaces by means of the trichloroethylene degreasing process.

1.1 The process may be used for degreasing all kinds of metals generally used in the construction of aircraft and their engines. However, care must be taken when processing magnesium alloys and aluminium alloys to reduce to a minimum the quantity of finely divided swarf entering the plant (see paragraph 6.3), since this swarf is highly reactive to trichloroethylene and, under certain conditions, may cause its decomposition and produce hydrochloric acid. If unchecked, the reaction described above can become violent.

1.2 The two trichoroethylene processes most commonly used in the aircraft industry are those utilizing either a vapour plant or a liquid-vapour plant.

2 DESCRIPTION OF PLANT

2.1 **Vapour Plant.** The vapour plant consists essentially of a galvanised mild steel tank equipped with heating facilities and having a water-cooled condensing coil in its upper part to prevent the escape of solvent vapour. Vapour rising from the boiling trichloroethylene in the sump condenses on the surface of any cold metal introduced into the working space below the condensing coils, dissolves any oil or grease which may be present, and runs back into the sump.

2.2 **Liquid-Vapour Plant.** The liquid-vapour plant is divided into two sections, each equipped with heating facilities; one compartment is kept full of boiling solvent and the other is used as an ordinary vapour plant. The plant is used particularly when foreign matter has to be removed in addition to oil and grease. The metal is first immersed in the boiling solvent, where the ebullient action removes solids such as polishing compounds, dirt, swarf, etc.; this is followed by a final dip in the vapour compartment to remove any remaining oil or grease.

2.3 **Ultrasonic Cleaning Equipment.** The incorporation of ultrasonic cleaning in a trichloroethylene degreasing plant is recommended only in exceptional cases where very finely divided solids have to be removed. Work immersed in the ultrasonically irradiated solvent is subjected to an intense mechanical effect which is particularly useful in removing small particles from crevices or surface irregularities on the metal. Work so treated should finally be immersed in trichloroethylene vapour so that it emerges dry as from an orthodox degreasing plant.

3 TRICHLOROETHYLENE Trichloroethylene is a non-flammable, colourless organic solvent and is a powerful grease solvent.

3.1 Only a small heat input is required to boil trichloroethylene, since its boiling point is only 87°C and its latent and specific heats are also low. For example, the heat required to convert 1 lb of water into steam would vapourise 8½ lb of trichloroethylene. When boiled, trichloroethylene gives off a clear vapour 4½ times as heavy as air, therefore the solvent can be boiled in the lower part of the plant and condensed in the upper part without serious loss.

3.2 Hot trichloroethylene may react with finely divided aluminium or magnesium (see paragraph 6.3) resulting in decomposition of the trichloroethylene and acidity. Exposure to sunlight or temperatures above 52°C can also result in slow decomposition and acidity, but to minimise this effect a small quantity of stabilizer is added to trichloroethylene used for degreasing.

3.3 Trichloroethylene is perfectly safe if used in accordance with the maker's instructions in a properly installed plant. Care is necessary at all times to ensure that the plant is well ventilated, since trichloroethylene vapour has a narcotic effect which, if inhaled, may cause drowsiness or unconsciousness and, in extreme cases, may prove fatal. The plant should be free of draughts to avoid a waste of vapour.

NOTE: Various equipment, e.g. Tilley lamps and electronic detectors, are available for the detection of vapour in atmosphere.

3.4 Trichloroethylene should not be allowed to come into frequent contact with the skin, since it removes natural body grease and leaves the skin dry and tender. It is recommended that a suitable preparation should be applied to the skin before degreasing operations commence.

3.5 When subjected to very high temperatures trichloroethylene undergoes a fundamental change and gases injurious to health are formed, therefore smoking and the use of naked lights should be forbidden in the vicinity of the plant.

4 INSTALLATION OF PLANT The plant should be installed in a well ventilated position, free from direct draughts (see paragraph 3.3). The Factories Act requires special precautions to be taken to prevent dangerous fumes affecting persons entering a confined space. An efficient extraction system should be installed in the plant, exhausting to the outside air.

4.1 Ample space should be provided around the plant so that doors and lids can be opened and closed easily, and sump scrapers, burners, coils of steam-heated plant, etc., can be removed for servicing.

4.2 **Water Separators.** A water separator is fitted to some plant for the purpose of removing water from the solvent. Water is distilled with the solvent, collected in the distillate trough and passed to the water separator where it is removed by gravity and discarded to drain whilst the trichloroethylene is returned to the plant.

4.3 Some plant are equipped with a pump which enables a stream of clean solvent to be directed onto the surfaces being degreased, thereby assisting in the removal of suspended solids.

4.4 **Thermostats.** Plant heated by gas, electricity or oil are fitted with thermostats to prevent overheating of the liquor in the sump, and with "safety" thermostats to prevent the accidental overflow of vapour. Overheating of plant heated by steam or high-pressure hot water is avoided by the installation of reducing valves and by orifice plates. These plants are also fitted with safety thermostats to prevent overflow of vapour should the cold water supply to the condenser fail.

NOTE: Thermostats used for heat control can only operate correctly if they are completely immersed in the solvent and are free from contamination by solid matter (or any shielding) which would insulate the thermostat from the solvent.

5 OPERATION OF PLANT The plant must be operated in accordance with the manufacturer's instructions and any notices regarding methods of operation or safety precautions should be installed in a prominent position near the plant. The following is a summary of the essential factors which will ensure that the cleaning process will have no detrimental effects on the materials or parts being cleaned.

5.1 Whilst the trichloroethylene process is used mainly for cleaning metal items, it can be used without detriment or hazard for cleaning other non-absorbent material such as glass, minerals and plastics of the phenol-formaldehyde type. However, parts containing rubber, fabric or other material may absorb trichloroethylene and should not be introduced into the degreasing plant. If a component contains any plastics or insulating materials, an approved test should be carried out to ensure suitability before trichloroethylene degreasing is adopted. Not all grades of trichloroethylene are suitable for the degreasing of titanium alloys, and the following is recommended:

(i) "Triklone A" (Type 1 trichloroethylene) is satisfactory for use with commercially pure titanium only.

(ii) "Triklone N" (Type 2 trichloroethylene) is satisfactory for use with titanium alloys but the total immersion time (in liquid or vapour) should not exceed two minutes for each degreasing operation.

NOTE 1: In some circumstances immersion may be prohibited or limited to less than two minutes. The manufacturer's specified limitations for immersion times should be closely followed.

NOTE 2: The use of methanol for degreasing titanium alloys should be avoided.

NOTE 3: It is particularly important that all traces of solvent are removed from the part immediately after cleaning.

5.2 Care should be taken to ensure that the parts to be cleaned are dry before being placed in the plant. In some cases it may be necessary to dry components of complicated shape in a heated oven; when this is done the component must be allowed to cool before being placed in the plant. The inside of the plant should be kept free from water or steam which could cause corrosion of ferrous parts and ultimately of the plant itself. Condensation of atmospheric moisture in the plant can be reduced by adjusting the temperature of the water in the cooling coils so that the outlet water is tepid.

5.3 Shrink-fitted articles should not be placed in the plant unless a keeper has been fitted to retain the parts in position.

5.4 After ensuring that the plant is functioning properly, the parts may be degreased by suspending them from wires in the vapour (rope or string must not be used) and small parts may be placed in wire baskets. Most plant have perforated plates near the bottom of the tank and, if found convenient, the parts may be placed on the plates.

5.5 When the parts become so warm that the vapour will not condense on them, they should be removed from the plant. If further degreasing is necessary, the parts should be allowed to cool before replacing in the plant, but such "double treatment" can be rendered unnecessary by the use of a dip or wash in the solvent. The advice of the manufacturer should be sought as to the best method of achieving this, and any ban on the use of "double treatment" to be observed, e.g. titanium.

5.6 When removing parts of complicated form from the plant they should be turned over several times, allowing the solvent which may have collected in cavities to drain back into the plant. Parts should be withdrawn slowly so that they are dry by the time they are clear of the plant.

5.7 Whilst it is good practice to allow parts to cool off before any further operation or protective treatment is applied, the parts must not be exposed to the atmosphere for too long a period as they are very susceptible to corrosion in the fully degreased condition. Temporary or permanent protection must be provided for degreased parts which are to be stored.

NOTE: Caustic soda must not be used in the immediate vicinity of trichloroethylene as the resulting chemical reaction may be dangerous. When caustic soda is used for washing engine parts, it is essential to ensure that all traces of caustic solution are removed before the parts are put in the plant.

6 MAINTENANCE OF THE PLANT The successful operation of the plant can only be ensured by systematic and careful maintenance in accordance with the maker's instructions. The following is a summary of essential points which should receive attention to ensure that the cleaning process will have no detrimental effects on the parts to be cleaned.

6.1 The solvent should be maintained at the correct level, and should not fall below the level of any immersed thermostat or heating coil. The temperature of the solvent should be strictly controlled and should not exceed 120°C as above this temperature trichloroethylene tends to decompose and form hydrochloric acid which would cause corrosion of the plant and of the articles under treatment.

6.2 The solvent should be re-distilled at regular intervals, depending on the amount of work passing through the plant. Re-distillation should only be effected in accordance with the manufacturer's instructions applicable to the type of plant. Indications of the need for re-distillation are a low vapour line in the plant and an excessive time being required to clean a batch of parts. If, after re-distillation and topping-up, the vapour line is still low, the heating apparatus may be at fault.

6.2.1 The amount of oil present in the solvent can be determined by taking a hydrometer reading of the solvent in the sump or by direct analysis of a sample of the solvent by laboratory test.

6.2.2 The amount of oil and grease present should not exceed 40 per cent. At regular intervals, usually determined by the nature of the work, all grease deposit and solid matter should be removed from the sump. When this is done, the plant should be checked for corrosion, the presence of which may indicate acidity. Reference should be made to the manufacturer's instructions regarding the cleaning of the plant.

6.2.3 Many of the larger degreasing plant, where large quantities of contaminated solvent require distilling, have small auxiliary stills for reconditioning the sump liquor from the main plant. Recovery of solvent is increased by the addition of water to the contaminated solvent in the distillation plant.

6.3 **Aluminium and Magnesium Reaction.** Aluminium and magnesium, or their alloys, in finely divided form (swarf or dust) will react with trichloroethylene complying with B.S.580, Type 1, causing acidity. The presence of acid will result in serious corrosion of the plant and of any parts being cleaned. This reaction can be avoided by the use of a proprietary neutral stabilised trichloroethylene complying with B.S.580, Type 2. There are several signs which indicate that aluminium reaction is commencing, as follows:—

(i) The presence of unusual fumes as distinct from the sweet smell of trichloroethylene.

(ii) The formation of a black sticky substance.

(iii) The colour of the copper cooling coils, which are normally tarnished, changing to a vivid green, accompanied, in some instances, by a crystalline deposit.

(iv) The rapid corrosion of parts removed from the plant.

6.3.1 Twice weekly, the trichloroethylene should be tested by the laboratory to ensure that it is not acidic.

NOTE: A rapid test for acidity may be done by shaking vigorously 25 ml of solvent (condensed from the vapour) and 25 ml of distilled water with a few drops of phenolphthalein. If the mixture remains colourless, it is possible that acid is present and an accurate laboratory test should be made.

6.3.2 "Triklone N" Type 2 may require a modified form of alkalinity check, the frequency of which will be determined by usage, considering the following factors:—

(i) Frequency of distillation and tank cleaning.

(ii) Proportion of new solvent required to make good the evaporation losses.

(iii) Work output of plant.

6.3.3 To prevent acidity, the following precautions should be observed:—

(i) All traces of small particles of aluminium or magnesium swarf or dust, etc., should be removed from the articles to be degreased by brushing off or by using a dry air jet. This may be done by washing in a light fuel oil or, when there is no risk, in paraffin or white spirit.

NOTE: It is recommended that, if the degreasing plant is heated by gas, flammable fluids should not be used as it is possible for vapour to be produced from trichloroethylene and paraffin which could ignite at the plant burner. The manufacturer's instructions, that the plant should not be topped up with trichloroethylene if the plant liquor is boiling, should be observed.

(ii) The plant should be cleaned thoroughly (at least once a week) ensuring that every trace of finely divided metal is removed from the sump, heating coils, etc. However, when Trichloroethylene Type 2 is used, it should be possible to relax the weekly cleaning of baths; it is, nevertheless, still necessary to ensure that no undue contamination of the heating surfaces occurs.

(iii) Ensure that the level of trichloroethylene never falls too low. (See paragraph 6.1.)

(iv) Small quantities of powdered soda-ash (anhydrous sodium carbonate) should be added twice daily to neutralise acidity in B.S.580 Type 1 Baths, but the amount added per week should not exceed 0·1 per cent by weight of the trichloroethylene charge. With the Type 2 trichloroethylene it should be possible to relax this requirement.

NOTE: Trichloroethylene weighs approximately 15 lb per gallon.

6.3.4 If acidity does develop, the manufacturer's advice should be sought and the plant treated in accordance with the manufacturer's instructions.

6.3.5 After a contaminated plant has been cleaned, it should be filled to above the condensing pipes with a solution of 5 per cent soda-ash solution and boiled for several hours. Any work basket, scraper, etc., which may have been contaminated with the products of reaction should be immersed in the plant during boiling. After this treatment the plant should be well rinsed out with clean water and dried before filling with fresh trichloroethylene.

6.3.6 After the plant has been returned to service a careful watch should be kept for any recurrence of acidity.

BL/6-12

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BASIC

ENGINEERING PRACTICES AND PROCESSES

RESISTANCE WELDING—SPOT WELDING

1 INTRODUCTION This Leaflet gives guidance on the application of the spot welding process to both ferrous and non-ferrous metals. It is not concerned with other resistance welding processes such as seam welding, which is the subject of Leaflet **BL/6-16**.

NOTE: Guidance is given on oxy-acetylene welding in Leaflet **BL/6-4** and on arc welding in Leaflet **BL/6-5**.

1.1 Spot welding is a method of providing a joint between two or more metal sheets, but in modern designs is not used in any significant load-bearing applications. It is a pressure welding process in which a 'slug' of welded metal is produced at the interface (or interfaces) of the sheets; a heavy localised electric current is passed through the parts to be welded by means of two opposed water-cooled, copper-alloy electrodes, whilst these are subjected to mechanical pressure.

1.2 The fundamental requirements for a spot weld are ability to resist shear stress, freedom from internal cracks and cavities, correct penetration (i.e. the relationship of the thickness of the slug, to the total thickness joined), freedom from excessive surface indentation or burning, freedom from flash or 'spits' either on the surface or between sheets, and consistency of properties beween one weld and others made under the same conditions.

1.3 The strength of spot welded joints depends to a large extent on machine factors such as the accurate repeatability of the electrical and mechanical operating cycles, the stability of the electrical supply and the rigidity of the welding machine, which is of particular importance where heavy mechanical loads are concerned, since distortion under load can negate otherwise satisfactory conditions.

1.4 Accurate repeatability of the electrical and mechanical operating cycles usually necessitates the use of fully automatic control with electronic timing of the current flow, especially when welding stainless steels and heat-resisting alloys. Full strength welds cannot consistently be obtained in any material from non-automatic machines, and it is essential that special attention should be given to welds produced on such equipment.

1.5 Other factors which influence the strength of spot welded joints include adequate and uniform preparation of the surfaces to be welded, the method of presentation of the work to the machine, and the spacing and placing of the welds. Surface preparation is of particular importance with aluminium alloys, since the presence of an oxide film on the surfaces of these materials creates a high and variable resistance in comparison to the resistance of the parent metal which, apart from causing the generation of excessive heat at the electrode tips, results in welds of varying strength.

1.6 As the only certain method of testing the strength of spot welded joints would result in the destruction of the workpiece, acceptance of the joints must, therefore, depend on adequate inspection supervision of the whole process, backed up by a system of test sampling. A recommended test sampling procedure is described in paragraph 11.

2 DESCRIPTION OF PROCESS Figure 1 illustrates the general arrangement of a typical air-operated spot welding machine. Machines of a similar type produced by various manufacturers will obviously vary in detail. Air-operated machines are usually manufactured in capacities up to 400 kVA. Further information on different types of equipment is given in paragraph 6.2.

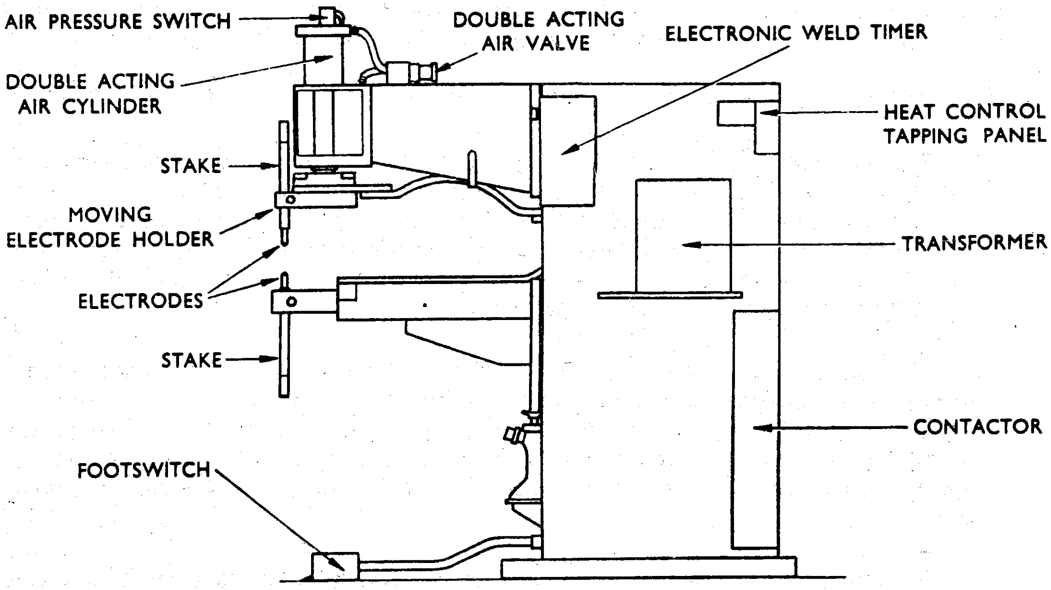


Figure 1 LAYOUT OF TYPICAL WELDING MACHINE

2.1 During the welding operation, the top electrode is brought down into contact with the workpiece by the depression of the foot switch. When pressure has built up on the workpiece, an electrical contactor closes, completing the circuit to the primary winding of the welding transformer and causing a secondary current of predetermined amperage to flow through the secondary circuit and through the workpiece.

2.2 The pressure on the workpiece of the water-cooled electrodes is maintained automatically for a predetermined period, during which the material is heated by the current flow through the resistance of the workpiece. At the conclusion of the pre-set period of current flow, the contactor opens and de-energises the welding transformer, but the electrode pressure is maintained for a further set period to permit the consolidation of the weld. At the end of this latter period, the top electrode pivots and the workpiece is freed for movement to the next welding position.

NOTE: It is essential that the electrodes should bed firmly upon the surfaces of the workpiece so that the axes of the electrodes are at right-angles to the plane of the surfaces, otherwise inconsistent and burnt welds may result. Supports may be necessary to ensure correct alignment where heavy or very long workpieces are being welded.

3 THE DESIGN OF SPOT WELDED JOINTS Considerable attention is given at the design stage to the various factors which can affect the strength, stiffness and suitability of spot-welded joints. In order that these factors may be more readily understood, they are discussed in general terms in paragraphs 3.1 to 3.6.

3.1 **Strength of Spot Welds.** Usually a minimum strength requirement per spot is assumed for design purposes, and whilst it is not possible actually to test the strength of production parts, indirect tests which give guidance on their strength are described in paragraph 11. The tensile strength of a spot weld is considerably lower than its shear strength; therefore, spot welding is not normally used for applications where loads acting out of the plane of the joint will occur. The stiffness of a spot welded joint is much greater than that of a comparable riveted joint. Factors which have a significant effect on the strength of the weld include the distance of the weld from the edge of the sheet, the pitch of the weld and the thickness ratio of the parts being joined.

3.2 **Edge Distance.** A minimum edge distance of 1·5D and a minimum overlap or flange width of 3D (D being the weld diameter) is generally recommended. Smaller values than these may lead to some loss of strength in the joint, an increase in the likelihood of splashing of metal from the interface, and an increase in the possibility of deformation during welding due to inadequate supporting material around the molten weld slug. The overlap, or flange width, is the width over which the materials being welded are in contact, and additional allowances must be made for any radiused corners which may be present on formed parts. Examples of good and bad design where radiused corners are concerned are shown in Figures 2(A) and 2(B), respectively, which illustrate the attachment of stringers to sheets.

Figure 2 ATTACHMENT OF STRINGERS TO SHEETS

3.3 **Pitch of Welds.** Weld spacing is associated with a definite minimum strength for the joint, since welds spaced closer than the predetermined optimum are reduced in strength due to current shunting (i.e. the passage of part of the welding current through the previously made weld). On the other hand, excessive spacing of the spot welds would result in the joint as a whole being weak. The effect of shunting is not of great importance where thin sheets are concerned, but becomes more pronounced with heavy gauge material, thus the weld pitch in these thicker materials is limited to dimensions which incur the least penalty in weld strength and joint strength. However, with titanium, which has a high electrical resistance, shunting is not a critical factor and weld strengths are not appreciably reduced until spacings are small enough to produce spot overlap. Figure 3 illustrates the action of shunting.

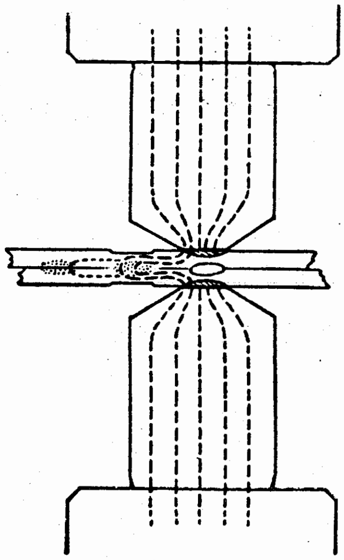


Figure 3 THE ACTION OF SHUNTING

3.4 **Material Thickness.** The total thickness of material which can successfully be joined by any one machine will obviously depend on the capacity of the machine and the nature of the material, but joint thickness of up to about 10 mm (0·4 in) in aluminium alloys and up to about 4 mm (0·16 in) in stainless steels are rarely exceeded. Excessive differences in the thickness of the sheets forming the joint tend to give inconsistent welds with little or no penetration of the thinner sheet. It is recommended that a thickness ratio of 2:1 to 2·5:1 should not be exceeded for any material. The joining of more than three sheets together is seldom attempted, since this results in the production of very weak welds.

3.5 **Surface Indentation.** The surface indentation of any sheet due to spot welding should normally not exceed 10% of the sheet thickness. Where indentation has to be avoided on one face of the workpiece, the tip diameter of the corresponding electrode can be increased up to three times the diameter normally recommended for the particular material thickness.

3.6 **Fitting of Surfaces.** It is important that the surfaces to be joined should be the best possible fit so that the electrode pressure is not required to overcome any stiffness of the sheets or sections, since this would result in a reduction of the pressure available for forging the weld. It is this factor which precludes the welding of contoured sections to flat sheets to form a contoured surface, or the placing of welds on radiused corners of sections and angles. Whenever necessary, a system of clamping should be used to hold the parts in correct register and to control the location of the weld. When welding assemblies containing numerous welds and, in particular, when welding heavy gauge material requiring large energy inputs, it is important to minimise distortion or deformation of the assembly caused by heat expansion; this can be done by commencing to weld at the centre of a seam and working outwards towards the ends or edges.

4 **CLASSIFICATION OF MATERIALS** Table 1 lists the types of materials which are commonly joined by spot welding techniques, together with brief guidance on post-welding heat treatment and other relevant factors. No attempt should be made to weld materials not listed, or to weld combinations of listed materials, unless this is specified by the drawing and a reliable technique has been developed.

TABLE 1

WELDABLE MATERIALS

Materials	Remarks
Aluminium and Aluminium Alloys	These materials do not require heat treatment after welding, as the speed of welding is so great that mechanical properties are not impaired.
Magnesium and Magnesium Alloys	The resistance welding of these materials must be controlled with special care, preferably under direct laboratory supervision.
Nickel Base Alloys	Nickel base precipitation-hardening alloys will require heat treatment after welding to improve their physical properties, but the solid solution alloys will only require to be stress-relieved after welding.
Austenitic Corrosion-Resisting Steels and Heat-Resisting Steels (Non-Magnetic)	Materials in this group generally require no heat treatment after welding.
Corrosion-Resisting and Heat-Resisting Ferritic Steels (Magnetic)	These materials may require heat treatment after welding due to embrittlement of the weld zone. Since the materials are magnetic, they should be welded on single-phase machines with constant current control or three-phase frequency conversion equipment.
Plain Carbon and Low Alloy Steels	These materials have a maximum carbon content of 0·26% and normally require no heat treatment after welding. Since the materials are magnetic, they should be welded on single-phase machines with constant current control or three-phase frequency conversion equipment.
Titanium Alloys	Generally require no heat treatment after welding.

5 SURFACE PREPARATION The success of resistance welding depends very largely on correct surface cleaning, since it is essential that the surfaces of the material should have a low and uniform contact resistance. Guidance on the surface preparation of various materials is given in paragraphs 5.1 to 5.6. It is difficult to lay down a standard mean period which can be permitted to elapse between surface preparation and welding, since this depends on such factors as the nature of the material, ambient conditions, etc., but the period should always be as short as possible. After surface treatment, the parts should be adequately washed and dried. DEF STAN 03/2 gives further details on the cleaning and preparation of metal surfaces.

NOTE: The use of cotton gloves when handling prepared surfaces is recommended.

5.1 **Aluminium Alloys.** The presence of a thin, tough, oxide surface film of high electrical resistance is characteristic of the aluminium alloys, and its removal prior to welding is essential, otherwise discoloured, surface-burnt welds, and rapid electrode deterioration will result. Furthermore, since the oxide film is not uniform in thickness, its presence causes variations in the heat developed at the sheet interfaces, resulting in considerable variation in the size of the welds.

5.1.1 The variation in electrical resistance is further aggravated by the presence of extraneous matter such as dirt, grease or paint, and since no satisfactory method exists for the removal of the oxide film and the extraneous matter together, surface preparation must be considered in two stages.

5.1.2 Firstly, the surface must be efficiently degreased by, for example, a process such as that described in Leaflet **BL/6-8**, using trichloroethylene. The oxide film must then be removed by a chemical process such as the ones described in (a) and (b) or by a suitable proprietary process.

(a) **Chromo-Sulphuric Acid Pickle.** The solution should consist of de-mineralised water containing:—

Sulphuric acid (d=1·84)	150 ml/litre
Chromic acid (CrO_3)	50 g/litre

The solution should be contained in a lead-lined tank and should be maintained at 60°C. The treatment period should not exceed 30 minutes, after which the parts should be thoroughly washed.

(b) **Sulphuric Acid and Sodium Fluoride Bath.** The solution consists of de-mineralised water containing:—

Sulphuric acid (d=1·84)	100 ml/litre
Sodium fluoride (NaF)	10 g/litre

The solution should be maintained at room temperature, and the parts should be immersed until uniformly clean (5 to 10 minutes). The parts should then be rinsed in cold water, dipped in an aqueous solution of 500 ml/litre nitric acid (d=1·84) for one minute and then thoroughly washed in clean water.

5.1.3 The cleaning of aluminium alloys of the type which are solution treated and naturally aged, should not be commenced until 24 hours after solution treatment. Great care should be taken to ensure the complete removal of all cleaning and pickling solutions, by efficient washing and rapid drying.

5.2 **Magnesium Alloys.** These materials should first be degreased and then carefully cleaned by a mechanical means. They should finally be air-blasted to ensure the removal of any particles left by the cleaning process.

5.3 **Corrosion-Resisting Steels.** The surfaces to be welded should be degreased and then prepared by cleaning with a brush having stainless steel bristles. Pickling is not necessary for these materials unless vapour-blasting or abrasive paper cleaning is employed, in which case contamination should be removed by pickling or swabbing in a 20% (by volume) nitric acid solution.

5.4 **Nickel Alloys.** The surfaces should first be degreased and then immersed in one of the following aqueous solutions:—

(a) Nitric acid (d=1·42)	200 ml/litre
Hydrofluoric acid	50 ml/litre

The solution should be used at a temperature not exceeding 65°C.

(b) Hydrofluoric acid	125 ml/litre
Ferric sulphate ($Fe_2(SO_4)_3$)	200 g/litre

The solution should be used at a temperature of 65 to 70°C.

NOTE: Nickel alloys should be in the solution heat-treated condition prior to immersion in these liquids.

5.5 **Plain Carbon Steels.** After degreasing, plain carbon steels should be pickled in an aqueous solution containing 10% sulphuric acid (d=1·84) by volume. The solution should be contained in a lead-lined or rubber-lined tank and should be used at room temperature. Welding should be carried out immediately after washing and drying the parts.

5.6 **Titanium Alloys.** The requirements for the surface preparation of titanium alloys are similar to those for other materials, i.e. the surface must be clean and free from grease. The surfaces may be cleaned by the use of any approved solvent which leaves no residue, but if the material has been heat treated for manipulation purposes prior to welding, a light oxide film will be present on the surfaces; this should be removed by an acid pickle (the solution described in paragraph 5.4 (a) is suitable) or by brushing with a wire brush.

6 SPOT WELDING OF ALUMINIUM ALLOYS The successful spot welding of aluminium alloys necessitates careful control of the welding technique, with particular attention to surface preparation (see paragraph 5.1), electrode maintenance (see paragraph 14) and component design; otherwise even the best equipment will give poor results.

6.1 General

6.1.1 The welding of aluminium alloys is considerably more difficult than the welding of low carbon steels due to the inherent nature of the materials, their surface condition and their tendency to alloy with copper and copper-based electrodes. In general, the high-tensile, heat-treated alloys show greater consistency of weld strength than the low-tensile alloys, although variations due to cleaning procedures and machine settings may result in greater inconsistency than is likely to arise from differences between alloys. The heat-treated materials usually tend to show cracks and porosity in the weld more than non-heat-treated alloys, but shrinkage cracks in the weld metal are confined almost entirely to the copper-bearing alloys. There is a tendency for the weld strength of aluminium-clad alloys to be less, and the weld consistency poorer, due to the cladding, which has a higher melting point and a lower resistance than the core.

6.1.2 The above factors have necessitated the production of specialised high capacity machines giving close control of the heat/pressure cycle, so designed as to give rapid electrode follow-up (i.e. the ability of the electrodes to follow rapidly the contraction of the solidifying and cooling spot weld so that it is always subject to the effective weld pressure).

6.1.3 Aluminium alloys are materials of high thermal and electrical conductivity. The amount of heat developed by electrical resistance welding methods depends on the resistance offered to the welding current; thus, despite the relatively low fusion temperature of these materials (compared with low carbon steel) a considerably greater rate of energy input is required, necessitating the use of high currents and short welding times, the latter being necessary to minimise conduction losses. However, advantage cannot be taken of the highly resistant oxide film which forms on the surface of these materials, since, as indicated in paragraph 5.1, its inherent lack of uniformity results in variation in weld size and quality.

6.1.4 The temperature range between the liquid and solid states is very small, and because of this, very close control must be exercised over the energy input, since small variations in energy may produce relatively large variations in weld size. The high thermal conductivity of the aluminium alloys (which results in rapid dissipation of heat) causes the welds to solidify very quickly, increasing the tendency to form shrinkage cracks and porosity. In practice, this factor is overcome by various machine refinements, e.g. by rapid electrode follow-up, by the application of a relatively high pressure after welding (which serves to close up pores and eliminate the tendency to form shrinkage cracks) and by decreasing the rate of cooling during the solidification of the weld by passing a relatively small but long duration post-heating current after the main welding current has been switched off.

6.1.5 The tendency for aluminium alloys to alloy with copper or copper-based electrodes is known as electrode 'pick-up' and is caused by one or more of the following factors:—

(a) Insufficiently cooled electrodes.

(b) High contact resistance caused by incompletely cleaned materials.

(c) Low electrode pressure.

(d) Incorrectly contoured or misaligned electrodes.

(e) Relatively long duration welding currents.

(f) The use of unsuitable electrode material.

6.2 **Types of Equipment.** Fully automatic machines are universally used for the welding of aluminium alloys, so that the predetermined welding cycle can be reproduced indefinitely, independent of the operator. Compressed air is generally used as a means of applying the load to the electrodes.

6.2.1 'Stored energy' single impulse, uni-directional machines are generally used. These machines can be sub-divided into two groups, i.e. the 'induction storage' and the 'condenser storage' types. With the induction storage type, energy is stored in the electro-magnetic field of a large iron-cored inductor, whilst with the condenser type, energy is stored in the electrostatic charge of a large condenser. These machines are, however, gradually being replaced by three-phase frequency conversion machines.

6.2.2 Portable and semi-portable machines, known as 'gun' or 'pinch' welders, are also used, and are of value when used in conjunction with jigs for mass production work. Such machines are not normally used for aluminium alloys except, in certain circumstances, for tacking.

6.3 **Electrodes.** The main requirements for an electrode for spot welding aluminium alloys, are that it should possess the maximum conductivity compatible with high resistance to deformation and the minimum tendency to alloy with the material to be welded. The most careful adjustment of current and pressure settings will be invalidated if badly worn or deformed electrodes are used, since current and pressure per unit area of contact between the electrode and the workpiece is reduced, resulting in poor quality welds.

6.3.1 Because of its high electrical and thermal conductivity, copper is used as the base for all spot welding electrode materials. However, pure copper, even when hardened by cold working, would soon soften at the temperatures reached during welding. In practice, therefore, conductivity has to be sacrificed to some extent in order to obtain a material capable of withstanding, for economic periods, the pressures and temperatures to be applied.

6.3.2 Special alloy electrode materials are available (such as chromium-copper) which have an electrical conductivity of 80% of that of annealed copper, coupled with high resistance to wear and to softening at elevated temperatures. The relationship between the size of the machine and the workpiece is also important in these respects, since underpowered machines necessitate excessive welding time, which heats the electrodes beyond the critical temperature and rapidly reduces their physical properties.

6.3.3 Domed electrodes are normally used for the welding of aluminium alloys, the radius of the dome varying from 50 to 125 mm (2 to 5 in) according to the thickness of the workpiece. Truncated cone type electrodes, having an included angle of between 150 and 160° are often used with stored energy machines. The relevant sizes of both types of electrodes for various sheet thicknesses are indicated in Table 2.

TABLE 2

COMMON FACTORS FOR WELDING ALUMINIUM ALLOYS

Material Thickness		Flat Electrode Tip Diameter		Domed Electrode Dome Radius		Minimum Weld Diameter	
(mm)	(s.w.g.)	(mm)	(in)	(mm)	(in)	(mm)	(in)
0·37	28	3·175	0·125	50	2	2·78	0·100
0·45	26	3·175	0·125	50	2	2·87	0·113
0·55	24	3·969	0·156	50	2	3·18	0·125
0·70	22	3·969	0·156	50	2	3·37	0·133
0·90	20	4·762	0·1875	50	2	4·03	0·159
1·20	18	5·556	0·2187	50	2	4·47	0·176
1·60	16	6·350	0·250	100	4	5·08	0·200
2·00	14	7·144	0·281	100	4	5·71	0·225

6.3.4 Straight-thrust electrodes should be used wherever possible, but in some instances, e.g. when attaching angle sections with narrow flanges, the use of eccentric or offset electrodes is necessary. In such instances the minimum amount of eccentricity or offset should be used, so as to restrict eccentric loading and to provide maximum support to the tip.

6.3.5 In general, electrodes should not be permitted to touch adjacent structure, otherwise shunting (see paragraph 3.3) may occur through this structure, depending on the relative resistance of the direct and indirect current paths. However, where contact is unavoidable any tendency to shunting can usually be counteracted by adjustment to machine settings.

6.3.6 Information on the maintenance of electrodes is given in paragraph 14.

6.4 **Machine Settings.** Due to a number of factors, such as individual machine characteristics, the nature of the material, the method of surface preparation and the peculiarities of a particular job, it is not possible to recommend specific machine settings. These can only be determined by experience based on comprehensive tests. However, certain factors in the welding process can be considered to have common values and those for aluminium alloys are listed in Table 2. The tip diameters recommended in this table are based on the accepted formula of D = t, where D is the tip diameter, and t is the thickness of the workpiece. This formula may be used for determining the most suitable tip diameter for any material, but slight adjustment may be necessary when welding materials of unequal thicknesses. In general, the minimum weld pitch should not be less than three times the diameter of the electrode tip.

6.4.1 Optimum machine settings are those which give the best weld strength, consistency and metallurgical weld quality, compatible with good electrode life and simplicity of operation under production conditions. Close co-operation between production and design staff is essential in order that the strength value chosen can be readily obtained and maintained in production.

6.4.2 Machines should be set only by skilled and authorised persons, and once settings have been made, the control of the process must be such that the settings may be used indefinitely for a particular set of conditions, although it must be borne in mind that variations in material composition and surface condition may give rise to complications necessitating an alteration to the original setting.

6.4.3 The importance of electrode tip cleaning cannot be over-emphasised and should be rigidly enforced, since worn or dirty electrodes may not only affect the strength and uniformity of the welds but will invalidate the machine settings. It is not possible to recommend precisely how welds may be made before cleaning is necessary, because of the number of factors to be taken into account, but a good general rule is to clean electrodes immediately any sticking is detected. Information on electrode maintenance is given in paragraph 14.

6.4.4 The quality of spot welding should be controlled by means of control test pieces, and a recommended system is described in paragraph 11. Details regarding the inspection of spot welded joints are given in paragraph 12, and a list of typical weld defects and their causes is given in paragraph 13.

7 SPOT WELDING OF MAGNESIUM ALLOYS

Although magnesium alloys can be spot welded, the process is not recommended for stressed applications. The equipment used for spot welding aluminium alloy is suitable also for magnesium alloys, provided that positive control of the spot welding cycle can be achieved. Magnesium alloys have a rather lower electrical conductivity than aluminium alloys, consequently lower current values will be required for equivalent thicknesses. The recommendations given in Table 2 and paragraph 6.4 are equally applicable to magnesium alloys.

8 SPOT WELDING OF PLAIN CARBON AND LOW ALLOY STEELS The spot welding of the plain carbon and the low alloy steels is, in comparison with the aluminium alloys, a relatively simple operation because of the readily weldable nature of the materials and the absence of an interfering oxide film. However, if the welds are to be of a consistent size and strength, cleanliness is essential and the surfaces should be prepared as indicated in paragraph 5.5.

NOTE: No attempt should be made to spot weld materials which are cadmium plated. The plating should first be removed, the process described in Leaflet BL/7-2 being suitable.

8.1 With steels having a carbon content of up to about 0·2%, a high rate of cooling is generally desirable, since this improves the properties of the weld, particularly in respect of the avoidance of brittleness. However, with steels having a higher carbon content and those having small additions of nickel, chromium, manganese, etc., considerable variations in properties may result from different rates of cooling, and there is a limit to which such variations can be tolerated.

8.2 So far as the higher carbon and low alloy steels are concerned, increases in the rate of cooling will result in proportional increases in the hardening effect, producing welds of relatively high tensile strength but with poor ductility. In addition, the volumetric changes brought about by the formation of the hardened structure and the shrinkage during cooling of the weld, may result in the formation of quenching cracks in the surrounding metal.

8.3 Rapid rates of cooling can be obtained by employing very short welding times (i.e. by using high currents) which will limit the zone affected by the heat. On the other hand, slow rates of cooling can be obtained by employing long welding times (i.e. by using low currents) which will give a gradual accumulation of welding heat, resulting in a comparatively large heat-affected zone.

TABLE 3

COMMON FACTORS FOR WELDING PLAIN CARBON AND LOW ALLOY STEELS

Material Thickness		Electrode Tip Diameter		Minimum Weld Diameter	
(mm)	(s.w.g.)	(mm)	(in)	(mm)	(in)
0·37	28	3·175	0·125	2·388	0·094
0·45	26	3·175	0·125	2·692	0·106
0·55	24	3·175	0·125	2·870	0·113
0·70	22	4·762	0·1875	3·581	0·141
0·90	20	4·762	0·1875	4·292	0·169
1·20	18	6·350	0·250	4·775	0·188
1·60	16	6·350	0·250	5·232	0·206
2·00	14	6·350	0·250	5·715	0·225
2·50	12	7·937	0·3125	6·096	0·240

8.4 Neither of the methods given in paragraph 8.3 is, on its own, capable of producing satisfactory welds in high carbon and low alloy steels, because of the greater hardenability of these materials, and a means has to be provided for improving the ductility of the weld and the adjacent metal. Such a method consists of subjecting the whole component (including the test piece where applicable) to a tempering process after welding.

8.5 **Electrodes.** The recommendations given in paragraph 6.3 are equally applicable to plain carbon and low alloy steels, but electrodes with an included tip angle of 120° should be used.

8.6 **Machine Settings.** The remarks concerning machine settings given in paragraph 6.4 are equally applicable to plain carbon and low alloy steels, except that common factors should be as given in Table 3.

9 SPOT WELDING OF STAINLESS STEELS Austenitic stainless steels have an electrical resistance approximately six times that of ordinary carbon steel, with a lower heat conductivity and melting range; therefore, considerably less heat input is required for spot welding these materials compared with plain carbon steels.

9.1 The welding of this type of material is made more difficult because of 'weld decay', which results from the precipitation of chromium carbide in metal near the weld when it is heated to a temperature within the range of 500 to 900°C. The corrosion resistance of these materials is dependent on the retention of chromium in solid solution; therefore, the corrosion resistance is reduced if precipitation of chromium carbide occurs near the weld.

TABLE 4

COMMON FACTORS FOR WELDING STAINLESS AND HEAT RESISTING STEELS

Material Thickness		Electrode Tip Diameter		Minimum Weld Diameter	
(mm)	(s.w.g.)	(mm)	(in)	(mm)	(in)
0·37	28	3·175	0·125	2·540	0·100
0·45	26	3·175	0·125	2·845	0·112
0·55	24	3·175	0·125	3·022	0·119
0·70	22	4·762	0·1875	3·810	0·150
0·90	20	4·762	0·1875	4·521	0·178
1·20	18	6·350	0·250	5·080	0·200
1·60	16	6·350	0·250	5·562	0·219
2·00	14	6·350	0·250	6·045	0·238
2·50	12	7·937	0·3125	6·096	0·240

9.2 The extent of precipitation is directly related to welding times, so that short welding times are essential for these materials, since this not only reduces the heat affected zone, but permits a high rate of cooling after welding, which also reduces the tendency for precipitation.

9.3 Austenitic steels are available which contain small additions of titanium or niobium in amounts sufficient to combine with all the carbon present so that no chromium can be precipitated as carbide.

9.4 **Electrodes.** The recommendations given in paragraph 6.3 are equally applicable to stainless steels, but electrodes having an included tip angle of 120° should be used.

9.5 **Machine Settings.** The remarks concerning machine settings given in paragraph 6.4 are equally applicable to stainless steels except that the common factors should be as given in Table 4.

10 SPOT WELDING OF TITANIUM ALLOYS

Resistance spot welding characteristics of titanium are essentially similar to those of stainless steel and for this reason satisfactory welds can be made on a wide range of conventional machines and under a wide variety of conditions. The requirements for producing satisfactory spot welds in titanium are less stringent than those required for welding aluminium and its alloys.

10.1 **Electrodes.** Electrodes should be made of heat-treated, copper-chromium alloy; several proprietary makes of electrode are available. Either domed or truncated cone electrodes may be used, but experience has indicated that the use of domed electrodes with a dome radius of 63·5 to 100 mm (2·5 to 4 in), depending on sheet thickness, avoids the risk of excessive electrode indentation.

10.2 **Welding Conditions.** Sound welds can be obtained with conventional machines over a wide range of machine settings, but to secure the optimum mechanical properties, welding current should be adjusted so that for sheets of approximately equal thickness, the depth of the fusion zone is not less than 75 to 80% of the total thickness.

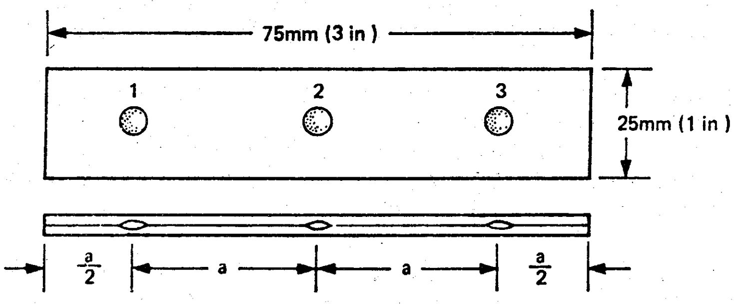
10.3 **Machine Settings.** The remarks concerning machine settings given in paragraph 6.4 are equally applicable to the spot welding of titanium alloys.

11 CONTROL OF SPOT WELDING

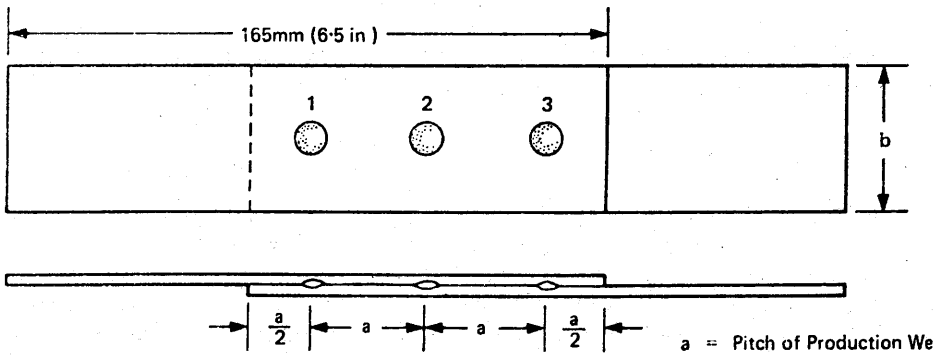
For design purposes a minimum strength per spot weld is assumed. Since it is not possible actually to test the strength of welds in production parts, this aspect has to be controlled by the examination of results of tests conducted on separately welded test samples, which simulate the production parts in respect of the material specification and thickness, surface preparation, machine settings and weld pitch. The test samples for the tests and examinations of paragraphs 11.4, 11.5 and 11.6 should be prepared at suitable intervals, an acceptable basis being one set of tests and examinations at the beginning and end of each shift, whenever a machine setting is changed, and after the replacement of electrodes.

NOTE: When spot welding is used for location purposes only and the loads on the joint are to be carried by other means of attachment, test samples are not normally required.

11.1 Production control test samples can only be used to determine whether the weld strength obtained with the samples exceeds the minimum strength per weld prescribed on the relevant drawings. It should be borne in mind that the strengths obtained with samples do not necessarily indicate that the individual weld strengths in the production assembly are acceptable, since it is not possible for such a test sample to be entirely representative of the production part as regards spacing and edge distance. Further, the sample cannot take into account the 'mass effect' in welding large panels. Minimum strength figures must be chosen with care, and should be determined by welding production assemblies and control test samples under the same conditions, breaking the welds in the assembly and comparing the results with the shear strength obtained with the test samples.



(A) MACRO AND PEEL OR CHISEL TEST SPECIMEN



(B) SHEAR TEST SPECIMEN

a = Pitch of Production Welds
b = 31mm (1·25in) up to 18 s.w.g.
38mm (1·5 in) thicker than 18 s.w.g.

Figure 4 TEST SPECIMENS

11.2 Some work of particular importance may require 100% X-ray inspection or X-ray inspection of the first part produced. These requirements should be stated on the drawing and should also be the subject of an approved technique.

11.3 As a further check on the efficiency of a welding process, random samples may be selected from actual production work, to be tested by an appropriate method.

11.4 **Peel or Chisel Test.** This test has the advantage that it can be quickly performed. The test sample should be prepared as shown in Figure 4(A), and the two strips of metal should be torn apart or separated with a blunt chisel, working on each side of the weld. The first weld (which should be marked when welding the sample) should be ignored and the remaining spots should be examined. The weld nugget should be torn from one of the strips and remain in the other; it should not shear along the mating surfaces of the sheets.

11.5 **Shear Test.** Test samples should be made up to the dimensions shown in Figure 4(B), the spots being marked in the order of welding.

11.5.1 The first weld should then be removed by drilling.

11.5.2 The test sample should be held at one end and a load applied to the other end, so that a pull force is applied to the second and third welds in shear, no twisting action being exerted on the welds. Load should be applied at a controlled rate, and the load at failure should be noted.

11.5.3 The strength per spot is taken as half the load at failure and should be at least equal to the value quoted on the relevant drawing or associated documentation.

11.5.4 If a test sample fails at a load below the specified load, two further test samples should be made. If one or both of these additional samples fails the test, the material welded since the last satisfactory test should be subjected to closer examination and the entire welding process should be examined to identify the cause; if the technique has been closely controlled this should not prove difficult.

11.6 **Macroscopic Examination.** The samples for macroscopic examination should be prepared to the dimensions given in Figure 4(A), the spots being marked in order of welding.

11.6.1 The first weld should be ignored and the second and third welds should be carefully sectioned through the centreline and polished.

11.6.2 When examined through a lens of low magnification the welds should be well shaped and show freedom from overheating and from excessive cavitation and porosity. Slight cracks in the nugget may be permissible, but not if they extend into the parent metal.

11.6.3 Penetration should be adequate but not excessive, and for welds in sheets of approximately equal thickness the depth of the fusion zone should be 40 to 80% of the sheet thickness and at least 20% in any one sheet (but see paragraph 10.2 for titanium alloys). The fusion zone should not reach the surface of the sheet or, where clad materials are concerned, the cladding.

11.6.4 The minimum weld (nugget) diameter should be approximately that shown in Tables 2, 3 and 4, or as specified on the relevant drawing.

11.6.5 Pick-up (see paragraph 6.1.5) from the electrodes is not acceptable in aluminium alloys.

11.6.6 Electrode indentation should not exceed 10% of the thickness of the individual sheets.

11.7 **Identification of Test Samples.** All test samples should be marked with the machine number, the date and time of manufacture, the part number of the item represented, and the test serial number.

12 INSPECTION OF SPOT WELDED PARTS In addition to indicating the examination to be afforded the parts after welding, this paragraph summarises the responsibilities for inspection for the process as a whole.

12.1 Inspection should verify that the period of pressure and heating, current values, etc., are as specified on the drawing and are in accordance with the results of experiments and past experience with the particular type of weld and machine used.

12.2 It should be ensured that the metal to be welded has been suitably cleaned and that the highest standard of cleanliness is observed throughout the process, that the welding technique is correct, that all drawing requirements are complied with, and that the electrodes used are of the correct form and size required by the drawing.

12.3 After welding, the surfaces of each weld should be examined to ensure that they show no obvious signs of overheating, and that both they and the adjacent metal are free from visible cracks.

12.4 The electrode indentation should be checked to ensure that it does not exceed 10% of the original thickness of the sheet being welded. The indentation should be a well radiused impression without sharp edges.

12.5 The sheet separation at the weld should be checked to ensure that it is not greater than 10% of the combined thickness of the sheets being welded.

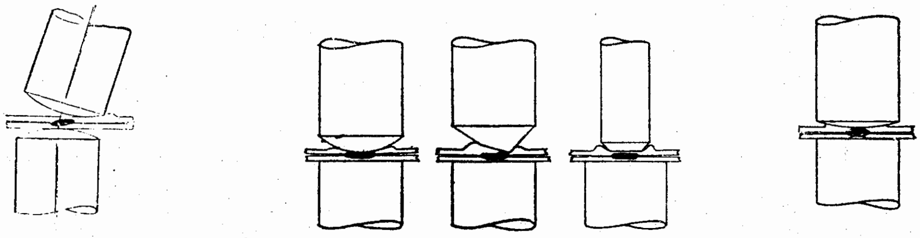
12.6 The inspections of 12.1 to 12.5 should be backed up by the evidence afforded by the shear, macroscopic and peel or chisel tests described in paragraph 11 and, where stressed parts are concerned, by the specified radiological examinations.

13 COMMON FAULTS IN SPOT WELDING Table 6 indicates common faults which may occur in the spot welding process, together with the probable causes of such faults. Figure 5 illustrates some of these faults.

TABLE 6

COMMON FAULTS IN SPOT WELDING

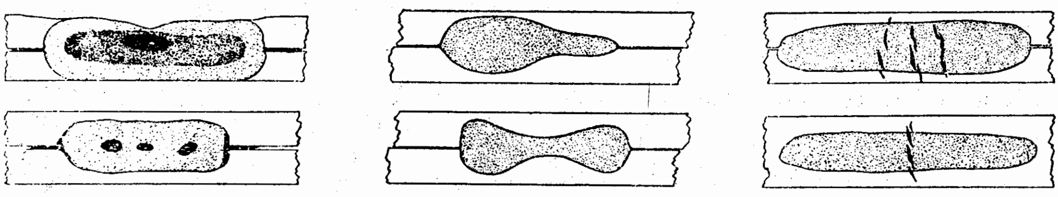
Fault	Probable Causes
Poor Strength Welds	This fault may result from a combination of various factors, the most important of which are insufficient current, weld pressure too high and misalignment of the electrode tips, producing irregular shaped welds.
Irregular Shaped Welds	Electrode tip misalignment. Incorrect surface preparation.
Surface Burning	Any factor which affects the energy input to the weld and the surface contact resistance may cause surface burning. The most important factors are incorrect surface preparation whereby the material has too high a contact resistance. Badly cleaned electrodes (e.g. electrodes from which 'pick up' has not been removed). Misaligned electrode tips, giving excessive local current concentration. High current.
Heavy Indentation	Sharp electrode contour (i.e. the use of electrodes of too small a radius or too small an included cone angle). Excessive energy input to weld with marked collapse surrounding the weld under pressure of the electrodes, and usually associated with interfacial splashes between the sheets (i.e. expulsion of weld metal at sheet separation). High electrode pressure.
Concave Shaped Nugget	Insufficient weld time. Insufficient current. Excessive electrode pressure.
Cracks in Nugget	Insufficient forging time. Insufficient electrode pressure. Excessive current. Insufficient overlap.
Unbalanced Nugget	Misalignment of electrodes. Component held at angle to electrodes.
Unequal Penetration of Equal Gauges	Electrodes of unequal sizes.
Surface Cracking	Excessive welding current. Insufficient forging time or pressure too low. Inadequate surface preparation leading to excessive heating and rapid cooling.



INCORRECTLY ALIGNED ELECTRODES

HEAVY INDENTATION

SPLASHING AND SHEET SEPARATION



POROSITY

IRREGULAR SHAPED WELDS

CRACKS

Figure 5 TYPICAL WELD FAULTS

14 **MAINTENANCE OF ELECTRODES** The electrodes fitted to some small machines are sometimes solid, but with most modern machines they are hollow, water-cooled and fitted with removable tips.

14.1 The cleanliness of electrode tips is of the utmost importance and the tips should be cleaned in accordance with a definite schedule and whenever evidence of 'sticking' is noted. Light erosion may be blended out using a fine grade of emery paper, but deeper erosion should be blended out by machining. Filing or other cleaning methods which would alter the shape of the electrodes must not be used.

14.2 Deformation of electrodes will occur during use. An increase in diameter of the flat tip of a truncated cone electrode produces a corresponding reduction in current density, and weld strength will be affected accordingly; no definite rule can be given regarding the permissible extent of distortion, but in any case it should never exceed 10%. Similarly the diameter of the flat which forms on domed electrodes should not be allowed to exceed the corresponding flat tip diameter by more than 10%. Profile gauges are helpful in checking deformation. Where deformation exceeds agreed limits, the electrode tip should be machined to the original diameter.

14.3 Before electrodes are inserted in the holders on the machine, they should be wiped with a clean rag to remove any dirt. This ensures that the tapers of the electrode and the holder are maintained in good condition, facilitating the removal of electrodes and preventing water leakage.

15 MAINTENANCE OF WELDING EQUIPMENT In general, the maintenance of the machines and equipment used for spot welding should be in accordance with the instructions prepared by the manufacturers of the machines or equipment. However, to ensure continued efficiency, the following points should receive regular attention.

15.1 Each week all machine bearings should be lubricated and the air line water traps should be drained.

15.2 Monthly maintenance should include the following:—

(a) A calibration check of all instruments and gauges.

(b) A check on the water cooling system to ensure an unrestricted flow and freedom from leaks.

(c) A check to ensure that all indicator lights on the control panel function correctly.

(d) A check to ensure that all relays on the control panel and on the machine are clean, in good condition, and are holding correctly.

(e) A check on thermionic valves for satisfactory operation.

(f) A check to ensure that the moving arm is completely free from side play and twist, and is free to fall under its own weight with the compressed air switched OFF.

(g) A check to ensure that the air pressure line from the reducing valve to the air pressure head is pressure tight and free from air leaks, and that the reducing valve is functioning correctly.

(h) A check to ensure the correct operation of the timing device on the control panel.

(j) A check to ensure cleanliness of the welding machine and its mechanical components.

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BASIC

ENGINEERING PRACTICES AND PROCESSES

LOCKING AND RETAINING DEVICES

1 INTRODUCTION This Leaflet gives guidance on the methods of locking screw-threaded components, and the retention or location of circular parts in various assemblies. Chapter **D4-1** of British Civil Airworthiness Requirements prescribes that an approved means of locking must be provided on all connecting elements in the primary structure, fluid systems, controls and other mechanical systems essential to the safe operation of an aircraft. Information on the assembly and locking of turnbuckles is given in Leaflet **AL/3-7,** on the assembly and inspection of critical bolted joints in Leaflet **AL/7-8,** and on stiffnuts in Leaflet **BL/2-6.**

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet **BL/5-1,** Issue 3, 1st February 1967.

1.1 The purpose of a locking device is to prevent loosening or disengagement of mating components under varying conditions of stress, vibration and temperature, and its effectiveness may be of the utmost importance to the safety of an aircraft. Locking devices should be fitted in such a way as to prevent the possibility of fretting, distortion, displacement or uneven stressing of the locked parts.

1.2 During inspection of the assembly, it is necessary to ascertain that all locking or retaining devices are of the type and material specified in the relevant drawings or the appropriate publication, and that the locking or fitting operation has been correctly performed with the appropriate tools.

2 SPLIT PINS Split pins are manufactured from corrosion resisting steel, and are used in conjunction with drilled bolts and slotted or castellated nuts. The pins should be a reasonably close fit in the nut and bolt/stud assembly. Table 1 indicates the diameters and length of pins normally used in conjunction with bolts/studs up to 1 inch diameter.

TABLE 1

SPLIT PIN SIZES

Bolt Diameter (inch)	Pin Diameter (inch)		Pin Length (inch)
	British (SP 90)	American (MS 24665)	
1/4 or 2 BA	1/16	1/16	3/4
5/16	1/16	1/16	1
3/8	1/16	3/32	1
7/16	3/32	3/32	1.1/4
1/2	3/32	3/32	1.1/4
9/16	1/8	1/8	1.1/2
5/8	1/8	1/8	1.1/2
3/4	5/32	1/8	1.3/4
7/8	5/32	1/8	2
1	3/16	1/8	2.1/4

NOTE: It will be seen that British and American practice differs with regard to split pin diameters for different thread sizes and care must be taken to ensure that the correct pin is selected for any particular drilled bolt. The size of the split pin hole in the bolt should be checked before fitting the nut.

2.1 The legs of split pins should be turned as indicated on the design drawings, but when the method is not specified it is recommended that one of the methods illustrated in Figure 1 should be used. If necessary, pins should be cut to a suitable length to prevent pick-up in clothing, cleaning cloths, etc., and the surplus ends accounted for to prevent their becoming a loose article hazard.

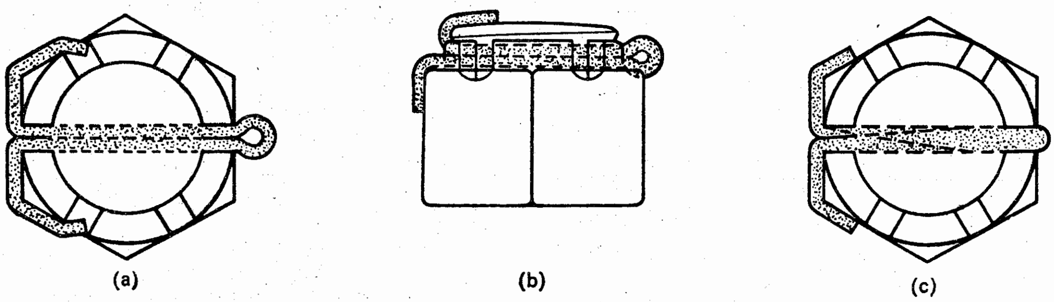


Figure 1 SPLIT PINNING

2.2 After turning and closing the legs to the nut faces, an inspection should be made to ensure that cracking or cutting has not occurred at the bends. The most common methods of split pinning are illustrated by Figure 1 (a) and (b). The method shown in Figure 1 (c) is used where clearances are critical.

2.3 For bolted joints, one pair of slots must be in alignment with the hole in the bolt when the specified degree of tightness has been obtained. Undrilled bolts should be prepared for drilling by tightening the nut to the specified torque loading and marking the hole position. The nut should be removed and the split pin hole drilled with the aid of a drilling jig. Burrs should then be removed, the nut fitted and tightened to the required torque loading, and the correct size of split pin fitted.

2.4 In instances where torque loading is not specified, it may be permissible to tighten the nut slightly to achieve alignment, but in no circumstances should a nut be eased back from the normally tight position since this may result in slackness between the parts of the assembly. Nuts must not be filed to facilitate the fitting of split pins. Alignment is more difficult with drilled bolts, and selective assembly of nuts and/or washers may be required.

2.5 Split pins should not be used more than once. Split pin holes should not be enlarged, nor split pins filed to facilitate fitting.

3 LOCKING WASHERS There are several types of locking washers in general use consisting of spring washers, cup washers, shakeproof washers, crinkle washers and tab washers (Figure 2).

3.1 **Spring Washers.** These washers are available in two forms, i.e. as a single coil (SP 47) or as a double coil (SP 55 and 56).

3.1.1 In some instances, particularly with light alloy assemblies, spring washers are assembled with plain facing washers between the spring washer and the component, to prevent damage to the surface of the component or the protective treatment when the spring washer is compressed. Often, however, particularly in steel assemblies, plain washers are not specified.

3.1.2 It is good practice to renew spring washers during overhaul or repair. This is essential in engines and engine components, and units with reciprocating parts, such as compressors or pumps.

3.2 **Cup Washers.** These washers (AS 8690 to 8699) are manufactured in spring steel and are dished to form a spring of high rating; assembly should be in accordance with the manufacturer's instructions.

3.3 **Shakeproof Washers.** Flat washers of this type (AGS 2034 and 2035, steel; AGS 2037, phosphor bronze) are sometimes used instead of spring washers and, in certain circumstances, conical shakeproof washers (AGS 2036, steel) are used for locking countersunk screws. Either the internal diameter (AGS 2035 and 2037) or external diameter (AGS 2034 and 2036) is serrated, the serrations being set to bite into the component and nut to prevent rotation. Shakeproof washers should only be used once.

NOTE: These washers will not normally be specified in assemblies where anti-corrosion treatment of components has been carried out.

3.4 **Crinkle Washers.** These washers (SP 134 to 138, copper alloy, and SP 139 to 140, corrosion resisting steel) are often used in lightly loaded applications in instrument and electrical installations.

3.5 **Tab Washers.** Tab washers are manufactured from thin metallic sheet materials, to SP 41 to 46 or SP 107 to 112, or to proprietary specifications, and have two or more tabs projecting from the external diameter; they may also be designed for locking two or more nuts. When the washer is fitted, one tab is bent against the component or fitted into a hole provided for that purpose, whilst a second tab is bent against a flat or flats of the nut, after the nut has been correctly tightened down. The component tab should not be bent against a curved surface, since this would permit movement of the washer, and result in loosening of the nut.

3.5.1 Before bending the second tab, an examination should be made of the tab already fixed to ensure that it is not disturbed, sheared or distorted as a result of the washer turning with the nut. When the second tab has been bent, this too should be examined for cracks.

3.5.2 In some assemblies, washers having a tab projecting from the inside diameter are used. The tab fits into a slot machined in the bolt thread or the component hole, whilst an external tab is turned up as described in paragraph 3.5.

3.5.3 Tabs must not be bent more than once. Multiple tab washers may be re-used after removing the used tab, dressing sharp edges, and carefully inspecting the remaining tabs for cracks or scoring.

4 LOCKNUTS Generally, locknuts are thin plain nuts which are tightened against ordinary plain nuts or against components into which male threaded items are fitted, although proprietary locknuts are available which are formed from sheet material. Control rods, swaged-end cables and jack ram eye-end fittings are common examples of the use of locknuts, but in some instances wire locking is also specified. To ensure efficient locking, the bearing surface of the nuts and the component must bed together evenly and the correct degree of tightness must be obtained by applying the stipulated torque loading. It is emphasised that the locknut should not be over-tightened, since this will result in the stripping of the nut threads or over-stressing of the male component. In cases where rotation can occur, the plain nut must be held stationary whilst the locknut is tightened.

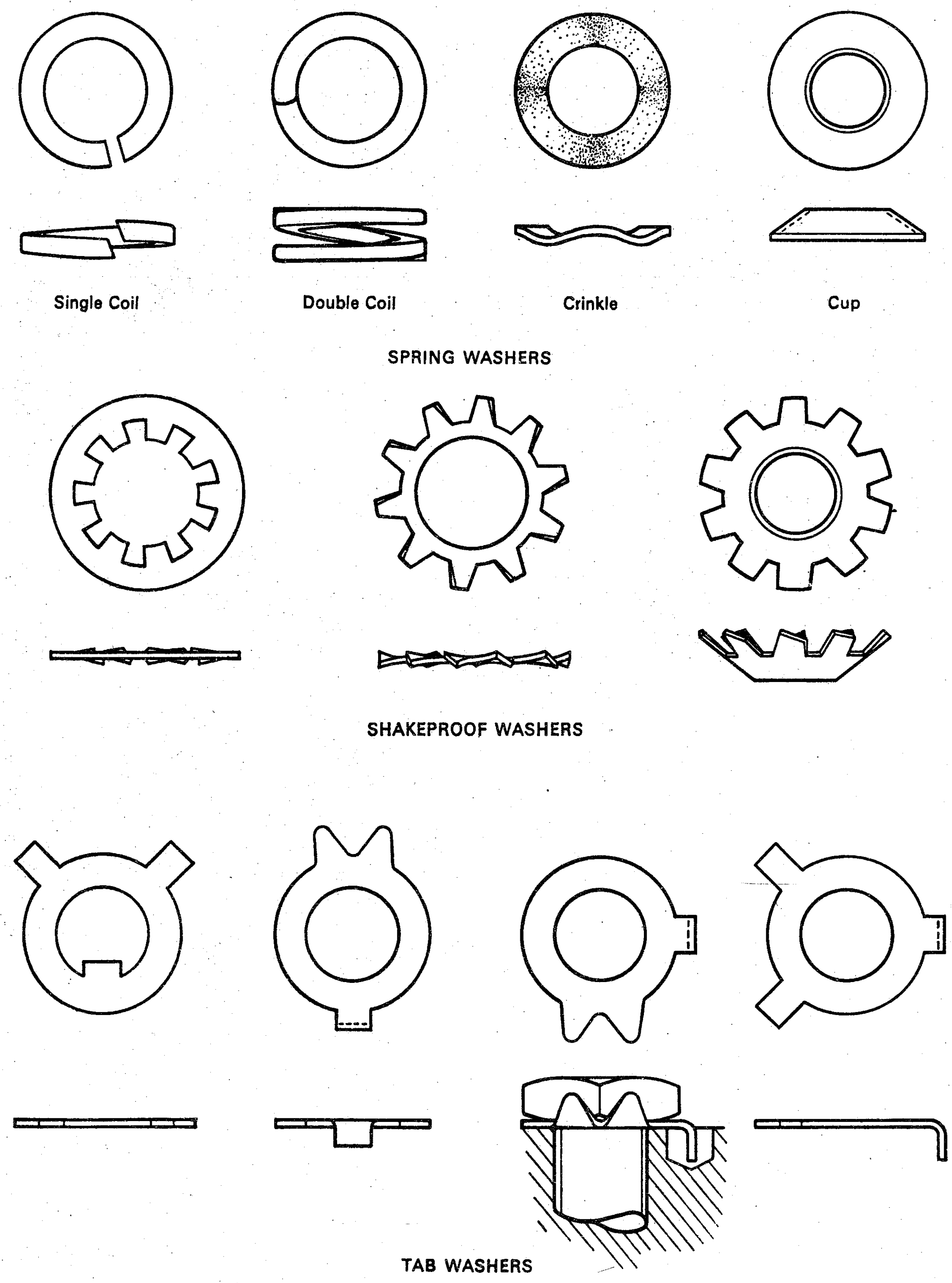


Figure 2 TYPES OF WASHERS

5 LOCKING PLATES Locking plates are usually manufactured from steel. They are placed over hexagonal nuts or bolt heads after these items have been tightened down, and secured, usually by a screw, to an adjacent part of the structure. A typical application is shown in Figure 3.

5.1 Locking plates may be used repeatedly provided they remain a good fit around the hexagon of the nut or bolt head.

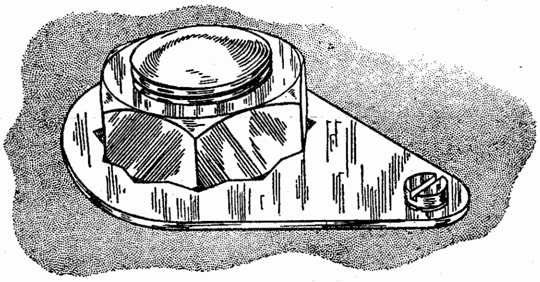


Figure 3 LOCKING PLATE

5.2 In certain instances, particularly where vibration is likely, locking plate screws are fitted with spring or shakeproof washers. Some plates may be located by counter-sunk screws, which may be locked by peening (see Figure 8). Plates may also be provided with a retaining screw slot which permits a limited amount of angular adjustment to suit the position of the nut.

6 CIRCLIPS AND LOCKING RINGS Many of these locking devices (see Figure 4) are standard AGS parts manufactured from spring steel wire, sheet or plate, but they may also be specially designed for a particular application. All are hardened and tempered to give inward or outward spring for locking screwed parts together, for locking grub screws (paragraph 10), or for locating components within bores or housings.

6.1 Wire circlips have both ends bent whilst other types have drilled ends which facilitate expansion or contraction for fitting into position.

6.2 Generally, wire locking rings have one bent end which is inserted into a radial hole drilled through the outer or inner component, depending on whether it is an external or internal type. Locking rings of sheet or plate are seldom provided with a bent end, and the fitting of these entails the use of special expanding/contracting tools and protecting sleeves.

6.3 Grooves for circlips and locking rings are semi-circular for wire types and of rectangular section for others and, before fitting, precautions should be taken to ensure that these are free from deformation, burring or dirt.

6.4 Inspection should ensure that all of these devices are bedding correctly, and that the locking end of locking rings is correctly engaged.

6.5 Identification of these devices is difficult and every care should be taken to ensure that the correct items are fitted. Items should be obtained by part numbers and not identified by comparing the old and new, since the diameters of the old are likely to differ considerably from those of new items. Part numbers of the correct part to be fitted should be verified from the appropriate drawings, Overhaul or Repair Manuals or Parts Catalogue.

6.6 Some manufacturers stipulate that circlips and locking rings must not be used more than once. However, in some instances, it is specified that the gap between the ends of a circlip or locking ring should, after fitting, be within prescribed limits, and individual selection may be necessary. The radial position of the gap may also be specified.

7 WIRE LOCKING Corrosion resisting steel and heat resisting nickel alloy are the materials normally recommended for wire locking, except in the circumstances described in paragraph 7.6. Care should be taken to ensure that the wire used is to the correct specification and gauge required by the relevant drawing. In the normal twisting method of wire locking, a suitable length of wire should be cut from the coil and passed through the hole provided for the purpose in the component. The wire should be twisted over the length required to reach the locking point, through which one end of the wire should be passed, and then twisted for not less than a further ½ inch whilst being pulled taut. It is necessary to pull the wire taut to ensure that the final twists are close to the locking hole, but neither this nor the twisting should be too severe. After surplus wire has been removed, the twisted ends should be bent in such a manner as to prevent their catching in clothing, cleaning cloths, etc. There should be no untwisted lengths in excess of ⅜ inch, and lengths of unsupported wire should not normally exceed 3 inches.

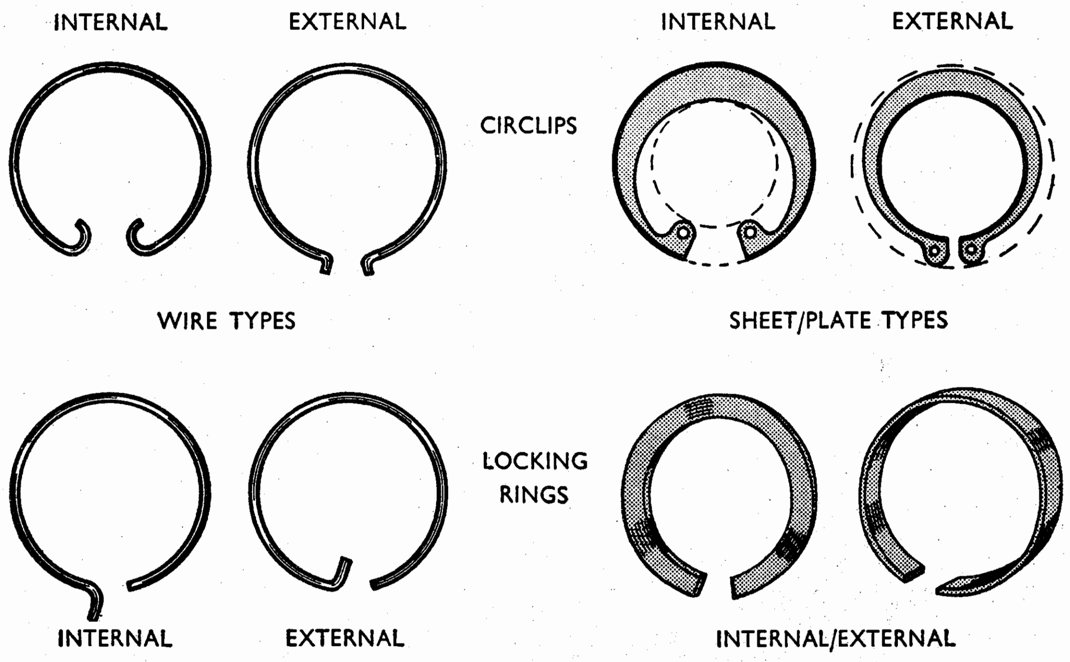
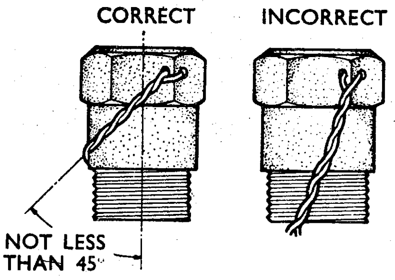


Figure 4 CIRCLIPS AND LOCKING RINGS

7.1 The angle of approach of the wire should not be less than 45° to the rotational axis of the component to be locked (see Figure 5), whilst the line of approach should be tangential to the parts being locked (see Figure 6). The lay of the wire must always be such as to resist any tendency of the locked part or parts to become loose, and for this reason it is essential to ascertain whether the parts have left or right hand threads before fitting the wire.



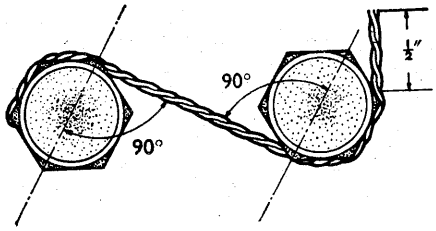


Figure 5 ANGLE OF APPROACH

Figure 6 TANGENTIAL APPROACH

7.2 In instances where the method of wire locking is not indicated on the drawing, great care is necessary when deciding on a locking method to ensure that there is no possibility of the parts becoming loose. For example, when adaptors are used in pipe joints, it is essential that the adaptor is secured to each union nut by separate locking wires to adjacent corners of the adaptor nut, with the approach angle shown in Figure 5. It may be specified that the adaptor is locked additionally to some external point.

7.3 When locking tabs are used, they should be fitted in such a way that the tabs and the wire are in complete alignment. Examples of correct and incorrect use of locking tabs are shown in Figure 7. Whenever possible, the closed end of the wire should be in the tab and the open end at the component to be locked.

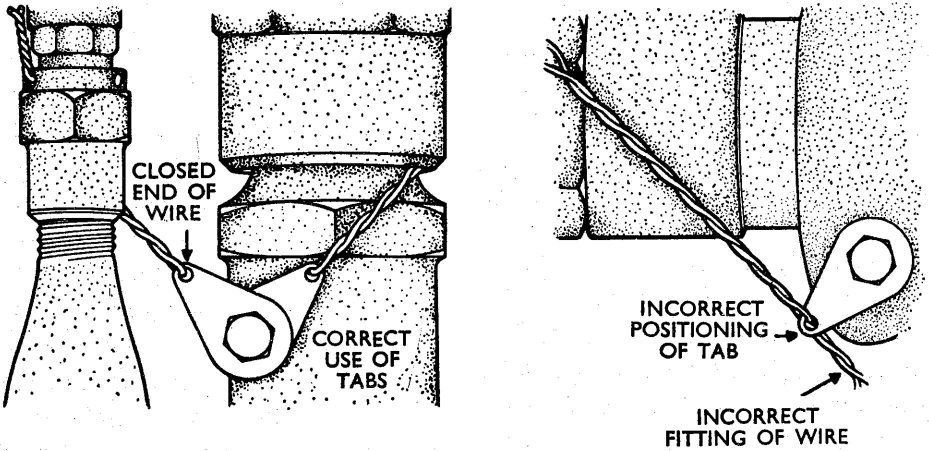


Figure 7 CORRECT AND INCORRECT USE OF LOCKING TABS

7.4 Some wire locking is done with a single strand of the specified wire, particularly in instances of complete ring or similar formations of nuts. The wire is passed in sequence through the nut slots and bolt/stud holes around the formation until the wire ends meet. The ends are cut to suit and twisted together to tension the loop. The wire direction through all nuts must be such that any loosening of a nut will further tension the wire.

7.5 Locking wire must not be used more than once. The wire must be adequately tensioned; over-tensioning may lead to fracture of the wire, or of the metal around the locking hole. Sharp edges of locking holes must be removed, and there must be no obstruction by the locking wire of any moving parts, controls, etc.

7.6 In some instances controls or switches are wire locked into their normal operating position, and selection of an emergency position necessitates physically breaking the wire. The use of stainless steel wire in these instances could prevent operation of an essential service, and thin copper wire is usually specified. The method of installing this type of locking (sometimes known as 'wire sealing') is normally detailed in the appropriate Maintenance Manual.

8 SELF-LOCKING FASTENERS These fasteners include stiffnuts and screws, nuts or bolts in which an inset nylon patch or stud applies friction between the male and female components. To provide effective locking, the friction element in each device must be fully engaged with complete threads on the mating component; with stiffnuts this consideration requires that the male threads extend at least one full thread (not including the chamfer), through the friction element.

8.1 Fasteners with a fibre or nylon friction element should only be used once, and must not be used in locations where all-metal stiffnuts are specified. All-metal stiffnuts should not be re-used in locations vital to aircraft safety (e.g. control runs) but may be re-used in other locations provided the locking quality remains satisfactory.

8.1.1 Most aircraft manufacturers lay down the assembly conditions (e.g. dry or lubricated) and acceptable limits of in-built torque for the re-use of stiffnuts, and require that each nut should be checked with a torque wrench during assembly.

NOTE: The use of torque wrenches is discussed in Leaflet **BL/6-30.**

8.1.2 A recognised method of checking the friction elements of small stiffnuts which are not being used in locations vital to aircraft safety is to screw the nut on to the male thread, using finger pressure only. If it is possible to turn the nut far enough for the male thread to protrude through the friction element the locking is unsatisfactory. This test is suitable for small nuts where the torque applied by the fingers approximates to the in-built torque requirement of the nut specification, but is unrealistic for larger nuts.

8.1.3 Unsatisfactory locking may also result from a worn male thread, and if either of the above tests leads to rejection of a stiffnut the male thread should be closely inspected. If a new stiffnut fails to provide adequate friction then it may be necessary to replace the bolt or stud on which it is to be assembled.

9 PEENING The peening of bolts for locking purposes should only be carried out when specified in the drawing, or the relevant manual, as the operation prevents re-use of the nut and bolt and may cause difficulty in dismantling. About 1½ threads of the bolt should be projecting and the peening carried down to the nut to prevent it slackening. Adequate support should be given to the bolt during the peening operation, and care taken to prevent damage to the part by misdirected blows with the hammer. Countersunk screws may be locked by the method illustrated in Figure 8 when the thread is inaccessible. Protective treatment damaged by the peening operation must be restored.

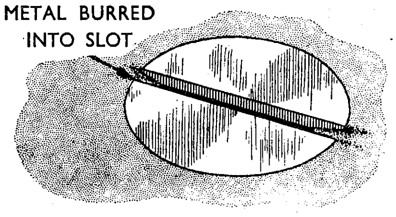


Figure 8 PEENING TO LOCK COUNTERSUNK SCREWS

10 GRUB SCREWS These are used as a method of locking two threaded components together. In one method the outer component only is drilled and threaded and the grub screw may be machined at the inner end to a tapered point or a parallel plain shank to fit either a conical recess or parallel hole in the inner component. Other grub screws may be fitted into a single hole drilled and threaded in both inner and outer components. Grub screws may be locked by peening using the method illustrated in Figure 8, by a wire type locking ring or by means of a nylon insert in either the male or female thread.

10.1 Grub screws are also used, with the variations already mentioned, in non-threaded assemblies to retain the parts and ensure correct alignment. They may be fitted as additional or precautionary locking devices in assemblies with interference fits or bonded joints, or, in some cases, they may be the only means of retention. In these cases, however, several grub screws may be fitted around the component and these may be locked by lock nuts or clamping type lock rings.

11 TAPER PINS AND PARALLEL PINS Taper pins, with taper of 1 in 48, and parallel pins, are used on both tubular and solid sections, to secure control levers to torque shafts and forked ends to control rods, etc. Some taper pins are bifurcated and the legs spread for locking, whilst other taper pins, and parallel pins, are locked by peening, or by forming reaction rivet heads. To avoid slackness, the pins are usually assembled in reamed holes, the head being supported during the locking process. Careful inspection is required after fitment of pins through hollow tubes, to ensure that undue force during the peening operation has not bent the pins, and thus impaired the security of the fittings.

12 LOCKING BY ADHESIVES

12.1 Many small components, particularly those in instruments, valves, switches, etc., may be locked by the application of Shellac, Araldite or similar materials to DTD 900 specifications. The adhesive is applied to the outside of the nut face and protruding screw thread, or the component and screw head, after tightening, and prevents movement between the two parts.

12.1.1 When using Araldite it is good practice to mix a separate sample under similar conditions, to check that it hardens within the specified time period.

12.2 Threaded metal fasteners may also be locked using a liquid sealant such as Loctite. This is an approved proprietary material (DTD 900 Approval No. 4588) which hardens in the screw threads after assembly, and is supplied in various grades to give a predetermined locking torque in a variety of applications from stud locking to retaining bearings in housings. In using Loctite it is advisable to have the parts free from grease to achieve maximum strength. It is possible, however, to use Loctite on threaded parts which have not been degreased but retain the original lubrication applied by the manufacturer. In these cases a 15 per cent decrease in the strength of locking usually occurs. Loctite should only be used when specified by the approved drawings or instructions, and applied in accordance with the manufacturer's instructions.

BL/6-14

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BASIC

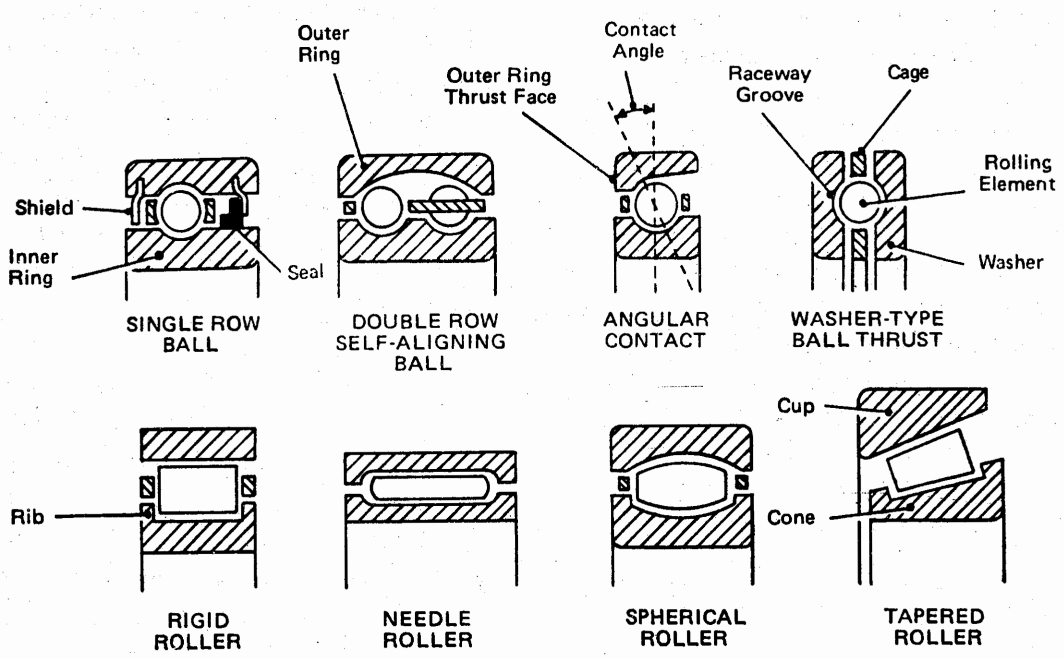
ENGINEERING PRACTICES AND PROCESSES

BALL AND ROLLER BEARINGS

1 INTRODUCTION This Leaflet gives information on the uses of the various types of ball and roller bearings, and general guidance on installation, maintenance and inspection. Methods of assessing wear are described, but the appropriate aircraft manual should be consulted for the amount of play or clearance permitted, in any installation in which rolling bearings are used.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet BL/5-2, Issue 1, dated 1st July 1957.

2 TYPES OF BEARINGS AND THEIR USES Bearings are broadly classified by the type of rolling element used in their construction. Ball bearings employ steel balls which rotate in grooved raceways, whilst roller bearings utilise cylindrical, tapered or spherical rollers, running in suitably shaped raceways. Both types of bearings are designed for operation under continuous rotary or oscillatory conditions, but, whilst ball bearings and tapered roller bearings accept both radial and axial loads, other types of roller bearings accept mainly radial loads. The following paragraphs amplify the uses of the various types of bearings, and examples are shown in Figure 1.



SINGLE ROW BALL

DOUBLE ROW SELF-ALIGNING BALL

ANGULAR CONTACT

WASHER-TYPE BALL THRUST

RIGID ROLLER

NEEDLE ROLLER

SPHERICAL ROLLER

TAPERED ROLLER

Figure 1 EXAMPLES OF BALL AND ROLLER BEARINGS

2.1 Caged bearings are in general use for engine applications and in equipment with rotational speeds in excess of approximately 100 rev/ min. Most other bearings on an aircraft are intended for oscillating or slow rotation conditions and do not have a cage; they are generally shielded or sealed and pre-packed with grease, but some have re-lubrication facilities.

2.2 **Ball Bearings.** These bearings may be divided into four main groups, namely radial, angular contact, thrust and instrument precision bearings.

2.2.1 **Radial Bearings.** This is the most common type of rolling bearing and is found in all forms of transmission assemblies such as shafts, gears and control-rod end fittings. The bearings are manufactured with the balls in either single or double rows, rigid for normal applications, or self-aligning for positions where accurate alignment cannot be maintained. Such bearings may also be provided with metal shields or synthetic rubber seals to prevent the ingress of foreign matter and retain the lubricant, and with a circlip groove or flange for retention purposes. The balls are often retained in a cage, but in some cases filling slots in the inner and outer rings permit individual insertion of the balls, thus allowing a larger number of balls to be used and giving the bearing a greater radial load capacity; however, axial loads are limited due to the presence of the raceway interruptions.

2.2.2 **Angular Contact Bearings.** These bearings are capable of accepting radial loads, and axial loads in one direction. The outer ring is recessed on one side to allow the ball and cage assembly to be fitted, thus enabling more balls to be used and the cage to be in one piece. The axial loading capacity of an angular contact bearing depends to a large extent on the contact angle. To achieve the contact angle large radial internal clearances are usually employed; the standards of clearance specified for radial bearings (paragraph 3) do not normally apply.

(i) In applications where axial loads will always be in one direction, a single angular contact bearing may be used, but where axial loads vary in direction an opposed pair of bearings is often used, and adjusted to maintain the required axial clearance.

(ii) A particular type of angular contact bearing, known as a duplex bearing, is fitted with a split inner or outer ring, and is designed to take axial loads in either direction. The balls make contact with two separate raceways in each ring, and one essential condition of operation is that the bearing should never run unloaded. The bearings are not adjustable, and radial loads should always be lighter than axial loads. This is a most efficient form of thrust bearing and is not speed-limited as is the washer type described below.

2.2.3 **Thrust Bearings.** Thrust bearings are designed for axial loading only, and are normally used in conjunction with a roller bearing or radial ball bearing. The balls are retained in a cage and run between washers having either flat or grooved raceways. Centrifugal loading on the balls has an adverse effect on the bearings and they are, therefore, most suitable for carrying heavy loads at low speeds.

2.2.4 **Instrument Precision Bearings.** These bearings are used mainly in instrument and communication equipment, and are manufactured to a high degree of accuracy and finish. They are generally of the radial bearing type without filling slots, although other types are obtainable. Tolerances quoted in BS 3469 for instrument precision bearings are closer than those quoted in BS 292 for standard ball and roller bearings, and only three classes of radial internal clearance are specified. BS 3469 also contains details of test procedures for instrument precision bearings.

NOTE: **Neither BS 3469 nor BS 292 quotes tolerances for axial clearance.**

2.3 **Roller Bearings.** Roller bearings may be divided into three main groups, according to whether they have cylindrical, spherical or tapered rollers.

2.3.1 **Cylindrical Roller Bearings.** These bearings are capable of carrying greater radial loads than ball bearings of similar external dimensions, due to the greater contact area of the rolling elements. Bearings with ribs on both rings will also carry light, intermittent, axial loads.

(i) The type of cylindrical roller bearing most commonly used is that in which the diameter and length of the rollers are equal, and standard sizes within this type are listed in BS 292. Bearings having rollers of a length greater than their diameter are also used for special applications.

(ii) A different kind of bearing in this category is the needle roller bearing, in which the length of the rollers is several times greater than their diameter. These bearings are designed for pure radial loads and are often used in locations where the movement is oscillatory rather than rotary, such as universal couplings and control-rod ends. Needle bearings are particularly useful in locations where space is limited, and are often supplied as a cage and roller assembly, the shaft of the components acting as the inner ring. The dimensions and surface finish of the shaft must be closely controlled to the standards specified by the bearing manufacturer. These bearings are particularly susceptible to the effects of misalignment and lack of lubricant, and may also be subject to brinelling, due to the lack of rotational movement.

NOTE: "Brinelling" is indentation of the surface of a material, resembling the indentations formed during a Brinell hardness test (Leaflet BL/10-3).

2.3.2 **Tapered Roller Bearings.** These bearings are designed so that the axes of the rollers form an angle with the shaft axis. They are capable of accepting simultaneous radial loads and axial loads in one direction, the proportions of the loads determining the taper angle. Tapered roller bearings are often mounted back to back in pairs, and adjusted against each other to obtain a working clearance. Because the axial load on the rollers results in rubbing contact on the cone rib, careful lubrication is essential, particularly at high speeds.

2.3.3 **Spherical Roller Bearings.** A spherical roller bearing may have one or two rows of rollers which run in a spherical raceway in the outer ring, thus enabling the bearing to accept a minor degree of misalignment between opposite bearings. The bearing is capable of withstanding heavy radial loads, and moderate axial loads from either direction.

3 RADIAL INTERNAL CLEARANCE Radial ball bearings and cylindrical roller bearings are manufactured with various amounts of radial internal clearance. Standard bearings are available in four grades of fit, namely Group 2, Normal Group, Group 3 and Group 4, while instrument precision bearings are supplied in the first three groups only. Bearings are usually marked in some way to indicate the class of fit, a system of dots, circles or letters often being used. It is important that replacement bearings are of the same standard.

3.1 Group 2 bearings have the smallest radial internal clearance and are normally used in precision work where minimum axial and radial movement is required. These bearings should not be used where operating conditions, such as high temperatures, could reduce internal clearances, and are not suitable for use as thrust bearings or for high speed

3.2 Normal Group bearings are used for most general applications where only one ring is an interference fit and where no appreciable transfer of heat to the bearing is likely to occur.

3.3 Group 3 bearings have a greater radial internal clearance than Normal Group bearings and are used where both rings are an interference fit, or where one ring is an interference fit and some transfer of heat must be accepted. They are also used for high speeds and where axial loading predominates.

3.4 Group 4 bearings have the largest radial internal clearance; they are used where both rings are an interference fit, and the transfer of heat reduces internal clearances.

4 LUBRICATION Adequate lubrication is essential for all types of rolling bearings. The purposes of the lubricant are to lubricate the areas of rubbing contact, e.g. between the rolling elements and the cage, to protect the bearing from corrosion, and to dissipate heat. For low rotational speeds, or for oscillating functions such as are found in a number of airframe applications, grease is a suitable lubricant; at higher rotational speeds grease would generate excessive temperatures because of churning, and oil is more suitable. Because of the variety of uses to which rolling bearings are put, and the varying requirements of different locations, it is important that only those lubricants recommended in the approved Maintenance Manual should be used.

4.1 External bearings on aircraft are often of the pre-packed, shielded or sealed types, and are usually packed with anti-freeze grease because of the low temperatures encountered; these bearings cannot normally be re-packed with grease, and when unserviceable must be rejected. Wheel bearings are normally tapered roller bearings, and should be re-packed with the correct grease when refitting the wheel (see Leaflet **AL/3—19**).

4.2 Bearings fitted in engines and gearboxes are generally lubricated by oil spray, splash, mist, drip feed, or controlled level oil bath, and loss of lubricant is prevented by the use of oil retaining devices such as labyrinth seals, felt or rubber washers, and oil throwers.

5 INSTALLATION OF BEARINGS The majority of bearing failures are caused by faulty installation, unsatisfactory lubrication, or inadequate protection against the entry of liquids, dirt or grit. To obtain the maximum life from a bearing, therefore, great care must be exercised during installation and maintenance, and strict cleanliness must be maintained at all times.

5.1 Where bearings carry axial loads only, the rings need only be a push fit in the housing or on the shaft, as appropriate, but bearings which carry radial loads must be installed with an interference fit between the revolving ring and its housing or shaft, otherwise creep or spin may take place and result in damage to both components. In instances where light alloy housings are used, the bearing may appear to be a loose fit during installation owing to the need to control bearing fit in the housing at the low temperatures experienced at high altitude.

5.2 Before installation, a bearing should be checked to ensure that it is free from damage and corrosion, and that it rotates freely. In some cases bearings are packed with storage grease, which is unsuitable for service use and must be removed by washing in a suitable solvent as specified in paragraph 8.1. All open bearings should be lubricated with the specified oil or grease before installation.

5.3 Bearings must be assembled the right way round, i.e. as specified in the appropriate drawing or manual, and should be seated squarely against the shoulders on shafts or housings so that raceways are at right angles to the shaft axis. Damage to the shoulders or bearing rings, or the presence of dirt, could prevent correct seating, impose uneven stress on the bearing and promote rapid wear. It is important, therefore, to ensure that there is no damage likely to prevent correct seating of the bearing rings, and that all mating surfaces are scrupulously clean.

NOTE: Some bearings are supplied as matched pairs, and it is important that they are mounted correctly.

5.4 Bearings may often be installed using finger pressure only, but where one ring is an interference fit (usually the rotating inner ring), an assembly tool or press should be used; in some instances it may also be necessary to freeze the shaft or heat the bearing in hot oil, depending on the degree of interference specified. If these tools are not available, the use of a soft steel or brass tube drift may be permitted in some instances; any force necessary must be applied only to the ring concerned, since force applied to the companion ring may result in damage to the rolling elements, or brinelling of the raceways.

NOTE: If a drift is used, the tube must be a close fit over the shaft and must not transmit force to the ring ribs. Light taps from a hammer should be distributed evenly round the top of the drift, to prevent misalignment. On no account should a copper drift be used, as work-hardening could result in chips of copper entering the bearing.

5.5 Retaining devices are used to prevent axial movements of the inner and outer rings of a bearing. Stationary outer rings are normally held in place by circlips or retaining plates, and shims are often used in conjunction with the latter to adjust the clearances in thrust or location bearings. All bearings capable of clearance adjustment must be adjusted to the correct clearance or preload specified in the relevant Maintenance or Overhaul Manual, otherwise damage or excessive wear may result. Rotating inner rings are usually firmly held by means of a washer and nut on the shaft and, although the thread may be handed to prevent loosening during operation, care should be taken to ensure that the nut is securely locked to the shaft.

NOTE: In the case of rod end bearings, the outer races may be retained in their housings by indentations at the entry faces of the housings, or by use of an epoxy sealer.

5.6 On completion of assembly, the bearing housing should, where applicable, be lightly packed with grease to provide an adequate reserve of lubricant, and oil-lubricated bearings should be lightly lubricated with the appropriate oil. Excessive greasing should be avoided, however, since grease is expelled from the bearing as soon as it begins to rotate, and, if insufficient space is left, churning and overheating may occur, causing the grease to run out and the bearing to fail; as a rough guide, the bearing should be approximately one third full.

6 **MAINTENANCE OF BEARINGS** Ball and roller bearings, if properly lubricated and installed, have a long life and require little attention. Bearing failures may have serious results, however, and aircraft Maintenance Manuals and approved Maintenance Schedules include inspections and, where applicable, lubrication instructions for all types of rolling bearings.

6.1 **Lubrication.** Most bearings used in airframe applications are shielded or sealed to prevent the entry of dirt or fluids which could adversely affect bearing life; these bearings cannot normally be regreased, and must be replaced if it is evident that the lubricant has been washed out, or otherwise lost through failure of the seals or bearing wear. Grease nipples are provided for some open bearings so that the grease may be replenished at specified intervals, or when grease is lost through the use of solvents, paint strippers, detergents or de-icing fluid. Nipples should be wiped clean before applying the grease gun, to prevent the entry of dirt into the bearing. Grease forced into the bearing will displace the old grease, and any surplus exuding from the bearing should be wiped off with a clean lint-free cloth.

6.2 **Inspection.** Ball and roller bearings are deliberately selected by aircraft and component designers, for use in installations where play or lost motion are unacceptable; wear or corrosion, once started, progress rapidly, and bearings showing evidence of these faults should be discarded. Frequent removal of bearings from shafts or housings may result in damage to either the bearing rings or mating surfaces, and for this reason a routine inspection of a bearing is normally carried out in situ; wheel bearings, however, are normally inspected when the wheel is removed. If doubt exists as to the serviceability of a bearing, it should be removed, cleaned and inspected as described in paragraphs 7, 8 and 9.

6.2.1 It may not often be possible to examine the rolling elements and raceways while a bearing is in position, but it is usually possible to examine the rings externally for overheating, damage and corrosion, and to examine the cage for loose rivets and damage, after removing surplus grease with a clean lint-free cloth. In all cases a bearing should be checked for wear as follows:—

(i) Actuate the moving parts slowly to check for smoothness of operation. Roughness may result from grit in the bearing or surface damage to the rolling elements or raceways, caused by corrosion or excessive wear.

(ii) Check for wear by moving the inner race or shaft in both axial and radial directions. The amount of clearance will depend to a large extent on the initial grade of fit of the bearing, but some wear will be acceptable with all classes of fit and may only be considered as unsatisfactory if it leads to excessive backlash in controls, or vibration during operation.

(iii) Check shielded bearings to ensure that there is no rubbing contact between the stationary and rotating components. Contact between the shield and inner ring is evidence of excessive wear in the bearing and could lead to contamination of the lubricant by particles of metal rubbed off the shield.

6.2.2 With some bearings, creep or spinning of the races may occur and lead to damage to the shaft or outer ring housing. Where housing end covers or shaft nuts can be removed, these faults may be recognised by polishing of the ring faces.

6.2.3 The internal condition of a bearing may sometimes be revealed by an examination of the lubricant exuding from the bearing. Metal particles reflect light, and give a rough feeling when the lubricant is rubbed into the palm of the hand.

6.2.4 A problem frequently encountered with airframe bearings is moisture contamination, which may result in freezing and inability to operate a control in low temperature conditions. Every precaution should be taken to prevent the entry of liquids into bearings, and relubrication of open bearings is often specified after washing. During inspection, particular attention should be given to rust stains, which may be a good indication of the presence of moisture.

6.2.5 The condition of landing wheel bearings on small aircraft, on which wheels are changed at infrequent intervals, may be checked by rocking and spinning the wheel. This check would normally be impractical and unnecessary on larger aircraft, since the wheels are changed more frequently in order to replace worn tyres.

7 REMOVAL OF BEARINGS Many roller bearings are made in two parts, which can be separated for cleaning and inspection without removing the outer ring from its housing or the inner ring from its shaft; all that is necessary is partial dismantling of the associated components to allow the bearing to be inspected and rotated. When it is necessary to remove separated rings or complete bearings, care is necessary to ensure that they are not damaged. A suitable extractor should normally be used, but if this is not available, light hammer blows transmitted through the medium of a soft tubular drift may prove effective. Any force necessary should be applied to the ring concerned, since force applied to the companion ring may result in damage to the raceways and rolling elements. Force should not be applied to the ribs of a roller bearing as this may result in fracture or damage, which would necessitate the rejection of the bearing.

NOTE: **Bearings are selectively assembled to match rolling elements very closely for size, and ensure correct internal clearances. When disassembly is permitted, care must be taken to ensure that rings and loose rolling elements are not interchanged between partly dismantled bearings, and are reassembled in their original configuration.**

8 CLEANING BEARINGS Bearings to be cleaned for further examination should first be wiped free of all grease adhering to the outer surfaces; dry compressed air will assist in dislodging it from the cage and rolling elements, but the bearing should not be allowed to rotate.

8.1 The bearings should then be soaked or swilled in white spirit to remove any remaining grease or dirt. It is permissible to oscillate or turn the races slowly to ensure that all foreign matter has been removed, but the bearing should not be spun in this condition, otherwise the working surfaces may become damaged due to the lack of lubrication.

8.2 If a bearing cannot be completely cleaned by the above method, a forced jet of white spirit may be used to advantage. The jet may be obtained by fitting a pump to the washing tank, but an efficient filter must be provided.

8.3 Jet cleaning can be considerably assisted if the bearing is mounted on a tapered mandrel so that the inner ring will remain stationary, whilst allowing the outer ring to revolve slowly as a result of the action of the fluid from the jet passing through the bearing.

8.4 After cleaning, the bearing should be dried with clean, warm, dry compressed air, taking care to permit only very slow rotation, and lightly lubricated with oil to prevent corrosion. The bearing should be slowly rotated during oiling to ensure that all surfaces are covered.

9 INSPECTION AFTER REMOVAL After removal and cleaning, bearings should be inspected for corrosion, pitting, fracture, chips, discolouration and excessive internal clearances. With self-aligning bearings or bearings having detachable rings, the condition of the rolling elements and raceways can be seen by swivelling the outer ring through 90° or by separating the outer ring, as appropriate. With bearings having non-detachable rings, the raceways and balls or rollers are sometimes accessible for visual examination, but if not, their condition may be judged by holding the inner ring and oscillating the outer ring. Provided there is no foreign matter inside the bearing, any roughness will indicate internal damage.

9.1 Slight corrosion on the outer surface of the rings is usually acceptable, provided that it does not prevent proper fit of the rings in housings or on shafts. Staining on the raceways or rolling elements may be acceptable on non-critical bearings, but deep pitting or scaling of the surface would not be acceptable on any types of bearings. Fracture, chips or damage to the rings, balls, rollers or cage, would necessitate rejecting the bearing.

9.2 If the rings show signs of creep or spinning, the outside and inside diameters of the bearing should be checked with a micrometer and plug gauge respectively. The shaft and housing should also be inspected for damage and wear, to ensure that a proper fit will be obtained when the bearing is replaced.

9.3 The running smoothness of a bearing may be determined by mounting it on a shaft which is mechanically rotated at 500 to 1000 rev/min. With the shaft running and the bearing oiled, the outer ring should be held, and the smoothness and resistance should be determined by applying alternate axial and radial loads in either direction. The outer ring must be square to the shaft, or a false impression of roughness may result.

9.4 Excessive wear in a bearing will result in large internal clearances, and a badly worn bearing will normally have been rejected following the initial inspection in situ. Axial clearance in a bearing is seldom quoted since it depends on the internal design of the particular bearing, but, where necessary, a rough guide to the radial internal clearance may be determined by mounting the inner ring on a shaft and measuring, with a dial test indicator, the average radial movement obtained at various angular positions of the outer ring. It is important that the outer ring is moved in the same plane as the inner ring, or an incorrect reading will result.

10 PROTECTION AGAINST CORROSION Bearings which have been found satisfactory and are to be re-used immediately, should be lubricated with oil or grease as appropriate, and reinstalled; bearings which are to be stored should be dipped in rust preventive oil, wrapped in greaseproof paper and suitably boxed and labelled. Bearings should be stored horizontally, in a clean, dry atmosphere, and it is recommended that, after one year in storage, the bearings should be inspected for corrosion and re-protected.

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BASIC

ENGINEERING PRACTICES AND PROCESSES

MANUFACTURE OF RIGID PIPES

1 INTRODUCTION This Leaflet gives guidance on the manufacture, testing and inspection of rigid pipes. Where applicable, it should be read in conjunction with Leaflet **AL/3-14,** 'Installation of Rigid Pipes', and with the relevant manuals for the aircraft concerned.

NOTE: The term 'manufacture' is used in this Leaflet to describe the actual production of a pipe complete with its end fittings, and not to describe the manufacture of the tubular material from which it is made.

1.1 The efficiency and safety of an aircraft depend to a large extent on the integrity of its pipe systems. It is essential, therefore, to ensure that the manufacture and inspection of individual pipes are performed with care and attention, and in accordance with the requirements of the drawings.

1.2 Guidance on flexible pipes is given in Leaflet **AL/3-13,** on hydraulic systems in Leaflet **AL/4-1,** on pneumatic systems in Leaflet **AL/5-1,** on pressurisation systems in Leaflet **AL/3-23,** on fuel systems in Leaflet **AL/3-17,** and on pitot-static systems in Leaflet **AL/10-1.**

2 GENERAL Pipe assemblies are usually formed and flared in accordance with a particular drawing but, since interchangeability is a very important consideration, each completed assembly is usually checked in a checking fixture or compared with a master pipe assembly. This practice is necessary to prevent stress at end fittings, and to avoid contact with adjacent parts during service.

2.1 Certain pipes which convey liquids or gases are required to be protected internally, and only the process specified on the relevant drawing should be used.

2.2 The method of working metal tubes for use on aircraft is dependent upon the type of material from which they are manufactured and the system in which they are to be used; the characteristics and heat treated condition of the material must be known before bending or flaring operations are carried out. Some of the most commonly used pipe materials are described in subsequent paragraphs.

3 MATERIALS Metal tubing for aircraft pipe lines is available in various materials, and in a variety of sizes, conforming to either British Standards, DTD Specifications or, in some instances, to approved proprietary specifications. The method of marking tubes after manufacture is given in Leaflet **BL/2-2.**

NOTE: These markings are for material identification of the tubes only, and bear no relation to the identification scheme for aircraft installations described in paragraph 15.

3.1 When stored, the tubes must be adequately supported to prevent bending.

NOTE: Storage procedures are described in Leaflet BL/1-6.

3.2 **Copper and Copper Alloy Tubes.** Seamless copper tubes complying with BS T7 are available in a range of sizes up to 2½ inch outside diameter. The material can be flared, brazed or silver soldered. Tubes up to 1 inch outside diameter are supplied in the fully softened condition, but above 1 inch outside diameter the tubes are supplied in the half-hard condition.

3.2.1 High pressure seamless copper tubes complying with BS T51 are widely used in aircraft high pressure air and oxygen systems. The material can be flared, brazed or silver soldered, and is available in sizes up to ⅝ inch outside diameter.

3.2.2 If care is taken during flaring or bending copper tubes the slight hardening unavoidably induced should not prove harmful to the service life of the pipes.

3.2.3 Copper tubes supplied in the half-hard condition, or tubes which may be subjected to severe bending operations, may be annealed by heating to between 600°C and 700°C and either quenching in water or cooling in air.

3.2.4 **Aluminium-Nickel-Silicon Brass Tubes.** Aluminium-Nickel-Silicon Brass material, often known as 'Tungum', is widely used for the manufacture of tubing used in hydraulic systems (DTD 253, low pressure tubes and DTD 5019, high pressure tubes) and can be flared, brazed or silver soldered. The tubes are supplied in the annealed condition, and should be worked at room temperature. When the tubing hardens due to working, stresses can be relieved by heating to a carefully controlled temperature of 400°C for a period of one hour, and then cooling by any convenient method.

3.2.5 **High Nickel Copper Alloy Tubes.** Tubes complying with specification DTD 477 are used for high, medium and low pressure pipe lines, according to size and gauge, and can be flared readily.

3.3 **Steel Tubes.** Steel tubes are available in various grades, and are often supplied in the half-hard condition, but may normally be softened for working purposes. However, softened tubes must be subsequently re-heat-treated to restore the specified strength. Tubes complying with BS T26 or DTD 503 are used extensively for high pressure systems in aircraft.

3.3.1 Corrosion-resistant steel tubes, such as 35-ton chromium-nickel non-corrodible steel tubes to BS T55, are widely used for cabin-heating and fuel pipes, and for exhaust manifolds.

3.3.2 Solder and fusible alloys must not be allowed to come into contact with high-tensile steel tubing (i.e. tubing with a tensile strength greater than 50 tons/in^2) due to the possibility of intercrystalline penetration. A suitable method of preventing contact during bending is described in paragraph 4.4.7.

3.3.3 40-ton chromium non-corrodible steel tubes to DTD 5016 are suitable for high pressure systems where flaring is required.

3.4 **Aluminium Alloy Tubes.** The working and heat treatment of aluminium alloy tubes vary according to the chemical composition and condition of the alloy. It is essential, therefore, to ensure that all manufacturing operations comply with the instructions on the relevant drawing.

NOTE: For information on the heat treatment of aluminium alloys, see Leaflet BL/9-1.

4 PIPE BENDING

4.1 The preferred method of bending aircraft system pipes is by use of a mandrel-type bending machine (paragraph 5.4) but, because of the tooling required, the method is generally used only for repetitive work. In some instances, where complicated shapes cannot be produced by this method, a proprietary wax filler is used and the pipe bent on a normal bending machine.

4.2 For small quantity work it is generally possible, depending on the nature of the pipe material, to make large radius bends by hand in pipes up to ½ inch outside diameter. For pipes larger than ½ inch outside diameter, or where considered necessary due to the type of material or radius of bend, it is usual to fill the pipe with fusible alloy of low melting temperature and to bend the pipe either by hand or in a bending machine. Sand is generally used as a filler when bending oxygen pipes, so that contamination with oil is avoided.

4.3 **Cleaning.** It is essential that pipes are properly cleaned before any heat treatment, as the introduction of carbon could lead to weld decay problems with certain materials. Paraffin at high pressure may be used for initial cleaning, but should be followed by trichloroethylene de-greasing and drying in warm dry air.

4.4 **Fusible Alloys.** Fusible alloys used for tube bending usually contain lead, tin, bismuth, and cadmium. The material must be ductile, have a low melting point and should tend to expand on solidifying. Resin, lead or bituminous fillers should not be used when bending pipes which are intended for use on aircraft systems because of the difficulty of ensuring that every trace of the filler has been removed.

4.4.1 Fusible alloy of the type recommended for use on aircraft pipes has a melting point below 100°C. Boiling water can, therefore, be used to melt the alloy for loading and unloading. Since the alloy must not be subjected to a temperature above 100°C, the alloy containers should be completely surrounded by water maintained at 85°C to 95°C. Under no circumstances must a flame be used in conjunction with fusible filler alloys. If a tube requires heat treatment, this must be carried out before filling operations are started.

NOTE: Black iron or stainless steel tanks are generally used as fusible alloy containers. All joints should be welded or riveted, and containers having soldered joints must not be used. Fusible alloys in the molten state are corrosive and should not be left for long periods in contact with lead, aluminium, zinc or copper.

4.4.2 Low tensile steel tubes complying with BS T26, T55 and DTD 97, are often bent by using a higher melting point filler alloy than that described in paragraph 4.4.1. Alloys of the lead-tin variety may be used provided the loading and unloading operations are carried out at a temperature not exceeding 400°C.

4.4.3 With high tensile tubes complying with BS T2, T50, T57, T58, T59, T60 and specification DTD 203, fusible filler alloys may only be used if direct contact is avoided. (See paragraph 4.4.7.)

4.4.4 For aluminium alloy tubes subject to precipitation treatment, the following precautions must be taken:—

(i) When pre-heating the tube prior to filling with fusible alloy, it should only be immersed in boiling water for the time necessary for the tube to acquire the temperature of the water.

(ii) The bending operation must take place as soon as the fusible alloy has solidified.

(iii) Unless the pipes are annealed, the loading, unloading and bending operations must be completed within two hours after solution treatment.

4.4.5 **Loading.** Before filling the tube, the bore of the tube must be thoroughly clean and dry; it should then be coated with a continuous film of lubricating oil, or lubricating oil and paraffin, as may be prescribed by the makers of the fusible alloy. Oiling should be done either by completely filling the tube or immersing the tube in an oil bath; an oily wad drawn through the tube is not satisfactory. It is essential that only clean oil is used for this purpose. A straight mineral lubricating oil of viscosity equivalent to SAE 10 is usually recommended, as detergent additives in engine oils tend to cause sticking of the alloy on emptying the tube.

(i) When the tube has been lubricated it should be plugged at one end and immersed in hot water to within a few inches of the open end.

(ii) When the tube has acquired the temperature of the water and while still immersed, the fusible alloy should be poured gently into the open end of the tube. It is essential not to damage the oil film or to create air pockets during this filling operation.

(iii) Immediately after filling, the whole tube should be cooled by immersion in cold water. To prevent the formation of cavities the cooling should take place progressively from the plugged end.

(iv) The ductility of filler alloys depends on rapid, efficient quenching. After quenching, the loaded tubes should be allowed to attain room temperature before bending commences.

4.4.6 **Unloading.** After a tube has been bent to the desired shape, it should be unloaded by completely immersing it in boiling water to melt the filler alloy. The hot water enters the tube at this stage and care must be taken to preserve the protective oil film. Violent agitation of the tube and contents should be avoided. Breaking of the oil film will cause the fusible alloy to adhere to the bore either as beads or in the form of tinning which, once formed on a tube, may be impossible to remove.

(i) Even without breaking the oil film, beads of fusible alloy may form around particles of dirt. These beads can be removed only when they are in the solid condition, and any attempt to remove them in the molten condition may cause tinning.

(ii) A stiff, rotating wire brush may be used for cleaning some tubes, but must be of a type which will not damage the bore. Alternatively a steam jet may be used, but it is important to ensure that the steam is not superheated. As a final cleaning operation, and where neither of these methods is considered advisable, a tight-fitting felt pull-through should be passed through the pipe in both directions.

4.4.7 As an alternative to oiling, a thin plastics sheathing can be used to prevent contact of the filler alloy with the interior of the tube, thereby eliminating the possibility of tinning. The plastics sheath is passed through the tube and is secured by expanding it over the end of the tube. Sheathing should not exceed 0·010 inch wall thickness, otherwise the rate of quench will be retarded, adversely affecting the ductility of the filler alloy. Plastics sheathing should be examined after removal to ensure that it is still intact and that no leakage of filler has occurred which may adhere to the inside of the pipe.

4.4.8 As visual examination of the bores of bent pipes is impracticable, if contamination is suspected, radiographic inspection techniques should be used. If contamination is found the manufacturer of the fusible alloy should be consulted.

5 PIPE BENDING MACHINES These are normally either compression or mandrel machines and may be hand operated, power assisted or fully automatic.

5.1 Compression bending machines are provided with circular formers in various diameters, grooved around their circumferences to fit a particular diameter pipe. The pipe is bent by rolling a similarly grooved guide round the former, the semi-circular grooves exactly fitting the outside diameter of the tube and preventing distortion from taking place. When the mean radius of the bend is larger than four times the outside diameter of the pipe, bending is possible on a compression bender without using a filler but the insertion of a close-fitting spring may be recommended. A compression bender can also be used when the mean radius is less than four times the outside diameter provided that a fusible filler alloy is used to maintain full bore.

5.2 When springs are used internally for pipe bending they must be of the correct size and form, have a high standard of finish and be free from deformation. They should be examined prior to insertion to ensure that they are thoroughly clean and that no foreign matter is trapped between the coils. Immediately upon removal from a pipe the springs should again be examined for signs of 'pick-up' or flaking of the pipe bore.

NOTE: The formation or ripples at pipe bends can be caused by the use of incorrectly designed or deformed springs.

5.3 When a filler alloy is used, the setting expansion of the alloy causes the tubes to become oversize. This must be allowed for when manufacturing formers and usually amounts to approximately 0·002 inch per inch diameter. Bending machines are available which have been specially designed to accommodate loaded tubes.

5.4 When it is required to produce full bore bends without the use of a filler on mean radii less than four times the outside diameter of the pipe, mandrel benders are used. These machines are also provided with interchangeable formers grooved to receive any particular size of tube but, in addition, plain or articulated mandrels are used which are machined to closely fit the inside diameter of the tube and support it at the bend. The method of bending called for on the drawing will, however, depend largely on the material from which the tube is made, its diameter and the wall thickness.

5.5 According to the tube material, heat treatment may be required before or after bending, but in all cases the actual bending operation is carried out at room temperature.

6 PIPE FLARING Flaring is necessary to fit certain standard types of pipe couplings. The flared end of the pipe must seat on the coned face of an adaptor nipple or externally coned adaptor. By means of a collar and union nut, the flared end and coned face are joined together, forming a connection capable of holding considerable fluid pressure. It is important that tools used for flaring are periodically examined for damage likely to cause scoring of the flared ends and thus prevent proper seating of the mating components.

6.1 **AGS Pipe Flaring Tools.** These tools are made in two sizes; the small tool for expanding the ends of pipes 3/16 inch to 1/2 inch outside diameter and the large tool for pipes from 5/8 inch to 1½ inch outside diameter. Both tools are provided with sets of half bushes, in pairs, to cover the range of pipe sizes to be flared.

NOTE: The cones on AGS unions and adaptors have an included angle of 32°, the pipe flaring machines being shaped accordingly. American AN couplings, however, have a 74° included angle, and special tools are required to flare pipes to fit these couplings.

6.2 **Flaring Operation.** Before a pipe is flared, it must be ascertained that it is of the specified material and in the correct heat treatment condition for this operation. It is advisable that the pipe should be bent to shape before flaring.

6.2.1 The pipe end should be square, smoothly finished and clean; a rough or burred edge may cause the pipe to split when flared.

6.2.2 The sleeve or union nut, and collar, should be assembled on the pipe, then the appropriate half bushes fitted to the pipe end and clamped in the flaring tool with the pipe end level with the faces of the bushes. It is most important that the half bushes used are dimensionally accurate and carefully maintained. If a gap exists between the bushes when they are fitted to the pipe, diametrically opposed flash lines may be formed on the pipe flare, representing a potential source of failure.

6.2.3 For all materials except stainless steel (paragraph 6.2.7), the expanding cone of the flaring tool should then be screwed in until it starts to expand the end of the pipe. At this stage the expanding cone should be rotated by the handle provided and gently fed inwards until the pipe end is expanded to the limit imposed by the countersunk half bushes.

6.2.4 When the flare is formed the pipe should be freed from the half bushes and inspected for cracks, splits, thinning, eccentricity, or other visible faults.

6.2.5 To check the flaring it is recommended that each coupling is connected to a coned adaptor test fitting and then dismantled. If the test fitting is made from steel, this will allow it to withstand repeated use, but over-tightening is to be avoided. When assembled, the flare should pass through the union nut thread with not more than $\frac{1}{64}$ inch clearance.

6.2.6 With the collar as far as it will go towards the flared end of the pipe, the projection of the pipe beyond the collar face must be measured. The tolerances given in Table 1 are permissible.

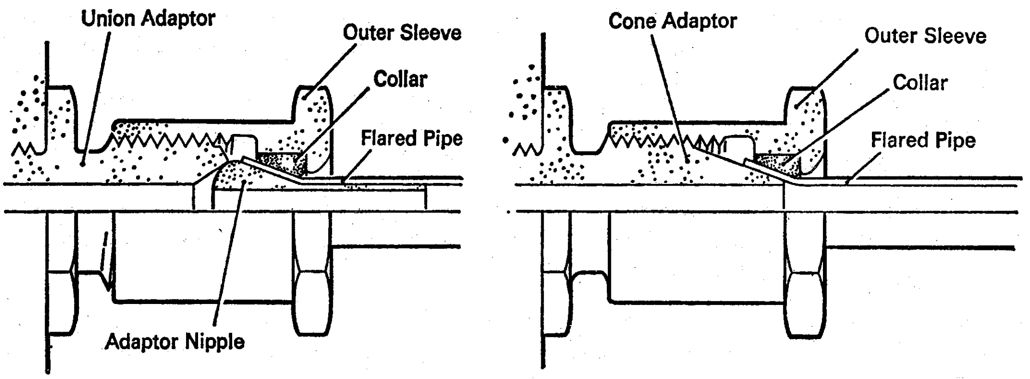
TABLE 1

Tube Outside Diameter (inches)	*Projection Tolerance (inches)*
$\frac{3}{16}$ to $\frac{1}{4}$	0 to 0·010
$\frac{5}{16}$ to $\frac{3}{8}$	$\frac{1}{64}$ to $\frac{1}{32}$
$\frac{7}{16}$ to $1\frac{1}{2}$	$\frac{1}{32}$ to $\frac{1}{16}$

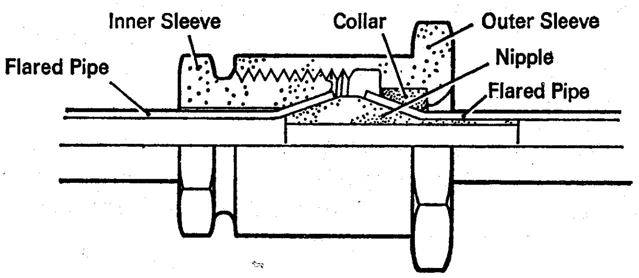
6.2.7 **Stainless Steel.** Under no circumstances should the expanding cone be used with stainless steel, since 'pick-up' and subsequent damage to the flare may occur. For this material, a single operating tool and a special buffer lubricant (e.g. Trilac Lacquer) are recommended.

7 **PIPE BEADING** Pipe beading is used to assist in the efficient coupling of hoses to rigid pipes in low pressure connections.

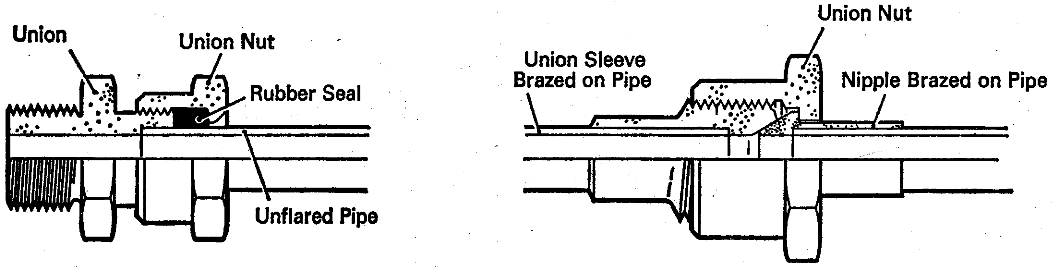
7.1 Pipe beading is usually formed by means of a beading machine, the rollers of which may be changed to suit the size of beading required.



PIPE-TO-COMPONENT, HIGH PRESSURE COUPLINGS



PIPE-TO-PIPE HIGH PRESSURE COUPLING



LOW PRESSURE COUPLING

BRAZED COUPLING

Figure 1 TYPICAL AGS PIPE COUPLINGS

7.2 The pipe is usually expanded approximately $\frac{1}{8}$ inch in diameter at a distance of $\frac{1}{4}$ inch from the end of the tube, but reference should be made to the relevant drawing or manufacturer's instructions for details, as the bead will vary according to tube size and type of hose used.

8 'AGS' AND 'AS' COUPLINGS A wide range of pipe couplings, adaptors, bulkhead unions and banjo unions are covered by AGS and AS specifications. Some typical couplings are shown in Figure 1 in which the main parts are annotated.

8.1 **High Pressure Coupling.** All couplings now use a similar method of assembly, a flared pipe, adaptor nipple, collar, outer sleeve and inner sleeve being the basic components in the high pressure joint. Nipples which do not have a parallel extension may still be found in use, but these have been replaced by the type shown in Figure 1 to prevent incorrect assembly. The parallel extension should always be inserted into the flared pipe which is fitted with a collar and outer sleeve.

8.2 Cone adaptors have an included angle of 32° to match the pipe flaring, and union adaptors have a 60° countersunk end to match the spherical end of an adaptor nipple.

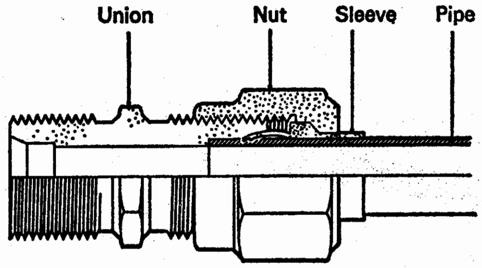
8.3 Pipe coupling nipples must only be used in pipe to pipe joints since the outer conical face of the nipple has a 32° included angle to match the bore of an inner sleeve and will not form a proper joint with a 60° countersunk face.

8.4 Standard pipe couplings are made from a variety of materials, including aluminium alloy, brass, mild steel and stainless steel, and generally have a working pressure, depending on size, of between 200 and 3000 lbf/in².

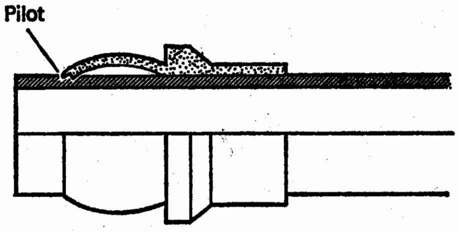
8.5 After a pipe coupling has been assembled for the first time, it should be disassembled and the extension of the flared end beyond the collar checked as described in paragraph 6.2.6.

8.6 **Low Pressure Couplings.** This type of coupling is used in certain low pressure pipe lines and vents. It consists of a rubber ring which is compressed around the pipe when the union nut is tightened. The end of the pipe, which is not flared, butts against a shoulder in the body of the union.

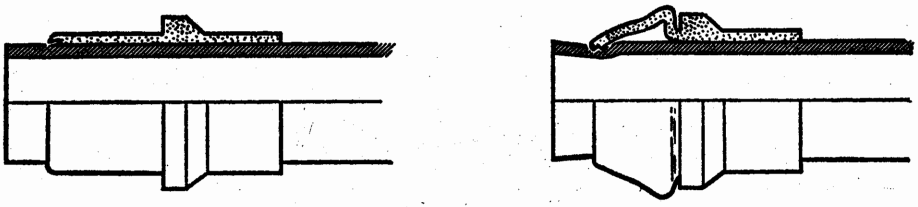
8.7 **Brazed Nipple Couplings.** A conical nipple is brazed or silver-soldered to the end of the pipe and held in position by a union nut, which butts against a shoulder on the nipple. The conical face of the nipple mates with a countersunk adaptor, which may also be brazed or silver-soldered in position.



COMPLETE COUPLING



CORRECT PRESET



UNDERTIGHTENED PRESET

OVERTIGHTENED PRESET

Figure 2 FLARELESS PIPE COUPLING

9 FLARELESS COUPLINGS The flaring operation leaves the tube end in a stressed condition and, since it is the flare which carries the load in a fitting, vibration may eventually result in fatigue failure. To prevent pipe couplings from failing in this way a different type of coupling known as the 'flareless' coupling was devised and is in common use on civil aircraft. The individual parts of the coupling are assembled as shown in Figure 2 and the nut screwed on to its fitting until it is finger tight. The nut is then turned a further full turn with a spanner, this action bowing the sleeve and causing it to bite into the tube at its forward end. When the nut is slackened the sleeve remains permanently bowed and attached to the pipe.

9.1 This pre-setting operation may be carried out using the fitting which is to be used in service, but a special hardened steel fitting is often used for pre-setting purposes.

9.2 After pre-setting, the pipe should be inspected to ensure that the sleeve is correctly bowed and that the sleeve end has bitten into the pipe (Figure 2). The pilot should be close to or touching the pipe, and end play should be less than 0·010 inch. It is permissible for the sleeve to rotate on the pipe.

9.3 In service, the nut should be tightened until a distinct increase in torque is felt, then turned a further one to two hexagon flats. If the joint leaks, the nut should be unscrewed and the mating parts inspected for foreign matter, scratches or similar damage; excessive tightening will permanently damage the tube end and sleeve, and result in further leakage.

10 BRAZED COUPLINGS Screwed couplings will always be a potential source of leaks and add considerable weight to an aircraft system. It is obvious that a complete piping system cannot be installed in an aircraft in one piece, but a method has recently been devised of brazing pipes together after positioning in the aircraft. Pipe ends meet in a butt joint and a connecting sleeve is brazed on to the outside, by induction heating, to form a permanent joint.

10.1 To ensure that molten brazing alloy flows easily through the joint by capillary action, the gap between the pipe and the sleeve is carefully controlled. The sleeve is manufactured to close tolerances and the pipe ends are expanded slightly over nominal diameter, so that tube manufacturing tolerances are prevented from affecting the fit.

10.2 Thorough cleanliness is essential to a brazed joint and all parts are cleaned by acid pickling prior to assembly; to prevent oxidation, brazing is carried out within a portable chamber through which inert gas (e.g. argon) is passed during the brazing operation.

11 AVIMO COUPLINGS This type of coupling is used for connecting pipe lines in a semi-flexible manner. It is mostly used in engine service pipes carrying coolant or oil at pressures up to 60 lbf/in² and at temperatures up to 130°C.

11.1 The coupling consists of:—

(i) Two specially corrugated sleeves, made of material similar to that of the tubes to be coupled, into which the ends of the tubes are welded or brazed.

(ii) A neoprene (synthetic rubber) collar which fits over the adjacent ends of the sleeves and beds into their corrugations.

(iii) Two semi-circular flanged packings of steel, specially designed to compress the collar uniformly.

(iv) A screw-action hose clip of the AGS 605 type which encircles the joint and clamps the packing pieces together.

11.2 Couplings embodying an attachment flange are also available for fitting through bulkheads.

11.3 A fireproof version of the above type of coupling is available, but is restricted to internal pressures of 50 lbf/in².

12 SELF-SEALING COUPLINGS Self-sealing couplings are used in hydraulic, fuel, oil and other pipeline systems. They eliminate the necessity of draining a system when a connection is broken to change a component, e.g. a fuel or hydraulic pump. Bleeding and priming operations for the complete system are often unnecessary after the parts concerned are re-connected.

12.1 With the exception of couplings which have a bayonet and socket action, when the two halves of a self-sealing coupling are brought together by screwing home the coupling nut, a spring in each half is compressed and associated valves slide back simultaneously. Full bore is obtained when the flange of the male half is brought into contact with the face of the female portion.

12.2 When making or breaking the joint of a self-sealing coupling, care must be taken to avoid turning between the two halves, otherwise the seating for the valve in the union half of the coupling may damage the seat in the fixed half of the coupling and prevent a fluid-tight joint being made.

12.3 When the two halves of a self-sealing coupling have been disconnected, blanking caps should be fitted to each half coupling. The caps will protect the threads and the valves, prevent the ingress of dirt, and form an independent pressure seal.

12.4 When self-sealing couplings are fitted to pipe assemblies, they must be pressure tested with the pipe, special attention being given to signs of leakage from the valve seats.

13 BORE TEST Pipes should be tested to ensure that the bore is clear and dimensionally correct after forming. One method of satisfying this requirement is to pass a steel ball, with a diameter of 80 per cent of the internal diameter of the pipe, through the pipe in both directions. When, owing to the design of the pipe or the size of the end fittings, this test is impracticable, or when a more searching test is required, the drawing will normally require a flow test to be performed. In this test it must be demonstrated that the pipe is capable of passing a specified quantity of fluid, in the time, and under the conditions stipulated on the drawing.

14 PRESSURE TESTS Before pressure testing it is necessary to verify that: (i) the test equipment and instruments are adequate for the tests specified on the drawing, (ii) the test fluid is clean and suitably safeguarded by filters against the ingress of dirt, and (iii) the test equipment and instruments are checked at regular intervals. A record should be kept of the checks and the results.

14.1 The component parts of a flared coupling require bedding-in to ensure freedom from leaks, and the following procedure should be adopted when fitting flared pipe assemblies to a test rig:—

(i) Assemble the component parts of the coupling and run up the union nut by hand.

(ii) Using a suitable spanner to prevent rotation of the union, tighten the union nut to the specified torque value.

(iii) Slacken the nut a half to one turn then retighten to specified torque value.

14.1.1 Should the connection fail to seal properly the coupling should be critically examined for likely causes such as scratches or dirt. The specified torque should never be exceeded as this may damage the joint.

NOTE: The assembly of flareless couplings is described in paragraph 9.3.

14.2 **Hydraulic Pressure Testing.** After coupling to the appropriate pressure delivery point on the test rig, the pipe to be tested must be checked for full bore flow by pumping fluid through it and checking the flow at the open end. If satisfactory, the open end should be suitably blanked. The pressure should then be built up to that prescribed on the drawing, which is usually 1½ times the maximum working pressure of the pipe in service. The pressure should be maintained long enough to ascertain that no leaks occur, or for such a period of time as may be specified on the drawing.

NOTE: The fluid used for hydraulic pressure testing may be either oil, paraffin or water. It is, however, recommended that, whenever possible, the fluid should be the same as that used in the completed system.

14.3 **Testing Pneumatic and Oxygen Pipes.** Pneumatic and oxygen pipes are normally given a hydraulic pressure test using water as the test medium, followed by a compressed air test which is limited to maximum system pressure. Using high pressure air can be extremely dangerous and the pipes should be located behind a heavy plastics screen and submerged in water during the test.

14.3.1 The pneumatic test rig should include a pressure regulator, pressure gauge, relief valve, oil and water trap, and adequate filters to ensure that the air supplied during test is not contaminated. All of these components should be inspected at frequent intervals and every precaution taken to prevent the entry of dirt or grease into the pipe being tested.

14.3.2 When conducting the test the relief valve and regulator should be set at test pressure, and air slowly introduced into the pipe. Test pressure should normally be maintained for a period of five minutes and the pipe examined for leakage, indicated by bubbles.

14.4 **Cleaning After Test.** After a pipe has been tested it should normally be flushed through with white spirit or other similar solvent, dried with a jet of clean, dry air and securely blanked.

14.4.1 Special care must be exercised when cleaning pipes used in high pressure air and gaseous or liquid oxygen systems; these pipes must be scrupulously clean and free from any possible contamination by oil or grease. It is usually recommended that pipes for use in these systems are flushed with trichloroethylene, blown through with double filtered air, and blanked-off immediately.

14.4.2 Nipple plugs, cone plugs and sealing caps to AGS specifications are often used for sealing the end connections of pipe assemblies but, if these components are unsuitable, special blanking devices should be provided. These blanks must be so designed that it is impossible to leave them in position when the pipe is connected into the aircraft system. Pipes should never be blanked with adhesive tape or rag.

14.5 **Marking.** Pipe assemblies should be marked to indicate that they have passed the prescribed pressure test. The marking should conform to the method specified for the identification of pipes by the aircraft manufacturer, and will usually be by rubber stamp on the pipe itself or by metal stamping on a label attached to the pipe.

14.5.1 Where the drawing requires identification labels to be attached by soldering, the solder must be continuous round the whole label. Serious corrosion may occur if spot soldering is employed or if gaps are present in the solder fillet.

15 IDENTIFICATION SCHEME All pipe line systems in aircraft are marked at convenient intervals throughout their runs, so that the particular system can be traced without the possibility of confusion with other systems.

15.1 The requirement for the identification of pipe lines is specified in Chapter **D4-1** of British Civil Airworthiness Requirements.

15.2 A suitable scheme for identification marking is described in British Standards M23. This method provides clear identification of pipes on a code basis. The marking consists of a written description of the main function of the system, together with a geometrical symbol and a colour scheme.

16 INSPECTION When all stages of manufacture of a pipe assembly are completed, the following points should be verified:—

(i) The material and dimensions are in accordance with the relevant drawing.

(ii) The material has received the correct heat treatment both during manufacture and as a finished pipe.

(iii) When fusible alloy has been used during pipe bending, all the necessary precautions have been taken for the removal of the alloy (see paragraph 4.3.6).

(iv) Bends are not made too near the pipe ends, thereby preventing the union nut from being withdrawn its entire length.

(v) The pipes are correct in respect of form and length after bending, and there is no evidence of ovality, ripples, flakes, kinks, bulges, splits, scores, flaking of bores or thinning of gauge in excess of specified limits.

(vi) The end fittings are in accordance with the drawing.

(vii) Flares are free from cracks, splits or thinning and are concentric to the pipe.

(viii) The pipe has successfully withstood the specified pressure test.

(ix) The pipe is clean internally and externally and has received the correct protective treatment.

(x) The pipe is correctly part numbered and, where applicable, has the correct code marking (for part marking see Leaflet **BL/2-1** and for code marking BS M23).

NOTE: Identification labels on pipelines should be affixed sufficiently far from the end fittings to prevent interference with the union nut or pick-up of the label when the fitting is assembled. It is recommended that this distance should not be less than nine inches.

(xi) The pipe is properly blanked by an approved method.

BL/6-16

Issue 2

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BASIC

ENGINEERING PRACTICES AND PROCESSES

RESISTANCE WELDING – SEAM WELDING PROCEDURE

1 INTRODUCTION This Leaflet gives guidance on the application of the seam welding process to both ferrous and non-ferrous materials. It should be noted that, in the paragraphs dealing with the description and operation of seam welding machines, imperial measurements have been retained in this Leaflet; the figures for metric sized material and machines calibrated in accordance with the metric system, should be obtained by experiment. Other forms of resistance welding are the subjects of separate Leaflets.

1.1 Seam welding is a method of producing a load-carrying and/or pressure-tight joint between two or more (usually only two) parts manufactured in sheet metal. The seam weld is produced by feeding the parts between two rotatable copper alloy electrode wheels, passing a high intensity pulsating current through the parts whilst the electrode wheels are being rotated, and applying a steady pressure to the wheels sufficient to forge the local areas heated by the welding current into a series of spaced or overlapping spot welds.

1.2 'Seam' welding is the term usually employed to describe the process in which the electrode wheels rotate during the flow of the pulsed welding current and is usually employed on light gauge (up to 1·5 mm) material where the current ON and OFF times do not exceed 7 or 8 cycles (0·14 to 0·16 seconds). 'Roller spot' welding is the term usually employed to describe the process in which the electrode wheels are halted at the commencement of each current pulse, and rotate only during the OFF period between welds. Each weld is therefore completed with the electrodes stationary, allowing each weld to be forged, i.e. to cool from welding temperature whilst under pressure. Roller spot welding is normally employed on thick materials and on heat-resisting alloys where the current ON time for each welding pulse exceeds 6 cycles (0·12 seconds).

NOTE: The term 'cycles' refers to the normal electrical mains supply of 50 Hz, i.e. cycles/second.

1.3 Seam welding is the fastest method of making pressure-tight joints on thin gauge materials and can produce 1500 overlapping spot welds per minute at a setting of 1 cycle ON, 1 cycle OFF. The welding speed obtainable is determined by the weld ON and OFF time settings, and the number of welds required per inch using the equation:–

$$\text{Welding Speed (ins/min)} = \frac{\text{Number of cycles/minutes}}{\text{Sum of ON and OFF times x required number of spots/inch}}$$

EXAMPLE:–

Assuming a required weld spacing of 10 per inch and a machine setting of 2 cycles ON, 3 cycles OFF:–

$$\text{Welding Speed} = \frac{50 \times 60}{(2+3) \times 10} = 60 \text{ inches/minute}$$

1.4 As with spot welding, the strength of a seam welded joint depends largely on machine factors such as the track width of the electrode wheels, the welding force applied, the value of the welding current flowing during each weld and the speed or rotation of the electrode wheels. These must be set to values appropriate to the gauge and type of material to be welded, and the weld quality checked by test samples before production welding is commenced, at suitable intervals during the production period, and whenever any change is made to the machine settings or electrodes are replaced. The standard test samples and methods of testing are described in paragraph 14.

1.5 The weld quality is also affected by the condition of the workpiece and appropriate steps should be taken to ensure that the material specification, gauge thickness and surface condition are maintained within acceptable limits during the period of production.

2 WELDING EQUIPMENT Seam welding machines vary widely in design and construction but can be broadly categorised as described in 2.1 to 2.4.

2.1 **Circumferential Machines (Figure 1).** These, as the name implies, are used for welding around the girth or the ends of cylindrical workpieces, which either project into the machine to partially enclose the lower (or upper) arm or project away from the machine toward the operator.

2.2 **Longitudinal Machines (Figure 2).** These are designed to produce straight welds on flat components, or the side welds on roll-formed cylindrical components. Welding is accomplished by movement of the workpiece into the throat of the machine, or out of the machine throat towards the operator, the maximum length of weld in one uninterrupted run being limited to the depth of the throat of the machine.

2.3 **Universal Machines (Figure 3).** These can carry out longitudinal or circumferential welding by swivelling the upper weld head through 90° and using the appropriate circumferential or longitudinal lower arm extension supplied with the machine.

2.4 **Travelling Head of Travelling Table Machines.** These are usually designed specifically for one particular application and employ one electrode wheel only, which is attached to the upper head of the machine. The lower wheel and its supporting arm are replaced by a bar-type lower electrode to which the overlapping workpieces are clamped and which is connected to the welding transformer to complete the welding circuit. The upper welding electrode, which is always allowed to rotate, is then traversed along the weld joint of the stationary workpiece to form a travelling head machine, or in some cases, the workpieces and their supporting bar electrode are moved under the stationary upper machine head to form a travelling table machine.

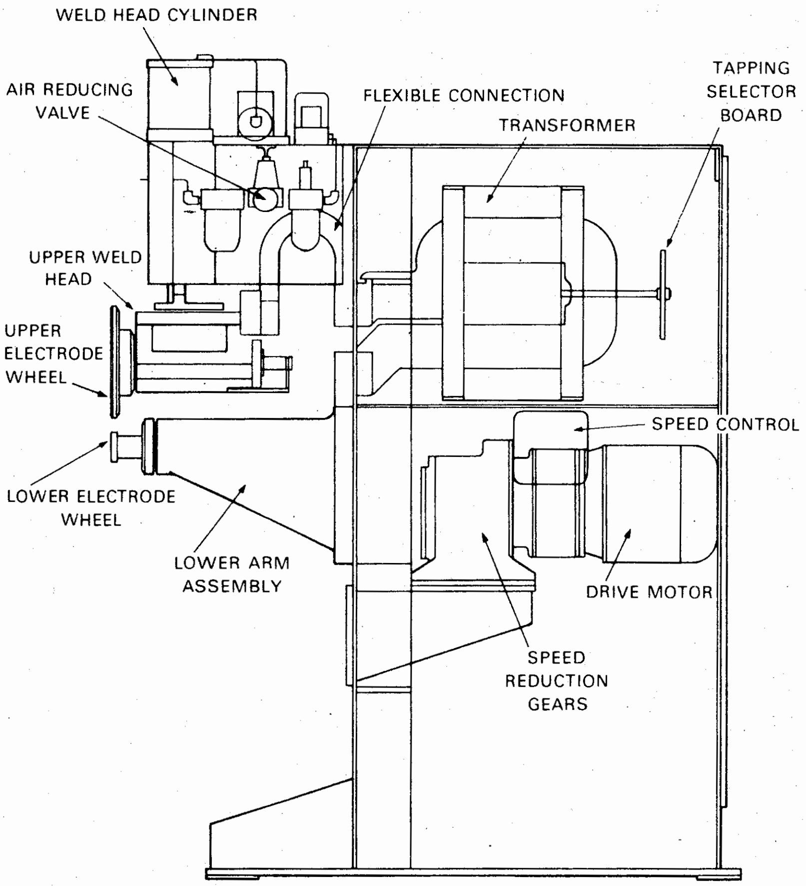

Figure 1 CIRCUMFERENTIAL SEAM WELDER LOWER WHEEL SPINDLE DRIVE

3 **ELECTRODE DRIVES** A variety of methods are employed to rotate the electrode wheels during the welding sequence. These fall into two basic categories, as described in 3.1 and 3.2.

3.1 **Shaft or Spindle Drive.** In this method either or both electrode wheels are rotated by means of an electric motor connected through suitable gearing to the spindle to which the electrode(s) is (are) attached (see Figure 1). The surface of the electrodes is smooth and should produce a good surface finish to the weld, but the electrode surface spreads progressively during use, and the wheels must be removed periodically and re-machined to restore the original track width. As the welding speed varies with any change in wheel diameter the motor speed must be adjusted whenever an electrode wheel is machined or replaced so as to maintain a constant welding speed.

3.1.1 Roller spot welding is nearly always associated with shaft or spindle driven machines and the intermittent rotation of the electrode wheel necessary to this method of welding is produced either by repeated stopping and starting the wheel drive motor, or by the repeated operation of a clutch and brake inserted in between the drive motor and the electrode wheel shaft. As the clutch and brake system allows the drive motor to run continuously, this system is capable of higher welding rates than the motor stop/start system. In both cases, the flow of current is synchronised with the wheel dwell periods so that the weld current flow time (weld or heat time) and the subsequent forge or cool period take place while the wheels are stationary. The electrode wheels then rotate for a timed 'run' or 'index' period to move on to the next weld position, and the sequence is repeated for as long as required.

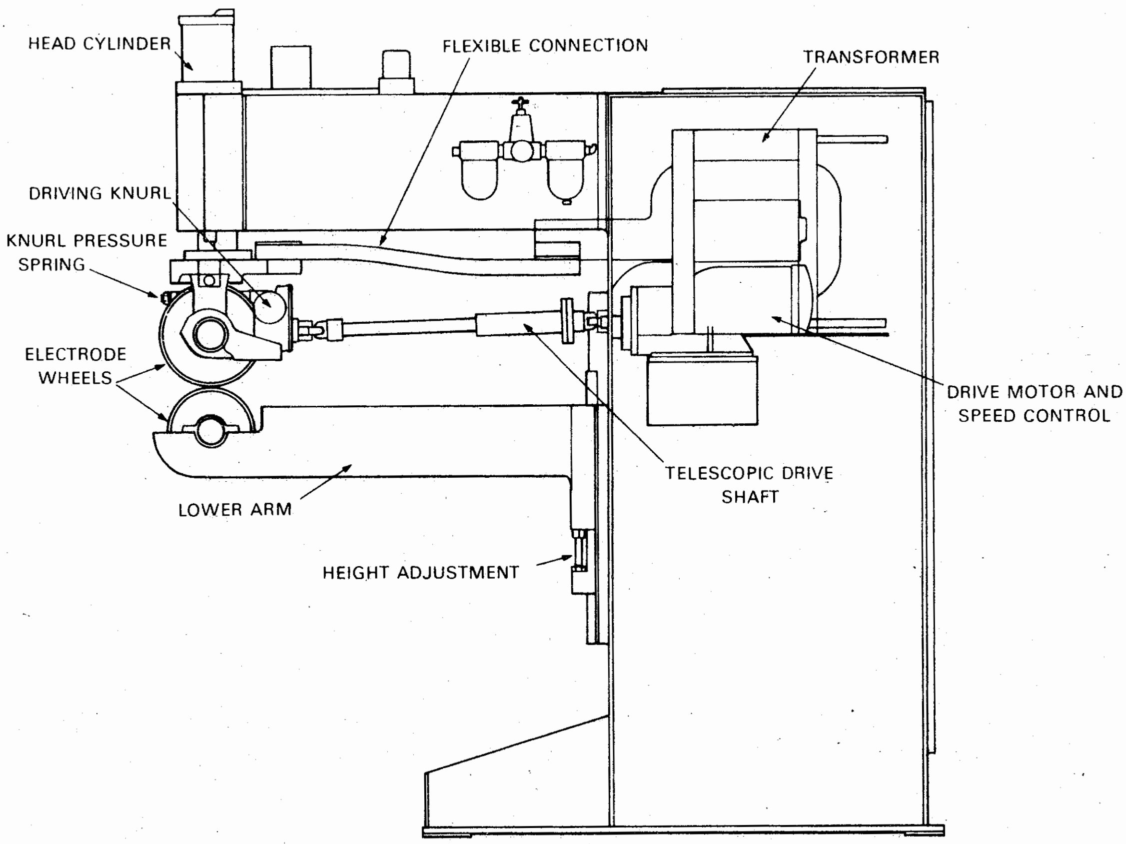

Figure 2 LONGITUDINAL SEAM WELDER UPPER WHEEL KNURL DRIVE

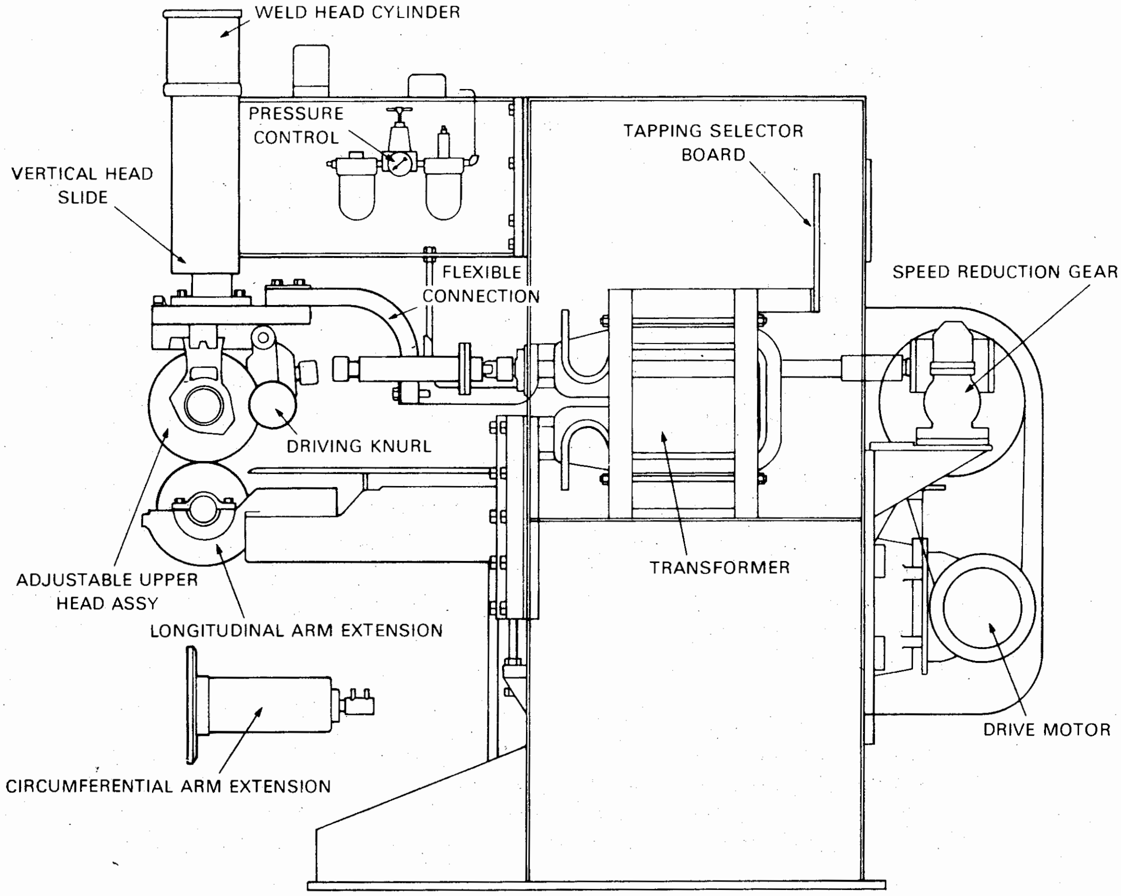

Figure 3 UNIVERSAL SEAM WELDER
UPPER WHEEL KNURL DRIVE

3.2 **Knurl Drive.** In this method either or both electrode wheels are rotated by means of a serrated knurl wheel, spring or air loaded on to the welding wheel rim and driven by a suitable electric motor (see Figures 2 and 3). As the knurl wheel is rotating at a constant speed and is relatively free from wear, the welding speed is virtually independent of the diameter of the electrode wheels and does not require adjustment as the electrodes wear.

3.2.1 The knurl wheel has a cutting action as it rotates against the flanks of the electrode wheel, and except under severe conditions, maintains a constant track width for the full life of the electrode. It is common practice in circumferential welding to drive both electrode wheels from a single electric motor to eliminate the 'slip' which can occur between the workpiece and an undriven electrode wheel, and knurl driving allows precise speed matching of the upper and lower wheels even when these have widely differing diameters.

3.2.2 One disadvantage of the knurl drive is that the pattern of the driving knurl is reproduced on the surface of the electrode wheel, and is then 'printed' on to the surface of the workpiece, producing a serrated finish which can precipitate the formation of cracks in alloy and heat resisting steels. For this reason, knurl drive seam welders should not be used for the welding of low alloy medium carbon steels, nickel, inconel or nimonic alloys, or for the welding of aluminium or magnesium alloys where the serrated surface of the electrodes could promote the dispersion of copper on to the surface of the weld seam and the transfer of workpiece material on to the surface of the electrode wheel.

4 **WELDING TRANSFORMER** The current which flows through the electrodes to heat and weld the workpieces is usually produced by a single phase transformer mounted inside the frame of the welding machine and connected to two phases of the incoming three phase mains supply by a special thyristor power switch. This enables the transformer to be switched ON and OFF with extreme rapidity and absolute accuracy over timing intervals ranging from 1 to 99 cycles, adjustable in 1 cycle steps. The welding transformer usually incorporates two or three parallel-connected single-turn secondary windings of water cooled cast copper construction, interleaved with multi-turn primary coils to transform the incoming supply (nominally 400/440 V) down to a low voltage level (typically 5 to 10 V) to produce 2000 to 25,000 amperes or more, dependent on the rating of the machine. The secondary windings are connected to the upper and lower electrode wheels via rotatable current-carrying bearings with flexible links to permit vertical movement of the upper sliding head assembly.

4.1 One leg of the secondary winding is solidly earthed to the machine frame, which is itself connected to earth by a heavy copper cable. A primary tapping selector on the welding transformer is used to provide coarse adjustment of the welding current by altering the secondary voltage applied to the electrode wheels. The mains voltage supply must always be disconnected before adjusting any tapping selector.

5 **WELDING FORCE** The pressure applied by the electrode wheels to the workpiece is an important factor in the production of satisfactory welds and must be carefully controlled during the welding process. This force is usually produced by compressed air applied to a double-acting pneumatic actuator to control the movement of the upper welding head, with a reducing valve and a pressure gauge to control and indicate the air pressure applied to the actuator. Actuators vary widely in design and allow accurate settings of weld force over a wide range of values.

5.1 Balanced pressure systems in which the downward force applied by the upper chamber of the actuator is partially counterbalanced by a separate controlled air pressure applied at the same time to the lower chamber is sometimes used to extend the available force range, and this technique, together with the use of two tandem coupled pistons or diaphragms can be used to provide a force range from 200 to 4000 lb on machines currently used in gas turbine engine manufacture.

5.2 Careful control of the welding force is essential and it should be borne in mind that fluctuations in the supply pressure may affect the welding force, and hence the quality of the weld. A stable pressure supply is therefore desirable, together with a pressure switch in the supply line, set to prevent the machine from operating if the supply pressure falls to a level at which the weld quality will be affected.

6 **ELECTRODE WHEELS** The design, choice of material and maintenance of adequate cooling of the electrode wheels, are of prime importance if efficient welding is to be achieved. With 'tracked' wheels the track width will depend on the thickness of the components being welded in the approximate ratio of 2 x t (where t is the thickness in mm of the material in contact with the electrode wheel, i.e. the upper or the lower workpiece). The welding track should not be more than half the thickness of the electrode wheel (except in special 'thin-wheel' machines) and the flanks either side of the wheel track should have an included angle of 120° (see Figure 4). Radiused wheels are sometimes employed in preference to tracked wheels, and in these cases the width of the wheel rim is machined to a radius usually between 1 and 2 inches.

7 **TIMING CONTROLS** Electronic timing controls of various types are employed to operate the weld force cylinder, initiate the rotation of the electrode wheels, and control the welding sequence. Roller spot welding requires additional controls in the form of an adjustable OFF or RUN time after each cool period, to rotate the electrode wheels for the preset time before the commencement of the next current flow period.

8 **CURRENT CONTROL** The heat developed in each of the overlapping welds is controlled mainly by the welding current, and this must be adjusted to the maximum value which can be obtained without 'splashing', or the expulsion of metal from the workpiece.

8.1 The primary means of current adjustment is by means of the transformer tapping selector referred to in paragraph 4 but this will only alter the current to a number of fixed values corresponding to the number of taps available. Stepless adjustment of the current between the tapping levels is provided by phase shift heat control in which the start of the conduction periods is delayed by an accurately controlled period of time. This prevents the flow of mains voltage supply in the primary windings of the transformer for part of each conduction period, and therefore reduces the heating effect of the secondary current produced.

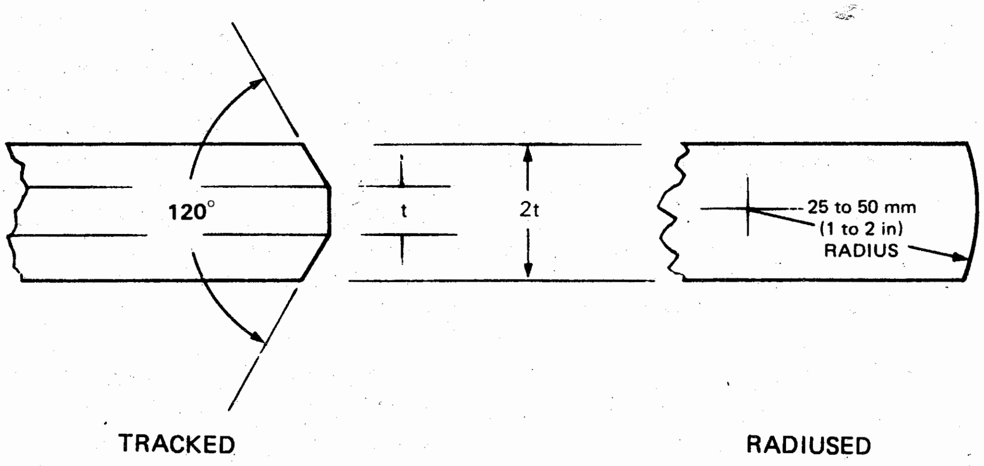

Figure 4 TYPES OF ELECTRODE WHEELS

8.2 The heat control potentiometers are usually included in the timing control Panel, and provide a range of adjustment at each tapping level.

9 VOLTAGE COMPENSATION Seam welding machines are commonly equipped with special controls to minimise the variation of welding current which normally accompanies any fluctuation in the supply voltage. These controls continuously compare the incoming supply voltage with a non-varying reference source and automatically adjusts the internal phase shift setting to maintain the preset secondary voltage constant to±2% against mains voltage variations of up to ±15%.

10 CONSTANT CURRENT Seam welding machines used extensively on highly stressed heat resisting alloy workpieces are usually provided with an additional control facility called 'Constant Current Control'.

10.1 This system monitors the current flowing in the transformer primary (primary feedback) or through the electrode wheels (secondary feedback) and compares the current to a reference corresponding to the setting of the tapping switch and phase shift potentiometers. Any variation of current due to the insertion of ferrous material into the throat of the machine, variation of the mains voltage supply, or any other cause, can be detected and automatically corrected to leave sufficient power in hand to allow the appropriate compensation to take place.

11 THE WELDING OPERATION

11.1 **Procedure.** The metal sheets to be welded are placed between the rollers with a predetermined overlap; the rollers then clamp the joint to a predetermined and preset welding pressure. A current is applied through the rollers which heats the joint sufficiently to form a weld with the aid of the pressure imparted by the rollers. At the same time that the current is applied to the rollers, they start rotating, and the work is passed steadily between them at a carefully controlled speed. Each weld spot is completed in a fraction of a second and the OFF period occurs before the pulse of current makes the next weld; as this cycle is continued, a seam weld is produced. Accurate control and repeatability of machine settings is essential. This is accomplished by the use of welding schedules.

11.2 **Welding Conditions.** The precise welding conditions and machine settings depend upon the particular work in hand, and it would be misleading to generalise.

11.2.1 The electrode roller pressure, weld time and current value should be based on test welds made with increasing current values until 'splashing' or expulsion of the metal occurs between the sheets. The current should then be reduced until 'splashing' ceases, when the weld strength should approach maximum. A correct combination of pressure, timing and current is essential if excessive indentation is to be avoided.

11.2.2 When sample welds to represent large sheets are made in small strips, some adjustment will have to be made, especially where a substantial amount of metal will be in the throat of the machine. Small variations in the quality of the material will also affect the machine settings and any table of machine settings must be considered as a rough guide only; sample welds will have to be taken to achieve optimum welds.

11.3 **Seam Weld Design.** In designing seam welds, the following factors are taken into consideration:–

(a) The seam must be accessible to the rollers of the welding machine, and care taken to ensure that, if external water cooling is used, the water is not trapped in the vessel or component being welded.

(b) If the machine is not provided with self-cleaning rollers there will be a danger of pick-up from the sheet being welded, and this pick-up, usually in the form of oxide, should be removed frequently otherwise there will be a danger of indentation and pitting in the sheet.

11.4 Considerable attention is given at the design stage to the various factors which can affect the strength, stiffness and suitability of welded joints. In order that these factors may be more readily understood they are described, in general terms, in paragraphs 11.4.1 to 11.4.5.

11.4.1 **Strength of Welds.** Usually a minimum strength requirement is assumed for design purposes, and whilst it is not possible actually to test the strength of production parts, indirect tests which give guidance on their strength are described in paragraph 14. Factors which have a significant effect on the strength of the weld include the distance of the weld from the edge of the sheet, and the thickness ratio of the parts being joined.

11.4.2 **Edge Distance.** A minimum edge distance of 1·75 D and a minimum overlap or flange width of 3·5 D (D being the weld diameter) is generally recommended. Smaller values than these may lead to some loss of strength in the joint, an increase in the likelihood of splashing of metal from the interface, and an increase in the possibility of deformation during welding due to inadequate supporting material around the molten weld slug. The overlap or flange width, is the width over which the materials being welded are in contact, and additional allowance must be made for any radiused corners which may be present on formed parts. Edge distance should be measured from the centre line of the weld to the edge of the material.

11.4.3 **Material Thickness.** The total thickness of material which can successfully be joined by one machine will depend on the capacity of the machine and the nature of the material, but joint thickness of up to about 10 mm (0·4 in) in aluminium alloys and up to about 4 mm (0·16 in) in stainless steels are rarely exceeded. Excessive differences in the thickness of the sheets forming the joint tend to give inconsistent welds with little or no penetration of the thinner sheet; it is recommended that a thickness ratio of 2:1 to 2·5:1 should not be exceeded for any material. The joining of more than three sheets together is seldom attempted since this results in the production of very weak joints.

11.4.4 **Surface Indentation.** The surface indentation of any sheet due to welding should normally not exceed 10% of the sheet thickness. Where indentation must be avoided on one face of the workpiece, the tip diameter of the corresponding electrode can be increased up to three times the diameter normally recommended for the particular material thickness.

11.4.5 **Fitting of Surfaces.** It is important that the surfaces to be joined should be the best possible fit so that the electrode pressure is not required to overcome any stiffness of the sheets or sections, since this would result in a reduction of the pressure available for forging the weld. It is this factor which precludes the welding of contoured surfaces, or the placing of welds on radiused corners of sections and angles. Whenever necessary, a system of clamping should be used to hold the parts in correct register and to control the location of the weld. When welding assemblies containing numerous welds and, in particular, when welding heavy gauge material which requires large energy inputs, it is important to minimise distortion or deformation of the assembly caused by heat expansion; this can be done by commencing to weld at the centre of the seam and working outwards to the ends or edges.

12 SURFACE PREPARATION The success of resistance welding depends very largely on correct surface cleaning, since it is essential that the surfaces of the material should have a low and uniform contact resistance. Guidance on the preparation of various materials is given in paragraphs 12.1 to 12.6. It is difficult to lay down a standard mean period which can be permitted to elapse between surface preparation and welding, since this depends on such factors as the nature of the material, ambient conditions, etc., but the period should always be as short as possible. After surface treatment the parts should be adequately washed and dried. DEF STAN 03-2 gives details on the cleaning and preparation of various metal surfaces.

NOTE: The use of cotton gloves when handling prepared surfaces is recommended.

12.1 **Aluminium Alloys.** The presence of a thin, tough, oxide surface film of high electrical resistance is characteristic of the aluminium alloys, and its removal prior to welding is essential, otherwise discoloured, surface-burnt welds, and rapid electrode deterioration will result. Furthermore, since the oxide film is not uniform in thickness, its presence causes variations in the heat developed at the sheet interface, resulting in considerable variation in the size of the welds. The variation in electrical resistance is further aggravated by the presence of extraneous matter such as dirt, grease or paint and since no satisfactory method exists for the removal of the oxide film and the extraneous matter together, surface preparation must be considered in two stages.

12.1.1 Firstly, the surface must be efficiently degreased by, for example, a process such as that described in Leaflet **BL/6-8**, using trichlorethylene. The oxide film must be removed by a chemical process such as the ones described in (a) and (b) below, or by a suitable proprietary process.

(a) **Chromo-Sulphuric Acid Pickle.** The solution should consist of de-mineralised water containing:–

Sulphuric Acid (d = 1·84)	150 ml/litre
Chromic Acid (CrO_3)	50 g/litre

The solution should be contained in a lead-lined tank and should be maintained at 60°C. The treatment period should not exceed 30 minutes, after which the parts should be thoroughly washed.

(b) **Sulphuric Acid and Sodium Fluoride Bath.** The solution consists of de-mineralised water containing:–

Sulphuric Acid (d = 1·84)	100 ml/litre
Sodium Fluoride (NaF)	10 g/litre

The solution should be maintained at room temperature, and the parts should be immersed until uniformly clean (5 to 10 minutes). The parts should then be rinsed in cold water, dipped in an aqueous solution of 500 ml/litre nitric acid (d = 1·42) for one minute and then thoroughly washed in clean water.

12.1.2 The cleaning of aluminium alloys of the type which are solution treated and naturally aged, should not be commenced until 24 hours after solution treatment. Great care should be taken to ensure the complete removal of all cleaning and pickling solutions, by efficient washing and rapid drying.

12.2 **Magnesium Alloys.** These materials should first be degreased and then carefully cleaned by a mechanical means. They should finally be air-blasted to ensure the removal of any particles left by the cleaning process.

12.3 **Corrosion-Resisting Steels.** The surfaces to be welded should be degreased and then prepared by cleaning with a brush having stainless steel bristles. Pickling is not necessary for these materials unless vapour-blasting or abrasive paper cleaning is employed, in which case contamination should be removed by pickling or swabbing in a 20% (by volume) nitric acid solution.

12.4 **Nickel Alloys.** The surfaces should first be degreased and then immersed in one of the following aqueous solutions:–

(a) Nitric Acid (d = 1·42) 200 ml/litre
Hydrofluoric Acid 50 ml/litre

The solution should be used at a room temperature not exceeding 65°C

(b) Hydrofluoric Acid 200 g/litre
Ferric Sulphate ($Fe_2(SO_4)3$) 200 g/litre

The solution should be used at a temperature of 65° to 70°C

NOTE: Nickel alloys should be in the solution heat-treated condition prior to immersion in these liquids.

12.5 **Plain Carbon Steels.** After degreasing, plain carbon steels should be pickled in an aqueous solution containing 10% sulphuric acid (d = 1·84) by volume. The solution should be contained in a lead-lined or rubber-lined tank and should be used at room temperature. Welding should be carried out immediately after washing and drying the parts.

12.6 **Titanium Alloys.** The requirements for the surface preparation of titanium alloys are similar to those for other materials, i.e. the surface must be clean and free from grease. The surfaces may be cleaned by the use of any approved solvent which leaves no residue, but if the material has been heat treated for manipulation purposes prior to welding, a light oxide film will be present on the surfaces; this should be removed by an acid pickle (the solution described in paragraph 12.1.2(a) is suitable) or by brushing with a wire brush.

13 MATERIALS Table 1 of Leaflet **BL/6-12** lists the types of material suitable for seam welding, together with brief details of heat treatment and other relevant factors. No attempt should be made to weld materials not listed or to weld combinations of listed materials, unless this is specified on the drawing and a proven technique is available.

13.1 **Low Carbon Steels.** Low carbon or mild steel has a carbon content in the range of 0·01% to 0·26% and a manganese content of below 0·7%. The advantage of this material is that it is not heat-treatable and is, therefore, very suitable for all forms of welding. Table 1 gives general guidance on suitable machine settings.

TABLE 1
TYPICAL SETTINGS FOR SEAM WELDING MILD STEEL

SWG	Tread Width (Inches)	Pressure (lb)	Timing Cycles On Off	Inches Per Minute	Spots Per Inch
24	$\frac{5}{32}$	550	1 1	120	$12\frac{1}{2}$
22	$\frac{3}{16}$	660	1 1	120	$12\frac{1}{2}$
20	$\frac{3}{16}$	660	1 1	120	$12\frac{1}{2}$
			2 2	75	10
18	$\frac{7}{32}$	770	2 2	75	10
			3 3	60	10
16	$\frac{1}{4}$	880	3 2	60	10
			3 3	50	10
14	$\frac{9}{32}$	990	4 3	45	$9\frac{1}{2}$
			4 4	40	$9\frac{1}{2}$

13.2 **Low Alloy Steels.** The low alloy steels contain one or more elements such as nickel, chromium, molybdenum, vanadium, etc, which improve the heat treatable qualities of the steel. These steels are easily seam welded, but will generally require heat treatment after welding to restore the properties of the steel.

13.3 **Medium Carbon Steel.** To obtain satisfactory mechanical properties, it is necessary to temper the welds. This tempering can be carried out by passing a current through the welds but it is more satisfactory, where possible, to temper the work in a furnace.

NOTE: With both low alloy steels and medium carbon steel cracking in the weld area may occur, especially at the higher end of the carbon range, unless careful attention has been paid to the heat treatment schedule specified for the material concerned.

13.4 **Nickel and its Alloys.** The need for cleanliness of the surfaces cannot be overemphasised. Oxide films greatly increase the electrical resistance and will seriously affect the weld quality. Mechanical methods of removing the film, e.g. by the use of abrasives, are best. Pickling alone is satisfactory on nickel and monel, but for the other high-nickel alloys this should be followed by abrasive cleaning. Such treatments should be applied immediately before welding.

13.4.1 Table 2 gives recommended settings for seam welding high nickel alloys, and provides a starting point from which optimum settings for the equipment available can be determined. Very often however, the precise welding conditions depend upon the particular component.

TABLE 2
TYPICAL SETTINGS FOR SEAM WELDING NICKEL ALLOYS

Material	SWG	Tread Width (Inches)	Pressure (lb)	Timing Cycles On Off	Inches Per Minute	Spots Per Inch
Monel	20	$\frac{3}{16}$	700	4 12	19	10
	16	$\frac{3}{8}$	2500	8 12	20	$5\frac{1}{4}$
Nimonic 75	20	$\frac{3}{16}$	1850	4 8	24	$10\frac{1}{2}$
	16	$\frac{1}{4}$	2500	12 16	12	9
Nimonic 80	20	$\frac{3}{16}$	2300	4 8	30	$8\frac{1}{4}$
	16	$\frac{3}{16}$	4000	8 16	12	$10\frac{1}{2}$

13.4.2 Inconel and Nimonic alloys are characterised by their high mechanical strength at elevated temperatures and high electrode pressures are, therefore, needed to ensure satisfactory forging of the weld. Electrode roller pressure should be at least one third higher than that for mild steel. These alloys also have high electrical resistivity, which enables them to be welded with shorter welding times than those required for mild steel.

13.5 **Corrosion and Heat Resisting Steels.** Many of these steels are easily weldable provided care is taken with the joint preparation. The electrical resistance is approximately six times greater than that of ordinary mild steel, with a lower heat conductivity and melting range, so that considerably less heat input is required for seam welding these materials as compared with mild steel.

13.5.1 Some difficulty has been experienced in the welding of austenitic steels due to 'weld decay' being caused by the precipitation of chromium carbide in metal near a weld which has been heated to a temperature within the range of 500°C to 900°C. The corrosion resistance of these materials is dependent on the retention of chromium in solid solution, so that the corrosion resistance is reduced if precipitation of chromium carbide occurs near the weld.

13.5.2 The extent of precipitation increases with increased welding times, so that short welding times are essential for those materials, since this not only reduces the heat affected zones, but permits a high rate of cooling after welding, which also reduces the tendency to precipitation. However, the majority of specifications for austenitic steels now require that small additions of titanium or niobium be added in amounts sufficient to combine with all the carbon present so that no chromium can be precipitated as carbide.

13.6 **Aluminium and Aluminium Alloys.** Aluminium alloys are materials of inherently low resistance and of high thermal conductivity. The amount of heat developed by electrical resistance welding methods depends on the resistance offered to the welding current thus, despite the relatively low fusion temperature of these materials (as compared with low carbon steel) a considerably greater rate of energy input is required, necessitating the use of high currents and short welding times, the latter being necessary to minimise conduction losses. However, advantage cannot be taken of the highly resistant oxide film which forms on the surface of these materials, since, as indicated in paragraph 12.1 its inherent lack of uniformity results in variation of weld size and quality.

13.6.1 The majority of the aluminium alloys can be satisfactorily welded but special machines and carefully controlled surface cleaning are necessary. Pure aluminium is the most difficult material in this group to weld, being extremely soft and easily indented by the roller; in addition, its oxide film is difficult to remove and it has high conductivity. The seam welding of aluminium alloys presents more difficulty than seam welding low carbon steels, due to the inherent nature of the material, its surface condition and its tendency to alloy with the copper-based welding rollers. In general the high tensile heat-treated alloys show greater consistency of weld strength than the low tensile alloys.

13.6.2 Because of the high thermal and electrical conductivity of these materials, high welding currents and short welding currents and short welding times are needed. Special stored energy machines are employed to reduce the sudden surge of demand on the electrical supply system. These machines are currently being replaced with the phase frequency conversion machines.

NOTE: When seam welding aluminium and its alloys the welding rollers require frequent trimming and must be cleaned continuously to avoid 'pick-up' which damages the welded surfaces.

13.7 **Magnesium Alloys.** The seam welding of magnesium alloys presents rather more difficulties than the seam welding of aluminium alloys and is not recommended.

13.8 **Titanium Alloys.** The requirements for the surface preparation of titanium alloys are similar to those for other materials, i.e. the surface must be clean and free from grease. The surfaces may be cleaned by the use of any approved solvent which leaves no residue, but if the material has been heat treated for manipulation purposes prior to welding, a light oxide film will be present on the surfaces; this should be removed by an acid pickle (the solution described in paragraph 12.1.2 is suitable) or by brushing with a wire brush.

14 CONTROL OF WELDING For design purposes a minimum strength per inch is assumed. Since it is not possible actually to test the strength of the welds in production parts, weld efficiency must be controlled by examination of the results of tests conducted on separately welded test pieces, these test pieces simulating the production parts in respect to material specification and thickness, including surface preparation, machine settings and speeds of welding, with all other parameters and data affecting welds put on schedules. Test pieces should be prepared at appropriate intervals, a suitable basis being one test piece before a day's run and another at the end, with an additional test whenever a fresh machine setting is made or after the replacement of rollers.

14.1 Production control test pieces can only be used to determine whether the weld strength obtained with the specimen exceeds the minimum strength per inch weld prescribed in the relevant drawings. It should be borne in mind that the strength obtained with test pieces does not necessarily indicate the weld strength in the production assembly, since it is not possible for such an assembly to be entirely representative of the production part. Further, the specimen cannot take into account the 'Mass effect' in welding large panels.

14.2 Minimum strength figures should be chosen with care, and should be determined by welding production assemblies and control test pieces under the same conditions, destructively breaking the welds in the assembly and comparing the results with the shear strength obtained with the test pieces (paragraph 14.5), and by microscopic examination of cross-sections (paragraph 14.6). If the number of test pieces selected on the basis given above is large, and satisfactory results are obtained, the number of sections submitted for microscopic examination may be reduced to 10% of the total number of test pieces.

14.3 As a further check on the efficiency of welding, the Chief Inspector may, at his discretion, select samples from actual production to be tested by an appropriate method. Where engine parts are concerned, and particularly those used in gas turbines, the manner in which the weld will withstand heat stressing and vibration may be of more importance than static strength. Whilst a shear strength test provides a useful guide in this respect, a 'prising' test is additionally informative, and has the advantage that it can be quickly performed on the workshop floor, giving a positive indication as to the validity of information written into schedules and subsequently used on test pieces.

14.4 **Prising Tests.** The test specimen should be placed in a vice and plates prised apart with a chisel. A good weld does not shear at the weld interface, but will break away along the edge of the weld leaving the weld complete with both sheet thicknesses included.

14.4.1 Schedule sheets with all parameters appertaining to the particular weld should accompany the test specimen through inspection/radiography/NDT and destructive metallurgical tests, receiving necessary stamps and signatures to final acceptance.

14.4.2 Radiographs of the test pieces should be used as final comparison with radiographs of the workpiece.

14.5 **Shear Test.** The test samples for shear tests should be made as indicated in Figure 5, curved or flat as required by the controlling authority.

14.5.1 The sample should be cut so that the first 50 mm (2 in) of the weld is discarded, as indicated, leaving a test piece similar in type to that used for spot welding tests. The test piece should then be pulled in a similar manner as for spot welding tests (see Leaflet **BL/6-12**).

14.5.2 If it is desired to employ a testing machine with pin grips for this test, the width of the ends of the test piece should be increased accordingly to compensate for the presence of the locating holes. In no instance should the length of the portion of the weld to be tested be less than 25 mm (1 in).

14.6 **Microscopic Examination.** The furthest portion of the sample on the side of the test piece remote from the discarded piece should be used for examination. Seam welds should be sectioned centrally and longitudinally for the purpose of examination.

14.6.1 After sectioning and polishing, the sample should be examined microscopically, in both the unetched and etched conditions, first at low magnification (x 10) and at higher magnification (x 100). At low magnification the welds should show freedom from cavitation and from excessive porosity. A slight amount of cracking is generally permissible in the weld itself but no cracks should appear outside the weld area. There should be adequate but not excessive penetration. For welds in sheets of approximately equal thickness, the depth of the fusion zone should be 40 to 80% of the sheet thickness, but should not reach the surface of the sheet or for clad materials, the coating.

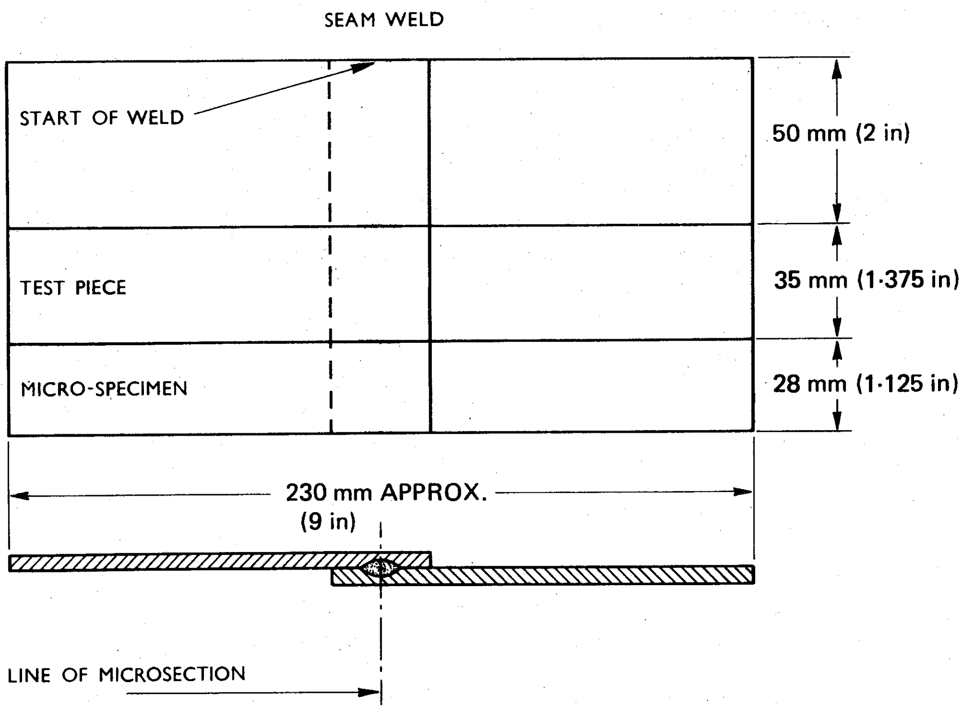

Figure 5 SHEAR TEST SPECIMEN

14.6.2 Pick-up from the electrode rollers is not permissible on aluminium alloys, as experience has shown that this defect seriously reduces the resistance to corrosion (this is often indicated on visual examination by a roughening of the surface).

14.6.3 The examination at higher magnification should be made to check and confirm the observations made at low magnification. Information on suitable etching reagents is given in paragraph 12.

15 **INSPECTION** In addition to indicating the examination to be afforded the parts after welding, this paragraph summarises the inspectional responsibilities for the process as a whole.

15.1 Inspection should verify that pressure and heating, current values, etc., are as specified in the drawing, welding schedule or other document and are in accordance with the results of experiments and past experience with the particular type of weld and machine used.

15.2 It should be ensured that the metal has been suitably cleaned and that the highest degree of cleanliness is observed throughout the process, that the welding technique is correct, that all drawing and other requirements are complied with, that electrode rollers used are correct in form and size and that the weld size is in accordance with that produced on the pre-production test piece.

15.3 After welding, the surface of the weld should be examined to ensure it shows no obvious signs of overheating, that the weld and adjacent metal is free from visible cracks and pitting, and that the distance between the centre line of the weld and the edge of the material being welded is not less than the minimum specified on the drawing.

NOTE: Slight cracks in the seam weld are generally permissible provided they do not extend into the parent sheet. However, in some cases of primary structure, such cracks may not be acceptable.

15.4 The roller indentation should be checked to ensure that it does not exceed 5% of the combined thickness of the sheets being welded.

15.5 The sheet separation at the weld should be checked to ensure that it is not greater than 10% of the combined thickness of the sheets being welded.

15.6 The above inspections should be backed up by evidence afforded by the mechanical, microscopical and prising tests described in paragraph 14, and where stressed parts are concerned, by suitable radiological examination to approved techniques. In addition, the use of a penetrant dye process will facilitate the inspection. An application of dye on one side and examination on the reverse side will reveal the presence of burning, cracks and, in the case of edge welding, lack of fusion.

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BASIC

ENGINEERING PRACTICES AND PROCESSES

CLEANLINESS OF AIRCRAFT

1 INTRODUCTION The degree of cleanliness achieved, both internally and externally, during the construction and maintenance of aircraft has a direct bearing on airworthiness. To ensure that engineers and inspectors are able to certify that aircraft are fit for flight, it is essential, particularly where closed structures are concerned, that the component history cards and aircraft build sheets used during construction and overhaul, should contain a clause requiring inspection to certify that each part has been inspected at the appropriate stage, and that it is free from loose articles, dirt, swarf and other extraneous matter.

2 THE EFFECTS OF EXTRANEOUS MATTER The presence of extraneous matter inside aircraft, components, systems, etc., can have serious consequences and special care is necessary to ensure thorough cleanliness at all times. In the following paragraphs some of the adverse effects are briefly outlined.

2.1 Extraneous matter in the form of dirt or grit in moving parts may cause excessive wear and other damage. Working clearances of many components are relatively minute and small particles of dirt may cause scoring or seizure of working surfaces and rapid deterioration of seals and glands. Where systems are concerned (e.g. hydraulic, fuel and pneumatic systems), scrupulous cleanliness is essential during assembly and maintenance operations; contamination inside a system will often present a difficult cleaning problem and many cases are on record of malfunctioning due to ingress of extraneous matter.

2.2 The presence of loose extraneous articles inside a structure is always a dangerous hazard. Such items as nuts, bolts, rivets, off-cuts of wire or sheet metal and hand tools have been found inside the more intricate and boxed-in type of structures. These can cause jamming or restriction of vital controls and have been known to result in serious aircraft incidents. Furthermore, loose items, especially of a heavy nature, which are trapped inside structures can, due to vibration, erode the protective treatment of the structure and cause damage to bag-type fuel tanks or the sealant of integral tanks. Heavy loose items trapped inside control surfaces can result in their becoming unbalanced.

2.3 In structures where there are electrical installations, small metal particles can cause damage to the insulation of wires and looms, and these can produce short-circuits at terminal points. The ingress of such particles into switches, solenoids, actuators, etc., is a common cause of malfunctioning. Where inverters, generators, etc., are cooled by means of ducted air, special care is necessary with regard to cleanliness as the cooling air can collect dust and grit and deposit this inside the component; foreign matter can also block the cooling-air filters of avionic equipment, resulting in overheating and failure.

NOTE: Loose particles of ferrous metal, such as filings, in the vicinity of electromagnetic mechanisms are particularly dangerous and difficult to remove; such mechanisms should, therefore, be adequately protected prior to filing and sawing ferrous parts in the vicinity.

2.4 Where pipes run in banks, loose extraneous parts may become wedged into the pipe clearances, and might restrict the natural whip or flexing of the pipes under surge loads, resulting either in fracture or perforation through chafing.

2.5 Grit or small metal particles inside bays fitted with flexible tanks will damage the tank envelope and produce leaks and, in the case of integral tanks, metal particles embedded in the tank sealant might cause leaks and promote corrosion of the structure from electrolytic action.

2.6 The presence of extraneous fluids, due to spillage or leaks, may have serious deleterious effects. Certain fluids, such as ester-base engine oil, hydraulic oil, glycol, de-icing fluid, etc., will damage most protective treatments or materials not intended to be in contact with these fluids, and bonding compounds, electric cables, rubber mouldings, tyres, etc., will deteriorate rapidly if these are left in contact with such fluids; the spillage or leaks of some fluids may increase the fire hazard, especially if they occur in the vicinity of electrical equipment or engine installations. Serious contamination can also be caused by spillages of toilet fluids, mercury, gallium and other chemicals.

NOTE: Leaflet **AL/3–8** gives guidance on general fire precautions.

2.7 In remote areas of the structure where access and periodic cleaning are difficult, dirt or dust will tend to accumulate and could act as a wick for moisture which, in time, may penetrate the protective treatment and promote corrosion.

2.8 Special precautions are required regarding oxygen installations. The presence of extraneous matter, especially of an oily or greasy nature, in contact with pressure oxygen is explosive. It is important, therefore, to follow the special instructions regarding cleanliness of oxygen systems given in the installation drawings or Maintenance Manual.

3 **GENERAL PRECAUTIONS** It will be difficult to ensure a high standard of cleanliness of aircraft, components, etc., unless a similar standard is maintained in hangars and workshops. Vigilance is necessary to ensure that conditions and workshop practices are such that extraneous matter will not enter or come into contact with any part of the aircraft, its systems or its components.

NOTE: It is recommended that placards and warning notices (preferably illustrated), pointing out the seriousness of extraneous matter in aircraft, should be placed in all departments.

3.1 In order to prevent small tools, torches, pencils, etc., from falling into the aircraft structure, personnel engaged on servicing operations should wear overalls fitted with closed pockets. Suitable footwear should also be provided, or vulnerable surfaces should be protected with mats, as even small scratches can destroy anti-corrosive treatment and lead to deterioration of a component.

3.1.1 An inventory should be made of all tools, spares or equipment taken to an aircraft for servicing purposes, and checked when the work has been completed. This action will reduce the possibility of such items being left in the structure.

3.2 Dirty floors, stagings, benches, test equipment or open tins of jointing compound, sealants, grease, paint, etc., (which may gather extraneous matter), should not be permitted. For instance, no matter how careful an engineer might be regarding the final cleanliness of a component he may not be able to detect the presence of extraneous matter in jointing compound from a tin that has been left open; yet this may result in a serious attack of electrolytic corrosion or prevent the joint from closing completely. All tins and containers should be kept closed when not in use and any tins and containers which have been open for an unknown length of time should be discarded.

NOTE: This trouble can be avoided if the compound is obtained from squeeze tubes and applied directly to the joint.

3.3 Engines, accessories, instruments, ball bearings, etc., which are usually supplied, as appropriate, in special transport cases or packagings, should not be unpacked until required for use. Blanking plates on engines or components and blanks fitted to pipe connections or other openings, should only be removed for installation or functioning tests.

3.4 Parts that are not required for immediate installation should be kept in stores. For information on storage conditions for aeronautical supplies see Leaflet **BL/1-7.**

3.5 Whenever it is necessary to open or dismantle an accessory, component or system, the work should be done under controlled conditions where dust, grit, etc., (e.g. from cleaning operations), cannot enter the accessory, component or system. Stripping and cleaning sections should be adequately segregated from inspection and assembly areas.

NOTE: Care is necessary when using sawdust for cleaning hangar floors. Cases have arisen during maintenance work on fuel systems where the lighter particles of sawdust had entered the system and subsequently been found in the fuel filters. Investigation revealed that these particles emanated from the sawdust used for cleaning purposes.

3.6 Transparent plastics panels (acrylic sheet), widely used for cabin window glazing, are affected by certain organic fluids and in some cases their vapours. Some of these fluids are in common use during aircraft maintenance operations and reference should be made to Leaflet **AL/7-4,** Transparent Plastics Panels, which lists these fluids and gives guidance on the necessary precautions and the cleaning procedures involved.

3.7 Engine runs should be carried out at some distance from maintenance installations or other aircraft, on hardstandings with clean, firm and well drained surfaces. This will minimise damage to external parts of the aircraft and help to prevent water, grit or debris from entering engine intakes, breathers and vents.

4 **AIRCRAFT IN SERVICE** When an aircraft is in service it should be cleaned periodically as part of the routine maintenance. The cleaning solvents recommended for use on a particular aircraft are usually detailed in the relevant Maintenance Manual but in any case no unauthorised solvents or detergents should be used. Chlorinated solvents such as trichlorethylene or carbon tetrachloride should not be used inside the aircraft due to the danger of toxic fumes given off by these liquids.

4.1 **Normal Exterior Cleaning.** Before commencing cleaning operations all panels and covers should be in place and apertures sealed off. Thick mud, grease or oil should be removed by, first, hand scraping using wood or soft plastic scrapers and then lint free cloth soaked in solvent. Care should be taken to avoid damage to paint or other anti-corrosive treatment. Cleaning should then be carried out using a recommended solvent. These solvents are usually used diluted in hot water. Application to the aircraft surface is best made with spraying equipment but care should be taken to ensure that the solution does not become atomised. After allowing the solution to penetrate, the dirty surface should be washed thoroughly with clean water until all traces of the solution are removed. Care should be exercised when using water hoses for rinsing as too high a pressure may cause damage or ingress of moisture. Undiluted solvents should never be allowed to come into contact with acrylic windows, etc., as crazing is likely to ensue. In all cases the recommended solvent manufacturer's instructions should be adhered to. Re-lubrication of mechanical parts may be necessary after washing, and application onto sealed bearings, etc., should be avoided.

4.1.1 **Exterior Cleaning of Heavily Contaminated Areas.** Certain areas of an aircraft may become heavily contaminated by exhaust gas deposits, the areas varying with different types of aircraft. This contamination, if not removed, could cause severe corrosion and require expensive repairs. Stronger cleaners recommended for the particular aircraft or part should be used with extreme care. Dilution may be required with either water or white spirit, and application can be made with a non-atomizing spray. In all cases, the solvent manufacturer's instructions must be strictly complied with. The solution, when applied, should be allowed to soak for a given period and care taken to avoid areas becoming dried out. After soaking, further application is usually required and agitation or scrubbing with a soft brush may be advantageous. Very thorough rinsing, preferably with clean warm water, is necessary. Painted surfaces as well as acrylic windows may become damaged if these stronger solutions are allowed to come into contact with them.

4.1.2 **Snow and Ice.** Chemical salts and other melting agents are often used on runways during the winter months. This slush will inevitably become splashed or sprayed onto the aircraft and could be detrimental. The contaminated areas should be washed down with clean water as soon as possible after exposure. The use of a wetting agent may prove helpful.

4.1.3 **Acrylic Windows.** After aircraft washing, the windows should be washed with soap or a mild detergent in warm water. Polishing minor scratched surfaces may be accomplished with an approved plastics polish and finally finished with an anti-static polish or cloth. Further guidance on this subject is given in **AL/7-4.**

4.1.4 **Radioactive Contamination.** This is usually confined to aircraft regularly flying above the stratosphere. Regular monitoring of high flying aircraft with a Geiger counter should be made. Normal regular cleaning will in most cases keep contamination within acceptable limits.

4.1.5 After cleaning of windows has been completed, the aircraft should be inspected for signs of damage, deterioration of protective treatment, cracks, corrosion, etc. A careful check should be made to ensure that all blanks and sealing fitted have been removed and that cleaning equipment such as rags, sponges, etc., are not left in the intakes, flying controls or other susceptible places. Vents and drain holes, etc., should be checked and cleared if necessary.

4.2 **Interior Cleaning.** The inside of the aircraft should be kept clean and special attention should be given to areas where spillages can occur. Dirt and grit are best removed by use of a vacuum cleaner but oil or grease stains should be removed with the aid of a cleaner recommended by the manufacturer. This should be applied in small quantities to prevent soaking the fabric or padding. Loose covers may be removed for washing but must be thoroughly dry before refitting in the aircraft. Where the materials have a non-permanent flame-proof protection they must be re-proofed after washing.

4.2.1 At the intervals prescribed in the appropriate Maintenance Schedule, the floor panels should be removed and an inspection of the underfloor skin and structure carried out. Corrosion and residues which result from spillages in the cabin, galleys or toilets should be removed, together with any extraneous material; if necessary, any corrosion-prevention treatment should be restored, and soaked or damaged insulation bags should be renewed. Debris may also be found in the compartments used for luggage and cargo.

4.2.2 Particular care is required when cleaning the cabins of pressurised aircraft since these tend to produce far more condensation than those of unpressurised aircraft. The moisture attracts dust and dirt and can quickly lead to corrosion of metal surfaces if the protective film is damaged. Dirt and grit could also lead to malfunction of the relief and vent valves used in the pressurising system and result in potentially dangerous cabin pressure conditions.

4.2.3 Plastic (polyester) foam may, under conditions where it is repeatedly moistened and dried, exude a mild acid capable of causing serious corrosion to aluminium alloys, particularly in poorly ventilated areas. Such plastic foam may have been used in the upholstery of seats and also in thermal/acoustic lining. If there is evidence of staining on such plastic it should be lifted to enable direct inspection of the adjacent seat frames or structure to be carried out. Appropriate action should be taken with the structure dependent upon the degree of attack, but, in any case, deterioration of the protective finish of the structure should be made good after thorough cleaning. Contaminated plastic foam should be renewed.

4.2.4 **Carriage of Livestock.** Very thorough internal cleaning is necessary after the carriage of livestock with particular attention being paid to the bilge areas. A disinfectant should be used recommended by the aircraft manufacturer. If any signs of vermin such as cockroaches, mice, etc., are found it may be necessary to contact the Health Authority to ascertain whether or not complete fumigation of the aircraft is necessary. Disinfestation is usually carried out by contractors who specialise in this work and complete ventilation of the aircraft is required afterwards for a period of several hours.

5 PARKED AIRCRAFT

All doors and windows should be closed, and covers and protective blanks should be fitted to aircraft which are to stand for extended periods; this equipment often forms part of the aircraft flight kit, and is designed to protect air intakes, ducts, vents, pitot heads, etc., from ingress of extraneous matter.

5.1 Covers, blanks and other protective devices are usually interlinked by cords or fitted with warning streamers, to ensure that they are all removed when the aircraft is prepared for flight.

5.2 On turbine-engine aircraft, the air intake and jet pipe blanking covers should be fitted at all times when the aircraft is not in use, and only removed for maintenance purposes or engine runs when special engine running guards might be necessary.

NOTE: Dependent on the length of time out of service, the engine may require rotating or inhibiting in accordance with the instructions in the engine Maintenance Manual.

5.3 When aircraft are to be 'parked out' for long periods, special precautions in addition to those normally given in the Maintenance Manual will be required, and the manufacturer's advice should be sought.

6 CLEANLINESS OF AIRFRAME STRUCTURES AND COMPONENTS The task of ensuring cleanliness should begin at the initial assembly stage, even though further work may be required before final assembly is completed.

NOTE: Boxes or special trays should always be used for small items, such as hand tools, AGS parts, etc., which are to be used on aircraft. Items left loose on the aircraft or adjacent trestles and stagings, may fall into the structure undetected and result in serious incidents when the aircraft is in service. Supervision should also ensure that refreshments (e.g. mineral-waters, tea, etc.) are not taken onto the aircraft as spillages of these are common causes of corrosion.

6.1 Components such as flying control surfaces, wings, tail units and boxed-in structures should be inspected progressively for cleanliness. When a structure is to be closed, either permanently or by a removable panel, inspection should verify that the compartment is entirely free of extraneous matter. The inside of structures or components should be inspected for cleanliness using the visual aids and methods outlined in Leaflet **AL/7-13** which gives guidance on the internal inspection of structures.

NOTE: If any part of the aircraft or engine control system is inside a closed-in compartment, consideration should be given to the requirements for duplicate inspections detailed in BCAR Chapter **A5-3**.

6.2 Large modifications, skin repairs, spar changes, etc., involve the production of large quantities of swarf, redundant parts and sealant; as much debris as possible should be removed as it is produced but a proper cleaning programme should also be implemented. A thorough inspection should be carried out on the internal structure before it is sealed. When the work involves fuel compartments the low pressure filters and booster pump screens should be checked after filling the tanks and again after initial engine runs.

6.3 The method of cleaning will be governed to some extent by size and structural features, but where possible the smaller structures such as ailerons, flaps, etc., should be rotated in all directions and shaken to dislodge any items which might be trapped or retained inside. In instances where normal cleaning is not possible, full use should be made of powerful vacuum cleaners with suitable adaptors. The use of an air jet as a cleaning medium is not recommended, since in the main it merely succeeds in distributing the extraneous matter over a wider area, sometimes into freshly cleaned compartments, and may drive unwanted particles into lap joints, bearings or electrical components. Compressed-air supplies frequently have a high moisture content and their use in inaccessible places could lead to corrosion.

6.4 The final inspection should be made when there is no likelihood of the compartment being re-opened, except of course for assembly purposes, test flight adjustments, etc., and when it is certain that no further operations are necessary which might introduce extraneous matter into the compartment. Compartments which are re-opened should be given further careful examination after the work which necessitated re-opening has been completed.

NOTE: Radiography is often used to examine boxed-in structures which have been progressively inspected for cleanliness but there may be small openings through which rivets or other small items could have gained access during work on adjacent structures.

6.5 On completion of the work, the engineer, having satisfied himself that the structure or component is perfectly clean, should witness its closing, and should endorse this inspection stage on the related history card.

6.6 Most aircraft have provision in the lower surfaces of the fuselage, wings, control surfaces and cowlings for the drainage of accumulated fluids, normally water. Some of these can be fully effective only when the particular structure is correctly positioned, e.g. stabilisers set to 'Aircraft nose-down trim position'. Engineers should therefore ensure that such drainage features are clear and effective when the aircraft is parked and at all times during maintenance.

7 **CLEANLINESS OF INSTALLATIONS AND SYSTEMS** Compartments into which engines, etc., are to be installed should be thoroughly cleaned immediately prior to the installation.

7.1 During the installation, all connections should be examined for cleanliness and freedom from obstruction immediately prior to fitting. Any items, such as nuts, bolts and washers, which are dropped should be recovered immediately, and not left until the installation is complete, since by that time the incident may be forgotten.

7.2 On completing the installation and immediately prior to closing the compartment, a careful final examination should be made of the compartment and installation, and of any associated cooling ducts, panels, controls, etc., to ensure complete freedom from loose articles and other matter.

7.3 Electrical multipin plugs and sockets, which are extensively used in engine installations, are particularly susceptible to trapping of fine swarf or dirt and this can easily lead to electrical faults of a type very difficult to trace. When not coupled up, all multipin plugs and sockets should be suitable protected.

7.4 On completion of engine installations, inspection should verify that engine bays are clean and free from loose articles. Care should also be taken to ensure that drains are clear so that no accumulations of fuel or oil can be trapped in cowlings. Where temporary covers or blanks are fitted to turbine engines, inspection should ensure that covers and blanks are of the correct type, are clean and have no loose parts which, if detached, could enter the air intakes.

7.5 The cleanliness of all systems such as hydraulic, pneumatic, fuel systems, etc., cannot be over-emphasised. This applies not only to the systems installed or being installed in the aircraft, but also to any related ground equipment (see paragraph 9).

NOTE: Guidance on cleanliness procedures for systems is given in the following Leaflets:

AL/3-13 Hose and Hose Assemblies,
AL/3-14 Installation of Rigid Pipes,
AL/3-17 Fuel Systems,
AL/3-19 Wheel Brakes,
AL/3-21 Hydraulic Systems,
AL/3-23 Pneumatic Systems.

7.5.1 Whenever an orifice or connection in a system has to be left open, protection against the entry of extraneous matter must be provided by means of blanks or specially-made covers.

7.5.2 The design of blanks and covers is very important. In many cases standard AGS blanks are used in the form of plugs or caps, but where a non-standard orifice is concerned, it is often necessary to make a special cover, in which case the design and choice of material must be carefully considered. Cotton and other textile materials should not be used because of danger of small particles of fluff entering the system; for the same reason, paper, wood or cork should be avoided, as small fragments of these materials may become detached and enter the system. Blanks should be so designed that it is impossible to connect up the system with a blank in position.

7.5.3 For short-term protection, especially in the case of a group of open connections such as a junction block, a polythene bag tied over the unit is often used. However, where plastics protective devices are concerned it is important that they are not used on systems the fluids of which may have a deleterious effect on the plastics material. The possibility of plastics slivers being cut by engagement with a metallic coupling and gaining entry into a component should also be considered.

7.5.4 Wear of control cables is accelerated very considerably where dirt clings to surplus grease or protective films on the surface of control cables where they pass through fibre, tufnol or ferrobestos fairleads and over pulleys. It is therefore important that lubricants or sticky protective films to which dirt might adhere are removed from cables in positions where wear may take place. This should be done by wiping with a cloth and not by washing with solvents or detergents.

8 CLEANLINESS OF COMPLETE AIRCRAFT Prior to the final inspection of a new or overhauled aircraft, inspection should verify that all boxed-in compartments have been checked for internal cleanliness.

8.1 Special attention should be given to compartments which have been opened for the purpose of adjustments; all sections through which engine and flying controls pass; the cockpit and associated equipment; the landing gear bays and the landing gear.

8.2 The cleanliness of warning notices, data plates, transparent covers of notices or indicators and instruments should also be checked.

8.3 On completion of the inspection, the engineer, having satisfied himself that the aircraft is clean, should endorse this inspection stage on the aircraft history sheet.

NOTE: It is good practise to carry out a final inspection for loose articles immediately following the ~~first~~ flight after construction or overhaul.

9 GROUND EQUIPMENT The cleanliness of ground equipment is important, particularly in respect of test rigs which are connected into an aircraft system.

9.1 The degree of filtration demanded in modern fuel and hydraulic systems is such that particles which are not visible to the naked eye are capable, if not filtered out, of causing malfunction of a component. It is, therefore, most important that the filtering arrangements included in the test rig should be at least equal to those in the system itself. Before using a rig the connections should be thoroughly cleaned and when not in use the hoses should be blanked off and properly stowed.

9.2 Mobile dispensers used for fuel, oil, de-icing fluids, etc., must be kept clean and all covers and blanks should be fitted when the equipment is not in use.

9.3 Regular checks should be made for water contamination in fuel dispensers and in bulk storage. Reference should be made to Leaflet **AL/3-17**, Fuel Systems, for guidance on the procedure for checking fuels for contamination.

BL/6-20

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BASIC

ENGINEERING PRACTICES AND PROCESSES

PAINT FINISHING OF METAL AIRCRAFT

1 INTRODUCTION This Leaflet gives guidance on the application of paint to metal aircraft and aircraft parts. The treatment of wooden structures is described in Leaflet **BL/6-25**, and the doping of fabric-covered aircraft is described in Leaflet **BL/6-26.** The term 'paint' is used in a general sense, and includes primers, varnishes, lacquers and enamels.

1.1 The primary reason for applying paint to an aircraft, is to protect the skin and structure from corrosion. Paint does this by excluding the atmosphere and liquids, and by providing a supply of chromate in the primer, which leaches out in the presence of moisture and inhibits corrosive action on the metal surface. The top coat of paint provides an abrasion and fluid resisting cover to the primer, and also the decorative finish.

1.2 The various paint schemes used, may be in accordance with British Standards or DTD specifications, or may be specially prepared by the manufacturer. No single scheme would be satisfactory for use on all parts of an aircraft, because of the particular requirements for the different areas and for the different metals to be treated. For example, engines are subjected to heat, and require the use of a heat-resistant paint; skin and structure in the lower fuselage may be in contact with condensation and spilled corrosive fluids, and may require more protection than other areas; magnesium always requires special treatment.

1.3 The effectiveness of a paint scheme depends on the proper preparation of the surface, the maintenance of suitable conditions in the paint shop, and the application of the paint in accordance with the relevant specifications.

2 PAINTING MATERIALS A paint scheme is broadly classified according to the type of material used in the finishing coats, but the undercoat or primer and, where applicable, the filler coats, may be manufactured from different materials. The various types of primers and finishing coats are discussed in the following paragraphs.

2.1 **Primers.** The main purpose of a primer coat is to provide adhesion to the metal surface. There are four main types of primers—synthetic, stoving, etch and epoxy—with wide variations within each type.

2.1.1 Synthetic and stoving primers are very similar, and are usually derived from resins and fatty acids. They are pigmented with chromates and produce a thick coating, but their resistance to fluids used in modern aircraft is not particularly good.

2.1.2 Etch primers contain resin, chromate, solvent, and phosphoric acid, and have very good adhesion on untreated sheet metals. Etch primers can often be applied directly to aluminium without any pre-treatment other than cleaning, but some sheet metals possess a surface to which the adhesion of etch primers may be unsatisfactory; such surfaces should be given an etching pre-treatment prior to application of the etch primer.

2.1.3 Epoxy primers are twin-pack materials (i.e. the two ingredients must be mixed before use) and often consist of an amine cured epoxy resin, with strontium chromate as an inhibitor. They have a very good resistance to fluids used in modern aircraft, and may also be used for stoving. They are generally used where maximum resistance to corrosion is required.

2.2 **Finishes.** There are many different types of finishes used on aircraft, the main types being cellulose, synthetic, stoving enamel, acrylic, epoxy and polyurethane. Other materials may be used in small areas where a particular property, such as resistance to battery acid, is required.

2.2.1 Cellulose and synthetic finishes were widely used in the past, mainly because they are easily applied, polished, and repaired. Cellulose nitrate is used as a tautening dope on aircraft fabric coverings, and is also used, to a certain extent, on wooden and metal aircraft. Synthetic finishing schemes such as BS X 28, are often used as an alternative to cellulose schemes on metal aircraft. As the thinners, primer and filler used in some synthetic finishing schemes are not always compatible with cellulose materials, care must be taken to use only the approved materials. Both cellulose and synthetic finishes have good adhesion and weathering properties, but are not usually resistant to fluids used in modern aircraft.

2.2.2 Stoving enamels generally have a high resistance to abrasion, and are used for power plant and airframe components which are not adversely affected by the stoving temperature. Stoving temperature is normally below 125°C (257°F), and does not have any deleterious effect on aluminium alloys, although stoving must be carried out at any early stage of manufacture, before the inclusion of heat-sensitive parts. One stoving scheme (DTD 56) calls for one or two coats of enamel to be stoved separately, without use of a primer, whilst with another scheme (BS X 31), a primer coat is used, which may be allowed to air dry and then both primer and top coats are stoved together.

2.2.3 Acrylic paint for use on aircraft, is usually developed from methyl methacrylate. This paint has good resistance to high temperatures, but has poor resistance to fluids; it is rapid drying and is a single-pack material.

2.2.4 Epoxy paint relies on a chemical reaction for curing, and is supplied in twin-pack form. It produces a hard glossy surface, and is resistant to aircraft fluids and acids. Its weathering properties are rather poor from the appearance point of view, and it tends to 'chalk' quickly.

2.2.5 Polyurethane paint is generally derived from polyester and di-isocyanate, and is supplied in twin-pack form. It dries to a hard glossy finish, and has exceptional weathering properties and resistance to organic fluids. One drawback to the use of polyurethane is its toxicity during spraying.

2.3 Whilst most painting materials are manufactured to meet DTD or BS specifications, individual manufacturers usually vary the chemical compositions to suit their own particular purposes, and although a number of paints may satisfy the requirements of a specification they may not be compatible with one another. Paints supplied by different manufacturers should not, therefore, be used in the same paint scheme, unless they are proved to be compatible.

3 SURFACE PREPARATION Paint and primer are rarely applied directly to a metal surface which has not received some form of anti-corrosive treatment, or surface preparation designed to assist adhesion of the paint. The type of pre-treatment applied depends on the type of metal, and on the corrosive conditions likely to be encountered in

service. DEF STAN 03-2/1 describes the methods which may be used for the cleaning and preparation of metal surfaces prior to painting. These methods, which are briefly described in the following paragraphs, consist essentially of de-greasing, followed by a pre-treatment such as chromating, etching, anodising and cadmium plating.

3.1 **De-greasing.** All new metal should be thoroughly de-greased, preferably using trichloroethylene, unless the metal is known to be adversely affected by chlorinated solvents (Leaflet **BL/6-8**). A liquid or vapour de-greasing bath may be used for small items, and heavily contaminated parts may be scrubbed with liquid solvent. Where an item is too large for de-greasing in a bath, its surface should be washed with rags dipped in solvent. It is important to use clean rags, and frequent changes of solvent, to prevent the spreading of contamination from one area to another.

NOTE: Trichloroethylene should not be used for hand cleaning, particularly in poorly ventilated areas, because of the health hazard to the operator.

3.2 **Aluminium.** Aluminium and its alloys should be anodised, or chemically pre-treated, using an approved etching or filming process.

3.2.1 Anodising is a process by which a thin film of oxide is formed on a surface by electrolysis (Leaflet **BL/7-1**). Anodising is often used on aluminium parts, since it is also a method of crack detection. Initially the anodic film is porous, and readily absorbs dirt and grease, but after a few days the film hardens, and provides a poor surface for paint to adhere to; thus it is important that the surface is primed as soon as possible after anodising.

3.2.2 A chromic/sulphuric acid etching treatment which may be applied to unanodised surfaces prior to painting, is described in DEF STAN 03-2/1. Other etching treatments, which are approved under DTD 900, are also available. The parts to be treated are usually immersed in a bath containing the specified pre-treatment chemicals at a pre-determined concentration. After immersion for a time governed by the particular process, the parts are removed and thoroughly washed in water.

3.2.3 A useful combined cleaning and pre-treatment agent, which complies with a DTD 900 specification, is available for use on assembled aircraft and parts. This agent is in the form of a paste which, when applied to the surface, removes corrosion products and grease, and also etches the surface. All traces of the paste must be washed off with water, using a brush to remove it from skin joints and rivet heads. After the surface has dried, it is usually given a filming treatment.

3.2.4 A number of filming pre-treatment processes are approved to DTD 900 specifications, and these are generally simple chemical processes, which may be applied by dipping, spraying or brushing. A filming treatment provides a chromate rich film on the surface, which gives good protection from corrosion and good paint adhesion; this treatment is particularly useful for repair work. On some aircraft surfaces, subsequent painting is unnecessary.

3.3 **Magnesium.** Magnesium rich alloys are very prone to corrosion, and should be treated in accordance with DTD 911. The treatment consists of dipping the parts in one of several types of chromating baths (Leaflet **BL/7-3**), and is usually followed by a surface sealing process (Leaflet **BL/7-5**). One method used by a particular aircraft manufacturer consists of an epoxy primer applied over the chromate film, followed by a nylon coating process, but other approved methods may be used.

3.4 **Titanium.** Titanium alloys have very good resistance to corrosion and do not require any special surface preparation. Solvent cleaning may be used, but care must be taken to ensure that the solvent will not cause hydrogen embrittlement or stress corrosion (see DEF STAN 03-2/1 and Leaflet **BL/6-8**). When titanium is to be painted, an etch primer is normally used.

3.5 **Steel.** Non-stainless steels are generally cadmium plated (Leaflet **BL/7-2**), but a phosphate dip or spray process is sometimes used instead. Where paint is to be applied directly to the steel, the surface to be painted should be mechanically cleaned by abrasive blasting or scouring. Stainless steels are not usually painted, but if they are, an etch primer should be used after cleaning.

3.6 **Glass Fibre.** Before glass fibre is painted, all traces of parting agent should be removed. Warm water will remove water soluble agents, but white spirit or methyl ethyl keytone (MEK) should be used for other types. The surface to be painted should then be rubbed down with fine emery cloth, and the dust should be removed using a lint-free cloth soaked in white spirit or MEK. An epoxy primer is generally used, the first coat being brushed on, to fill any pinholes which may be present.

3.7 **General Precautions.** Pre-treatment materials, solvents and their vapours, may have a deleterious effect on many components and materials used in an aircraft. Individual items can generally be treated away from parts which are liable to be affected, but when assemblies and complete aircraft are to be painted, precautions must be taken to prevent these liquids and vapours from coming into contact with any parts which are liable to be affected by them. All such parts, such as bearings, vents, drains, sealant, transparencies, aerials and insulators, must be masked, with plugs or adhesive tape and non-absorbent paper. Any parts in the area which do not require treatment should also be covered up, to guard against the effects of splashes, overspray and vapour. Masking material and plugs must be removed after the completion of painting.

3.7.1 Chemically pre-treated metal surfaces should, where possible, be primed immediately after the pre-treatment is completed, so as to avoid any risk of contamination. This procedure may be difficult to follow when a complete aircraft is being painted externally, and the use of a suitable covering is recommended. The surface should be covered after pre-treatment, and progressively uncovered as the primer is applied.

3.7.2 All traces of aqueous washes containing acids or alkalies should be thoroughly washed off, since their residues may affect the adhesion of the paint. Water used for washing or rinsing the surface after cleaning, pre-treatment, or 'flatting', should be blown off with clean oil-free compressed air, and drops of water should be prevented from drying on the surface.

3.7.3 When bare metal components are solvent-de-greased, the temperature of the surface may fall as a result of evaporation. In such instances the components should be allowed to stabilize at ambient temperature before painting is commenced.

4 PAINTING SCHEMES Apart from commercial considerations, the paint schemes applied to a particular aircraft will depend mainly on the corrosive fluids likely to be encountered. The aircraft manufacturer may specify schemes of his own, but often the schemes will be devised by the paint manufacturer and approved under DTD or BS specifications.

4.1 A painting scheme will normally contain full details concerning pre-treatment, materials to use, extent of thinning required, paint viscosity, and methods of application.

4.2 Pre-treatment, cleaning and painting involve a number of operations, and provision must be made to ensure that all specified operations, including previously carried out repairs and inspections, have been checked and certified by an inspector. Evidence that a particular operation has been carried out may not always be visually apparent, and could well be covered up by a subsequent operation.

4.3 The general procedures and precautions which should be taken when painting aircraft or aircraft parts, are outlined in paragraphs 5 to 12.

5 PAINTING CONDITIONS The evaporation of solvents, and the presence of spray dust, necessitate draught-free ventilation in paint shops. The temperature should, generally, be maintained between 15°C (60°F) and 25°C (77°F), and the humidity should be kept below 75%. However, some paints require closer control of the temperature; for example, DTD 5555 requires epoxy materials to be applied at a temperature above 18°C (65°F). In addition, for the application of etch primers, the humidity should not be less than 30%.

5.1 Ventilation may be provided by extractor fans and filtered air inlets, but the most satisfactory method of maintaining the required conditions is by filtering and cooling the incoming air to a sufficiently low temperature to remove excess moisture, then re-heating the air before passing it to the paint shop. The air conditioning system should be capable of changing the air in the paint shop every two minutes, and it is recommended that the paint shop should be kept at a slight positive pressure in order to prevent dust and draughts from entering through doors and windows.

5.2 The temperature and humidity should be checked at frequent intervals. A wet and dry bulb hygrometer is normally used for this purpose, the dry bulb indicating the actual temperature, and the difference between the dry and wet bulb readings being used, in conjunction with appropriate tables (Leaflet **BL/6-26**), to determine the humidity.

5.3 Cleanliness is essential to a good standard of paint finishing. Paint shop floors should be painted or sealed to prevent 'dusting', and should be swept at the end of each day so that the air is free from dust and contamination the following morning. Dried paint and spray dust present a serious fire hazard, and these should be removed at least once per week. When the paint shop is also used for pre-treatment and flatting, floor drainage should also be provided, so that rinsing water can be quickly removed and the floor can be dried before painting is commenced. Clean and dirty rags should be stored in separate bins.

5.4 The surface to be painted must be adequately illuminated, and portable flameproof lamps may be necessary when painting the undersurfaces of wings and fuselage. The provision of good scaffolding or working platforms will be necessary with large aircraft, so that the paint can be correctly applied (see paragraph 7).

5.5 When ideal painting conditions are not available, e.g. when it is necessary to paint in an open hangar, a reasonable paint finish may be obtained by observing a few simple precautions.

(a) Freedom from dust, draughts and condensation must be ensured.

(b) The item to be painted must be allowed to assume room temperature, and should be slightly warmed, if necessary, to prevent condensation.

(c) Care must be taken to prevent the surface being handled after it has been cleaned.

(d) All parts adjacent to the item to be painted which might be affected by the painting operation should be masked or covered with dust sheets.

5.5.1 Precautions must also be taken to prevent the possibility of fire, by removing naked lights and arcing electrical equipment; suitable fire-extinguishing equipment must be readily available.

5.6 **Regulations.** Because of the flammability of the materials used in painting, a number of laws and by-laws have been issued relating to the handling, storage and use of paints, particularly for cellulose and other low flash point materials generally. Reference should be made to the Cellulose Solution Regulations, The Petroleum Act, the General Sections of the Factories Acts, and any relevant local by-laws, for particulars regarding these materials, and the types of equipment to be used in paint shops.

6 PAINT PREPARATION

6.1 **Stirring.** Solid particles in a pigmented paint tend to settle whilst the paint is left standing, and, even when no sediment is apparent, the paint may vary in consistency from top to bottom. In order to ensure that consistent results are obtained, therefore, all paints, except glossy varnishes and lacquers, should be thoroughly stirred before use. The top of the can should be wiped clean before the lid is opened, and if a skin has formed on the paint, this should be removed by running a knife round the inside of the tin and lifting the skin out complete.

6.1.1 Mechanical stirring is preferable to hand stirring, and when the amount of work justifies it, a mechanical agitator or tumbler should be used.

6.1.2 For hand stirring, a flat bladed non-ferrous metal paddle should be used. This may be used with a spiral lifting action to circulate the solid particles throughout the paint.

6.1.3 When the sediment is hard, and difficult to disperse, the upper liquid should be poured into a separate container, and the sediment should then be stirred to a smooth paste, after this the poured-off liquid should be added gradually, until it is all returned to the original container.

6.2 **Thinning.** Paint manufacturers normally recommend the amount of thinners to be added to a paint, depending on the method of application. This basic mixture will often need to be adjusted to suit local conditions. To ensure satisfactory and consistent results, some manufacturers recommend that the viscosity of the thinned paint should be checked before application, by the use of a British Standards Type B flow cup (see BS 1733), the size of which depends on the viscosity range of the paint. The equipment consists of a cup and stand, a stop-watch, a thermometer and a suitable container. The temperature of the paint should be checked before the test to ensure that it is at approximately room temperature. A finger is placed under the calibrated orifice of the cup, and the cup is filled with the paint to be tested. The stop-watch is started simultaneously with removal of the finger from the cup orifice, and the time taken for the stream of paint to break into droplets, is noted. The viscosity is expressed as 'X seconds BS B3 or B4 cup', as appropriate. Thinners or paint are then added to bring the mixture to the required viscosity.

6.3 **Straining.** In many cases, paint manufacturers recommend that paint should be strained before use, to remove any extraneous matter which may have been picked up after the can is opened. Metal gauze of 60-120 mesh is the most suitable filter for this purpose, but paper or lint-free cloth or muslin may also be used. Metal gauze should be cleaned in solvent immediately after use, but other types of filters should be discarded. The paint should be allowed to flow through the filter, and not worked through with a brush. Some manufacturers recommend that all filters used with epoxy materials should be discarded after use, to avoid subsequent contamination.

6.4 **Twin-pack Materials.** Before mixing twin-pack materials, each of the constituents should be stirred separately. If thinning is required, only the approved thinner should be used; the proportions of the activator and base material must not be altered in an attempt to correct the viscosity. To avoid wastage, the amount mixed at any one time should be limited to the amount which can be used within the pot-life period. After mixing, the paint should be strained, then allowed to stand for a specified period before use, so that entrapped air may escape.

7 METHODS OF APPLICATION There are numerous methods of applying paint to a metal surface, including spraying, dipping, brushing and rolling. Exterior surfaces are generally sprayed, and small components may be sprayed, dipped or brushed.

7.1 **Conventional Spray.** This is the method used for the application of the majority of aircraft paints. It is a convenient, fast and easily controlled method of application, which gives consistent results The main disadvantage of this method is that the overspray may become a nuisance when other work is being carried out in the area. For small areas the use of spray guns with integral paint containers is satisfactory, but for larger areas pressure feed equipment is generally recommended.

7.2 **Airless Spray.** This method is particularly suitable for applying polyurethane paint, with which spray dust in the atmosphere must be kept to a minimum for health reasons. Since no air is used in atomising the paint, atmospheric pollution is minimised. The spraying equipment is more expensive, however, and the thickness of the paint film is difficult to control. Many paints cannot be applied by this method, either because their viscosity is unsuitable, or because their pigments are too coarse to pass through the spray orifice.

7.3 **Dipping.** This method can only be used with single-pack materials, since twin-pack materials have a limited pot life. When dipping is used, the smallest dip tank consistent with the size of the work should be used, and the viscosity of the paint should be checked frequently. Straining and stirring of paint used for dipping is most important, and the best method of stirring is by pump circulation, in which the paint is filtered before it is returned to the tank. Where small tanks are used, hand stirring should be carried out frequently, and the paint should be drained off and strained at appropriate intervals. Dip tanks should be provided with lids, in order to minimise contamination and evaporation of solvents when the tank is not in use.

7.4 **Brushing.** Brushing should only be used for small repairs, and for surfaces and corners which are not accessible for spraying.

7.5 **Rolling.** Where an open surface has to be painted, and other work is being carried out in the vicinity, use of a hand roller may be recommended. However, this method results in a thick layer of paint thus adding to the weight of the finish, and spraying is generally preferred.

8 PAINT SPRAYING Prior to the commencement of spraying, the effects of the paint on surrounding structure, aerials, sealants, sealed bearings, joints and grease nipples must be considered, and precautions must be taken to shield these parts if this has not already been done prior to pre-treatment (paragraph 3.7). Identification plates and windows should be blanked with greaseproof paper and masking tape, or with paper and soft soap, and any open pipes or intakes which are not to be painted should be suitably protected.

8.1 The paint should be applied as an even, wet coat, which will flow out smoothly. Spray dust and inadequate coverage will result from spraying too lightly, and 'runs' or 'sags' will result from spraying too heavily.

8.2 For conventional spraying, the air pressure at the spray gun should be maintained at 275 to 550 kN/m² (40 to 80 lbf/in²), to produce a satisfactory spray. When pressure feed equipment is used the air pressure at the container should be varied according to the viscosity of the paint, so that the paint reaches the gun in a gentle continuous flow; generally, a pressure of between 35 and 105 kN/m² (5 to 15 lbf/in²) should be used. For airless spraying, the pressures recommended by the equipment manufacturer should be used. In all cases allowance should be made for the loss of pressure between the gauge and gun, and some manufacturers provide tables showing the pressure drop which can be expected with hoses of various diameters and lengths.

8.3 A spray gun should be adjusted to give the required spray pattern (generally fan shaped for normal painting, and circular for 'spotting in'), and its operation should be checked briefly on scrap material. The gun should be held 15 to 25 cm (6 to 10 in) from, and at right angles to, the surface being painted, and each stroke should follow the contour of the surface. Each stroke of the gun should be straight, and the trigger should be released at the end of each sweep, the speed of movement being regulated to deposit an even wet coat. Each successive stroke of the gun should overlap the previous stroke, to keep a wet paint film and to provide an even overall coating.

8.4 When the paint scheme requires a number of coats to be applied, or a filler coat to be flatted, the drying times specified by the paint manufacturer should be observed. After flatting, the surface should be washed-off and allowed to dry before the next coat is applied.

8.5 Care of Equipment

8.5.1 Spray guns should be thoroughly cleaned immediately after use, using the solvent appropriate to the type of paint. Cleaning is particularly important after using twin-pack paints, since once these have cured they are very difficult to remove. It is recommended that, where possible, a spray gun is set aside solely for use with twin-pack materials. A gun should be cleaned by firstly flushing it through with solvent and then partially stripping it in order to remove any residual paint; stiff bristle or nylon brushes should be used for cleaning areas which are difficult to get at. The gun should not be immersed in solvent, since this would remove lubricant from the working parts and glands.

8.5.2 Paint hoses in pressure feed and airless spray systems should also be washed out with solvent immediately after use, since once the paint has dried it could flake off and cause blockages during future use.

8.5.3 The air compressor should be well maintained, and the air storage tank should be drained daily. Oil and water traps, and air filters, should be located adjacent to the coupling point for the spray equipment, so as to prevent contamination from the main supply and to be readily available for servicing. It is recommended that a record should be kept of all equipment servicing operations.

9 PAINTING FAULTS Provided that the metal surface is properly cleaned and pre-treated, and the paint is applied in accordance with the particular specification and the manufacturer's recommendations, the paint should adhere satisfactorily, and, when cured or dried, should not be easily removable by abrasion or washing. The main faults which can occur when applying a paint scheme to an aircraft, are described in the following paragraphs.

9.1 **Lifting of Paint.** Lifting of paint is usually the result of the lifting of the primer from the metal surface, and is usually first indicated by blistering, swelling, or wrinkling of the paint film. In the majority of cases this is caused by inefficient cleaning of the metal surface, but may result from the presence of corrosion under the primer. It may also be caused by incompatibility of the primer and the top coat.

9.2 **Poor Adhesion.** Poor adhesion may result from inadequate cleaning, pre-treatment or preparation of the paint, from application under adverse conditions, or from failure to comply with the drying requirement specified for the particular scheme.

9.3 **Spray Mottle.** Sometimes known as 'orange peel' or 'pebble', spray mottle may be caused by incorrect paint viscosity, air pressure, spray gun setting, or the distance the gun is held from the work.

9.4 **Spray Dust.** Spray dust is caused by the atomised particles of paint drying before reaching the surface being painted. The usual causes are excessive air pressure, the gun held too far from the surface, or incorrect gun setting.

9.5 **Runs and Sags.** Runs and sags result from too much paint being applied, so that the film of paint falls under its own weight before drying. The faults may be caused by over-thinning of the paint, incorrect adjustment of the gun, and, occasionally, by inadequate surface preparation.

9.6 **Blushing.** This is a fault most commonly experienced with cellulose materials, and appears as a 'clouding' or 'blooming' of the paint film. It may be caused by moisture in the air supply, excessive humidity, draughts, or sudden changes of temperature. The use of 'anti-chill' thinners is recommended when conditions are such that blushing can be expected. Blushing can often be removed by softening the paint surface with thinners, and drying in a warm, dry atmosphere.

10 PAINT REPAIRS After an aircraft has been in use for some time, the paintwork ages and hardens, and accumulates a layer of dirt, grease and polish, which may be very difficult to remove. In addition, greases and lubricants may contaminate the paint and be absorbed into crevices, sealing strips, soundproofing and furnishings. When it becomes necessary to repair chipped or blemished paintwork, to re-paint part of an aircraft after repairs have been carried out, or to apply new paint over the existing paintwork (e.g. lettering, stencilled instructions and crests), these contaminants must be removed in order to obtain satisfactory adhesion of the new paint.

10.1 Parts of an assembly which may be adversely affected by the materials used in re-painting, and parts not needing to be re-painted, should be blanked or masked (see also paragraph 3.7). Any absorbent material adjacent to the areas to be re-painted should, where possible, be removed to prevent contamination; where removal is not practicable, the part should be thoroughly de-greased and dried before painting is commenced.

10.2 When an area is re-painted after the removal of corrosion, or after repairs have been carried out, all debris, swarf, globules of sealant, and oil or dye penetrant which may have been used for non-destructive testing, should be cleaned off.

10.3 All loosely-adhering or chipped paint should be removed from the area to be re-painted using paint stripper or aluminium wire wool, and the area should be thoroughly cleaned with solvent to remove any contamination. Several applications of solvent may be required to remove contamination from older paintwork. The area should then be wet 'flatted' with fine emery cloth, to roughen the paint, to form a feathered edge where paint has been removed, and to remove pre-treatment from bare areas.

Residues should then be removed, by washing and by use of a brush in seams and crevices. The area should then be thoroughly dried, and allowed to assume room temperature before painting.

NOTES: (1) When emery cloth is used for rubbing down, care must be taken to avoid damage to clad or plated surfaces, and to exposed joints incorporating sealant and structural adhesives.

(2) When glass fibre surfaces are being prepared for re-painting, they must be thoroughly roughened in order to ensure adhesion of the paint.

10.4 When painting over existing paintwork, and when applying lettering, crests, or stencilled instructions, the compatibility of the new paint with the original paint should be checked. The surface to be painted should be lightly wiped over with a clean cloth moistened with the thinners appropriate to the paint to be applied; a reaction such as wrinkling or blistering of the old paint will indicate incompatibility, but light removal of pigment from the paint will indicate that the new paint is compatible, and that the cleaning operation was satisfactory.

10.5 After the surface to be painted has been cleaned and prepared, the original paint scheme should be restored, and any dry spray edges should be polished to blend in with the existing paintwork. Materials, drying times and painting precautions, should be the same as those specified for the original paint scheme, except that if a filler coat is used it must be of the same material as the top coat. For example, the original filler may have been synthetic and the top coat cellulose, but for the repair both filler and top coat must be cellulose.

10.6 Any masking or plugs which have been fitted must be removed after the paint has dried.

11 **PAINT STRIPPING** When re-finishing an aircraft, it is usual to strip back the paint to the bare metal and to re-apply the desired paint scheme. The ease with which the paint can be removed depends on the paint type, its thickness and its age, but approved proprietary paint strippers are available, which are specially prepared for removing particular types of paint. Epoxy and polyurethane paints are the most difficult to remove.

11.1 Some paint strippers may have an adverse effect upon structural bonding adhesives, some may affect the adhesives used for the attachment of sealing and chafing strips, and others may result in hydrogen embrittlement of high strength structural steel parts. Only the approved paint stripper should be used, and precautions should be taken to prevent its contact with susceptible materials, by masking or plugging. An inspection should be carried out after stripping, to ensure that these precautions were effective. Vents and drains should also be plugged, to prevent the entry of paint stripper, washing water and paint particles.

11.2 The paint stripper should be applied freely to the surface of the paint, and left until the paint has softened; the paint can then be removed with a wooden scraper. Residues should be washed off with water, and care should be taken to remove all paint and paint remover from seams and crevices, using a short-bristled nylon brush. When the paint is particularly thick it may be necessary to apply the paint stripper a second time after the initial softened coat has been removed. The removal of debris after stripping is most important, since the softened paint could harden in piano wire hinges, control rod bearings and other moving parts, and present a serious hazard. After the surface has been washed, it should be wiped with a rag soaked in solvent, to remove the final traces of paint.

11.3 Some paint schemes involve the use of an epoxy primer, followed by an air-drying synthetic or acrylic finish, and, provided that the primer is in a satisfactory condition, the top coat can be selectively stripped, using a specially formulated paint remover. This paint remover is applied in the normal way, but a rubber scraper should be used to prevent damage to the primer. After removal of the top coat, the primer should be thoroughly washed with solvent to remove any contaminants, and the finish should be re-applied.

12 HEALTH HAZARDS As stated in paragraph 5, a paint shop must be well ventilated, to remove solvents and spray dust which may present a health hazard. Solvents have an irritating effect on the skin and eyes, and may be toxic. Constant contact with solvents may dry out the skin and cause dermatitis, and the use of a barrier cream is recommended. Inhalation of solvent vapours and spray dust should be avoided, and a face mask should be worn in areas where concentrations may be high.

12.1 Polyurethane spray dust can cause chest irritation if inhaled, and this is the main reason for using an airless spray to apply this material. When polyurethane is applied by conventional spray, it is recommended that a full face mask with an independent air supply is worn.

12.2 When mixing twin-pack materials, care should be taken to avoid splashing the skin or eyes. If this does occur, the material must immediately be washed off with running water.

12.3 When using paint strippers, it is advisable to wear goggles and PVC gloves, and all contact between the stripper and the skin should be avoided.

13 STORAGE Paints should be kept at room temperature, in a dry store. Containers should be marked with the date of receipt, and used in strict rotation; they should not be held longer than their stated storage life. Unpigmented glossy material should be disturbed as little as possible, so that any sediment may settle at the bottom of the can, but cans containing other materials should be inverted at frequent intervals, to reduce the settlement of pigments.

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BASIC

ENGINEERING PRACTICES AND PROCESSES

THREAD INSERTS

1 INTRODUCTION This Leaflet gives guidance on the design, fitting and removal of thread inserts, which are frequently used in threaded attachment holes of airframe and engine components.

2 GENERAL Thread inserts are usually fitted in light alloy materials such as aluminium, magnesium, bronze and brass, to provide a larger diameter thread and thus a stronger attachment point for bolts or studs. In addition, thread inserts are often specified for repair work, where the original thread has been damaged and fitment of an insert enables the original size bolts to be used without affecting interchangeability.

2.1 There are basically two types of inserts available. One is known as a wire thread insert and is made from specially formed wire wound into a helical coil, and the other is known as a thin wall insert and is made from a tube with threads formed on both the inside and the outside surfaces. Both types are manufactured in a variety of materials and finishes, and may have either plain or self-locking threads.

2.2 Thread inserts should only be used when specified in the relevant manual, drawing or repair scheme and care should be taken to ensure that the correct insert is used. Inserts should be installed strictly in accordance with the manufacturer's instructions, since there may be slight variations between inserts conforming to the same specifications.

2.3 Because of the basic differences between wire thread and thin wall inserts, these are dealt with separately in paragraphs 3 and 4 respectively.

3 WIRE THREAD INSERTS A wire thread insert (Figure 1) is a precision formed wire of diamond section (usually of spring steel or stainless steel) wound into a helical coil, the cross-section of the wire forming a thread both inside and outside the coil. When correctly installed the coil provides a thread which conforms to a particular British Standard or other specification, with a good surface finish and the inherent flexibility to compensate to some degree for any errors of form in the engaging bolt or screw; the radial pressure attained in fitting the insert produces good self-locking characteristics, and the possibility of thread failure from vibration, fatigue, corrosion or seizure is reduced. Wire thread inserts have a tang at the inner end to facilitate fitting with a special tool; this tang may be removed after installation if required.

3.1 **Identification.** Wire thread inserts manufactured in the UK generally conform to SBAC(AS) standards, those with BA, BSF and BSP threads being identified by having the tang painted yellow. This range of inserts is supplied in five standard lengths of approximately 1, 1½, 2, 2½ and 3 times the nominal thread diameter. Wire thread inserts manufactured to different standards are often identified in a different way, and reference should be made to the particular manufacturer's literature for details concerning identification.

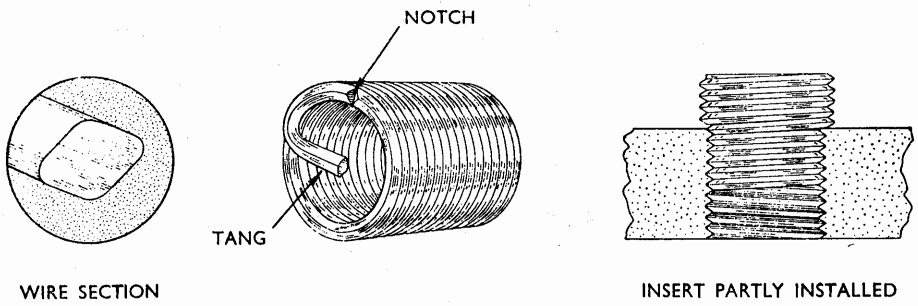


Figure 1 TYPICAL WIRE THREAD INSERT

3.1.1 In its free state an insert is shorter and has a larger diameter than when installed, and, since the Parts Lists refer to the installed dimensions, identification by measurement is not practical.

3.2 **Installation.** Since the internal and external threads on a thread insert have the same number of threads per inch, and the internal thread is designed to be of standard size, then a special size tap is required to cut the threads into which the insert is fitted. These special taps and checking gauges are provided by the insert manufacturers. Installation procedures, which comprise drilling and tapping the hole, thread gauging, insertion of the insert and removal of the tang, are outlined in paragraphs 3.2.1 to 3.2.5.

3.2.1 **Drilling.** The hole for the insert should be drilled to the diameter and depth specified in tables supplied by the insert manufacturer, the depth being calculated from the fitted length of the insert, plus the thread runout, plus a half pitch gap at each end of the insert (see Figure 2). Care should be taken to ensure that the hole is drilled in the correct location and square to the surface, and that all swarf is removed before tapping. In some cases, particularly when the hole is near to the edge of the component, it may be necessary to check for cracks by a specified non-destructive testing method.

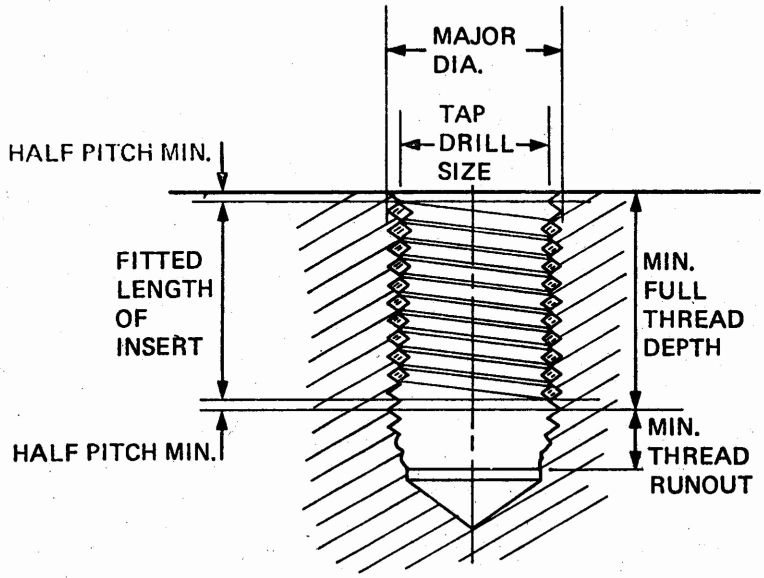


Figure 2 **WIRE THREAD INSERT HOLE DATA**

3.2.2 **Thread Tapping.** The thread should be tapped with a special tap provided by the insert manufacturer, a straight-fluted tap being used for hand tapping and a spiral-fluted tap for machine tapping where this is possible. Normal workshop practices should be used for tapping, with special emphasis on cutting the thread coaxially with the hole. Lubricant should be used according to the type of metal being cut, e.g. a light mineral oil is generally recommended for tapping light alloys.

3.2.3 **Thread Gauging.** After the insert thread has been cut it should be cleaned of all swarf and foreign matter. The thread should then be checked with a special GO/NO GO plug gauge provided by the insert manufacturer to ensure that the thread is satisfactory. Any thread imperfections indicated by tightness of the GO gauge should be removed by further use of the original tap or, if this is ineffective, by use of a new tap.

3.2.4 **Fitting the Insert.** An insert should be screwed into the tapped hole by the use of either an inserting key or an inserting tool of the prewind type (see Figure 3), depending upon which is recommended for the particular insert. A different sized key or tool is provided for each size of insert.

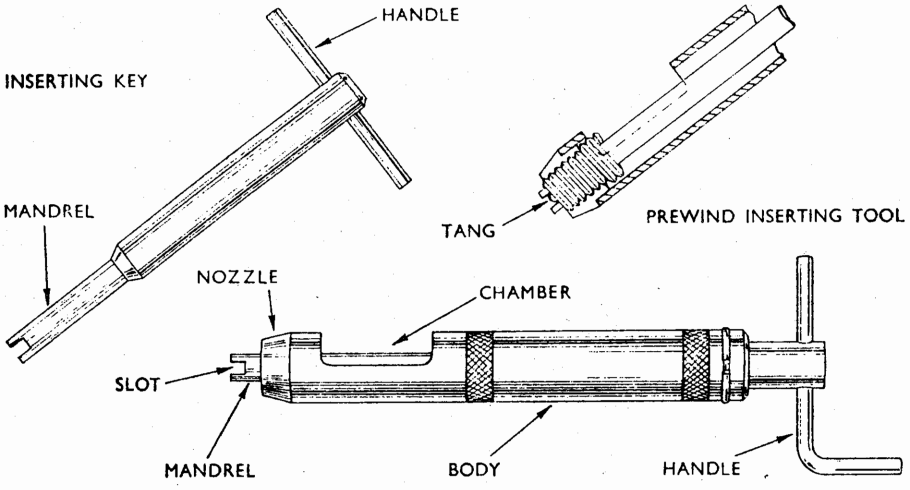


Figure 3 INSERTING KEY AND PREWIND INSERTING TOOL

(a) The inserting key should be used by sliding the insert onto it so that the tang is engaged in the driving slot at its forward end; the assembly should then be applied to the tapped hole, compressing the insert downwards with the thumb and forefinger of one hand while turning the key with the other hand; no downward pressure should be applied on the key. The insert will wind into the thread and should be installed so that the outer end of the insert is at least half a pitch below the surface of the component.

(b) When a prewind tool is used the insert should be placed in the chamber with the tang towards the nozzle and the mandrel pushed forward through the insert to engage the tang in the slot. The mandrel should be rotated clockwise and pushed gently forward to engage the insert coil in the nozzle threads, rotation being continued until the insert is about to emerge from the outer end of the nozzle. The tool should then be placed squarely over the tapped hole and the handle rotated to transfer the insert from the tool into the tapped hole; no forward pressure should be used.

(c) Unless otherwise stated, inserts should be installed so that the outer coil is at least half a pitch below the component surface.

(d) Absolute cleanliness of the tapped hole and freedom from burrs is essential to prevent distortion of an insert. When jointing compound or anti-corrosive compounds are specified, they should be applied strictly according to the relevant instructions and surplus compound should be removed as specified after installing the insert.

3.2.5 **Removal of the Tang.** It is not always necessary to remove the tang of a wire thread insert, but removal may be specified in some cases for screw clearance or product appearance, both in blind holes and through holes. A tang in a through hole is removed by use of the inserting key used as a punch, with the tang outside the engaging slot, or by use of a special punch (Figure 4). A sharp blow with a hammer on the key or punch will fracture the wire at the notch where the tang joins the coil. To remove the tang from an insert fitted in a blind hole, long round-nosed pliers are required; the tang should be bent backwards and forwards through the insert bore until it fractures at the notch and can be removed.

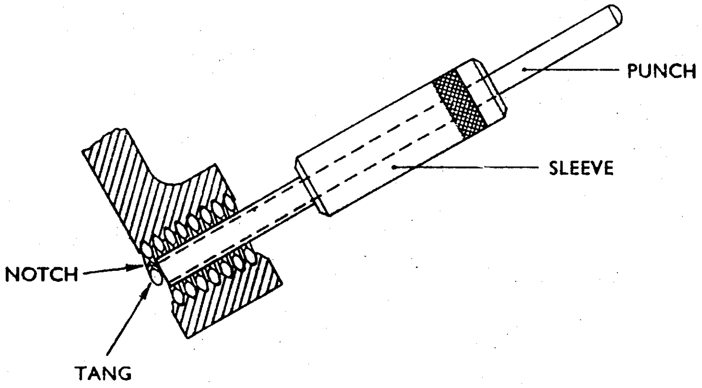


Figure 4 TANG BREAK-OFF PUNCH

3.3 **Removal of Inserts.** Under normal circumstances, particularly when fitting instructions have been carefully carried out, the removal of inserts should be unnecessary. However, if an insert has to be removed because of bad fitting, damage or wear, this can be done by bending the top coil inwards to form a rough tang and unscrewing the insert with the insertion tool or a pair of pliers. Some manufacturers recommend the use of a tapered left-hand tap of appropriate size, which grips the top coils internally and unwinds the insert when rotated. Other manufacturers provide a range of extractor tools which are fitted with hardened and tempered blades (Figure 5); the blade will bite into the inner surface of the insert, which can then be unscrewed. After removal of an insert, the threads in the hole should be carefully examined for damage before fitting a new insert.

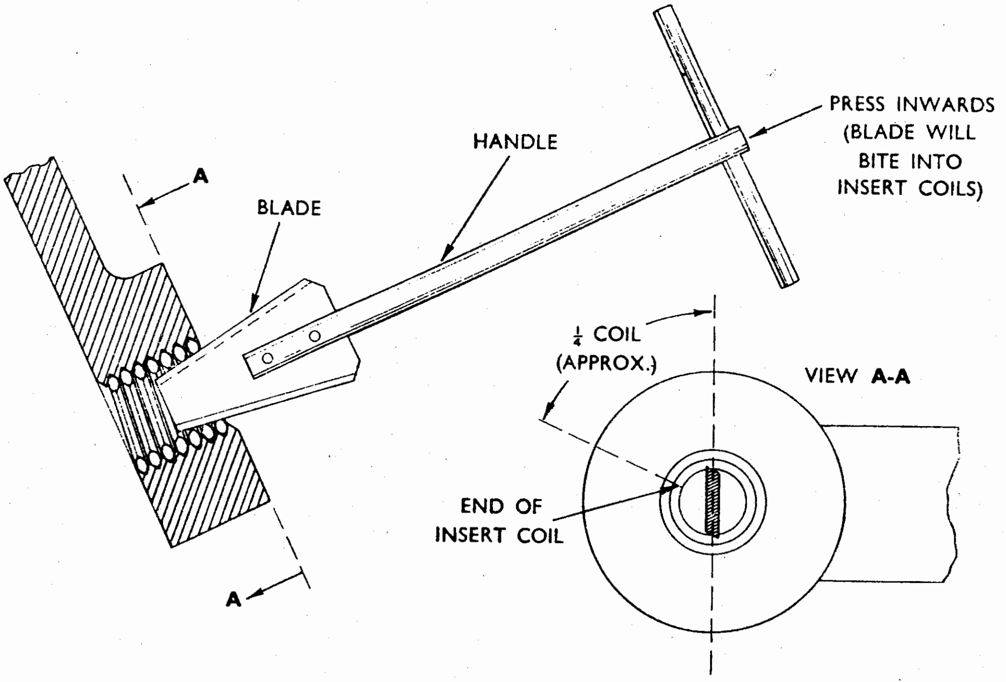


Figure 5 TYPICAL EXTRACTOR TOOL

4 THIN WALL INSERTS A thin wall insert (Figure 6), comprises a tube with threads formed on its internal and external surfaces. These inserts do not exert any outward radial pressure on the threaded holes into which they fit, and are locked in position by driving a number of pre-assembled keys into slots round the outer surface of the insert, by swaging a knurled outer portion into a counterbore, or by fitting a separate serrated locking ring after the insert is installed. Inserts are supplied in a variety of types, materials and finishes, and the internal thread may be non-locking, or self-locking by means of a deformed thread or nylon insert; inserts are identified and ordered by manufacturer's part numbers.

4.1 **Key-locked Inserts**

4.1.1 **Drilling and Tapping.** Tables provided by the manufacturer give details of the drill diameters, hole depths and taps to be used to form the threaded holes for each size of insert; with key-locked inserts the outer edges of the holes should also be countersunk to a specified depth. When preparing the threaded holes, the general precautions outlined in paragraph 3.2.1 and 3.2.2 should be carefully followed.

4.1.2 **Installation.** The inserts may be screwed in by hand or by the use of an installation tool (Figure 7), until the keys butt against the component surface, this being the correct installed depth. The keys are then driven into place by hammer blows or a press, using the installation tool as a punch. When the keys are flush with the top of the insert, installation is complete.

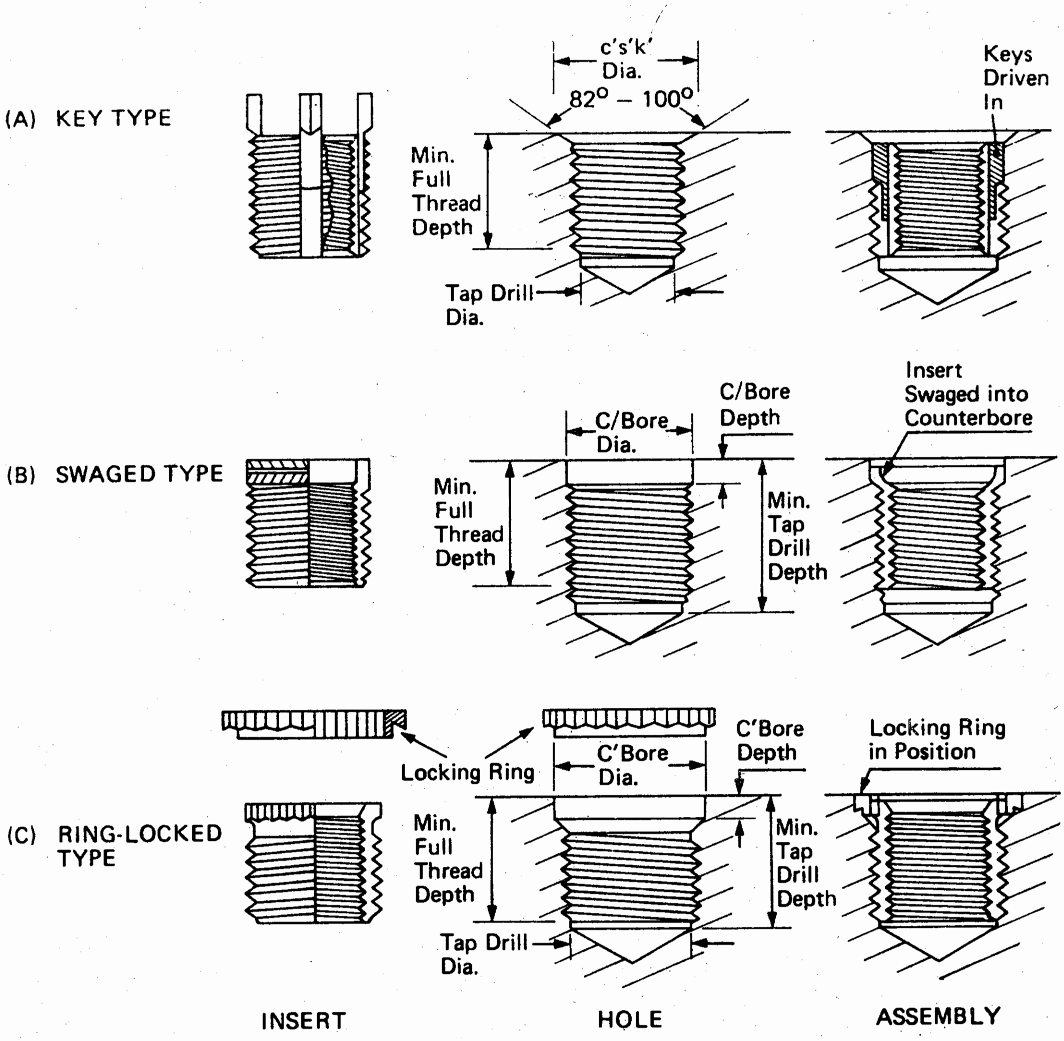


Figure 6 THIN WALL INSERTS

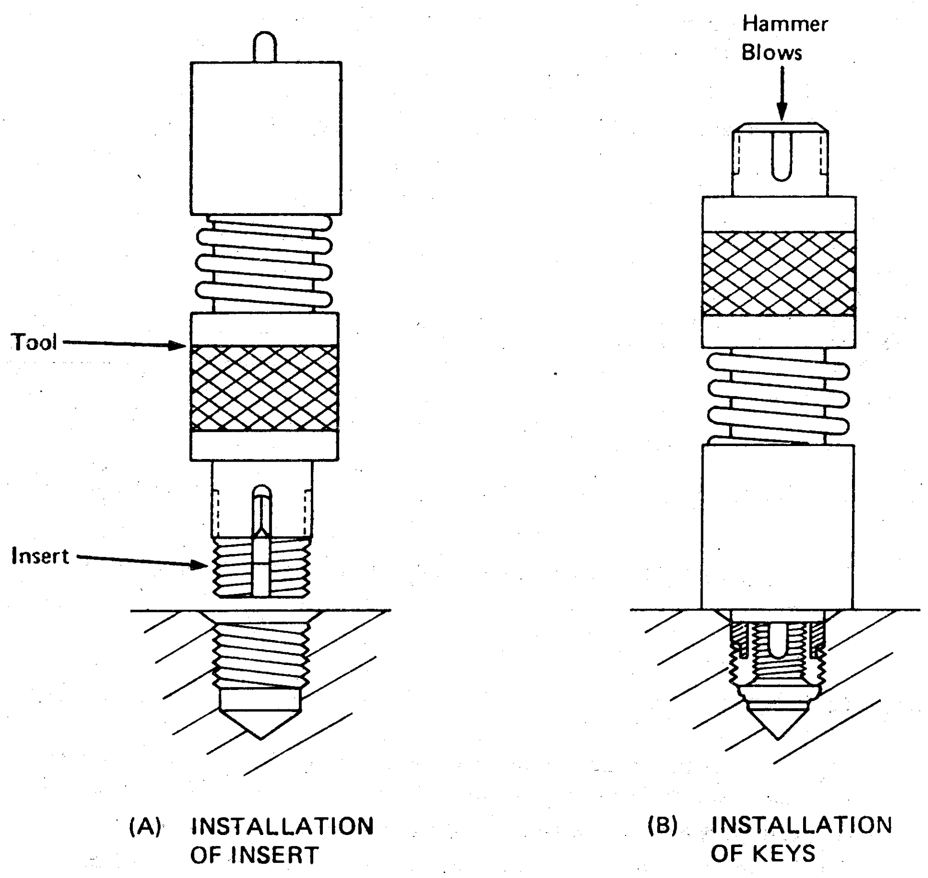
4.1.3 **Removal.** Should it become necessary to remove a key-locked insert, this may be done as follows:—

(a) Drill out the insert to a diameter equal to the distance between two opposing key slots and to the depth of the key heads.

(b) Deflect the keys inward with a punch and break them off.

(c) Remove the insert with a standard extractor.

(d) After removal of the insert, the threads on the part should be inspected for damage. If the threads are undamaged a replacement insert of the same size may be fitted, but care should be taken to ensure that the keys are located in different places from the original keys.



(A) INSTALLATION OF INSERT

(B) INSTALLATION OF KEYS

Figure 7 INSTALLATION TOOL (KEY-LOCKED INSERTS)

4.2 Swaged Inserts

4.2.1 **Drilling and Tapping.** The holes for these inserts must be drilled with a special drill and counterboring tool supplied by the insert manufacturer for each size of insert. Holes should be drilled so that the counterbore depth is as specified in the relevant tables for the insert concerned, and the precautions outlined in paragraph 3.2.1. should be observed. The hole should be tapped using a tap of the relevant size, to the drawing requirements. All swarf should then be removed and the thread inspected.

NOTE: The drill/counterboring tool has a drill portion of sufficient length to permit regrinding a number of times before the minimum drilling depth is reached. It is important to check the length of the drill portion when drilling blind holes, to prevent breaking through the lower surface.

4.2.2 **Installation.** A special insertion tool is used for installing these inserts (Figure 8). The insert internal thread is deformed in such a way as to permit the insertion of the hexagonal driver (unified-threads), or has three axial grooves (metric threads), so that the insert can be rotated. The insert should be screwed into the threaded hole until it is the specified distance below the component surface. The insert is swaged by hammer blows on the end of the tool and installation is complete when the stop washer face contacts the component surface.

NOTE: Insertion tools for the larger sizes of inserts are power operated.

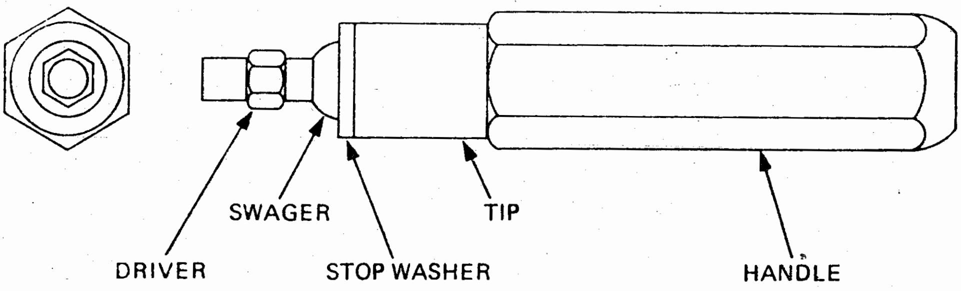


Figure 8 TYPICAL INSERTION TOOL (SWAGED INSERTS)

4.2.3 **Removal.** Where necessary, swaged inserts may be removed in the following way:—

(a) Using a drill of the relevant diameter, drill the insert to the depth specified in the manufacturer's tables to separate the swaged portion of the insert.

(b) Carefully remove the swaged portion with a scriber or similar tool.

(c) Using the installation tool, unscrew and remove the threaded part of the insert.

(d) The thread and counterbore should be checked for size and damage. If satisfactory, a replacement insert of the same size may be fitted.

4.3 Ring-locked Inserts

4.3.1 **Drilling and Tapping.** The holes for these inserts should be drilled and counterbored in a similar way to those for swaged inserts. Similar drilling/counterboring tools should be used and the dimensions of the holes should conform to those listed in the tables provided by the manufacturer; the precautions outlined in paragraph 3.2.1 should also be observed. The holes should be tapped using a tap of the specified size, to drawing requirements. All swarf should then be removed and the thread should be inspected.

4.3.2 **Installation.** A special tool is used to install these inserts (Figure 9), the bore having serrations which fit the serrations of one particular size of insert. The insert should be screwed into the prepared hole until its upper surface is 0·25 to 0·5 mm (0·010 to 0·020 in) below the component surface. The locking ring should then be placed over the insert, so that the inner serrations engage those of the insert. Installation is completed by fitting the drive tool (Figure 9) into the locking ring (ensuring that it is square to the component surface), and hammering the end of the tool so that the outer serrations on the locking ring bite into the material surrounding the counterbore. The installed locking ring should be flush with the surface of the component.

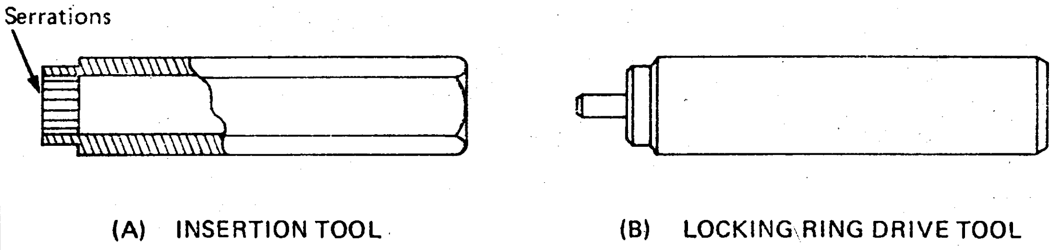


Figure 9 TOOLS FOR RING-LOCKED INSERTS

4.3.3 **Removal.** When necessary, ring-locked inserts may be removed in the following way:—

(a) Drill out the insert to the depth of the counterbore, using a drill of the diameter specified in the tables provided by the manufacturer.

(b) Remove the insert by use of a standard stud extractor or a left-hand threaded tap of suitable size.

(c) If necessary, use a punch to separate and remove the remaining portion of the locking ring.

(d) Provided the hole thread is not damaged, a replacement insert and locking ring of the same size may be fitted.

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BASIC

ENGINEERING PRACTICES AND PROCESSES

CABLE—SPLICING AND SWAGING

1 INTRODUCTION This Leaflet gives guidance on the recommended procedures for splicing and swaging the cable used in aircraft control systems. The methods by which completed cable assemblies may be identified are described in Leaflet **BL/2-1.**

2 CABLE

2.1 The cable used in British aircraft control systems is preformed, and complies with British Standards (BS) Specifications W9, W11, W12 or W13, or with American Specification MIL-W-83420 (formerly MIL-W-1511 and MIL-L-5424). Preforming is a process in which each individual strand is formed into the shape it will take up in the completed cable. This makes the cable more flexible, easier to splice, and more resistant to kinking. Preformed cable will not unravel; also, if a wire in a preformed cable should break, the broken wire will lie flat, and, therefore, be less likely to prevent the cable from passing round pulleys and through fairleads.

2.2 The construction of a cable is determined by the number of strands it contains, and by the number of individual wires in each strand. For example, a cable designated 7×19, consists of 7 strands, each strand containing 19 wires. Wires are wound round a king wire in one or two layers, and strands are generally wound round a core strand in one layer, the direction of winding being stipulated in the relevant specification. The two most common forms of construction are illustrated in Figure 1, and the construction of the various sizes of cable is included in Tables 1 and 2.

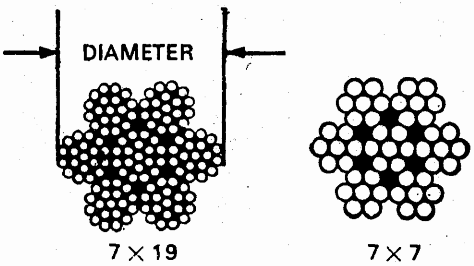


Figure 1 STEEL WIRE CABLE

2.3 Preformed cable is manufactured from either galvanised carbon steel (BS W9 and W12, and American Standard MIL-W-83420, Composition A) or corrosion resisting steel (BS W11 and W13, and American Standard MIL-W-83420, Composition B), and is impregnated with friction preventive lubricant during manufacture. The American specification also provides for a range of nylon-covered cable. Non-preformed single strand cable may be found on some aircraft, but will normally only be used for relatively unimportant systems. Tables 1 and 2 list the more common sizes of cable according to the method of classification.

TABLE 1
CABLE CLASSIFIED BY BREAKING LOAD IN HUNDREDWEIGHTS

Minimum breaking load (cwtf)	Construction	Maximum diameter of cable (in)	
		BS W9	BS W11
3	4×7	0·065	0·065
5	7×7	0·08	0·08
10	7×14	0·12	0·12
15	7×19	0·15	0·15
20	7×19	0·16	0·16
25	7×19	0·18	0·18
30	7×19	—	0·21
35	7×19	0·21	—
40	7×19	—	0·24
45	7×19	0·24	—
55	7×19	—	0·27
60	7×19	0·27	—

TABLE 2
CABLE CLASSIFIED BY NOMINAL DIAMETER

Nominal diameter of cable		Construction	Minimum breaking load*		
			Carbon steel	CR steel	
(in)	(mm)		MIL-W-83420 type A and BS W12 (lbf)	MIL-W-83420 type B (lbf)	BS W13 (kN)
1/16	1·6	7×7†	480	480	2·15
3/32	2·4	7×7†‡	920	920	4·10
1/8	3·2	7×19	2000	1760	7·85
5/32	4·0	7×19	2800	2400	10·70
3/16	4·8	7×19	4200	3700	16·50
7/32	5·6	7×19	5600	5000	22·25
1/4	6·4	7×19	7000	6400	28·40

* The breaking loads listed are those quoted in the current issues of the specifications. 1 lbf = 4·448 N.
† $\frac{1}{16}$ in and $\frac{3}{32}$ in cable to specification MIL-W-83420 may also be of 7 × 19 construction.
‡ 2·4 mm cable to BS W13 may also be of 7 × 19 construction.

3 HANDLING OF CABLE Cable may be permanently damaged, or its working life may be considerably curtailed, by careless handling and unwinding. Care is necessary to prevent the cable from forming itself into a loop, which, if pulled tight, could produce a kink. A kink is shown by the core strand leaving the centre of the rope, and lying between the outer strands or protruding in the form of a small loop.

3.1 Cable should always be stored on suitably designed reels. The diameter of the reel barrel should be at least forty times the cable diameter. British Standards stipulate that reels should be made from a wood which will not corrode the cable, and that interior surfaces should be lined with an inert waterproof material. Precautions should also be taken to protect the cable from grit and moisture, and from damage in transit.

3.2 To remove cable from a reel, a spindle should be placed through the centre of the reel, and supported in a suitable stand. Cable may then be removed by pulling the free end in line with the reel, allowing the reel to rotate. Cable should not be unwound by paying off loose coils, or by pulling the cable away from a stationary reel laid on its side.

3.3 When a long length of cable has been cut from a reel, and it is necessary to coil the cut piece, the coil diameter should be at least 50 times the cable diameter, with a minimum diameter of 150 mm (6 in). Care must be taken to prevent dust, grit and moisture, from coming into contact with the coiled cable.

3.4 The ends of stored cable are whipped to prevent fraying, and, if a length has been cut from the reel, the remaining free end should be whipped.

3.5 When a coil is being unwound, the coil should be rotated so that the cable is paid out in a straight line.

3.6 **Cutting Cable.** Cable should always be cut using mechanical methods. Cable cutters or heavy duty pliers should normally be used, but alternatively, the cable may be laid on an anvil and cut with a sharp chisel and hammer blows. Cable should not be cut by flame. If a non-preformed cable is being cut, it should be whipped with waxed cord on both sides of the cut, prior to being cut. With a preformed cable it will normally only be necessary to bind the cable temporarily with masking tape.

4 SWAGING Swaging is an operation in which a metallic end fitting is secured to the end of a cable by plastic deformation of the hollow shank of the end fitting. The end of the cable is inserted into the hollow shank of the fitting, and the shank is then squeezed in a swaging machine, so that it grips the cable. This is the most satisfactory method of attaching an end fitting to a cable, and it can be expected to provide a cable assembly at least as strong as the cable itself. Most transport aircraft, and a large number of light aircraft, use control cables manufactured in this way.

4.1 Manufacturers of cable assemblies normally swage with rotary machines. In these machines the shank of the end fitting is placed between suitable dies, and is subjected to a series of forming blows, which reduce the shank diameter, and lock the fitting to the cable.

4.2 Swaging may also be carried out on a portable swaging machine, which squeezes the shank of the end fitting between dies. The use of a portable swaging machine is discussed in paragraph 5.

4.3 A range of swaged end fittings is covered by BS specifications, but some older types of aircraft may be fitted with cable assemblies containing components complying with SBAC AS specifications which are now obsolete. When it is necessary to make up control cables for these aircraft, approval may be granted for the use of equivalent BS parts, but the complete cable control run may have to be changed.

4.4 BS specifications provide a range of fittings which prevent incorrect assembly of control cables. Turnbarrels and tension rods are designed to connect to screwed end and tapped end swaged fittings respectively. For each size of cable two alternative sizes of end fittings are available, and each size is provided with either a left or right hand thread. Swaged fittings can thus be arranged to ensure that a control run cannot be incorrectly assembled.

5 PORTABLE SWAGING MACHINES Although unserviceable cables are usually replaced by cables which have been manufactured, pre-stretched and proof loaded in accordance with an approved drawing, and which have been supplied by the aircraft manufacturer, occasions may arise when such a cable is not available, and it is necessary to make up a cable assembly locally. Provided that the process is permitted, and that the appropriate drawings or instructions are available, end fittings may be swaged onto a cable using a hand-operated machine such as the one illustrated in Figure 2.

NOTE: The proficiency of a person engaged in the manufacture of locally made cable assemblies, should be established by trial swagings on test cables, which should be tested to the satisfaction of the supervising inspector. The effectiveness of subsequent swaging operations should be checked periodically, by selecting a representative sample, and subjecting it to a tensile test to destruction.

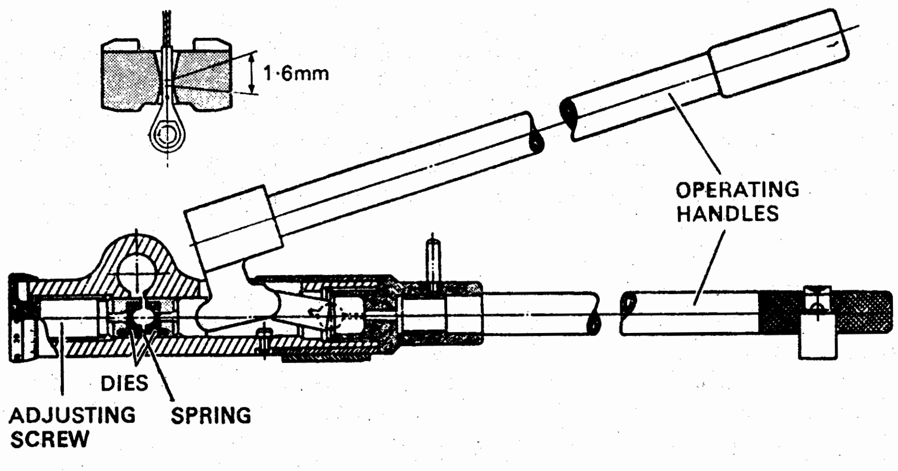


Figure 2 PORTABLE SWAGING MACHINE

5.1 A portable swaging machine is supplied with sets of dies for swaging various types of fittings to cables of appropriate size, and with gauges for checking shank diameter after swaging. It is normally mounted on a wooden block, and should be used on a low bench so that adequate pressure can be applied to the lever. An adjusting screw in the head of the machine alters the amount of squeeze applied, and a graduated scale permits accurate setting.

5.2 **Swaging Procedure.** The procedure outlined below is applicable when a machine of the type illustrated in Figure 2 is used. Where use of a different type of machine is authorised, the procedure is similar, except for the setting and operation of the machine, which in all cases should be in accordance with the manufacturer's instructions.

(a) Ensure that the new cable is the correct size, by using a suitable gauge, or by measuring the diameter as indicated in Figure 1.

(b) Cut the cable to the length specified on the drawing (see paragraph 3.6), and ensure that the ends are clean and square.

NOTE: Swaging elongates the end fitting, and an allowance for this must be made when cutting the cable. The allowance to be made should be stated on the appropriate drawing or specification.

(c) Select the appropriate end fitting, and clean it by immersing it in solvent; then shake, and wipe dry.

(d) Assemble the end fitting to drawing requirements. With drilled-through fittings, the cable end must pass the inspection hole, but be clear of the locking wire hole. For fittings with a blind hole, the cable must bottom in the hole. Bottoming may be checked by marking the cable with paint, at a distance from the end equal to the depth of the hole, and by ensuring that the paint mark reaches the fitting when the cable is inserted. When the cable and the fitting are correctly assembled, they should both be lightly lubricated.

(e) Fit the dies for the particular end fitting in the swaging machine, open the handles of the machine, and unscrew the adjuster until the end fitting can be placed in the dies. With the end fitting centred in the die recess, close the handles fully, and screw in the adjuster until the dies grip the fitting. Open the handles, and tighten the adjuster by the amount of squeeze required for the particular end fitting; normally this should be approximately 0·18 mm (0·007 in).

(f) Place the fitting in the position shown in the small sketch in Figure 2, so as to swage to within approximately 1·2 mm (0·050 in) from the inspection hole. Check that the cable is in the correct position (see (d)), and operate the handles to squeeze the fitting.

(g) Release the handles and rotate the fitting through approximately 50°. Repeat the squeezing and rotating until the fitting has been moved one full turn.

(h) Withdraw the end fitting from the dies 1·6 mm ($\frac{1}{16}$ in) and repeat the cycle of squeezing and turning.

(j) Continue operation until the whole shank is swaged. Check the diameter of the shank, and if it has not been reduced to the size required by the appropriate drawing or specification, re-set the adjusting screw and repeat the swaging operation.

(k) When the shank of the end fitting has been reduced to the correct diameter, remove and inspect the fitting (see paragraph 5.3).

(l) Fit the identification device as prescribed in the drawing, and mark it with the cable part number in the prescribed manner (in some cases the part number may be etched directly onto the end fitting). The identification may be in the form of a wired-on tag, as illustrated in Leaflet **BL/2-1**, or a cylindrical sleeve lightly swaged onto the shank of the end fitting.

(m) Assemble any fittings, such as cable stops, on the cable, and swage on the opposite end fitting.

(n) Dip the end fittings in lanolin, to prevent corrosion resulting from damaged plating, and to exclude moisture.

5.3 **Inspection of Swaged Fittings.** On completion of the swaging operations, the following inspection should be carried out.

(a) Check that the correct combination of cable and fittings has been used.

(b) Re-check the diameter of the swaged shank, using a GO–NOT GO gauge or a micrometer. If the diameter of the fitting is too small, it has been over-swaged, and the cable and the fitting must be rejected. Excessive work hardening of the fitting will cause it to crack, and may also damage the cable.

(c) Check, by means of the inspection hole or paint mark, that the cable is correctly engaged in the end fitting (see paragraph 5.2 (d)).

(d) Check that the swaging operation has not disturbed the lay of the cable, where the cable enters the end fitting.

(e) Ensure that the shank is smooth, parallel, and in line with the head of the fitting, and that the swaged shank length is correct.

(f) Proof load the completed cable assembly in accordance with the appropriate drawing (see also paragraph 8).

(g) Inspect the fittings for cracks using a lens of 10×magnification, or carry out a crack detection test, using magnetic or dye processes, as appropriate.

(h) Check that the cable assembly is the correct length (see paragraph 8.7), and ensure that any required identification marking, including evidence of proof loading, has been carried out, and that any specified protective treatment has been applied.

NOTE: The first swaged fitting in a production batch is usually sectioned after proof loading, so that the interior surface can be examined for cracks. If this check is satisfactory, the settings on the swaging machine should be noted, and used for completion of the batch.

6 SWAGED SPLICES A number of proprietary methods are used to secure cable in the form of a loop, which may then be used to attach the cable to a terminal fitting or turnbuckle. The 'Talurit' swaged splice is approved for use on some British aircraft control cables, and is also widely used on ground equipment. The process provides a cable assembly which, when used with cable to BS W9 and W11, has a strength equal to approximately 90% of the breaking strength of the cable. It may only be used to replace cables employing the same type of splice, or hand splices, and must not be used where swaged end fittings were used previously.

6.1 A typical 'Talurit' splice is illustrated in Figure 3. To make this type of splice, the end of the cable is threaded through a ferrule of the appropriate size, looped, and passed back through the ferrule. A thimble is fitted in the loop, and the ferrule is squeezed between swages (dies) in a hand-operated or power-operated press. The metal of the ferrule is extruded between the two parallel lengths of cable, and around the cable strands, and firmly locks the cable without disturbing its lay.

6.2 Ferrules are made in a variety of shapes, sizes and materials. Aluminium alloy ferrules are used with galvanised or tinned carbon steel cable, and copper ferrules are used with corrosion resisting steel cable.

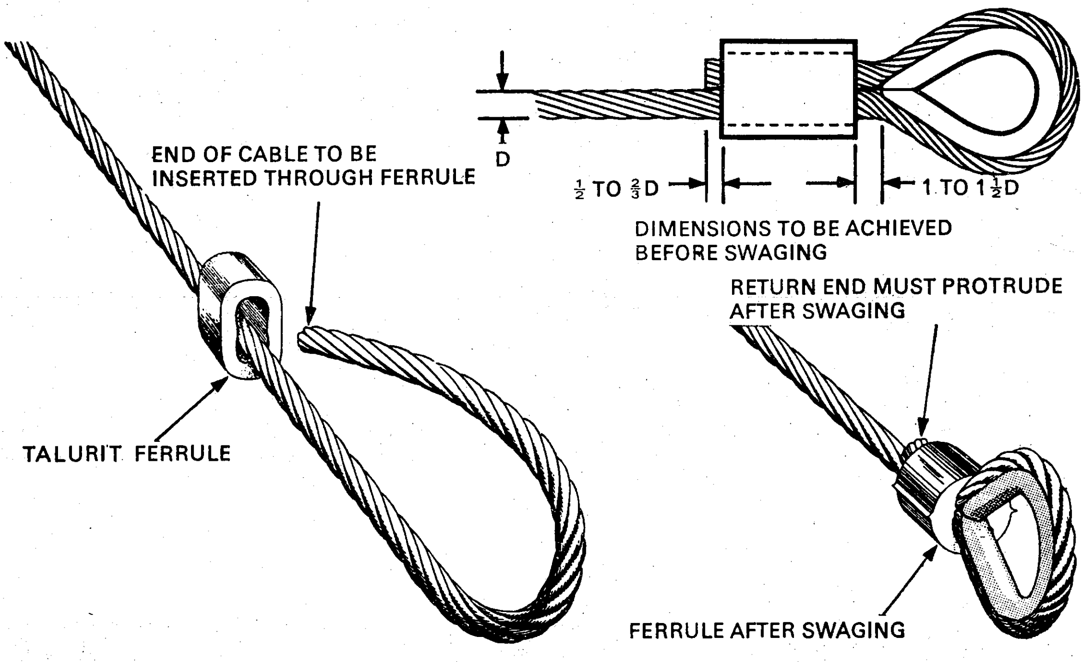


Figure 3 'TALURIT' SWAGED SPLICE

6.3 When making a splice, the proper ferrule should be selected by the code numbers indicated on the appropriate drawing, and the associated swages should be fitted to the press. The loop and thimble should be adjusted after the swages have closed sufficiently to grip the ferrule; the cable must grip the thimble firmly, and the dimensions indicated in Figure 3, must be obtained before swaging commences.

6.4 The press should be operated until the faces of the swages are touching, then the pressure should be released. Continuing to apply pressure after the faces have met, may cause damage to the press and swages. Only one pressing operation is normally required, but some long ferrules are designed for swaging in two separate operations, the swages in these cases being half the length of the ferrule.

6.5 After swaging, surplus metal is visible as a flash along each side of the ferrule, and may be removed with a file. If no flash has been formed, the sizes of the ferrule and swages should be re-checked, and it should be ascertained that the press is operating correctly.

6.6 The inspection of the finished splice consists of ensuring that the ferrule is correctly formed and not cracked, and of carrying out a proof test, as described in paragraph 8. In some instances a dimensional check is also specified, but, since the swages meet during the pressing operation, little variation in diameter will normally be obtained.

7 MANUAL SPLICING Although manual splicing may be permitted for some particular applications, it is seldom used on modern aircraft. It is less strong than either the swaged fitting or the swaged splice, and considerable experience is required in order to consistently obtain splices of adequate strength by this method. Persons engaged on splicing should be given an initial competency test, and representative samples of their work should be selected periodically, for tensile tests. Splices on cable manufactured to BS W9 or W11, should not fail at less than 80% of the breaking strength of the cable. There are several methods of splicing, the procedure in each case varying in detail. A recommended method is given in the following paragraphs, but other methods may be used, provided that the resulting splice is no less strong.

7.1 **Splicing Procedure.** The cable is normally spliced around a brass or steel thimble. The identification tag and, where applicable, the turnbuckle eye-end, should be placed on the thimble, and the centre of the thimble bound to the cable. The cable should be whipped with waxed thread on either side of the thimble, as shown in Figure 5.

NOTE: When cutting the cable to length, approximately 23 cm (9 in) should be allowed for each splice on cable up to 3·2 mm (⅛ in) diameter, and 30 cm (12 in) should be allowed for each splice in cable between 4·0 mm ($\frac{5}{32}$ in) and 6·4 mm (¼ in) diameter.

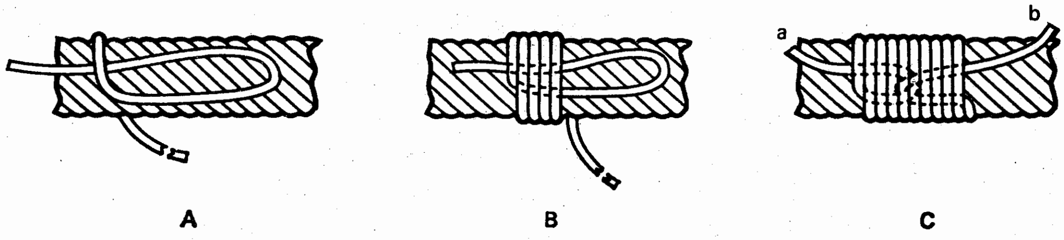


Figure 4 METHOD OF WHIPPING

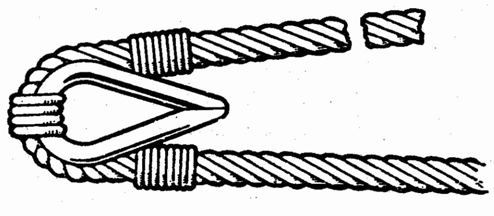


Figure 5
WHIPPING OF CABLE

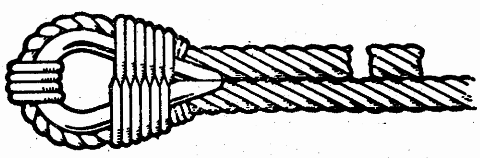


Figure 6
FIGURE-OF-EIGHT BINDING

7.1.1 The method of whipping with a waxed thread is illustrated in Figure 4. A loop is formed in the thread (sketch A), and binding commenced from the open end of the loop towards the closed end (sketch B). When a sufficient length has been whipped, end 'b' of the thread is passed through the loop, and secured under the whipping by pulling end 'a' (sketch C); the loose ends are then cut off.

7.1.2 It is essential that the cable and thimble are securely held in a vice, using cable clamps or specially prepared vice blocks, and bound with a figure of eight binding as illustrated in Figure 6. No attempt should be made to splice a cable without fully effective clamping devices.

7.1.3 The strands at the end of the cable should be separated, and whipped or soldered to prevent unlaying of single wires. The cable is then ready for splicing.

NOTE: For descriptive purposes, the six outer strands of the free end of the cable will, in paragraphs 7.1.4 to 7.1.9, be called the 'free strands', and will be numbered 1 to 6, while the outer strands of the main cable will be lettered 'a' to 'f', as shown in Figures 7 and 8.

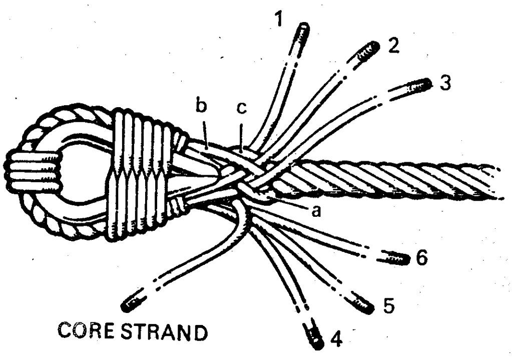


Figure 7
FIRST ROUND OF TUCKS (FRONT)

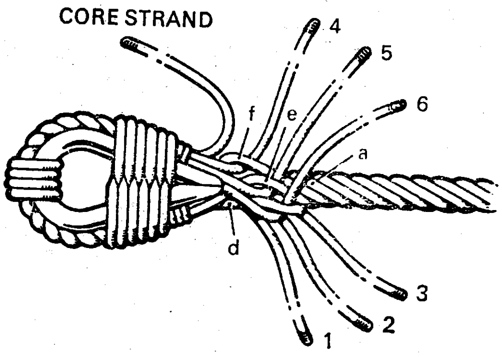


Figure 8
FIRST ROUND OF TUCKS (REVERSE)

7.1.4 The core strand should be positioned so that there are three free strands on either side, and it should be bent back slightly (see Figure 7).

7.1.5 The first round of tucks should be completed as follows— 3 under a, 1 under b and c, 2 under b (see Figure 7); turn over and tuck 4 under f, 5 under e, and 6 under d (see Figure 8). All free strands should be pulled tight, and then bent back to lock them in position. Care should be taken to avoid disturbing the lay of the cable by excessive pulling.

7.1.6 The core strand should be taken forward and temporarily secured to the main cable with thread, then pulled under a suitable free strand into the centre of the splice. The six free strands should then, in turn, be tucked over a strand and under a strand, e.g. 3 over b and under c, 1 over d and under e. On completing the second round of tucks, the free strands should be pulled tight, and locked back as before.

7.1.7 The third round of tucks should be completed in a similar manner to the second, taking care to bury the core strand in the centre of the splice.

7.1.8 The last full round of tucks, i.e. the fourth, should be the same as the second and third rounds.

7.1.9 The half round of tucks for finishing the splice should be completed by tucking alternate free strands over one, and under two main cable strands. To finish and shape the splice, it should be beaten with a hardwood or rawhide mallet on a hardwood block, while the cable is held taut. The splice should be rotated against the direction of tucking during the beating process. Excessive hammering must be avoided. Free strands should be cut off flush with the splice, and the last one and a half tucks should be whipped with waxed cord. The central binding and figure-of-eight lashing should be removed.

7.1.10 If both ends of the cable are to be spliced, the cable length should be checked before commencing the second splice, so that the completed cable will be of the required length.

7.2 Inspection of Splice

7.2.1 The splice should be inspected for symmetry and appearance. The wires should be close together, and no light should show between the strands or wires. A typical splice is shown in Figure 9.

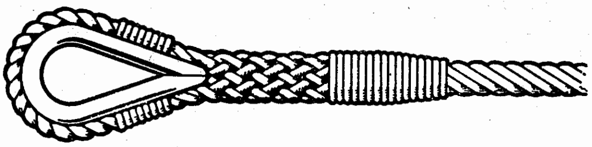


Figure 9 TYPICAL SPLICED JOINT

7.2.2 The resistance of the splice to bending should be checked. A bad splice will not be resistant to bending, and, when it is bent, the strands and wires will slacken.

7.2.3 The tightness of the thimble in the loop should be checked. The lay of the strands in the cable should be maintained as far as the splice permits, as disturbance in the lay of the cable adjacent to the splice may result in considerable weakening of the cable.

7.2.4 The completed cable must be proof loaded in accordance with paragraph 8.

8 PROOF LOADING

8.1 All cables must be proof loaded after swaging or splicing, by subjecting the cable to a specified load. The purpose of proof loading is both to ensure that the end fittings are satisfactorily installed, and to pre-stretch the cable, i.e. to bed-in the strands and wires. British practice is to load the cable to 50% of its declared minimum breaking strength, and American practice is to load the cable to 60% of its declared minimum breaking strength. If no specific instructions are included in the drawing, then loading of the cable should be carried out in accordance with whichever of these practices is appropriate.

8.2 If end fittings have been fitted or splices have been made on pre-stretched cable, no appreciable elongation will result from proof loading. If the cable was not pre-stretched, it may be expected to elongate slightly, and this should have been taken into consideration on the appropriate drawing.

8.3 A test rig suitable for proof loading cables is illustrated in Figure 10, but other similar methods would be acceptable. The cable should be contained within a trough or other protective structure, to safeguard the operator in the event of failure of the cable. Adaptors should be used to attach the cable end fittings to the test rig, and these should be at least as strong as the cable. Particular care should be taken not to damage the thimbles on spliced cables; packing or bushes should be used to spread the load.

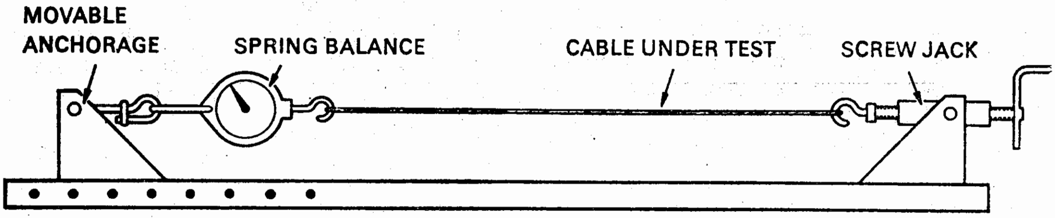
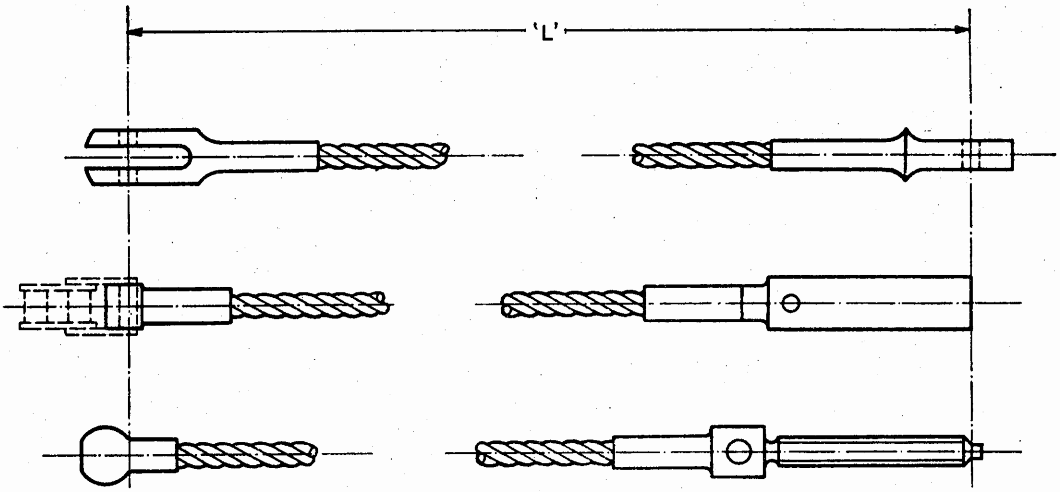


Figure 10 TEST RIG FOR PROOF LOADING

8.4 Before proof loading a cable with swaged end fittings, the cable should be painted with a quick-drying paint at its point of entry into the fittings, and allowed to dry. Cracking of the dried paint during proof loading will indicate slipping of the cable resulting from an unsatisfactory joint.



Length 'L' ±1·6 mm ($\frac{1}{16}$ in) up to 2 m (6 ft)
±3·2 mm ($\frac{1}{8}$ in) over 2 m (6 ft) up to 6 m (20 ft)
+9·6 mm ($\frac{3}{8}$ in) } over 6 m (20 ft)
—3·2 mm ($\frac{1}{8}$ in) }

Figure 11 LENGTH OF ASSEMBLIES

8.5 The test should consist of slowly applying the specified load, maintaining this load for a minimum specified period (normally 30 seconds for swaged fittings, but up to 3 minutes for splices), then releasing it, and carefully examining the cable for signs of pulling out of the end fittings, or stretching of the splice.

8.6 'The end fittings should be checked for cracks using an electro-magnetic method (Leaflet **BL/8-5**) or, if the fitting is of stainless steel, a penetrant dye process (Leaflet **BL/8-2**).

8.7 The length of the completed cable assembly should be measured after proof loading. Prior to measurement cables longer than 120 cm (4 ft) should be tensioned with a load of approximately 550 N (112 lbf), or 2% of the breaking load of the cable, whichever is the least. Figure 11 shows the datum points and tolerances for the measurement of cables fitted with swaged end fittings to British Standards. Cables with different types of end fittings, or loops, should be measured according to the appropriate drawings or specifications.

BL/6-25

Issue 3.

18*th May*, 1978.

BASIC

ENGINEERING PRACTICES AND PROCESSES

FABRIC COVERING

1 INTRODUCTION This Leaflet gives guidance on the covering of aircraft components with fabric and on the methods employed for repairing and testing such coverings. Guidance on the application of dope to fabric is given in Leaflet **BL/6-26.**

2 GENERAL Before the covering of any component is commenced the structure must be inspected, all foreign matter removed, and protective treatments (as prescribed in the relevant drawings) must be applied. Often it is necessary to install flying control cables, electric cables, fuel tanks and other systems before covering large components, and these should be inspected as necessary and checked for security. The most suitable conditions for the application of fabric are a room temperature of 16°C to 21°C and a relative humidity of not more than 70%.

NOTE: Information on the method of determining relative humidity is given in Leaflet **BL/6-26,** and on the testing and inspection of textiles in British Standard F100.

3 MATERIALS This paragraph describes the natural-fibre materials used in the covering of British-manufactured aircraft. Foreign fabric-covered aircraft use these or similar materials manufactured in accordance with equivalent specifications. Information on the use of fabrics produced from man-made fibres for aircraft will be found in paragraph 12.

3.1 **Fabrics.** Aircraft fabrics are woven from spun threads or 'yarns'; those running lengthwise are termed the 'warp'; and those running crosswise are termed the 'weft'. The number of yarns per centimetre (inch) varies with different weights of fabric and is not necessarily the same in both warp and weft. The non-fraying edge of the fabric is termed the 'selvedge'.

3.1.1 When an unsupported fabric cover is required to carry air loads, unbleached linen to British Standard (BS) F1 is normally used, but some aircraft have coverings of cotton fabric complying with BS F8, BS F57, BS F116 or DTD 575.

3.1.2 A light cotton fabric complying with BS F114 (referred to as Madapollam) is generally used for covering wooden surfaces. This acts as a key to the doping scheme, giving added strength and improving surface finish.

3.2 **Tapes.** Linen tapes complying with BS F1 and cotton tapes complying with BS F8 are available in various widths for covering leading edges, trailing edges and ribs, and for repair work. The materials are supplied with serrated edges, as illustrated in Figure 2. Cotton tape complying with BS F47 (referred to as 'Egyptian tape') is generally used on those members where chafing may occur between the structure and the fabric (see also paragraph 4.1) and is also used externally to protect the fabric against damage by the stringing cord.

3.3 **Thread.** Linen thread complying with BS F34 is normally used. For hand sewing, No. 40 thread (minimum breaking strength 3 kg (7 lb)) used double, or No. 18 thread (minimum breaking strength 7·25 kg (16 lb)) used single, are suitable. For machine sewing, No. 30 thread (minimum breaking strength 4·5 kg (10 lb)) or No. 40 thread is used.

3.4 **Stringing.** Flax cordage complying with BS F35 or braided nylon cord (coreless) complying with DTD 786 is normally used.

3.5 **Eyeleted Fuselage Webbing.** On a number of older types of aircraft, cotton webbing braid with hooks, or lacing eyelets and kite cord, are used for securing the fuselage fabric.

3.6 **Storage.** All materials used for fabric covering should be stored at a temperature of about 20°C in dry, clean conditions and away from direct sunlight. When required for use the materials should be inspected for possible flaws (e.g. iron mould discoloration, signs of insect, rodent, or other damage) and any affected parts rejected.

4 PREPARATION OF STRUCTURE The structure to be covered should be inspected as outlined in paragraph 2. All corners or edges and any projections such as bolts or screw heads likely to chafe the fabric must be covered with tape. Where serious chafing may occur and a strong reinforcement is required, a canvas or leather patch may be sewn to a fabric patch, then doped into position.

4.1 In order to prevent dope from reacting with any protective treatment, and to prevent fabric from adhering to wooden structure, all aerofoil members which will be in contact with the fabric are normally covered with adhesive cellulose or aluminium tape, or painted with dope-resistant white paint. Exceptions to this requirement are discussed in paragraphs 7.3, 7.4 and 12.1.

4.2 On some aircraft, which have a tubular metal fuselage frame, the fuselage shape is made up with wooden formers attached directly to the main framework, and to these wooden formers are secured light longitudinal members onto which the fabric covering is doped. This secondary structure must be inspected for security, and any sharp edges removed with fine glass paper.

4.3 Where stringing is likely to be chafed by parts of the structure, protection should be provided by wrapping such parts with cotton tape. Before the tape is applied the structure should be treated with varnish to protect it from corrosion should the tape become wet.

4.4 Internal controls and cables should be tightened to assume their normal positions, and secured at the root rib. Their location should be noted so that stringing pitch can be selected to avoid chafing.

5 COVERING METHODS An aircraft fabric may be fitted with the warp or weft running at 45° to the slipstream, or in line with the slipstream. The former (bias) method is generally considered to be stronger and more resistant to tearing, but the latter method is used on most light aircraft. The two methods used to re-cover an aircraft are outlined in paragraphs 5.1 and 5.2, but the method used in a particular instance should follow that of the original manufacture unless otherwise approved.

5.1 **Prefabricated Envelopes.** A number of manufacturers produce fabric envelopes for re-covering various models of aircraft. Separate envelopes are made up from patterns for the mainplanes, fuselage, tailplane, fin and flying control surfaces, and greatly simplify the task of re-covering. The envelopes are made loose enough to facilitate slipping them over the structure, and to achieve the proper tautness after doping.

5.1.1 **Mainplanes.** The envelope is drawn over the wing tip and gradually worked down over the mainplane, generally keeping the spanwise seam in line with the trailing edge. When the cover is located it is secured (by stitching, cementing, or retaining strip) to the inboard end of the mainplane, any necessary openings for cables, struts, tank caps, etc., are cut, and stringing is applied as necessary (paragraph 6).

5.1.2 **Fuselage.** The fin and fuselage envelopes are often supplied separately, and in some cases the fuselage envelope is open, or partially open, at the bottom, to simplify fitting. The fin envelope is usually fitted first, then the fuselage envelope is stretched forwards over the fuselage and secured in the same way as the original fabric. The cover is usually cemented or doped to the fuselage formers (paragraph 4).

5.1.3 **Control Surfaces.** Control surface envelopes are usually left open at the hinge line, where they are secured by cementing, doping or stitching.

5.2 **"Blanket" Method of Covering.** With this method a bolt of fabric is used, and covers are made-up on the site of the aircraft, lengths of fabric, or a number of lengths joined side-by-side, being used to cover the aircraft structure.

5.2.1 **Mainplanes and Tailplanes.** The cover is normally made-up from lengths of fabric machine-stitched together side-by-side. This is laid round the surface, starting and finishing at the trailing edge, and joined by hand stitching as shown in Figure 3. On some aircraft with light alloy structure, hand stitching is dispensed with, the cover edges being wrapped round the tip and trailing edge, and doped into position. The cover is then attached to the ribs by stringing (paragraph 6).

5.2.2 **Fuselage.** A number of different methods are used to attach fabric to the fuselage; the more common being as described in paragraph 4.2. The fabric is not normally attached in one piece, but usually consists of several pieces (sides, top and bottom, for example) which are doped separately onto the frame, or sewn together at their edges. Joins or seams are covered with doped-on tape. Since the air loads on the fuselage are not as great as on the mainplanes, it is not usual to employ stringing, although it may be specified in some instances.

5.2.3 **Control Surfaces.** These are covered in a similar way to the mainplanes and usually require stringing. The fabric is normally folded round the hinge line, since this is usually straight, and sewn together round the remaining contour of the surface.

6 SEAMS, STITCHES AND STRINGING

6.1 **Seams.** The seams in the fabric covering should be either parallel to the fore-and-aft line of the aircraft or on a bias, depending on the covering method used (paragraph 5). With the exception of trailing edge or leading edge joints (where such action cannot be avoided) seams should never be made at right angles to the direction of airflow. Two types of machined seams are employed, i.e. the balloon seam and the lap seam.

6.1.1 **The Balloon Seam.** The balloon seam, sometimes referred to as the 'French fell', is normally specified for all fabric joints and is illustrated in Figure 1. To make the seam, the edges of the fabric are folded back 16 mm (0·625 in) and are then fitted into each other as shown, tacked together, and then machine sewn with four stitches per centimetre (nine stitches per inch) in two parallel lines 9 mm (0·375 in) apart and 3 mm (0·125 in) from either edge. After completion, the seam should be examined over a strong electric light (preferably a light-box) to ensure that the inside edges of the fabric have not been missed during sewing.

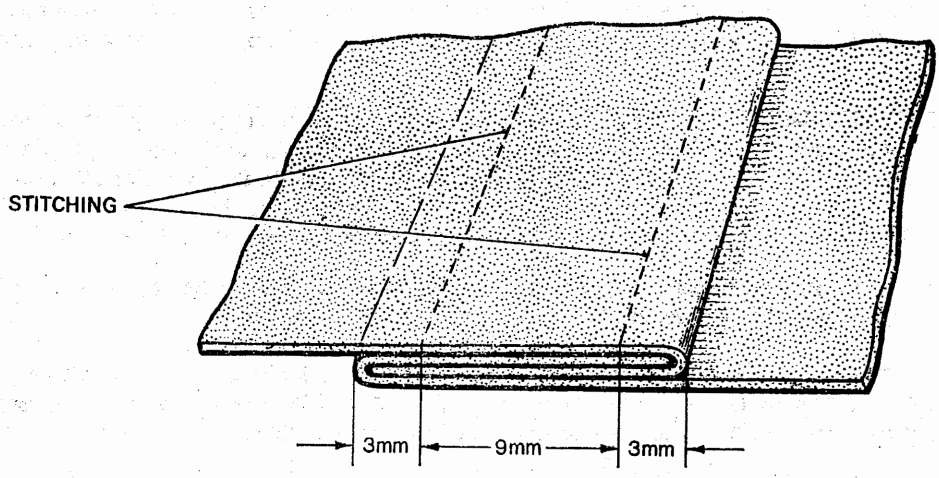


Figure 1 BALLOON SEAM

6.1.2 **The Lap Seam.** The lap seam, illustrated in Figure 2, should only be used when specified by the manufacturer. Unless the selvedges are present, the edges of the fabric should be serrated with 'pinking' shears. The edges should overlap each other by 31 mm (1·25 in) and should be machine sewn with four stitches per centimetre (nine stitches per inch), the stitch lines being 12 mm (0·5 in) apart and 9 mm (0·375 in) from the edges. After stitching, a 75 mm (3 in) wide serrated-edge fabric strip should be doped in position.

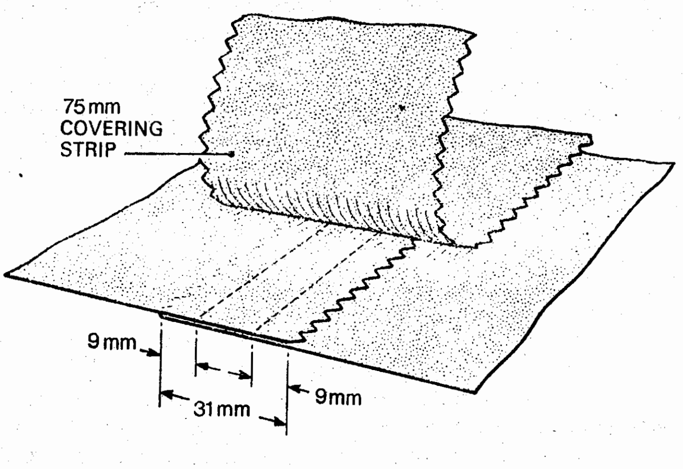


Figure 2 LAP SEAM

6.2 **Hand Sewing.** Apart from the herring-bone stitch (Figure 9) and the boot stitch (Figure 13), which are used for repair work and are described in paragraph 10, the only other stitches used are the overhand stitch (sometimes referred to as the 'trailing-edge' stitch) and the lock stitch. The overhand stitch is used for trailing edges, wing tips, wing root ends, and wherever a sudden change of section occurs.

6.2.1 **Overhand Stitch.** Sufficient excess fabric should be allowed for turning under before sewing is commenced; a 12 mm (0·5 in) turn-under is usually sufficient. An even gap of about 6 mm (0·25 in) (usually) should be allowed for pulling up the two edges to obtain the correct fabric tension, but this figure can only be determined finally by experience of the work in hand.

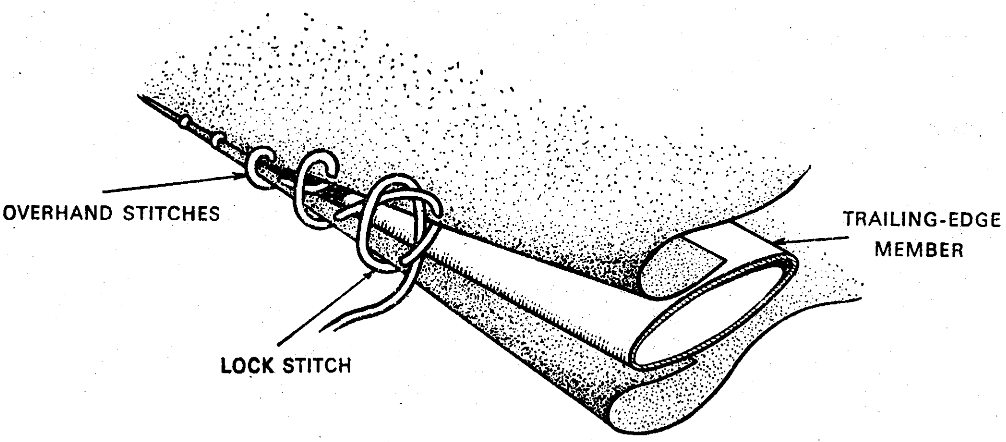


Figure 3 OVERHAND STITCH

6.2.2 The sewing should follow the contour of the component evenly to ensure a good finish after doping. The number of stitches should be three per centimetre (eight per inch), a lock stitch being included approximately every 50 mm (2 in). Overhand stitching is illustrated in Figure 3, the lock stitch being shown as the last stitch before the stitching is pulled tight.

6.3 **Use of Beeswax.** All threads used for hand sewing, and all cord used for stringing (when not pre-waxed), should be given a liberal coating of beeswax. This protects the thread, facilitates sewing, and reduces the likelihood of damaging the fabric or enlarging the stitch holes.

6.4 **Stringing.** Flax cord complying with BS F35 is normally used for stringing purposes and is generally applied in single strands as shown in Figure 4. As an alternative, but only when approved by the manufacturer, doubled No. 18 thread may be used during repair work.

6.4.1 When the fabric covering of the component has been completed, cotton tape to BS F47 should be stretched centrally over each rib, top and bottom, and stitched into position at the trailing edge.

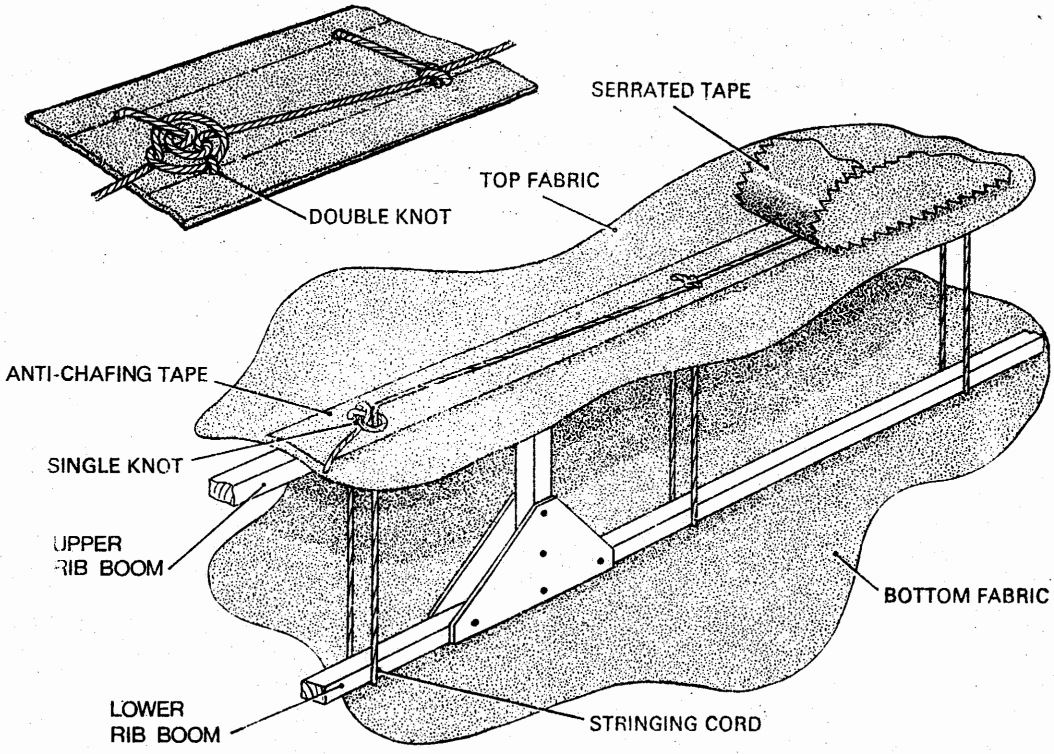


Figure 4 TYPICAL STRINGING

(a) Using a stringing needle and commencing at the top surface, the stringing cord should be passed through the tape and fabric as close to the rib as possible, out through the bottom fabric and tape, round the lower rib boom and back up through both surfaces again. A double knot should be used to secure the first and last stringing loops, and after each 450 mm (18 in). In between, single knots may be used.

(b) The stringing pitch is normally 75 mm (3 in) but in the slipstream area (see paragraph 6.4.4), or on aircraft of more than 910 kg (2000 lb) weight, the pitch is often reduced to 37 mm (1·5 in). Variations from these pitches will be stipulated in the relevant aircraft manuals, and it may be necessary to vary the pitch in order to avoid internal structure or control runs.

(c) When the stringing has been completed a strip of serrated tape, 37 mm (1·5 in) wide, should be doped over the stringing line on both surfaces, care being taken to ensure that no air is trapped under the tape and that the tape is securely attached to the main cover.

NOTE: The knots depicted in Figure 4 are typical but a different type of knot may be specified by the manufacturer.

6.4.2 **Boom Stringing.** This type of stringing is used on deep aerofoil sections. The procedure is similar to that described above, except that the cord is passed round the rib boom instead of round the entire rib. Top and bottom surfaces are therefore attached separately, and the inside of each boom must be taped to prevent chafing of the stringing cord. Alternate rib and boom stringing is sometimes used on aerofoils of medium depth, i.e. between 150 and 300 mm (6 and 12 in).

6.4.3 **Stringing Tension.** Care must be taken to ensure that all stringing is maintained at a satisfactory tension and that it is not so tight as to cause distortion of the ribs.

6.4.4 **Slipstream Area.** For stringing purposes, the slipstream area is considered to be the diameter of the propeller plus one rib on either side. In the case of multi-engined aircraft, the entire gap between the slipstreams, regardless of its width, is also considered to be slipstream area.

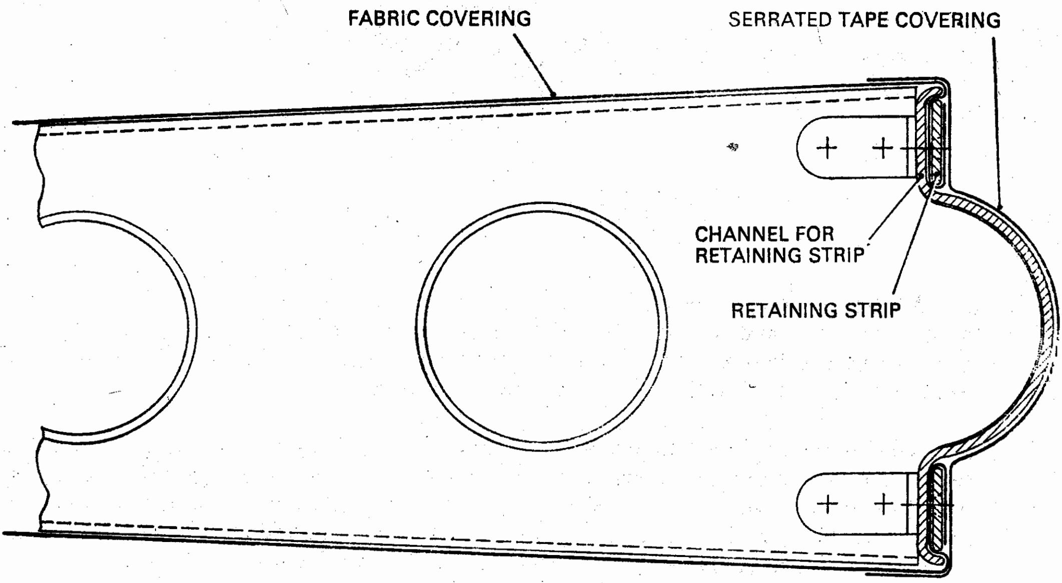


Figure 5 ATTACHMENT OF FABRIC BY STRIP

7 MISCELLANEOUS METHODS OF FABRIC ATTACHMENT

In addition to the standard methods of fabric attachment described in paragraph 6, other methods are sometimes employed, and those most commonly used are outlined below.

7.1 **Attachment by Strip.** Attachment of the fabric by wrapping it around a light alloy strip or rod which is then secured in a channel or groove is sometimes used with metal structures. This method is illustrated in Figure 5.

7.2 **Special Stringing.** A variation of the method described in paragraph 7.1, used for attaching fabric to metal ribs, and known as 'special stringing' is shown in Figure 6.

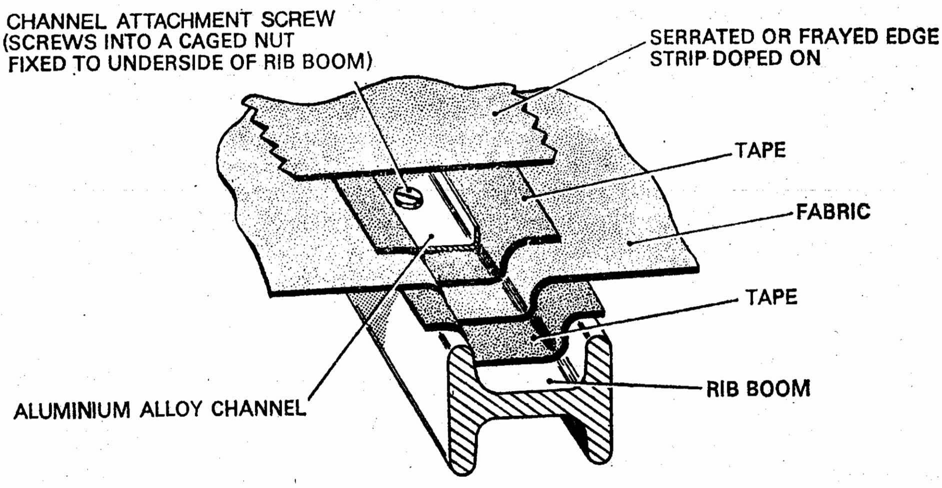


Figure 6 SPECIAL STRINGING

7.3 **Adhesives.** On some small aircraft, where air loads are light, stringing is dispensed with on the wing and tail surfaces and the fabric is attached to the structure by means of a proprietary adhesive. This method produces a much smoother surface on the components and saves time during construction and repair.

7.4 **Attachment of Fabric to Plywood.** Dope is generally used for the attachment of fabric to plywood, but before the fabric is applied, the wood surface should be smoothed with fine glass paper and any cavities, such as those caused by the countersinking for screwheads, filled and allowed to set. The filler area should be reduced to an absolute minimum because of the reduced adhesion of the doped fabric in such areas.

7.4.1 The wooden surface should then be treated with one coat of tautening dope, followed by a further coat after the first one has dried. After the second coat of dope has dried, the fabric should be spread over the wood and stretched evenly to avoid wrinkling. A coat of tautening dope should then be brushed into the fabric sufficiently to ensure good penetration. For this purpose a fabric pad is useful for rubbing in the dope.

7.4.2 After the dope has dried it should be lightly rubbed down using 'wet and dry' rubbing paper Grade 0 or Grade 00, and then the required finishing scheme applied.

7.5 **Attachment of Fabric to Metal Surfaces.** Where a light alloy is used as part of the structure of a mainplane (such as to form the leading edge profile) the fabric is generally doped into position. Alternatively, a thermoplastic adhesive may be used, and guidance on the use of this material may be obtained from the relevant aircraft manuals.

7.5.1 To ensure satisfactory adhesion of the fabric, the metal surfaces should be thoroughly cleaned, and primed with an etch primer.

8 DRAINAGE AND VENTILATION Drainage and ventilation holes are necessary in fabric-covered components to minimize corrosion of the structure, rotting of the fabric, etc., and, to ensure maximum efficiency, it is important that they should be positioned as prescribed on the relevant drawing.

8.1 Drainage holes are usually positioned in the lower surface of components or wherever entrapment of moisture is possible, but when holes are used for ventilating purposes, e.g. to permit the air pressure inside the component to equalize with the surrounding air at various altitudes, the holes may be located in sheltered positions regardless of drainage qualities.

8.2 **Drainage Eyelets.** Drainage eyelets are usually oval or circular in shape and are doped on to the surface of the fabric, but in some cases may be secured by stitching through pre-pierced holes in the eyelets before the finishing scheme is applied.

8.3 **Shielded Eyelets.** Shielded or shrouded eyelets are sometimes used in special positions to improve either drainage or ventilation. On marine aircraft they are used to prevent the entry of sea spray. These special eyelets must only be used in specified positions and must not be used as an alternative to standard eyelets. It is also important that the shroud is facing in the correct direction, otherwise it will not be fully effective.

NOTE: Inspectors must ensure that drain holes are clear; it is common practice to affix the eyelets at an early stage of doping and to pierce the fabric after the final finish has been applied.

9 INSPECTION PANELS For inspection and servicing purposes it is essential that access be provided at specified positions in all fabric coverings. The three methods commonly used are described below.

9.1 **Woods Frames.** These are light circular or square frames, made from celluloid sheet, which are doped onto the fabric cover at the required positions. The fabric is then cut away from inside the frames and a serrated edged fabric patch doped over the hole as shown in Figure 7. The disadvantage of this type of panel is that a new patch must be doped on after each inspection, and the finishing scheme re-applied.

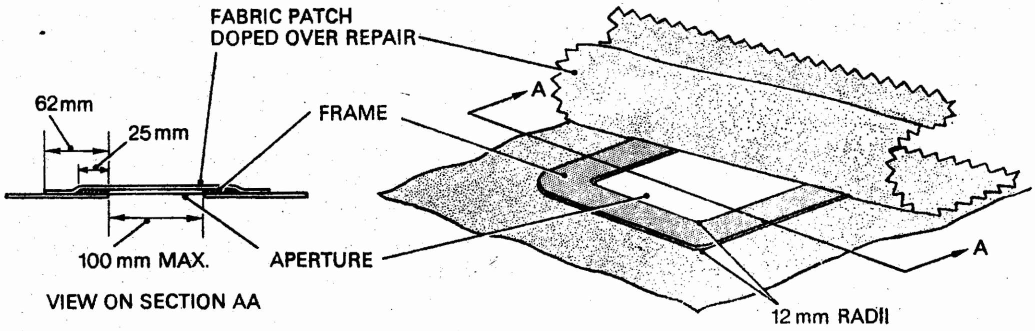


Figure 7 WOODS FRAME INSPECTION PANEL

9.2 **Zip Panels.** These consist of two zip fasteners sewn into the fabric in the form of a vee, the open ends of each fastener being at the apex of the vee. This type of access is suitable for positions where frequent inspection or servicing is necessary. Care should be taken to avoid clogging the zip segments when dope is applied to the fabric.

9.3 **Spring Panels.** A panel particularly suitable for use on light aircraft, the spring panel consists of a circular plastic ring and dished light alloy cover. The ring is doped into position in the same way as the Woods frame, and the fabric cut away from the inside. By pressing the centre of the cover the dish shape is reversed, allowing the clip to be inserted in the hole; when pressure is released the dish reverts to its normal shape and closes round the plastic ring as shown in Figure 8.

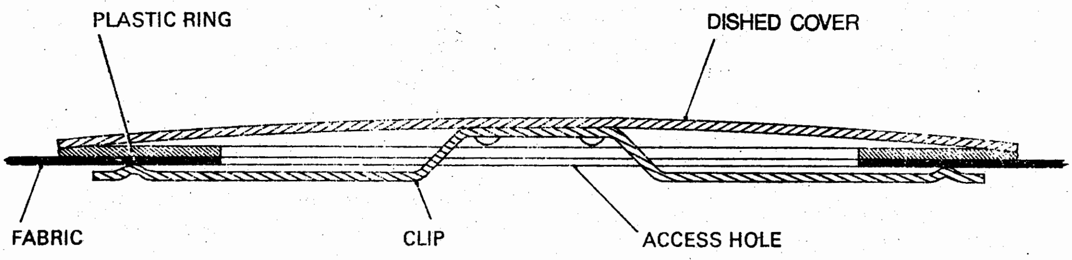


Figure 8 CROSS-SECTION OF SPRING PANEL

10 REPAIRS TO FABRIC COVERINGS If the fabric has been damaged extensively, it is usually impractical and uneconomical to make satisfactory repairs by sewing and patching. The extent and location of damage to the fabric that may be repaired will be detailed in the repair section of the aircraft manual concerned, but extensive damage is often made good by replacing complete fabric panels. However, the replacement of large fabric panels, particularly on one side of a component, may lead to distortion of the structure, and it may be advisable to completely re-cover the component.

10.1 Before attempting any repair to the fabric covering, the cause of the damage should be ascertained. The internal structure should be inspected for loose objects such as stones, remains of birds, insects, etc., and any structural damage made good. Using thinners, all dope should be removed from the fabric surrounding the damaged area before any stitching is carried out, since doped fabric will tear if any tension is applied to the repair stitches.

10.2 **Repair of Cuts and Tears.** Cuts and tears in fabric are sometimes caused by stones thrown up by the slipstream or wheels, but more generally result from accidental damage during ground movement or servicing. Damage may also be caused by bird strikes. Any damaged structure should be made good and fabric repairs carried out according to the type of damage, as detailed in the following paragraphs.

10.2.1 **Herring-Bone Stitch.** The herring-bone stitch (also known as the 'ladder stitch') should be used for repairing straight cuts or tears which have sound edges. The stitches should be made as shown in Figure 9, with a lock knot every 150 mm (6 in).

(a) There should be a minimum of two stitches to the centimetre (four stitches to the inch) and the stitches should be 6 mm (0·25 in) from the edge of the cut or tear. The thread used should be that described in paragraph 3.3.

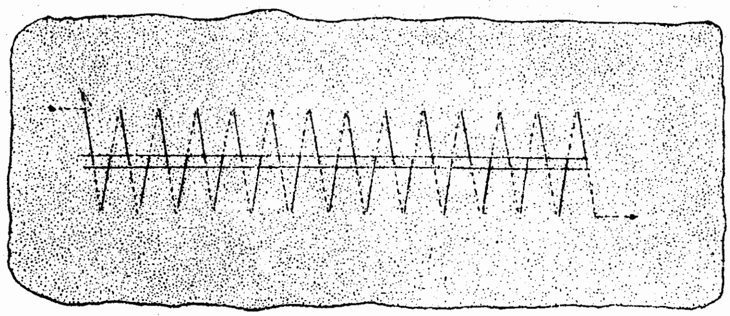


Figure 9 HERRING-BONE STITCH

(b) After the stitching has been completed, 25 mm (1 in) wide serrated tape should be doped over the stitching. A square or rectangular fabric patch should then be doped over the whole repair, ensuring that the edges of the patch are parallel to the warp and weft of the fabric covering, and that they overlap the repair by 37 mm (1·5 in). The original doping scheme should then be restored.

10.2.2 **Repairs with Woods Frames.** On some aircraft, repairs to cuts and tears with jagged edges, which cannot be stitched as described in the previous paragraphs, can be repaired by using the Woods frame method described for inspection panels in paragraph 9.1. Repairs of up to 50 mm (2 in) square may be made, provided they are clear of seams or attachments by a distance of not less than 50 mm (2 in). The affected area should be cleaned with thinners or acetone and repaired in the following manner:—

(a) The Woods frame should be doped into position surrounding the damaged fabric and, if the frame is of the square type, the edges should be parallel to the weft and warp of the covering. When the dope has dried, the damaged portion of the fabric should be cut out and the aperture covered by a fabric patch as described in paragraph 9.1.

(b) If Woods frames are not readily available they can be made from cellulose sheet 0·8 mm (0·030 in) thick with minimum frame width of 25 mm (1 in); in the case of the square type of frame the minimum corner radii should be 12 mm (0·5 in). In some special cases, aircraft manufacturers use 2 mm plywood complying with British Standard V3 for the manufacture of the frames, in which case it is important to chamfer the outer edges of the frame to blend with the aerofoil contour.

10.2.3 **Repair by Darning.** Irregular holes or jagged tears in fabric may be repaired by darning provided the hole is not more than 50 mm (2 in) wide at any point. The stitches should follow the lines of the warp and weft, and should be closely spaced, as shown in Figure 10. The whole repair should be covered with a serrated fabric patch in the usual way, with an overlap of 37 mm (1·5 in) from the start of the darn.

10.3 **Repair by Insertion.** For damage over 100 mm (4 in) square, insertion repairs are generally used, either of the two methods described below being suitable.

10.3.1 **Normal Insertion Repair**

(a) The damaged area of the fabric should be cut out to form a square or rectangular hole with the edges parallel to the weft and warp. The corners of the hole should then be cut diagonally, to allow a 12 mm (0·5 in) wide edge to be folded under the fabric, and this should be held in position with tacking or hemming stitches.

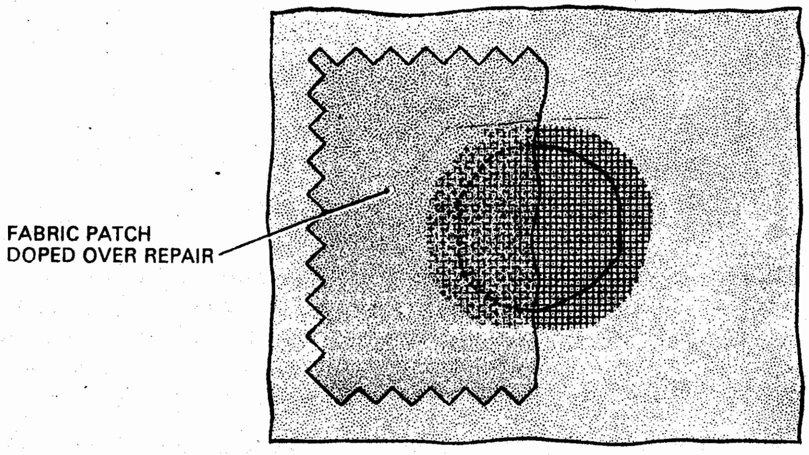


Figure 10 REPAIR BY DARNING

(b) The patch should be made 25 mm (1 in) larger than the cut-out area and its edges should be folded under for 12 mm (0·5 in) and tacked in position in a manner similar to that described in paragraph 10.3.1 (a). In this condition the size of the insertion patch should be similar to, or slightly smaller than, that of the cut-out area.

(c) The insertion patch should be held in position inside the cut-out area with a few tacking stitches and then sewn in position using a herring-bone stitch of not less than two stitches to the centimetre (four stitches to the inch), as shown in Figure 11. A 25 mm (1 in) wide tape should then be doped over the seams.

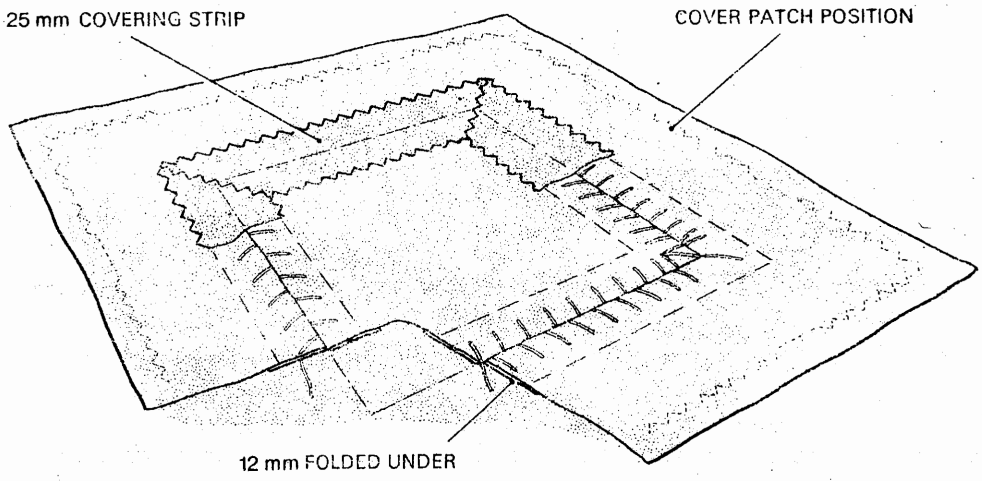


Figure 11 NORMAL INSERTION REPAIR

(d) For small repairs a square or rectangular cover patch, with frayed or serrated edges, should be doped in position ensuring that the patch overlaps the edge of the tape by 31 mm (1·25 in). Where the size of the insertion patch is more than 225 mm (9 in) square, a 75 mm (3 in) wide fabric serrated tape is often used; the tape should be mitred at the corners and doped in position. The original finish should then be restored.

10.3.2 **Alternative Insertion Repair.** An alternative repair is shown diagrammatically in Figure 12. This consists of cutting away the damaged fabric as described in paragraph 10.3.1, but, in this case, the edges of the aperture as well as the edges of the insertion patch are turned upwards. The insertion patch is attached to the fabric cover by stitching along the folded-up edges as near to the contour of the component as practicable (i.e. about 1 mm (0·0625 in) above the surface) using the boot stitch described in paragraph 10.3.3 (Stage 1 of Figure 12). The edges are then doped down (Stage 2 of Figure 12) and the repair covered with a doped-on fabric patch.

10.3.3 **Boot Stitch.** A single, well-waxed No. 18 linen thread to BS F34 should be used for the boot stitch. The stitches should be made as shown (diagrammatically) in Figure 13 and the ends of both threads tied together in a lock knot every 150 mm (6 in), and at the end of a seam.

11 CHECKING OF FABRIC The fabric covering of an aircraft will deteriorate in service, the rate of deterioration depending, to a large extent, on the type of operation, climate, storage conditions, and the maintenance of a satisfactory surface finish. In addition, as a result of water soakage, chafing against structure, and local wear, the covering will not deteriorate uniformly. In the case of fabric covered components on large aircraft an arbitrary life may be placed on the fabric, but with light-aircraft coverings the fabric should be checked at the periods specified in the approved Maintenance Schedule and prior to renewal of the Certificate of Airworthiness.

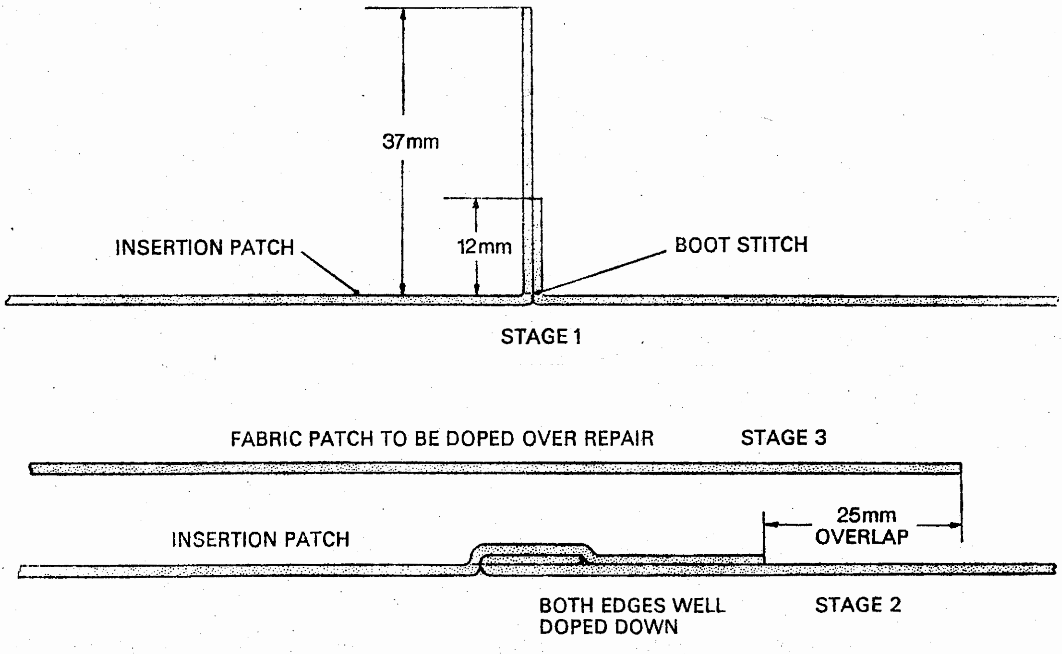


Figure 12 ALTERNATIVE INSERTION REPAIR

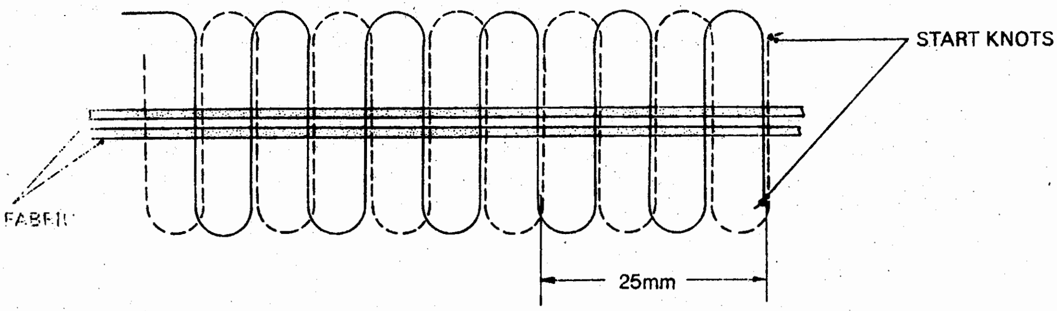


Figure 13 BOOT STITCH

11.1 A visual examination in which particular attention is given to places where water soakage, local wear, fretting or oil contamination are likely to occur, or are known to occur on that particular aircraft type, supplemented by a knowledge of the aircraft history, will often be sufficient to justify acceptance of the covering as a whole, or replacement of some local areas which have deteriorated. In cases of doubt as to the strength of the fabric, further tests will be necessary.

11.2 One method of checking the strength of an aircraft covering is by the use of a portable tester such as the one described in paragraph 11.3 and illustrated in Figure 14. These testers are, generally, only suitable for checking the condition of coverings on which the dope finish has penetrated the fabric. Finishes such as cellulose acetate butyrate dope do not normally penetrate the fabric, and experience has shown that the absorption of moisture in humid conditions can produce unreliable test results. In addition, butyrate dope, even when some penetration of the fabric has occurred, produces a finish which hardens with age; as a result the conical point on the tester will not readily penetrate the covering, and the test will tend to indicate that the fabric is stronger than it actually is. Thus where butyrate dope has been used, or the dope, irrespective of type, does not penetrate the fabric, laboratory tests should be carried out. For a laboratory test the dope should be removed from the fabric, using a suitable solvent where necessary. Fabric having a strength of at least 70% of the strength of new fabric to the appropriate specification (as assessed by either test), may be considered airworthy, but fabric which falls only just within the acceptable range should be checked more frequently thereafter to ensure continued serviceability.

11.3 **Portable Tester.** This consists of a penetrating cone and plunger housed within a sleeve assembly. When pressed against a surface the cone is forced up through the sleeve against spring pressure and the plunger projects through the top of the sleeve in the same way as a tyre pressure gauge. When inspecting fabric, the tester should be held at 90° to the surface and pressure applied towards the fabric in a rotary motion, until the sleeve flange touches the surface (Figure 14). The degree to which the cone has penetrated the fabric is indicated by the length of plunger showing above the sleeve, and this is marked either by coloured bands or a graduated scale.

11.3.1 A table is provided with the tester giving the colour or scale reading required for a particular type of fabric.

NOTE: The portable tester described here is of American manufacture and the table supplied refers to fabric complying with American specifications (A.M.S., T.S.O. and MIL). It can be adapted for use on fabrics complying with DTD and BS specifications by comparing the strength requirements of the fabrics.

11.3.2 The test should be repeated at various positions and the lowest reading obtained, other than in isolated repairable areas, should be considered representative of the surface as a whole.

NOTE: It is important to ensure that the test is not made through double layers of fabric, since this would not be representative of the entire surface.

11.3.3 All punctures produced by the tester should be repaired with a 50 mm or 75 mm (2 in or 3 in) diameter doped fabric patch.

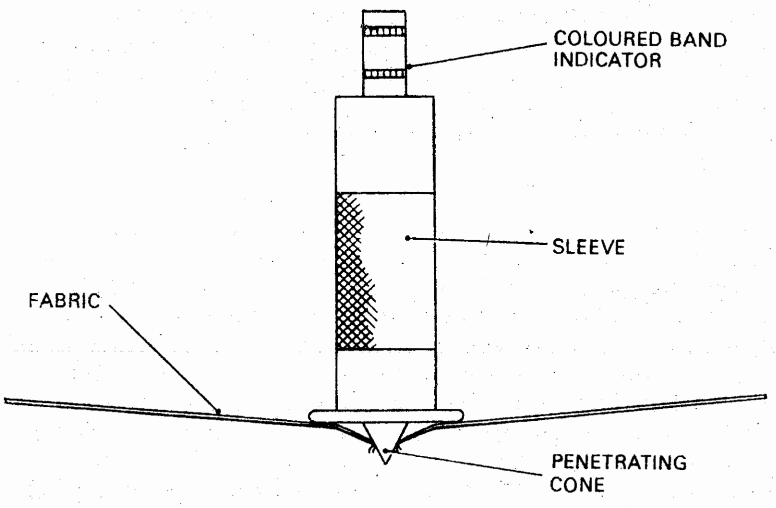


Figure 14 FABRIC TESTER

11.4 **Laboratory Tests.** Tensile strength tests are included in laboratory tests specified for new fabric and require the use of six warp and six weft samples, each 62 mm × 300 to 400 mm (2·5 in × 12 to 16 in). These tests are thus an uneconomical proposition for used fabric coverings on aircraft, since they would necessitate partial re-covering even if the fabric proved to be serviceable. It is recommended, therefore, that when the portable tester is considered unsatisfactory or inappropriate, samples of fabric should be sent to a laboratory acceptable to the CAA, for bursting strength tests in accordance with the specification for the particular type of fabric. These tests require the use of samples approximately 87 mm (3·5 in) in diameter.

11.4.1 Bursting strength tests can be carried out on a machine operating on the principle of applying force to a polished steel ball of 25·40 mm (1·00 in) diameter, the ball being in contact with the test sample, which is clamped between two circular brass plates having coaxial apertures of 44·45 mm (1·75 in) diameter. The load should be applied at a constant rate, and the load at break point is the bursting strength of the fabric. An Instron machine, which operates on this principle, is suitable for conducting tests on used aircraft fabric. As an alternative, a machine operating on hydraulic principles can be used; in such a machine, liquid pressure is applied at a constant rate to a rubber diaphragm, which is positioned to expand through a clamp aperture of 30·99 mm (1·22 in) diameter, exerting force against the fabric sample held between the clamps.

NOTE: The test methods referred to above are in accordance with the American Federal Test Method Standard No. 191, Methods 5120 and 5122 respectively.

12 MAN-MADE FABRICS Natural fabrics, such as cotton or linen, deteriorate in use as a result of the effects of sunlight, mildew or atmospheric pollution, and may require replacement several times during the life of an aircraft. With a view to lengthening the intervals between fabric replacements, several man-made fabrics have been developed and are approved in some countries for use on specific aircraft. The two main types of materials are polyester-fibre and glass-fibre, which are marketed under various trade names. The methods of covering aircraft with these fabrics are briefly discussed in paragraphs 12.1 and 12.2, but it is important that the instructions issued by the manufacturer of the aircraft or fabric should be carefully followed, and only the specified materials used.

12.1 **Polyester-Fibre Materials.** These materials may be attached to the structure by the method described in paragraph 5, by use of pre-sewn covering envelopes or by use of an approved adhesive at the points of contact with the structure. The materials used for attachment and stringing must be compatible with the main fabric.

12.1.1 Before stringing, polyester fibre covers are tautened by the application of heat, the degree of shrinkage being proportional to the heat applied. The most common method of applying heat is a household iron set at about 120°C ('wool' setting), and used in an ironing motion. Care is necessary to prevent the application of excessive heat as this may melt the fibre, or overtauten the cover and distort the underlying structure. Where non-tautening dope is used, the cover may be fully tautened prior to doping, but where tautening dope is used the initial shrinkage should leave the cover fairly slack, since tautening will continue over a period of months after the dope has been applied.

12.1.2 Repairs within the specified limits may be carried out as described in paragraph 10, or patches may be stuck on, using a suitable adhesive. Large patches should be tautened in the same way as the main cover.

12.2 **Glass-Fibre Materials.** Glass-fibre fabric is normally fitted to the mainplane and tailplane in a spanwise direction, being attached at the leading and trailing edges with a 50 mm (2 in) doped seam. Fuselages may conveniently be covered using four pieces of material at the top, bottom and sides, doped seams again being employed. Some glass-fibre material is pre-treated to make it compatible with cellulose acetate butyrate dope and is not suitable for use with cellulose nitrate dope.

12.2.1 The structure should be prepared by removing all sharp edges from the parts which will be in contact with the cover. Wooden parts should be lightly sanded, and metal edges taped to prevent chafing.

12.2.2 Glass-fibre material is only slightly tautened by doping, and must be a good initial fit, after which glass-fibre stringing should be fitted in the appropriate manner (paragraph 6.4).

12.2.3 Repairs within the specified limits may be made by cutting out the damaged area of fabric and doping on a cover patch which overlaps 50 mm (2 in) all round.

BL/6-26

Issue 2

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BASIC

ENGINEERING PRACTICES AND PROCESSES

DOPING

1 INTRODUCTION Fabric has been used from the early days of the aeroplane as a covering for fuselages and aerofoils. It still continues to provide good service for light aircraft but must be protected from deterioration by the application of a dope film. Natural fabrics, such as cotton or linen, deteriorate in use as a result of the effects of sunlight, mildew and atmospheric pollution. Man-made fibres resist some of these agents better than natural fabrics but still require protection. The dope film then achieves the following functions:

(a) Tautening of natural fabrics.

(b) Waterproofing.

(c) Airproofing.

(d) Lightproofing.

1.1 The object of this Leaflet is to provide guidance on the appropriate working conditions and methods of application of dope to aircraft fabric. Other Leaflets with related information are **BL/6-20** Paint Finishing of Metal Aircraft and **BL/6-25** Fabric Covering.

2 MATERIALS The basic film consists of dope but other materials are used in its application, as described in the following paragraphs.

2.1 **Dopes.** Dope consists of a number of resins dissolved in a solvent to permit application by brush or spray. This formulation is then modified with plasticizers and pigments to add flexibility and the required colour (see Figure 1). There are two types of dope in use, namely, cellulose nitrate and cellulose acetate butyrate. The former is usually known simply as nitrate dope and the latter as butyrate or CAB dope. The main difference between the two types of dope is the film base. In nitrate dope a special cotton is dissolved in nitric acid, whilst in butyrate dope cellulose fibres are dissolved in acetic acid and mixed with butyl alcohols. The plasticizers in the two dopes are also different, as are the resin balance and solvent balances. Dope must be stored under suitable conditions (see Leaflet **BL/1-7**), and has a tendency to become acid with age; if old dope is used for refinishing an aircraft it will quickly rot the fabric. Only fresh dope should be used, preferably buying it for the job in hand.

2.2 **Dope-proof Paints.** Due to the nature of the solvents used in dope, many paints will be attacked and softened by it. Dope-proof paint is therefore used to coat structure which will be in contact with the doped fabric. In the case of wooden structure, spar varnish provides a good dope-resistant finish, and an epoxy primer is suitable for metal structures.

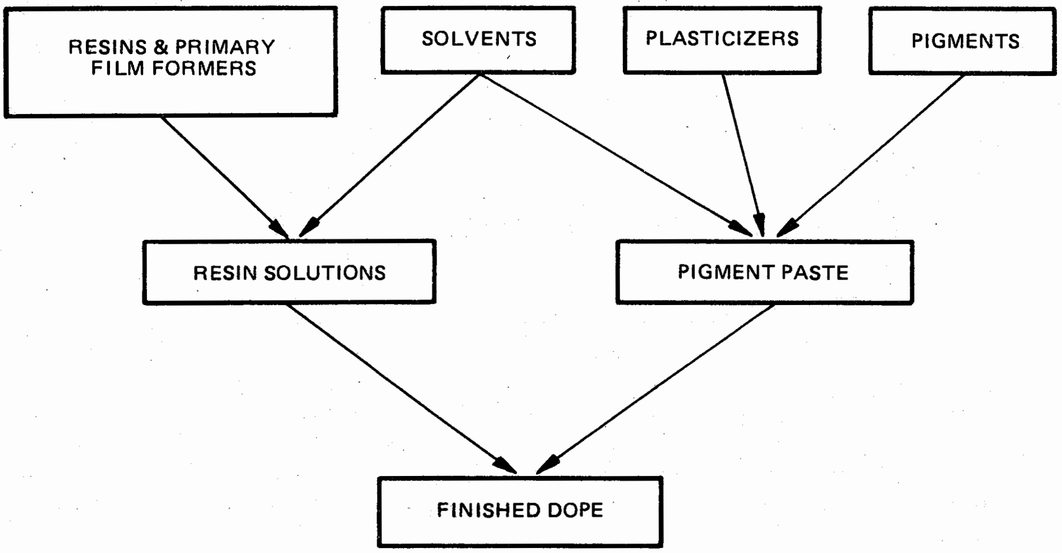


Figure 1 DOPE CONSTITUENTS

2.3 **Aluminium Dope.** To make the fabric lightproof and so prevent damage from ultra-violet radiation, an aluminium dope is used. This is usually supplied ready mixed but can be prepared by mixing aluminium paste or powder in clear dope but it is essential that the materials are obtained from an approved supplier and mixed in accordance with the manufacturer's instructions.

2.4 **Thinners.** Dopes are formulated in such a way that the solid constituents are suspended in the appropriate solvents. It will normally be necessary to thin or reduce the dope to make it suitable for spraying. It is important that only the thinners recommended by the manufacturer of the dope is used. The amount of thinners is determined from the manufacturer's recommendations and is modified by experience to take account of the equipment used and the atmospheric conditions. The viscosity can be measured by using a viscosity cup which contains a small hole in the bottom. In use, the cup is dipped into the dope and the flow of fluid is timed from when the cup is lifted from the container to the first break in the flow. In this way subsequent batches of dope can be mixed to exactly the same viscosity as the first batch. It is important that nitrate and butyrate dopes are mixed only with their own specialised thinners. A retarder, or anti-blush thinners, is a special type of thinners with slow-drying solvents. By drying more slowly they prevent the temperature drop and consequent moisture condensation that cause blushing in a dope finish. In use, the retarder replaces some of the standard thinners and can be used in a ratio of up to one part retarder to four parts of thinners. The use of more retarder than this is unlikely to achieve the desired result.

2.5 **Cleaning Agent.** Methyl-ethyl-ketone (MEK) is an important, relatively low cost, solvent similar to acetone. It is widely used as a cleaning agent to remove wax and dirt and to prepare surfaces for painting or re-doping. It is also useful as a solvent for cleaning spray guns and other equipment.

2.6 **Fungicides.** Since natural fabrics can be attacked by various forms of mildew and fungus, it may be necessary to provide protection for cottons and linens when doping. This is achieved by having a fungicide added to the first coat of dope. The dope is usually supplied ready mixed but can be prepared by using a fungicidal paste obtained from an approved supplier. If the latter course is necessary, the fungicidal paste should be mixed with the clear dope in accordance with the manufacturer's instructions; all fungicides are poisonous and, therefore, standard precautions should be taken to prevent any ill effects. Since mildew or mould form on the inside of the fabric, it is important to ensure that this first coat of dope completely penetrates the fabric.

2.7 **Tack Rags.** A tack rag is a rag slightly dampened with thinners and is used to wipe a surface after it has been sanded to prepare it for the application of the next coat. Proprietary cloths are also available.

2.8 **Sandpaper.** Sanding is carried out using wet-or-dry paper. This is a waterproof sandpaper that will remain flexible and not clog. The grades most likely to be used are 280, 360 and 600, the last mentioned being the finest grade.

2.9 **Drainage Eyelets and Inspection Rings.** Openings in the fabric cover for drain holes and inspection panels are always reinforced with eyelets or grommets (see Figure 2) and inspection rings. These are made from cellulose nitrate sheet and are doped into position (see Leaflet **BL/6-25**).

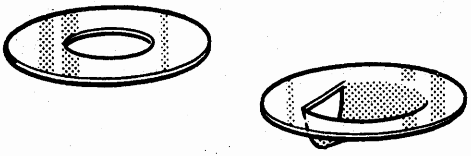


Figure 2 PLAIN AND SHIELDED DRAINAGE EYELETS

3 SAFETY PRECAUTIONS

The storage and use of dopes is covered by various Government regulations made under the Factories Act. This paragraph does not replace or override any of those regulations.

3.1 The hazard with the use of dopes comes about because of the flammability of the solvents that are used. The solvents have a low flash point and the vapour produced is heavier than air. Accumulations of vapour are readily ignited producing a serious fire which can spread very rapidly.

3.2 One of the most common causes of ignition is a spark produced by the discharge of static electricity. For example, during the course of doping, the fumes from the solvents will accumulate inside the structure. When the dope has dried, subsequent dry sanding and dusting will build up a static charge on the surface. If the operator is wearing rubber soled shoes he will be at the same electrical potential as the surface and nothing will happen. Should the charge on the operator now be lost through his touching some metal part of the spray shop, for example, and he then touches some metal part of the structure being doped the static charge will jump to earth creating a spark and igniting the fumes. The best way to prevent this type of problem is to eliminate the static charge altogether by grounding the structure being doped. A wire connected from the structure to a clean metal part of the spray shop will do the job satisfactorily. Clothing that is made of synthetic fibres will build up a static charge more readily than that made from cotton. Leather soled shoes will allow any static charge to be dissipated to ground. When spraying nitrate dope ensure that the spray gun, the operator and the structure being doped are all grounded together.

3.3 The standard of housekeeping in the spray shop is an important aspect of safety. If the floor becomes contaminated with dried nitrate dope overspray, subsequent sweeping will produce a static charge with the attendant risk of ignition and possible explosion. To clean the floor, it should be doused well with water and then swept whilst it is still wet. Since dopes will not be the only materials used in a spray shop, it should be noted that spontaneous combustion can be the result of a mixing of dope and zinc chromate oversprays.

3.4 The fumes created during the spraying process are hazardous to health as well as being a fire risk. Proper operator protection must be provided as recommended in the dope manufacturer's technical literature. At the first sign of any irritation of the skin or eyes, difficulty in breathing or a dry cough, the operator should stop work and seek medical advice.

3.5 Electrical equipment to be used in the spray shop must be of such a nature that it cannot ignite the vapours that will be present. Lead lamps must be of the explosion-proof variety and dopes must not be mixed using stirrers driven by portable electric drills.

4 WORKING CONDITIONS In order to accomplish a proper dope job it is important to control both the temperature and humidity of the air in the spray shop. In addition to this it is necessary to maintain sufficient airflow through the shop to remove the heavy vapours caused by atomisation and evaporation of the solvents used.

4.1 To maintain a suitable airflow through the spray shop it is necessary to install a fan at floor level since the vapours produced are heavier than air. The fan must be explosion proof, as must be all other electrical equipment installed in the area. The rate of air flow is dictated by the size of the spray shop and is the subject of various Government regulations. The discharge of the vapours may also be the subject of further requirements and the advice of the Factory Inspectorate should be sought. The air inlet to the spray shop should preferably be in an adjoining room, or at least behind a suitable baffle, in order to reduce draughts to a minimum. If the inlet is in a separate room then the air temperature can be raised to that required before entering the spray shop.

4.2 Many problems associated with doping can be traced to incorrect temperatures of the air or the dope. If the dope has been left overnight in a cold place then it will take many hours to bring it to the room temperature. Overnight heating of the spray shop is the most satisfactory method to prepare for doping since it usually results in more uniform temperatures throughout the shop. Rapid heating tends to result in stratified heating with the ceiling being considerably hotter than the floor level. Air temperature should be maintained between approximately 21 and 26 C for best results. If the temperature is too low the rapid evaporation of the solvents will lower the temperature of the surface to the point where moisture will condense and be trapped in the finish. Too high a temperature causes very rapid drying of the dope which can result in pin holes and blisters. The only satisfactory way to operate is to constantly monitor and control the air temperature as necessary.

4.3 In addition to the proper control of air temperature, the humidity of the air must also be controlled. The desirable range of air humidity is 45 to 50%. Satisfactory work can be produced with air humidity as high as 70% or as low as 20%, depending upon other variables such as temperature and air flow, but the control of the dope application at extremes is always more difficult.

4.4 Humidity should be measured with a hygrometer and, although direct reading instruments are available, the wet and dry bulb type is still the most common. In this instrument two thermometers are mounted side by side, the bulb of one being kept wet by water evaporating through a wick. To take a reading of humidity, both thermometers should be read and the difference between them noted; the wet bulb thermometer will be lower. After finding the dry bulb reading in Table 1, a reading should be taken across to the column headed with the depression of the wet bulb. The relative humidity as a percentage is given at the intersection of the two lines. **Example.** Assuming a dry bulb reading of 17°C and a wet bulb reading of 14°C, the depression of the wet bulb, that is the amount by which the reading of the wet bulb is reduced below that of the dry bulb, is 3°C. Reading across from 17°C in the dry bulb column to the depression column headed 3°C indicates a relative humidity of 72%.

4.5 In order to produce a satisfactory dope film, it is vitally important that all brushes, spray equipment and containers should be scrupulously clean. It is important that oil and water traps in the air lines are properly cleaned and that air reservoirs are drained of accumulated moisture. Pressure pots and spray guns should be thoroughly cleaned with thinners before the dope hardens. If passages have become obstructed with dried dope, the equipment should be dismantled and the parts soaked in methyl-ethyl-ketone or a similar solvent. Packings and seals should never be soaked in solvents or they will harden and become useless.

5 **PREPARATION PRIOR TO DOPING** Before the component is moved into the spray shop, normal housekeeping tasks should be carried out. All dirt, dust and dried overspray should be removed, bearing in mind the safety precautions in paragraph 3.3. Then the working conditions of temperature and humidity should be achieved with the dope and other materials being brought to the correct temperature.

5.1 An inspection should be made of the fabric-covered component to verify the following points:

(a) The structure has been painted with dope-proof paint where required.

(b) Correct and secure attachment of the fabric to the structure.

(c) Correct allowance for tautening of the cover where this is of a natural fabric such as cotton or linen. If the cover is too slack, no amount of doping will rectify this. If it is too tight, a lightweight structure, such as a control surface, could easily be distorted.

(d) All dust has been removed from the fabric.

(e) The fabric has reached the temperature of the air in the spray shop.

(f) Plastics components, such as windows and windscreens, are adequately protected against solvent attack; newspaper is not satisfactory for this purpose.

BL/6-26

TABLE 1

RELATIVE HUMIDITY (%)

Dry Bulb Reading (°C)	Depression of the Wet Bulb (°C)									
	1	2	3	4	5	6	7	8	9	10
0	82	–	–	–	–	–	–	–	–	–
1	83	–	–	–	–	–	–	–	–	–
2	84	68	–	–	–	–	–	–	–	–
3	84	69	54	–	–	–	–	–	–	–
4	85	70	56	42	–	–	–	–	–	–
5	86	72	58	45	32	–	–	–	–	–
6	86	73	60	47	35	23	–	–	–	–
7	87	74	61	49	37	26	14	–	–	–
8	87	75	63	51	40	29	18	7	–	–
9	88	76	64	53	42	31	21	11	1	–
10	88	77	65	54	44	34	24	14	5	–
11	88	77	66	56	46	36	26	17	8	–
12	89	78	68	57	48	38	29	20	11	3
13	89	79	69	59	49	40	31	23	14	6
14	90	79	70	60	51	42	33	25	17	9
15	90	80	71	61	52	44	36	27	20	12
16	90	81	71	62	54	46	37	30	22	15
17	90	81	72	64	55	47	39	32	24	17
18	91	82	73	65	56	49	41	34	27	20
19	91	82	74	65	58	50	43	35	29	22
20	91	83	74	66	59	51	44	37	30	24
21	91	83	75	67	60	52	46	39	32	26
22	92	83	76	68	61	54	47	40	34	28
23	92	84	76	69	62	55	48	42	36	30
24	92	84	77	69	62	56	49	43	37	31
25	92	84	77	70	63	57	50	44	38	33
26	92	85	78	71	64	58	51	46	40	34
27	92	85	78	71	65	59	52	47	41	36
28	93	85	79	72	65	59	53	48	42	37
29	93	86	79	72	66	60	54	49	43	38
30	93	86	79	73	67	61	55	50	44	39
31	93	86	80	73	67	62	56	51	45	41
32	93	86	80	74	68	62	57	52	46	42
33	93	87	80	74	69	63	58	52	47	43
34	93	87	81	75	69	64	58	53	48	44
35	93	87	81	75	70	64	59	54	49	44

NOTE: Intermediate values may be obtained by interpolation.

5.2 With the dope at the correct temperature, it should be mixed and then thinned to a suitable consistency for brush or spray application as appropriate. Whilst the dope is in storage the solid materials tend to settle and the purpose of mixing is to bring these materials back into suspension. To mix any dope satisfactorily, half the contents of the tin should be poured into a clean tin of the same size. The remaining material should be stirred until all the solid material is in suspension, paying particular attention to the bottom of the tin. The contents of the first tin should then be poured into the second tin and a check made that all pigment has been loosened from the bottom. Finally, the dope from one tin should be poured into the other, and back again, until it is thoroughly mixed.

6 APPLICATION TO NATURAL FABRIC The best looking and most durable film is produced by using multiple coats of a dope that is low in solids. A large number of thin coats, however, requires a great deal of time and modern dope schemes tend to use fewer, but thicker, coats than the earlier schemes. The dope scheme is a schedule listing the number and order of coats of each type of dope. Typical examples of schemes detailed in British Standard BS X26 are given in Tables 2, 3 and 4. The standard aircraft doping scheme is 752, but 751 is used on light structures that would be distorted by overtautening and 753 is used where an extra taut cover is required.

6.1 **Priming Coats.** This name is given to the first coats applied to the raw fabric. The first coat of dope provides the foundation for all the subsequent coats and as such its mechanical attachment to the fabric is very important. This mechanical attachment is formed by the dope encapsulating the fibres of the fabric. Nitrate dope has much better properties with regard to encapsulating the fibres and is therefore preferred for the first coat. The dope should be thinned by 25 to 50% and then applied by brush. The dope should be worked into the fabric to ensure adequate penetration, but not to the point where it drips through to the opposite surface. Since organic fabrics are subject to attack by mildew, a fungicide should be added to the dope used for this first coat (see paragraph 2.6). When applying the first coat of dope to the wings, the entire wing should first be doped on both sides aft of the front spar. The dope should be allowed to shrink the fabric before doping the leading edge. In this way the fabric will tauten evenly and adjust itself over the leading edge cap without forming wrinkles.

TABLE 2

LOW TAUTNESS SCHEME BS X26/751

Dope	Weight		Normally obtained in the following number of coats
	g/m²	oz/yd²	
(a) Transparent tautening dope	68	2·0	3 or 4
(b) Aluminium non-tautening finish	34	1·0	2
(c) Pigmented non-tautening finishes	34	1·0	1 or 2
Where a glossy finish is required, follow with:			
(d) Transparent non-tautening finish	34	1·0	1 or 2

NOTE: Where an aluminium finish is required, it is necessary to apply only (a) and (b) above, followed by (d) if required.

TABLE 3

MEDIUM TAUTNESS SCHEME BS X26/752

Dope	Weight		Normally obtained in the following number of coats
	g/m²	oz/yd²	
(a) Red oxide tautening dope	68	2·0	3
(b) Aluminium tautening dope	34	1·0	2
(c) Pigmented non-tautening finishes	34	1·0	1 or 2
Where an aluminium finish is required, the scheme should be:			
(d) Red oxide tautening dope	102	3·0	4
(e) Aluminium non-tautening finish	34	1·0	2
Where a glossy finish is required, follow with:			
(f) Transparent non-tautening finish	34	1·0	1 or 2

TABLE 4

HIGH TAUTNESS SCHEME BS X26/753

Dope	Weight		Normally obtained in the following number of coats
	g/m²	oz/yd²	
(a) Red oxide tautening dope	25·5	0·75	1
(b) Transparent tautening dope	161	4·75	6 or 7
(c) Aluminium tautening dope	34	1·0	2
(d) Pigmented non-tautening finishes	34	1·0	1 or 2
Where an aluminium finish is required, the scheme should be:			
(e) Red oxide tautening dope	25·5	0·75	1
(f) Transparent tautening dope	195	5·75	8
(g) Aluminium non-tautening finish	34	1·0	2
Where a glossy finish is required, follow with:			
(h) Transparent non-tautening finish	34	1·0	1 or 2

NOTE: A tolerance of ±20% is permissible on any of the weights given in Tables 2 to 4.

6.2 After the dope has dried for a minimum of 1 hour, the tapes, drainage eyelets or grommets and inspection panel rings may be applied. (See Leaflet **BL/6-25** for rib stitching procedures.) A heavy coat of nitrate dope should be brushed on where required and the tape laid into it, working it down to the surface and rubbing out any air pockets as the tape is laid. A further coat of clear dope is brushed over the top of the tapes. Drainage eyelets or grommets and inspection rings are attached in a similar fashion at this time. To ensure the best adhesion, eyelets or grommets and rings may be soaked in dope thinners for no more than two minutes to soften them. Inspection rings are best reinforced with a circular pinked-edge patch, a little larger than the ring, doped over the top. The holes in eyelets or grommets and rings are opened with a sharp, pointed knife after doping is complete. The taping is followed by another coat of clear dope which may be butyrate and may be applied by spray gun.

6.3 **Filling Coats.** When the first butyrate coat has fully dried, the fabric will feel rough due to the short fibre ends (the nap) standing up. This nap should be very lightly sanded off, using dry sandpaper, to leave a smooth finish. The surface should then be rinsed clean with water and dried thoroughly. Two full wet cross-coats of butyrate dope should now follow; a cross-coat is a coat of dope sprayed on in one direction and then covered with a second coat at right angles to it before the first coat dries. These in turn should be followed with one good cross-coat of aluminium dope after lightly sanding the clear dope to encourage adhesion. The aluminium coat is in its turn lightly wet sanded to produce a smooth surface, and the residue rinsed off with water. Once the aluminium coat has dried, it should be checked for continuity by shining a light inside the structure. The film should be completely lightproof.

6.4 **Finishing Coats.** The finishing coats of pigmented butyrate dope may now be sprayed on. The number of coats will be determined as a balance between quality and cost but should not be less than three. A high gloss finish is obtained by lightly sanding each coat when dry and spraying multiple thin coats rather than several thick coats. The use of a retarder in the colour coats will allow the dope to flow out and form a smoother film. The final coat should be allowed to dry for at least a month before it is polished with rubbing compound and then waxed. The surface should be waxed at least once a year with a hard wax to reduce the possibility of oxidation of the finish.

7 APPLICATION TO POLYESTER-FIBRE FABRIC Polyester-fibre fabrics are being increasingly widely used for covering aircraft because of their long life and resistance to deterioration. For this reason it is extremely important that the dope film is of the highest quality so that its life will match that of the fabric.

7.1 **Priming Coats.** Tautening of the fabric cover is not a function of the dope film where synthetic fabrics are used, although all dopes will tauten to some extent. Polyester-fibre fabrics are heat shrunk when the structure is covered. The most notable difference in doping a synthetic cover is the difficulty, when compared with natural fabrics, of obtaining a good mechanical bond between the dope and the fibres of the material. Unlike natural fibres the polyester filaments are not wet by the dope, and the security of attachment depends upon them being totally encapsulated by the first coat of dope. The first coat must be nitrate dope thinned in the ratio of two or three parts of dope to one part of thinners. This coat is then brushed into the fabric in order to completely encapsulate every fibre. The dope should form a wet film on the inside of the cover but it should not be so wet that it drips through to the opposite side of the structure. The initial coat should be followed by two more brush coats of nitrate dope thinned to an easy brushing consistency. Certain additives are approved by the material manufacturer for use with the first coat for improving adhesion to the fabric. However, since polyester is not organic, there is no need for a fungicide to be added to the first coat of dope.

7.2 **Filling Coats.** Taping and attaching of drainage eyelets or grommets and inspection rings follows the same procedure as for natural fabrics. The priming coats should be followed by spraying two full-bodied cross-coats of clear butyrate dope. After these coasts have completely dried they should be lightly sanded (400 grit) and cleaned thoroughly with a tack rag. One full cross-coat of aluminium dope should then be sprayed on and lightly wet sanded when dry, the residue being rinsed off with water. This coat should be tested to verify that it is lightproof by shining a light inside the structure.

7.3 **Finishing Coats.** The finishing coats should now be applied in the same manner as for natural fabrics. It should be noted that with a properly finished polyester cover the weave of the fabric will still show through the dope film. Because the fibres are continually moving, any attempt to completely hide them will result in a finish that does not have sufficient flexibility to resist cracking.

8 APPLICATION TO GLASS-FIBRE FABRIC Glass-fibre fabric has a loose weave which tends to make it difficult to apply to aircraft structures. To overcome this problem it is pre-treated with butyrate dope, and the covering and doping must be carried out in accordance with the manufacturer's installation instructions.

8.1 **Priming Coats.** Nitrate dope must not be used under any circumstances with this type of fabric. The first coat of clear butyrate dope is sprayed on with the dope being thinned only enough to permit proper atomisation. The atomising pressure must be set to the lowest possible that will permit proper atomisation without the dope being blown through the fabric. The coat should be heavy enough to thoroughly wet the fabric and soften the dope in the fabric, but must not be so heavy that it causes the dope to run on the reverse side of the fabric. If the dope is allowed to run in this way an orange peel finish will develop and the fabric will not tauten properly.

8.2 After the first coat has dried, further coats of butyrate dope should be sprayed on, each a little heavier than the one before it, until the weave fills and the fabric tautens; this may take as many as five coats. Tapes, drainage eyelets or grommets and inspection rings are applied in a coat of butyrate dope.

8.3 **Filling Coats.** Once the fabric is taut and the weave has been filled, two full-bodied brush coats of clear butyrate dope should be applied and allowed to dry thoroughly. The film should then be very carefully sanded, making sure that it is not sanded through to the fabric. Whilst the fabric is not damaged by ultra-violet radiation, the clear dope can deteriorate as a result of exposure and, therefore, a coat of aluminium dope should be sprayed on for protection and lightly wet-sanded smooth. After the aluminium dope has been sanded, the residue should be removed by washing with water and then the surface thoroughly dried.

8.4 **Finishing Coats.** The application of the finishing coats is carried out in the same manner as for natural fabrics. Several thin, wet coats of coloured butyrate dope will allow the surface to flow out to a glossy finish.

9 DOPING PROBLEMS The production of a doped finish that is both sound and attractive is dependent upon a great deal of care and attention being paid to detail at each stage of the finishing process. In spite of this, problems do occur and the following paragraphs detail some common ones and their possible causes.

9.1 **Adhesion.** There are two basic areas in which adhesion may be poor; between the fabric and the first coat of dope and between the aluminium coat and subsequent coats. Adhesion to the fabric, particularly polyester fabric, is largely dependent upon the technique used to ensure the encapsulation of the fibres. Adhesion to the aluminium coat may be impaired if too much aluminium powder was used or if the surface was not thoroughly cleaned after sanding. The use of a tack rag to finally clean a surface before applying the next coat is always recommended.

9.2 **Blushing** is a white or greyish cast that forms on a doped surface. If the humidity of the air is too high, or if the solvents evaporate too quickly, the temperature of the surface drops below the dew point of the air and moisture condenses on the surface. This water causes the nitrocellulose to precipitate out. Moisture in the spray system or on the surface can also cause blushing. Blushing can be controlled by reducing the humidity in the air (raising the temperature by several degrees may achieve this) or by using a retarder in the place of some of the thinners. A blushed area can be salvaged by spraying another coat over the area using a retarder instead of some of the thinners; the solvents attack the surface and cause it to flow out.

9.3 **Bubbles or Blisters** are caused by the surface of the dope drying before all the solvents have had time to evaporate. This may happen if a heavy coat of dope is applied over a previous coat that had not fully dried.

9.4 **Dull Finish.** The gloss of butyrate dope may be improved by the addition of up to 20% retarder in the last coat. Excessive dullness may be caused by holding the spray gun too far from the surface so that the dope settles as a semi-dry mist. Small dull spots may be due to a porous surface under the area.

9.5 **Fisheyes.** These are isolated areas which have not dried due to contamination of the surface with oil, wax or a silicone product. Cleanliness is important, especially when refinishing a repair. All wax should be removed using a suitable solvent before attempting to re-dope the surface.

9.6 **Orange Peel.** This is caused by insufficient thinning of the dope or holding the spray gun too far from the surface. It can also be caused by too high an atomising pressure, use of thinners that is too fast drying or by a cold, damp draught over the surface.

9.7 **Pinholes.** These are smaller versions of a blister. Apart from the causes listed in paragraph 9.3, they can be caused by water or oil in the spray system. An air temperature that is too high can also be a cause.

9.8 **Roping.** This is a condition in which the surface dries as the dope is being brushed, resulting in an uneven surface. This is common when the dope is cold and has not been brought up to the temperature of the spray shop. When applying dope with a brush, it should not be overbrushed. The brush should be filled with dope then stroked across the surface and lifted off. The pressure applied to the brush should be sufficient to ensure the proper penetration of the dope.

9.9 **Rough Finish.** Dirt and dust on the surface, insufficient sanding and too low a working temperature can all cause a rough finish.

9.10 **Runs and Sags.** This type of defect is caused by too thick a coat, especially on vertical surfaces. This can be the result of incorrectly adjusted spray equipment or incorrect technique.

9.11 **Wet Areas.** This is a larger version of the defect described in paragraph 9.5.

10 GENERAL CONSIDERATIONS

10.1 The weight of the dope applied to the fabric is an indication that the scheme has been correctly applied. In the BS X26 doping schemes the weight per unit area is given and should be checked by doping a test panel at the same time as the structure. The fabric is weighed before doping and then again after doping, the difference being the weight of the dope film. United States Military Specifications call for a minimum dope weight of 161 g/m^2 (4·75 oz/yd^2). A tolerance of ±20% may be applied to the weights given in BS X26.

10.2 When an aircraft is re-covered and re-doped it is essential that it is re-weighed and a new Weight Schedule raised (see Leaflet **BL/1-11**).

10.3 After the re-covering, repair and doping of control surfaces it is essential that the static balance of each surface is checked against the manufacturer's requirements. Addition of weight aft of the hinge line without correction of the static balance is likely to cause flutter of the control surface.

BL/6-27

Issue 1.

1*st April*, 1972.

BASIC

ENGINEERING PRACTICES AND PROCESSES

SOLID RIVETS

1 INTRODUCTION This Leaflet gives guidance on the various types of solid rivets used in aircraft structures. It includes tables of the principal types of British and American rivets and gives guidance on the heat treatment of aluminium alloy rivets. Similar information concerning hollow rivets is given in Leaflet **BL/6-28** and guidance on riveting practice is given in Leaflet **BL/6-29.**

NOTE: This Leaflet incorporates all the relevant information previously published in Leaflet AL/7-5, Issue 4.

2 GENERAL Rivets are designed to be strong in shear and should not be subjected to excessive tension loads. The two main groups of solid rivets are those with protruding heads, mostly used in the interiors of aircraft, and those with countersunk heads which are used on exterior surfaces where a flush finish is required. If protruding rivets are used externally they are usually of the mushroom (Figures 1 and 2) or universal (Figure 3) head types.

2.1 British and American rivets are not manufactured to identical specifications nor from identical materials but, since American rivets are not always available, it is often necessary to repair American-built aircraft using British rivets. Unless there are specific instructions to the contrary the information given in paragraph 5 may be used as a guide in choosing British substitutes for American rivets. When American rivets are available, all protruding-head rivets in American-built aircraft may be replaced by universal head rivets which have now been adopted as the standard for protruding-head rivets in that country.

NOTE: Deviations from the original repair scheme approved for an aircraft type, e.g. use of rivets of a different material, may only be made if written authority is obtained from an approved design organisation. The possibility of electro-chemical reaction between rivets and the surrounding material must always be considered.

2.2 Both British and American rivets are identified by head or shank end markings except where a material is easily identified by its natural colour or weight. Certain British rivets are also coloured all over to enable them to be more readily distinguished.

NOTE: Identification colouring requirements for British aluminium or aluminium alloy rivets are contained in Specification DTD 913.

2.3 Some aircraft manufacturers specify rivets made to the standards of their own companies, and may also use a different colour identification for standard rivets.

3 BRITISH SOLID RIVETS Standards for British rivets are issued by the Society of British Aerospace Companies (AS series) and the British Standards Institute (SP series). Rivets are identified by a Standard number and a part number. The Standard number

identifies the head shape, material and finish, and the part number indicates the size in terms of shank diameter (thirty-seconds of an inch or millimetres × 10) and length (in sixteenths of an inch or millimetres). For example, an AS162 rivet $\frac{1}{8}$ inch diameter and $\frac{1}{2}$ inch long would be AS162-408, and an SP160 rivet 4 mm in diameter and 16 mm long would be SP160-40-16.

NOTE: 'AS' close tolerance rivets are supplied in length graduations of 1/32 inch. The part number system remains the same, however, and odd 1/32 inches in length are shown by the addition of '·5' after the normal part number.

3.1 **Materials.** The materials used for the manufacture of British rivets comply with DTD or British Standards (BS) Specifications, the actual material being quoted in the relevant tables. Rivets now manufactured from BS L86 were, until September 1961, manufactured from BS L69. Where the rivets require heat treatment, i.e. all BS L37 rivets, this is also indicated in the tables by the symbol '††' and the procedures explained in paragraph 6.

3.2 **'AS' Rivets.** Table 1 gives a list of the solid rivets which conform to the Aircraft Standards of the Society of British Aerospace Companies; these rivets are made in a range of sizes from $\frac{1}{16}$ inch to $\frac{3}{8}$ inch diameter and from $\frac{1}{8}$ inch to 2 inches long except that copper rivets to AS 469 are only made in diameters up to $\frac{1}{4}$ inch. Figure 1 illustrates the AS solid rivets and indicates the method of measuring the length 'L'. It will be seen from the Table that most of these rivets are obsolescent and have been replaced by rivets conforming to SP Standards.

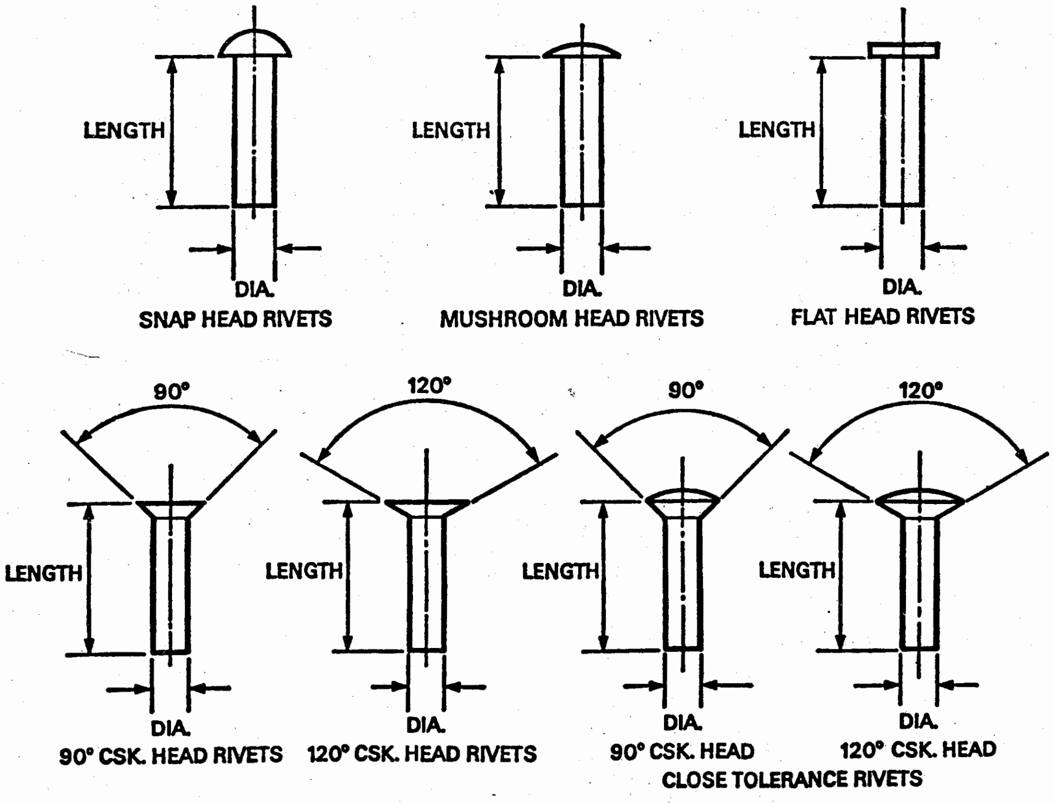


Figure 1 'AS' RIVETS

TABLE 1

Aircraft Standard Number	*Material*	*Material Specification*	*Head Type*	*Finish*	*Identification mark on end of shank*	*Remarks*
AS 155*	aluminium	L 36	snap	black anodic	A	superseded by SP 77
AS 156*	aluminium alloy	L 37††	snap	natural	D	superseded by SP 78
AS 157*	aluminium alloy	L 58	snap	green anodic	X	superseded by SP 79
AS 455*	mild steel	BS 1109	snap	cadmium		superseded by SP 76
AS 457*	monel	DTD 204	snap	natural	M	superseded by SP 81
AS 458*	tungum	DTD 367	snap	cadmium		
AS 459	copper		snap	natural		non-magnetic
AS 2227*	aluminium alloy	L 86	snap	violet anodic	S	superseded by SP 80
AS 4694*	monel	DTD 204	snap	cadmium	M	superseded by SP 82
AS 158*	aluminium alloy	L 37††	mushroom	natural	D	superseded by SP 83
AS 159*	aluminium alloy	L 58	mushroom	green anodic	X	superseded by SP 84
AS 2228*	aluminium alloy	L 86	mushroom	violet anodic	S	superseded by SP 85
AS 160*	aluminium	L 36	90° csk.	black anodic	A	
AS 161*	aluminium alloy	L 37††	90° csk.	natural	D	
AS 162*	aluminium alloy	L 58	90° csk.	green anodic	X	
AS 460	mild steel	BS 1109	90° csk.	cadmium		magnetic
AS 462	monel	DTD 204	90° csk.	natural	M	
AS 466*	tungum	DTD 367	90° csk.	cadmium		
AS 467	copper		90° csk.	natural		non-magnetic
AS 2229*	aluminium alloy	L 86	90° csk.	violet anodic	S	
AS 4695	monel	DTD 204	90° csk.	cadmium		
AS 4645	aluminium alloy	L 86	90° csk.	violet anodic	S	shank $\frac{1}{64}$ in. oversize, "R" on head
AS 4646	aluminium alloy	L 37††	90° csk.	plain anodic	D	
AS 163*	aluminium	L 36	120° csk.	black anodic	A	
AS 164*	aluminium alloy	L 37††	120° csk.	natural	D	
AS 165*	aluminium alloy	L 58	120 °csk.	green anodic	X	

TABLE 1—*continued*

Aircraft Standard Number	*Material*	*Material Speci-fication*	*Head Type*	*Finish*	*Identi-fication mark on end of shank*	*Remarks*
AS 463	mild steel	BS 1109	120° csk.	cadmium		magnetic
AS 465	monel	DTD 204	120° csk.	natural	M	
AS 468*	tungum	DTD 367	120° csk.	cadmium		
AS 2230*	aluminium alloy	L 86	120° csk.	violet anodic	S	
AS 4696	monel	DTD 204	120° csk.	cadmium	M	
AS 4647	aluminium alloy	L 86	120° csk.	violet anodic	S	shank $\frac{1}{64}$ in. oversize, "R" on head
AS 4648	aluminium alloy	L 37††	120° csk.	plain anodic	D	
AS 469	copper		flat	natural		non-magnetic
AS 2918	aluminium alloy	L 37††	90° raised csk.	natural		close tolerance
AS 3362	aluminium alloy	L 86	90° raised csk.	violet anodic		close tolerance
AS 2919	aluminium alloy	L 37††	120° raised csk.	natural		close tolerance
AS 3363	aluminium alloy	L 86	120° raised csk.	violet anodic		close tolerance

* Obsolescent.

†† Require heat treatment before driving.

3.3 **'SP' Inch Size Rivets.** Table 2 gives a list of the solid rivets which conform to the British Standards Institute Aerospace Standards for rivets in inch sizes. These rivets are made in a range of sizes from $\frac{1}{16}$ inch to $\frac{3}{8}$ inch in diameter and from $\frac{1}{8}$ inch to 3 inches long, and are illustrated in Figure 2.

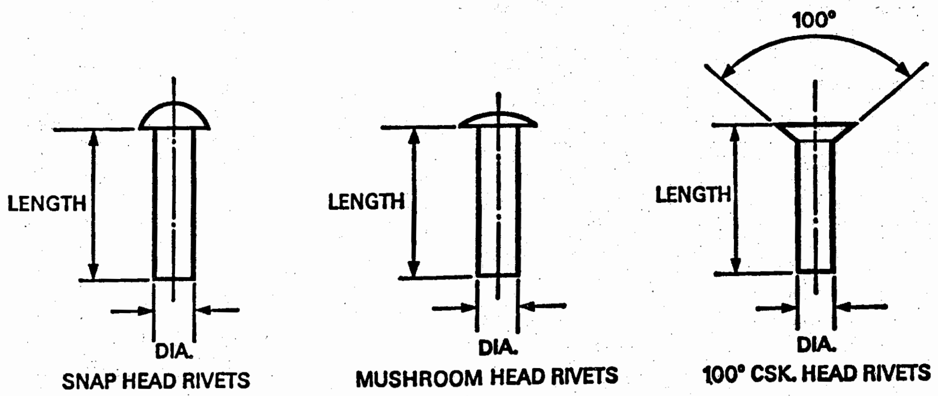


Figure 2 'SP' INCH SIZE RIVETS

TABLE 2

British Standard Number	*Material*	*Material Specification*	*Head Type*	*Finish*	*Identification mark***	*Remarks*
SP 68	aluminium	L 36	100° csk.	black anodic	I*	
SP 69	aluminium alloy	L 37††	100° csk.	natural	7	
SP 70	aluminium alloy	L 58	100° csk.	green anodic	8	
SP 71	aluminium alloy	L 86	100° csk.	violet anodic	O†	
SP 76	steel	BS 1109	snap	cadmium		magnetic, superseding AS 455
SP 77	aluminium	L 36	snap	black anodic	I	superseding AS 155
SP 78	aluminium alloy	L 37††	snap	natural	7	superseding AS 156
SP 79	aluminium alloy	L 58	snap	green anodic	8	superseding AS 157
SP 80	aluminium alloy	L 86	snap	violet anodic	O	superseding AS 2227
SP 81	monel	DTD 204	snap	natural	M	superseding AS 457
SP 82	monel	DTD 204	snap	cadmium	M	non-magnetic, superseding AS 4694
SP 83	aluminium alloy	L 37††	mushroom	natural	7	superseding AS 158
SP 84	aluminium alloy	L 58	mushroom	green anodic	8	superseding AS 159
SP 85	aluminium alloy	L 86	mushroom	violet anodic	O	superseding AS 2228
SP 86	steel	BS 1109	100° csk.	cadmium		magnetic
SP 87	monel	DTD 204	100° csk.	natural	M	non-magnetic
SP 88	monel	DTD 204	100° csk.	cadmium	M	non-magnetic

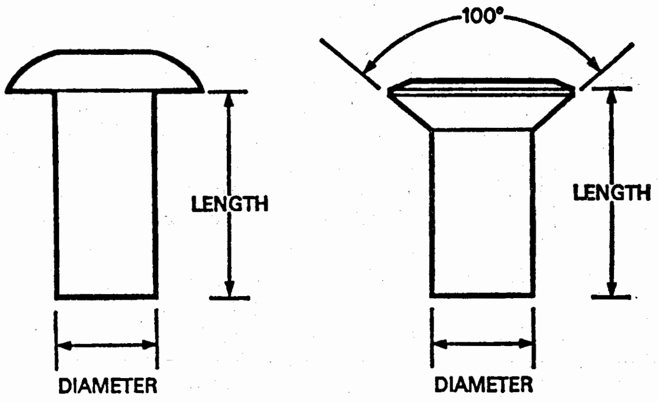
* SP 68 rivets, prior to Amendment No. 1 to the Standard, published in September, 1959, bore no identification marks.

† SP 71 rivets, prior to Amendment No. 1 to the Standard, published in September, 1959, bore the identification mark '9' to signify manufacture from L 69 material.

†† Require heat treatment before use.

** May be on head or shank end, depending on rivet size.

3.4 **'SP' Metric Size Rivets.** Table 3 gives a list of rivets which conform to the British Standards Institute Aerospace Standards for rivets in metric sizes. These are confined, at present, to universal head and 100° countersunk truncated radiused head rivets in diameters of 2·4 to 9·6 mm and lengths of 4 to 60 mm. The identification marks listed in the table are applied to the shank end only. Figure 3 illustrates the shape of these rivets.



UNIVERSAL HEAD

100° COUNTERSUNK
TRUNCATED RADIUSED HEAD

Figure 3 'SP' METRIC SIZE RIVETS

TABLE 3

British Standard Number	*Material*		*Head Type*	*Finish*	*Identification*
	Type	*Specification*			
SP 142	al. alloy	L 86	100° csk.†	violet anodic	indented dot
SP 157	al. alloy	L 86	universal	violet anodic	indented dot
SP 158	monel	DTD 204	universal	natural	two indented dots
SP 159	monel	DTD 204	universal	cadmium	nil
SP 160	al. alloy	L 58	universal	green anodic	raised cross
SP 161	al. alloy	L 58	universal	plain anodic	raised cross
SP 162	al. alloy	L 37††	universal	natural	raised broken line and centre point
SP 163	al. alloy	L 86	universal	plain anodic	indented dot

† 100° countersunk, truncated radiused head.
†† Require heat treatment before driving.

4 AMERICAN SOLID RIVETS American rivets in general use are listed in Table 4, together with the means of identification which, since all the aluminium alloy rivets are anodised, is by means of head markings rather than colour. The code used for the classification of American rivets is similar to that used for British rivets and is best illustrated by an example such as MS 20470 AD 5-12, which has the following meaning:—

(i) MS signifies Military Standard

(ii) 20470 is a code for the head shape and basic material (aluminium universal head in this instance)

(iii) AD is a code for the rivet material (2117 aluminium alloy in this instance, see paragraph 4.1)

(iv) 5 is the diameter in thirtyseconds of an inch

(v) 12 is the length in sixteenths of an inch.

TABLE 4

Rivet and Material Code	*Material*	*Material Specification*	*Head Type*	*Identification mark on head*	*Remarks*
MS 20426A	aluminium	1100	100° csk.	nil	supersedes AN 426A
MS 20426B	aluminium alloy	5056	100° csk.	raised cross	supersedes AN 426B
MS 20426AD	aluminium alloy	2117	100° csk.	dimple	supersedes AN 426AD
MS 20426DD	aluminium alloy	2024††	100° csk.	raised double dash	supersedes AN 426DD
MS 20426D	aluminium alloy	2017††	100° csk.	raised dot	supersedes AN 426D
MS 20427	carbon steel	QQ-W-409 or QQ-S-633	100° csk.	recessed triangle	supersedes AN 427
MS 20427F	corrosion resistant steel	QQ-W-423	100° csk.	recessed dash	supersedes AN 427F
MS 20427M	monel	QQ-N-281	100° csk.	nil	supersedes AN 427M
MS 20427C	copper	QQ-W-341	100° csk.	nil	supersedes AN 427C
MS 20470A	aluminium	1100	universal	nil	supersedes AN 470A
MS 20470B	aluminium alloy	5056	universal	raised cross	supersedes AN 470B
MS 20470AD	aluminium alloy	2117	universal	dimple	supersedes AN 470AD
MS 20470DD	aluminium alloy	2024††	universal	raised double dash	supersedes AN 470DD
MS 20470D	aluminium alloy	2017††	universal	raised dot	supersedes AN 470D
MS 20613 P/Z	carbon steel	QQ-S-633	universal	recessed triangle	supersedes MS 20435
MS 20613 C	corrosion resistant steel	QQ-W-423	universal	nil	supersedes MS 20435
MS 20615 M	monel	QQ-N-281	universal	double dimple	supersedes MS 20435
MS 20615CU	copper	QQ-W-341	universal	nil	supersedes MS 20435

NOTE: For MS 20613 rivets the letter P is added to indicate cadmium plated carbon steel and the letter Z to indicate zinc plated carbon steel.

†† Require heat treatment before use.

4.1 American wrought aluminium and aluminium alloys are identified by a four digit index system. The first digit indicates the main alloying element, the second indicates modifications to the original alloy and the last two indicate the aluminium purity or the specific alloy. These numbers are followed by a letter indicating the temper condition. Table 5 shows the aluminium and aluminium alloys used in the manufacture of rivets and the condition in which they are normally supplied to the user. Further information on temper designations is contained in paragraph 4.3.

4.2 MS Standards provide for two types of rivets, i.e. the universal head which is standard for protruding head rivets, and the 100° countersunk head which is standard for all flush head rivets.

TABLE 5

Specifications of aluminium/alloy	*Condition in which normally supplied*
1100	— F as fabricated
2017	— T4 solution heat-treated
2024	— T4 solution heat-treated
2117	— T4 solution heat-treated
5056	— H32 strain hardened and then stabilised

4.3 **American Temper Designations.** American aluminium alloy rivets are given a temper designation to signify their condition. Non heat-treatable alloys such as 5056 have attained their maximum strength by working and are driven in the 'as received' condition. Of the heat-treatable alloys, 2117 does not benefit from further heat treatment and is driven in the 'as received' condition, 2024 must be solution treated before use and it is recommended that 2017 rivets of ⅜ inch diameter and larger are also solution treated to prevent cracking. Heat-treatable alloy rivets are supplied in the T4 condition (solution treated by the rivet manufacturer); when solution treated by the user before driving the final temper is T31 and when driven 'as received' the final temper is T3.

5 SELECTION OF RIVETS

The following paragraphs give general guidance on the factors which must be considered when rivets of either British or American manufacture are specified for a particular application.

5.1 The rivet material must be compatible with the material in which it is to be used, for reasons of strength and resistance to corrosion. L 58 (or 5056) rivets must be used in magnesium structures, monel rivets in titanium and stainless steel, and aluminium or copper rivets in parts of similar or non-metallic materials in non-structural applications. The type of aluminium alloy rivets to be used for a particular repair depends on the strength of the alloy with which it is used. Table 6 indicates the shear strengths of various rivet materials. Rivets of less shear strength than those specified in a Repair Manual or drawing should not be used without the approval of the manufacturer. L 37 (or 2024) rivets require heat treatment before use and if they are to be replaced by L 86 (or 2117) rivets through lack of treatment facilities, the number of rivets must be increased to provide the same shear strength. Cadmium plated rivets should not be used in areas where temperatures of 250°C or more are likely to be encountered.

5.2 The shear strength of the rivets used is not the only factor which determines the strength of a riveted joint. Generally, if the thickness of the sheets is less than half the diameter of the rivets used, failure of the joint will depend on the bearing stress rather than on the shear stress in the rivets.

5.3 The diameters and types of rivets to be used in repairs are normally specified either in the Repair Manual or in the repair scheme, but in the absence of specific instructions, 3/32 inch rivets should be used for 24 and 22 s.w.g. material, 1/8 inch rivets for 20 and 18 s.w.g. material and 5/32 inch for 16 s.w.g. If rivets of reduced diameter have to be substituted during repair work, the total number of rivets must be increased to provide equivalent cross-sectional area. Where 22 s.w.g. and thinner material is concerned, and there are no specific instructions regarding repair after a riveting failure, the substitution of mushroom head rivets for snap head rivets should be considered.

NOTE: Shear strength of a rivet is proportional to its cross-sectional area and not its diameter. Thus four rivets 1/16th inch diameter must be used to replace one rivet 1/8 inch diameter.

5.4 Where a large diameter rivet is used with thin sheet metal, the pressure required to close the rivet generally causes an undesirable bulging of the sheet around the rivet head. A diameter/thickness ratio not exceeding 3 is satisfactory for protruding head rivets but for countersunk rivets this ratio should not exceed 1·5.

5.5 When British rivets have to be used in American-built aircraft, rivets of the material with the nearest equivalent shear strength to the material of the original American rivets should be selected. If, as occurs in some instances, the available British rivets have lower shear strengths than the American rivets, either the total number of rivets should be increased or rivets of larger diameter should be used to make the strength of the joint in bearing and shear not less than it was originally. However, it should be borne in mind that an increase in the size of the rivets does not necessarily increase the strength of a joint; indeed, if the rivet sizes are increased beyond a certain amount, a reduction in strength will result.

TABLE 6

American Rivet Materials			*British Rivet Materials*		
Material Specification	*Tensile Strength lb/in²*	*Shear Strength lb/in²*	*Material Specification*	*Tensile Strength lb/in²*	*Shear Strength lb/in²*
5056–H32	38000	24000	L 58	35500	28500
2117–T4	38000	26000	L 86	38000	29500
2017–T4	55000	33000	L 37	56000	36000
2024–T4	62000	37000	L 37	56000	36000

5.6 To ensure correct seating, countersunk head rivets should always be installed in dimples or countersunk holes of the same angle as the rivet head. Rivets with countersunk heads of 70° or 82° included angle are often used in positions where sealing is of primary importance, such as in integral fuel tanks, and when these rivets require replacement care is necessary to ensure that rivets with the correct angle heads are selected.

6 **HEAT TREATMENT** Rivets which require heat treatment prior to driving should be treated in accordance with the requirements of the relevant specification.

6.1 Generally the most satisfactory way of heating rivets is to immerse them in a salt bath, although muffle furnaces of the circulating hot air type are also used. The rivets should be placed in wire baskets or perforated containers and immersed in the salts for 15 minutes, then quenched in water at a temperature of not more than 40°C. The time between removal from the bath and quenching must be not more than 10 seconds to achieve satisfactory properties. The temperature of the bath must be 495 ± 5°C (maximum 496°C for 2024 rivets) and if the maximum is exceeded at any time the rivets should be rejected. Rivets which have been heated in a salt bath must be thoroughly washed after quenching to remove all traces of salt.

6.2 BS L37 rivets commence to age harden immediately after quenching and should normally be used within 2 hours of treatment (a period of 20 minutes is specified for 2024 rivets). Age hardening can be delayed by storing the rivets at a low temperature immediately after quenching. At a temperature of 0°C to –5°C they will keep satisfactorily for 45 hours and at a temperature of –15°C to 20°C for 150 hours, but must be used within 2 hours of removal from cold storage.

6.3 If the treated rivets have not been used within the prescribed time after solution treatment they may be re-treated up to a maximum of three times. Further heat treatments would increase the grain size and result in low strength even after ageing. Further guidance on the heat-treatment of wrought aluminium alloys is given in Leaflet **BL/9–1.**

6.4 Precautions must be taken to prevent the accidental use of aged rivets. A satisfactory method of ensuring this is to use the rivets from trays or boxes which are coloured to indicate the periods during which the rivets may be used. Thus a suitable colour code might permit only rivets from green trays to be used during the first two hours of a working day, after which only rivets from blue trays should be used for the next two hours and so on. American 2024 rivets could be controlled in a similar manner but the elapsed time should not exceed 20 minutes.

BL/6-28

Issue 1.

1*st April,* 1972.

BASIC

ENGINEERING PRACTICES AND PROCESSES

HOLLOW RIVETS AND SPECIAL FASTENERS

1 INTRODUCTION This Leaflet gives general information on the various types of hollow rivets used in aircraft structures. It lists the principal types of British and American tubular, hollow and self-sealing rivets and also includes information on other types of fasteners which are widely used as replacements for nuts and bolts. Information on solid rivets is given in Leaflet **BL/6-27** and guidance on the appropriate riveting practices in Leaflet **BL/6-29**.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet AL/7-6, Issue 1, dated 1st July, 1956.

2 GENERAL Hollow rivets may be broadly classified into two main groups, those which are closed by drawing a mandrel through the bore and those which are closed by hammering. The first group are known as 'blind' rivets, because they may be installed when only one side of the rivet hole is accessible.

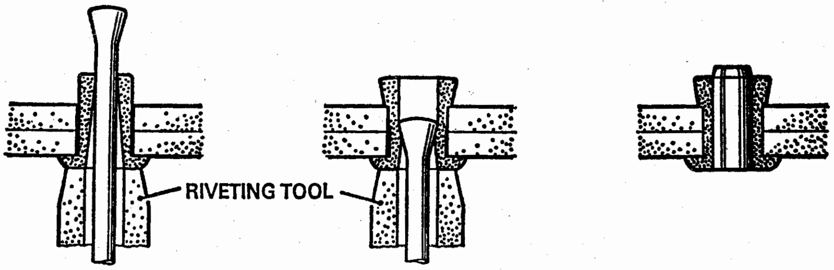
2.1 It is most important that the correct tools are used, with the types of rivets mentioned in this Leaflet, a variety of tools being available for each type of rivet. Power tools are normally used by aircraft manufacturers, but hand tools are often used with the smaller rivet sizes for repair work.

2.2 Blind rivets may only be used to replace solid rivets when this is permitted by the repair scheme. In the absence of specific instructions it is important to ensure that the rivet is either of the same material as the original solid rivet or, if dissimilar, has the minimum potential difference with the material being riveted, otherwise there may be a risk of corrosion (see Leaflet **BL/4-1**). The blind rivet must also possess equivalent shear strength and this may be achieved by plugging the rivet bore.

3 BLIND RIVETS The blind rivets discussed in this paragraph are all closed by pulling a mandrel through the bore. In some cases the mandrel also plugs the rivet, but in others a separate sealing pin must be driven in after the rivet has been closed.

3.1 **Chobert Rivets.** Chobert rivets are manufactured with either snap or countersunk heads and are normally supplied in tubes for ease of assembly on the mandrel. The action of closing a Chobert rivet is shown in Figure 1, initial movement of the mandrel down the tapered bore forming the head and subsequent movement expanding the shank to fill the rivet hole. Sealing pins are an interference fit in the rivet bore and, apart from increasing shear strength, will prevent the ingress of moisture.

3.1.1 The Chobert rivets which have been given AGS numbers by the Society of British Aerospace Companies are shown in Table 1, but many other types are suitable for



RIVET THREADED ON MANDREL AND INSERTED IN HOLE

BROACHING ACTION: MANDREL EXPANDING RIVET SHANK

RIVET PLUGGED BY SEALING PIN

Figure 1 CLOSING CHOBERT RIVETS

use on aircraft, full details of materials, size and grip lengths being quoted in the manufacturer's literature. For ordering purposes Chobert rivets may be identified by either the AGS number or a four figure code number assigned to it by the manufacturer. This is followed by a further four figures indicating the size of the rivet. The first two figures of the size code indicate the diameter and the second two the length (both in thirtyseconds of an inch), except that if the AGS number is being quoted a zero in the diameter code is disregarded. As an example, a steel snap head rivet, $\frac{5}{32}$ inch diameter and $\frac{3}{8}$ ($\frac{12}{32}$) inch long, would be known by the manufacturer as 1201-0512, but the same rivet could also be ordered as AGS 2040/512.

NOTE: The length referred to for ordering purposes is the length of the rivet as supplied (i.e. shank length of snap head rivets and total length of countersunk rivets) and not the thickness to be riveted (i.e. grip).

3.1.2 The size code used for sealing pins fitted to snap head rivets is the same as the code used for the rivet itself, but if a sealing pin is to be fitted to a countersunk rivet the preceding length should be quoted. For example, a sealing pin for an AGS 2045/512 rivet (snap head) would be AGS 2047/512, but a sealing pin for an AGS 2068/512 rivet (100° countersunk) would be AGS 2047/510.

TABLE 1
CHOBERT RIVETS

AGS Number	*Maker's Code*	*Head Type*	*Material Spec.*	*Anti-corrosive treatment*	*Identification*
2040	1201	snap	DTD 720	cad. plated	magnetic
2045	1211	snap	L86	anodised	dyed violet
2041	1203	120° countersunk	DTD 720	cad. plated	magnetic
2046	1213	120° countersunk	L86	anodised	dyed violet
2067	1204	100° countersunk	DTD 720	cad. plated	magnetic
2042	1281	sealing pin	DTD 904	cad. plated	magnetic
2047	1282	sealing pin	L64	anodised	plain

3.1.3 A range of Chobert rivets with oversize shanks is also available and may be used for repair work on aircraft. This is an advantage when rivets have been removed, since the increase in diameter is of the order 0·015 to 0·020 inches, depending on rivet size, so that repositioning of holes or re-stressing of joints is unnecessary.

3.2 **Avdel Rivets.** These rivets are similar to Chobert rivets, but each is fitted with its own stem (mandrel), the component parts being referred to as the body and stem respectively. The stem is pulled into the body to close the rivet and, at a predetermined load, breaks proud of the manufactured head, leaving part of the stem inside the body in the form of a plug. Excess stem material may be nipped off and milled flush with the rivet head when required, e.g. on external surfaces, but stainless steel and titanium rivet stems break flush with the rivet head at the maximum grip range limit, and milling may not be necessary. The action of closing an Avdel rivet is shown in Figure 2.

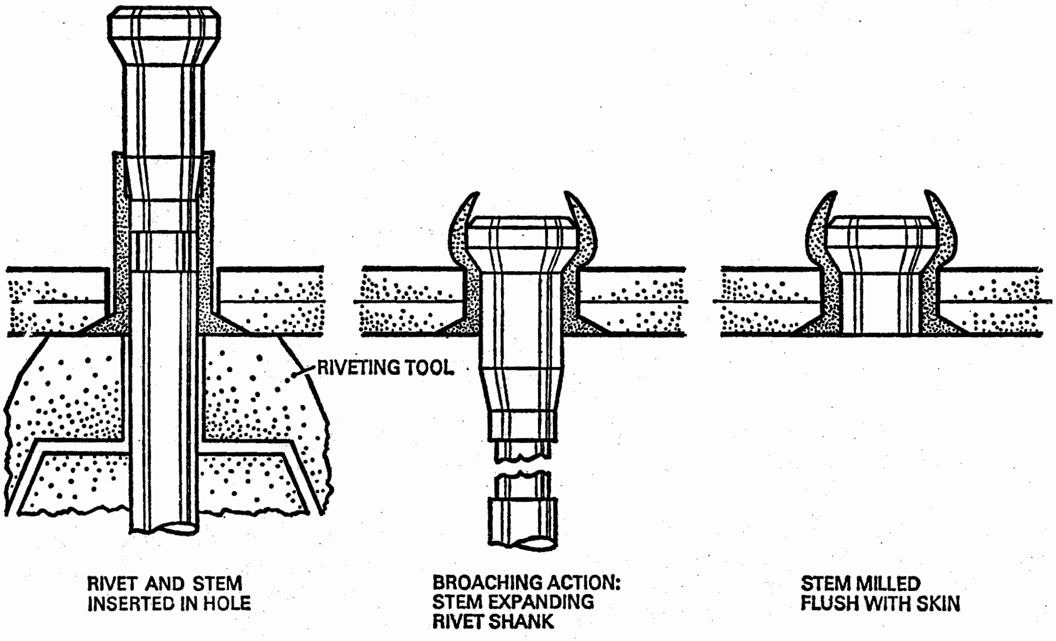


Figure 2 CLOSING AVDEL RIVETS

3.2.1 The Avdel rivets which have been given AGS numbers are shown in Table 2, and some of the more common rivets which may be used on aircraft, but do not have AGS numbers, are also included.

3.2.2 The code used for the identification of Avdel rivets is the same as that used for Chobert rivets, i.e. the AGS number or the manufacturer's product code, followed by the size code.

3.2.3 The oversize rivets listed in Table 2 are used for repair purposes. The increase in diameter is similar to that quoted in paragraph 3.1.3 for Chobert rivets, and the same advantages apply.

3.2.4 Avdel rivets are lubricated by the manufacturer to facilitate forming the rivet and on no account should the rivets be cleaned in solvent before use. The lubricants used are specially prepared for each type to obtain consistent results.

TABLE 2
AVDEL RIVETS

AGS Number	*Maker's code*	*Head Type*	*Material spec.*		*Finish*	*Remarks*
			Body	*Stem*		
2065	4022	snap	L86	DTD 5074	anodised	—
2066	4032	100° countersunk	L86	DTD 5074	anodised	stem dyed red
—	4102	snap	L86	DTD 5074	anodised	oversize rivet, stem dyed violet
—	4132	100° countersunk	L86	DTD 5074	anodised	oversize rivet, stem dyed green
3920	4051	snap	DTD 189	FV 448	plain	stainless steel
3921	4057	100° countersunk	DTD 189	FV 448	plain	stainless steel
3922	4061	snap	DTD 189	FV 448	body cad. plated	stainless steel
3923	4067	100° countersunk	DTD 189	FV 448	body cad. plated	stainless steel
—	4074	universal	I.M.I. 230	I.M.I. 138A	plain	titanium
—	4077	100° countersunk	I.M.I. 230	I.M.I. 138A	plain	titanium

NOTE: Until recently all Avdel rivets manufactured from L86 were dyed violet. This practice has been discontinued because of the frequent need to use these rivets in exterior aluminium surfaces which are not subsequently painted. The stems only are now dyed for identification purposes.

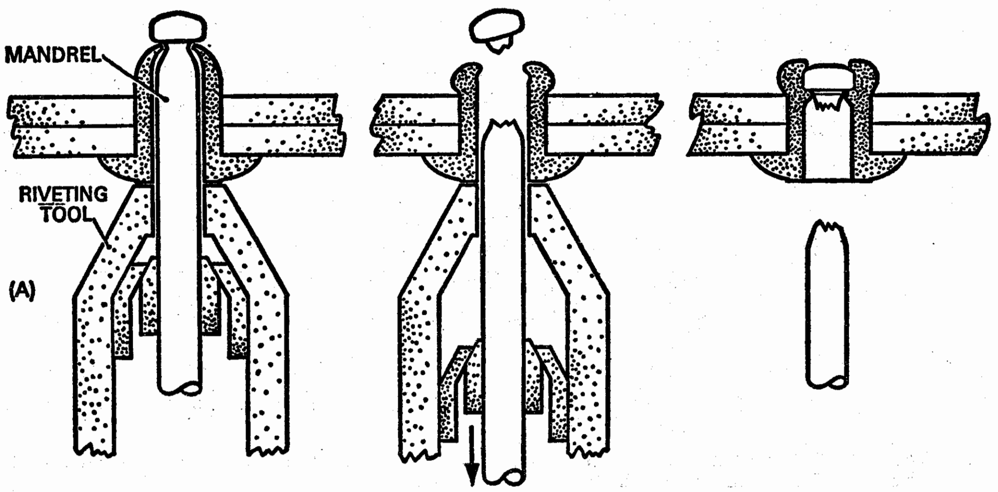
3.2.5 The shear strength of Avdel rivets is similar to that of solid rivets and is somewhat greater than that of Chobert rivets of similar material and size.

3.3 **Tucker 'Pop' Rivets.** Tucker 'Pop' rivets are manufactured with either domed or countersunk heads, and are supplied threaded on individual mandrels. There are, basically, two different types of rivets, known as 'standard' (open) and 'sealed'. The action of closing both types of rivet is shown in Figure 3.

3.3.1 The mandrels of standard type rivets are of two types, namely break head and break stem. With the former type the mandrel head separates from the formed rivet, but with the latter the head is retained in the rivet bore and provides a measure of sealing. The break head rivets are not widely used on aircraft due to the difficulty of recovering broken mandrel heads.

3.3.2 The mandrels of sealed type rivets are also of two types, the short break and the long break. The short break mandrel breaks immediately under the head, but the long break mandrel breaks outside the rivet thus greatly increasing shear strength of the rivet and providing a flush finish when the protruding stem is nipped off.

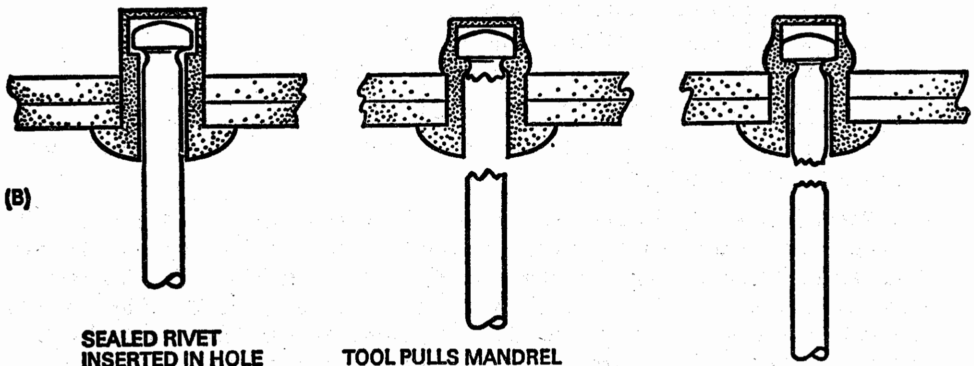
3.3.3 A wide variety of tools is available for closing 'Pop' rivets, ranging from plier type hand tools to pneumatically or hydraulically operated power tools. A range of interchangeable heads for these tools permits closing the rivets where access is restricted.



STANDARD OPEN RIVET INSERTED IN HOLE

TOOL PULLS MANDREL AND BREAK-HEAD SHEARS OFF

BREAK-STEM TYPE MANDREL SHEARS LEAVING HEAD IN RIVET



SEALED RIVET INSERTED IN HOLE

TOOL PULLS MANDREL AND SHORT BREAK MANDREL SHEARS LEAVING HEAD IN RIVET

LONG BREAK MANDREL SHEARS OUTSIDE THE RIVET HEAD

Figure 3 CLOSING TUCKER 'POP' RIVETS

3.3.4 The manufacturer's identification code varies according to the type or rivet (i.e. standard or sealed) but similar letters are used to indicate material and head shape as follows:—

(i) Standard rivets,

T = Tucker

L, A, S or C = Monel (DTD 10B), L58, steel (E.N.2a) or copper respectively.

P = 'Pop' rivet

D or K = domed or countersunk head (120°) respectively.

BH or BS = break head or break stem respectively.

Size is indicated by three figures, the first indicating diameter and the last two the length of shank.

Thus a rivet coded TAP/K412 BH would be a Tucker, L58, 'Pop' rivet, with a countersunk head, $\frac{4}{32}$ ($\frac{1}{8}$) inch diameter with a shank length of 0·12 inch and a break head mandrel.

(ii) Sealed rivets,

A or C = L58 or copper respectively.

D or K = Domed or countersunk head (120°) respectively.

R = Reinforced (i.e. long break mandrel). Size is indicated by two or three figures, the first indicating diameter and the remainder the maximum riveting thickness.

Thus a rivet coded AD 48R would be an L58, domed head rivet, $\frac{4}{32}$ ($\frac{1}{8}$) inch diameter, capable of riveting material up to $\frac{8}{32}$ ($\frac{1}{4}$) inch thick and having a long break mandrel.

NOTE 1: The above details apply to the majority of aircraft rivets but rivets of different materials and head shapes are also available.

NOTE 2: Mandrels are normally of steel but are also available in different materials.

3.3.5 AGS numbers have been given to some of the standard 'Pop' rivets and the most common are as follows:—

AGS 2048, L58 domed head
AGS 2049, L58 120° countersunk head
AGS 2050, Monel (DTD 10B) domed head
AGS 2051, Monel (DTD 10B) 120° countersunk head
AGS 2070, Monel (DTD 10B) 100° countersunk head

The AGS number is followed by the manufacturer's coding for size and mandrel type as given in paragraph 3.3.4 (i).

3.4 **Cherry Rivets.** These are rivets of American manufacture and are very similar to Avdel rivets, except that the stem is positively locked in the rivet bore. During the final stages of forming, a locking collar, located in a recess in the rivet head, is forced into a groove in the stem, and prevents the stem from further movement. Alternative types of blind head may be formed, and these are known as 'standard' and 'bulbed'. The only practical difference between these types is that the bulbed rivet stem has a stepped head, and the finished blind head is flatter and broader than the standard head. The action of closing a Cherry rivet is shown in Figure 4.

3.4.1 After forming, the stem protrudes slightly beyond the rivet head and this excess, plus part of the locking collar, may be milled off to provide a flush finish.

3.4.2 Cherry rivets are installed using hand or power operated tools, and it is important that the tools are fitted with the correct type of head for the particular size or type of rivet. Details are normally supplied by either the aircraft or tool manufacturer.

3.4.3 Cherry rivets are identified by a four figure number followed by a figure indicating the diameter in thirtyseconds of an inch, and a further figure indicating the maximum grip in sixteenths of an inch. As an example, CR 2162-3-6 refers to a Cherry rivet in aluminium alloy, with a countersunk head and standard stem, $\frac{3}{32}$ inch diameter and a maximum grip of $\frac{3}{8}$ inch. Table 3 shows some of more common Cherry rivets, together with identification details.

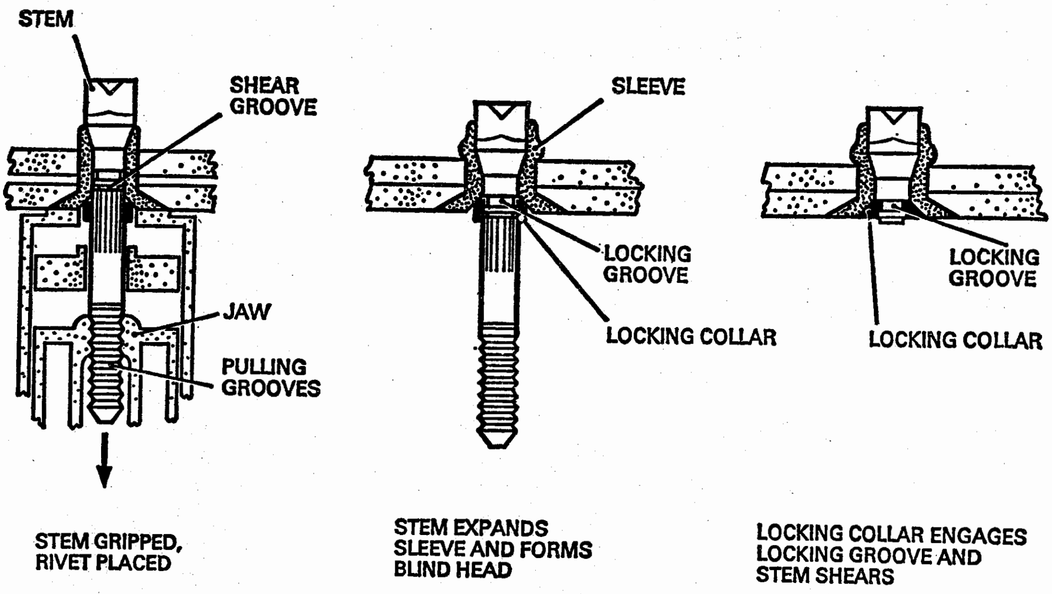


Figure 4 CLOSING CHERRY RIVETS

TABLE 3
CHERRY RIVETS

			Material		*Finish*	
Code	*Type*	*Head*	*Rivet*	*Stem*	*Rivet*	*Stem*
CR 2162	standard	countersunk	2017	7075	205 Alumite	1200 Alodine
CR 2163	standard	universal	2017	7075	205 Alumite	1200 Alodine
CR25625	standard	countersunk	monel	monel	silver plate	natural
CR25635	standard	universal	monel	monel	silver plate	natural
CR 2662	standard	countersunk	st. steel	st. steel	dry film	natural
CR 2663	standard	universal	st. steel	st. steel	dry film	natural
CR 2248	bulbed	countersunk	5056	steel	anodised	cad. plate
CR 2249	bulbed	universal	5056	steel	anodised	cad. plate

NOTE: A figure indicating maximum grip is marked on the rivet head.

4 TUBULAR RIVETS Tubular rivets were, at one time, quite often used on tubular structures, such as engine mountings or fuselage frames, for joining tubes to fittings, or for repair work. These parts are now more often welded or fixed with taper pins, but tubular rivets may still be found on a number of aircraft. These rivets are closed by hammering, using specially shaped punches and snaps, and care is necessary to prevent buckling the rivet or tube. To prevent buckling and to maintain the tube shape, distance tubes are often used.

4.1 The most common type of tubular rivet is the one manufactured in accordance with AGS 501, and is obtainable in various materials, diameters and gauges. Another type of tubular rivet (covered by AGS 513, 514, 515 and 516) is the 'split' or 'Cox' rivet, which is formed from sheet material and may have a straight or serrated joint running axially along the rivet length. This type of rivet is only used in non-structural applications.

5 SPECIAL FASTENERS The special fasteners discussed in this paragraph are closed by means of a collar which is swaged into grooves in the fastener shank or expanded over the shank to form a blind head. The fasteners are generally used instead of bolts and present a considerable saving in weight.

5.1 **Hi-shear.** The Hi-shear fastener consists of a pin of high shear strength and a collar of softer material which is forced into the pin groove by the riveting action (see Figure 5). The pins are supplied with standard or close tolerance shanks and may have either of two differently shaped grooves (the '100' series which uses aluminium alloy collars only, and the '200' series which uses collars in a variety of materials). Some pins are supplied with oversize shanks for repair work.

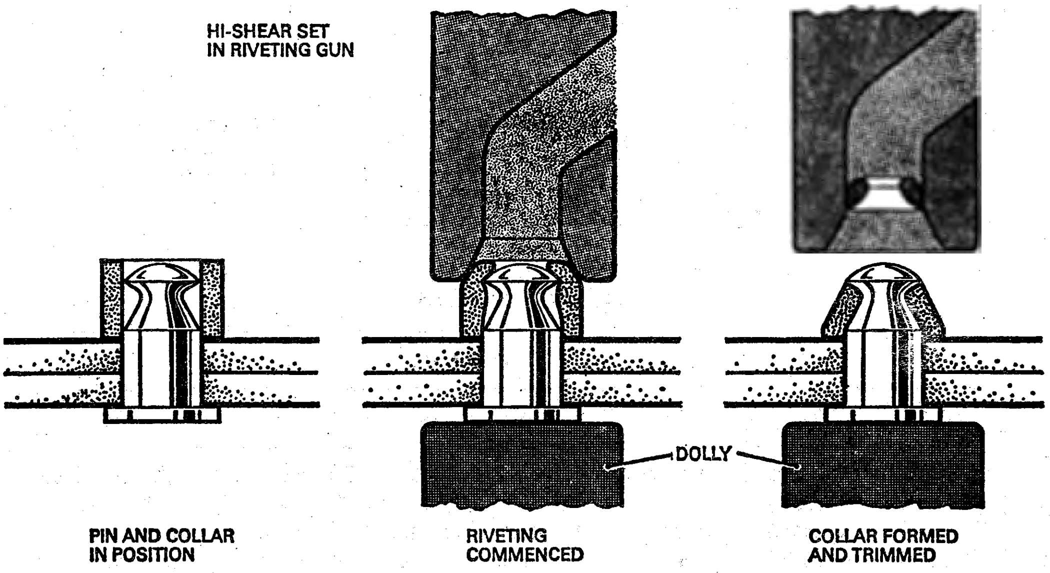


Figure 5 CLOSING HI-SHEAR FASTENERS

5.1.1 For ordering purposes Hi-shear pins and collars are identified by a prefix (BBH), followed by a series of numbers or letters indicating type, material and size. Pins and collars are ordered separately from the following codes:—

(i) A three figure number indicating shank tolerance and collar material.

(ii) A letter indicating head shape (C=countersunk, F=flat).

(iii) A letter indicating pin material (N=55/65 ton steel, H=75/85 ton steel, S=stainless steel, K=monel, T=titanium and A=aluminium alloy).

(iv) Two figures indicating nominal diameter in thirtyseconds of an inch (in addition the letters C & D may be used for pins the same size as No. 8 and No. 10 Unified bolts).

(v) Two figures indicating maximum grip length in sixteenths of an inch.

As an example, a close tolerance flat head pin in stainless steel, ⅛ inch diameter, with a grip length of ½ inch and for use with an aluminium alloy collar, would be BBH/101/FS/04/08; the matching collar would be BBH/104/04.

5.1.2 For recognition purposes symbols are marked on pin heads, or a dyed finish is added, as shown in Table 4. In addition the letter 'P' is added to precision (close tolerance) pins, and '$\frac{1}{32}$' or '$\frac{1}{64}$' added to oversize pins as appropriate.

TABLE 4
HI-SHEAR RECOGNITION FEATURES

Material	*Marking*	*Finish*
Pins		
55/65 ton steel	B+	cadmium plated
75/85 ton steel	Ⓑ	cadmium plated
stainless steel	$\underline{.\ B\ .}$	natural
monel	BM	natural
titanium	BT	natural
aluminium alloy	nil	anodised and dyed blue
Collars		
(a) for '100' series pins:—		
aluminium alloy	nil	anodised and dyed mauve
(b) for '200' series pins:—		
aluminium alloy	nil	anodised and dyed green
stainless steel	nil	natural
mild steel	nil	cadmium plated
annealed monel	nil	natural

5.1.3 Hi-shear pins are placed using a special hi-shear rivet set which forms and trims the collar. Collars are pre-lubricated and should not be washed in solvent before use.

5.1.4 Some Hi-shear pins were produced with a grooved shank to release trapped jointing compound; in all other cases where wet-assembly is called for the exposed pin shank must be wiped clean to ensure correct forming of the collar.

5.2 **Avdelok Fasteners.** These fasteners are typical of a wide variety of proprietary fasteners available in America and the United Kingdom. The bolt portion of the fastener is solid and a collar is swaged onto grooves in the bolt shank as shown in Figure 6. When swaging is complete the bolt shears flush with the collar. Avdelok fasteners are manufactured with a number of different head shapes, in steel or aluminium alloy, with diameters of $\frac{3}{16}$ inch to $\frac{1}{2}$ inch. They are normally placed with power operated tools.

5.2.1 Some aircraft manufacturers recommend that the holes for Avdelok fasteners should be reamed to an interference fit, and lay down the tolerances to be achieved. This practice requires a different technique for placing the fasteners, the bolt first being inserted without its collar and pulled into place by use of the riveting gun, then the collar is fitted and swaged by a second operation of the gun.

5.2.2 As with other similar fasteners the Avdelok is pre-lubricated and should not be de-greased before assembly except that, if an interference fit is specified, lubricant must be removed from the bolt. If wet assembly is specified the sealant must be removed from the bolt shank before swaging.

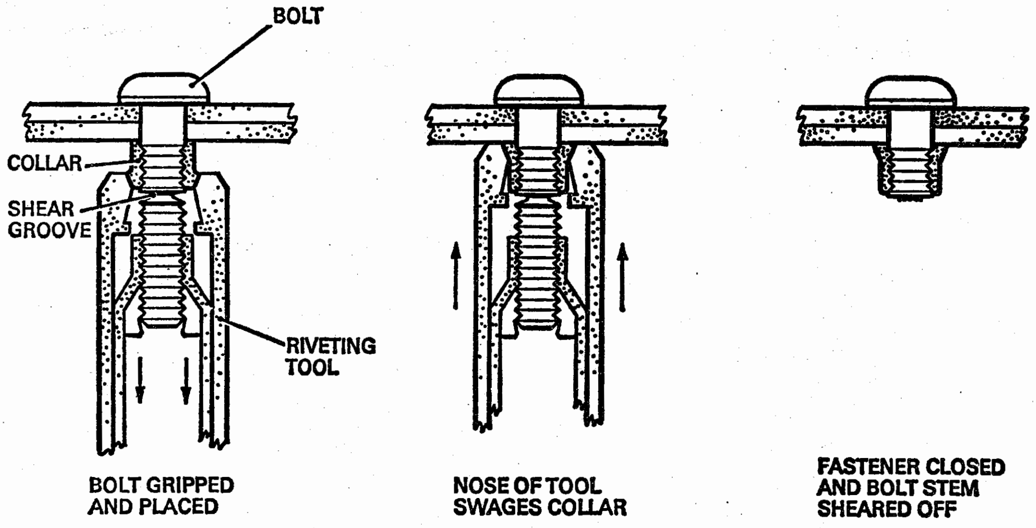


Figure 6 CLOSING AVDELOK FASTENERS

5.2.3 Avdelok fasteners are identified by a code system similar to that used for Chobert and Avdel rivets, namely a four figure product code and a four figure size code.

5.3 **Jo-bolts.** Although Jo-bolts may be classified as blind rivets, the method of closing is different from the methods previously discussed. The complete item consists of a threaded bolt with a round head, a rivet shaped nut and a sleeve, assembled as illustrated in Figure 7. Rotation of the bolt forces the sleeve up the tapered nut shank, clamping the materials to be joined, and at a predetermined load the bolt shears just inside the nut head leaving, virtually, a solid steel rivet in the hole.

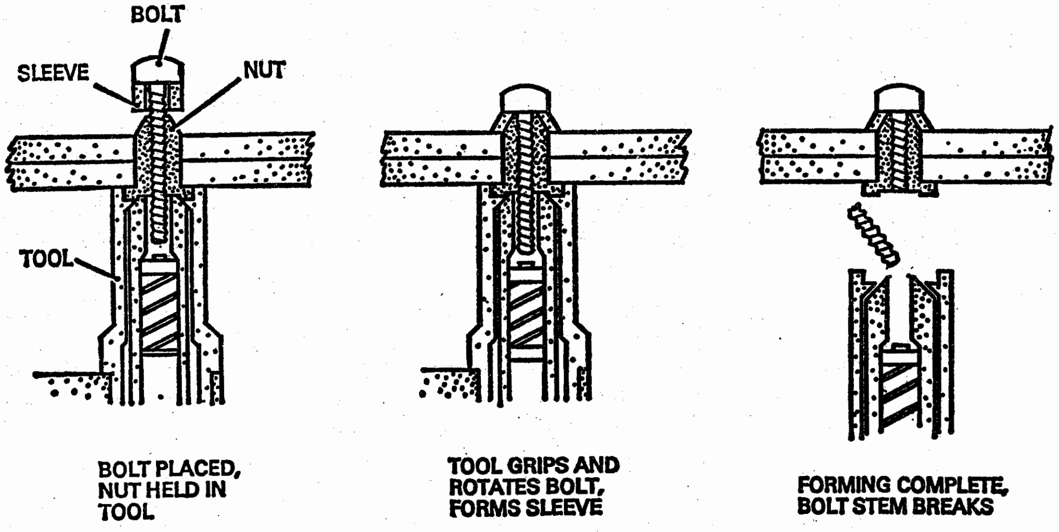


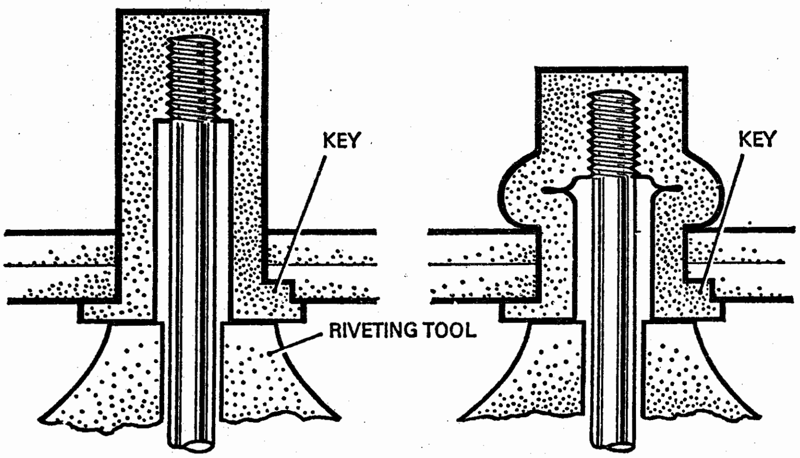
Figure 7 CLOSING JO-BOLTS

5.3.1 Jo-bolts are manufactured with hexagon or 100° countersunk heads, in either stainless or alloy steel, and have a shear strength almost equal to a bolt of equivalent size and material. The bolts are pre-lubricated and must not be washed in solvent, since this would alter the gripping strength at which the bolt breaks.

5.3.2 The tools used for placing Jo-bolts are in two concentric parts, the outer part holding the nut and the inner part gripping the bolt shank. Different adaptors must be fitted to the tools to accommodate the different size hexagon heads, or cruciform slots of countersunk bolts.

5.3.3 Jo-bolts are identified by an eight figure code number, the first four figures indicating type and material, and the remainder the size, in a similar way to Avdel rivets. As an example the code 2103-0607 indicates a 100° countersunk bolt in cadmium plated alloy steel, with a diameter of $\frac{3}{16}$ inch and nominal grip of $\frac{7}{16}$ inch.

5.4 **Rivnuts.** Rivnuts were originally developed for securing rubber de-icing boots to the leading edges of aerofoil sections but they are now also used, for example, for securing floor coverings and other non-structural parts. They are a form of blind rivet which can be used as an anchor nut, the internal bore being threaded to receive a bolt or screw. Rivnuts used on de-icing boots have a 6-32 thread and have either flat or countersunk heads. The countersunk head types are open ended and may or may not have a locating key, but the flat head types all have a locating key and are supplied with either a closed or open end. Marks on the head indicate length in accordance with a manufacturer's code. Rivnuts are installed with a special tool fitted with a threaded mandrel; the mandrel is screwed into the rivnut, and when the gun is operated the shank expands as shown in Figure 8.



INSERTED

CLOSED

Figure 8 CLOSING RIVNUTS

BL/6-29

Issue 1.

1*st April*, 1972.

BASIC

ENGINEERING PRACTICES AND PROCESSES

RIVETING

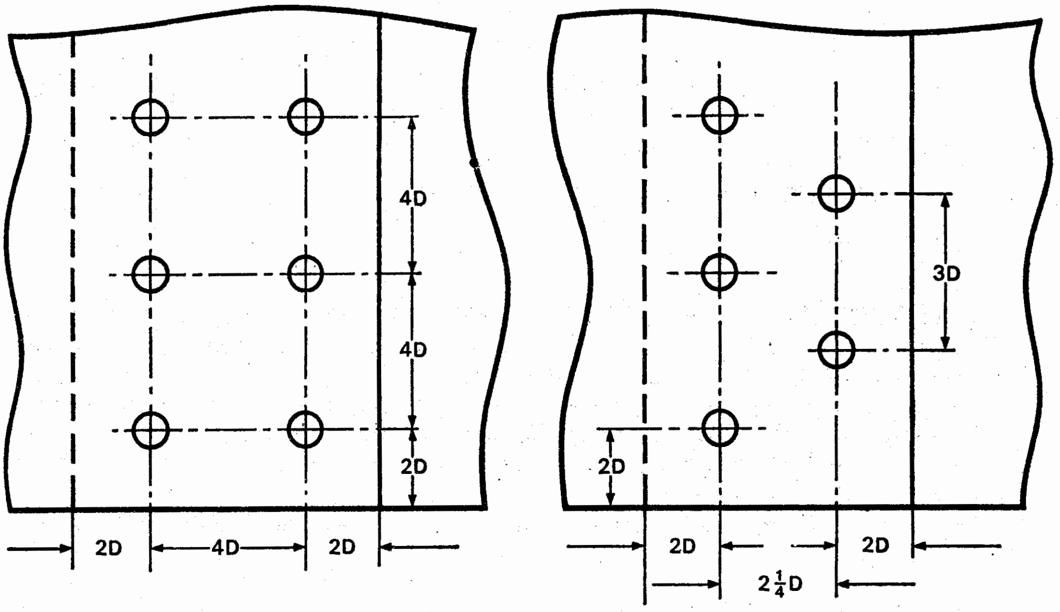
1 INTRODUCTION This Leaflet gives guidance on the riveting of aircraft structures, particularly from the repair aspect. It also outlines some of the factors involved in preparing work for riveting and gives the procedures for closing various types of rivets. Information on the classification and identification of the main types of British and American rivets is given in Leaflets **BL/6-27** and **BL/6-28,** which should be read in conjunction with this Leaflet. Further information on the repair techniques applicable to riveted structures is contained in Leaflet **AL/9-1.**

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet AL/7-7, Issue 1, 1st July, 1956.

2 GENERAL Information on the size and type of rivets to be used, and the spacing to be employed for a particular repair, is normally specified in an approved repair scheme for a particular aircraft type. Unless otherwise stated the repair should follow the system of riveting used elsewhere on that aircraft at similar locations. It must be appreciated that the original pattern of riveting will have been deliberately selected and on all modern aircraft will have been proven in both static and fatigue structural test programmes. In carrying out any repair of major structural components, such as pressurised cabins and integral fuel tanks, the same type of riveting and a comparable quality of riveted assembly are vital to the integrity of the structure. If departure from the normal methods of construction is necessary, for example, different rivets or rivet spacing, approval of the manufacturer should be sought, since the strength of the repair might be affected. Provided that the approved repair scheme is followed in every detail, and that drilling and riveting techniques are of a high standard, the integrity of the structure will not be degraded. On completion, the repair should be inspected as outlined in paragraph 9 and any exposed metal reprotected.

3 RIVET SELECTION A number of factors must be taken into account when selecting the rivets to be used for a particular application. Generally the strength of the rivets must be similar to that of the material in which they are used; the size, number and spacing of rivets is calculated from the tensile strength and bearing strength of the sheet material and the shear strength of the rivets. The rivet diameter should be approximately three times the thickness of a single sheet of the material being joined, for example, $\frac{1}{8}$ inch diameter rivets should normally be used with 20 s.w.g. (0·036 inch) sheet, and $\frac{5}{32}$ inch diameter rivets with 18 s.w.g. (0·048 inch) sheet, but this may be unsuitable when holes are cut-countersunk (see paragraph 5.1).

3.1 Figure 1 shows the spacing normally applied to double chain and staggered lap joints to obtain maximum strength; in other types of riveted structures a rivet pitch (i.e. distance between rivets in a row) of four times rivet diameter (D) and distance from sheet edge (land) of 2D are typical. Where a rivet is used to fasten an angled member, the rivet must not be so close to the bend that the rivet cannot be properly closed when using the appropriate dollies or special tools.



(D = DIAMETER OF RIVET SHANK)

Figure 1 MINIMUM SPACING FOR RIVETED JOINTS

4 HOLE PREPARATION

4.1 **Marking Out.** Careful marking out is a prerequisite for accurate drilling. Aluminium alloy parts used on aircraft should not be marked out with a scriber or other tool which will scratch the surface, unless the marks are subsequently machined off or otherwise removed. A thin coat of zinc chromate primer makes a suitable background for pencil lines, but it may be preferable to manufacture a template which can be used as a drilling jig on the aircraft.

4.2 **Hole Size.** The size of the rivet holes has a positive bearing on the strength of a riveted joint. A clearance must exist between the rivet and the hole in which it is fitted to accommodate expansion of the shank during forming. If the clearance is too small the sheets will tend to buckle, whereas if the clearance is too large separation of the sheets may occur (see Figure 4). The selection of the correct size rivet countersink, dimple and rivet hole, should be made by reference to tables published by the aircraft manufacturer. The recommended sizes vary according to the gauge of the structural materials being joined and the size, form, length and material of the rivets being used. In general the harder and longer the rivet the smaller the clearance, but close tolerance holes and interference fits are often a requirement.

4.2.1 As a result of laboratory tests and engineering development at the design stage, carefully controlled hole sizes and rivet fits are used in critical fatigue-prone locations. Should it be necessary to disturb structure of this type it is imperative that reassembly be carried out in accordance with the original drawings or repair schemes, or as advised by the aircraft manufacturer.

4.2.2 In order to allow for slight misalignment during assembly work, it is usual to drill pilot holes at positions where rivets are to be fitted. When the assembled structure is ready for riveting, the holes should then be opened out to the required size.

4.2.3 When a structure has to be dimpled to accommodate countersunk rivets, the holes should first be drilled undersize, since the dimpling action enlarges the hole. After the dimple is formed the hole may then be drilled or reamed out to the appropriate size; this action must also remove any small radial cracks which have formed round the hole during the dimpling operation. Some aircraft manufacturers may permit dimpling to be carried out from final size holes, but this practice is normally only applicable to lightly loaded structures.

4.3 **Drilling Technique.** It is always important to use a drill which is sharp and accurately ground, and to prevent the drill 'wandering off' it is advisable to mark the drilling position with a centre punch. Care must also be taken to ensure that the drill is held perpendicular to the work surface, and it may be advisable in certain circumstances to use a drilling jig to prevent error. A badly drilled hole will prevent accurate riveting and may result in failure to meet the design strength requirements of a joint.

NOTE: When drilling out rivets on complete aircraft care must be taken to prevent damage to pipes, wiring looms or subsidiary structure, and precautions taken to prevent the ingress and facilitate recovery of swarf and pieces of rivets.

4.4 **Deburring of Holes.** One aspect of riveting which often receives insufficient attention is the deburring of holes. It is most important that all rough edges and swarf are removed after drilling or reaming operations, for example, where holes are finally drilled on assembly, the structure must be disassembled for deburring and swarf removal before final assembly and riveting. A special deburring tool must be used for removing rough edges, an ordinary drill larger than the rivet hole being considered unsuitable. A power driven cutter with a locating spigot and concentric stop sleeve is normally used when a large number of holes have to be deburred. Burrs should not be removed with files or emery paper.

5 COUNTERSINKING When countersunk rivets are to be fitted, there are two methods of accommodating the rivet head to ensure a flush fit. Cut-countersinking is employed where sheet thickness is greater than the depth of the rivet head, but for thinner sheets dimpling is necessary. Where sheets of different thicknesses are joined together it may be found that both methods are used, a thin outer sheet being dimpled into a countersunk thick inner sheet.

5.1 **Cut-countersinking.** Table 1 shows the minimum sheet thickness which may be countersunk for particular rivet diameters, and is applicable where 100° or 120° countersunk head rivets are used. Where special rivets with different head angles are used the aircraft manufacturer may specify a different minimum sheet thickness, and when oversize rivets are being fitted it may be recommended that the rivet heads are milled in preference to cut-countersinking into supporting structure.

TABLE 1 MINIMUM SHEET THICKNESS FOR COUNTERSINKING

Rivet diameter (inch)	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{1}{4}$
Minimum sheet thickness (s.w.g.)	18	16	14	12

5.1.1. Special countersinking tools should be used for cut-countersinking. The tools should have a centralising spigot and an adjustable depth stop which will limit the depth of cut. The rivet head should always be slightly proud of the work before riveting, and this can be set by trial drilling in scrap material. Aircraft manufacturers usually specify a tolerance on head protrusion after riveting, and this is usually of the order of 0·005 inch above the skin surface. It is not normally permissible for the rivet head to be below the skin surface.

5.2 **Dimpling.** This is a process for indenting thin sheet material (not normally thicker than 16 s.w.g.) around a drilled hole to accommodate a countersunk rivet. If correctly preformed, dimpling has a beneficial effect on the strength of a joint, but the method of dimpling must be related to the ductility of the material to prevent overstressing and cracking.

5.2.1 **Dimpling Characteristics.** The aluminium alloy skin panels commonly used for stressed skin structures are either solution treated and naturally aged or solution treated and artificially aged. The naturally aged materials and some of the artificially aged clad materials may be satisfactorily dimpled at room temperature, although if dimples of 90° or less are required, hot dimpling may be specified. Carefully controlled spin dimpling processes are considered suitable for L70, L72, L73, DTD 746 and 2024–T4 aluminium material and stainless steel, but hot dimpling should be used for the stronger but less ductile L71, DTD 687, 2014–T6 and 7075–T6 aluminium alloys, and for titanium.

5.2.2 **Control Tests for Dimpled Sheet.** Before dimpling any aircraft material of which the dimpling characteristics are uncertain, either because of lack of familiarity with the material itself or because of the use of a new dimpling technique or tool, tests should be made on sample material of the same gauge, specification and heat treatment condition.

(i) Specimens of the material should be cut approximately 8 inches long and 1 inch wide, and dimpled along the centreline of the strip at the pitch to be used on the aircraft. When the strip is bent across the dimples as shown in Figure 2, cracks across the dimples at the bend may be expected and are acceptable, but if other radial or circumferential cracks develop the process must be considered unsatisfactory.

(ii) Before any method of dimpling is approved for production, its suitability for the particular combination of material, gauge, dimple and rivet size should be assessed by the Design Department. A number of dimpled and riveted specimens should be sectioned to check the nesting of the dimples and the fit of the rivet.

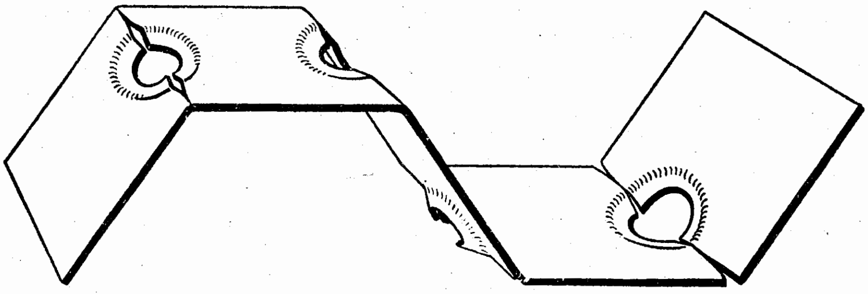


Figure 2 DIMPLE TEST SPECIMEN

5.2.3. **Punch Dimpling.** This is the simplest method of dimpling but is generally only suitable for minor repairs in sheet steel or soft aluminium alloys. The type of tool used is similar to a centre-punch but has a spigot which engages in a female tool of the same form. The hole should first be drilled to the spigot size and then the male die should be driven or squeezed into the female die to form the dimple.

5.2.4. **Spin Dimpling.** This is the most widely used method of cold-dimpling. The sheet is first pre-drilled and backed by a female die as for punch dimpling, then a rotating male die is pressed into the hole. The metal around the rivet hole is stretched over the edge of the female die and, if the material is clad, the aluminium cladding is spread by the spinning action. The cladding may form a ridge around the outside of the dimple but this will only be slight, and should not be removed.

5.2.5 **Hot Dimpling.** There are basically two methods of hot dimpling. In the first method, sometimes known as 'coin dimpling', electrically heated dies are used; in the second, the sheet is heated by its resistance to the passage of an electric current. Each material has a different rate of conducting heat, or a different electrical resistance, and the applied current or time and temperature will be different for different materials and gauges. These details are normally found by experiment and the instructions given by the aircraft manufacturer should be followed.

NOTE: In order to obtain consistent results during aircraft construction, large static machines with automatically controlled temperature, current and tool pressure are often used but for repair work portable hot squeeze-dimpling tools are generally satisfactory.

5.2.6 **Dimpling Technique.** To ensure that rows of dimples fit satisfactorily together, the pilot holes should be drilled with the structure fully assembled. The structure may then be disassembled and the individual components deburred and dimpled separately. However, if sheets are to be bonded together, it may be recommended that dimpling is carried out after bonding.

(i) To produce dimples which are free from cracks around the holes it is essential that the pilot holes are free from burrs or other defects and that the correct lubricant is used. The ideal procedure is to drill the holes undersize, ream to suit the size of dimpling tool spigot, then deburr on both sides before dimpling. For maximum shear strength the hole should be finally drilled or reamed to give a hole with parallel sides and ideal rivet clearance. This second drilling should start from the dimpled side so that any burrs are on the raised edge and easily removed with a deburring tool.

(ii) When countersunk rivets are used to join several thin sheets of material there are two ways in which dimples may be formed. If the same tools are used for successive sheets the dimples will be identical, but will not nest satisfactorily. This may be acceptable when joining two sheets of ductile material but, for stiffer materials and when joining more than two sheets, the dimples may be overstressed by the riveting action. A more satisfactory method is to use tools of a slightly larger diameter and shallower angle with successive sheets, the innermost sheet having the largest and shallowest dimple.

6 USE OF SEALANTS After components have been prepared for riveting the mating surfaces are normally given a coat of jointing compound or sealant before final assembly. The purpose of the jointing compound is to inhibit electrolytic action between materials of different electrical potential and prevent the ingress of moisture, whereas a sealant (normally a polysulphide type synthetic rubber) is used to seal joints in fuel tanks and pressurised compartments. Jointing compound should be applied in a thin even film, just sufficient to ensure that all mating surfaces, including rivets, are adequately covered, but sealant should normally be applied in a layer approximately 0·030 inch thick so that it exudes

from the joint when the rivets are closed. It may be recommended that rivets are dipped in the compound before use but the exposed shanks of some types of rivets should, after insertion, be carefully wiped clean to ensure correct closing of the rivet (see Leaflet **BL/6-28**). Riveting must be completed before the compound or sealant has set and any excess material on external surfaces should be wiped off or to a prescribed fillet while still wet.

7 SUPPORT AND ALIGNMENT OF STRUCTURE During the manufacture of an aircraft extensive jigging is used to locate detail parts in accurate relationship to one another while they are being secured by rivets or other types of fasteners. This provides not only for interchangeability of structural components but for correct external contour. When carrying out repairs on riveted structures, adequate support must be provided to maintain the original size, contour and alignment (see also Leaflet **AL/9-1**); this is particularly important in the case of extensive repairs. On high speed aircraft the achievement of correct external contour is vital, but on all aircraft care should be taken to prevent an increase in aerodynamic drag through poor shape or finish.

7.1 Major stress concentrations are spread from principal transport joints into the lighter structure through progressively reduced reinforcing fittings. Such assemblies involve the use of bushes, taper pins, bolts and rivets, each designed to take a share of the load. The sequence of assembly during repair or replacement may be vital to ensure correct alignment and the use of jigs may be required when drilling or reaming holes for rivets.

7.2 During the assembly of sheet metal fabricated structure each mating part must fit snugly together. This accuracy of fit must be achieved before the application of interfaying material and any forming or packing necessary must be carried out before final assembly. Panel shape should be adjusted to achieve perfect fit against supporting frames, stringers or ribs.

7.3 On high speed aircraft embodying heavy riveted skins or bonded laminated reinforcements which are extremely rigid, the design may call for the use of sophisticated skin grips to hold the skin in contact with the structure during riveting. Certain forms of interfaying sealant require a specific torque loading to be applied to such grips, with a minimum time of clamping and a maximum time between releasing the grips and closing the rivets. Such precautions as these should be obtained from the manufacturers process sheets or the aircraft Repair Manual.

8 CLOSING RIVETS When the appropriate actions of drilling, countersinking, dimpling, deburring, cleaning and adjustment have been completed, the work to be riveted should be assembled, sealant applied, and mating surfaces brought tightly into contact by use of skin grips, care being taken not to damage the skin surface. It is important that no gaps are present between layers, as this will prevent the correct forming of the rivet and reduce shear strength. Riveting may stretch thin sheets slightly, particularly with minimum rivet clearances, and this should not be allowed to accumulate by riveting, for example, straight along a line of rivets. The correct sequence of closing rivets can only be obtained by experience, and with each type of joint the order of riveting may vary slightly.

8.1 **Solid Rivets.** The length of protruding shank which is flattened to close a rivet is known as the 'allowance', and is expressed in terms of the rivet diameter 'D'. For normal reaction riveting the allowance is 1·5D, and this is sufficient to form a flat head 1·5D in diameter and 0·5D thick; for this type of riveting these are the dimensions to be aimed at. On the rare occasions on which hand riveting may be required, an allowance of 1·5D is sufficient to form a snap head and 0·75D is sufficient to form a countersunk head. Rivets should always be used which are manufactured to the length required; cutting rivets to length is not recommended, since any tool marks in the rivet tail are possible sources of cracks when the tail is hammered.

8.1.1 **Hand Hammering.** Riveting by hand is only appropriate to certain types of older aircraft and elementary repairs to simple structures. When solid rivets are closed with a hand hammer, the manufactured (pre-formed) head should be supported by a suitably shaped dolly and the tail hammered to a thickness of 0·5D; if a snaphead is required on the shank end, the tail should first be partly formed by hammer blows, then finished with a suitably shaped snap. It is most important that the dolly is backed by a heavy block or holder, and as few hammer blows as possible used. A large number of light blows will work-harden the rivet and result in cracks in the tail or difficulty in forming.

8.1.2 **Pneumatic Hammering.** In some instances it may be specified that a similar procedure should be used for pneumatic hammering as is described in paragraph 8.1.1. However, since the preformed rivet head is invariably on the outside of the aircraft and access to the interior often restricted, a type of riveting known as reaction riveting is more generally used. A suitably shaped snap (or 'set') is held in the riveting gun and a dolly (or 'bucking bar') held against the tail end. When the riveting gun is operated the tail is spread by the reaction of the dolly.

(i) To prevent damage to the surface of the work when protruding head rivets are being closed, the radius of the recess in the snap should be slightly greater than the radius of the rivet head. For this reason, since rivets to different specifications (e.g. SP or AS) have slightly different shaped heads, use of the correct snaps is imperative.

(ii) When flush rivets are being closed a flat snap should be used, but it may be found advantageous to use one with a slightly convex surface to prevent damaging the surrounding skin.

(iii) The dolly should be as heavy as practicable, bearing in mind the space available, and should have a smooth surface to prevent damage to the rivet tail.

(iv) The type of gun to use will depend on the size and type of rivets, but generally on aircraft work a fast-hitting type is used on rivets up to ¼ inch diameter and a single-blow or slow, long-stroke type for larger rivets. As with hand hammering a few heavy blows are preferable to a large number of light blows.

8.1.3 **Squeeze Riveting.** On large modern aircraft, extensive use of squeeze riveting is made when securing spanwise stringers to preformed wing skins. It is part of an automatic process using large tape-controlled machines which drill, countersink, deburr, rivet and mill flush in one continuous action. This method of riveting is also used for the production of small assemblies or, when both sides of the work are accessible, during repair work. Squeeze riveting is also preferred when bonded laminated structures are to be riveted since, unless skill and care are exercised, reaction riveting tends to damage the bond. The rivets are closed by hydraulically or pneumatically operated machines, of which both static and portable types are available.

(i) Before riveting with squeeze tools the working pressure should be adjusted, by experiment, to obtain the optimum value for the work in hand. Test pieces of the same materials, thickness and rivet diameter as the work in hand should be used and may be sectioned across the rivets to study the plastic distortion to which the rivets and sheets have been subjected. Once adjusted the tools may be used for all work for which similar conditions apply, but must be readjusted if any changes occur in material, thickness or rivet size.

8.2 **Blind Rivets.** Special tools are required to close blind rivets, and it must be ensured that the correct types of nose piece and gripping jaws are fitted for the type and size of rivet to be closed.

8.2.1 **Chobert Rivets.** A different sized mandrel is used with each diameter of rivet and it is important that the correct mandrel is selected. Before use it should be checked for diameter using an approved gauge, inspected for scratches or other damage likely to mark the rivet bore, and must be clean and lightly lubricated. Mandrels are subject to wear during use, and should normally be replaced when the head diameter has been reduced by approximately 0·002 inch. Use of a mandrel worn beyond these limits may result in incomplete closing of the rivet.

(i) The correct length rivet must be chosen for the work in hand, and it should be noted that the size code for the rivet indicates the rivet length and not the grip range; this is approximately $\frac{1}{8}$ inch less that the rivet length, but reference should be made to the manufacturer's literature or the appropriate aircraft manual for exact details.

(ii) In the case of single action tools the mandrel should be threaded through the rivet and inserted into the tool until the rivet head contacts the tool nose piece. The rivet should then be pushed into the hole and steady pressure applied at right angles to the work while the broaching action is completed.

(iii) It is advisable to use a repetition gun when a large number of rivets have to be closed. The mandrels in these tools may be threaded into a tube containing approximately thirty rivets, and these are automatically positioned as each rivet is closed. High rates of closing are easily obtained.

(iv) When sealing pins are used it must be ensured that they are the correct diameter for the particular rivet.

8.2.2 **Avdel Rivets.** Avdel rivets are coded according to diameter and length, the grip, like Chobert rivets, being approximately $\frac{1}{8}$ inch less than the length. They are pre-lubricated and must not be washed in solvent before use, but surplus sealant or jointing compound could be detrimental to the forming process and should be wiped off.

(i) Each rivet should be assembled individually into the riveting gun, then inserted into the prepared hole and steady pressure applied at right angles to the work whilst the gun is operated.

(ii) Milling of the sheared ends of stems is quite often specified and this normally involves the use of a special milling attachment on a standard air-operated drill, an adjustable stop being set to prevent cutting the rivet head or adjacent skin.

(iii) When the rivets have been closed, the tightness of the stem should be checked with an Avdel Pin Tester, which is a tool having a retractable spring-loaded pin. The pin is pushed against the stem, and tightness may be considered satisfactory if there is no stem movement when the spring is fully compressed.

8.2.3 **Cherry Rivets.** A gauge is supplied by the manufacturer of these rivets, which may be inserted into the rivet hole to measure the thickness of material to be riveted. The maximum grip of each rivet is marked on the rivet head, in sixteenths of an inch, and this figure should correspond to the gauge reading.

(i) It is important that the appropriate pulling head for the riveting tool should be used, in accordance with the type and size of rivet. The rivet should be inserted into the prepared hole and the gun pressed over the stem until firm resistance is felt. The gun should then be operated while light pressure is applied towards the rivet.

(ii) To check the stem locking, a stem tester should be pressed against the sheared end of the stem; as with Avdel rivets, the stem locking may be considered satisfactory if no movement results when the tester is fully compressed.

(iii) The sheared stem and locking collar may be milled to maintain specified protrusion limits, but care must be taken not to remove material from the rivet head or surrounding skin.

(iv) On aircraft which have a bare metal exterior finish, it is sometimes specified that clear varnish should be applied to the heads of these rivets.

8.2.4 **'Pop' Rivets.** These rivets are most often closed by hand tools of the 'lazy tong' type when used for repair work, although other types of hand and power tools are also available. The mandrel should be inserted while the tool is extended, the rivet placed in position and the tool operated by pressing firmly towards the rivet until the mandrel shears. If break-head type rivets are used the sheared heads should be collected, and not allowed to fall inside the aircraft structure. Long-break mandrels are specified where increased shear strength is required and should not be replaced by break-head or short-break types.

8.3 Special Fasteners

8.3.1 **Hi-shear.** With these fasteners a simple check may be carried out to ensure that the pin is the correct length for the work to be joined. With the pin inserted in the hole, the edge of the pin groove should be proud of the work surface and with the collar fitted the pin trimming edge should be inside the collar as shown in Figure 3. The fasteners are normally closed by hammering a special Hi-shear set against the collar, the pin head being supported by a dolly, but squeeze or reaction riveting may also be used if the normal method is impracticable.

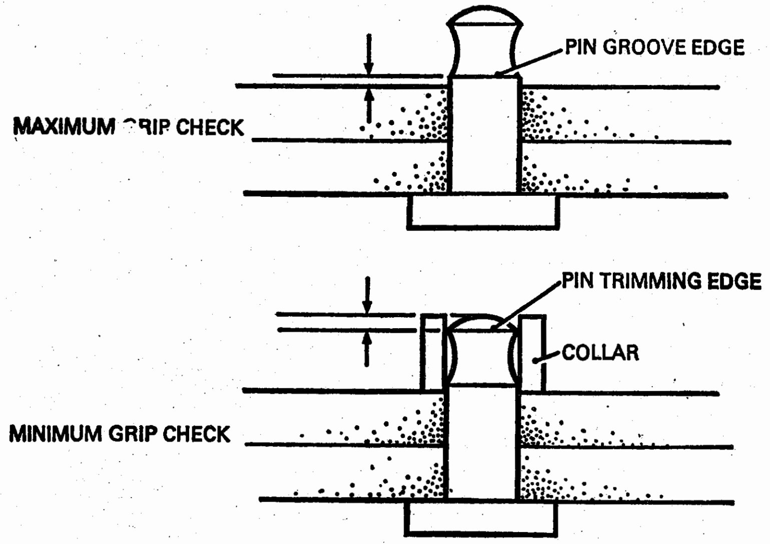


Figure 3 HI-SHEAR PIN LENGTH CHECK

8.3.2 **Avdelok.** The plain shank of these fasteners should be approximately equal to the thickness to be joined. The fasteners are normally closed by power operated tools, the gripping jaws pulling on the shank and the nose piece pushing against the collar, first clamping the plates together then swaging the collar into grooves on the shank. When swaging is complete the pin shears approximately level with the collar. If an interference fit is specified, closing should be in two operations, the first (without the collar fitted) pulling the pin into place and the second (with the collar fitted) completing the swaging operation.

8.3.3 **Jo-bolts.** Due to the method of closure of these fasteners it is particularly important that the nut length is suitable for the thickness of the work. If the maximum grip of the fastener exceeds the thickness of work by more than $\frac{1}{16}$ inch then the sleeve may not be properly expanded and a loose fastener could result.

(i) The tool used to close these fasteners consists of an outer portion to prevent the nut from turning and an inner portion by means of which the bolt is rotated. Rotation of the bolt (which has a left-hand thread) forces a sleeve up the tapered nut shank to form a blind head; when the work is securely clamped, continued rotation shears the bolt inside the nut head. Grip of the bolt may be checked by attempting to turn the nut anti-clockwise (i.e. tightening further).

(ii) Different adaptors for the tools must be used for each size and type of Jo-bolt.

8.3.4 **Rivnuts.** When Rivnuts have a locating key to prevent rotation, the keyway should be cut with a special tool supplied by the nut manufacturer. To close Rivnuts the threaded mandrel of the special tool is screwed into the nut, and when the tool is operated the nut shank bulges towards the far side of the work to form a blind head. When the mandrel is removed a fixed nut is left in the structure and may be used for the attachment of de-icing boots, etc.

9 **INSPECTION** Riveted structures should be inspected after each of the following operations:—

(i) After marking-out, to ensure conformity with the repair scheme or the riveting methods used elsewhere on the aircraft.

(ii) After drilling, to confirm the position of holes and ensure that hole size and condition are suitable for the type of rivets to be used.

(iii) After countersinking or dimpling, to check the mating of the parts involved, the condition of the countersink or dimple, and the flushness of rivet heads.

(iv) After final assembly prior to riveting, to confirm the fit of the component and condition of any protective treatments.

(v) After riveting, to ensure that rivets are satisfactorily formed, that there has been no significant distortion of the parts and, where specified, that jointing compound has been correctly applied.

9.1 It is important to ensure that techniques used for dimpling, countersinking, deburring, etc. are satisfactory, having regard to the type of materials and the tools available. As an example, the tools used to countersink aluminium alloys might be quite unsuitable for use with titanium, which work-hardens very quickly. Satisfactory techniques are best established by the manufacture of test pieces in similar materials, and using the same tools that will be used in the final work. Test pieces can be inspected by both destructive and non-destructive methods, and any faults eradicated by variation of the technique, until satisfactory samples are produced.

9.2 **Pre-riveting Inspections.** Particular attention should be paid to the following points when inspecting parts prior to riveting.

(i) Holes should be round, drilled at right angles to the work surface, have a diameter within the limits quoted by the aircraft manufacturer for the type of rivet, and sharp corners should be removed but not excessively chamfered. In certain instances a surface roughness may be specified by the manufacturer, and this should be checked by accepted methods. Normally, a finish consistent with good workshop practice and without axial scores, is satisfactory.

(ii) A countersunk surface must be coaxial with the hole and cut to the required angle. The depth must be such that the rivet will comply with the flushness requirements of the aircraft manufacturer and on no account may the rivet head be below the skin surface. As with ordinary holes a surface roughness may be specified, but provided the countersunk surface is free from 'chatter' marks a finish consistent with good workshop practice is normally adequate.

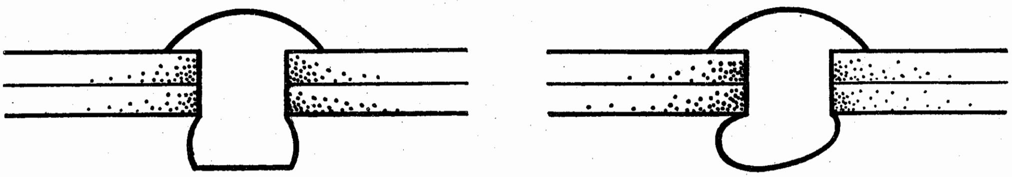
(iii) Dimples should be free from scores and should be of the correct angle. In this respect it should be noted that if several sheets are dimpled for a countersunk rivet, the angle of the dimples in successive sheets should vary to ensure correct nesting. Small radial cracks round the hole are generally acceptable in tertiary structures which have been dimpled from final size holes, but circumferential cracks round the dimple are cause for rejection.

(iv) Mating parts should fit snugly without bending or forcing and should conform to the shape of the surrounding area.

(v) Before final assembly all parts should be separately deburred and swarf removed. The final protective treatment should be checked and, if necessary, rectified before application of jointing compound.

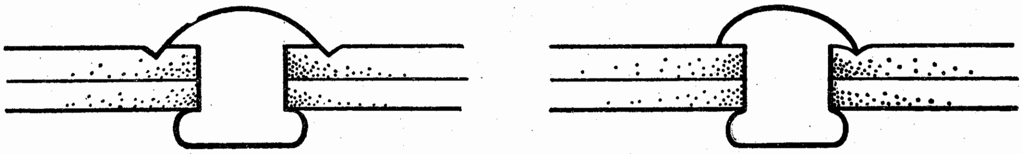
9.3 **Inspection of Rivets.** After the rivets have been closed they should be inspected to ensure that they are tight and fully formed. Rivet heads must not be deformed or cracked, and the surrounding area should be free from distortion and undamaged by the riveting tools. Rivets which are obviously not performing their function should be replaced, but replacement of rivets which are found to be only slightly below standard might do more harm than leaving them in position, particularly in thin materials. Before rejecting such rivets, the strength requirements of the particular joint and the effectiveness of the rivets in question, should be considered. When a flushness tolerance is specified for countersunk rivets, this is normally checked before riveting is commenced; however, the milling of solid rivet heads may sometimes be permitted after riveting to obtain a uniform protrusion. In this case protective treatments must be re-applied after milling.

9.3.1 **Solid Rivets.** Figure 4 shows some of the faults which may be found with solid rivets. Superficial cracks round the periphery of the head are usually acceptable, but not if intersecting cracks could lead to part of the head breaking off. Cracks in the inner area of the head, corresponding to the shank diameter, are not permitted. If snap heads are formed on the tail of the rivet a number of further faults may occur. These include a 'flash' round the rivet head if the shank was too long, and a small head, possibly accompanied by snap marks on the skin, if the shank was too short.



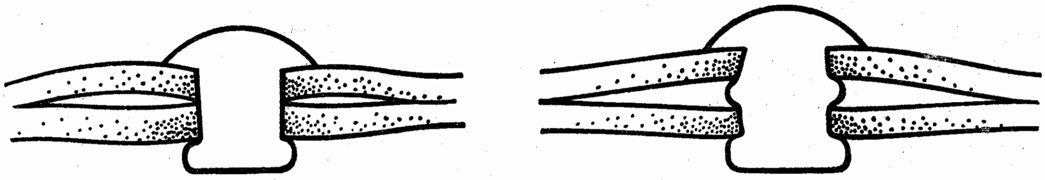
INSUFFICIENT HAMMERING

DOLLY NOT SQUARE



INCORRECT SNAP

SNAP NOT SQUARE



HOLE TOO SMALL

HOLE TOO LARGE

Figure 4 TYPICAL RIVETING FAULTS

9.3.2 **Blind Rivets.** The blind heads formed when these rivets are closed are not usually accessible for visual inspection and in some cases radiological examination may be specified. Visual inspection is normally limited to ensuring that the head is square to and in contact with the skin surface, that the locking collar (Cherry rivets) is properly engaged, and that no damage or buckling has been caused to the surrounding area. Where required, the flushness of countersunk rivets should also be checked.

9.3.3 **Special Fasteners.** These should be inspected to ensure that the axis of the fastener is at right angles to the work, that the head or collar, as appropriate, is correctly formed in accordance with the manufacturer's instructions, and that the work is not cracked or otherwise damaged around the hole.

9.4 **Post Repair Inspections.** When a riveted repair has been completed and finally checked for freedom from swarf and foreign matter, consideration should be given to the necessity for tests or inspections to determine whether the component is fit once again for service. The nature of the test or inspection will depend on the type of component repaired, but one or other of the following examples may be applicable:—

(i) Flying control surfaces should be checked for balance and operation.

(ii) Pressure cabins may require a pneumatic inflation and leak test or proof pressure test in accordance with the approved aircraft manual.

(iii) Integral fuel tanks should be given a pressure test, followed by a flow test or other test relevant to the repair.

(iv) Structure adjacent to moving mechanisms. The moving parts should be operated through their complete range of movement to ensure freedom from fouling. In some cases a minimum clearance may be specified to allow for flexing during aircraft operation.

10 REMOVAL OF RIVETS There are several methods of removing the rivets and fasteners described in this Leaflet, and these are outlined in the following paragraphs. For any particular situation the thickness and strength of the structure should be considered and the method likely to cause the least damage should be used. Before refitting a rivet of the same diameter, the hole should be checked to ensure that its diameter is within the limits specified by the aircraft manufacturer. If it is not within limits, an approved oversize rivet must be fitted and the hole enlarged accordingly.

10.1 The usual method of removing solid rivets is as follows:—

(i) Centre punch the manufactured head.

(ii) Drill down to the depth of the head with a drill slightly smaller than the rivet shank.

(iii) Carefully tap off the head with a flat chisel or prize off with a pin punch.

(iv) Punch out the remainder of the rivet with a parallel punch of the same diameter as the rivet shank, supporting the underside with a hollow dolly as necessary.

10.1.1 The utmost care should be taken when drilling and punching, to ensure that the original hole is not enlarged.

10.1.2 When removing rivets from assemblies which include bonded laminations or reinforcements it is essential not to apply shear loads liable to part the bond.

10.2 A different method of removing solid rivets, which is specified by some aircraft manufacturers, is to drill off the tail of the rivet with a drill slightly larger than the rivet shank and then punch out the shank and manufactured head.

10.3 Cherry rivets may be removed by punching out the stem from the locked end, then drilling off the head and punching out the shank with a parallel punch. If the rivets are installed in thin sheet, however, the locking collar should be removed first by drilling into the stem with a pilot drill, then opening up the hole to shank diameter and prizing out the collar.

10.4 Other types of blind rivet may be removed by drilling off the head with a drill the same size as the hole and punching out the remainder of the rivet.

10.5 Fasteners which have collars swaged onto the shank (i.e. Hi-shear and Avdelok) may be removed by either of two methods:—

(i) Using a hollow mill with an internal diameter slightly larger than the fastener shank, the collar should be milled off to just above the skin surface. The fastener may then be driven out, using a hollow dolly to support the structure.

(ii) The head should be removed by the method described in paragraph 10.1 and the remaining pin and collar punched out.

10.6 In some instances a drill-out bushing is available for use with particular fasteners and this may be used as a guide when drilling out the head or shank.

NOTE: When drilling out loose rivets, care must be taken to prevent the rivet from rotating with the drill, as this would tend to enlarge the hole and damage the skin surface under the head.

BL/6-30

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BASIC

ENGINEERING PRACTICES AND PROCESSES

TORQUE LOADING

1 INTRODUCTION The purpose of torque loading threaded fasteners is to ensure efficient clamping of mating parts and prevent overstressing. The majority of nuts, bolts and set screws on an aircraft are subject to a standard torque value, depending on their material, finish, lubrication, thread type and size, but particular applications may necessitate a different torque loading and this will be specified in the appropriate Maintenance Manual. The normal method of applying a torque loading to a fastener is by means of a torque wrench, but in some critical bolted joints the use of pre-load indicating (PLI) washers may be specified and these are discussed in Leaflet **AL/7-8.**

2 GENERAL 'Standard' torque loading values are those generally applied to steel fasteners used in tension applications on aircraft, and lower values are generally quoted for shear nuts or nuts used in shear applications. Lower torque values are also necessary for union nuts (bearing in mind the actual thread size and not the pipe diameter). 'Special' torque loadings may be used for a variety of reasons, examples of which are the loadings applied to the bolts fitted to flexible engine mountings and those applied to non-standard fasteners such as cylinder holding-down nuts.

3 RECOMMENDED TECHNIQUES Torque-loading instructions in aircraft Maintenance Manuals will be found to vary slightly between different aircraft and engines. Most manufacturers specify lubricated torque values, i.e. the threads and all mating surfaces lightly lubricated with oil, sealant or anti-seize compound as appropriate, but some manufacturers specify dry torque values, i.e. parts clean and dry or as pre-lubricated during manufacture. Due to the varying effects of friction under different conditions of assembly, it is important that the torque applied to any particular fastener should be in accordance with the manufacturers instructions; the pre-load applied to a fastener at a specified lubricated torque would be considerably higher than if the same torque were applied dry.

3.1 **Initial Assembly.** In order to remove the roughness from threads and mating surfaces when assembling new components which require high torque loadings, the following procedure should be followed:—

(i) Clean and, where specified, lubricate threads and mating surfaces of nut, bolt and washer.

(ii) Tighten nut to approximately half the specified torque value.

(iii) Slacken nut then finally re-tighten to specified torque value.

NOTE: Where cadmium plated fasteners are used in locations subject to fluctuating loads the manufacturer may recommend a different procedure.

3.2 **Sealants.** When sealant is used in a joint the torque loading of fasteners should be carried out within the application time of the sealant. After ten minutes, but within twice the application life of the sealant, the loading should be checked and re-applied as necessary.

3.3 **Union Nuts.** The component parts of a flared pipe coupling require bedding-in to ensure freedom from leaks, and the following procedure should be adopted when tightening union nuts:—

(i) Assemble the component parts of the joint and run-up the nut by hand.

(ii) Tighten to specified torque value.

(iii) Slacken the nut half a turn, then re-tighten to specified torque value.

NOTES: (1) Torque loading is not usually specified for flareless couplings. The procedure normally recommended is to tighten the nut using finger pressure until positive resistance is felt, then tighten a further half to one turn.

(2) Lubrication of components is usually by the type of fluid used in the system but connections in oxygen systems must be dry unless a special preparation is recommended.

3.4 **Stiffnuts.** In order to check the effectiveness of the friction element of a stiffnut it is general practice to turn the nut onto its mating thread by hand. If it is possible to pass the thread through the friction element by hand, then the locking is unsatisfactory (**BL/5-1**). However, certain manufacturers specify acceptable limits of 'in-built' or frictional torque for various thread types and sizes, and in these instances each stiffnut should be checked with a torque wrench before re-use.

3.5 **Torque Tables.** Tables of standard torque values for different thread types and sizes, and for special applications, are normally found in the appropriate Maintenance Manual, separate tables often being included for ordinary nuts, stiffnuts, union nuts and studs. Manuals for older types of aircraft may be found to contain only special torque loading requirements and a single table applicable to non self-locking nuts; in these cases the frictional torque of a stiffnut must be added to the torque quoted for the type and size of thread.

3.5.1 Tables usually specify the upper and lower limits of torque for different types and sizes of fasteners, but if a single figure is quoted, it is generally accepted that this may be exceeded for the purpose of lining up a split pin hole, tab washer or locking plate. However, an upper torque limit should not be exceeded, and nuts should never be slackened to line up these locking devices.

3.5.2 Table 1 shows typical torque loading figures for steel non self-locking fasteners with lubricated Unified threads. It is applicable to general purpose bolts and nuts used in tension and shear applications (e.g. British Standards A102 to A217 or American AN3 to AN20 bolts, and appropriate nuts), and should not be used with higher strength fasteners or when different values are specified by the aircraft or engine manufacturers. It may be used when no other standard torque values are specified and, if applied to self-locking fasteners, the frictional torque of the particular nut should be added to the figures shown.

TABLE 1

TYPICAL TORQUE VALUES (LUBRICATED)

Thread (UNF)	Torque (lb in)	
	Tension	Shear
10–32	20 to 25	12 to 15
$\frac{1}{4}$–28	60 to 70	30 to 40
$\frac{5}{16}$–24	115 to 125	60 to 85
$\frac{3}{8}$–24	200 to 215	95 to 110
$\frac{7}{16}$–20	335 to 355	270 to 300
$\frac{1}{2}$–20	500 to 530	290 to 410
$\frac{9}{16}$–18	720 to 760	480 to 600
$\frac{5}{8}$–18	980 to 1020	660 to 780
$\frac{3}{4}$–16	1650 to 1790	1300 to 1500
$\frac{7}{8}$–14	2500 to 2700	1500 to 1800
1–12	3500 to 3700	2200 to 3300

NOTE: For the purpose of conversion, 1 lb in = 1·15 kg cm or 0·113 Nm.

4 TORQUE WRENCHES There are basically two types of torque wrenches. One type contains a flexible beam which bends under load, the amount of bend being recorded on a dial which is graduated in units of torque. The second type contains a spring loaded ratchet device which may be preset before use, and when this preset torque is reached the wrench 'breaks' to prevent further tightening.

4.1 The torque applied to a nut is a function of the force applied to the wrench handle multiplied by the distance between the point of application of the force and the centre of the nut. This may be measured in appropriate units such as pounds inches (lb in), kilogramme centimetres (kg cm) or newton metres (Nm). The scale on the wrench is marked to show the torque applied to its driving tang, i.e. force applied to the handle multiplied by the distance between its driving tang and the centre of the hand grip.

4.2 If a torque wrench is used in conjuction with a socket type of spanner, the nut and tang centres will coincide and the torque applied to the nut may be read directly from the wrench scale. However, in some cases an extension spanner is used in conjunction with a torque wrench and the torque applied to the nut will be different from the torque shown on the wrench scale.

4.3 Figure 1 shows a typical beam type torque wrench which has an extension spanner attached. If this combination is used to torque load a fastener then the following formula should be used to calculate the wrench scale reading which corresponds to the specified torque value:—

$$\text{Scale reading} = \text{specified torque} \times \frac{L}{L + X}$$

Where L = distance between the driving tang and the centre of the handle

X = length of extension spanner between centres.

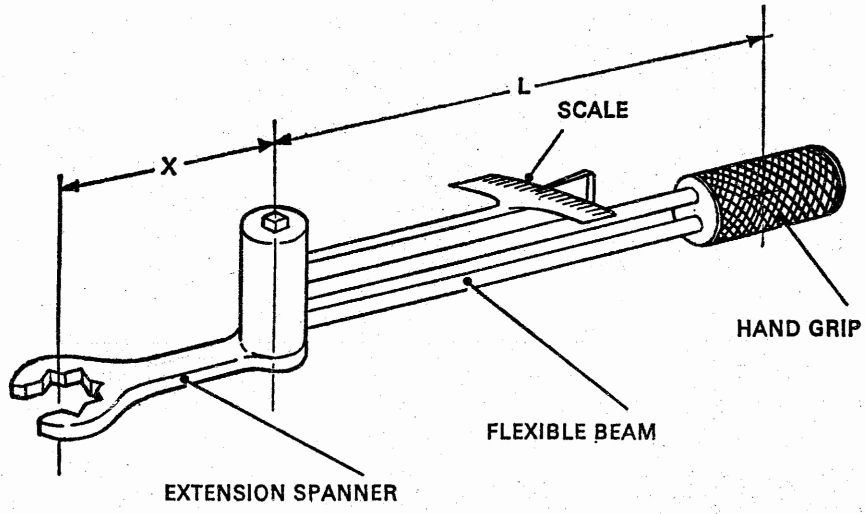

Figure 1 TYPICAL BEAM-TYPE TORQUE WRENCH

4.3.1 A simple way of calculating the scale reading required without using the formula is set out in the following example, for which the specified torque loading is 300 lb in and the lengths of the wrench and spanner are 10 and 5 inches respectively.

(i) Force required on wrench handle to produce a torque of 300 lb in is 300 lb in divided by the distance between nut and wrench handle,

which is, $\frac{300 \text{ lb in}}{10 \text{ in} + 5 \text{ in}} = 20 \text{ lb}$

(ii) Scale reading when force on handle is 20 lb is, 20 lb × 10 in = 200 lb in

Force must therefore be applied to the wrench handle until a reading of 200 lb in is shown on the wrench scale, and this will represent a 300 lb in torque load applied to the nut. With the 'break' type wrench, the adjustment must be preset at 200 lb in.

4.4 General Considerations

4.4.1 When using an extension spanner with a torque wrench, the spanner and wrench should be as nearly as possible in line. If it is necessary to diverge by more than 15° from a straight line (due, for example, to intervening structure), then the direct distance (D) between the nut and wrench handle must be substituted for 'L + X' in the formula (paragraph 4.3) for calculating wrench scale reading. This is shown in Figure 2, and the scale reading in this instance will be equal to specified torque $\times \frac{L}{D}$.

4.4.2 Whenever a torque wrench is used, it must be confirmed that the specified torque and the wrench scale are in the same units; if not, then the specified torque should be converted, by calculation, to the units shown on the wrench scale, and any measurements taken in appropriate units.

4.4.3 When applying torque the wrench handle should be lightly gripped and force applied smoothly at 90° to the axis of the wrench.

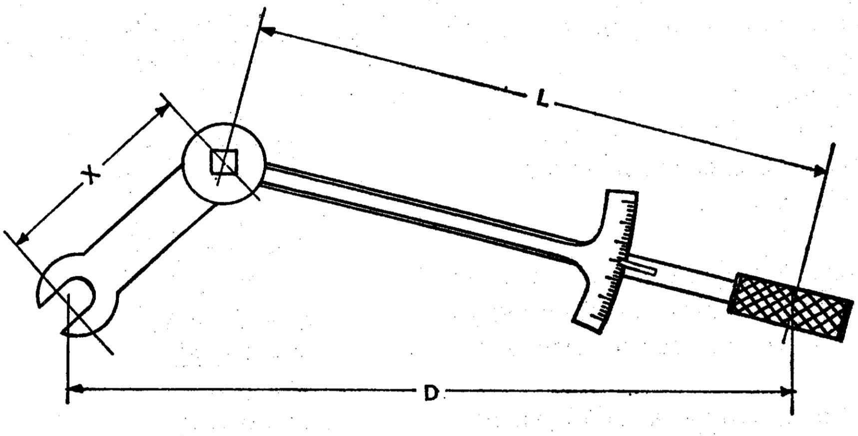

Figure 2 ALTERNATIVE METHOD OF USE

4.4.4 Values of torque within the first quarter of the wrench scale may be difficult to read accurately, and some manufacturers specify that the torque wrench selected for a particular use should have a range such that the specified torque falls within the upper range of the scale.

4.4.5 When using a ratchet type wrench with a floating drive (i.e. a driving tang which is located in a socket in the wrench and is moved axially through the socket to reverse the direction of operation of the wrench), it is important to ensure that the wrench is used the right way round. If incorrectly used, severe overstressing of the fasteners could occur before the error is noticed.

4.4.6 Beam-type torque wrenches should be checked before use to ensure that the scale reading is zero.

4.4.7 All torque wrenches should be checked for accuracy at frequent intervals. If a spring balance is attached to the centre of the wrench handle, and force applied tangentially to the arc of movement, the wrench scale reading should correspond to the spring balance reading multiplied by the wrench length. Checks should be made at several values within the wrench scale range.

BL/7-1

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BASIC

PROTECTIVE TREATMENTS

ANODIC OXIDATION

1 INTRODUCTION This Leaflet gives general guidance on the processes used for the anodic oxidation of aluminium and aluminium alloys. It should be read in conjunction with Defence Specification DEF-151 entitled "Anodising of Aluminium and Aluminium Alloys".

1.1 Aluminium-based materials obtain some corrosion resistance from the natural formation of a thin oxide film on the surface of the metal which occurs when the metal is exposed to air, and this prevents further oxidation of the metal.

1.2 The electrolytic process known as "anodic oxidation" or "anodising" produces a much thicker oxide film or coating which is more resistant to corrosion and abrasion but does not necessarily give complete protection. The corrosion resistance obtained by anodising depends on several factors such as the specification of the base metal, the type of anodising process used, and the efficiency of the sealing procedure.

1.3 An anodic oxidation process may be specified for any of the following purposes:—
- (i) To provide a temporary protection against corrosion.
- (ii) To provide a suitable surface for the application of a more permanent protective scheme.
- (iii) To provide a suitable surface for bonding with plastics materials.
- (iv) To improve resistance to wear.
- (v) As an aid to inspection, (see paragraph 2.3).

2 GENERAL Unless otherwise specified by the approved Design Organisation, all anodising processes and related inspections and tests must comply with the latest issue of Defence Specification DEF-151. For information only, descriptions of typical processes are given in the following paragraphs but detailed information must be obtained from the Specification.

NOTE: There are various proprietary treatments approved under the terms of DTD 900 which are suitable for general anodising.

2.1 There are three types of anodic coating in general use which are designated according to their anodising process: the sulphuric acid process, the chromic acid process and the hard anodising process.

2.2 **Sulphuric Acid Process** The sulphuric acid process is widely used and is generally preferred for its decorative and protective qualities. It gives a wide range of coat thicknesses and is transparent in the thinner ranges. It is, however, not suitable for use on parts containing riveted, lap or folded joints. Unless otherwise specified the coating thickness should be between 0.0003 and 0.0005 inch and it should be sealed in a chromate solution, except in some circumstances where sealing by immersion in boiling water is specified on the drawing or order.

2.3 **Chromic Acid Process** This process can be used for the protection of some riveted assemblies and thin aluminium sheet (normally sheet below 0.01 in thick). It is usually preferred for the treatment of castings of suitable composition and as a surface for bonding to plastics materials. It gives a relatively thin coating (e.g. 0.0001 in) but minimises loss of fatigue strength due to anodising. The process will show surface defects such as cracks which are revealed through the residual electrolyte in the crack drying out to form a brownish-yellow stain. Chromic acid is less corrosive to aluminium than sulphuric acid and is therefore used in cases where the electrolyte can become trapped such as may occur with riveted assemblies, lap or folded joints and small blind holes.

NOTE: If castings of high silicon alloy are anodised in chromic acid there is a tendency for the amperage to rise rapidly with a risk of burning and therefore extra cooling is needed. The sulphuric acid process is better in this case but a prompt rinse is necessary to neutralize the acid.

2.4 **Hard Anodising Process** The thicker and harder anodic coating (0.001 to 0.003 in) produced by this process provides excellent corrosion protection and good abrasion resistance, it also has good insulation properties. The process may reduce the fatigue strength of the metal, as proved in rotating beam type tests, by about a half but the fatigue strength can be partly restored by sealing the coating in an aqueous dichromate solution at the cost of some loss in abrasion resistance.

NOTE: The requirements of the Factories Act and the Chromium Plating Regulations should be given careful consideration before installing or operating an anodising plant. Because of the danger to health from inhaling fumes from an anodic oxidation plant suitable fume extractors are usually necessary. Protective clothing including rubber gloves, aprons and boots are also required.

3 PREPARATION FOR ANODISING

3.1 To obtain a satisfactory anodic coating the surface of the metal must be absolutely clean and free from blemishes, (anodising tends to emphasise rather than conceal blemishes). The trichlorethylene process (Leaflet **BL/6-8**) is a widely used method of cleaning; as an alternative, a mixture of equal parts of white spirit and solvent naphtha can be used, but this must be dried off immediately after cleaning. Particular attention must be paid to removing all traces of flux from welded parts.

NOTE: When trichlorethylene is used for cleaning it is important to ensure that all traces of the fluid are removed before the anodising procedure. Special care should be given to lapped joints or blind holes where trichlorethylene could remain trapped.

3.2 When parts have been buffed or heavily rolled, a certain amount of grease may become embedded in the surface and be difficult to remove. In such instances, degreasing followed by the use of a mildly alkaline cleaner is necessary. Mild alkali cleaning is also permissible as an alternative to, or as an additional operation after, the other degreasing methods.

3.2.1 A suitable solution for this purpose will be found in Process Specification DTD 901 entitled "Cleaning and Preparation of Metal Surfaces" which should be referred to when preparing parts for anodising. Also applicable is DTD 915 entitled "Process for Cleaning Aluminium and Aluminium Alloy Plating". Caustic soda must not be used.

3.2.2 The time of immersion of aluminium alloy in alkali cleaner should be strictly limited and should be followed promptly by immersion in a weak chromic acid to neutralise the alkali, followed by a further wash in running water. Great care should be taken when handling cleaned material to ensure that it does not become contaminated in any way. It is recommended that gloves be worn when handling parts, since perspiration may cause staining under the anodising.

NOTE: When preparing close tolerance parts for hard anodising, it is important that machining allowances are made for dimensional growth.

3.3 When parts which have been in use are to be re-treated, the original anodic coating should be removed. Re-anodising without previous stripping is undesirable due to the difficulty of ensuring proper electrical contact because of the insulating properties of the coating. Parts previously treated by the sulphuric acid process should never be re-anodised without previous stripping, as pitting may occur on the surface and a soft coating may result.

NOTE: In some instances parts freshly anodised by the sulphuric acid process, if found to be inadequately coated, can be returned to the bath and the process continued.

3.4 Anodic coating may be removed by one of several chemical solutions. The following solutions may be used:—

(i)	Sulphuric acid (s.g. 1.84)	15% v/v
	Chromic acid	5% w/v
	Water	Remainder
	Used at about 50°C (123°F).	
(ii)	Phosphoric acid (s.g. 1.75)	3.5% v/v
	Chromic acid	2.0% w/v
	Water	Remainder
	Used gently boiling.	

(iii) After the coating has been dissolved, the parts should be thoroughly washed in water.

4 ANODISING PROCESS

4.1 **Suspension and Racking** The articles form the anode and should be suspended in the anodising baths so that all parts to be treated are exposed to the solution. Hooks, wires, racks or other suspension devices should be made of aluminium or titanium. Good electrical contact is necessary and spring or screw contacts are recommended which should be cleaned before use. The area of contact should be as small as possible but sufficient to allow the current to pass without overheating the metal. Large articles may require connecting at several points and in some cases they are bolted to special racks. The articles must not come in contact with the tank, the stirring device, heating or cooling pipes, cathode plates or other suspended parts. This is particularly important when the solution is agitated.

4.1.1 Hooks, wires and other suspension devices should be checked for temperature rise. Heating up at any point of the electrical circuit indicates either poor contact or a suspension device too small in cross section.

NOTE: The aluminium alloy used for the suspension devices must be at least comparable in purity with the parts to be anodised, if not there is a danger of galvanic action.

4.1.2 Rivets and similar small articles may be clamped in a perforated aluminium or titanium canister (which may be plastics coated on the outside), and a means of adequate circulation of the electrolyte inside the canister should be provided. This can be done by pumping the solution into the canister through a flexible tube connected to the circulating pump. Parts with flat surfaces, such as washers, should be separated by aluminium wire so attached and formed to act as spacers.

NOTE: For longer life and more efficient coating, hooks, racks and other suspension devices are often made of titanium. The choice of this more costly material will depend on the type of production anticipated.

4.1.3 Special care is necessary when suspending hollow articles in the bath, since the trapping of air or the evolution of gas bubbles will prevent the formation of the anodic film. Internal pitting will also occur unless good circulation of the electrolyte is maintained. It is often necessary to provide an internal cathode for anodising hollow articles, and the size of the cathode should be approximately 10% of the internal area. Care should be taken to prevent the cathode touching the sides of the article and where necessary this must be done by fixing a suitable insulating material, such as wood or fibre, to the cathode. Special care is necessary when containers such as oil, fuel or water tanks are withdrawn from the bath otherwise the structure may be strained by the weight of electrolyte in the container.

4.2 **Temperature Control** Close temperature control is important because the current density alters considerably with temperature variations and this affects the properties of the coating. Automatic temperature control (e.g. by thermostat) to within ±1°C (1.8°F) should be used for consistent results. The electric current passing through the electrolyte generates a considerable amount of heat and efficient means of agitation and means of cooling the electrolyte are necessary. Cooling coils fitted at the sides of the tank just below the surface of the liquid, or water jackets in which cold water is circulated, are the normal ways of cooling the electrolyte.

4.2.1 In some instances refrigeration of the electrolyte is necessary, (a) when the load in amperes exceeds the bath volumes in gallons, (b) for hard anodising, and (c) where the ambient temperature is high.

4.2.2 When the heating of baths is necessary, immersion heaters, graphite heat exchangers or steam coils may be used.

4.2.3 The electrolyte can be agitated by an external pump which circulates the electrolyte through a rubber hose. Air injection is also satisfactory when anodising articles of simple form. An air pressure of 10 lb/in^2 in pipes about nine inches apart with holes of about 0.05 inch diameter at 3 to 6 inch centres can be used. To avoid oil contamination the air pressure should be supplied by a water lubricated rotary pump.

4.3 **Solution** It is recommended that for more effective anodising and economy of electrolyte the solution should be continuously and effectively filtered. This can easily be done when using an external agitation pump. The quality of water used in anodising and sealing is important. The use of other than distilled or deionised water can produce coatings of lower corrosion resistance, cause drying stains and shorten the bath life.

NOTE: Deionised water is water from which almost all impurities have been removed, it is processed by passing tap water through ion-exchange resins to remove mineral constituents.

4.4 **Sulphuric Acid Anodising**

4.4.1 The tank or bath used for this process should be lined with either lead or rubber but a ceramic bath is also suitable. When lead lining is used this will form the cathode, but with ceramic or rubber linings cathode plates made of lead or aluminium are necessary. The insulated anode bars or rails for suspending the articles are made of copper and should be kept bright and all connections should be electrically efficient and free from corrosion. Direct current from a rectifier or generator is generally used and the supply should be sufficient to meet the requirements of paragraph 4.4.5.

4.4.2 The electrolyte used should be within the range of 5 to 22% by volume of sulphuric acid in water, (most operators use 10 to 15% by volume solutions). Contamination by chlorides or other foreign matter should be avoided. The chloride content of the electrolyte should not exceed 0.20 g of sodium chloride per litre. When the solution is being made up, the bath should be half filled with cold water and the requisite quantity of sulphuric acid poured very slowly into the water, stirring vigorously all the time. Considerable heat will be generated, and the solution should be allowed to cool before adding further cold water to produce the required density figure.

4.4.3 The temperature and voltage at which the bath is operated is dependent on the free sulphuric acid content of the electrolyte. When the bath is in use, aluminium dissolves in the acid, increasing the metal content and this decreases the acid strength.

4.4.4 The temperature at which the bath should be operated should be fixed in relation to the free sulphuric acid content, and should not exceed that indicated on the graph (Figure 1).

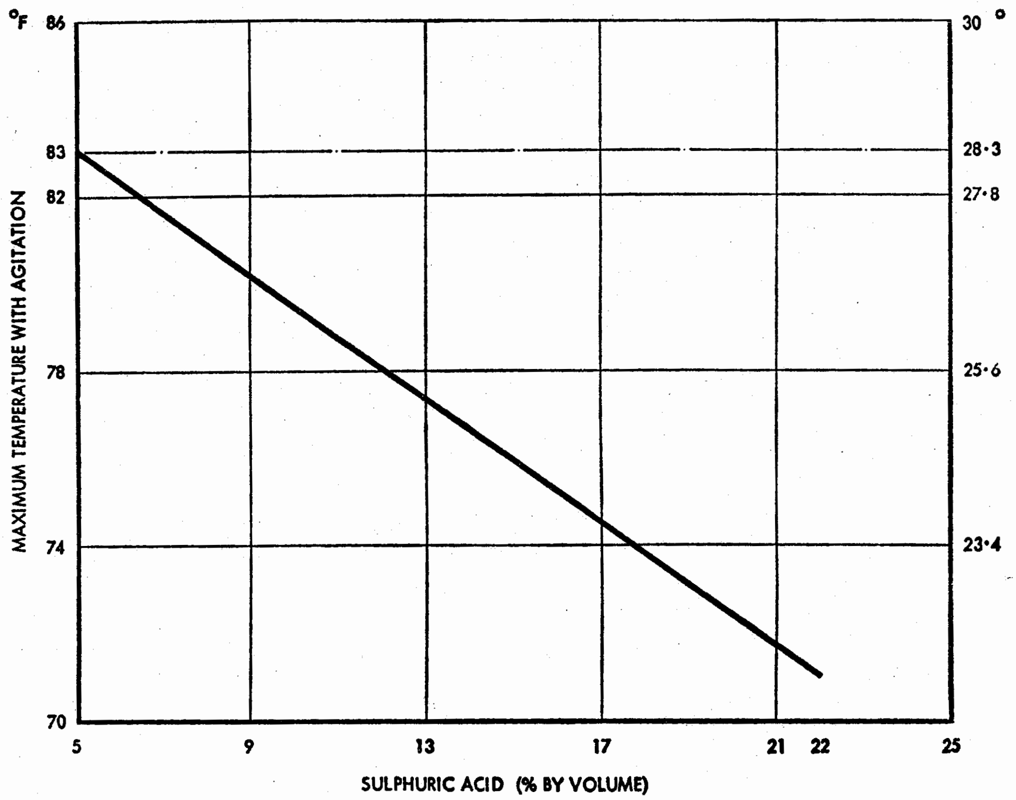

Figure 1

4.4.5 The voltage required to operate the bath at the selected temperature should be determined by suspending in the electrolyte a test sheet or sheets of aluminium of 99% purity, having a surface area requiring at least 10% of the normal electrical load of the bath. The current density should then be regulated to a steady 12 to 15 amperes per square foot, calculated on the total sheet area, and the voltage noted. The operating voltage of the bath should be determined during the test and usually results in a figure of 15 to 18 volts. In this process a steady voltage is maintained throughout the treatment period.

4.4.6 The intervals at which the tests are carried out should be related to the quantity of the work which passes through the bath and changes in the concentration of the electrolyte that occur due mainly to drag-out losses and bath additions. The test samples can be used repeatedly, provided the film is stripped before each test and the surface has not become unduly roughened.

4.4.7 It is permissible with this process to remove or immerse parts for treatment if desired, as the potential is maintained at a constant figure. It should be noted that the current density may depend on the total surface area of the bath load.

4.4.8 After anodising, the parts should be washed in cold running water and transferred directly to the sealing or dye bath.

NOTE: Modern plants catering for large scale production have automatic or semi-automatic transfer machines to convey work from one treatment bath to another. To minimise deterioration of solutions it is essential that the "dwell" time between each treatment is adequate to allow for proper draining and reduce the carry over of solution from one bath to the next. Work pieces such as channels or tubes should be supported so as to drain naturally or should be rotated to pour out trapped electrolyte or water.

4.4.9 The parts can be sealed by immersing for 5 to 10 minutes in a solution composed of 70 to 100 grammes of potassium or sodium dichromate, and 18 grammes of sodium carbonate, added to one litre of water. The temperature of the solution should be maintained at 94 to 98°C (201 to 208°F) during the process, and the parts should be dried immediately upon removal from the solution. The parts should be sealed as soon as possible after anodising as, due to porosity, the new film is highly absorbent, and serious corrosion may result if the parts are exposed to humid atmosphere for long periods. In addition, contamination of the parts may occur if in contact with certain oils or greases. The pH value of the solution should be maintained between 6·0 and 7·0 as measured with a glass electrode, or 6·3 to 7·3 if measured with indicators.

4.4.10 An alternative sealing solution is a composition of 45 to 55 grammes of potassium or sodium dichromate added to one litre of water. The sealing time is the same as that for the anodic treatment, and the temperature of the solution should be maintained at 94 to 98°C (201 to 208°F). The pH value of the solution should be maintained at 5·6 to 6·6 if measured with a glass electrode, or 5·9 to 6·9 if measured with indicators.

4.5 Chromic Acid Anodising

4.5.1 The electrolyte for this process may consist of a solution of 30 to 100 grammes of chromic acid per litre. The chromic acid should be of 99·5% purity and chloride in the electrolyte should not exceed the equivalent of 0·02 g per litre.

4.5.2 The tank used to contain the electrolyte should be of steel and be provided with anode bars or rails, usually manufactured in copper and insulated from the tank, from which the articles to be treated are suspended. The tank or separate plates of mild steel or stainless steel form the cathode. When plates are used for this purpose, it will be necessary to provide cathode bars, and the plates should be firmly attached to these to prevent movement when the electrolyte is agitated.

4.5.3 The working temperature of the bath should be maintained at 40 ± 2°C (104 ±4°F), for the treatment of wrought aluminium alloy parts, but in the case of aluminium alloy castings, particularly those having a high copper content, it is recommended that the temperature should be lowered to between 25 and 30°C

(77 to 86°F) in order to prevent pitting on the surface of the parts. Under full load conditions heating can be dispensed with after two or three loads, as sufficient heat will have been generated by the passage of the electric current through the electrolyte to maintain the temperature at the required level.

4.5.4 Metals other than aluminium-base alloys should not be introduced into the bath, since copper or copper-rich alloys, steel, zinc-base die castings or magnesium, for example, do not build up an oxide film and are severely corroded. This results in excessive absorption of current by the foreign metal, preventing or retarding the anodic oxidation of the aluminium and contaminating the solution. Care should also be taken to prevent contamination of the bath by the copper-rich drippings, which would occur if the anode bars were attacked by the solution or its fumes.

4.5.5 Current can be supplied by a dynamo or a rectifier and transformer. Voltage should be controlled within the range of 0 to 50 volts D.C. in steps of not more than 5 volts. The amperage should be sufficient to deal with the largest bath load. A voltmeter should be provided to measure the potential difference across the bath, and an ammeter to measure the current flow.

(i) With the operational temperature of the electrolyte between 38 to 42°C, current should be supplied so that the voltage across the bath is increased in steps of not more than 5 volts from 0 to 40 volts in the first 10 minutes, maintained at 40 volts for 20 minutes, gradually raised to 50 volts in the next 5 minutes and maintained at 50 volts for 5 minutes. These times should be regarded as minima.

(ii) At the commencement of the process the current density may be as high as 10 amperes per square foot but this will drop during processing to about 3 to 4 amperes per square foot of treated surface.

NOTE: The maximum voltage can be taken to 60 volts with advantage on work being prepared for redux bonding.

4.5.6 When castings are being treated at the temperature recommended in paragraph 4.5.3, the voltage should be increased in steps of not more than 5 volts from 0 to 40 volts during the first 10 minutes, then be maintained at 40 volts for 30 minutes. As castings generally take a much heavier current than wrought materials, care is necessary not to treat too much material at the one time in order to avoid overloading the electrical supply or causing excessive temperature rise of the electrolyte.

4.5.7 On completion of the process, the anodised parts should be sealed by swilling thoroughly in cold running water, then rinsed in boiling water and allowed to dry in air. This is an essential part of the normal anodising protection process as it serves to seal the pores of the coating.

NOTE: When chromic acid anodising is to be carried out on a surface which is to be painted it is preferable not to seal it. Paint keys better to an unsealed surface, especially if carried out promptly after anodising. If chromic acid anodising is carried out before redux bonding, it is important to omit any sealing and to dry the work promptly after the cold wash by drying at a temperature of not more than 40°C. (In this case the surface to be redux bonded must not be touched by hand. Operators should wear clean linen gloves.) The hot water wash must also be avoided when chromic acid anodising is used as a flaw detection procedure (see paragraph 6.2).

4.6 Hard Anodising

4.6.1 The electrolyte used and the processing procedures are basically similar to the ordinary sulphuric acid process. Low concentrations of sulphuric acid (e.g. 10 per cent by volume) are recommended and should be used with low electrolyte operating temperatures (e.g. between —5 to +5°C (23 to 41°F). Low temperature on the surface of the work is important and this is normally achieved by a vigorous flow of cooled electrolyte flowing over all the surfaces to be treated. This low temperature is achieved by pumping the electrolyte through cooling coils immersed in refrigerated anti-freeze solution before passing it back to the bath.

4.6.2 The process can be operated with direct current or a combination of direct and alternating currents. The current density in a typical sulphuric acid electrolyte may vary from about 25 to 400 amperes per square foot depending on the process employed and the alloy being treated. Likewise the final voltage may vary from about 40 to 120 volts, depending largely on the thickness of coating required and the alloy being treated. The work should be suitably jigged and the electrical connections made very firmly to withstand the considerable agitation of the electrolyte necessary with this process.

4.6.3 Care and attention to detail is essential for satisfactory hard anodising and the requirements of the Specification DEF-151 together with any approved Design instructions must be closely followed.

4.6.4 The conditions of hard anodising must be selected to suit the material being treated and the thickness of coating required. Sample parts of the material should be anodised for trial purposes and, when found satisfactory, the method of treatment (i.e. electrolyte, temperature, agitation, current, voltage, time, suspension and sealing treatment) should be recorded in detail and the batch hard anodised under the same conditions as the sample. Particular attention should be given to maintaining good agitation and the temperature of the electrolyte should be maintained within 2°C (3·5°F) of the nominal value.

NOTE: When determining the optimum conditions for hard anodising a particular work the composition of the alloy is important. It is therefore essential to segregate work of different casts or batches and for the operator to be informed of any change in alloy so that he can adjust his technique accordingly.

4.6.5 Hard anodising may impair the surface finish, and this should be considered in relation to the surface required on the finished part. In order to produce good coatings and to reduce possible damage to the coating, edges of parts should be radiused to a minimum of 0·06 inch.

4.6.6 The sealing of hard anodic coatings is optional. Some softening of the coating is caused by sealing but sealing may also partially restore the loss of fatigue strength resulting from hard anodising.

4.6.7 Hard anodising is often applied to limited areas of aluminium alloy items, the remaining surfaces of which have to be protected by some other means, usually ordinary chromic acid anodising.

(i) It is usual to carry out the ordinary chromic acid anodising before hard anodising and the areas to be hard anodised stopped off with a suitable lacquer. When this has been completed and the work washed, the stopping off lacquer is removed and the area to be hard anodised thoroughly cleaned (usually by mechanical means) to ensure that all traces of lacquer have been removed. The original anodised area is then stopped off and the hard anodising carried out on the cleaned area.

(ii) Stopping off must be in accordance with the requirements of the approved process or drawing instructions. It is much easier to end a masked area at an external angle or shoulder than in an internal angle. Where an anodised area is required to achieve a satisfactory fit then the stopping off must be particularly carefully done as hard anodising produces a distinct growth.

4.6.8 In some instances parts are hard anodised all over, after which the coating is machined off in the areas where close tolerances are required and where protection is applied by another method.

5 INSPECTION

5.1 Experience is essential in estimating the quality of an anodic coating. In general an anodic coating appears warmer to the touch than the bare metal and some resistance is felt when passing the fingers over an anodised surface. (It should be noted that a thin unsealed coat will offer more resistance than a good sealed coat.) As contamination of the surface can easily occur from the natural oils exuded by the skin it is essential that such checks are made on representative test samples only.

5.2 **Gauge Check** Anodic oxidation will cause slight increase in the volume of the part treated. With the sulphuric acid process, however, as the metal is soluble in the electrolyte, prolonged or incorrect treatment may cause a serious loss of base metal and, therefore, thin sheet treated by this process should be checked for gauge occasionally.

5.3 **Dye Test** This test should be made immediately after washing and drying but before any sealing process. The anodic coating should be such that when dyed with methyl violet dye, vigorous rubbing with a damp cloth shall not produce any appreciable loss of colour. The dye should be applied either by using violet endorsing ink on a rubber pad or by a copying pencil rubbed over the moistened anodised surface. Dye tests should not be used where appearance is important. The marks can never be removed and tend to appear through any subsequent paint coat.

5.4 **Sealing Test** To test whether anodic coatings have been sealed or made non-absorptive, a drop of violet dye solution made by dissolving 1 gramme of anthraquinone violet R in 50 ml of water, should be applied at room temperature to the coated surface of the item, which must not have been contaminated by handling. The solution should be allowed to stand for five minutes and should then be washed off with running water and the test area rubbed with soap and water. If the surface is properly sealed, no colour will remain.

5.5 **Electrical Tests** The electrical test may be used to ascertain the quality of a sealed coat but is not reliable on rough surfaces such as those found on the unmachined portions of castings.

5.5.1 The test can be made with a 60 volt dry battery connected to a spring clip and a metal ball of not less than ½ inch diameter. A voltmeter should be connected into the circuit.

5.5.2 The spring clip should be attached to the component, ensuring that the points of the jaws penetrate the film. The ball should then be passed over the surface of the component and, if the coating is satisfactory, the voltmeter will read 60 volts. At raised points, sharp edges or corners, the coat will be thinner, and consequently the resistance will be less, resulting in a drop in voltage. Pressure should not be exerted on the ball during the test otherwise the anodic coating may be damaged.

5.5.3 The main use for this test is to determine whether or not a part has been anodised.

5.6 **Visual Inspection** Various factors affect the colour of an anodic coat but a distinct, even colour is a good indication of a satisfactory coat. The coat produced by the sulphuric acid method is more transparent than that produced by the chromic acid process, and is consequently more difficult to assess.

5.6.1 The chromic acid coat is translucent to opaque, and should be light grey in colour on pure aluminium. On alloys having a high silicon content, however, it will appear as dark gray or purple.

5.6.2 The sulphuric acid process, although producing an almost transparent coat, will again appear darker on alloys having a high silicon content.

5.6.3 Some variation of colour may appear between different batches of the same material. Coatings vary in colour according to the composition of the material and between different forms of the same material. Absence of coloration does not necessarily indicate a poor coating, but dense coloration may be regarded as a favourable sign.

5.6.4 Hard anodising should have a continuous coating free from visible defects and there should be no signs of powdering. An assessment of the hardness of the film can be made by rubbing the surface two or three times with emery paper or cloth to B.S. 871, Grade 00, using medium finger pressure. The paper or cloth should not abrade the surface but should skid over the surface and should show not more than a trace of whitening on the surface.

5.7 **Thickness of Coating** The average coating weight can be determined by weighing a dry test piece before and after stripping the anodic coating in a phosphoric/chromic acid mixture such as given in paragraph 3.4 (ii). The stripping sequence is continued until the weight remains constant. The test piece should form part of, and be treated with, the batch of work which it represents.

5.7.1 The test piece should have a total surface area of not less than 5 square inches and should be of such shape that the surface area of coating can be easily determined. On removal from the stripping bath the test piece should be washed in hot distilled water and dried before re-weighing.

5.7.2 An average thickness can be calculated from the formula:—

$$T = \frac{W}{44 \times A}$$

where T = average thickness of coating in inches.
W = weight of coating in grammes.
A = surface area of coating in square inches.

The formula is based on an assumed density of 2.7 g/cm^3 for anodic coating sealed in aqueous solution.

6 CRACK DETECTION The use of chromic acid anodising as an inspection aid makes it easier to detect such defects as coarse grain or segregation. It also shows up surface cracks, laps, or subcutaneous faults which break through to the surface and could remain undetected.

NOTE: As a suitable method of flaw detection for Class 1 castings, forgings and extrusions, the process has been largely superseded by fluorescent flaw detection. It is known that in some instances the anodic coating can 'bridge' small cracks.

6.1 During the anodising process, which should be effected in the minimum permissible period, chromic acid will be deposited in any cavity which may exist in the material. Upon removal from the bath, the acid will be carried to the surface by the absorbent anodic film in the vicinity of the defect, causing a yellow or brown stain to appear.

6.2 When the parts are removed from the bath they should be washed by a brief swill in cold water to remove the chromic acid from the outer surface. The parts should be allowed to become thoroughly dry, and should be left for at least 24 hours before commencing the examination.

NOTE: Prolonged washing or the use of hot water may remove the chromic acid from the crevices and render the test abortive.

6.3 It is preferable to carry out the examination either in daylight or under a mercury vapour lamp, as the stains may be difficult to recognise in a yellow light. Electrolyte which has been in use for some time is darker than newly made solution, and used electrolyte will therefore give a more positive indication of a defect.

6.4 Contamination caused by perspiration will tend to appear as a yellow stain after chromic acid anodising.

7 MAINTENANCE OF THE ELECTROLYTE

7.1 **Chromic Acid Process** When the bath is in use, a gradual reduction of the chromic acid occurs, together with the formation of trivalent chromium compounds in which the chromium is no longer effective. The bath may be regenerated with chromic acid, provided the total chromium content does not exceed 10% by weight.

7.1.1 Additions to the chromic acid content should also be made when the titration value falls below 3. Analysis of the electrolyte for total chromium content, titration value, and chloride content should be carried out as detailed in the latest issue of Specification DEF-151.

7.2 **Sulphuric Acid Process**

7.2.1 The concentration of a new solution should be within the range of 5 to 22% by volume of sulphuric acid in water, and losses should be made good by the addition of water or sulphuric acid as necessary.

7.2.2 When the bath is in use aluminium dissolves in the acid, thus the metal content increases and the acid strength decreases; this should be rectified by the addition of sulphuric acid. Analysis of the electrolyte for free sulphuric acid content, aluminium content and chloride content should be made as detailed in the latest issue of Specification DEF-151.

BL/7-2

Issue 7

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BASIC

PROTECTIVE TREATMENTS

CADMIUM PLATING

1 INTRODUCTION This Leaflet gives guidance on the processes used for the cadmium plating of carbon and low-alloy steel parts for protection against corrosion, and on the requirements for the cadmium plating of copper-base materials and corrosion-resisting steels for the reduction of contact corrosion of less noble metallic materials. The requirements for cadmium plating are contained in Specification DEF STAN 03-19.

1.1 Parts made of steel of specified minimum tensile strength exceeding 1400 N/mm^2 or equivalent hardness (see paragraph 1.6) are subject to the special limitations and requirements of Specification DEF STAN 03-4, further guidance on which is given in paragraphs 4.5 and 5.3. Cadmium plating must not be used on parts liable to be subject to temperatures in excess of 235°C (455°F).

NOTE: Throughout Specification DEF STAN 03-19 the unit of force called the Newton (N) has been used and is therefore also used in this Leaflet. 1 N is the force which, when acting on a body of mass 1 kg, gives an acceleration of 1 m/sec^2.

1.2 Preparation for plating and stress-relieving heat treatment, when required, should be carried out in accordance with DEF STAN 03-2.

1.3 The cadmium-plating process deposits a protective coating of cadmium on the surfaces of the parts by electro-chemical means; it is used mainly for the protection of ferrous metals and provides protection against nearly all forms of surface corrosion, except that the cadmium itself is liable to attack from the vapours emitted from some organic varnishes and plastics insulating materials. The resistance of cadmium to these vapours can be increased if the plating is subjected to the chromate passivation process prescribed in Specification DEF 130.

1.4 The treatments applied to steel parts before and after cadmium plating depend partly on:–

(a) the tensile strength (or hardness) of the steel,

(b) the presence of surface-hardened areas,

(c) the need or otherwise for stress-relieving heat treatment, and

(d) whether the steel is of carbon, low-alloy or corrosion-resisting type.

1.5 In view of 1.4 above, it is essential that the piater be given the necessary information by the Design Organisation specifying the process to enable him to select the appropriate pre-treatment and, where applicable, the post-plating treatment for the removal of embrittlement, or that he be given precise instructions regarding the treatments to be applied for these operations.

1.6 If no minimum tensile strength is specified for the steel, the treatments must be based on the minimum specified hardness number (Vickers hardness number – HV). Hardness values of 300 HV and 425 HV may be regarded as equivalent to tensile strengths of 1000 N/mm² and 1400 N/mm² respectively. Steels which have been wholly or partly surface hardened must be considered as being in the category appropriate to the hardness of the surface layer.

1.7 General guidance on the protection of aircraft parts against corrosion, and on the selection of suitable protective treatments, is given in Leaflets **BL/4-1, BL/4-2** and **BL/4-3**. Leaflet **BL/4-3** also describes methods of assessing the effectiveness of cadmium plating and should be read in conjunction with this Leaflet. A list of associated Standards and Specifications is given in paragraph 11.

2 PLATING PLANT The cleanliness of the plating equipment and of the plating room is of the utmost importance if consistently good plating is to be obtained. Sludge should be removed each time the plant is cleaned and the electrolyte should be filtered periodically.

2.1 **Plating Baths.** The electrolyte should be contained in a steel or plastics-lined tank; the use of a lead-lined tank is prohibited. The tank should be provided with insulated copper or brass rails from which the parts to be plated can be suspended and which should be clean and free from verdigris. The parts being treated serve as the cathode, and plates, balls or oval extruded sections of solid cadmium serve as anodes.

NOTE: The anodes must conform to the requirements of British Standard 2868 and must be certified free of mercury.

2.1.1 To prevent the cadmium content of the electrolyte becoming too high, a proportion of insoluble anodes, such as iron or mild steel plates or balls, may be used.

2.1.2 To obviate the necessity of 'wiring up' very small items such as nuts, bolts and washers for suspension in a tank-type bath, a rotating barrel-type bath may be used.

2.2 **Electrical Control.** Direct current is required for the operation of the bath. This is usually supplied by a rectifier and is controlled according to the current density required, both voltage and current density varying with the composition of the electrolyte.

2.2.1 The electrical control should be capable of operation within reasonably fine limits and accurate voltmeters and ammeters should be provided.

2.2.2 Porous plating of poor quality will result if the voltage and current density are of too high a value during the plating operation. The time taken to obtain a plating of acceptable thickness varies between 15 and 40 minutes, depending on the efficiency of the plant. However, when high-speed bright plating solutions are used, current densities of approximately 300 A/m² (30 A/ft²), at a pressure of 1½ to 2½ V are often specified, and a deposit of 0·00762 mm (0·0003 in) thickness can be obtained in 8 to 10 minutes.

2.3 **Heating the Electrolyte.** The electrolyte can be heated to the prescribed operating temperature by means of gas, electricity or steam.

NOTE: The operating temperature of a proprietary electrolyte should be as recommended by the supplier.

3 PREPARATION OF PARTS FOR PLATING The surfaces of the parts to be plated must be quite clean otherwise the process will not be successful. In addition, for certain materials, stress-relieving heat treatment is essential before plating. Suitable cleaning and stress-relieving heat-treatment processes are prescribed in Specification DEF STAN 03-2.

3.1 Where copper-base materials are concerned, it is recommended that the cleaning process prescribed in DEF STAN 03-2 should be followed by nickel plating to a thickness of between 0·00127 mm (0·00005 in) to 0·00254 mm (0·0001 in).

3.2 Steel parts which are to be chromium plated locally and then heated in the range of 440°C to 480°C, as prescribed in DEF STAN 03-14, must be given these treatments before cadmium plating is commenced.

3.3 Where steels having a specified minimum tensile strength exceeding 1400 N/mm^2 are concerned, the special requirements regarding surface preparation prescribed in Specification DEF STAN 03-4 must be taken into account.

4 THE PLATING PROCESS Cadmium plating is usually effected with a cyanide electrolyte, but when freedom from hydrogen embrittlement is a primary consideration, the use of a modified cyanide or fluoborate electrolyte may be advantageous. Addition agents, such as those used to improve the properties or appearance of the coating, may also accentuate hydrogen 'pick-up' during plating.

NOTE: The throwing power of fluoborate electrolyte is less than that of cyanide electrolyte.

4.1 Any suitable electrolyte may be used provided that:–

(a) the plating satisfies the quality and thickness requirements prescribed in DEF STAN 03-19,

(b) the materials are certified mercury-free by the suppliers, and

(c) when a proprietary electrolyte is used the proprietary salts, i.e. brighteners, are employed for the maintenance of this, then the composition of the electrolyte for standard chemicals as given in paragraph 4.2 must be controlled.

4.2 Guidance on the composition of suitable cyanide electrolytes for bath and barrel plating is given in the following paragraphs. The units used are grammes per litre (g/litre) and ounces per gallon (oz/gal).

4.2.1 **Composition for Baths.** A suitable electrolyte is as follows:–

Cadmium	14–17 g/litre (2·25 to 2·75 oz/gal)
Total cyanide (as NaCN)	56–63 g/litre (9 to 10 oz/gal)
Sodium hydroxide	11–14 g/litre (1·75 to 2·25 oz/gal)

Addition agents may be included if desired.

(a) The bath should be operated at a temperature of between 15°C and 35°C at a current density of approximately 50 to 100 A/m^2 (5 to 10 A/ft^2).

(b) An electrolyte having approximately the composition of that given above may be prepared, using cadmium cyanide or cadmium oxide to provide the metal content, as follows:–

Cadmium cyanide	25 g/litre (4·0 oz/gal)
Sodium cyanide	43 g/litre (6·9 oz/gal)
Sodium hydroxide	9 g/litre (1·5 oz/gal)

or

Cadmium oxide	19 g/litre (3·1 oz/gal)
Sodium cyanide	58 g/litre (9·3 oz/gal)

4.2.2 **Composition for Barrels.** A suitable electrolyte is as follows:–

Cadmium	23–27 g/litre (3·75 to 4·25 oz/gal)
Total cyanide (as NaCN)	94–100 g/litre (15 to 16 oz/gal)
Sodium hydroxide	17–20 g/litre (2·75 to 3·25 oz/gal)

Addition agents may be included if desired.

(a) The bath should be operated at a temperature of between 15°C and 35°C at a current density of approximately 50 A/m^2 (5 A/ft^2).

(b) An electrolyte having approximately the composition of that given above may be prepared, using cadmium cyanide or cadmium oxide to provide the metal content, as follows:–

Cadmium cyanide	38 g/litre (6·0 oz/gal)
Sodium cyanide	75 g/litre (12·0 oz/gal)
Sodium hydroxide	19 g/litre (3·0 oz/gal)

or

Cadmium oxide	29 g/litre (4·7 oz/gal)
Sodium cyanide	97 g/litre (15·5 oz/gal)

4.2.3 **High-Speed Bright-Plating Electrolyte.** A high-speed bright-plating electrolyte suitable for use with both baths and barrels is as follows:–

Cadmium	19–25 g/litre (3·0 to 4·0 oz/gal)
Total cyanide (as NaCN)	94–137 g/litre (15·0 to 22·0 oz/gal)
Sodium hydroxide	19–38 g/litre (3·0 to 6·0 oz/gal)

It is essential that a suitable addition should be used.

(a) The bath should be operated at a temperature of between 15°C and 35°C at a current density of approximately 300 A/m^2 (30 A/ft^2).

(b) An electrolyte having approximately the composition of that given above may be prepared, using cadmium cyanide or cadmium oxide to provide the metal content, as follows:–

Cadmium cyanide	32 g/litre (5·1 oz/gal)
Sodium cyanide	106 g/litre (17·0 oz/gal)
Sodium hydroxide	31 g/litre (5·0 oz/gal)

or

Cadmium oxide	25 g/litre (4·0 oz/gal)
Sodium cyanide	125 g/litre (20·0 oz/gal)
Sodium hydroxide	16 g/litre (2·5 oz/gal)

4.3 **Suspension of Parts.** Large components or parts should be suspended from the cathode rails by means of clips or wire having several contact points of small area rather than a few points of large area. The clips or wire should be removed from time to time so that unplated patches on the parts are avoided.

NOTE: Laminated or assembled parts must not be cadmium plated due to the risk of corrosion resulting from entrapped electrolyte.

4.3.1 Small parts which cannot be suspended individually should be placed in wire baskets, the baskets being suspended in the usual way. However, they should be shaken up from time to time to ensure that an even plating is obtained. Where very small parts are concerned, the barelling process described in paragraph 2.1.2 is more suitable.

4.3.2 Parts having very deep recesses, such as tubular parts, will not receive a satisfactory internal plating unless internal anodes are used. Such anodes should have a minimum surface area of 10% of the internal area of the part under treatment, and should be positioned centrally.

4.3.3 Close coil springs (heat-treated before plating) should be slightly extended during the process of plating to ensure satisfactory deposition between the coils.

4.4 **Masking.** Where necessary components may be masked to avoid plating various sections but the practice of plating all over and then removing the plating not required by final machining operation is considered more satisfactory. However, if machining is not possible, steel parts from which the masking has been removed should be suitably protected, immediately after the plating and subsequent washing, to prevent corrosion.

4.5 **Very High Tensile Steels.** Parts manufactured of materials having a specified minimum tensile strength exceeding 1400 N/mm^2 are subject to the specific requirements of DEF STAN 03-4. The parts must be cleaned and prepared, as prescribed in DEF STAN 03-4 by one or more of the methods described and numbered in DEF STAN 03-2, after which the general requirements of DEF STAN 03-19 should be applied, including chromate rinsing and chromate passivation.

NOTE: Unplated areas must not be allowed to come into contact with the passivation solution, i.e. stopping-off compound should be left on.

4.5.1 An alkaline cyanide bath is generally used. There is evidence to show that acid baths based on fluorborate or perchlorate cause less embrittlement but, unfortunately, the latter baths have relatively poor throwing power.

4.5.2 There is evidence that embrittlement is less in baths of high cadmium concentration, baths of low cyanide concentration, and baths operated at high current density. Brightening agents must not be added to the bath.

5 **TREATMENT AFTER PLATING** Immediately after plating the parts should be washed in clean running water until all traces of the electrolyte are removed and, unless they are to be immediately passivated without drying, should then be dipped in a 5% (48 g/litre (8 oz/gal)) aqueous solution of chromic acid free from other acids, maintained at a temperature of not less than 60°C (140°F) for 15 to 30 seconds. The parts should then be washed in clean running water, finally in warm water, and dried.

5.1 Washing should normally be followed by chromate passivation conforming with Specification DEF 130, and may only be omitted when the parts are to be etch-primed or at the specific request of the Approved Design Organisation.

NOTE: In some districts it may be found desirable to use de-mineralised water in washing or chromate dip operations in order to avoid staining.

5.2 Parts not required to be heated for removal of embrittlement (see paragraph 5.3) must be passivated immediately after plating and washing without intermediate drying. Parts made of high tensile steel must be treated for removal of embrittlement before chromate passivation.

5.3 **Removal of Embrittlement**

5.3.1 All plated steel parts of specified minimum tensile strength of 1000 N/mm² or greater (or of equivalent hardness) must be heated as described below as soon as practicable but not more than 16 hours after plating. This treatment must also be applied to parts of this tensile strength after any stripping, except that the minimum time of heating of stripped parts may be reduced to not less than half of that specified for plated parts. Parts of minimum specified tensile strength exceeding 1400 N/mm² must not be replated without the consent of the Approved Design Organisation responsible for the design.

5.3.2 Plated parts, other than those with carburised areas, made of steel of specified minimum tensile strength of 1000 N/mm² or greater up to and including 1400 N/mm² must be heated at a temperature between 190°C (374°F) and 230°C (446°F) for not less than 8 hours. Parts of minimum specified tensile strength exceeding 1400 N/mm² must be heated in accordance with the requirements of DEF STAN 03-4.

5.3.3 Plated steel parts having carburised areas which would suffer an unacceptable reduction in hardness by treatment as outlined in paragraph 5.3.2 must be heated at not less than 130°C (266°F) for not less than 8 hours.

6 INSPECTION

6.1 **Visual.** Before chromate passivation or chromate dipping, the plating should be smooth and silvery-white in colour; it should also be continuous and free from burns or blisters, or any tendency to flake off. The colour should be uniform in appearance on any one part.

NOTE: The appearance of the plating may be affected by the chromate passivation treatment or by the chromate dip (as appropriate), therefore visual inspection should be made before the application of either of these treatments.

6.2 **Selection of Test Samples**

6.2.1 **Bath-plated Parts.** A sample (minimum of two parts) of production parts should be selected from each bath load and should be checked for freedom from porosity (if applicable) (paragraph 6.3), adhesion (paragraph 6.4) and thickness (paragraph 6.5), the tests being made in that order. Where a continuous form of bath plating is in operation, a representative sample should be taken at intervals of not more than one hour.

6.2.2 **Barrel-plated Parts**

(a) A sample normally consisting of ten parts or more, from each group of parts of the same size and shape from each barrel load, should be selected and checked for freedom from porosity (where applicable), adhesion and thickness. The number of parts selected must be such that significant weighing errors are avoided.

(b) For groups of not more than 100 parts of the same size and shape plated together, two or more samples should normally be selected and should be checked for freedom from porosity, adhesion and thickness. The number of parts selected must be such that significant weighing errors are avoided.

6.2.3 **Parts Plated in Small Numbers.** In exceptional circumstances, e.g. the bath plating of single large parts or the barrel plating of small numbers of parts, DEF STAN 03-19 permits, under the conditions prescribed in that specification, a modification of the sampling procedure described in paragraph 6.2.2 (a) or (b). In suitable instances coupon samples may be used, due consideration being given to their shape, size and material and, if applicable, their position in the bath. The treatment of the coupon samples must be suitably representative of that applied to the parts being plated.

6.3 **Freedom from Porosity.** Freedom from porosity should be determined as soon as convenient after the plating process is completed. The test is applicable to all cadmium-plated steel parts plated all over, except screws and bolts of major thread diameter not greater than 3 mm (0·126 in) and parts made from corrosion-resisting steel. Internal threads, screw-driver slots and similar shielded areas can also be excepted from the test at the discretion of the Chief Inspector. Large or complete parts plated to the normal requirements of thickness (see Table 1) may be excepted if so specified by the Designer.

6.3.1 The samples should be carefully cleaned in a suitable solvent vapour and should then be immersed in a solution of 1% (v/v) of hydrochloric acid (d = 1·16) at room temperature for 5 minutes, after which active evolution of hydrogen, as distinct from infrequent bubbling, should lead to rejection.

6.3.2 The test is non-destructive to the plating and after testing, the samples which pass the test should be thoroughly washed in hot water and dried.

NOTE: The test is not suitable for non-ferrous or corrosion-resisting steel parts.

6.4 **Adhesion.** When the shape and size of the part permits, a small area of the plated surface should be rubbed rapidly and firmly with a suitable tool for about 15 seconds and visually inspected, when there should be no indication of the deposit becoming blistered or otherwise detached from the base metal. The pressure applied must be sufficient to burnish the plating at each stroke but not to cut the deposit. Suitable tools are a 6 mm (0·25 in) diameter steel rod with a smooth hemispherical end or a copper disc used edgewise and broadside.

6.5 **Thickness Tests.** The amount of cadmium deposited on the parts varies at different points, e.g. areas which are recessed or shielded, or those which are furthest from the anodes, plate less rapidly than those areas which are more favourably situated; conversely the plating tends to build up on the extremities of the parts. However, the thickness of the plating must be reasonably uniform and, when tested by the procedures described in paragraphs 6.5.2 and 6.5.3, must not be less than the requirements prescribed in DEF STAN 03-19 (see Table 1). For parts plated by the bath process, the difference between the plating thickness of the parts (mean local thickness or average thickness as appropriate) must not exceed 50% of the thickness specified in Table 1.

NOTE: Wherever practicable, the local thickness test (paragraph 6.5.2) should be used.

6.5.1 Where the tolerance requirements of mating parts or where interchangeability considerations apply, e.g. screw-threads, a maximum limit on the thickness of the plating may be prescribed by the drawing. (For reference to threaded parts, see Leaflets **BL/3-1** and **BL/3-2**.)

6.5.2 **Local Thickness.** The local thickness of the coating should be determined by a method agreed by the Approved Design Organisation, and should have an accuracy of 10% or better of the thickness being measured. Where possible, four measurements should be made on each selected sample, and where practical these measurements should be made at places which are widely separated and which can be expected to be comparatively thinly coated. Normally the measurement points should be capable of being touched by a sphere of 20 mm (0·8 in) diameter and should not be less than 6 mm (0·25 in) from any edge. On some items the coating may be required to have an adequate thickness in recesses and other areas which would be excluded from the test by this limitation; in such cases the drawing should specify the special requirements.

6.5.3 **Average Thickness.** The average thickness of the cadmium coating and, where applicable, the nickel undercoat, should be determined as follows:–

(a) The plated sample should be cleaned in a suitable solvent vapour, weighed and then totally immersed in a solution prepared by dissolving 30 g of ammonium nitrate in 100 ml of water. The solution should be stirred occasionally until the plating is dissolved (10 minutes usually being sufficient). The sample should then be removed from the solution, washed, dried and re-weighed.

$$\text{Cadmium thickness } (\mu\text{m}) = \frac{\text{loss of mass (g) x } 116 \text{ x } 10^3}{\text{Area of coating (mm}^2\text{)}}$$

(b) Alternatively the sample may be cleaned and weighed as in (a) then totally immersed in a solution containing 2·5 g of antimony trichloride and 600 ml of hydrochloric acid (d = 1·16) per litre. The solution should be stirred occasionally until the plating is dissolved (2 minutes usually being sufficient). Immediately effervescence has ceased the sample should be removed from the solution, washed, dried and re-weighed. The coating thickness is determined from the formula shown in (a).

(c) To determine the thickness of a nickel undercoat on copper-base materials, after the cadmium coating has been removed ((a) or (b)), the sample should be immersed in a solution of 70% (v/v) sulphuric acid (d = 1·84) with a little glycerine added. The sample should be treated anodically at 6 to 12 volts and immediately solution of the nickel is complete it should be removed, washed rapidly, dried and re-weighed.

$$\text{Nickel thickness } (\mu\text{m}) = \frac{\text{loss of mass (g) x } 113 \text{ x } 10^3}{\text{Area of coating (mm}^2\text{)}}$$

TABLE 1
THICKNESS REQUIREMENTS (DEF STAN 03-19)

Application	Minimum Local Thickness μm	Minimum Average Thickness (see Note 1) μm
1 Normal requirements:		
Steels (non-corrosion resisting)	10	14
Copper-base materials and corrosion resisting steels	8	12
2 Threaded items not exceeding 20 mm dia. (see Notes 2 and 3), screws, bolts and nuts of nominal major thread diameter:		
Up to 3 mm	–	4
Over 3 mm up to 5 mm	–	5
Over 5 mm up to 13 mm	–	6·5
Over 13 mm up to 20 mm	–	7·5
3 Washers	–	5
4 Rivets, taper pins, and split cotters	–	8

NOTES: (1) For barrel-plated items average thickness is normally based on the whole sample, but if used for vat-plated items it is normally based on individual items.

(2) Thickness requirements for copper-base materials are inclusive of nickel undercoating (see clause 7.3 of DEF STAN 03-19).

(3) The coating thickness requirements for threaded items are dictated by dimensional tolerance limits. Such thicknesses will not necessarily provide adequate protection against corrosion.

6.6 **Freedom from Mercury.** Tests for mercury in the deposit shall be made periodically at the discretion of the Approved Design Organisation. Suitable tests for mercury contamination are given in DEF STAN 03-19.

7 **PERIODIC SOLUTION TESTS** The electrolyte should be checked periodically in accordance with the supplier's instructions to ensure continued efficiency; suitable standards for the bath described in 4.2.1, for example, are:–

(a) Cadmium (as metal) 12–19 g/litre (2–3 oz/gal)

(b) Free sodium cyanide 15–19 g/litre (2·5–3·0 oz/gal)

(c) Caustic soda 5–9 g/litre (0·75–1·25 oz/gal)

7.1 The metal content will maintain itself provided there is adequate anode surface and a normal amount of free cyanide present. However, should the solution become depleted of metal but is found to contain ample free cyanide, or if the free cyanide content is found to be excessive, cadmium carbonate should be used. One part by weight of this will introduce 0·6 part of cadmium into the electrolyte and will neutralise one part of free sodium cyanide. The cadmium carbonate should not be added directly to the bath but should be dissolved in some of the plating solution which has been heated to a temperature of about 60°C (140°F) in a suitable vessel. Excessive free cyanide content will result in poor throwing power and considerable gassing at the cathode.

8 RE-PLATING STEEL PARTS When steel parts are to be re-plated, the original cadmium should be removed and, prior to re-plating, the parts should be inspected for absence of corrosion and damage and for dimensional accuracy. Where appropriate, the parts should be examined for cracks by the electro-magnetic method (Leaflet **BL/8-5**) or some other suitable method. The parts should be re-plated in accordance with the recommendations given in the previous paragraphs of this Leaflet.

9 STORAGE All plated parts should be stored in suitable containers and protected from excessive changes in temperature and humidity until required for use. Where the period of storage is likely to be lengthy, the parts should be further protected by means of a thin coating of suitable grease or oil, such as de-watering oil. Cadmium plated parts should never be stored in close proximity to phenolic plastics in poorly ventilated places, since the vapours emitted by such materials tend to cause corrosion of the plating (see paragraph 1.3).

10 FAULTS IN CADMIUM PLATING The following paragraphs give some common faults in cadmium plating, together with the possible methods of rectification.

10.1 **Imperfect Adhesion and Blisters.** Such faults may be due to lack of free cyanide in the ectrolyte, this being indicated by black slime on the anodes and little, if any, gassing at the cathode. The faults can usually be remedied by the addition of sodium cyanide as indicated in paragraph 7. Other reasons for these results include the presence of grease, oxide or stains on the metal before plating, occlusion of hydrogen by the base metal due to cleaning hardened steel cathodically and presence of acid on the base metal immediately prior to plating.

10.2 **Rough, Dark, Granular Deposit.** A coating of this nature results from the use of excessive current, causing a 'burnt' deposit; the tendency may be aggravated by lack of free cyanide. In such instances, any deficiency in free cyanide content should be made good (paragraph 7), the voltage should be reduced and the parts coated at a lower density. It may also be necessary to reduce the anode surface by removing a number of plates or balls, but if the effect is usually found only on small parts, these should be suspended between larger parts.

10.3 **Rough Upper Surfaces.** When the deposit is of good colour and appearance but the surfaces which have been uppermost during treatment are rough, this is due to suspended matter in the electrolyte. In such instances the solution should be filtered or, after removing the sediment from the tank and allowing the solution to settle, clear solution should be syphoned into a spare tank.

10.4 **Thin, Meagre Deposit.** This fault, coupled with slow deposition, indicates that the solution is deficient in metal. The metal content should be checked and made good (see paragraph 7.1).

10.5 **Non-Deposition.** Non-deposition may be due to reversed electrical polarity, faulty contacts, or passivity of the parts being plated. In the first instance the electrical conditions should be checked, but where passivity is suspected, the passive surface of the parts can be removed by scratch-brushing or polishing, depending on the importance of the surface or part.

11 ASSOCIATED STANDARDS AND SPECIFICATIONS

BS 2868	Cadmium Anodes and Cadmium Oxide for Electroplating.
DEF 130	Chromate passivation of Cadmium and Zinc Surfaces.
DEF STAN 03-2	Cleaning and Preparation of Metal Surfaces.
DEF STAN 03-4	The Pre-treatment and Protection of Steel Parts of Specified Maximum Tensile Strength Exceeding 1450 N/mm^2.
DEF STAN 03-14	Electro-deposition of Chromium for Engineering Purposes.
DEF STAN 03-19	Electro-deposition of Cadmium.

BL/7-3

Issue 3.

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BASIC

PROTECTIVE TREATMENTS

CHROMATE TREATMENT OF MAGNESIUM ALLOYS

1 INTRODUCTION This Leaflet gives general guidance on the initial protection of magnesium-rich alloys by chromate treatment. The purpose of the treatment is to provide a temporary protective and an initial treatment prior to surface sealing, painting, stove enamelling and other filming processes. The Leaflet should be read in conjunction with Leaflet **BL/7-5** entitled "Protection of Magnesium Alloys" and the latest issue of Specification DTD 911. Chemical formulae for the chemicals used in these treatments will be found in Specification DTD 911.

1.1 Chromating produces a film on the surface integral with the basis metal (as distinct from a deposited coating) and, in addition to conferring a useful measure of protection from corrosion, it provides a key for subsequent applications of surface sealing resin or paint.

1.2 In order that the materials will show the greatest resistance to corrosion after chromating, it is important that the materials themselves should be reasonably free from impurities and that their surfaces should not be contaminated by fluxes or other impurities which may be introduced during workshop processes such as rolling, forging, bending, welding, forming, etc. It has been shown that when colloidal graphite is used as a lubricant during drawing operations, graphite residues reduce the corrosion resistance of magnesium alloy sheet. A suitable method for removing graphite consists of (a) immersion of the material in nitro-benzene and (b) a dip in 10 per cent aqueous nitric acid and then chromate treatment.

1.3 The latest issue of Specification DTD 911 provides for the use of three types of chromating processes, i.e. the Hot Half-Hour Chromate Bath (Bath iii), the Acid Chromate Bath (Bath iv) and the Chrome Manganese Bath (Bath v). The purposes of these various processes are described in subsequent paragraphs of this leaflet.

1.4 Guidance on the Anodic Oxidation of Aluminium Alloys is given in Leaflet **BL/7-1,** on Cadmium Plating in Leaflet **BL/7-2,** on Phosphating of Steels in Leaflet **BL/7-4** and on Painting in Leaflet **BL/16-20.**

2 PREPARATION FOR TREATMENT—CLEANING The method of surface preparation depends to a large extent on the nature of the part and the degree of surface finish accorded to it. Irrespective of the cleaning process used, however, all parts must be transferred to the chromating bath immediately after cleaning.

NOTE: Emery should never be used for dressing operations unless its use is followed by Fluoride Anodising (see paragraph 2.1.1).

2.1 **Castings in the "As Cast" Condition.** Such castings, which are normally chromate treated for protection during storage and machining, should be treated by one of the following processes.

2.1.1 **Electrolytic Cleaning by Fluoride Anodising.** This process is described in Leaflet **BL/7-5** and is recommended for maximum corrosion resistance. The process for the removal of the fluoride film is also given as this is necessary before chromating by means of Bath (iii) paragraph 3.1 and Bath (v) paragraph 3.3. Removal of the fluoride film is not necessary prior to chromating by means of Bath (iv) paragraph 3.2.

2.1.2 **Acid Pickling.** When this process is used, the parts should be immersed in a 5 to 10 per cent (by volume) solution of nitric acid, or in a 5 per cent (by volume) solution of sulphuric acid, for short periods until uniformly clean.

2.1.3 **Abrasive Blasting.** When an abrasive blasting process is used, this should preferably be followed by machining or scurfing all over or by Fluoride Anodising. The use of abrasive blasting is not permitted on high purity magnesium alloys unless they are subsequently machined all over to a depth of 0·04 in.

2.2 **Castings in the "Finished Machined" Condition.** After machining and degreasing in an organic solvent such as trichloroethylene (Leaflet **BL/6-8**) the parts, according to the dimensional tolerances applicable, should be cleaned preferably by Fluoride Anodising or by one of the following processes.

2.2.1 **Parts not Machined to Very Fine Tolerances.** The parts should be immersed in a 5 to 10 per cent (by volume) solution of nitric acid, or in a 5 per cent (by volume) solution of sulphuric acid, for short periods until uniformly clean. Alternatively, any of the methods described below may be used.

NOTE: When cleaning wrought magnesium-zirconium alloys by this method, any smut produced in the acid bath should be removed by dipping the parts in a solution of 10 per cent w/v chromic anhydride plus 1 per cent v/v nitric acid (sp. gr. 1.42) for 30 seconds, followed by thorough washing in water.

2.2.2 **Parts Machined to Fine Tolerances.** The standard treatment for such parts is immersion for 15 minutes in a boiling 2 to 5 per cent solution of caustic soda or of a suitable alkaline metal cleaning solution.

NOTE: For parts that have been treated as outlined in paragraphs 2.2.1 and 2.2.2 a hydrofluoric acid immersion treatment as described in paragraph 2.2.3 is beneficial.

2.2.3 **Parts Previously Chromate Treated.** Such parts can usually be cleaned by the treatment described in paragraph 2.2.2, but where a thick chromate film is present, this treatment may not be entirely satisfactory when judged by the appearance of the film after re-chromating. In such instances the parts should be immersed for 5 to 15 minutes in a boiling 5 per cent caustic soda solution, washed, and then immersed for 2 to 15 minutes in a 10 to 15 per cent boiling chromic acid solution to remove the film. This should be followed by immersion of the parts in a boiling 5 per cent caustic soda solution for 10 minutes, or in a cold 15 to 20 per cent hydrofluoric acid solution for 5 minutes. Where hydrofluoric acid is used, this should be contained in a lead, plastic, guttapercha or rubber-lined receptacle, and can be prepared by diluting one volume of technical grade "50/60" HF with 2·5 volumes of water. Fluoride Anodising is also effective in softening and removing old chromate films.

NOTE: (i) If the sulphate content of the chromic acid solution used to remove the film exceeds 0·03g SO_4 per 100 cms^3 the solution will attack the metal appreciably. The chromic acid should be contained in a mild steel vessel.

(ii) Chloride ions present in chromic acid will also attack the metal. Small additions of barium chromate and silver chromate will precipitate sulphate and chlorides respectively and so minimise any attack.

2.3 **Sheets, Extrusions and Forgings.** Any one or more of the processes described in the preceding paragraphs are suitable. The use of abrasive blasting processes is prohibited (unless otherwise agreed, see Note), unless the parts are subsequently machined or scurfed all over to a depth of 0·04 in. or more. If desired, chemical precleaning may be preceded by scouring with pumice powder applied with a moist rag.

NOTE: The prohibition of abrasive blasting processes on wrought forms of magnesium is waived in certain instances, e.g. production of forgings.

2.4 When abrasive blasting is employed, clean alumina grit should be used and its cleanliness controlled. No accumulations of iron, carborundum, rust, graphite or dirt residue should be allowed to collect in the blasting plant.

2.5 Vapour blasting can sometimes be employed with advantage since it has the abrasive blasting effect with less tendency to contaminate the surface of the material. Since this process removes only very little metal, it can be applied to semi-finished work.

2.5.1 Although contamination is not so severe as with abrasive blasting, Fluoride Anodising after vapour blasting is still recommended.

3 THE CHROMATE TREATMENT PROCESSES When applying any of the following processes, care must be taken not to inhale the fumes given off by the baths and acids or other chemicals must not be allowed to come into contact with the skin. It is essential that the chromate treatments outlined below comply with the latest issue of Process Specification DTD 911.

NOTE: The chromate films produced by the Chrome Manganese (Bath v) process and the Hot Half-Hour (Bath iii) process are superior to that produced by the Acid Chromate (Bath iv). Consequently they are recommended for use wherever possible.

3.1 **Hot Half-Hour Chromate Bath (Bath iii).** This process is suitable for all types of magnesium alloys, but fairly close control is necessary when treating alloys of the magnesium-manganese and magnesium-zirconium classes. The process is particularly suitable where a high degree of protection is required but where significant dimensional changes cannot be tolerated.

3.1.1 The treatment is applied by immersion of the parts in a boiling solution of the following composition:—

Potassium dichromate	1·5 per cent w/v (15 lb/100 gal)
Ammonium dichromate	1·5 per cent w/v (15 lb/100 gal)
Ammonium sulphate	3·0 per cent w/v (30 lb/100 gal)

NOTE: The potassium dichromate may be replaced by the same weight of sodium dichromate.

3.1.2 Ammonia solution having a specific gravity of 0·880 should be added to the solution to establish a pH value (Leaflet **BL/10-1**) suitable for the alloy to be treated (see Table 1). The solution should be contained in a tank of pure aluminium or mild steel equipped with heating coils and a fume extractor. Providing all the salts are in solution, the method of mixing is unimportant, but care should be taken to ensure that the solution is well stirred and that there is no layer of undissolved crystals in the bottom of the tank.

TABLE 1

Alloy	*pH Range*	*Percentage of Ammonia Necessary to Bring pH of Bath to Start of Range (by volume)*
Magnesium-zirconium alloys	5·90 to 6·00	0·27
Magnesium-aluminium alloys	5·90 to 6·05	0·27
Magnesium-manganese alloys:—		
DTD 118	6·05 to 6·13	0·37
DTD 140, DTD 142	6·13 to 6·18	0·43

3.1.3 The pH measurement of the bath may be controlled by any convenient method, but care must be taken to ensure that the measuring instrument used gives true pH values or that readings given by it can be converted into true values, since it is these which are quoted above. A list of apparent pH values and the corresponding true pH values covering the pH range applicable is given in Table 2. Further information on the determination of pH values is given in Leaflet **BL/10-1.**

NOTE: The discrepancy between observed and true pH values is only found when using colorimetric instruments in which bromocresol-purple is used.

TABLE 2

Apparent pH Value	*True pH Value*
5·1	4·8
5·3	5·0
5·5	5·2
5·7	5·4
5·9	5·6
6·1	5·8
6·4	6·0
6·6	6·2

3.1.4 **Operation of the Bath.** The parts should be immersed for 30 minutes in the boiling solution and after removal from the bath should be washed immediately in warm water, the temperature of which should not exceed 50°C.

(i) Losses by evaporation should be made up from time to time by the addition of water.

(ii) The pH value of the solution should be checked daily and, if low (but see note below), additions of ammonia should be made as necessary. If the pH value is too high, this can be corrected by additions of chromic acid or sulphuric acid. The quantities of chemicals to be added to correct the pH value are given in Table 3.

NOTE: As the bath ages (due to accumulation of magnesium salts) it will be necessary to lower the pH value to produce a satisfactory film; nevertheless, the pH value should be as high as possible consistent with a good film appearance.

TABLE 3

Additive	*Quantity*	*Effect on pH Value*
Ammonia (sp. gr. 0·880)	8 fl. oz. per 100 gal of chromate bath (0·05 per cent v/v)	Raised by approximately 0·1
Chromic Acid	10 oz. per 100 gal of chromate bath (0·063 per cent w/v)	Reduced by approximately 0·1
Sulphuric Acid (sp. gr. 1·84)	5 oz. (2.7 fl. oz.) per 100 gal of chromate bath (0·17 per cent v/v)	Reduced by approximately 0·1

NOTE: The ammonia should be diluted with at least its own volume of water and the sulphuric acid with at least twice its own volume of water before being added to the hot solution. The acid must always be added to the water and not vice versa.

(iii) The chloride content of the bath must not exceed 0·5 per cent calculated as sodium chloride.

3.1.5 **Inspection of Film.** On completion of treatment, the surfaces treated should be covered with an adherent, unbroken film of uniform colour, free from bloom. The actual colour of the film will vary, according to the alloy treated, from straw to jet black, as shown in Table 4. The adhesion of the film can be tested by rubbing with white paper, after which the film must show no signs of damage and only the faintest stain must show on the paper.

NOTE: Parts which have been welded may exhibit variations of film colours in the welded areas.

TABLE 4

Material	*Film*
Magnesium-manganese alloys:— DTD 118, DTD 140, DTD 142	Uniform straw to light brown without blemishes.
Magnesium-aluminium alloys	Brown-black through jet black to grey-black with increasing content of aluminium in the alloy from 4 per cent upwards.
Magnesium-zirconium alloy (with or without rare earth elements, zinc or thorium)	Brown to black on wrought or machined surfaces.

NOTE: On Magnesium-manganese alloys, chocolate coloured films, which result from an excessively acid bath, are brittle and non-adherent, whilst patchy and uneven films are sometimes caused by surface impurities. The quality of chromate treatment on castings should be judged by the appearance on machined surfaces.

3.2 **Acid Chromate Bath (Bath iv).** This process is particularly suitable for the treatment of magnesium-manganese alloys or generally for the treatment of unmachined parts subject to temporary storage. It is not recommended for the treatment of parts machined to fine tolerances, since approximately 0·0005 in. of metal will be removed from each treated surface during the process.

NOTE: Parts previously treated in an acid chromate bath may be re-treated directly in the same bath.

3.2.1 The treatment is applied by immersing the parts in a solution of the following composition:—

Sodium or potassium dichromate	15 per cent w/v (150 lb/100 gal)
Nitric acid (sp. gr. 1·42)	20 to 25 per cent v/v (20 to 25 gal/100 gal)

3.2.2 The solution should be contained in a tank lined with earthenware, slate, pure aluminium or stainless steel; because of the acidity of the solution mild steel should not be used. The tank should be fitted with an efficient fume extractor.

3.2.3 The solution should be prepared by adding the nitric acid to the water and then stirring in the dichromate, making sure that it is completely dissolved.

3.2.4 The parts should be immersed for about 20 seconds with the solution at a temperature of 5°C. to 25°C., but longer soaking periods may be necessary if the solution is partly spent. On removal from the solution the parts should be drained for about 10 seconds and then washed thoroughly in clean warm water, the temperature of which should not exceed 50°C. When large structures are treated, longer immersion times may be required, i.e. from 15 seconds upwards, but in such cases the nitric acid content of the bath may be reduced to lessen the activity of the bath.

3.2.5 The specific gravity of the bath should be checked at regular intervals with a hydrometer. It should be approximately 1·20 for a freshly prepared solution but will rise with use. When the specific gravity reaches 1·22, the solution may be revived by adding 5 per cent to 8 per cent by volume of nitric acid. This may be done two or three times, but when the specific gravity reaches 1·24 the solution should be rejected.

3.2.6 **Inspection of Film.** The film should be adherent and free from bloom, and should be tested with white paper as described in paragraph 3.1.5. On magnesium-aluminium alloys the colour of the film varies with the condition of heat treatment; in the "as cast" and solution-treated conditions the film tends to be brassy yellow in colour but in the annealed and fully heat-treated conditions the film tends to be light grey in colour. On other alloys the film should be of a clear brassy yellow colour.

3.3 **Chrome-Manganese Bath (Bath v).** This process is suitable for the protection of all types of magnesium alloys where a high degree of protection is required with negligible dimensional change.

3.3.1 The treatment is applied by immersing the parts in a solution of the following composition:—
Sodium dichromate 10 per cent w/v (100 lb/100 gal)
Manganese sulphate 5 per cent w/v (50 lb/100 gal)
Magnesium sulphate 5 per cent w/v (50 lb/100 gal)
The addition of a small amount of a suitable detergent (in amounts not exceeding 1 per cent) is beneficial, but should not be used if the bath is to be boiled, as frothing will result.

3.3.2 The solution may be contained in tanks of glass, pure aluminium or steel, and provision should be made for suspending parts so that they do not touch the sides or bottom of the tanks, especially if these are metal.

3.3.3 After mixing the concentrated solution of the salts, water should be added to dilute to the correct strength. Care should be taken to ensure that the solution is well stirred and that there is no layer of undissolved crystals at the bottom of the tank. The bath can be operated at any temperature up to boiling point, but the time of treatment will have to be varied according to the temperature selected. Table 5 gives a guide on suitable times.

TABLE 5

Temperature	*Time of Treatment*
20°C. to 30°C.	1½ hours
50°C. to 60°C.	30 minutes
70°C. to 80°C.	15 minutes
Boiling	3 to 10 minutes

3.3.4 The pH value of the solution is not critical and will range from about 4 when freshly made to about 6 when almost spent. An exhausted solution may be rejuvenated by the addition of 5 per cent of manganese sulphate or, alternatively, sulphuric acid or a mixture of equal weights of sulphuric acid and chromic acid may be added until the pH value is reduced to not less than 4.

3.3.5 **Inspection of Film.** The film on machined or extruded surfaces should be adherent and free from loose powdery deposit and should be tested with white paper as described in paragraph 3.1.5. The film should be of a dark brown to black colour, light golden films not being acceptable except on magnesium-manganese sheet complying with DTD 118.

4 FAULTS IN CHROMATE FILMS

4.1 Faults Produced by the Bath (iii) Process

4.1.1 **Loose, Powdery Coatings, Without Lustre.** This fault results from an excessively acid bath, so that it is advisable to work the bath on a pH value on the high side rather than on the low side. The method of correcting this condition is given in paragraph 3.1.4.

4.1.2 **Thin Coatings.** This fault usually results from an excessively alkaline bath, caused by the gradual dissolution of magnesium, and indicated by a rise in pH above the specified value. The method of correcting this condition is described in paragraph 3.1.4.

4.1.3 **Chocolate Colour Films on Magnesium-Manganese Alloys.** Such films, which are brittle and non-adherent, result from the use of an excessively acid bath. The method of correcting this condition is given in paragraph 3.1.4.

4.1.4 **Patchy and Uneven Film.** This condition is often caused by surface impurities in the material being treated, or by inadequate cleaning or handling before chromating. Surface segregation effects may also lead to patchiness of films on cast surfaces. The quality of films may best be assessed on machined areas.

(i) When impurities are suspected the manufacturer of the material should be notified.

(ii) Chill castings, and, especially pressure die-castings, in magnesium alloys of high aluminium content, tend to give a patchy finish due to the presence of aluminium-rich areas on the surface of the material. A similar effect is also found in sand castings on an area where the metal chill has been inserted in the mould. On this class of material, it may be necessary to increase immersion times or, alternatively, to remove the surface skin of the casting prior to immersion.

4.2 Faults Produced by the Bath (iv) Process.

4.2.1 **Loose, Powdery Coatings.** This fault is due to the nitric acid content of the bath being too low or to a spent bath. The bath should be controlled as described in paragraph 3.2.5.

4.2.2 The chrome-nitric bath should be discarded when the parts, after washing, show yellow staining, since these stains will lead to poorly adherent coatings.

4.3 Faults Produced by the Bath (v) Process.

4.3.1 **Loose and Powdery Coatings.** Wrought magnesium-zirconium alloys will show this fault if the smut produced in the acid bath described in paragraph 2.2.1 is not removed before treatment in the Chrome-Manganese Bath.

5 REPAIR OF CHROMATE FILMS

5.1 **Chromic Anhydride.** Chromated parts requiring local repair can be cleaned by swabbing with a solution of 2 oz chromic anhydride in 1 pint of water, with 8 drops of concentrated sulphuric acid added to acidify the solution.

5.2 **Selenious Acid.** The solution for selenious acid treatment consists of 10 per cent by weight of selenious acid in water and the treatment consists of brushing or wiping the solution over all surfaces exposed by damage to the original chromate film. A soft rag can be used for the application, which should be continued until the metal assumes a permanent brown or brownish-black colour.

5.3 After the treatment the surface should be thoroughly washed with water and wiped dry.

NOTE: The solution should not be allowed to come into contact with the skin.

6 FURTHER TREATMENT Unless otherwise specified, parts which have been chromated should receive further protection against corrosion as soon as possible. For temporary protection during transit and storage, parts should be treated as described in paragraph 3 of Leaflet BL/7-5. Where surface sealing or paint is ultimately to be used, it is recommended that the process is applied as soon as possible after chromating. Unless surface sealing techniques are employed, painting should commence with a priming coat containing barium or zinc chromate. Priming paints containing lead or iron compounds should not be used.

NOTE: Lanolin as a temporary protective is not recommended for use on chromated surfaces which have to be painted subsequently. Lanolin bearing protectives cannot be completely removed from chromated surfaces by degreasing processes.

BL/7-4

Issue 2

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BASIC

PROTECTIVE TREATMENTS

PHOSPHATING OF STEELS

1 **INTRODUCTION** This Leaflet gives general guidance on the coating of steel parts with the hot immersion phosphate process as applied to impart corrosion resistance; it is not concerned with the phosphate coatings which are sometimes applied as an aid to manufacturing processes (e.g. deep drawing) or with the coatings which are applied for heat resistance purposes or for passivation treatment.

1.1 The purpose of the phosphate coating is to increase the resistance of the steel to corrosion. This is achieved by converting the surface of the metal to an inorganic phosphate coating, thereby providing the metal with a physical barrier against corrosion. The degree of protection is dependent upon the uniformity of the coating, coverage and crystal size. Immediately on production of the inorganic coating, which provides a key or base, a subsequent organic coating is added, e.g. certain paints, varnishes, lacquers, oil and greases. The phosphate coating is produced by immersing the steel in a solution containing one or more metal phosphates (e.g. iron, magnesium, zinc) and phosphoric acid, with or without additives, for a specified period and temperature, according to the process used. Phosphate coatings are classified by class numbers, in accordance with Specification DEF STAN 03-11.

1.2 When the processing solution is of the plain metal phosphate/phosphoric acid type, it is termed 'unaccelerated', and is generally characterised by the large crystal size of the coating. When additives (e.g. water-soluble oxidising agents such as nitrate, nitrite, and chlorate) are used, these have the effect of reducing the crystal size and speeding up the process, hence it is termed the 'accelerated' process.

NOTE: Additives other than oxidising agents, e.g. a mixture of zinc, nickel, cobalt and magnesium, are sometimes used as accelerators and grain-size reducers.

1.3 For detailed guidance, this Leaflet should be read in conjunction with DEF STAN 03-11 and BS 3189, both entitled 'Phosphate Treatment of Iron and Steel'.

2 **PHOSPHATING PLANTS** The cleanliness of the equipment used for phosphating is of the utmost importance if consistently good coatings are to be obtained.

2.1 There are a number of proprietary processes which comply with the requirements of Specification DEF STAN 03-11, and new baths must be made up as prescribed by the supplier.

2.2 The total 'pointage' (see Note) of the solution must be determined at least once daily when the bath is in operation; if this value falls below that specified by the supplier, the bath should be brought up to strength before further work is commenced.

NOTE: Pointage is the measure of total acidity of a phosphating solution. The pointage of a phosphating bath is the number of ml of N/10 sodium hydroxide solution (Na0H) (4·0 g/l) required to neutralise 10 ml of the phosphating solution to the phenolphthalein end-point.

2.3 It may be desirable to determine periodically the 'free acid' contents of the bath, this being defined as the number of ml of N/10 sodium hydroxide solution (Na0H) required to neutralise 10 ml of phosphating solution (to pH 4) using the methyl orange end-point or an equivalent indicator system.

2.4 The free acid content of the bath is usually expressed as a percentage of the total pointage, i.e.,

$$\text{Percent Free Acid} = \frac{\text{Volume of (Na0H) for neutralisation (methyl orange)}}{\text{Volume of (Na0H) for neutralisation (phenolphthalein)}} \times 100$$

2.5 For new baths the percentage of free acid should be within the recommended range; if the free acid is found to be in excess of this figure, the supplier's instructions regarding 'working-in' the bath should be followed.

NOTE: The percentage of free acid varies with the type of process and although normally within the range of 10 to 14%, this figure may be exceeded with non-accelerated processes.

2.6 The solution should be contained in a suitably constructed tank, heated by electricity, gas or steam; to minimise heat losses it is recommended that the tank should be lagged and provided with a lid. Mild steel is generally used for tank construction where unaccelerated processes are concerned and such tanks are sometimes rubber lined. Stainless steels and acid resistant materials, such as polythene, PVC, etc., are also sometimes used, stainless steel tanks being particularly suitable for containing accelerated processes. Bottom heating of baths is not desirable since this results in a continuous disturbance of sludge. It is recommended that, where possible, a sludge trap should be fitted.

2.7 To reduce evaporation and heat losses, the free surface of the solution may be covered by a 'seal', such as a large number of small plastics spheres, rods or tubes which float on the surface, or suitable oil-based compounds which incorporate a detergent to prevent the formation of an oil film on the parts being processed as they pass through the seal.

NOTE: When an oil base seal is used, special attention must be given to washing the parts after processing to ensure complete removal of the seal compound.

2.8 Materials such as copper or brass (but see paragraph 4.1) must not be introduced into the accelerated solution baths, since such materials adversely affect the quality of the coating.

3 **PREPARATION FOR TREATMENT** Immediately prior to coating, all foreign matter, such as rust, scale, grease, oil and paint, must be removed from the surfaces to be treated.

NOTE: A slight film of surface rust may not interfere with the coating action for certain processes.

3.1 Parts should be cleaned in accordance with the requirements prescribed in the latest issue of Specification DEF STAN 03-2, entitled 'Cleaning and Preparation of Metal Surfaces', or in accordance with any special instructions prepared by the manufacturer of the parts. Where necessary, the parts must be thoroughly rinsed in hot or cold water after cleaning to remove all traces of the cleaning residue, since the introduction of this into the solution may affect the quality of the coating and that of the solution.

3.2 Special attention to the removal of foreign matter should be given to any parts which have folds, laps or seams.

3.3 Parts made of steel having specified tensile strength of 1000 N/mm² or more must be given a suitable stress-relieving heat treatment before phosphating if the parts contain residual stresses which may cause cracks or loss of ductility to develop during processing. Unless a treatment is specified on the drawing, a suitable treatment consists of heating the parts to 130°C to 200°C (270°F to 390°F), or up to the tempering temperature, for not less than one hour. Steels which have been carburised, flame or induction hardened or carbonitrided should not be heated over 150°C (300°F).

4 **THE PHOSPHATING PROCESS** Since there are a number of proprietary processes which conform to the requirements of Specification DEF STAN 03-11, little general guidance can be given on the actual processes, and the supplier's instructions should be followed in all instances. However, the temperature of the bath is usually maintained at 50°C to 98°C (122°F to 208°F) and the correctness of the temperature should be checked before the immersion of the parts. The process should continue for the period stipulated by the supplier or, in solutions which 'gas', until the cessation of gassing.

NOTE: It may be necessary to pre-heat large parts to avoid a drastic reduction of bath temperature on immersion.

4.1 Composite parts made up of ferrous and non-ferrous parts must normally have the ferrous parts phosphated before assembly, but exceptions are permitted where the non-ferrous metals are zinc-base or copper-base materials, providing that in the case of copper-base materials, they do not constitute more than 10% of the total surface, and providing that, in any case, joints are unlikely to be penetrated by the phosphating solution.

4.2 Where necessary, parts should be suitably jigged before immersion in the phosphating solution. Springs or other components subject to flexing, that are manufactured of steel having a tensile strength greater than 1000 N/mm² must be free of applied stress during the phosphating treatment and until the subsequent baking treatment (paragraph 5.2) is complete. The phosphating process used for such items must be an accelerated, copper-free type, working at a pointage of not more than 30 points.

NOTE: The normal strength for these processes is 20 to 30 points.

4.3 Care must be taken at all times for preventing the formation of air locks (see paragraph 7.2).

5 TREATMENT AFTER PHOSPHATING

5.1 **Washing.** Immediately after phosphating, the parts must be washed thoroughly in hot or cold water to remove any residue of the treatment and any adhering oil seal (paragraph 2.7) if this has been used.

5.1.1 After processing by an unaccelerated process, the parts must be rinsed in hot or cold water or in a hot diluted chromic solution of the type specified in paragraph 6(d)(3) of DEF STAN 03-11.

5.1.2 After processing by an accelerated process, the parts must be thoroughly rinsed, first in running cold water, and then in hot water maintained at a minimum temperature of 75°C (167°F) and finally rinsed in a chromic solution of the type described in paragraph 6(d)(3) of DEF STAN 03-11. Special care is necessary when rinsing parts having folds, seams or crevices to ensure complete removal of the solution residue.

5.1.3 After the parts have been washed, they should be thoroughly dried either in an oven or in a current of warm air.

5.1.4 The contamination of the hot water rinse, where used, must be determined at least once daily. The sample should be taken after the bath has been agitated and should be allowed to cool before titrating. The acidity of the water rinse is defined as the number of ml of N/10 sodium hydroxide solution (Na0H) required to neutralise a 50 ml sample of water to the phenolphthalein end-point, and must not exceed 0·75 ml.

5.2 **De-Embrittlement Treatment.** Immediately after washing and drying, and before application of the sealing process (paragraph 5.3) parts made of steels having a minimum specified tensile strength in the range of 1000–1400 N/mm² must be baked at 130°C to 220°C (270°F to 390°F) for not less than one hour to relieve embrittlement.

5.2.1 Parts made of steels having a minimum specified tensile strength in the range of 1400–1850 N/mm² must be baked at 150°C to 200°C (300°F to 390°F) for not less than four hours or not less than one hour when the section thickness does not exceed 6 mm (0·25 in).

5.2.2 Parts made of steels having a minimum specified tensile strength in excess of 1850 N/mm² must be baked at 170°C to 210°C (338°F to 410°F) for not less than six hours.

5.2.3 For certain springs, e.g. where tempering may be affected, and parts having soldered joints, the baking temperature may be required to be restricted to not more than 130°C (270°F).

5.3 **Sealing.** Phosphate coatings are porous and absorbent and offer little resistance to corrosion unless sealed. The sealing process must be applied immediately after rinsing and drying and, if applicable, de-embrittling treatment.

NOTE: This process must not be confused with the 'seal' used for reduction of loss of solution by evaporation, etc., as described in paragraph 2.7.

5.3.1 The type of sealing applied must be in accordance with drawing requirements, and may consist of an organic coating such as oil, grease, paint, varnish or lacquer. The method of application must be such as will provide a satisfactory coating.

5.3.2 Where the sealing process cannot be applied immediately, the phosphated parts should be stored in conditions that preclude contamination or condensation of moisture on the parts, but in any case parts so stored should be 'force-dried' before sealing.

6 INSPECTION

6.1 **Visual Inspection.** A zinc or magnesium phosphate coating must be continuous and adhere well to the surface; it should be of uniform crystalline texture suitable for the intended use. Its colour should be from grey to black, and it should be free from loose smut, white powder blotchiness, excessive coarseness and poor adhesion. An iron phosphate coating, unlike the previously mentioned coatings, has no apparent crystalline structure, and its colour will vary from blue to brown.

6.2 The coating weight of the various types of processes, the method of determining this weight and the methods of testing the coating for freedom from corrosive residues and resistance to salt spray are prescribed in Specification DEF STAN 03-11.

7 FAULTS IN PHOSPHATE COATINGS

In the following paragraphs are given some possible faults in phosphate coatings, together with possible causes.

7.1 **Coarse or Sparkling Surface.** Such faults may be due to inadequate or unsuitable cleaning, inadequate washing before processing or incorrect bath composition. Such surfaces will not provide an efficient key for the subsequent finish and should be stripped in a suitably inhibited mineral acid and re-coated correctly. The use of acid pickling or alkaline degreasing before phosphate processes should be avoided as coarse coatings will always result from such treatments; solvent vapour degreasing and mechanical cleaning such as grit blasting are to be preferred.

7.2 **Untreated Patches.** This fault is generally the result of an airlock forming when the part is immersed in the bath, but can also result from insufficient cleaning.

7.3 **Flaky and Uneven Deposit.** These faults normally occur as a result of excessive sludge in the bath or insufficient cleaning.

7.4 **Minor Variations of Colour or Surface Texture.** These variations are usually due to previous surface treatments, heat treatments or degrees of cold work, but are normally acceptable providing they meet all other requirements of Specification DEF STAN 03-11.

BL/7-5

Issue 2

June, 1985

BASIC

PROTECTIVE TREATMENTS

PROTECTION OF MAGNESIUM ALLOYS

1 INTRODUCTION

1.1 This Leaflet gives general information on the protection of magnesium-rich alloy parts and components. Experience has proved that failures caused by corrosion are mainly due either to inadequate or damaged protective treatments.

1.2 Like many other metallic materials, magnesium-rich alloys have an intrinsically low resistance to corrosion and require special protective treatments. These normally start with cleaning, followed by chromating, sealing and painting, but other treatments may be specified.

1.3 This Leaflet should be read in conjunction with Leaflet **BL/7-3** which deals with the chromating processes for magnesium alloys and is complementary to this Leaflet.

NOTE: All the protective processes used on magnesium alloy parts should comply with the latest issue of Process Specification DTD 911 entitled 'Protection of Magnesium Rich Alloys against Corrosion'.

1.4 Failure of corrosion protection on magnesium alloys is often due to insufficient attention to detail during production or inspection, and especially to lack of control of fitting or assembly techniques and subsequent failure to re-protect or repair the damage so caused.

1.5 It is essential that all machined or accidentally exposed areas are adequately protected as soon as possible. This applies equally to removable parts and permanent structural parts.

2 CORROSION

2.1 Corrosion is largely an electro-chemical phenomenon and is liable to occur whenever a difference in electrical potential exists between adjacent parts of different material. Corrosion is assisted by the presence of an electrically conducting solution/liquid between parts where the protective treatment has been damaged or is inadequate.

2.2 In general the corrosive substances to be avoided are aqueous solutions of salts and acids which may be derived from saline atmospheric conditions (e.g. coastal regions) or industrial atmospheric pollution which contains acids. Most of the impurities in the atmosphere which produce rust on iron and steel will also attack magnesium alloys. Other corrosive agents are rain, runway spray, fog, condensed moisture, spillages, some cleaning fluids, etc.

3 PROTECTION The principle of protection adopted depends on completely isolating magnesium alloy parts from any aqueous solution with a coating of organic media at least 0·1 mm (0·04 in) thick. All surfaces should be covered after chromating (Leaflet **BL/7-3**) with at least 0·025 mm (0·001 in) of high quality stoving resin (surface sealing, paragraph 5), followed by a coat of pigmented paint approximately 0·075 mm (0·003 in) thick (paragraph 6).

4 STORAGE With certain exceptions, such as welding rods, all wrought and cast magnesium alloys should leave the material manufacturers in the 'chromated' condition (see Leaflet **BL/7-3**), that is, the bare metal has been given a chemical treatment which results in the formation of a chromate-bearing surface film. Such a film provides some chemical protection against corrosion and is considered adequate where storage conditions are good, e.g. dry, warm and clean.

4.1 The chromating treatment of magnesium alloys is regarded as a foundation treatment only. The other protective processes required may not be applied until forming and machining operations are completed.

4.2 Dampness in stores should be rigorously avoided and when magnesium alloys are kept in unheated or intermittently-heated stores they should be coated with a temporary protective applied liberally over the chromated surface. One of the following temporary protective media is generally specified for storage purposes:–

(a) A compound of 30% lanolin in white spirit, containing optionally a green dye (Specification DEF 2331A).

(b) A mixture of kerosene and light mineral oil with additions of corrosion inhibitor and wetting agent (Specification CS 2060 C).

(c) A 15% lanolised mineral oil (Specification DEF STAN 80-34/1).

4.3 For overseas transit or storage in coastal regions the recommended minimum protection is a liberal coating of lanolin compound to Specification DEF 2331A.

NOTE: For information on Storage Conditions reference should be made to Leaflet **BL/1-7**.

5 SURFACE SEALING Surface sealing is a non-pigmented high temperature baked epoxy resin waterproofing treatment. It has features in common with painting and stove enamelling and is normally employed as a foundation for painting.

5.1 The surface sealing process (described in paragraph 5.3.1) consists of baking or pre-stoving the component to ensure complete removal of surface moisture, then dipping in the sealing resin whilst still hot. This prevents picking up moisture through cooling and ensures that the resin penetrates any surface porosity or minute surface flaws.

5.2 Subsequent painting may be either a stove enamelling or an air-drying process since both types of paint adhere well to surface sealing resin. In either case a zinc chromate primer should be used as a first coat. The function of the chromate in a primer is to give a reserve of chromate capable of being leached away slowly in damp conditions, thereby protecting areas of magnesium which have been bared by scratches or other minor local damage.

NOTE: The surface-sealing resin is too waterproof to permit leaching of chromate from below the resin, but chromate primers applied over sealed surfaces will perform this function if and when minor damage occurs to the protective treatment.

5.3 Before surface-sealing operations the components should be cleaned, preferably by fluoride anodising (described in paragraph 7), and chromated. The surface sealing should be carried out without delay after chromating and should comply with the latest issue of Process Specification DTD 5562, 'Clear Baking Resin for Surface Sealing Magnesium'.

5.3.1 **Process for Surface Sealing.** The following sub-paragraphs give a brief description of a typical process which is fully detailed in Process Specification DTD 935:–

(a) The component should be heated to 200°C for 30 minutes or for a sufficient length of time to ensure that this temperature has been attained uniformly throughout the component.

(b) The component should be allowed to cool to 60°C then immediately dipped in the resin and agitated as necessary to avoid air traps and to ensure that every part comes into contact with the resin.

(c) The component should then be withdrawn slowly, being turned as necessary to allow drainage of resin. It should then be allowed to drain for between 15 and 30 minutes in a dust-free atmosphere. Any drips or tears should be removed with a brush or palette knife.

(d) The component should be stoved at 200°C for 15 minutes.

(e) After stoving, any remaining tears or drips should be removed with a sharp knife or glass paper, taking care not to damage the chromate film.

(f) Operations (a) to (e) should be carried out twice more so that a total of three coats is applied, turning the component each time to keep the coating uniform.

(g) The final coat should be stoved at 200°C for 45 minutes.

NOTE: Just before hardening, the resin passes through a labile (unstable) state. It is for this reason that the part is turned to a different attitude at each baking operation to assist uniform coating.

5.3.2 A compound which for some reason cannot be dipped may be coated by spraying. A full wet coat should be applied followed by heating and cooling as described in paragraph 5.3.1. The process should be repeated so that at least three coats are applied. Spraying should only be used when dipping is not practical.

5.3.3 Parts may be left overnight in the chromate-only condition, but for periods in excess of this they should be immersed in a storage protective (see paragraph 4.2) and thoroughly degreased before surface sealing.

6 PAINTING As with most paint schemes, thorough cleanliness of the surface is essential, and after surface sealing the part should be degreased if necessary. The success of the subsequent painting scheme is largely governed by the thoroughness of the degreasing operation. A primary coat containing not less than 15% of a chromate pigment is necessary and lead or iron compounds should be avoided. The purpose of the protective scheme is to keep corrosive conditions away from the metal and the total thickness of the completed coating should not be less than 0·1 mm (0·004 in).

6.1 The organic materials should preferably comply with either Material Specification DTD 5555A 'Exterior Glossy Finishing Schemes (Cold curing epoxide type) Schemes I, II and III', or DTD 5580 'Exterior Glossy Finishing Scheme (Cold curing polyurethane type) Schemes I and II'. The priming coat may be applied by spraying, dipping or brushing and a second or even third thin coat may be given with advantage. The undercoat or filler (where applicable) may also be applied by any conventional method. The finishing coat will have been chosen for its colour and texture. There are no special conditions of application other than those which are usual with a good painting technique.

6.2 The general principles outlined in the preceding paragraph apply equally to the use of stoving enamels, but care should be taken to ensure that the materials are suitable for the stoving temperatures used.

NOTES: (1) For further information on the application of paint, reference should be made to Leaflet **BL/6-20**, Paint Finishing of Metal Aircraft.

(2) Stoving will improve the durability of the DTD 5555A scheme but will render it very difficult to remove should this ever become necessary.

6.3 **Local Treatment of Exposed Metal.** The treatments described are intended for use over small areas. If large areas are damaged, immersion treatment will be necessary.

6.3.1 Parts on which the protective treatment has been damaged should preferably be returned for re-chromating, sealing and painting. Where this is impossible and where there is no danger of entrapment of treatment chemicals, the exposed metal should be treated locally as follows:–

(a) **Acid Chromate Method.** In this method a solution similar to the acid chromate bath solution (Bath (iv), as described in paragraph 3.2 of Leaflet **BL/7-3**) should be lightly applied to the bare metal using a brush or wool swab until a golden colour develops on the metal surface. The surface should then be thoroughly washed and dried by dabbing or warm air jet. This method is suitable for use prior to the application of any primer for magnesium alloys.

(b) **Selenious Acid Method.** In this method a solution containing 10% w/v selenious acid is applied by brushing or by swabbing with cotton wool until a dark brown stain develops. The surface should then be washed and dabbed or blown dry. This method is not suitable for use prior to the application of an etch primer.

NOTE: Neither the acid chromate solution nor the selenious acid solution should be allowed to come into contact with the skin.

6.3.2 Where there is a possibility of entrapment of treatment chemicals, the bare metal should be treated as follows:–

(a) **Mating Surfaces.** These should be given no chemical treatment but should be wet assembled and over-painted after assembly with not less than one coat of primer and two coats of finish.

(b) **Non-Mating Surfaces.** After cleaning with a nylon pad or glass paper, and removing the resultant debris, the surface should be treated with two coats of chromate primer followed by the normal paint scheme for the part.

NOTE: A coat of etch primer applied before the usual chromate primer will improve the adhesion of the paint scheme on un-chromated magnesium surfaces.

6.3.3 The treatments given in paragraphs 6.3.1 and 6.3.2 omit the surface sealing process and therefore give a less effective protection. Where this procedure cannot be avoided every effort should be made to give efficient paint protection by careful application of the paint scheme. Areas to be treated should first be degreased.

6.4 **Paint Repairs in the Field.** The paint schemes used on magnesium alloys are extremely difficult to remove when aged and stripping techniques may often be harmful to the surrounding structure. Unless corrosion has occurred below the surface sealing and paint scheme, it is preferable merely to degrease, lightly scuff and apply further coats of primer and finish.

7 FLUORIDE ANODISING CLEANING PROCESS This process is intended to supersede abrasive blasting as a method of cleaning magnesium alloy castings. It is also a method of substantially restoring the corrosion resistance lost as a result of abrasive blasting, and can be applied to magnesium alloys in all forms. The process renders unnecessary many of the pickling and degreasing processes used for chemical and electrochemical protective treatments.

7.1 It is not necessary to use any form of cleaning prior to anodising, but loose sand on castings should be removed by tapping or brushing and any layer of grease or paint (e.g. where the component is being reconditioned) should be removed either by vapour degreasing and/or immersion in a suitable alkaline metal cleaning solution. Pre-cleaning will also increase the useful life of the anodising bath.

7.1.1 **Anodising Bath.** The bath should be lined with a hard rubber or suitable plastic material which does not conduct electricity, and the electrolyte should consist of a 15 to 25% solution of ammonium bifluoride in water. The content of fluoride may be determined by any suitable analytical method. The solution should be kept up to strength by the addition of ammonium bifluoride, but should be discarded if it has become contaminated with foreign metals, acid radicals other than fluoride, or organic matter.

7.1.2 The parts should be fixed in pairs in good electrical contact on electrode bars across the bath, and suspended at least 230 mm (9 in) below the level of the solution. The parts should be arranged so that approximately equal surface areas are present at each electrode. The fixing clamps below the surface of the solution must be of magnesium rich alloy.

7.1.3 The high voltages used are dangerous and access to the bath must be prevented while the current is switched on. Spray from the bath is poisonous and adequate ventilation is necessary.

7.1.4 **Operation.** Alternating current should be applied and the voltage increased progressively until 90–120 volts is reached. Current flow will be heavy at first, but diminishes rapidly as impurities are removed and a coating of unbroken magnesium fluoride forms in their place. The treatment should be continued for 10 to 15 minutes or until the current falls to below 54 A/m^2 (5 A/ft^2) of the smaller electrode. The current should be switched off and the parts removed, washed in hot water and quickly dried.

7.1.5 The temperature of the bath should not exceed 30°C, and it is an advantage to stir the bath well between batches of items with a wooden pole to ensure that the upper layers of liquid are not depleted of fluoride or become warmer than the bulk of the bath. No foreign metal, organic matter, salts or acid radicals should be introduced into the bath.

7.2 **Appearance.** The parts should have a uniform clean white or pearly grey appearance and should be free from foundry sand.

7.2.1 **Defects.** A very thin semi-transparent film indicates treatment at too low a voltage, but on wrought surfaces in good condition or on machined surfaces such a film is acceptable. Dark areas in hollows may indicate entrapment of gas during treatment. An etched appearance indicates a bath too low in ammonium bifluoride, too hot, or possibly operated at too high a voltage. A thick dense film may indicate the presence of acid radicals other than fluorides. Pitting of the surface may be caused by chloride in the bath.

7.3 **Subsequent Treatment.** The presence of a fluoride film on anodised magnesium alloys does not prevent treatment by the acid chromate bath, (Bath (iv) Leaflet **BL/7-3**, paragraph 3.2) though somewhat longer times may be required to achieve the desired results. The fluoride layer is slowly displaced and a chromate film substituted. For chromating by the hot half-hour bath, (Bath (iii) or the chrome-manganese bath, Bath (v), Leaflet **BL/7-3**, paragraphs 3.1 and 3.3), the fluoride film should be removed (paragraph 7.4).

NOTE: The chromate films produced by the chrome maganese and hot half-hour baths are superior to that produced by the acid chromate bath. Consequently they are recommended for use wherever possible.

7.4 **Removal of Fluoride Film.** The film can be removed by immersion for 15 minutes in a boiling (10 to 15% w/v) solution of chromic acid, followed by immersion for 10 minutes in a boiling (5% w/v) solution of caustic soda or for 5 minutes in a cold (15 to 20% w/v) solution of hydrofluoric acid.

7.5 **Dimensional Change.** The anodising process outlined above does not lead to an appreciable decrease in the dimensions of a component, but material may be lost during film removal and chromating (especially the acid chromate bath) processes.

8 ASSEMBLY OF PARTS It is particularly important that the instructions for wet assembly with the appropriate jointing compound are carefully followed.

8.1 **Wet Assembly.** Wet assembly is the assembly of parts using a resinous jointing compound in the liquid state between faying surfaces. Rivets and bolts are also assembled in this manner.

8.1.1 A large variety of jointing compounds and sealing compounds are available but it is important that the compound specified for a particular joint or fitting technique is used. The compounds are usually selected from the DTD 900 series of approved proprietary materials and are listed in that document under the titles 'Jointing Materials' and 'Sealing Materials'.

8.1.2 Jointing compounds for magnesium alloy parts usually contain a percentage of chromate as an inhibitor. They vary in consistency from thin liquids to fairly stiff pastes, and their purpose is to separate metal faying surfaces with an electrically-inert medium and to fill gaps which would otherwise present a potential corrosion hazard in service. The compounds retain a solid but flexible consistency when dry while being thin enough to spread evenly when first applied. Many of the compounds are unaffected by fuels and oils and may be painted over.

8.2 **Galvanic Action – Assembly Techniques.** In general, liberal use of wet assembly media (paragraph 8.1) followed by painting, will effectively prevent galvanic attack at the junction of different metals.

8.2.1 A plastic insulating gasket is recommended where joints are made and broken repeatedly and wet assembly is also necessary. Special nuts incorporating plastic washers are often used. Nuts, bolts, washers and special fasteners of metallic materials other than aluminium, as well as mating surfaces of components, must be cadmium or zinc plated and wet assembled. In the case of studs, thread inserts, etc., the surface sealing resin itself may be used and the whole appropriately stoved (paragraph 5.3.1).

8.2.2 Where earthing points are involved, the whole area of the junction should be completely sealed by covering with a sealing compound or several layers of paint.

8.2.3 **Rivets.** Aluminium alloy rivets to specification L58 should be used (e.g. BS SP70, 79, 84, 160 and 161). Where stronger rivets (e.g. Monel, steel, etc.) are needed cadmium plating of the rivet is essential. In all cases wet assembly is necessary.

NOTE: See Leaflet **BL/6-26** for identification of rivets.

9 MAINTENANCE OF PROTECTIVE COATING It is essential that parts and components are kept thoroughly clean. Careful attention should be given to the condition of the organic protective coating. In severe environments the use of a de-watering oil on the surface of parts and components will materially reduce the corrosion hazard.

9.1 **Local Damage.** Any local damage to the surface coating should be touched-up with air drying paint (primers and top coats) as soon as possible after the damage has occurred.

9.2 **Superficial Corrosion**

9.2.1 Where the corrosion is of a superficial nature and occurs in a few isolated spots only, the protective paint should be scraped away and the corrosion removed by brushing with a stiff non-metallic brush (e.g. nylon), glass paper or by light blasting with non-metallic grit.

9.2.2 After smoothing down the surrounding areas of paint with glass paper, the debris should be removed and local damage should be made good by applying two coats of chromate primer followed by the normal paint scheme.

9.2.3 Where there is no danger of entrapment of treatment chemicals, the area should be cleaned by swabbing with a solution of 10% by weight chromic acid and 0·1% by volume sulphuric acid (D = 1·84) followed by rinsing with several changes of water. The treatment should be continued until all corrosion is removed then finally treated by the normal protective paint scheme for the part concerned. (See also paragraph 6.3.2(b) Note.)

9.3 Corrosion Rectification – Workshop Procedure

9.3.1 Wherever possible components should be dis-assembled, and parts made from materials other than magnesium alloy should be removed.

9.3.2 If necessary the components should be cleaned of surface sealing resin by either blasting with clean non-metallic grit, machining or scuffing, or by application of an approved chemical solvent or by a combination of both. Uncorroded areas on parts made to close tolerances should be masked during these operations.

9.3.3 Each part should be inspected and checked for cracks using a suitable non-destructive examination procedure. (Leaflets **BL/8-2, 8-3, 8-4, 8-5,** or **8-7** as appropriate.)

NOTE: The presence of a surface sealing resin may interfere with the dye-penetrant method of non-destructive examination.

9.3.4 Provided the part can be dis-assembled and stripped of surface sealing resin it may be re-sealed and finished in the normal way.

9.3.5 If the part cannot be stripped of surface-sealing resin and there is corrosion of a superficial nature, paint and surface sealing should be removed from around the corroded area using either a non-metallic brush or blasting with non-metallic grit.

(a) Provided the part can be washed completely free from chemicals, the corroded area should be cleaned using a solution containing 10% by weight chromic acid and 0·1% by volume sulphuric acid (D = 1·84) and rinsed with clean water. The process should be repeated until all corrosion is cleaned off, then the part should be rinsed in several changes of clean water until free from chemicals.

(b) The cleaned area should be treated with acid chromate solution as given in paragraph 6.3.1(a), then repainted with two coats of chromate primer followed by the normal paint scheme.

9.3.6 If the part cannot be washed clean with chemical cleaners it should be cleaned by mechanical methods (see paragraph 9.3.2), then debris should be removed and it should be painted with either etch or epoxy primer followed by a complete paint scheme.

(a) The final assembly should be carried out with the same care as that applied to a new component and should include the same wet assembly procedure, priming and painting.

(b) Care should be taken to avoid contaminating the surface of magnesium. Any abrasive papers or tools used must be free from all loose metal impurities and rust.

BL/8-1

Issue 3.

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BASIC

NON-DESTRUCTIVE EXAMINATION

OIL AND CHALK PROCESSES

1 INTRODUCTION This leaflet gives guidance on the detection of surface defects, such as cracks and porosity, by processes involving the use of oil and chalk. The principle upon which the process is based is the absorption by chalk of fluids. A penetrant oil is applied to the surface of the parts to be checked and, after removing the surplus oil, a layer of chalk is applied. Oil entrapped in defects is absorbed by the chalk, the resulting stains indicating their position.

1.1 There are two basic methods of applying the process, i.e. the "Hot Fluid Process" and the "Cold Fluid Process". Of these, the process employing hot oil is the more efficient and should be used wherever possible, but both methods suffer serious limitations, as indicated in paragraph 2. However, some proprietary processes, e.g. the "Bristol Modified Method of Oil and Chalk Test", which is an adaptation of the hot fluid process, are not subject to such deficiencies. The Bristol Modified Method is considered in more detail in paragraph 5.

1.2 Guidance on the use of penetrant dye and fluorescent ink processes, which have largely superseded the conventional oil and chalk processes, is given in Leaflet **BL/8-2.** Information on the use of ultrasonic equipment for the detection of flaws is given in Leaflet **BL/8-3,** and on the radiological examination of aircraft structures in **BL/8-4.** Guidance on magnetic methods of flaw detection is given in Leaflet **BL/8-5.**

2 LIMITATIONS OF THE PROCESSES The oil and chalk processes were devised for the detection of surface defects in non-ferrous and some non-metallic materials, but the deficiencies described in the following paragraphs should be considered before deciding upon the suitability of either of the processes for the work in hand. The processes are nor considered suitable for the detection of minute flaws or tightly shut cracks.

2.1 The processes are quite effective for such applications as the detection of large cracks in rough castings, but in general, the degree of contrast obtained by oil exudation is very poor and, unless the pre-cleaning and final drying processes are efficiently done, spurious indications of defects may be given.

2.2 Defect indications, at best, will appear only as dark grey stains on a light grey background, and are not sufficiently defined to make the detection of small cracks practicable, particularly when examining parts having dark surfaces, e.g. chromated magnesium alloy parts.

2.3 When the hot oil process is used for parts which are dimensionally large or are of intricate shape, it is often not possible to remove the surplus oil quickly enough to be able to apply the chalk before the parts become cool, thus the object of heating is defeated (see paragraph 3.4). On the other hand, if the drying is not done efficiently, masking of defects may occur due to the spontaneous staining of the chalk in damp areas.

3 HOT FLUID PROCESS To obtain satisfactory results it is essential that the parts should be thoroughly cleaned before immersion. If the parts have previously been immersed in an acid pickle bath, paint stripper, or some other strong solution, all traces of such solutions must be removed by adequate washing to avoid contamination of the test oil.

3.1 The parts to be examined should be immersed or (if a specified area only is to be examined) partly immersed, in a solution consisting of approximately 28 per cent (by volume) of lard oil in paraffin. The solution should be maintained at a temperature of approximately 80°C., and the period of immersion must be sufficient to allow the parts to attain this temperature. If preferred, solutions consisting of three parts paraffin and one part lubricating oil, or 50 per cent paraffin and 50 per cent spindle oil, may be used.

3.2 After immersion the parts should be dried quickly and thoroughly with a non-fluffy rag ; excellent final cleaning can be achieved by the use of unglazed tissue paper.

3.3 The parts should then be placed in the chalk cabinet and a fine layer of dry powdered French chalk should be applied, preferably by a method that will distribute the chalk in a gentle cloud. A paint spray gun with a conical funnel fitted in front of the jet, operated at a pressure of about 10 lb. sq. in., will be found suitable for this purpose. The gun should be provided with an efficient water trap. Surplus chalk should be removed by lightly tapping the parts on a block of wood.

NOTE : The chalk cabinet should form an enclosed area in which the parts to be examined can be placed. It should have a transparent front and should be fitted with an exhaust fan to remove surplus chalk. The parts can be coated more rapidly if a turntable is used.

3.4 The parts should be inspected for defects when quite cool and it will be found that if any cracks are present, the fluid will have been forced from them as the metal contracted on cooling, causing the chalk to become stained. A gentle air stream from a source pressurised at not more than 10 lb. sq. in., if directed on to the surfaces of the parts, may assist in the revelation of defects by removing the adjacent unstained chalk. It is essential that the examination should be made with the aid of a strong light.

4 COLD FLUID PROCESS As stated in paragraph 1.1, the efficiency of this process is not equal to that of the hot fluid process, and it should be used only where the application of the latter process would not be practicable, e.g. when examining parts of assembled structures or parts too large for immersion.

4.1 The parts should be thoroughly cleaned and then coated with a solution of lard oil and paraffin, or lubricating oil and paraffin, in the proportions recommended in paragraph 3. After the surfaces to be examined have been thoroughly coated, all traces of the solution should be removed with a non-fluffy rag, followed by final wiping with unglazed tissue paper. The surface should then be coated with French chalk (paragraph 3.3).

4.2 Any oil entrapped in defects will be drawn out by the absorbent chalk, the resulting stains indicating the position of the defects. It is essential that the examination should be made with the aid of a strong light.

5 THE BRISTOL MODIFIED METHOD In this process, finished parts or rough castings are immersed in hot oil, are removed and have the surfaces degreased, and are then sprayed or dusted with dry French chalk.

5.1 The parts to be examined should be immersed or (if a specified area only is to be examined) partly immersed, in a solution consisting of 50 per cent paraffin and 50 per cent spindle oil. The solution must be maintained at a temperature of 70°C., and the period of immersion should be sufficient to allow the parts to attain this temperature, one hour usually being sufficient.

5.2 After immersion, the parts should be allowed to stand until all surplus oil has drained off, after which they should be transferred to a degreasing tank containing a solution consisting of the following :

Teepol	5 per cent	by volume
Cresylic Acid	5 per cent	
Water	90 per cent	

The solution should be maintained at a temperature of between 70°C. to 80°C. When the cleansing action deteriorates, additions of Teepol and cresylic acid should be made to restore the above proportions.

NOTE : The cresylic acid should comply with the requirements of British Standard 524, Grades A or B.

5.3 The parts should be immersed in the degreasing solution for 3 to 5 minutes and should be agitated throughout this period.

5.4 After degreasing, the parts should be transferred to a tank containing clean hot water, and should be thoroughly swilled for a period of from 3 to 5 minutes, after which they should be allowed to drain.

5.5 When dry, the parts should be coated with a layer of dry French chalk, the equipment described in paragraph 3.3 being suitable for this purpose, except that an air pressure of 60 to 80 lb. sq. in. is recommended, after which surplus chalk should be removed by the application of a jet of air at about 25 to 30 lb. sq. in. pressure.

5.6 The parts should now be examined for defects, and cracks will be indicated by a thin white line of chalk.

BL/8-2

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BASIC

NON-DESTRUCTIVE EXAMINATION

PENETRANT DYE PROCESSES

1 INTRODUCTION This leaflet gives guidance on the penetrant dye processes used for the detection of defects which break the surface of the part, such as cracks, cold shuts, folds, laps and porosity.

1.1 Penetrant dye processes are used mainly for the detection of flaws in non-ferrous and non-magnetic ferrous alloys but may also be used for ferrous parts where magnetic flaw detection techniques are not specified or are not possible. However, in some instances both penetrant dye and magnetic flaw detection techniques may be specified for a particular part (see paragraph 1.5.4). Penetrant dyes may also be used on some non-metallic materials but their use with perspex-type materials is not recommended, since crazing may result.

1.2 Although the processes are usually marketed under brand names, those used on aircraft parts for which a penetrant process of flaw detection is a mandatory requirement must comply with the requirements of Process Specification DTD 929. It must be ensured that any storage limiting period prescribed by the manufacturer of the process is not exceeded.

1.3 The processes available can be divided into two main groups. One group involves the use of penetrants containing an emulsifying agent (termed water-emulsifiable or water-washable processes) whilst in the other group a dye solvent has to be applied separately after the penetration time (paragraph 4) has elapsed if the surplus dye is to be removed by a water-wash operation. The processes may be further sub-divided insomuch that with some processes the use of a dry developer is recommended whilst with others a wet developer is used. The manufacturers' recommendations and instructions for each individual process must be followed carefully to ensure satisfactory results.

NOTE : An emulsifier is a blending of wetting agents and detergents which enables excess dye to be removed with water and, in the case of wide flaws, assists in preventing the dye seeping out too quickly.

1.4 Basically all the processes consist of applying a red penetrant dye to the surface of the part to be tested, removing after a predetermined time the dye which remains on the surface and then applying a developer, the purpose of which is to draw to the surface any dye that has entered into defects, the resultant stains indicating the positions of the defects.

1.5 The selection of the most suitable type of penetrant process (e.g. penetrant dye or fluorescent penetrant (Leaflet **BL/8-7**) ; with or without post-emulsification) for any given application must largely be governed by experience, since when used correctly a high degree of efficiency can be obtained with any of the processes. Guidance on some of the factors which should be given consideration is provided in the following paragraphs.

1.5.1 Within a given type of process, the post-emulsification method is generally considered to be the most sensitive and is usually selected for finished machined parts and for the detection of "tight" defects. However, its use on rougher surfaces (e.g. castings) may be less effective than would be the use of a penetrant containing an emulsifier, since it may pick up the surface texture of the material, thus rendering the detection of actual defects more difficult.

1.5.2 Where large heavy parts are concerned, and particularly where mechanical handling is involved, the use of penetrant dyes may be more practicable than that of fluorescent penetrants, since the necessity of darkening a relatively large area before the examination can be made does not arise.

1.5.3 When making "in situ" checks on aircraft, the use of penetrant dyes may be more suitable where there is sufficient light but in darker areas a fluorescent process may provide better definition of defects.

NOTE : Battery-operated ultra-violet light sources are now available.

1.5.4 With steel castings, for example, porosity may be detected more easily by a penetrant process than by a magnetic flaw detection technique (Leaflet **BL/8-5**) and for this reason the application of both processes is sometimes specified. If the magnetic flaw detection test precedes the penetrant test, great care will be necessary with the intervening degreasing process to ensure that all traces of the magnetic testing medium are removed, otherwise the subsequent penetrant test may be unsuccessful.

1.6 Some of the materials associated with penetrant testing have low flash points and the appropriate fire precautions should be taken.

1.7 Guidance on fluorescent penetrant processes, which previously formed part of this leaflet, will be given in Leaflet **BL/8-7**, at present in preparation.

2 SURFACE PREPARATION The major reason for the failure of penetrant processes to provide indications of defects is incorrect or inadequate surface cleaning. For example, embedded extraneous matter can seal off cracks, etc., whilst contaminants remaining on the surface can trap the dye and give rise to false indications or, more detrimentally, obscure genuine defects. Thus the surface to be tested must be free from oil, grease, paint, rust, scale, welding flux, carbon deposits, etc., and the method of cleaning should be selected with the intention of removing extraneous matter from within the defects as well as from the surface to permit maximum dye penetration.

2.1 On unmachined steel stampings and forgings it may be necessary to remove rust or scale by sandblasting and to prepare aluminium alloy forgings by light sandblasting. However, the use of such processes must be given careful consideration, since they may result in the filling or "peening-over" of defects. Generally, unless specified otherwise, aluminium alloy forgings should be prepared by a suitable pickling process (e.g. by one of the methods prescribed in Process Specification DTD 901).

2.2 Magnesium alloy castings should be tested after chromating in order to reduce the risk of corrosion, but the requirements of Process Specification DTD 911, with regard to surface protection, must be taken into account and a suitable sequence devised.

2.3 Where contamination is mainly of an organic nature, degreasing by the trichloroethylene process (unless there are instructions to the contrary) is usually suitable. However, not all types of trichloroethylene are suitable for use with titanium alloys and further guidance on this and other aspects of trichloroethylene cleaning is given in Leaflet **BL/6-8.** The cleaning of titanium alloys by methanol should be avoided.

2.4 Where parts have to be tested "in situ", the use of volatile solvents (e.g. carbon tetrachloride) as cleaning agents should be given consideration. Where paint is present, this should be removed from the surface to be tested prior to cleaning. Subsequent to the test, the surface should be reprotected in the prescribed manner.

NOTE : Suitable fire precautions must be taken when flammable materials are used.

2.5 Sufficient time should be allowed after cleaning for drying out, otherwise the efficiency of the penetrant dye may be affected. The time interval allowed for the evaporation of solvents can only be determined by the prevailing conditions of temperature and humidity and the type of solvent used.

3 APPLICATION OF THE DYE The penetrant dye can be applied to the surface by dipping, spraying or brushing, the method used depending largely on the size, shape and quantity of the parts to be examined. The surface must be dry before the dye is applied. Even the condensation which forms on a cold surface in humid conditions may interfere with dye penetration ; in such conditions the part should be warmed to a temperature of about 90°F. to 100°F. but temperatures in excess of 140°F. must be avoided, since these may result in the volatilization of some of the lighter constituents of the dye.

3.1 **Dipping Method.** Dipping should generally be used where large numbers of small parts are to be examined. The parts must be completely dried before immersion, since apart from affecting penetration, water or solvents will contaminate the dye.

3.1.1 During dipping care must be taken to ensure that the parts are so racked that air pockets are avoided and all surfaces to be examined are completely wetted by the dye.

3.1.2 It is not necessary for the parts to remain submerged in the tank during the penetration time (see paragraph 4) but only for a period sufficient to permit thorough wetting. "Drag-out" losses can be reduced if the dye is allowed to drain back into the tank during the penetration time.

3.2 **Flooding Method.** The flooding method should generally be used where large areas are to be examined. The dye should be applied with low-pressure spray equipment which will not permit atomisation of the fluid, any surplus dye being allowed to drain back into the tank.

3.3 **Aerosol Can Method.** Penetrant contained in Aerosol type cans is often used for "in situ" inspections. The best results are obtained when the can is held about twelve inches from the surface under test.

3.4 **Brushing Method.** The brushing method is generally used for individual items and items of complicated shape. A clean soft bristle brush should be used and retained only for this purpose.

4 PENETRATION TIME The penetration time is the time which has to be allowed for the dye to penetrate effectively into the defects. It is dependent upon a number of factors, such as the characteristics of the process being used, the material from which the part is made, the size and nature of the defects being sought, the processes to which the part has been subjected and the temperatures of the atmosphere, the part and the dye. Clearly the time can be decided only by experience of the particular local conditions but is usually in the range of 5 minutes to 1 hour, the smaller the defect the longer the time necessary.

4.1 Temperatures below 60°F. will retard the penetrant action of the dye, thus the penetration time should be extended proportionately. Testing in temperatures at or near freezing point should, if possible, be avoided, since in such conditions the performance of the penetrant is considerably reduced.

4.2 Where the effectiveness of the pre-cleaning process cannot be guaranteed or where parts have been sandblasted, the penetration time should be extended but it should be borne in mind that this is no guarantee that defects will, in fact, be revealed in such conditions.

5 REMOVAL OF EXCESS DYE Any dye remaining on the surfaces of the parts after expiry of the penetration time should be removed as thoroughly as possible but without disturbing the dye which would have found its way into any defects present. Excessive cleaning, however, may result in the dilution of the dye or its complete removal from defects. The method of removal depends on whether a water-washable or post-emulsifiable dye was used and the size and condition of the surface under test.

5.1 **Water-washable Dye.** Water-washable dye should be removed as indicated in the following paragraphs.

5.1.1 The dye should be removed from "in situ" parts with clean rags saturated in water, followed by wiping with clean rags until the surfaces are both dry and free from dye.

5.1.2 The dye should be removed from small parts with clean rags saturated in water, followed by drying as recommended in paragraph 5.3.

5.1.3 The dye should be removed from large areas or irregularly shaped parts by flushing with an aerated spray of water, followed by drying as recommended in paragraph 5.3.

5.2 **Post-emulsifiable Dye.** Post-emulsifiable dye should be removed from small areas and "in situ" parts first by wiping with a clean rag damped with dye solvent, followed by wiping or blotting with a clean dry rag. The bulk of the dye may be removed from large areas, irregularly-shaped parts and rough-textured surfaces by a quick water wash (allowing this to drain) followed by the application of the dye solvent and a final water wash. The dye solvent should be applied by spraying, swabbing, dipping or brushing, except that brushing should not be used where relatively large defects are suspected. Washing should be followed by thorough drying, as outlined in paragraph 5.3.

5.3 **Surface Drying.** Prior to applying the developer (paragraph 6) it should be ensured that the surfaces of the part under test are completely dry. The following methods of surface drying are recommended which, although slower than the use of, for example, compressed air, are less likely to disturb entrapped dye.

5.3.1 Small areas may be wiped dry but since this may disturb the dye in the wider defects, the use of warm air is preferred.

5.3.2 Hot-air ovens and similar equipment may be used for drying, a temperature of about 130°F. being suitable ; temperatures in excess of 175°F. must be avoided.

The use of lamps for drying is not recommended unless uniform heat application can be guaranteed.

6 **APPLICATION OF THE DEVELOPER** The developer usually consists of a very fine absorbent white powder which may be applied in (a) the form of a spray, the powder being suspended in a volatile carrier liquid which rapidly evaporates, leaving a white coating on the surface, (b) as a dip with the powder suspended in water or (c) as a dry powder which may be blown on to the component or into which the component may be dipped. The action of the absorbent powder is to draw out the dye from the surface defects, thus indicating their position by the resulting stain.

6.1 Where it is suspected that microscopic defects may be present, great care is necessary to ensure that the developer is applied evenly and very thinly, since a thick layer might conceal completely a defect holding only a minute quantity of dye.

6.2 Where a wet developer is concerned, the best results are obtained when the developer is applied by means of a paint-type spray gun operating at an air pressure not in excess of 15 lb. sq. in. The pressure pot of the spray gun should be equipped with a stirrer to keep the developer agitated and the absorbent particles in suspension. Before pouring the developer into the spray gun it should be well shaken to ensure a thorough distribution of the absorbent particles.

6.3 When requirements are not too exacting, small parts can be dipped into a bath of developer but the action must be performed rapidly to minimise the possibility of the dye being washed out of shallow defects. The bath should be agitated from time to time to ensure that the absorbent particles are kept in uniform suspension. The formation of pools of developer on the parts during draining must be avoided, otherwise the resultant thick coatings may mask defects.

6.4 Due to the usually uneven results obtained, the use of a brush for applying the developer is not recommended.

6.5 If the developer dries with a slightly pinkish hue, this is probably due to faulty cleaning or "carried over" penetrant in the penetrant remover (see paragraph 7.2) but provided sufficient contrast remains to enable minute defects to be detected, the condition is acceptable.

6.6 Water must not be permitted to enter the developer containers, since its presence will retard considerably the drying rate of the developer.

7 **INTERPRETATION OF DEFECTS** If defects are present and all stages of the process have been applied correctly, the position of the defects will be indicated by red marks appearing on the whitened surface. The majority of defects are revealed almost immediately the developer dries but additional time (approximately equal to the penetration time (paragraph 4)) should be allowed for "tight" flaw indications to appear and for flaw patterns to reach their final shape and size. (Figure 1.)

7.1 By noting and comparing the indications that appear during the first 30 seconds of development with those which exist after about 10 minutes, a more accurate assessment of the characteristics of the defects is possible. For example, the dye exuding from a shallow crack is little more after 10 minutes than after 30 seconds but in the case of a deep narrow crack, considerably more dye is present, causing a much wider indication to develop over a similar period of time. Thus the rate of staining is an indication of the width and depth of the defect, whilst the extent of staining is an indication of its volume.

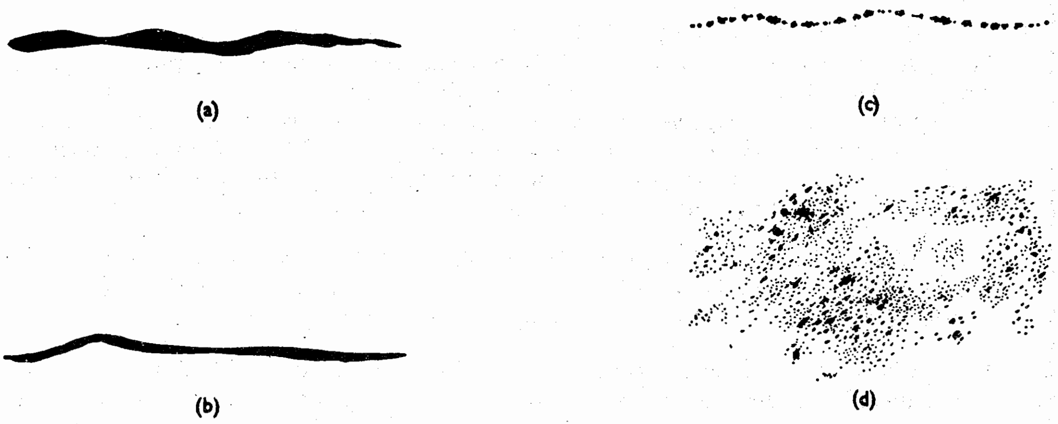

Figure 1 INDICATIONS GIVEN BY DEFECTS

7.2 Scattered dots of dye indicate fine porosity or pitting (Figure 1(d)) whilst gross porosity may result in an entire area becoming stained. Where doubt exists as to whether the overall pinkish effect is due to inadequate washing, the process should be repeated, more care being taken particularly during the stage of cleaning off the excess dye.

7.3 Closely spaced dots in a line or curved pattern (Figure 1(c)) usually indicate tight cracks or laps but such patterns are also characteristic of very wide defects from out of which most of the dye has been washed. Wide cracks, lack of fusion in welded parts and other similar defects are indicated by continuous lines as shown in Figures 1(a) and 1(b).

7.4 Examination by means of a powerful magnifying glass is often useful when minute defects are being sought.

7.5 All defects should be suitably marked prior to removing the developer, but crayons should not be used on highly-stressed components subject to heat treatment, since this is known to induce fractures.

8 REMOVAL OF DEVELOPER Developer can be removed by brushing or by air or water under pressure, but since the surface is then in a condition susceptible to corrosion (where this is applicable) the prescribed protective treatment should be applied with the minimum of delay. It should be noted that the adhesion of paints and resins may be seriously impaired by certain oil-base dyes if thorough cleaning is not ensured.

9 LEAK TESTING WITH PENETRANT DYES On components or assemblies where the main purpose of the test is to locate defects which would result in a fluid leakage (e.g. cracks in pressure vessels) the methods of testing described in the previous paragraphs may not be conclusive. In such cases the inner and outer surfaces should be thoroughly cleaned and degreased, the dye being applied to one surface (usually the inside of pressure vessels) and the developer to the other. After the pentration time (paragraph 4) has elapsed, the surface should be inspected for evidence of staining.

9.1 Where no definite penetration time has been determined then, with a wall thickness of from $\frac{1}{16}$ in. to $\frac{1}{8}$ in., the penetration time should be at least three times that which would be allowed for a standard "one-side-only" test.

9.2 More than one application of the dye is often required and as a general rule an additional application for each $\frac{1}{16}$ in. to $\frac{1}{8}$ in. wall thickness is recommended.

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BASIC
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ULTRASONIC FLAW DETECTION AND THICKNESS MEASUREMENT

1 INTRODUCTION The methods of crack detection dealt with in Leaflets **BL/8-1** and **BL/8-2** are of considerable value for finding surface defects but are unable to reveal the presence of internal flaws which are distant from the surface. This Leaflet gives general guidance on the application and scope of ultrasonic sound waves for detecting surface and internal flaws in materials and parts and for the measurement of thickness.

1.1 Ultrasonic testing is not a complete substitute for other methods of flaw detection and should generally be regarded as complementary to them. It should be considered an extension to efficient inspection but should not be regarded as a foolproof method without considered trials and its indiscriminate use could be uneconomical and misleading. There are instances, however, particularly in aircraft applications, where ultrasonic testing is the only satisfactory method, e.g. when a distant defect lies parallel with the only available surface of a component. The degree of skill and experience required to use ultrasonic apparatus, and to interpret the indications obtained, varies with the complexity of the parts to be examined, the type of equipment available and the acceptance standards specified. Operators should be properly trained and qualified on the equipment in use.

1.2 Cavities, inclusions and cracks in cast metal prior to fabrication by extrusion, rolling, forging, etc., can be found by ultrasonic techniques and automatic scanning devices are often used during the manufacturing process. Large steel or aluminium forgings, components welded by gas, arc or flash butt methods, and a variety of parts such as turbine discs, propeller blades and wing spar booms may all be examined at various stages during manufacture. Ultrasonic methods can also be used for finding fatigue cracks, and other defects arising from operating conditions, during the periodic inspection of airframe and engine parts.

1.3 Thickness measurement by ultrasonic methods has some aircraft applications. It provides a satisfactory means of measuring the skin thickness of hollow propeller or turbine blades and for checking tubular members or sheet metal assemblies. Delamination of bonded assemblies can also be checked by similar methods.

2 SOUND WAVES Ultrasound describes sound at a pitch too high to be detected by the human ear and the frequencies used in ultrasonic testing are normally within the range 500 kHz to 10 MHz.

2.1 **Sound Energy.** Sound is energy produced by a vibrating body, the energy being transferred through a medium by the wave-like motion of the particles making up that medium. The frequency of the waves is the same as that of the vibrating body and the wavelength is dependent upon the speed of sound in the particular material. This is illustrated in Figure 1, the 'y' axis representing the distance of a vibrating particle from its mean position and the 'x' axis its distance from the sound source. The time taken for the sound to travel one wavelength (λ) is the same as the time taken for the vibrating body to execute one complete cycle.

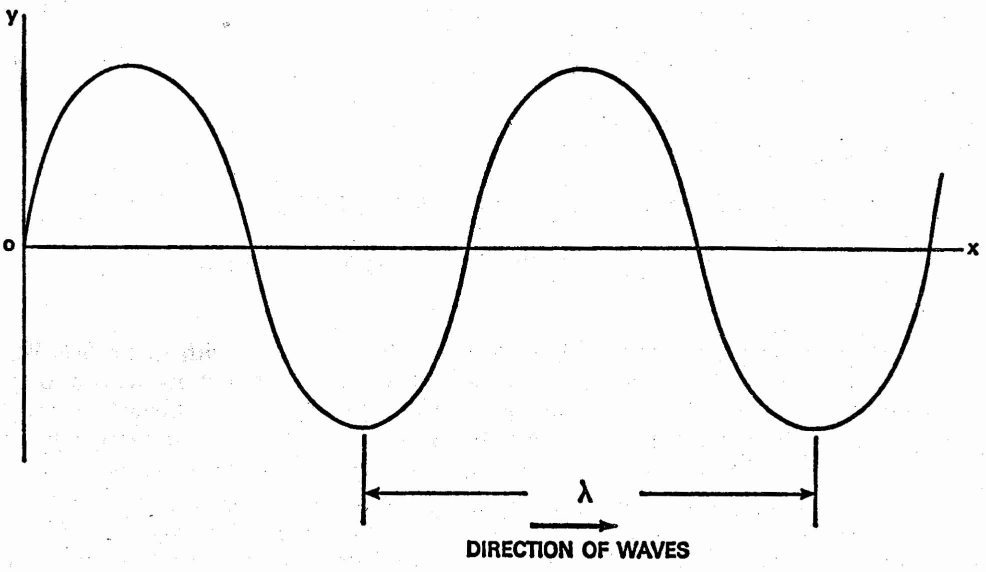

Figure 1 FORM OF SOUND WAVES

2.2 **Wave Types.** Three main types of waves may be generated. The vibrations in longitudinal (compression) waves are in the same direction as the sound motion and the vibrations in transverse (shear) waves are perpendicular to the sound motion. Waves generated along the surface of a material, known as surface waves, have an eliptical motion. Any of these types of waves may be generated in solids but only longitudinal waves can normally be generated in liquids or gasses. Other types of waves exist and are sometimes used in ultrasonic testing (e.g. Lamb Waves, which are vibrational waves capable of propogation in thin sheet material).

2.3 The speed of sound through any particular material depends on the density and elastic constants of that material. Transverse waves travel at approximately half the speed of longitudinal waves, and surface waves at approximately 90 per cent of the speed of transverse waves.

2.4 **Beam Characteristics.** When sound waves are generated by a flat disc vibrating at ultrasonic frequencies the beam of sound is initially parallel and then, at a distance from the disc related to its diameter and the sound frequency, spreads out and loses intensity, the spread increasing as frequency and disc diameter are reduced. Within the near (parallel) zone variations in sound intensity occur, and absorption results in a loss of energy with increased distance from the source. A material with a large grain structure or holes associated with porosity absorbs more energy than one with a fine grain structure but, since absorption is also a function of frequency, by decreasing the frequency absorption is also reduced.

2.5 **Mode Conversion.** When a beam of sound is directed at the boundary between two solid materials at an angle other than normal to the interface, both reflection and refraction occur as shown in Figure 2. If material 'A' is a liquid, as in ultrasonic testing, only longitudinal waves will be reflected. Adjustment of angle 'a' will enable any of the main types of waves to be injected into material 'B'. Unfortunately mode conversion also produces unwanted reflections from the surface of a component which, due to the different speeds of the various types of waves, may give confusing results.

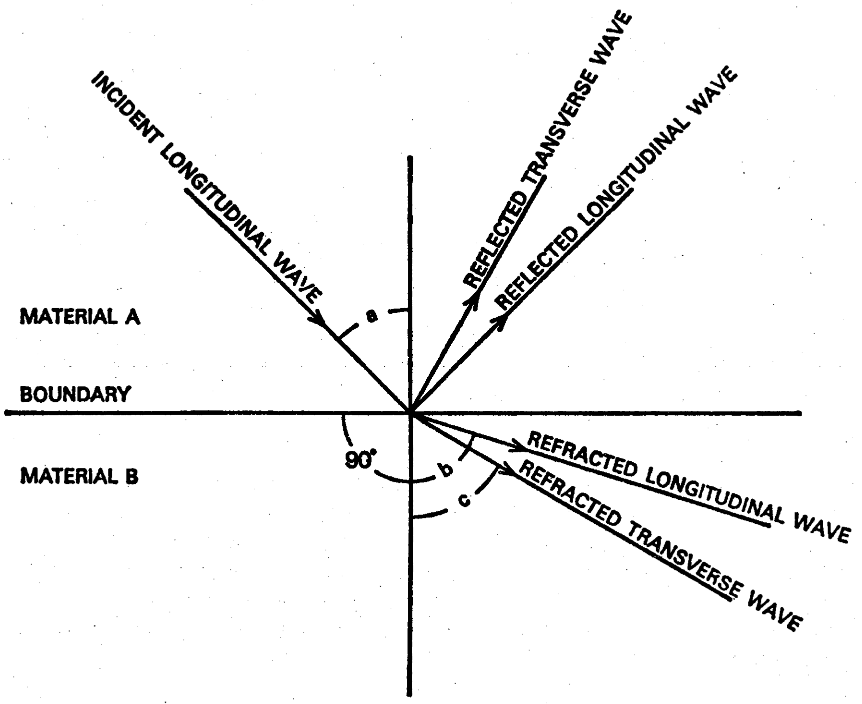

Figure 2 MODE CONVERSION

3 GENERATION AND DETECTION OF SOUND WAVES The sound waves used in ultrasonic testing are produced and detected by means of an electro-mechanical transducer, i.e. a device which converts electrical energy into mechanical energy and vice versa. The properties of the materials used in the manufacture of transducers are discussed in the following paragraphs.

3.1 **Piezoelectric Effect.** If a mechanical stress is applied in a specified direction to certain natural crystals such as quartz, an electrical field is produced in which the voltage is proportional to the magnitude of the stress. Similarly, if a voltage is applied between the crystal faces a proportional mechanical stress is produced in the crystal. By applying an electrical potential to the faces of an X-cut quartz crystal (i.e. a crystal cut in the form of a disc whose faces are normal to one of the 'X' axes) a vibration is produced, the frequency of which depends on the thickness of the crystal. Conversely, when such a crystal is caused to vibrate under the influence of a sound beam an alternating current is produced between the crystal faces.

3.1.1 A similar effect is produced in all electrically insulating materials, and certain ceramic materials such as barium titanate are particularly sensitive in this respect. Transducers made from these materials consist of a large number of tiny crystals fused together, and are permanently polarised during manufacture so as to vibrate in one plane only.

3.1.2 Piezoelectric crystals lose their activity when heated above a particular temperature and this may be a severe limitation for certain uses.

3.2 **Crystal Frequencies.** To achieve maximum efficiency crystals must be operated at their natural frequency (determined by their dimensions and elastic properties). Transducers used in ultrasonic testing are generally used in this way when searching for cracks but for resonance testing different methods are used (see paragraph 4.4).

3.3 **Acoustic Coupling.** The amount of energy transferred across a boundary between two materials depends on the Characteristic Impedance of each material, which may be taken as the product of the density and the speed of sound in each material. Good coupling will be provided when the Characteristic Impedance of the two media are closely matched, and the capability of ultrasonic flaw detection depends on these factors. The coupling between metal and air is extremely poor and it follows that if any air is present between a probe and the material being tested very little energy will be transferred across the interface. For this reason a liquid couplant such as water, oil or grease is normally used in ultrasonic testing.

3.4 **Reflection.** If an ultrasonic beam is injected into a material it will continue through that material until it strikes a surface and will then either pass through the interface or be reflected, depending on the factors outlined above. If the beam strikes a discontinuity, crack or void in the material the reflection may be picked up by a suitably placed transducer, the amount of reflected energy depending on the nature of the defect and its orientation. Most of the energy striking an external surface or void will be reflected but in cases such as bolt holes or bushes which have been well lubricated very little reflection may occur.

3.5 **Probes.** A probe consists of a transducer mounted in a damping material and connected electrically to the test set. For any particular application it may be necessary to use a probe of a particular design so that a sound beam is injected into the material at an angle normal to the expected defect. The required angle of the incident beam is achieved by mounting the transducer on a suitably shaped plastic block. Similar blocks are also used for injecting sound waves into a material with a uniformly shaped surface such as a tube. In certain applications a wheel probe, consisting of a transducer mounted inside an oil-filled plastic tyre, has been found suitable for high speed automatic scanning.

3.6 **Display.** The most usual method of displaying the information obtained in ultrasonic testing is by means of a cathode ray oscilloscope. A pulsed transmission technique is normally used and is described below; other methods are described in subsequent paragraphs.

3.6.1 In the cathode ray oscilloscope (Figure 3), a triggering device causes both the pulse generator and time base control to operate simultaneously. The time base control (connected to the 'X' plates of the oscilloscope) deflects the trace produced by a beam of electrons, so that the trace moves across the screen from left to right in synchronisation with the ultrasonic pulse transmissions. Vibration of the transducer results in an electrical signal at the 'Y' plates of the oscilloscope, which deflects the electron beam in the form of a peak (A) in the time base. Any returning echo acts on the receiving transducer to produce a second peak (B), the distance of the flaw from the surface being represented by half the distance between A and B. This distance can be calculated from knowledge of the speed of sound in the particular material and the time base scale. The time base scale is usually variable, and provision is often made for the attachment of a graticule scale to the oscilloscope screen so that direct measurements may be taken.

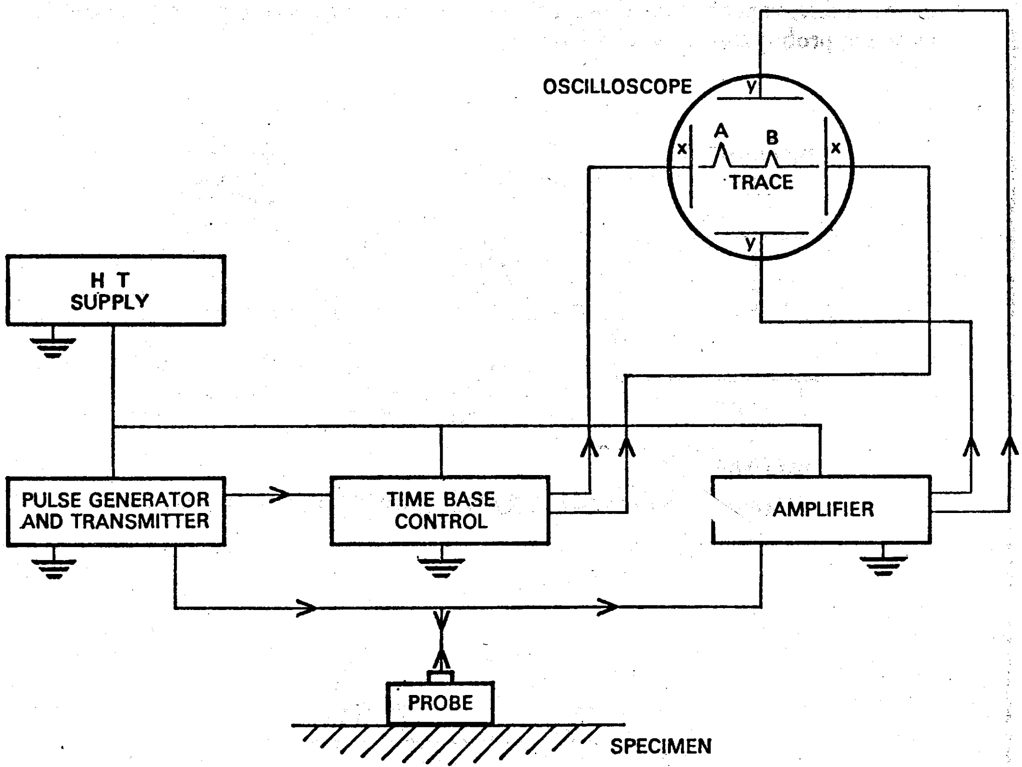

Figure 3 SIMPLE BLOCK DIAGRAM OF ULTRASONIC SET

3.6.2 Transducer crystals are usually damped to reduce the length of the pulse, but a layer (known as the 'dead zone') is left immediately below the surface of the test material in which defects parallel to the surface can only be examined from an opposite face. Increasing the ultrasonic frequency would reduce the depth of this layer but would also result in high absorption and might not be suitable for certain materials.

3.6.3 The pulse repetition frequency is extremely rapid to ensure a good trace on the oscilloscope, but must not be so quick that sound energy is still reflecting within the specimen when the next pulse is initiated.

3.6.4 The presentation described above is known as 'A scan' but the information may also be displayed in the form of a side elevation (B scan) or a plan view (C scan), the latter usually being used in automatically produced paper read-out form from a normal A scan oscilloscope.

4 METHODS OF OPERATION

4.1 **Transmission Method.** If a transmitting and a receiving probe are placed on opposite sides of a specimen (Figure 4), sound waves will be transmitted directly through the material and picked up by the receiving probe. If a flaw in the material interrupts the sound beam, a loss of signal will result and the second peak on the time base will disappear. Longitudinal wave probes are normally used for transmission scanning but angled probes may also be used when only one surface is accessible (Figure 5).

4.2 **Pulse-echo Method.** This method relies on reflections from a defect being detected by the receiving probe and either a single transceiver probe or separate transmitting and receiving probes may be used (Figure 6).

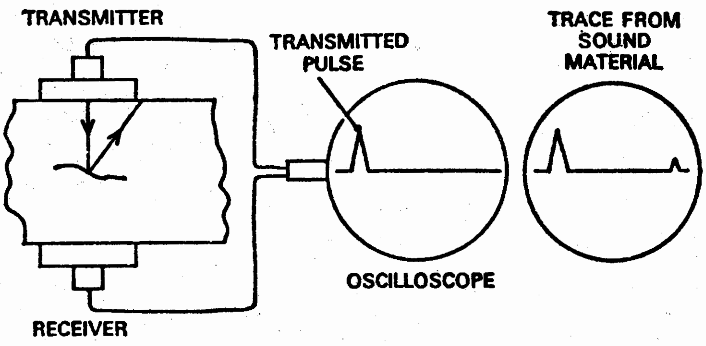

Figure 4 NORMAL TRANSMISSION TECHNIQUE

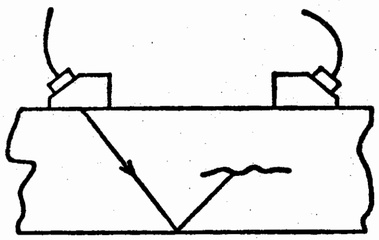

Figure 5 ALTERNATIVE TRANSMISSION TECHNIQUE

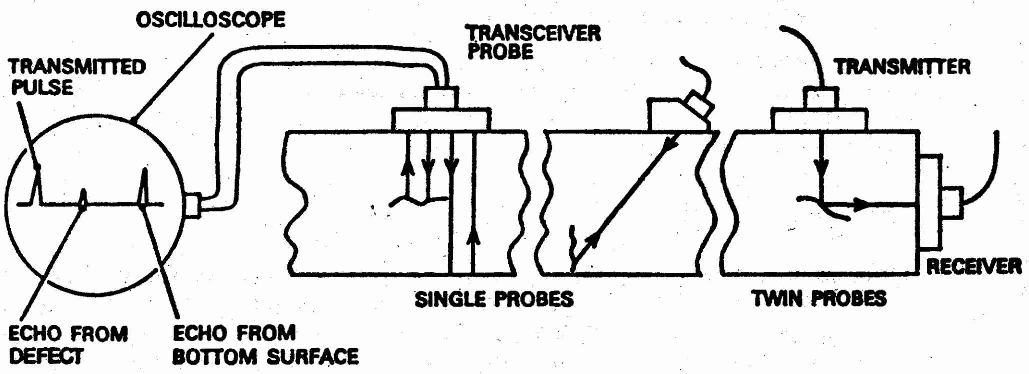

Figure 6 PULSE-ECHO TECHNIQUES

4.2.1 Pulse-echo methods are also used for finding cracks at right angles to a surface. An angled probe is used to inject surface waves into a material, the waves following the surface contour and reflecting back to the probe from any discontinuity (Figure 7).

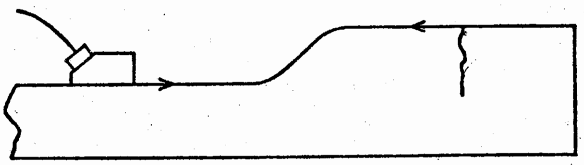

Figure 7 SURFACE WAVE TESTING

4.3 **Immersion Testing.** The technique of holding a probe in contact with the specimen is known as 'contact scanning', but there is also an important method of inspection known as 'immersion scanning', in which the specimen is immersed in a tank of water and a waterproof probe placed in the water, above the specimen (Figure 8). Pulse-echo techniques are normally used but transmission techniques would also be possible.

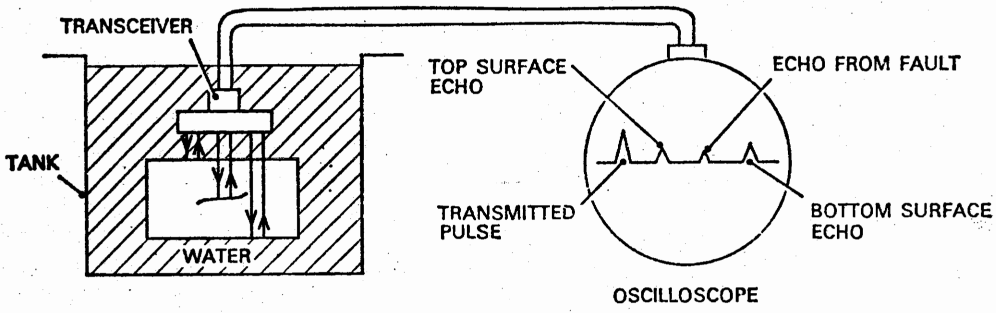

Figure 8 IMMERSION TESTING

4.3.1 Pulses of ultrasound are emitted by the probe and pass through the water into the specimen. The top and bottom surfaces of the specimen are shown on the oscilloscope, together with indication from the transmitted pulse and any flaws within the material.

4.3.2 The distance between the probe and specimen must be selected so that confusing repeat echoes are avoided, and can also be set to avoid use of the near zone in examining the specimen.

4.3.3 The trace produced by a fault-free specimen will normally produce three peaks, the space between the second and third, i.e., the depth of the specimen, being the only part of interest during inspection. The time base is usually delayed, and its scale expanded, so that indications of defects are more easily seen.

4.3.4 Immersion scanning lends itself to automation and is frequently used for the inspection of parts of simple shape. Parts of complicated geometric shape present difficulties in that expensive electronic circuits would be required to differentiate between surface reflections and internal flaws.

4.4 **Resonance Technique.** If a sheet or plate specimen is caused to vibrate in the direction of its thickness, resonance will occur if the thickness is equal to exactly half the wave length of the inducing vibrations. By using a quartz transducer to vary the frequency of the vibrations, resonance is produced in the specimen and this frequency is displayed to indicate the thickness. A laminar type of defect, or loss of bonding, can also be detected by resonance methods providing that the separation is dry.

4.5 **General Considerations.** A number of factors must be considered before making an ultrasonic inspection and special techniques may have to be developed for a particular situation.

4.5.1 **Surface Conditions.** There are various surface conditions, such as rust, scale, loose paint etc., which will prevent inspection by ultrasonic methods and these must be removed. The rough surfaces such as are found on cast billets may present difficulties, but the use of grease as a couplant may be effective, or, alternatively, the immersion technique may be used. The shape of the specimen should also be considered so that slipper blocks may be made to provide the best acoustic contact.

4.5.2 **Sensitivity.** With too great a sensitivity, porosity and large grain size will hide flaws in a material by producing numerous peaks on an oscilloscope. It is important, therefore, that the sensitivity of the test equipment be adjusted so that unimportant features can be disregarded. The amplitude of reflections depends mainly on the size of the flaw and if the maximum acceptable size of defect were specified, then any reflection producing peaks higher than this would be known to be unacceptable.

(i) For longitudinal wave scans the acceptable size of defect is related to a flat bottomed hole of a particular diameter. Test blocks are used in which holes of various sizes are drilled, and oscilloscope sensitivity is adjusted to give a peak of, say, one inch in height on the reflection from the hole of specified size. Blocks with holes drilled to different distances from the surface may be required to check the effect of attenuation on peak height. During test, defects producing peaks lower than one inch can then be ignored.

(ii) For transverse wave scanning the acceptable size of defect is related to a hole or saw cut made in a block of the same material and thickness as that to be inspected.

(iii) Notwithstanding the sensitivity setting of the oscilloscope, some defects, such as cracks, may extend over a considerable distance and therefore be unacceptable. These would be recognised by a constant peak as the probe was moved in the direction of the crack.

(iv) A special test piece has been designed by the International Institute of Welding and may be used for checking ultrasonic equipment in respect of both longitudinal and transverse waves; oscilloscope scale and resolution can also be verified.

NOTE: Most ultrasonic test sets are now fitted with an attenuator. This is a device which applies calibrated attenuation to the received signal, enabling received signal strength to be measured, in decibels, relative to the signal from a reference standard.

4.5.3 **Choice of Frequency.** Both absorption and diffraction of sound waves are a function of the frequency used. For any particular test it is necessary to take into account the size and position of possible defects, the nature of the material and the distances to be scanned. With a coarse grained material a low frequency must be used, especially in large specimens, but with a fine grained material a higher frequency may be used, with a consequent increase in sensitivity.

4.5.4 **Type of Defect.** When preparing a technique for the inspection of a particular item, knowledge of the type of defect which can be expected is of great assistance. For example, if a casting has a known tendency to crack at a particular position during service, sketches can be provided showing the oscilloscope patterns obtained from both sound and faulty castings; inspectors will then not be misled by spurious reflections due to the shape of the castings.

5 PRACTICAL APPLICATIONS

5.1 **Testing Ingots, Billets and Heavy Forgings.** Large blocks of metal of simple shape are particularly suited to testing by ultrasonic methods, provided that a suitable technique and frequency are used.

5.1.1 Rectangular blocks can be checked by systematically scanning three faces with a longitudinal wave probe. Because it is difficult to detect flaws which are close to the surface it may be advisable to scan all faces, but this will not be necessary if surface material is to be subsequently machined off.

5.1.2 Certain cast ingots may have such a coarse grain structure that the ultrasonic beam is scattered to a degree which renders flaw detection difficult or even impossible. If echo techniques prove to be unsuitable, the transmission method should be tried, but if this also is impracticable, it may be necessary to delay the inspection until rolling or forging have been carried out.

5.1.3 Inability to obtain satisfactory results can often be traced to poor acoustic coupling, a difficulty which can be overcome by use of the immersion technique.

5.1.4 It is common practice in industry to use automated ultrasonic techniques on billets, pipes and other similar products. A water jet, passing through a jacket within which the transducer is mounted, acts as the coupling agent, and electronic alarms trigger marking systems which record the position of a defect. An automated immersion technique is also sometimes used on finished size thin wall tubes, using Lamb waves for flaw detection.

5.2 **Testing Welded Joints.** Most types of welds in thick materials can be inspected by ultrasonic methods, but thin sheet metal welds are more satisfactorily checked by the use of X-rays (Leaflet **BL/8-4**). It is good practice to obtain a separate specimen in the same material, and to drill holes (as shown in Figure 9) which will indicate if it is possible to detect flaws at these positions. Experience has shown that this is not possible with all types of material and welding techniques.

5.2.1 Butt welds made by gas or arc welding methods can be checked by using an angled probe which injects transverse waves towards the weld line. If flaws are present in the weld, the beam will be reflected back to the probe. Experience in the application of scanning methods has made it possible to identify most types of welding defects, although it is not always easy to determine the acceptability of the weld from this information. When doubt exists, the information derived from the ultrasonic test should be correlated with other methods of testing, such as radiography.

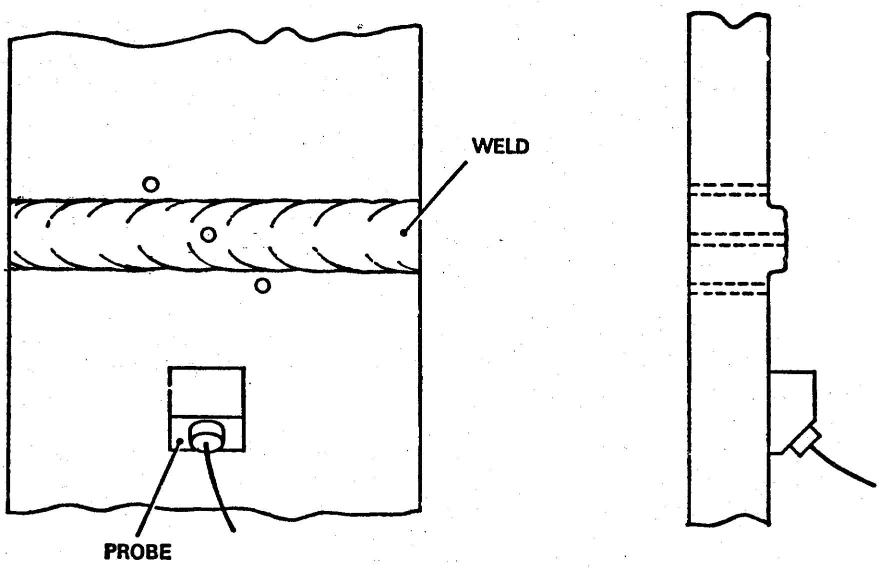

Figure 9 TEST HOLES IN WELD SAMPLE

5.2.2 Special techniques are required for testing flash butt welds, since they contain no filler metal, and flaws are normally in the plane of the weld. One method of testing is to position two probes as shown in Figure 10. Scanning is carried out by moving both probes simultaneously in opposite directions so that any flaws are detected by the receiver probe. The probes may, in some instances, be positioned on the same side, and certain specimens are best scanned by fixing the probes in a jig to ensure correct alignment. To determine the best method for inspecting a particular weld, all these methods should be tried until the most consistent results are obtained.

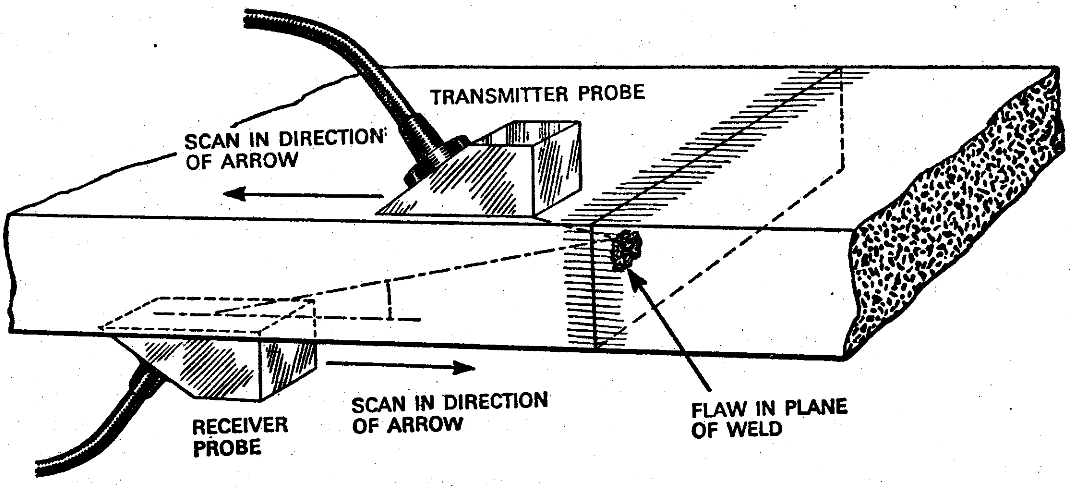

Figure 10 SCANNING METHOD FOR FINDING FLAWS IN FLASH BUTT WELDS

5.3 Thickness Measurement

5.3.1 **Pulse-echo Method.** By the choice of suitable probes and the selection of appropriate test frequencies, several types of flaw detectors can be used for measuring thickness, but the accuracy of most is limited when dealing with material of the thin gauges used in aircraft construction. Their main application is, therefore, to the measurement of thick material during machining and manufacturing operations, particularly when the parts concerned would have to be removed from jigs or machines in order to measure them by physical methods. Vertical probes are normally used, and may be either the transceiver type or a probe combining separate transmitting and receiving crystals.

5.3.2 **Resonance Method.** This method is suitable for the measurement of new aircraft skin, structure and tubing and is normally only used during aircraft manufacture. A quartz crystal is excited by means of a valve oscillator, at a frequency well below the fundamental resonant frequency of the crystal, and held in contact with the specimen. This causes the specimen to vibrate in its thickness direction, and the frequency of the sound wave is increased until the specimen resonates. An increase in the amplitude of the vibrations results, with a corresponding increase in crystal voltage. If the crystal frequency is further increased resonance recurs (i.e. at the next harmonic), and the fundamental frequency of the material, and hence its thickness, can be determined. Resonances may be shown on a suitably calibrated oscilloscope screen but more simple methods such as a voltmeter reading or an audible note in earphones are often used.

NOTE: The thickness is equal to an exact number of half-wave lengths, which can be calculated from the speed of sound in the material and the fundamental resonance frequency.

5.4 Detection of Lamination.

There are several ways of checking materials for internal laminations, and similar methods may also be used to determine the integrity of bonded structures. The pulse-echo technique may be used on plate over ½ inch thick but it is unsuitable for thinner sections.

5.4.1 **Transmission Method.** If a transmitting and a receiving probe are held in alignment on opposite sides of a specimen, any lamination inside the specimen will interfere with the transmission of the ultrasonic waves, and will be shown by a reduction in received signal strength. However, because of the need to have access to both sides of the specimen, this method has limited application in aircraft work.

5.4.2 **Resonance Method.** It has been explained that resonance occurs at one of the natural frequencies of the material, the thickness being related to an exact number of half-wavelengths of the ultrasonic beam. If a material is laminated, or the bond between two layers is defective, resonance will occur at a different frequency and will result in a change in the shape of the oscilloscope trace. Special test sets have been developed for the inspection of bonded structures, and techniques have been established from which it can be determined whether a bond is satisfactory or not when the bond is dry.

5.4.3 **Multiple Echo Method.** The time base and sensitivity of an ultrasonic set can be adjusted to give a number of boundary reflections. With a set adjusted in this way, any laminations present in a specimen being scanned will show up as a sudden increase in the number of reflections, e.g., if the specimen is laminated at its centre, the number of peaks on the oscilloscope screen will be doubled.

5.4.4 **'Lamb' Wave Method.** Laminations near to the surface of a metal plate are very difficult to detect. However, Lamb waves may be generated in plate which approximates, in thickness, to one wavelength of the sound beam, and any lamination will result in a change in the screen display. The angle of the probe is very important and varies with the thickness of the lamination; it is necessary, therefore, to scan with a variable angle probe.

6 TECHNIQUES FOR AIRCRAFT PARTS Ultrasonic testing is widely used on parts removed from aircraft, but is also applicable to the examination of parts in situ where other types of inspection would require extensive disassembly. Techniques are established to ensure consistent results and these are written into the appropriate manuals.

6.1 Aircraft structural parts which can be checked by ultrasonic methods include large forgings, wheels, engine bearers, axles etc. Before these parts are installed in aircraft, or at times when they are removed during overhaul, the immersion method of testing will often give good results. Large tanks and automatic testing equipment are not necessary for examining parts of manageable proportions; such parts can be submerged in water in a convenient container, the probe being mounted in a fixture to ensure that the required beam angle is maintained. However, certain parts, such as wheels, lend themselves to automated methods and some aircraft operators have found these to be worthwhile; their use also permits an electronic record of each inspection to be kept. The essential requirement for any test is a standard of reference and this may be provided by using an identical part of known condition as a specimen. As a check on sensitivity, defects can be introduced in the reference specimen, by drilling small holes or by spark erosion, at positions where defects are likely to occur. Reflections introduced by these artificial defects can be compared with the traces obtained from a part under test.

6.2 The chief value of ultrasonic examination in situ, is that defects, and in some individual cases corrosion, can be found in areas not accessible for visual examination. Provided that one smooth surface is accessible to the ultrasonic probe, most forgings, castings and extrusions can be satisfactorily inspected. On some aircraft, spar booms and some similar structural members require periodic examination for fatigue cracks, but the areas of suspected weakness may not be accessible for examination by visual or dye-penetrant methods. Ultrasonic testing gives quick results on those defects which lend themselves to this form of testing, i.e., the defect is normal to the directed beam. In this instance radiographic techniques would be quite unsuitable.

6.3 When carrying out ultrasonic tests in situ, the surface to be scanned by the probe should be thoroughly cleaned and covered with oil or grease to provide good acoustic contact. If parts are removed for testing, then water may be used as a couplant, but the parts should be thoroughly dried before being put into storage or service.

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28*th June*, 1971.

BASIC
NON-DESTRUCTIVE EXAMINATIONS
RADIOLOGICAL EXAMINATION OF AIRCRAFT STRUCTURES

1 INTRODUCTION This Leaflet gives guidance on the operation of radiological testing apparatus and the establishment of satisfactory inspection techniques.

1.1 The use of radiography in accordance with an approved technique will often facilitate the inspection of structures during manufacture, overhaul and maintenance, and can be used for the examination of structures which would otherwise be inaccessible. A number of airframe and engine manufacturers, and aircraft operators, have devised techniques for particular inspections, and these are written into the appropriate Maintenance Manuals and Maintenance Schedules or included in a separate Non-destructive Testing (N.D.T.) Manual. General information on radiographic techniques is included in British Standard (BS) M34.

1.2 Radiographic methods may also be used to advantage where normal physical methods of measurement are difficult or impractical. It has been shown, for example, that it is extremely difficult to detect eccentricity in items with long bored or counterbored holes and that wall thickness in these cases can be accurately determined by means of a radiograph. Where this type of measurement is considered necessary the appropriate technique should be quoted on drawings or inspection instructions.

1.3 Radiography should be considered as an extension to efficient inspection and is sometimes of value in providing a second opinion where inconclusive results have been obtained by other methods. It should not be regarded as a foolproof method of inspection without considered trials and its indiscriminate use would be both uneconomical and misleading.

1.4 The misuse of radiographic equipment could result in the release of physically harmful radiations and it is therefore extremely important that operators should be properly trained and aware of the regulations concerned with safety. The provision of adequate protection is not dealt with in this Leaflet; it is emphasised however, that the operating procedures and conditions set out in 'The Radioactive Substances Act (1960)' and the 'Ionising Radiations (Sealed Sources) Regulations No. 808 (1969)' must be observed at all times when radiography is used for aircraft inspection.

1.5 The importance of proper training is also evident in the interpretation of radiographs. Incorrect conclusions could result in the clearance of unsafe structures or components or, conversely, the scrapping of expensive items which are really sound.

2 SOURCES OF RADIATION There are two forms of electro-magnetic radiations which can be used in radiography, namely X-ray and gamma rays. The main difference between the two is in the method of propagation. The radiations are of very short wavelength (0.001 Å to 2Å) and are capable of penetrating solids, the rays passing through a specimen being used to expose a sensitised film. X-rays also cause the fluorescence of certain chemicals and this reaction is sometimes used to produce an image on a phosphor screen; this technique is known as fluoroscopy.

2.1 **X-Rays.** This particular form of electro-magnetic radiation is produced when electrons, travelling at high speed, collide with matter in any form.

2.1.1 The basic requirements for the production of X-rays are a source of electrons, a means of accelerating the electrons to high speed and a target to emit the X-rays. A typical circuit of an X-ray set is shown in Figure 1. The X-ray tube is an evacuated chamber in which the electrons are derived from a filament, set in a focussing cup and heated to incandescence by a low voltage current; electrons are released and form a 'space charge' around the filament. When a high potential is applied, electrons accelerate from the filament (the cathode) to the anode and strike the target, which then emits X-rays.

2.1.2 Only approximately 1% of the electron energy is converted into X-rays the rest being changed into heat and light. For this reason the anode consists of a substantial block of copper, in which the target is set, and is often cooled by the circulation of liquid. The target is made from tungsten to resist the high temperatures produced by the electrons at the focal spot.

2.1.3 X-rays are emitted in all directions from the target but the tube is normally shielded so that a beam is emitted in the shape of a 40° cone. However, some X-ray tubes are designed to emit different shaped beams for particular uses.

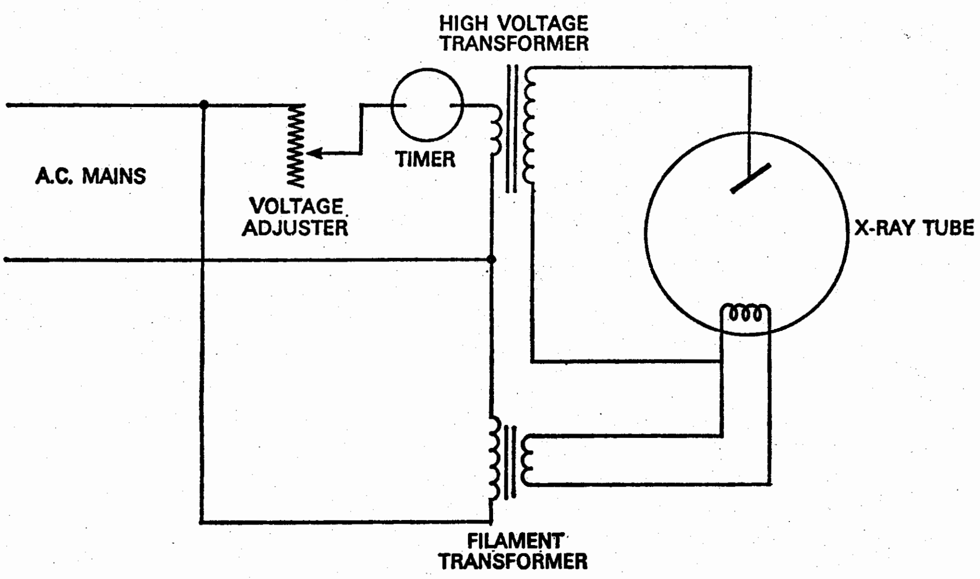


Figure 1 TYPICAL CIRCUIT OF AN X-RAY SET

2.1.4 The electrical supply to an X-ray tube is normally from the a.c. mains through a transformer and, since electrons can only flow from the cathode to the anode, a pulsed tube current results. Some X-ray sets use complex electrical circuits to produce a constant potential in the tube, but they are generally very expensive and unsuitable for the type of portable equipment which is generally used on aircraft. The wavelength of the X-rays is inversely proportional to the voltage applied and the X-rays produced will vary in wavelength down to a minimum value determined by the peak voltage. This is known as a 'continuous spectrum' and is a characteristic of all X-ray tubes. The penetrating power of X-rays increases as the wavelength decreases and high voltages are therefore used when radiographs of dense materials, such as steel, are required.

2.1.5 **Penetrating Power.** Although penetrating power is related to the voltage of the X-ray tube, it is often indicated by the 'half value layer' (H.V.L.) of the beam. This represents the thickness of a given material (usually aluminium or copper) which will reduce the intensity of the beam to half its original value. This method is not completely accurate however, since the longer wavelengths, being less penetrating, are removed first and the quality of the beam is changed. If additional filtration (i.e. thicker aluminium or copper sheets) is provided it will be seen that the H.V.L. increases progressively until a constant beam quality is obtained.

2.1.6 **Types of Equipment.** X-ray equipment is normally graded according to the voltage range over which it is designed to operate. The portable sets used in aircraft work normally cover voltages between 10kV and 250kV, but no single set will cover this whole range. Tubes designed for high voltages possess inherent filtration properties, which, combined with space charge effects, will preclude the emission of an effective X-ray beam at low voltages. Typical ranges covered by portable sets are 10kV to 100kV and 100kV to 250kV.

2.2 **Gamma Rays.** Electromagnetic radiations resulting from the disintegration of radioactive materials are known as gamma rays. The isotopes now used in radiography are artificially produced and emit rays of similar wavelength to those produced in X-ray tubes. Gamma radiation is not in the same form as X-rays however, and consists of one or more discrete wavelengths in what is known as a 'line spectrum'. The relative intensities of each wavelength are always the same for a particular material. The four most commonly used isotopes are Cobalt 60, Iridium 192, Caesium 137 and Thulium 170.

2.2.1 **Radioactive Decay.** Radioactive elements, whether natural or artificial, are subject to a specific rate of decay i.e. a reduction in strength of the radioactivity. This decay is measured in terms of the time over which half the original activity is lost and is called the 'half life' of the material. The half life of radioactive materials varies considerably, for example, Aluminium 28 has a half life of 2·27 minutes whereas Uranium 238 has a half life of 4·5 x 10^9 years. Radioactive materials can be used for radiography through several half life periods provided that an adequate working strength remains, and some are capable of re-irradiation in an atomic pile.

2.2.2 **Penetrating Power.** It is customary to express the penetrating power of gamma rays in terms of the voltage which would be required to generate X-rays of similar penetrating power. The unit used, the mega electron volt (MeV), represents the energy required to accelerate an electron through 1 000 000 volts. The energy emitted by Caesium 137 is 0·66 MeV and this is equivalent in penetrating power to the X-rays generated at 660kV by an X-ray set. Due to the differences in the radiation spectra of the two sources, however, gamma ray sources, which do not generally emit the longer wavelengths, have a mean penetrating power somewhat higher than X-rays.

2.2.3 **Gamma Ray Sources.** Radiographic gamma ray sources consist of a circular disc or cylinder of radioactive material encased in a sealed aluminium or stainless steel capsule. The capsule is kept in a container which acts as a storage safe and may also be used as a support during exposure. The container is made of a material, such as lead or depleted (non-radioactive) uranium, which will substantially reduce the emission of gamma trays. High intensity sources are kept in bulky, heavily shielded containers, exposure being achieved by positioning the source opposite a restricting aperture in the container. Some users employ an exposure head connected to the container by guide tubes, the isotope being positioned and controlled by a remote control device. Since gamma rays cannot be turned off, strict regulations have been devised to safeguard both operators and general public during the transportation and use of radioactive sources.

3 PHOTOGRAPHIC ASPECTS

3.1 **X-ray Film.** The films used in radiography are very similar to those used in photography except that the emulsion covers both sides of the flexible transparent base. The emulsion is sensitive to X-rays, gamma rays and light, and when exposed to those radiations a change takes place in its physical structure. When treated with a developer, a chemical reaction results in the formation of black metallic silver; it is this silver which, comprises the image. Handling of the undeveloped film is normally carried out in a 'dark room' which is illuminated by subdued yellow light.

3.1.1 Film is supplied in two classes, depending on whether flurorescent intensifying screens are to be used or not. Within these classes, film is available in a wide range of speeds and grain sizes.

3.1.2 Where the high clarity of a normal film is unnecessary, for instance when searching for debris or checking for correct assembly of a component, certain types of photographic paper can be used, with a consequent saving in cost.

3.1.3 Film is normally prepared for exposure by placing in a casette, which may be either rigid or flexible, or in a light-proof envelope. For many applications film is also prepared in roll form, an example of which would be the film used for taking radiographs of a complete fuselage former. An X-ray tube which emits a 360° beam is located in the centre of the fuselage, and a roll of film placed to encircle the fuselage.

3.2 **Intensifying Screens.** It is sometimes necessary to take a radiograph of a thick or dense material, necessitating a very long exposure time. This time may be reduced by converting the energy of the X-rays or gamma rays into another form of energy to which the film emulsion is more sensitive.

3.2.1 Phosphor coated screens (known as 'salt' screens) will fluoresce in the presence of X-rays and, if in contact with the X-ray film, will supplement the image formed by X-rays during exposure. The disadvantage of this arrangement is that the screen imparts a grainy appearance to the film and detracts from image sharpness. 'Screen' type film must be used in conjunction with fluorescent intensifying screens.

3.2.2 Metal foil screens are usually made of lead and assist the normal X-ray exposure by producing photo-electrons in the presence of X-rays. This intensifying effect is only evident at potentials above 120kV, but since the lead screens also reduce scattered radiation and are not granular in construction, they are always used in radiography carried out at energies above this value.

3.2.3 It is essential that both types of screen are held in close contact with the film (on both sides), as any gap will result in a spread of light (or photo-electrons) and produce a blurred or fogged image. Absolute cleanliness of the screen is also essential, since any dust or grease between the film and screen will be reproduced on the radiograph.

3.3 **Sensitivity.** The darkness of a radiograph depends on the quantity of radiation penetrating the specimen; the thicker the specimen, the lighter will be the image. Defects such as a crack or gas hole will show up as dark areas on the radiograph, since they will give less resistance to the rays. However, the ability to recognise a defect will depend on its size and the quality of the radiograph. The sensitivity of the radiograph is normally measured by an image quality indicator (I.Q.I.), also known as a penetrameter (Figure 2), but this should not be used as a means of calculating the smallest size of defect which may be detected. The shape of the defect and the plane in which it lies are most important; if a crack runs in a plane normal to the X-ray beam it will probably not be detected, and this must be taken into account when establishing a technique for a particular inspection.

3.3.1 Ideally I.Q.Is should be made of the same material as the radiographic subject, but in practice mild steel is suitable for all steel specimens, pure aluminium is suitable for all aluminium alloys and copper is suitable for most bronzes and brasses. The I.Q.I. should be placed on the upper surfaces of the area undergoing radiography, i.e. nearest to the beam source, so that it will appear on the radiograph. The thickness of the last detectable step (or wire) should be ascertained and expressed as a percentage of the specimen thickness.

3.3.2 It will be appreciated that the difference in the sizes of the steps or wires in the I.Q.Is shown in Figure 2 must be very small for use with aircraft structures. In fact, although the use of I.Q.Is is essential with thick specimens, the very nature of aircraft structures, comprising skins, ribs, stringers, paint, sealant, etc., is an adequate form of I.Q.I. for most radiographic needs.

3.3.3 The step-wedge I.Q.I. (Figure 2(a)), consists of a number of steps ranging in thickness from 0·005 in to 0·1 in or greater as required. Each step contains a number of holes, varying in size according to the step thickness, and these are used both for identification of the step and as an indication of image sharpness.

3.3.4 The wire I.Q.I. (Figure 2(b)), consists of a series of short lengths of wire in graduated diameters, embedded in thin rubber or plastic sheet. This type of I.Q.I. is sensitive to both sharpness and contrast, particularly in the smaller sizes.

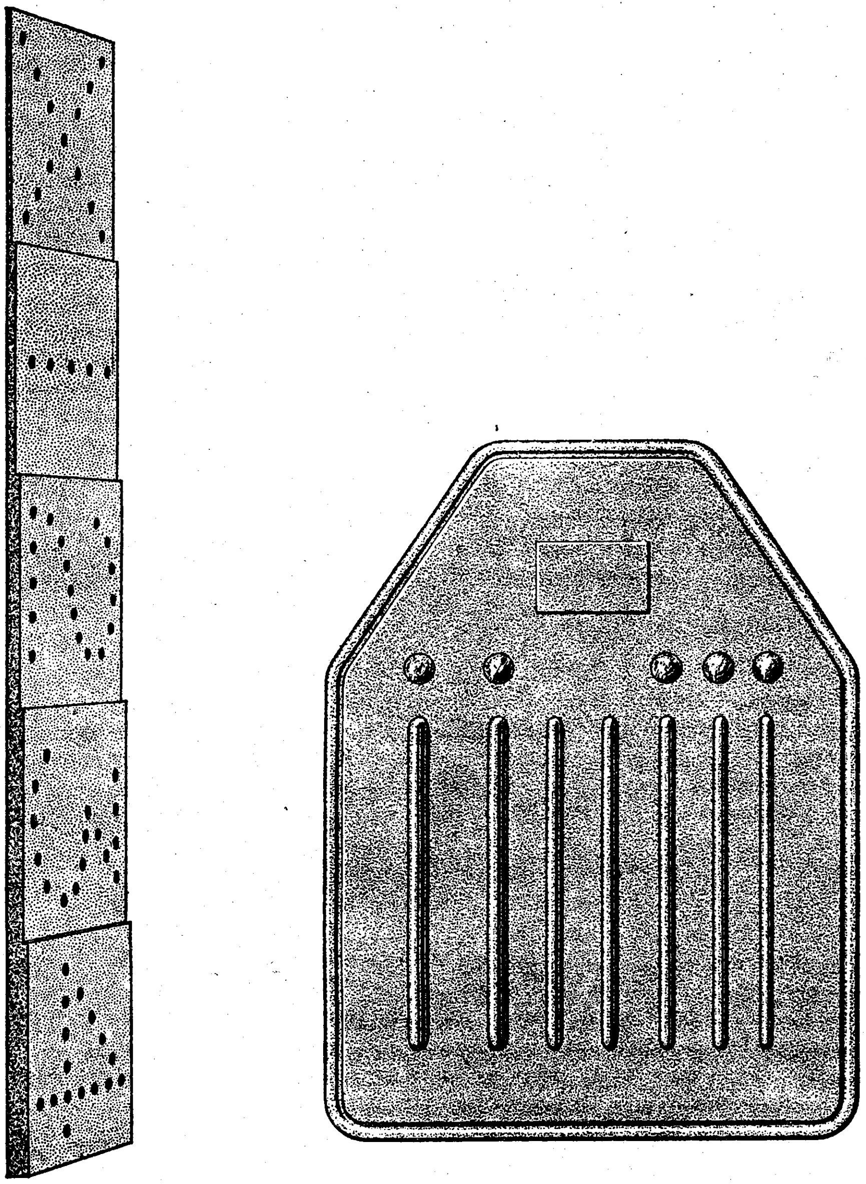
3.3.5 Variations of the standard I.Q.I. are sometimes used for special purposes, e.g., when searching for fatigue cracks an I.Q.I. containing a typical defect could be used (Figure 3). The I.Q.I. is placed on the surface of the member being examined and, provided that the simulated defect is clearly visible on the radiograph, it can be assumed that any other crack of similar size and orientation would also be visible.

3.4 **Geometric Considerations.** The sharpness of a radiographic image is influenced by the film characteristics and by geometric effects, which, since they are to a large extent under the control of the radiographer, are very important. The factors involved are the size of the radiation source, the distance between the source and the film, and the distance between the specimen and the film; these factors are illustrated in Figure 4.

3.4.1 It is generally accepted that a radiographic image viewed by the naked eye will appear to be sharp if the blurring of edges does not exceed 0·01 inches. The blurring, or sharpness, is caused by the finite size of the radiation source and this is quoted in the specification for the equipment concerned or can be found by experiment. From Figure 4 it can be seen that the closer the film is to the specimen then the sharper will be the image. However, practical considerations may prevent contact between the film and specimen and in this case acceptable sharpness can only be obtained by increasing the source-to-film distance. Alternatively, better coverage of a large or irregularly shaped part may be achieved by taking several radiographs from different angles, thus keeping the object-to-film distance to a minimum.

3.5 **Exposure Conditions.** The quantity of radiation affecting an area of specified size varies inversely as the square of the distance from the source; if the source-to-film distance is increased the exposure time must be increased accordingly. The ideal situation would obtain where the cone of radiation just covered the film area.

3.5.1 The required exposure conditions could be obtained by the use of exposure charts and calculations dependent on film characteristics. However, since a number of variables exist, it is more usual to establish a technique from knowledge of the structure involved, study of the aircraft manufacturing drawings and systematic trial and error methods. Once the geometric considerations have been determined a series of radiographs is usually taken, systematically varying the voltage, exposure time and, occasionally, the tube current or type of film, until an acceptable radiograph is produced; a double film technique is often used to reduce the number of exposures required. The lowest useable kilovoltage gives the highest contrast thus making recorded defects more distinct.



(a) STEP WEDGE TYPE

(b)WIRE TYPE

Figure 2 STANDARD IMAGE QUALITY INDICATORS

3.6 **Filtration.** When a beam of radiation passes through a material, some passes directly through (the primary radiation) and some is scattered by collision with the atoms making up the material (the scattered radiation). The primary radiation is the true image forming energy, but the scattered radiation results in a fogging effect on the film, reducing contrast and impairing definition. While scattered radiation is always present, its effects can be reduced by the use of metallic screens, masks or backing.

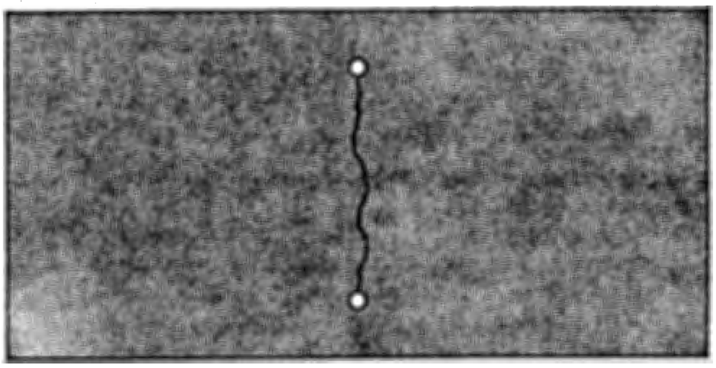
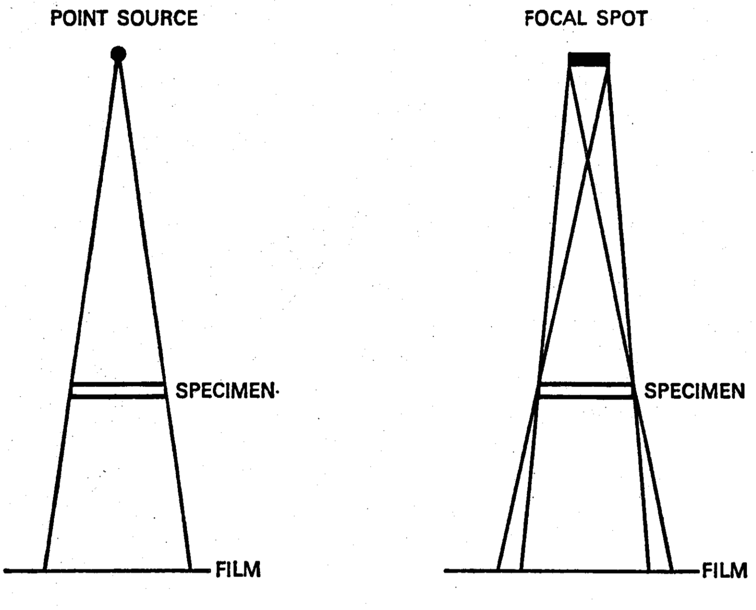


Figure 3 I.Q.I. SIMULATING A DEFECT



(a) SHARP EDGE

(b) BLURRED EDGE

Figure 4 GEOMETRIC UNSHARPNESS

3.6.1 **Primary Beam Filtration.** X-rays consist of a wide band of wavelengths, the shorter of which are the image forming radiations. The longer wavelengths have little penetrating power but are a significant source of scattered radiation, and can normally be eliminated from the X-ray beam by placing a metal filter close to the X-ray source. The thickness of the filter is important since it affects the total material to be penetrated, and it is usually found by experiment; a copper filter 0·1 mm thick would normally be used with a 100kV to 200kV set.

3.6.2 **Scatter Within the Specimen.** Some scattered radiation is generated within the specimen, particularly when it consists of a box-like structure, or dense material. This may be reduced by placing a filter, similar to that used for the primary beam, immediately above the film. Particular care is necessary to ensure that this filter is clean, since any dirt will show up on the radiograph. In the case of light alloy structures a limitation of 2 minutes exposure time will usually eliminate such scatter.

3.6.3 **Masks and Backing.** Scattered radiation can be produced from any point within the area of coverage of the radiation beam and will, therefore, be produced by structure situated beside or behind the film. This radiation is reduced by placing lead sheets adjacent to the film and specimen, immediately at the back of the film, and, in permanent radiographic rooms, by covering the floor and table with lead. With irregularly shaped specimens an opaque paste mask is sometimes used.

4 RADIOGRAPHIC TECHNIQUES The establishment of completely reliable techniques of examination is essential if confidence is to be placed in the resulting radiographs. It may be necessary to prove their effectiveness initially by dismantling the particular structure to ensure that no defects exist which have not been revealed in the radiographs, and to determine that the radiographs have been correctly interpreted.

4.1 The factors outlined in paragraph 3 should be taken into account in evolving a satisfactory radiographic technique, and a record should be kept of the conditions under which the technique was established. A typical Radiographic Technique sheet, as recommended in British Standard M34, is reproduced in Figure 5. This sheet should be given a number for identification purposes and should also include, in the 'Notes' section, such details as items which must be removed (including fuel from the fuel tanks, radiation sensitive items, sealant or paint, etc.), any jacking or trestling necessary and measurements from which the film, X-ray set or isotope may be positioned. A simple isometric drawing may also assist identification of an area under examination and the inclusion of photographs or drawings showing potentially defective items should also be considered.

4.2 It may often be necessary to penetrate a widely varying range of thicknesses and, if only a single radiograph is taken, this may result in the appearance of greatly contrasting light and dark areas, making accurate interpretation almost impossible. In such circumstances the simultaneous exposure of two or three films without intervening wrapping in a common cassette or envelope may be employed; if the films and exposure time are carefully selected, each different thickness will be shown at a suitable density on one of the radiographs. The use of a lead screen separating two films is sometimes useful in achieving satisfactory radiographs of different material thicknesses and also gives greater flexibility in the selection of a film pack.

5 GAMMA RAYS IN AIRCRAFT RADIOLOGY In general it may be considered that the majority of radiographs of aircraft structures are taken with an X-ray set. This is due to the unsharpness and lack of contrast normally obtained with gamma sources and the gradual decrease in radiated energy. However, there are occasions when a gamma source is used, mainly due to lack of space or access for X-ray equipment.

5.1 **Application.** By the use of guide tubes or handling rods attached to containers, it is often possible to place isotopes in positions which would be completely inaccessible to X-ray equipment. An example of this is where an internal portion of a structure is to be examined, there being no means of access for the X-ray equipment and the complexity of the structure precluding the taking of X-ray pictures from the outside. Provided it is possible to place the film in position, the isotope can be inserted through a convenient aperture and a direct radiograph of the particular area may be obtained.

(Company name and address)

Set used:
Type of radiation:
Source size:

RADIOGRAPHIC TECHNIQUE SHEET

Sheet .... of .... sheets

Technique sheet No.

Description

Part No.

Film processing:

Preparation:

Purpose of inspection:
Area to be inspected:
Acceptance standard:

Material and specification

Associated documents:
BS M.34

Prepared by:

Date:

Approved by:

Date:

Exposure details						Filters		Screens	*Ug*	Film	Size and pattern	Radiograph No.	Figure reference
Aspect or position	Angle of beam to film	s.f.d.	kV	mA	Time	on tube	on film						

NOTES:

Figure 5 TYPICAL RADIOGRAPHIC TECHNIQUE SHEET

5.2 Isotopes are also often used for the examination of internal features of turbine engines, such as the main rotor shaft, and provision of access points is sometimes included in the engine design.

5.3 **Isotopes.** The types of isotope used will be determined by the thickness of the subject, the source-to-film distance and the source output in terms of exposure time.

6 FLUOROSCOPY The luminescent property of phosphors enables them to transform X-rays into visible light. The effect is most pronounced with low energy X-rays, normal gamma ray sources are therefore unsuitable, being of too short a wavelength.

6.1 X-rays are passed through the specimen and impinge on a phosphor coated screen which emits light in proportion to the intensity of the X-radiations falling on it. A positive image is formed on the screen, showing internal details of the specimen in a similar manner to a radiograph.

6.2 Viewing cabinets are so constructed that the observer is protected from harmful radiations. Where low energy radiations are used the phosphor screen is viewed directly through a lead glass window but when high energy X-rays are necessary it is usual for an angled mirror to be interposed so that the screen is viewed at an angle to the primary X-ray beam.

6.3 Due to the coarse grain of the phosphor screen and the poor geometric sharpness resulting from the need to place the screen close to the X-ray source, fluoroscopic images are greatly inferior to those produced by radiographs; for this reason fluoroscopy is seldom used in aircraft work. However, one big advantage of fluoroscopy is that there is no film to be developed and the method is suitable for checking the correct assembly of components or inspecting for debris in aircraft. In general engineering fluoroscopy is also used in conjunction with image intensifiers, for the examination of welded tube and and other simple structures.

7 VIEWING CONDITIONS In order to recognise all the indications available on a good radiograph, it is essential that suitable viewing conditions are provided.

7.1 Ideally, radiographs should be examined in a room set aside for this purpose and situated away from distracting conditions such as a high noise level. The room should be capable of being darkened but, during viewing, should have a low intensity background light which does not reflect on the film.

7.2 The viewing of radiographs requires a good deal of concentration. It is recommended that continuous viewing periods should not exceed 90 minutes and should be followed by a period of at least 30 minutes doing associated work away from the viewing area.

7.3 The radiograph itself should be placed on a special viewing box where it can be illuminated from the back, preferably by diffused lighting. Any light appearing round the edge of the radiograph should be masked off since it would tend to dazzle the viewer, possibly resulting in fine defects in the denser parts of the radiograph being overlooked. Controllable shutters are usually provide on the viewing box for this purpose. In addition, the masking of light areas of the radiograph while viewing dark areas will increase the apparent contrast of the image. Where the radiograph has areas of widely differing density the provision of a dimming control may assist the viewing of very light areas.

7.4 In some instances it may be advisable to make use of a magnifying glass for the examination of fine detail, but a glass with high magnification should not be used.

8 INTERPRETATION OF RADIOGRAPHS The accurate interpretation of the defects indicated on a radiograph is a matter which requires considerable skill and experience and, if the maximum benefits are to be obtained from radiography it is essential that the viewer should have an intimate knowledge of the aircraft structure. Without such knowledge it would be possible to overlook faults which would be obvious to an engineer, e.g. distorted or missing parts. Interpretation of radiographs can be considerably simplified if radiographs of a sound structure are available as standards, for comparison with radiographs on which defects are recorded. For simple structures on isometric drawing of the area might be suitable. Some of the indications obtained on radiographs are described in the following paragraphs.

8.1 **Castings and Welds.** Metallurgical defects in castings and welds generally produce characteristic patterns which may be recognised by an experienced viewer. Porosity, for example, will reduce the amount of material through which the X-rays or gamma rays must pass and result in dark spots in the film, whereas segregated constituents of alloys, or inclusions, may be light or dark, depending on their relative density.

8.1.1 Cracks in welds may be difficult to detect and knowledge of the defects associated with the particular type of weld is essential. The angle at which the radiograph is taken is of particular importance, since defects in a plane normal to the radiation beam would not result in any significant change of density in the emulsion. Surface blemishes produced by welding are recorded on the radiograph and produce a complex image liable to misinterpretation.

8.2 **Corrosion.** The detection of corrosion is invariably difficult, the difficulties often being aggravated by the presence of paint, jointing compound and surfaces fouling which, by their radiographic density, may compensate for the deficiency of material caused by corrosion or give rise to a suspicion of corrosion which does not exist. However, corrosion normally has an irregular and possibly 'fuzzy' outline, while compounds will usually have a regular and sharply defined one. Intergranular corrosion may not be detectable by radiography until it has reached an advanced state and affects the metal surface.

8.2.1 Under laboratory conditions, where scattered radiation can be effectively reduced and ideal exposure conditions obtained, it is possible to detect very small cavities. However, when radiographs of an aircraft structure are being taken, ideal conditions will not normally exist and the size of detectable cavities may be much larger. For example, fuel tank sealant is particularly dense, and it is doubtful if pitting less than 10 to 15 per cent of the total thickness, including the sealant, would be revealed.

8.2.2 A corrosion pit giving rise to a sudden change of thickness in a given specimen is more readily visible on a radiograph than a pit of the same depth in the form of a saucer-shaped depression. This is due to the fact that a sudden change in the density level on the radiograph is more easily seen than a gradual merging of two areas of different density.

8.2.3 A further difficulty in the detection of corrosion is that the corrosion products often adhere to the surface and the difference in density might be so slight as to be undetectable. In some instances the build up of corrosion products can be detected when the radiograph is taken at an oblique angle to the surface of the metal.

8.2.4 In aircraft structures, stress corrosion often has a characteristic appearance, showing up as lines of spots on the radiograph. With experience this condition can be identified from similar indications caused by debris or poor developing.

8.2.5 Corrosion can sometimes be detected where successive radiographs, taken over a period of time by an identical technique in each instance, reveal a gradual change in density in a particular area.

8.3 **Cracks.** There is a tendency to regard cracks as straight gaps perpendicular to the working surface, but this is not invariably so. Unless appropriate techniques have been used in taking the radiographs, it is possible for fairly large 'dog-leg' cracks particularly in the thicker sections, to remain undetected.

8.3.1 Stress cracks around rivets in aircraft structures often have a characteristic appearance, running along a line of rivets in a series of arcs. In certain circumstances the edge of the jointing compound used during wet assembly of rivets can give the appearance of hair line cracks of this type, but masking down to a very small area will reveal the true nature of the indication.

8.3.2 When cracks are being sought on the tension side of a wing it is sometimes possible to open up the cracks by applying a tension load, normally by jacking. This will result in a more positive indication on the radiograph.

8.3.3 While cracks will normally appear as a darker line on the radiograph, instances may occur when a lighter line is present. This may result from a part, such as a stringer, being cracked right across and overlapping at the point of fracture, thus presenting a thicker section for the rays to penetrate.

8.3.4 Many radiographs of structure bear evidence of what appears to be structural cracking but, when such areas are examined physically, the cracks have been found not in the structure but in the sealing or jointing compound used in the area. Such conditions may occur inside integral fuel tanks, but with experience it is possible to distinguish between the two types of cracks by reason of their distinctive shape. Some sealants are very opaque to X-rays and may completely hide a defect.

8.4 **Leaded Fuel.** It is often necessary to take radiographs where the primary beam of radiation passes through a fuel tank (e.g. the lower surface of a wing containing integral fuel tanks). Since lead offers considerable resistance to the penetration of X-rays and gamma rays, the presence of even the small percentage of lead contained in most aviation gasolines will restrict the quantity of radiation reaching the film. It is imperative, therefore, that the fuel tanks should be completely drained before the film is exposed. Pools of fuel left in the tanks may also give misleading indications on the radiograph. Less difficulty is experienced with kerosene but some scatter does occur and may impair the qualitv of the radiograph.

9 GLOSSARY OF TERMS USED IN RADIOGRAPHY The following terms and abbreviations are used in radiological non-destructive testing and are taken from a complete list contained in British Standard 3683, Part 3.

Ångstrom unit (Å)	Unit of measurement of the wavelength of X-rays and gamma rays. $1Å = 10^{-8}$ cm.
Anode	The positive electrode of an X-ray tube which carries the target from which the X-rays are emitted.
Cathode	The negative electrode of an X-ray tube.
Casette (or cassette)	A light-tight container for holding radiographic film, paper or plates during exposure. Screens may or may not be included.
Contrast	The relative brightness of two adjacent areas on an illuminated radiograph.
Definition	The sharpness of image details on a radiograph.
Density	The degree of blackening of a radiograph.

Focus-to-film distance (f.f.d.)	The distance from the focal spot of an X-ray tube to a film set up for exposure.
Gamma (γ) rays	Electromagnetic radiation emitted by radioactive substances during their spontaneous disintegration.
Grain size	The average size of the silver halide particles in a photographic emulsion.
Image Intensifier	A device used to give a brighter image than that produced by X-rays alone upon a fluorescent screen.
Isotopes	Atoms of a particular element which have the same chemical properties and atomic number, but a different mass number from those normally present in the element.
Penumbra (Ug)	Blurring at the edges of a radiographic image due to the radiation source being of finite dimensions.
Quality	The penetrating power of a beam of radiation.
Radiograph	The photographic image produced by a beam of radiation after passing through a material.
Resolution	The smallest distance between recognisable images on a film or screen.
Source-to-film distance (s.f.d.)	The distance from the source of primary radiation to a film set up for exposure (i.e., f.f.d. related to gamma source).
Tube current	The current passing between the cathode and the anode during the operation of an X-ray tube.
Tube head	A type of X-ray shield which, in addition to the X-ray tube, may contain part of the high voltage generator.
Unsharpness	Image blurring caused by the penumbra, by movement, by grain size, or by light, electron or X-ray scatter.
X-rays	Electromagnetic radiation resulting from the loss of energy of charged particles (i.e. electrons).

BL/8-5

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11*th June*, 1974.

BASIC

NON-DESTRUCTIVE EXAMINATIONS

MAGNETIC FLAW DETECTION

1 INTRODUCTION This Leaflet gives guidance on the detection of surface and sub-surface defects in ferro-magnetic materials by magnetic processes. The procedures recommended in this Leaflet are complementary to British Standard (BS) M35, and should not be taken as overriding the techniques of examination prescribed by the manufacturer of a particular component, either in drawings or in approved manuals.

1.1 Magnetic flaw detection tests are applied to many steel parts at the manufacturing, fabrication and final inspection stages. The process is normally applied to all Class 1 aircraft parts manufactured from ferro-magnetic materials, and to any other parts where the designer or inspection authority considers it to be necessary.

NOTE: A Class 1 part is defined as a part, the failure of which, in flight or ground manoeuvres, would be likely to cause catastrophic structural collapse, loss of control, power unit failure, injury to occupants, unintentional operation of, or inability to operate, essential services or equipment.

1.2 The methods of magnetising in general use are the magnetic flow and the current flow processes, which are described in paragraph 3. By choosing the most suitable process, or combination of processes, for a particular component, both surface and subcutaneous defects may be revealed.

1.3 Great care must be taken when establishing a technique of examination suitable for a particular component, in order to ensure that consistent results are obtained. Operators of magnetic flaw detection equipment should be thoroughly trained in its use, and experienced in interpreting technique requirements and the indications obtained from a test.

2 THE PRINCIPLE OF MAGNETIC FLAW DETECTION If a component is subjected to a magnetic flux, any discontinuity in the material will distort the magnetic field and cause local leakage fields at the surface. Particles of magnetic material applied to the surface of the magnetised component will be attracted to the flux leakage areas and reveal the presence of the discontinuity.

2.1 The sensitivity of magnetic flaw detection depends largely on the orientation of the defect in relation to the magnetic flux, and is highest when the defect is at 90° to the flux path. Sensitivity is considerably reduced when the angle between the defect and the flux path is less than 45°, so that two tests are normally required with each component, the flux path in the first test being at 90° to the flux path in the second test. Components of complex shape may require tests in several different directions.

2.2 A component may be magnetised either by passing a current through it, or by placing it in the magnetic circuit of a permanent magnet or electromagnet. The required strength of the applied magnetic field varies considerably, and depends largely on the size and shape of the component and on the magnetic characteristics of the material from which it is made.

2.3 The magnetic particles used to reveal defects are either in the form of a dry powder, or suspended in a suitable liquid. They may be applied by spray, pouring, or immersion, depending on the type of component. Magnetic flaw detection 'inks' complying with BS 4069 are used in aircraft work, and consist of finely divided black or red magnetic oxides of low coercivity (i.e. they will not retain the magnetism induced during testing), suspended in a liquid (normally kerosene). Pigments may be added to provide a contrast with the surface of the specimen. Black inks are suitable for use on bright, machined components, but red inks may be more suitable for unmachined parts or, alternatively, a thin coat of white paint or strippable lacquer may be added to the component before carrying out the test.

2.3.1 If magnetic inks are left standing for long periods the solid particles settle at the bottom of the container and form a sediment which may be difficult to redisperse. If the machine does not have pump agitation, frequent manual agitation must be provided during tests to ensure satisfactory inking of the specimens. The solids concentration in inks manufactured to BS 4069 should be 0·8 to 3·2% by volume, but with fluorescent inks the solids content is approximately one tenth of these values. Methods of determining the solids content of magnetic inks are detailed in BS 4069. Magnetic ink should be discarded if it becomes diluted by solvents or contaminated with oil or any foreign substance likely to reduce its effectiveness as a detecting medium.

2.3.2 Fluorescent inks are also widely used and are often specified where high sensitivity is required. Inspection of a component to which fluorescent ink has been applied, should be carried out under black light.

3 METHODS OF MAGNETISATION

3.1 **Current Flow Method.** If an electric current is passed through a conductor, a magnetic flux is induced, both within the conductor and in the surrounding atmosphere, in a series of concentric circles at 90° to the direction of current flow. With steady current the strength of the internal magnetic flux is greatest at the surface of the conductor and decreases uniformly to zero at the centre, but with alternating current both the current and magnetic flux are confined to a thin layer at the surface, because of the effects of induction. Magnetisation at the surface can be greater with alternating current than with direct current, but direct current has the advantage of greater depth of penetration. In practice, machines are often designed so that alternating or rectified current can be applied to a specimen, to make use of the advantages of each method.

3.1.1 Current flow machines normally provide a sustained current through the specimen, ink being applied while current flows. The specimen is usually clamped between contact pads on a static machine, but portable units are available in which the contacts take the form of hand-held prods, and these are often used for checking components which are difficult to mount in a static machine. Good electrical contact is essential, and the contacts are usually provided with copper gauze pads, sufficient pressure being used to prevent arcing between the pads and the specimens. Because of the dangers of burning and possible subsequent fatigue cracking, the use of prods is often prohibited on finished parts, especially those of high tensile steel.

3.1.2 A variation of current flow magnetisation is the "impulse" method, which employs either direct or alternating current in the form of a short impulse (generally less than one second). Difficulty may be experienced in satisfactorily inking the specimen while current is flowing, and the specimen may be immersed in a bath of magnetic ink. Alternatively, with some materials, remanent magnetism may be sufficiently strong to provide defect indications when ink is applied after current has ceased to flow. The alternating current impulse method is not often used, due to the difficulty of interrupting the current at a point in the hysteresis loop which will leave the specimen adequately magnetised.

3.1.3 For testing purposes it is usual to apply a sufficiently heavy current to give a satisfactory magnetic flux in the specimen, and to use a low voltage to safeguard the operator. As a rough guide to the basic current setting to use, most steels can be satisfactorily tested using an alternating current of 500 A rms per inch diameter or, for specimens of irregular shape, 150 A rms per inch of periphery. Some steels, e.g. nickel-chrome steels, may require a higher magnetising force due to their low permeability. Current values for irregular shaped components should be decided by fixing an artificial defect to the area required, applying ink, and varying current value until a satisfactory indication is obtained.

NOTE: The effective current value with regard to magnetisation is the peak value. Ammeters do not usually record the peak value however, and testing techniques must state whether the current values specified are rms (root mean square) or peak. It is normally assumed that an ammeter reading rms is fitted to an a.c. machine, and an ammeter reading mean current is fitted to a rectified a.c. or constant potential d.c. machine. Current values producing a magnetic flux equivalent to that produced by 500 A rms, a.c., with these types of ammeter fitted, are:—

d.c. — 710 A
half-wave rectified a.c. — 225 A
full-wave rectified a.c. — 450 A

If a peak-reading ammeter is fitted to an a.c. machine, the current value should be the same as for d.c. (i.e. 710 A). In cases where the wave form is unknown, the relationship between peak and average values must be determined empirically, and the current adjusted accordingly.

3.1.4 The passage of a heavy current will have a heating effect on the specimen, particularly when direct current is used. This could cause burning in specimens such as thin tubes, and possibly have an adverse effect on any heat treatment previously applied. The duration of each test should, therefore, be limited to as short a time as possible, consistent with satisfactory inking of the specimen.

3.2 **Induction Methods.** In all induction methods, the magnetic field external to the current-carrying element is used to induce a magnetic flux in the specimen.

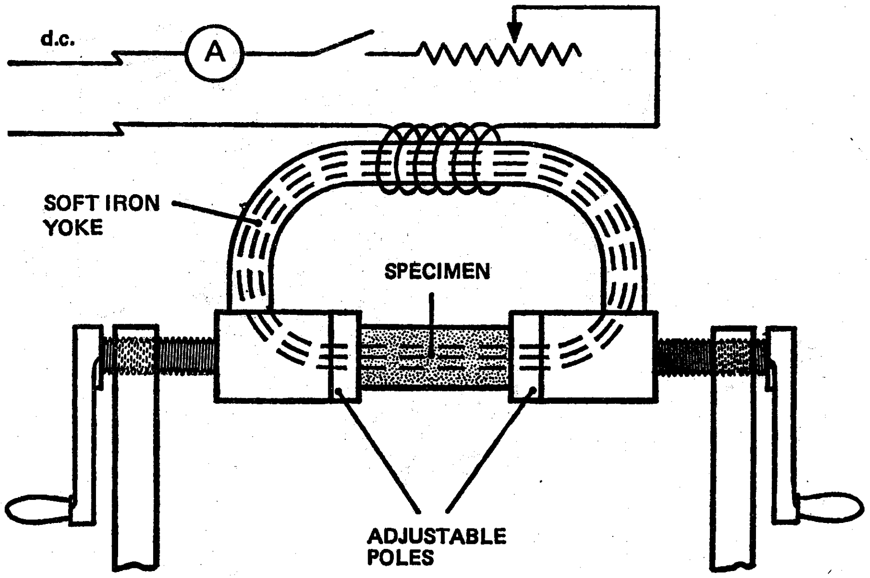

Figure 1 MAGNETIC FLOW MACHINE

3.2.1 **Magnetic Flow Method.** Figure 1 shows the arrangement of a typical magnetic flow machine, the specimen being clamped between adjustable poles in the magnetic circuit of a powerful electromagnet. Good contact between the poles and specimen is essential, otherwise a marked lowering of the field strength will result. Laminated pole pieces are often used to ensure that good contact is maintained with specimens of curved or irregular shape, and in some portable equipments which employ a permanent magnet, contact is obtained through a number of spring-loaded pins.

(i) The magnetising force required to carry out a test using a magnetic flux machine, will depend on the length, cross-section and permeability of the yoke, the number of turns of the windings, and the magnetic characteristics of the test piece. No set current value would be suitable with all machines, and tests should be conducted to ascertain the current value which will ensure magnetisation just below the saturation level. Saturation is indicated by a heavy build-up of magnetic ink at the ends of the specimen, or an overall coating on its surface. In all tests the cross-sectional area of the pole pieces should be greater than that of the specimen, but the maximum cross-sectional area which can be tested will normally be stated in the operating instructions for a particular machine.

(ii) To ensure that the strength of the magnetic flux in a specimen is sufficient to reveal defects during a test, it is common practice to employ portable flux indicators. These may take the form of thin steel discs containing natural cracks, which, when attached to the surface of a specimen during a test, will give an indication of flux strength and also, with some indicators, the flux direction.

(iii) With many machines it is easy to over-magnetise, particularly when carrying out tests on small specimens. If the machine does not have controls for adjusting the energising current, a reduction in magnetic flux can be achieved by inserting non-magnetic material between the pole pieces and the specimen.

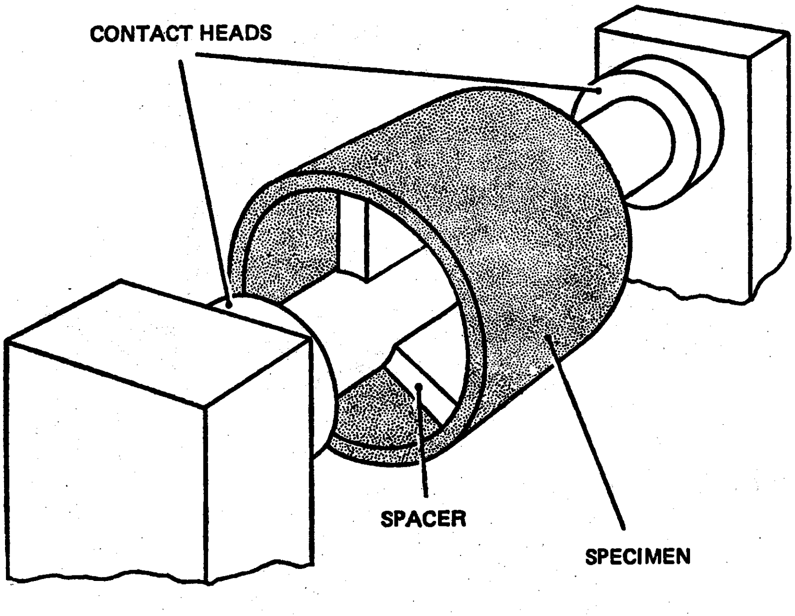

Figure 2 THREADING BAR METHOD

(iv) Magnetic flow machines are generally designed to operate with direct current, the magnetising coil containing a large number of turns of wire and carrying a current of a few amps only. This type of coil would be unsuitable for use with alternating current, since the coil would have too much inductance. If it is required to use alternating current for magnetic flow tests, the coil must be replaced by one having a few turns and carrying a heavy current.

3.2.2 **Threading Bar Method.** This method is used for testing rings and tubes, and is illustrated in Figure 2. A current flow machine is used, and a conductor connected between the contact heads of the machine. Current flowing through the conductor induces a magnetic flux in the specimen at 90° to the direction of current flow; this flux may be used to reveal defects in line with the axis on the specimen. Best results are obtained when the air gap is smallest, i.e. the conductor is only slightly smaller than the internal diameter of the specimen, but a larger air gap is often necessary in order to permit examination of the interior surface.

(i) A symmetrical flux may be obtained in the specimen by inserting non-conducting spacers between the conductor and the specimen, but this is not essential except to prevent burning should the conductor overheat. If the shape of the item undergoing test precludes the use of a straight conductor, a heavy flexible cable may be used.

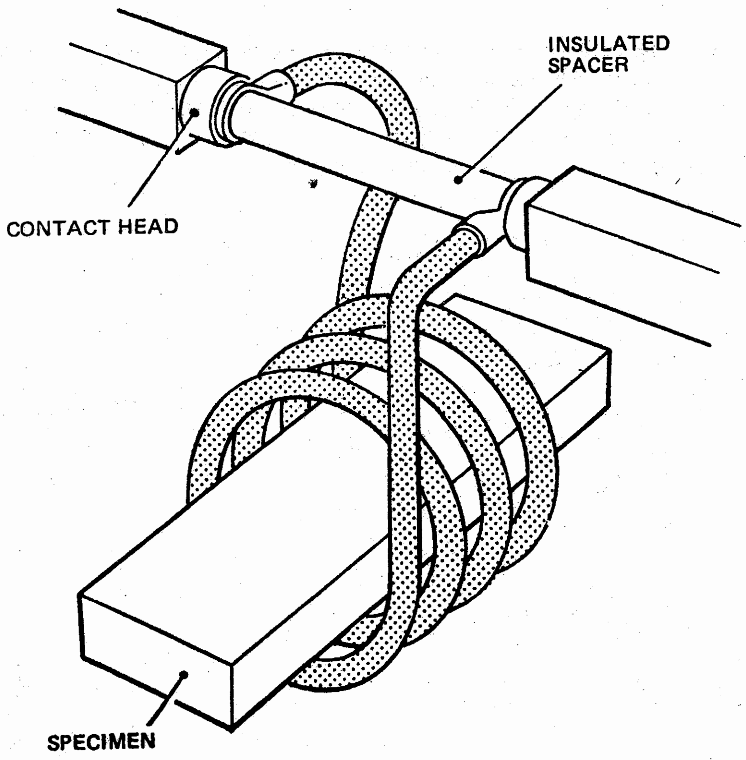

Figure 3 MAGNETISING COIL METHOD

(ii) The basic current setting should be determined from the length of the flux path, i.e. the outside periphery of the specimen, 100 to 200 amps per inch being a satisfactory basic setting for most steel specimens. The current required is unaffected by the length of the specimen, except that if the specimen is very long the resistance of the conductor may limit the available current.

3.2.3 **Magnetising Coil Method.** A current flow machine is also used for the magnetising coil method. An insulated heavy gauge copper wire or strip is connected between the contact heads of the machine as shown in Figure 3, and formed into a coil; a.c. coils have 2½ to 4 turns and d.c. coils 6 to 10 turns, the space between turns being less than the cross-sectional diameter of the wire in order to minimise flux leakage. The magnetic lines of force resulting from passing current through the coil, will induce a magnetic flux in the specimen, in the direction of the coil axis.

(i) Components of simple shape may be placed within the coil during a test, but satisfactory magnetisation will only be obtained within the length of the coil. Difficulty may be experienced with short components, due to the de-magnetising effect resulting from the close proximity of the free poles (i.e. the ends of the specimen), and it is often advisable to complete the magnetic circuit using a yoke manufactured from mild steel, or extend the effective length of the component with end blocks.

(ii) When components of complicated shape are being tested, it is difficult to estimate the strength and direction of the magnetic flux in all parts of the specimen during a single test. It is often preferable to make several tests with the coil located at several positions within or around the specimen, inspecting only those parts adjacent to the coil at each position.

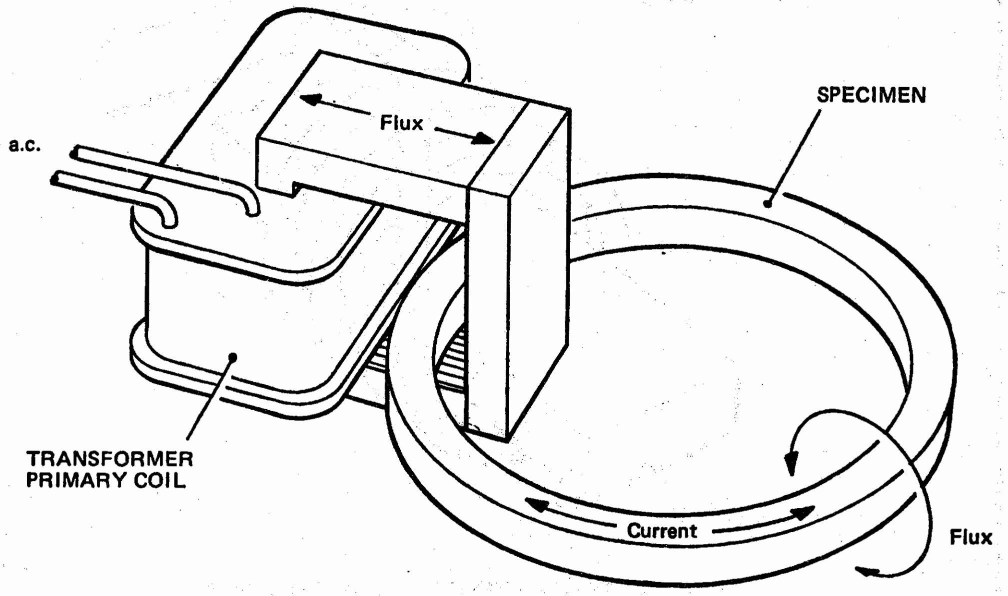

Figure 4 INDUCED CURRENT FLOW METHOD

(iii) As with the magnetic flow method, the current required depends on a number of factors, including the relative diameters of the specimen and coil, and the length/diameter ratio of the specimen. BS M35 gives a formula for calculating the current required under specified conditions, but the most suitable values are generally obtained by experiment, and by selecting a current which gives a field strength just less than that required to saturate the material.

3.2.4 **Induced Current Flow Method.** Figure 4 shows the coil arrangements for this method, in which current is induced to flow through the specimen by the action of the primary coil of a transformer. The induced current itself provides a magnetic field within the specimen, which may be used for detecting defects lying mainly in a longitudinal direction. This method is often used on ring specimens of large diameter.

4 TESTING PROCEDURES Techniques of testing by magnetic methods are established after preliminary tests have shown that defects can be consistently revealed in similar parts to those under test. When carrying out routine tests in accordance with a specified technique, each instruction must be carefully followed in order to obtain satisfactory results. The full test procedure consists of degreasing, magnetising, application of magnetic ink or powder and interpretation of indications, this process being repeated for each test specified on the technique sheet and concluding with final demagnetising and cleaning. The use of a hand lens of low magnification is normally specified for the examination of defects.

4.1 **General Considerations.** Before carrying out a test the equipment should be checked to ensure that it is functioning properly. The technique sheet (see paragraph 5) will usually specify the capacity of the machine required for a test, and stipulate the type of magnetic ink or powder to use. An initial test, using a specimen containing known defects, may be carried out to verify that these defects can be revealed. Alternatively, in the absence of a cracked specimen a test may be carried out using a "portable crack" taped to the surface of the specimen. This often consists of a thin strip of material in which a crack has been artificially induced, and may be used as a guide for acceptance or rejection of the specimen under test. Equipment is usually checked with standard test pieces.

4.1.1 Good lighting is essential for examining the specimen. Good daylight provides the best illumination for normal inks, but fluorescent lighting, free from highlights and of correct intensity, is a suitable substitute. When using fluorescent inks, black light is essential and daylight should, as far as possible, be excluded from the viewing area; efficiency of the black light source should be checked periodically (BS 4489).

4.1.2 Adequate bench space should be provided adjacent to the testing machine and, where the nature of the work permits, should be away from noisy or otherwise distracting locations.

4.1.3 When specimens are tested in batches and set aside in a magnetised condition for subsequent examination, they should not be permitted to come into contact with one another, or with any other magnetic material, such as steel-topped benches or steel brackets, until the examination has been completed. If specimens do come into contact with other magnetised objects a local dis-arrangement of the magnetic field may occur, giving an effect similar to that obtained with a real defect.

4.2 **Selection of Method.** In cases where a technique of examination has not been specified, tests must be made to ensure that defects in the specimen can be satisfactorily revealed.

4.2.1 Factors to be considered are the size and shape of the specimen, and the capacity of the machines available. Changes of cross-section in a component will result in variations in the intensity of magnetisation through the component, requiring several tests using different current settings at each change of cross-section. The shape of a component may also modify the distribution of magnetic flux and result in misleading indications in the ink pattern. Examples of difficult specimens are toothed gears, turbine blades with fir tree roots and threaded components, where over-magnetisation may result in build-up of iron oxide at the extremities, and cause defects to be hidden. This type of component may often be examined using a remanent magnetism technique, a d.c. supply being used with fluorescent ink; the part should be gently swilled in paraffin after application of the ink to clear the background, but retain any defect indications.

4.2.2 Since the majority of specimens must be tested for longitudinal and transverse defects, both current flow and magnetic flow tests are normally required; both tests may be carried out on a single universal machine.

4.2.3 Table 1 gives guidance on the most suitable methods of testing materials of various simple shapes; components of complicated shape may require special techniques. Tests using flux detectors and portable cracks will usually permit a satisfactory technique to be established, however, and great difficulty is not often experienced.

TABLE 1

Specimen	Suitable Test Methods
Bar	Current flow for longitudinal defects. Magnetic flow for transverse defects. Magnetising coil for transverse defects.
Tube	Threading bar for longitudinal defects. Magnetic flow for transverse defects. Current flow for longitudinal defects. Magnetising coil for transverse defects.
Ring	Threading bar for defects in line with ring axis, and radial defects. Current flow or induced current flow for circumferential defects.
Plate	Current flow or current flow using prods for both longitudinal and transverse defects.
Disc	Current flow or current flow using prods, with the disc rotated 90° between successive tests.
Sphere	Current flow or current flow using prods, sphere being rotated to reveal any defects. Magnetic flow or magnetising coil may also be used if flux path is extended using steel extension pieces.

4.3 **Preparation.** Specimens should be free from dirt, grease or scale, since these may hide defects and contaminate the magnetic ink. Scale may usually be removed by abrasive blasting or approved chemical methods, and trichloroethylene or other suitable solvents are normally used for degreasing when the parts are being tested away from their assembled positions. Trichloroethylene should not be used for cleaning parts in situ, due to the health hazard. It is not usually necessary to remove paint or plating except to provide good electrical contact for the current flow process.

NOTE: The fluorescent properties of certain magnetic inks may be diminished by chemical reaction with acids. When acid pickling is used as a cleaning process, care is necessary to ensure that all traces of acid are washed off.

4.3.1 Preparation of the specimen should also include demagnetisation. Magnetisation may have been induced by working, by machining in a magnetic chuck, or by lying adjacent to magnetised components or material. In the case of raw material, magnetisation may be removed by heating to a temperature above the Curie point for the material, but generally, for finished parts, it must be removed as detailed in paragraph 4.8.

4.3.2 Apertures such as oilways and deep tapered holes, which do not form part of the area to be examined, should be plugged to prevent the intrusion of ink, which may be difficult to remove.

4.4 **Magnetisation.** Components of simple shape will normally require magnetising in two directions, by a selection of the methods described in paragraph 3, so that defects of any orientation will be revealed. Components of complicated shape may require further magnetisation in selected areas to ensure complete coverage. A component should normally be demagnetised between each test, to remove the effects of residual magnetism, which could cause spurious indications.

4.5 **Inking.** Except where remanent magnetism is used to reveal defects (paragraph 3.1.2), magnetic ink should be applied gently, immediately before and during the period of magnetisation. With a.c. machines the magnetic flux should be applied for at least three seconds to allow time for the ink to build up at defects, but d.c. machines are often fitted with a time switch which limits the application of flux to between ½ and 1 second. When the immersion method is used, extreme care is necessary during removal of the specimen from the bath, in order to avoid disturbing the magnetic ink and any indications of defects which it may show.

4.6 **Interpretation of Indications.** Particles of magnetic ink are attracted to flux leakage fields, and these may occur at defects, brazed joints, the heat affected zone in welds, or sudden changes of section. The presence of a sudden build-up of ink on a specimen is not, therefore, necessarily an indication of a crack, inclusion or similar discontinuity, and experience is essential in interpreting the indications produced by a test.

4.6.1 Cracks are revealed as sharply defined lines on the surface of the specimen, the magnetic particles often building up into a ridge which stands proud of the surface.

4.6.2 Subcutaneous defects such as may occur during manufacture of the material, will be more blurred than surface cracks. Non-metallic inclusions are often revealed by a diffuse clustering of magnetic particles, but may sometimes give an indication which is as sharply defined as a crack.

4.6.3 Grinding cracks are usually readily identified, and consist of a pattern of irregular lines over the affected area, or, on small radius bends or teeth, they may appear as short parallel lines.

4.6.4 Tool marks may give an indication similar to cracks, but the bottom of a tool mark can usually be seen with the aid of a hand lens with approximately 5x magnification, whereas cracks are usually deep and narrow.

4.6.5 Localised magnetic flux resulting from ineffective demagnetisation, or careless handling after a specimen has been magnetised, may give indications known as magnetic writing. Careful demagnetising and retesting will show whether the magnetic writing is spurious, or an indication of a real defect.

4.6.6 Excessive magnetisation causes furring, and magnetic particles tend to follow the grain flow, giving the appearance of clusters of inclusions. The remedy is to reduce magnetisation when testing areas of reduced cross-section.

4.6.7 Changes in permeability within a specimen, such as may occur at welds, may give misleading indications. Magnetic detection methods may not be suitable in these instances, and radiography may have to be used.

4.7 **Recording of Defects.** Defects are normally marked with grease pencil or paint for future reference, but it may be necessary, for record purposes, to preserve the indications obtained in a test, either on the specimen or as a separate permanent record.

4.7.1 If the magnetic ink has an oil based carrier, the specimen should be drained and dried or, alternatively, another test may be carried out using an ink containing a volatile carrier fluid. If dry powder is used no preparation is necessary.

4.7.2 In cases where the specimen is to be retained, it should be gently sprayed with quick-drying lacquer or covered with a transparent adhesive film, care being taken not to disturb the surface indications.

4.7.3 If a separate permanent record is to be retained the specimen may be photographed, or one of the following actions taken:—

(i) The indications may be covered with a transparent adhesive tape, which may then be peeled off and applied to a paper or card of suitably constrasting colour, to show the defects.

(ii) A strippable adhesive coating may be gently sprayed on to the surface of the specimen. When carefully removed, this coating will retain the indications of defects, and these may be viewed on the surface which was in contact with the specimen.

(iii) The specimen may be heated and dipped in a thermosetting plastic powder material. When cured and stripped off, this material may be viewed as in (ii) above.

4.8 **Demagnetisation.** There are a number of reasons why specimens should be demagnetised before, during or after magnetic particle testing. These include the effects of magnetic writing (see paragraph 4.6.5), the difficulty which would be experienced in any subsequent machining operation due to the adherence of swarf, bearing wear due to the adherence of fine metallic particles, and interference with the aircraft magnetic compasses. A specimen should, therefore, be demagnetised before starting tests, between tests which involve a change in flux direction, and after tests have been completed.

4.8.1 The most commonly used demagnetiser is an aperture type of coil carrying an alternating current. The specimen should be placed inside the energised coil and withdrawn a distance of at least 1½ metres (5 feet) along the coil's axis with the current switched on, or may be placed inside the coil and the current gradually reduced to zero. Ideally, the coil should be just large enough to accept the specimen.

4.8.2 If a demagnetising coil is not available the crack detecting machine may be used. Alternating current from the machine may be passed through two or three turns of heavy cable, which may be used in the same way as a demagnetising coil. Alternatively, a suitably equipped direct current electromagnet machine may be used, the specimen being placed between the poles and the current being gradually reversed and reduced simultaneously to zero.

4.8.3 For demagnetising parts in situ an alternating current yoke is normally used. This consists of a coil wound on a laminated yoke, which is used in a stroking action on the specimen. The strokes should always be in the same direction along the specimen and the yoke should be moved away in a circle on the return stroke.

4.8.4 After demagnetising, the specimen should be removed from the vicinity of the demagnetising coil, the testing machine, or any other magnetised material.

4.9 **Tests for Demagnetisation of Parts.** Any components which are manufactured from steel and liable to affect the aircraft compass, should be demagnetised and a test for remanent magnetism carried out before assembly in the aircraft. The standard test for remanent magnetism in aircraft parts is the deflection of a magnetic compass needle under controlled conditions, but an alternative method, such as the use of a flux meter, may be permitted, and suitable limits prescribed.

4.9.1 The test consists of placing a suitable magnetic compass in a position away from all stray magnetic influences, and slowly rotating the component at a position along the east/west axis of the compass. The distance of the component from the compass should be specified for the test, and should be the same as the distance from the aircraft compass to the installed component. Deflection of the compass needle by more than 1° will require the component to be demagnetised again and the test to be repeated.

4.10 **Final Cleaning.** When a component has been accepted following a magnetic detection test, all traces of detecting ink, contrast paint or temporary marking should be removed. Wiping or washing in solvent, or immersion in an approved degreasing agent are the methods normally used. During cleaning, any plugs or blanks fitted during the preparation for the test, should be removed. A temporary rust protective should be applied after cleaning, and the part should be identified in accordance with the appropriate drawing, to indicate that magnetic flaw detection has been satisfactorily carried out.

5 TECHNIQUE SHEETS A technique sheet is a document detailing all the magnetising operations to be performed when inspecting a particular component by the magnetic particle method. It may be accompanied by an illustration of the component and by instructions applicable to all magnetic particle tests, such as the methods of cleaning and demagnetising to be used.

5.1 A technique sheet should show all the relevant details for each magnetising operation, including type of equipment, strength and form of current, acceptance standard, contact areas, positions of flux detectors, type of coil, size of threading bar, and test pattern, as appropriate to the particular test. It is recommended that the symbols used in BS M35 should be used on all technique sheets and, where appropriate, on related drawings or sketches.

BL/8-7

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BASIC

NON-DESTRUCTIVE EXAMINATION

FLUORESCENT PENETRANT PROCESSES

1 INTRODUCTION This leaflet gives guidance on the fluorescent penetrant processes used for the detection of defects in a component, such as cracks, cold shuts, folds, laps and porosity when these break the surface of the component.

1.1 Fluorescent penetrant processes are used mainly for the detection of flaws in non-ferrous and non-magnetic ferrous alloys but may also be used for ferrous parts where magnetic flaw detection techniques are not specified or are not possible. In some instances both fluorescent penetrant and magnetic flaw detection techniques may be specified for a particular part (see paragraph 1.5.4). Fluorescent penetrants may also be used on some non-metallic materials, such as plastics and ceramics, but in each case a suitable process for the particular material must be selected. The processes are not suitable for use on absorbent materials.

1.2 Although the processes are usually marketed under brand names, those used on aircraft parts for which a penetrant process of flaw detection is a mandatory requirement must comply with the requirements of Process Specification DTD 929. It must be ensured that any storage limiting period prescribed by the manufacturer of the process is not exceeded.

1.3 There are two types of fluorescent penetrants, a minor water-based group and a major oil-based group; the manufacturers of the processes usually specify the materials for which each process is suitable. There are variations in the processes which must be taken into account. For example, some types of penetrants contain an emulsifier, whilst in other processes the penetrant and the emulsifier are applied as separate stages. Again in some processes the use of a dry developer is recommended whilst in others a wet developer is used. The manufacturer's recommendations and instructions for each individual process must be followed carefully to ensure satisfactory results.

NOTE : An emulsifier is a blending of wetting agents and detergents which enables excess penetrant to be removed with water.

1.4 Fluorescent penetrant testing is based on the principle that when ultra-violet radiation falls on certain chemical compounds (in this case the penetrant) it is absorbed and its energy is re-emitted as visible light (i.e. the wavelength of the light is changed). Thus, if a suitable chemical is allowed to penetrate into surface cavities, the places where it is trapped and has been drawn to the surface by the developer will be revealed by brilliant greenish-yellow lines or patches (according to the nature of the defect) under the rays of an ultra-violet lamp.

1.5 The selection of the most suitable type of penetrant process (e.g. penetrant dye (Leaflet BL/8-2) or fluorescent penetrant; with or without post-emulsification) for any given application must largely be governed by experience, since when correctly used a high degree of efficiency can be obtained with any of the processes. Guidance on some of the factors which should be given consideration is provided in the following paragraphs.

1.5.1 Within a given type of process, the post-emulsification method is generally considered to be the most sensitive and is usually selected for finished machined parts and for the detection of "tight" defects. However, its use on rougher surfaces (e.g. castings) may be less effective than would be the use of a penetrant containing an emulsifier, since it may pick up the surface texture of the material, thus rendering the detection of actual defects more difficult.

1.5.2 Where large, heavy parts are concerned, and particularly where mechanical handling is involved, the use of penetrant dyes may be more practicable than that of fluorescent penetrants, since the necessity of darkening a relatively large area before the examination can be made does not arise.

1.5.3 When making "in situ" checks on aircraft, the use of penetrant dyes may be more suitable where there is sufficient light but in the darker areas a fluorescent process may provide better definition of defects.

1.5.4 With steel castings, for example, porosity may be detected more readily by a penetrant process than by the magnetic flaw detection techniques (Leaflet **BL/8-5**) and for this reason the use of both processes is sometimes specified. If the magnetic flaw detection test precedes the penetrant test, great care will be necessary with the intervening degreasing process to ensure that all traces of the magnetic testing medium are removed, otherwise the subsequent penetrant test may be unsuccessful.

1.6 Some of the materials associated with penetrant testing have low flash points and the appropriate fire precautions should be taken.

1.7 Guidance on dye penetrant processes is given in Leaflet **BL/8-2**. Information on the performance testing of penetrant testing materials is given in Leaflet **BL/10-9**.

2 SURFACE PREPARATION The major reason for the failure of penetrant processes to provide indications of defects is incorrect or inadequate surface cleaning. For example, embedded extraneous matter can seal off cracks, etc., whilst contaminants remaining on the surface can trap the penetrant and give rise to false indications or, more detrimentally, obscure genuine defects. Thus the surface to be tested must be free from oil, grease, paint, rust, scale, welding flux, carbon deposits, etc., and the method of cleaning selected must be capable of removing extraneous matter from within the defects as well as from the surface to permit the maximum penetration.

2.1 With unmachined steel stampings and forgings it may be necessary to remove rust or scale by sandblasting. Aluminium alloy forgings may also need light sandblasting. However, the use of such processes must be given careful consideration, since they may result in the filling or "peening-over" of defects. Generally, unless specified otherwise, aluminium alloy forgings should be prepared by a suitable pickling process (e.g. by one of the methods prescribed in Process Specification DTD 901).

2.2 Magnesium alloy castings should be tested after chromating in order to reduce the risk of corrosion, but the requirements of Process Specification DTD 911, with regard to surface protection, must be taken into account and a suitable sequence devised.

2.3 Where contamination is mainly of an organic nature, degreasing by the trichloroethylene process (unless there are instructions to the contrary) is usually suitable. However, not all types of trichloroethylene are suitable for use with titanium alloys and further guidance on this and other aspects of trichloroethylene cleaning is given in Leaflet **BL/6-8.** The cleaning of titanium alloys by methanol should be avoided.

2.4 Where parts have to be tested "in situ", the use of volatile solvents (e.g. carbon tetrachloride) as cleaning agents should be given consideration. Where paint is present this should be removed from the surface to be tested prior to cleaning. Subsequent to the test, the surface should be reprotected in the prescribed manner.

NOTE : Suitable fire precautions must be taken where flammable materials are used.

2.5 Sufficient time should be allowed after cleaning for drying-out, otherwise the efficiency of the penetrant may be affected. The time interval allowed for the evaporation of solvents can only be determined by the prevailing conditions of temperature and humidity and the type of solvent used.

3 APPLICATION OF THE PENETRANT PROCESS (WITHOUT POST EMULSIFICATION)

3.1 **Application of Penetrant.** The penetrant can be applied to the surface by dipping, spraying or brushing, the method used depending largely on the size, shape, and quantity of the parts to be examined. The surface must be dry before the penetrant is applied. Even the condensation which forms on a cold surface in humid conditions may interfere with penetration; in such conditions the part should be warmed, preferably within the temperature range of 70°F. to 90°F.

3.1.1 **Dipping Method.** Dipping should generally be used where large numbers of small parts are to be examined. The parts must be completely dried before immersion, since apart from affecting penetration, water or solvents will contaminate the penetrant.

(i) During dipping care must be taken to ensure that the parts are so racked that air pockets are avoided and all surfaces to be examined are completely wetted by the penetrant.

(ii) The parts should be dipped for a few seconds and allowed to drain, care being taken to ensure that the solution is able to drain away from any pockets or cavities in the parts. If there is a tendency for the penetrant to dry on the surfaces the parts should be redipped.

3.1.2 **Flooding Method.** The flooding method should generally be used where large areas are to be examined. The penetrant should be applied with low-pressure spray equipment which will not permit atomisation of the fluid, care being taken to ensure that the penetrant completely covers the surface and remains wet. On no account should the penetrant be allowed to dry during the penetration period (paragraph 3.2).

3.1.3 **Aerosol Method.** Penetrant contained in aerosol-type cans is often used for "in situ" inspections. The best results are obtained when the can is held about 12 in. from the surface under test.

3.1.4 **Brushing Method.** The brushing method is generally used for individual items and items of complicated shape. A soft clean bristle brush should be used and retained only for this purpose. On no account should the penetrant be allowed to dry during the penetration period.

3.2 **Penetration Time.** The penetration time is the time which has to be allowed for the penetrant to enter effectively into defects and usually a period of up to ten minutes is sufficient for the larger type defects, but longer times may be necessary where minute defects are being sought. (See Table 1).

3.2.1 Typical penetration times are given in Table 1 but these may vary according to the temperature and process used. The manufacturer's recommendations must always be followed where these differ from the figures given.

3.2.2 Where the effectiveness of the pre-cleaning process cannot be guaranteed or where parts have been sandblasted, the penetration time should be extended but it should be borne in mind that this is no guarantee that defects will, in fact, be revealed in such conditions.

TABLE 1

Material	Nature of Defect	Penetration Time (Minutes)
Sheets and Extrusions	Heat treatment cracks, grinding cracks and fatigue cracks.	15
Forgings	Laps, Cracks.	30
Castings	(i) Shrinkage, cracks and porosity. (ii) Cold Shuts.	3—10 20
Welds	(i) Cracks, porosity. (ii) Included flux.	20 1
Plastics	Cracks, crazing.	1—5

3.3 **Removal of Excess Penetrant.** Excess penetrant should be removed by spraying with running water at a mains pressure of about 30 lb. sq. in. or by the use of an air/water gun. In the case of self-emulsifying penetrants, it may be necessary with some surfaces to use a detergent solution, supplied by the manufacturer, prior to spraying the developer. It is most important to ensure that the rinsing operation is completely effective, otherwise traces of the residual penetrant may remain on the surface and interfere with the subsequent diagnosis of defects.

3.3.1 After rinsing, the surfaces of the component should be quickly inspected by means of ultra-violet light to ascertain the efficiency of the rinse. If any general fluorescence is still evident the rinsing operation should be repeated.

3.3.2 If a wet developer is to be used, the surfaces need not be dried but drying is essential if a dry developer is to be used. On large parts the excess water can be blown off with clean, dry, oil-free air but when parts are of convenient size, drying in a recirculating hot-air drier is recommended. Excessive time in the drier should be avoided, as the penetrant will slowly evaporate.

3.4 **Application of the Developer.** The developer usually consists of a very fine white powder which may be applied in (a) the form of a spray, the powder being suspended in a volatile liquid carrier, (b) as a dip with the powder suspended in water or (c) as a dry powder which may be blown on to the component or into which the component may be dipped. The action of the absorbent powder is to draw out the dye from the surface defects, thus indicating their position by the resultant yellowish-green stain when viewed under ultra-violet light.

3.4.1 Where it is suspected that microscopic defects may be present, great care is necessary to ensure that the developer is applied evenly and very thinly, since a thick layer might completely conceal a defect holding only a minute quantity of dye.

3.4.2 Where a wet developer is concerned, the best results are obtained when the developer is applied by means of a paint-type spray gun operating at an air pressure not in excess of 15 lb. sq. in. The pressure pot of the gun should be equipped with a stirrer to keep the developer agitated and the absorbent particles in suspension. Before pouring the developer into the spray-gun it should be well shaken to ensure thorough distribution of the absorbent particles.

3.4.3 When requirements are not too exacting, small parts can be dipped into a bath of developer but the action must be performed rapidly to minimise the possibility of the penetrant being washed out of shallow defects. The bath should be agitated from time to time to ensure that the absorbent particles are kept in uniform suspension in the solvent. The formation of pools of developer on the parts during draining must be avoided, otherwise the resultant thick coatings may mask defects.

3.4.4 Due to the usually uneven results obtained, the use of a brush for applying the developer is not recommended.

3.4.5 After the developer has been applied, the parts should be allowed to stand for at least 15 minutes and should then be examined in a darkened room, using ultra-violet light. Where doubt exists as to the validity of an indication, the part should be left for at least two hours and then re-examined. If viewing periods are to exceed 30 minutes, the use of special viewing goggles is recommended to reduce the risk of eyestrain and headaches.

NOTE : Portable lamps specially manufactured for fluorescent viewing are available.

4 APPLICATION OF THE PENETRANT PROCESS (WITH POST EMULSIFICATION)

In principle the process is similar to that described in the previous paragraph, except for the addition of the emulsification step. However, the separate application of penetrant and emulsifier does introduce additional factors which must be taken into account and these are described below.

4.1 After the parts have been dipped in the penetrant, the drain-off period should not be less than 15 minutes and not more than 2 hours. If the period is less than 15 minutes, dilution of the emulsifier by the penetrant may occur and penetration of contaminated defects may not be complete. If the period exceeds 2 hours, partial drying of the penetrant may occur, resulting in exceptionally long emulsification times. Once an optimum draining period has been determined for a particular part, it should be adhered to within ±20 per cent, since this period directly influences the process and effects of emulsification.

4.2 The parts should be dipped into the emulsifier (the length of time the emulsifier is allowed on the parts being somewhat critical), and should be held to the minimum time necessary to give a good water wash, since this will result in the highest sensitivity. It should be determined by experience for each type of part and finish and then strictly adhered to.

4.3 An average emulsification time is about 2 minutes, but may vary between 30 seconds to 5 minutes, according to the surface condition of the part.

4.4 After removal of the emulsifier, the part should be dried, treated in the dry developer and then inspected for defects.

5 **INTERPRETATION OF INDICATIONS** If defects are present and all stages of the process have been applied correctly, they will be indicated by brilliant greenish-yellow marks on the surface of the part; some may appear immediately as the developer dries but others may take longer to develop. The characteristics of the markings, such as the rapidity with which they develop and their final shape and size, provide an indication as to the nature of the defect revealed (see Figure 1).

5.1 The rate of staining is an indication of the width and depth of the defect, whilst the extent of staining is an indication of its volume. A wide shallow defect is revealed almost instantly but narrow deep defects may take some time to display the final pattern.

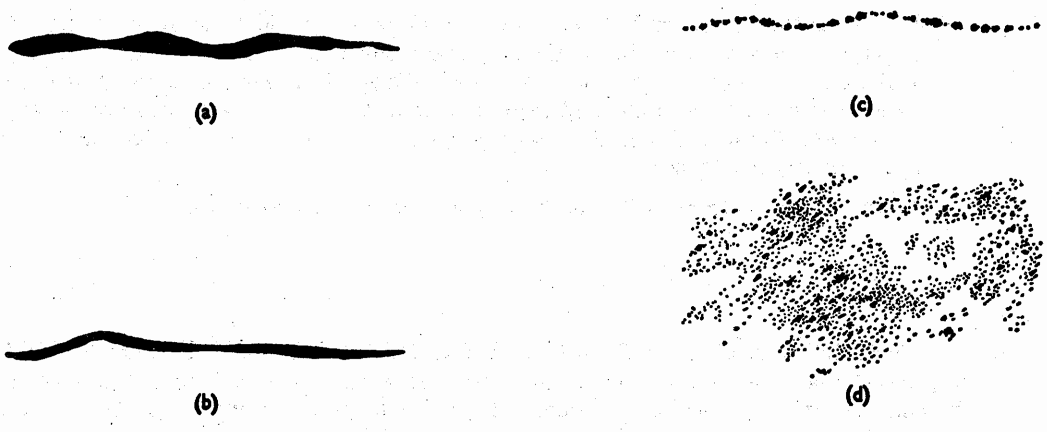

Figure 1 INDICATIONS GIVEN BY DEFECTS

5.2 Scattered dots indicate fine porosity or pitting (Figure 1 (d)), whilst gross porosity may result in an entire area becoming stained.

5.3 Closely spaced dots, in a line or curved pattern (Figure 1 (c)), usually indicate tight cracks or laps but such patterns are also characteristic of very wide defects from out of which most of the penetrant has been washed. Wide cracks, lack of fusion in welded parts and other similar defects are indicated by continuous lines as shown in Figures 1 (a) and 1 (b).

5.4 All defects should be suitably marked prior to removal of the developer, but crayons should not be used on highly-stressed components subject to heat treatment, since this is known to induce fractures.

6 REMOVAL OF DEVELOPER Developer should be removed by washing with water spray or by dipping the component in an aqueous solution of 2 per cent chromic acid. Since the surface is then in a condition susceptible to corrosion (where this is applicable) the prescribed protective treatment should be applied without delay.

BL/8-8

Issue 1

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BASIC

NON-DESTRUCTIVE EXAMINATIONS

EDDY CURRENT METHODS

1 INTRODUCTION This Leaflet gives guidance on the use of eddy current equipment for detecting cracks, corrosion or heat damage in aircraft structures, and also shows how the method can be used for the measurement of coating thickness or for sorting materials. Elementary theory of eddy currents is included to show the variables which are being measured and to indicate the interpretation of results which may be necessary for a particular application. Nothing in this Leaflet should be taken as overriding the information supplied by aircraft or engine manufacturers.

1.1 Eddy current methods can detect a large number of physical or chemical changes in a material, and the selection of the required parameter presents the equipment manufacturer with many problems; interpretation of the test indications would be very difficult if undesired parameters were not reduced or nullified. Conversely, equipment set up for a particular purpose is comparatively easy to use when indications are compared with a 'standard' or known defect. Eddy current equipment is normally built to perform only certain types of tests, these falling broadly into the categories of flaw detection, conductivity measurement and thickness measurement.

1.2 The main advantages of the use of eddy current methods are that they do not normally require extensive preparation of the surface or removal of the part to be tested, do not interfere with other work being carried out on the aircraft and, with surface defects, offer improved sensitivity over other non-destructive techniques. Small portable sets are battery powered and can easily be used in comparatively inaccessible places in aircraft structures.

1.3 Eddy current testing may be subject to certain difficulties, including depth of penetration and the effects of surface coatings and unseen changes in the geometry of the material under test. In addition the results of a test can only be related to the size of signal received, and are not necessarily an indication of the size of defect. Techniques are established after trials have shown a method which gives consistent results.

1.4 In aircraft work, eddy current testing is usually of the comparative type, a reference piece or standard in similar material containing an artificial defect, being used to compare indications from the part under test.

2 PRINCIPLES OF OPERATION Eddy currents are induced in an electrically conducting material when the material is subjected to a changing magnetic field, and normally flow parallel to the surface of the material (Figure 1). In eddy current testing a coil is supplied with alternating current and held in contact with (or in close proximity to) the test specimen. The alternating magnetic field produced around the coil induces an alternating eddy current in the specimen, and the eddy current itself produces an alternating magnetic field which opposes and modifies the original coil field. The resultant magnetic field is the source of information which can be analysed to reveal the presence of flaws in the test specimen.

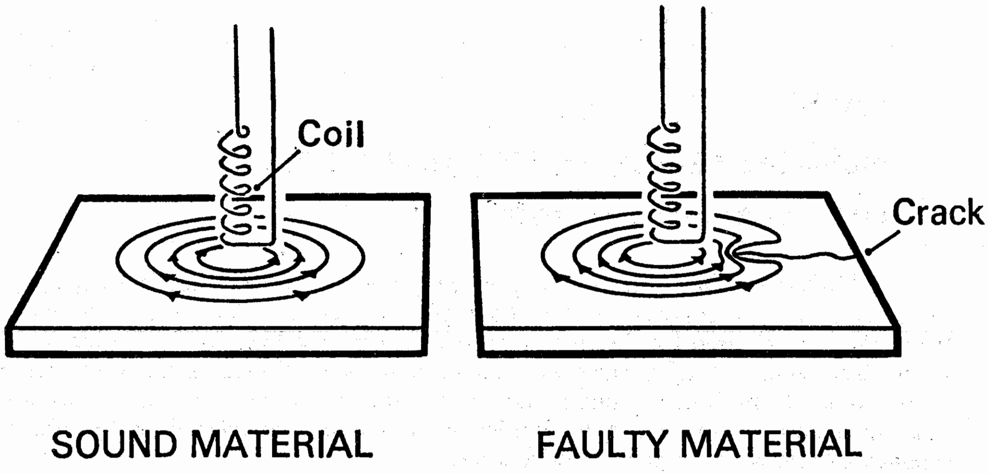

Figure 1 EDDY CURRENT FLOW

2.1 **Permeability.** This quality is a measure of the ease with which a material will conduct magnetic lines of force and decides the density of flux which can be induced in that material. Permeability is a function of magnetising force and flux density; air and non-magnetic materials have, for testing purposes, a permeability (μ) of 1, while ferromagnetic materials have a permeability greater than 1. Permeability is not constant in magnetic materials, and varies with the magnetising force (coil current). Eddy currents are induced by flux changes in a material and are directly related to flux density; as permeability increases so the strength of eddy currents increases. Non-magnetic materials do not generate additional flux densities, but magnetic materials produce high flux densities which can mask all other measurements. During tests on ferromagnetic materials, that is materials with a permeability greater than 1, these effects can be suppressed or made constant by saturation with high d.c. or a.c. fields which, in effect, restore the permeability to 1.

2.2 **Conductivity.** Conductivity (σ) is a measure of the ability of electrons to flow through a material and is one of the main variables in eddy current testing. Each material has a unique value of conductivity and this fact enables changes in chemistry, heat treatment, hardness or homogeneity to be detected simply by comparing the conductivity with a specimen of known properties; increased conductivity gives increased eddy currents (although depth of penetration decreases). Conductivity is measured in either of two ways; it can be compared to a specific grade of high purity copper known as the International Annealed Copper Standard (IACS), which is considered as 100%, or it can be measured in metres per ohm millimetre^2. (58 $m/\Omega mm^2 = 100\%$ IACS).

2.3 **Effects of Specimen on Test Coil.** A probe coil placed on the surface of a specimen will possess a particular value of impedance which can be found by measuring the voltage across the coil. The voltages due to resistance and reactance can also be separated and, if required, displayed on a cathode ray tube. Any change in conductivity, permeability or dimensions (d) of the specimen will, through the eddy current field, alter the coil's impedance, either in magnitude or phase, and, depending on the parameter sought, can be indicated on a meter or cathode ray tube display. Changes affecting apparent conductivity, e.g. a crack, will be 90° out of phase with changes affecting permeability or dimensions under certain test conditions.

2.4 **Geometry.** The size and shape of the test specimen may distort the primary magnetic field and mask defects in the affected area (Figure 2). The effects of geometry can be overcome by probe design, equipment calibration, frequency selection, or the use of jigs to maintain the probe in a particular relationship to the material surface, but must often be taken into account when conducting tests.

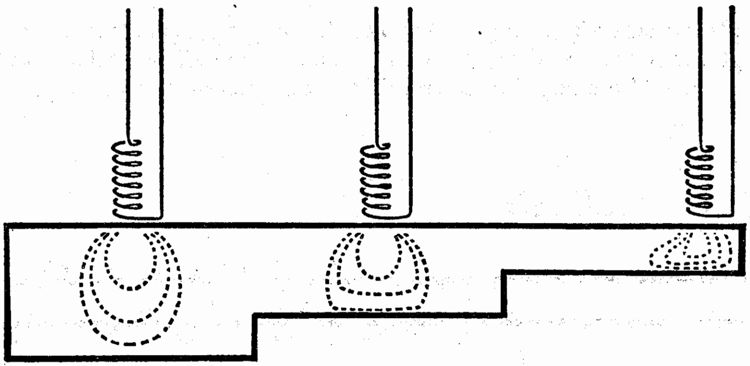

Figure 2 GEOMETRIC EFFECTS ON PRIMARY MAGNETIC FIELD

2.5 **Penetration.** Eddy currents are strongest at the surface of a material and weaken with depth. This effect becomes more pronounced with increased frequency (f) of the alternating magnetic field and is known as 'skin effect'. Increases in permeability (μ) and conductivity (σ) in a material also decrease penetration depth. In practice the depth of penetration (P) of eddy currents is related to a depth where tne current is reduced to 1/e (approximately 37%) of the surface current and may be calculated from the formula, $P \approx \frac{500}{\sqrt{f\sigma\mu}}$ where P is in mm, and σ is in m/Ωmm^2.

2.6 **Effects of Frequency.** Any particular material possesses what is known as a characteristic frequency (f_g), which depends on its conductivity, permeability and dimensions. A practical use of the characteristic frequency is that samples of different materials tested at the same f/f_g ratio will give similar indications for similar defects. Actual test frequency is selected to obtain the best results from a particular test and depends on the type of defect sought, the depth of penetration required and the geometry of the specimen. When it is necessary to determine the phase of a signal, the frequency should be within the range where phase angle is greatest. When testing for conductivity only, to check hardness, heat treatment, etc., some penetration is required so a low frequency would be used, but when testing for surface cracks greater sensitivity would be obtained at a higher frequency.

2.6.1 In aircraft work testing is often concerned with thin sheet structure in aluminium alloy, and test frequencies between 5 kHz and 4 MHz are used, depending on the defect sought. However, frequencies as low as 50 Hz are used for checking material properties in ferromagnetic materials.

2.7 **Lift-off.** This may be defined as the change in impedance of a coil when the coil is moved away from the surface of the specimen. This produces a large indication on the test equipment. In some equipment the lift-off effect is nullified by applying a compensating current to the probe circuit, thus enabling rapid testing without the need for special jigs, but in other equipment the lift-off effect is analysed to measure, for example, the thickness of a non-conducting coating. This effect, when applied to encircling coils and bar specimens, is known as 'fill factor'.

3 COIL ARRANGEMENTS A number of different coil arrangements may be used in eddy current testing, and some of the more common are discussed below. The types shown in Figures 3, 4 and 5 are not generally used during aircraft maintenance operations, but are widely used by material and component manufacturers.

3.1 **Single Primary Coil.** Figure 3 shows the simplest arrangement. If a sound specimen is placed in the coil the impedance of the coil is modified and if a faulty specimen is placed in the coil the impedance is modified to a different degree.

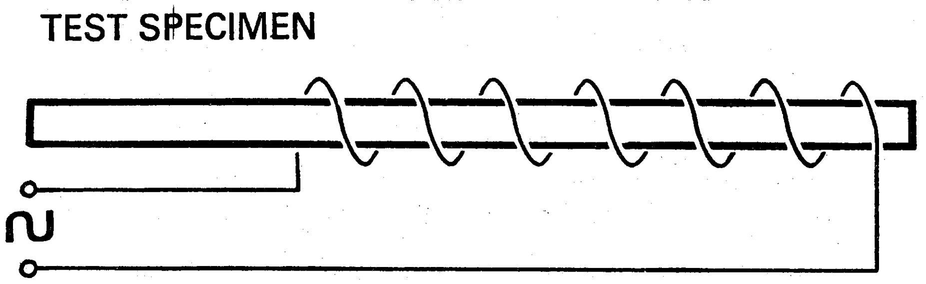

Figure 3 SINGLE PRIMARY COIL SYSTEM

3.2 **Comparative Coil System.** Figure 4 shows a coil arrangement which has two arms, one containing a flawless reference piece and the other the test specimen. Since the two sets of coils are identical any fault in the test piece will result in a voltage across AB.

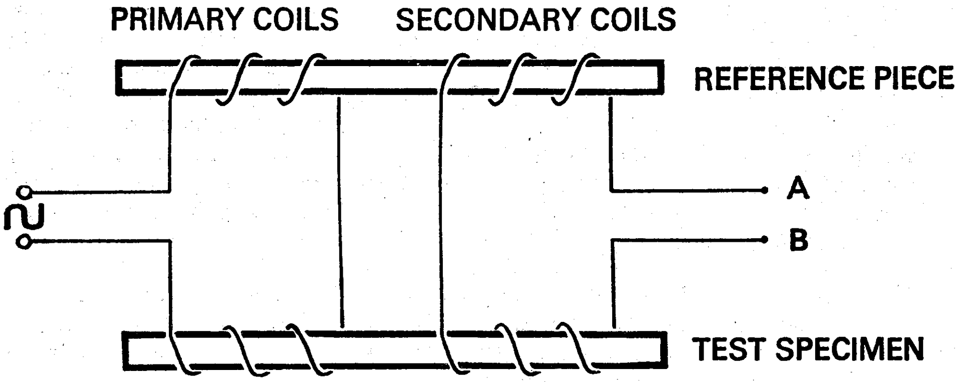

Figure 4 COMPARATIVE COIL SYSTEM

3.3 **Differential Coil System.** Figure 5 shows a coil arrangement which is also a comparison method, but in this case adjacent portions of the test specimen are compared with each other. The coil windings are, in effect, identical to the comparative coil system shown in Figure 4.

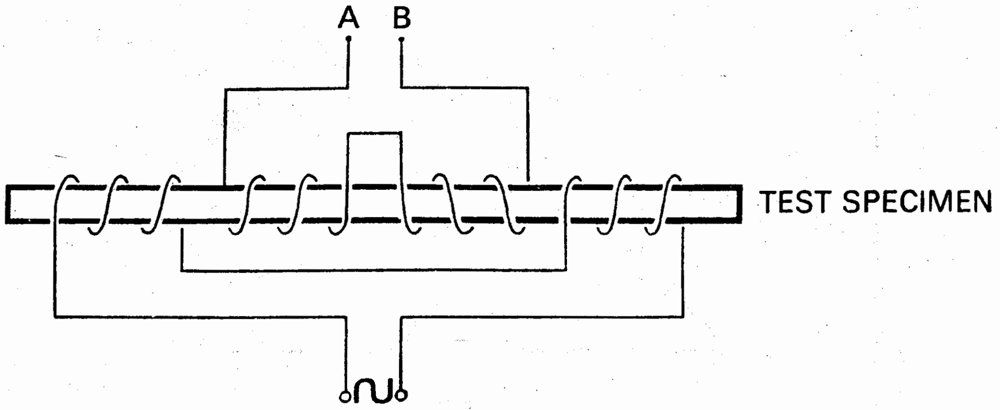

Figure 5 DIFFERENTIAL COIL SYSTEM

3.4 **Surface Coils.** In aircraft work a single coil is generally used, with the axis of the coil normal to the surface being tested (Figure 6). A ferrite core is used to increase sensitivity to small defects, and the arrangement is used for detecting cracks in flat surfaces, curved surfaces or holes, by mounting the coil within a specially shaped probe. Impedance changes obtained during a test are compared with those obtained from a defective part or a reference piece.

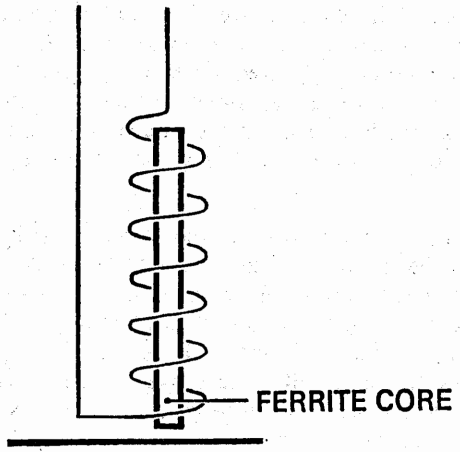

Figure 6 SURFACE COIL

4 TYPES OF CIRCUITS

4.1 **Bridge Circuits.** Figure 7 shows a bridge circuit, one arm of which consists of two adjustable controls and a coil, and the other arm comprises the reference and test coils. The bridge is balanced initially (meter zeroed by adjustment of the variable resistor and inductor) with the probe located on a flawless specimen. In use, any alteration in the impedance of the probe coil (due to faults in the test piece, or to lift-off) will unbalance the bridge and result in a deflection of the meter needle.

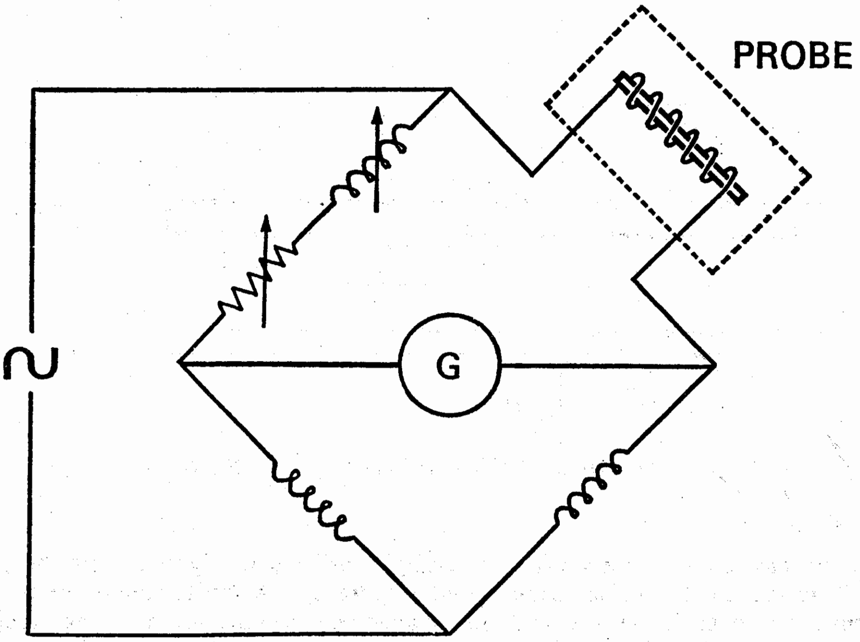

Figure 7 BRIDGE CIRCUIT

4.2 **Resonant Circuits.** The capacitance of a coil is usually small in relation to its inductance. However, if a capacitor is connected in the same circuit as a coil, since inductive reactance increases with frequency and capacitive reactance decreases with frequency, a condition will occur, at some frequency, when the effects are equal and opposite. This condition is known as resonance and the circuit then behaves as if it contained only resistance, resulting in a large change in current flow.

4.2.1 Figure 8 shows a typical eddy current circuit which operates on the resonance principle. The probe is a parallel tuned circuit connected to the grid of an oscillator and determines the frequency at which the circuit oscillates. If the flux density (and hence the impedance) of the probe coil is altered (e.g. by placing the probe on a metallic object) the oscillator frequency changes. Consequently, the frequency developed in the anode tuned circuit is no longer the frequency at which that circuit is tuned. This results in a change of impedance, which is recorded on the meter through the secondary windings of the anode coil.

4.2.2 Operation of the circuit shown in Figure 8 is dependent upon adjustment of the controls to suppress lift-off. With the probe located on the test specimen the anode circuit is tuned to a frequency in sympathy with the probe circuit by adjustment of the variable capacitor (i.e. the lift-off control) until the meter reads zero. If the probe is now removed from the specimen a change in impedance will again occur and result in deflection of the meter needle; this deflection can be counteracted by adjustment of the set-zero and lift-off controls. Further adjustment of these two controls will enable a zero meter reading to be obtained with the probe on or off the specimen. Any change in the specimen (e.g. a defect) will result in a change in the impedance of the probe coil and a deflection of the meter needle, regardless of the presence of, for example, a paint film of uneven thickness.

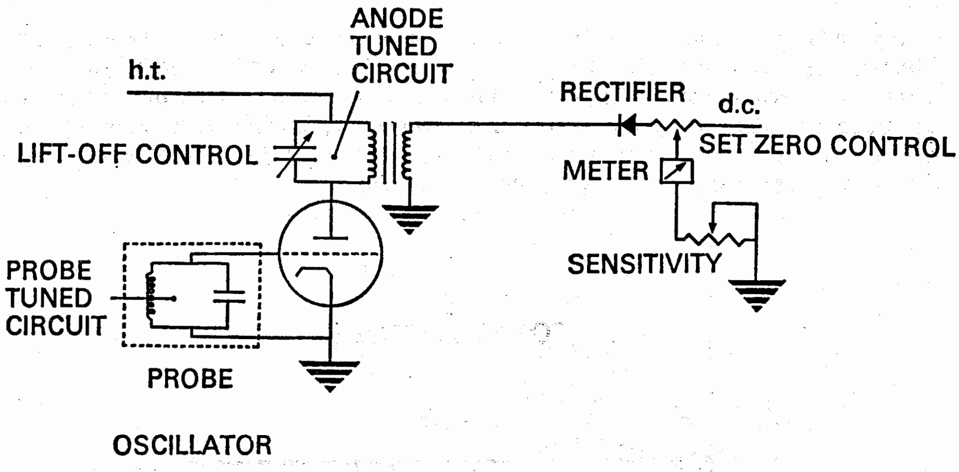

Figure 8 TYPICAL TUNED CIRCUIT

4.2.3 A different type of resonant circuit is shown in Figure 9, the probe coil and capacitor in this case being connected in series. Lift-off is suppressed by the addition of a compensating voltage to the measurement voltage.

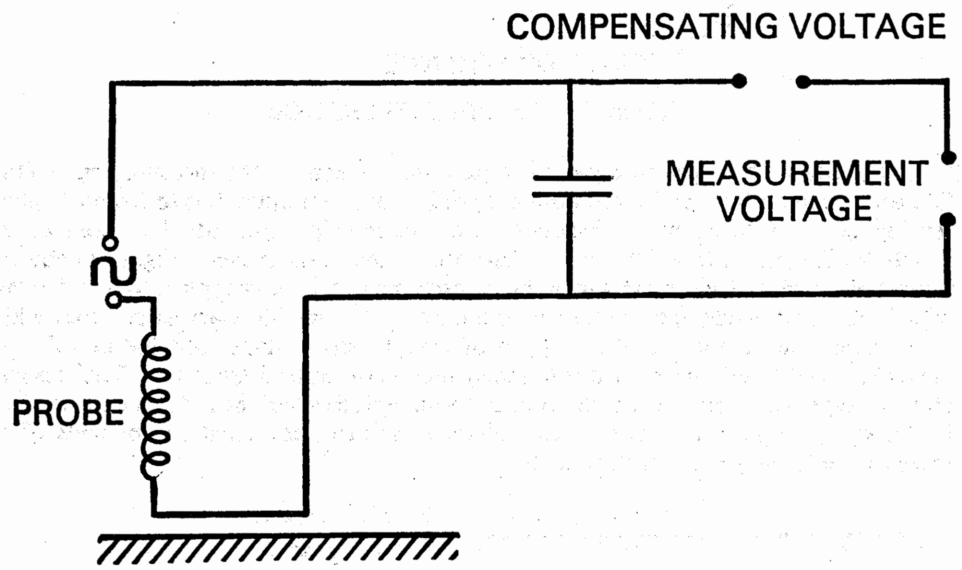

Figure 9 SERIES RESONANT CIRCUIT

5 **PHASE ANALYSIS** Where one of the parameters affecting impedance is required and all others can be assumed to be constant, the measurement of total impedance changes will satisfactorily reveal the presence of a defect or change in the unknown parameter, provided that a suitable reference piece is used for comparison. However, in many cases it is necessary to separate the reactive and resistive components of impedance in order to detect a particular type of defect and more sophisticated equipment becomes necessary.

5.1 Figure 10 shows the oscilloscope trace of a signal containing two voltages, V_1 and V_2, which are representative of the signal which could be obtained from eddy current equipment under certain test conditions. While the voltages are of the same frequency they can be seen to start at different points of the time scale, the difference resulting from the effects of reactance and being known as a phase change. Eddy current testing based on the use of phase changes is known as phase analysis.

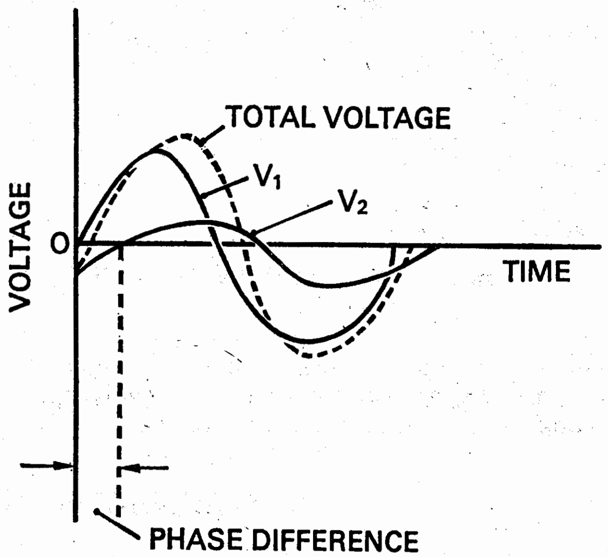

Figure 10 PHASE DIFFERENCE

5.2 One method of suppressing the unwanted components of the measurement voltage (i.e. probe coil voltage) and presenting only the parameter required, is to include a phase sensing device in the circuit. This operates on the principle that only those components which are in phase with a reference voltage are passed to the meter. Figure 11 shows a typical phase sensing circuit in which the measurement voltage is applied to one diagonal of a bridge and a reference voltage to the other. The rectifiers act as switches which pass current during one half of each cycle of the reference voltage only, but no reference current flows through the meter due to the symmetry of the bridge circuit. The measurement voltage is applied to the meter during those periods when the rectifiers are conducting, and, by varying the phase of the reference voltage, unwanted components of the measurement voltage can be eliminated.

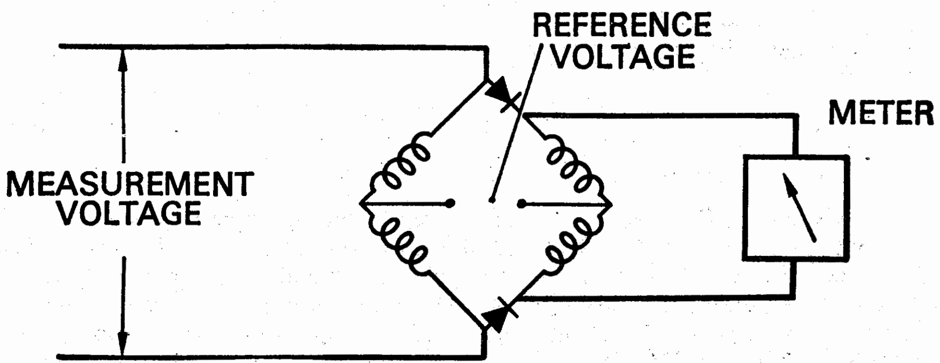

Figure 11 PHASE-SENSING CIRCUIT

5.3 The resistive and reactive components of the measurement voltage (V_1 and V_2 respectively) can also be separated, fed to separate plates of a cathode ray tube (CRT) and presented as a two-dimensional display on the screen. By suitable phase controls the vertical and horizontal components can be made to represent, for example, conductivity variations and dimensional variations respectively. The most common types of display are the vector point, ellipse and linear time base.

5.3.1 **Vector Point.** A spot is projected on to the screen of the CRT, representing the end of the impedance vector (Z) (Figure 12) and is adjusted to the centre of the screen when the test piece has the same properties as the reference specimen. Any anomaly in the test piece will result in movement of the spot, the direction of movement being an indication of the cause of the anomaly. If more than one variable is present, since the position of the spot indicates direction and magnitude, the cause can often be determined by vector analysis.

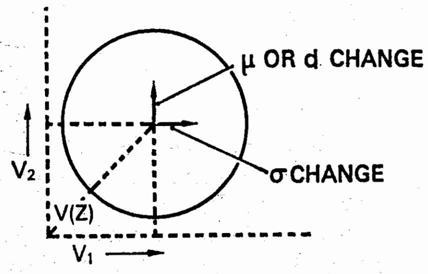

Figure 12 VECTOR POINT

5.3.2 **Ellipse Method.** A comparative coil arrangement is also used in this method. In the balanced condition a horizontal line is shown on the screen of the CRT whilst an unbalanced condition can be shown in either of two ways. One variable can be displayed by a change in the angle of the line and a second variable by the formation of an ellipse (Figure 13). By analysing the position and shape of the ellipse both variables can be evaluated.

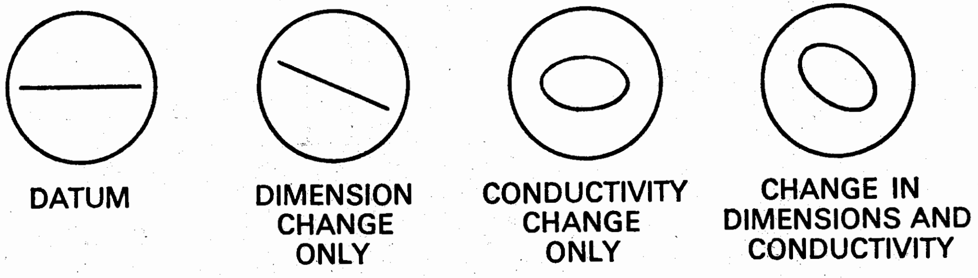

Figure 13 ELLIPSE METHOD

5.3.3 **Linear Time Base.** A spot moving across the screen at a constant rate can be adjusted to show the wave-form of the voltage from a comparative coil system. A change in impedance will alter the wave-form and either of the components of impedance can be measured by adjustment of the phase shift controls. To assist in measuring any changes, the screen is often fitted with a slotted cursor (Figure 14).

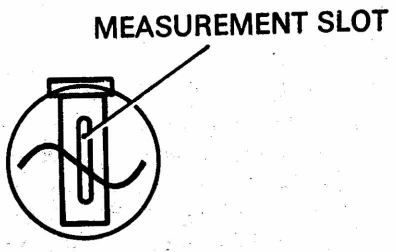

Figure 14 LINEAR TIME BASE

6 PROBES Unlike ultrasonic probes, the probes used in eddy current testing, because they are connected to the material by a magnetic field, do not require a coupling fluid, and no surface preparation is necessary other than the removal of any surface condition which would hinder free movement of the probe. Coils are also normally wound on a ferrite core, and this has the effect of concentrating the magnetic field and increasing sensitivity to small defects. Coils are often protected by enclosures in a plastics case, but the ferrite core is often left unprotected when required by particular test conditions. To maintain the coils in close proximity to the work it is often necessary to design a probe for one particular use only; some of the probes commonly used in aircraft work are discussed in 6.1, 6.2, and 6.3.

6.1 **Surface Probes.** Figure 15 shows two typical surface probes. (A) could be used for detecting surface cracks, and would be connected to a resonant circuit type of test set, whereas (B) could be used for coating thickness measurement or conductivity tests and would be connected in a bridge circuit type of test set. In the case of (A) a simple jig may be necessary to prevent spurious indications due to inadvertent probe angulation.

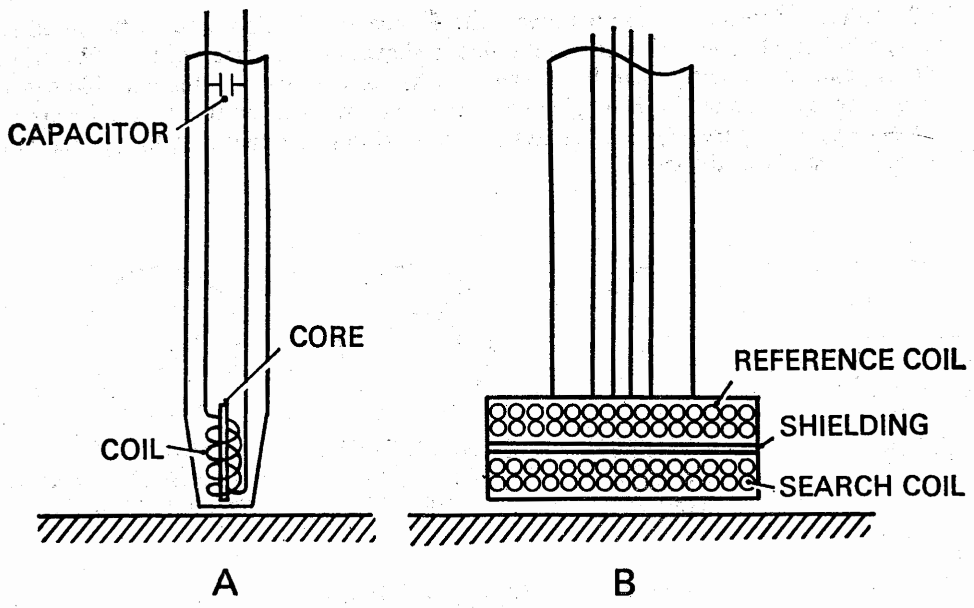

Figure 15 SURFACE PROBES

6.2 **Hole Probes.** Hole probes used during material manufacture would normally consist of a coil, the axis of which would be coincident with the axis of the tube under test, but in aircraft work a hole probe is normally located with the coil diametrically across the hole to achieve greater sensitivity. This type of probe is therefore a surface probe used for testing the surface of a hole. Figure 16 shows a typical hole probe of the latter type, the main use for which would be the detection of radial cracks round fastener holes.

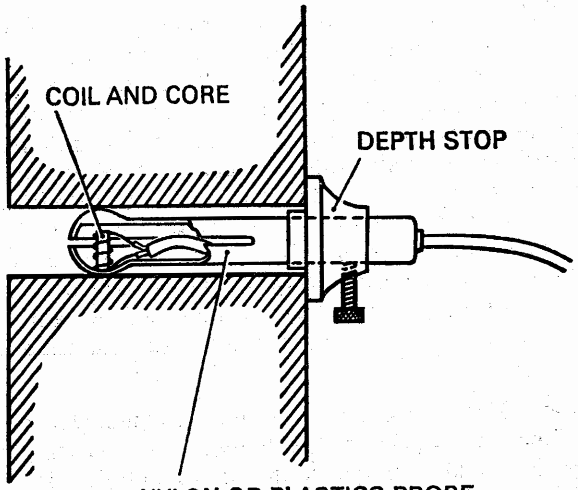

Figure 16 HOLE PROBE

6.2.1 The actual position of a crack can be determined by using an offset coil as illustrated, or by shielding one end of the coil.

6.3 **Special Probes.** Probes may be designed to suit any application, the object being to present a coil at a particular position on a component, so that information can be obtained from changes in the coil's impedance. Examples of the use of special probes would be for the detection of cracks in wheel bead seats, turbine engine compressor or turbine blades, and each of these probes could be connected to a single test set of suitable frequency and complexity. Probes are also designed with a view to eliminating the need for disassembly when carrying out routine maintenance operations.

7 REFERENCE PIECES In order to calibrate the equipment, standard reference pieces, manufactured from a material similar to that being tested, are necessary. These pieces should contain defects of known size and shape, so that the change in coil impedance against a known defect could be used as an acceptance limit.

7.1 A typical reference piece for surface crack tests would contain, for example, three cuts of different depths, the depth being marked adjacent to each cut, and the block being marked with the material specification. The test acceptance level could then be related to a signal of the same amplitude as that obtained on a specified cut in the block.

7.2 Reference pieces are usually small in size and can be taken to the test location so that quick cross-reference can be made between the reference piece and the test specimen.

NOTE: Since the manufacture of a reference piece involves the removal of metal (by saw cut or spark erosion), the phase and magnitude of the impedance changes will not be identical with those obtained from a natural crack of similar depth. For this reason, actual defective aircraft components are sometimes used to give comparative readings.

8 TYPICAL APPLICATIONS OF EDDY CURRENTS The eddy current equipment used in many material manufacturing processes is very sophisticated and completely automatic. Bar, tube and wire materials are normally passed through encircling coils of suitable size, and defects are both displayed on a cathode ray tube and recorded by tape or memory store. Audible warning, marking, and defective component rejection systems, actuated by the defect signal, are also often included. A recent innovation is the use of rotating probes through which bar material can be passed, the advantage of this method being an increase in the sensitivity to surface cracks. In aircraft maintenance work, however, eddy current equipment is usually restricted to conductivity tests and crack detection, mainly by the use of surface probes. Sophisticated equipment such as that described above is not normally required and equipment is usually portable and battery operated. The following paragraphs describe typical eddy current applications.

8.1 **Checking Fastener Holes for Cracks.** A suitable equipment for testing holes would be a simple impedance test set (i.e. not including phase analysing circuits) with lift-off control, and the probe would be similar to that shown in Figure 16, adjusted to be a snug fit in the hole. The reference piece should be of similar material to that being tested, and should contain holes of the same size as the probe with natural cracks or artificial notches at various depths in the hole to simulate cracks of maximum acceptable size.

8.1.1 The following procedure should be used when carrying out a test:—

(i) Clean loose paint, dirt, burrs, etc. from inside and around the holes being checked.

(ii) Calibrate instrument and adjust for lift-off in accordance with the manufacturer's instructions.

(iii) Insert probe in hole in reference piece and adjust depth stop to obtain maximum needle deflection from a selected notch or crack. Adjust sensitivity to give the specified scale deflection from the crack.

(iv) Insert probe in hole in test specimen and slowly rotate, noting and marking any holes producing needle deflections greater than that from the reference piece. Re-check probe in reference piece frequently.

NOTE: Any ovality in hole diameter will give a meter deflection which can be confused with the signal from a crack. Generally the indication from ovality shows a much slower change than that from a crack as the probe is rotated.

(v) Repeat (iii) and (iv) at incremental depths to cover the hole surface completely.

(vi) Ream out marked holes as recommended by aircraft manufacturer and repeat test with an appropriate sized probe and reference piece hole.

8.2 **Checking Heat Damaged Skin.** The conductivity of aluminium alloy sheet will increase with exposure to elevated temperatures up to approximately 500°C, and above this temperature obvious signs of damage such as melted or charred metal become apparent. Tests conducted on the surrounding material will show the extent of the area in which the metal is below strength requirements and must be replaced.

8.2.1 The acceptable range of conductivity readings depends on the type of material and its heat treatment condition, and these readings may be stipulated in the appropriate Maintenance Manual. As a rough guide, the conductivity of unclad 7075-T6 material is 31 to 35% IACS, but the important reading in relation to heat damage is the change in conductivity between sound and defective material.

8.2.2 A conductivity meter should be used for this test, and this will normally be an impedance change instrument, with a meter and separate scale graduated in percentage IACS. This equipment is supplied with a surface probe and two test samples, one of high purity copper (with high conductivity) and the other a material of low conductivity, for calibration purposes.

8.2.3 The following procedure should be followed when carrying out the test:—

(i) Thoroughly clean area to be inspected.

(ii) Calibrate instrument in accordance with the manufacturer's instructions.

(iii) Place probe on sound skin of similar material and thickness and remote from the heat affected zone, and adjust scale until meter is zeroed. Compare this reading with the expected conductivity.

(iv) Check conductivity all round the affected area, noting any meter deflection, and marking the skin accordingly. By this means a demarcation line can be drawn round the damaged area, and material removed up to this line.

8.3 **Detection of Corrosion.** Corrosion on hidden surfaces can be detected by eddy current methods using phase sensitive equipment. If a reading at the normal thickness of a sheet material can be taken, since corrosion reduces the thickness of a sheet, when the probe is over a corroded area a different reading will be obtained. The equipment can be set up by noting the readings obtained from a sound material of, say, 90% of the thickness of the test specimen, and a rough estimation of the volume of corrosion beneath the probe can be obtained during a test.

8.3.1 Equipment is available which is specially designed for thickness measurement having a meter graduated in appropriate units, but any equipment operating at a frequency which would give a penetration depth at least equal to the sheet thickness could be used to give an indication of the presence of corrosion. Equipment designed for detecting surface cracks and operating at very high frequency would be unsuitable.

8.3.2 Care is necessary when checking for corrosion to ensure that underlying structure (stringers, frames, etc.), chemically contoured areas, and loose debris, do not cause misinterpretation of results.

8.4 **Material Sorting.** Provided that a known sample is available, eddy current equipment can be used to ensure that a batch of materials is correctly identified, or that a component is made from the correct material. Simple impedance equipment could be used for coarse sorting, but in order to differentiate between materials closely related in composition, equipment with phase sensing circuits is necessary. By placing the known sample in an encircling coil the characteristic trace of that material can be displayed on an oscilloscope and unknown samples accepted or rejected by comparison.

8.5 **Coating Thickness Measurement.** The thickness of conducting or non-conducting coatings on ferrous or non-ferrous bases can be measured using basic eddy current methods; although measurement becomes difficult where the conductivity of the coating and base metal are similar. It is possible to utilise crack detection equipment for measuring thick coatings, by comparing the readings obtained from the test specimen with the lift-off effect obtained when the probe is placed on slips of non-conducting material (e.g. mica) of known thickness. When measuring very thin coatings however (i.e. less than 0·12 mm (0·005 inch)), it is recommended that equipment designed specially for coating thickness measurement should be used.

9 REFERENCE MATERIAL Further information on eddy current theory and operating principles may be obtained from the following publications:—

Standards

BS 3683 Terms Used in Non-destructive Testing.
Part 5, Eddy Current Flaw Detection.

BS 3889 Methods for Non-destructive Testing of Pipes and Tubes.
Part 2A, Eddy Current Testing of Ferrous Pipes and Tubes.
Part 2B, Eddy Current Testing of Non-ferrous Tubes.

Text Books

Non-destructive Testing Handbook Vol. II, 1963, by Robert C. McMaster.
(The Ronald Press Co.)

Non-destructive Testing, 1968, by William E. Schall.
(Machinery Publishers Ltd. London)

Non-destructive Testing No. CT-6-5, 1967,
(General Dynamics, Convair Division)

Electromagnetic Testing Handbook H54, 1965,
(Office of Assistant Secretary of Defense, Washington.)

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BASIC

NON-DESTRUCTIVE EXAMINATIONS

ENDOSCOPE INSPECTIONS

1 INTRODUCTION This leaflet gives guidance on the use of endoscope inspection equipment (also known as boroscope, introscope or fibrescope equipment, depending on the type and the manufacturer) for the assessment of engine serviceability, both on a routine basis and for the investigation of developed defects. Although endoscope inspections are utilised in other areas, the information in this Leaflet is intended primarily for the inspection of gas turbine engines; it is not related to any particular engine and should, therefore, be read in conjunction with the relevant Maintenance Manuals and approved Maintenance Schedules, which should also be consulted for specific damage and time limits.

1.1 Endoscope equipment permits the inspection of gas turbine engine parts which would otherwise be inaccessible with the engine installed and in service. Early gas turbine engines had poor provision of ports for this type of inspection, apart from the igniter plug and burner holes, but engine manufacturers now tend to provide improved facilities for endoscope inspection of the rotating and combustion sections of the engine. Other large engine components may also have limited facilities, as do some airframe air-conditioning turbine units, etc.

1.2 Engineers should be conversant with the techniques of endoscope inspection to enable them to use the equipment as an effective inspection and diagnostic tool and as part of normal inspection procedures. This form of use will result in a more effective assessment being made of damage caused by an in-service incident such as a bird strike or foreign object ingestion.

2 ENDOSCOPE EQUIPMENT Manufacturers of endoscopes tend to market the complete range of units required and it is, therefore, unusual to be able to interchange parts of one system with those of another. The following general description of the equipment is not related to any particular manufacturer and should be read in conjunction with the appropriate manufacturer's technical instructions or service manual.

2.1 **The Probe.** The probe is an optical instrument which performs two functions; (a) it relays and directs a beam of light for illumination, and (b) it displays a focused and undistorted image at the eye-piece. Probes differ in that some have an integral light source, while others rely on a remote 'light box'; another version has a small bulb at the tip of the probe to provide the illumination. In addition, facilities for adjusting the focus and magnification may be incorporated.

2.1.1 The probe shaft usually consists of concentric tubes, the inner one of which is the view tube, while the outer one provides a separate light path for the illumination beam. This beam is carried through an annular 'fibre optic bundle' to the tip where the necessary change in direction is made through prisms. The image is modified throughout its travel through the view tube by a series of lenses and may also be changed in direction by the same method.

2.1.2 At the tip, the prisms are protected by windows which prevent dust, grit or direct contact harming the optical clarity of the image. If the probe is of the non-adjustable type, the angle of view at the tip will be marked and there are the following four variations:

(a) Straight view, where the centre of the field of view is parallel to the probe shaft.

(b) Lateral view, where the centre of the field of view is at right-angles to the probe shaft.

(c) Oblique view, where the centre of the field of view is at an oblique angle to the probe shaft.

(d) Retro view, where the centre of the field of view is at an acute angle to the probe shaft, resulting in an amount of doubled-back view.

2.1.3 The field of view is designed to give a fairly useful amount of visible area and magnification at the kind of distances required in the internal inspection of a gas turbine engine. The eye-piece makes the final adjustment to the image before visual perception, and provision is usually made here to indicate the relative direction of view with respect to the engineer. An array of inscribed lines, called a graticule, is sometimes provided to indicate, under specific conditions of use, a measurement of distance useful for damage assessment. Accessories can enable a still camera to be used to provide a permanent record of defects, etc., and television and video equipment can be used for applications where direct access to the probe would be uncomfortable or unsafe.

2.1.4 Flexible endoscopes (Figure 1) rely on fibre optic bundles to transmit an image in the same way as the illumination beam is transmitted along the rigid probes. However, for the transmission of an image, the relationship of each fibre to all of its neighbours must be the same at the eye-piece as at the probe tip. The image bundle and the illumination bundle are concentric with each other, with the image bundle forming the central core. The flexible probe tips are usually changeable and are of less elaborate construction, allowing the tip to be shorter, thus not having a cumbersome non-flexible end to restrict use in a confined space.

2.1.5 Migration of fluids by capillary action along the bundles between the individual fibres is prevented by the application of a transparent resin to the bundle ends. Compression, twisting and kinking of the fibre optic bundles is prevented by fitting the bundles in a flexible conduit, normally of spiral or 'armadillo' construction, which will restrict the manipulation of the probe to within the capabilities of the bundles.

2.2 **The Light Source.** Most endoscope equipment now in use utilises a separate and remote light source to illuminate the view area. This normally takes the form of a self-contained 'light box' containing the lamps, transformers, switchgear and cooling fans to provide a high-intensity beam. This beam is focused upon an adaptor in the box to which the fibre optic light bundle from the probe is connected. Quartz/halogen or quartz/iodine lamps provide the source of light, which may be varied in intensity to suit both the application and personal preference. Mains power supplies are normally used although some equipment can be arranged to allow typical aircraft voltages and frequencies to provide the system with power.

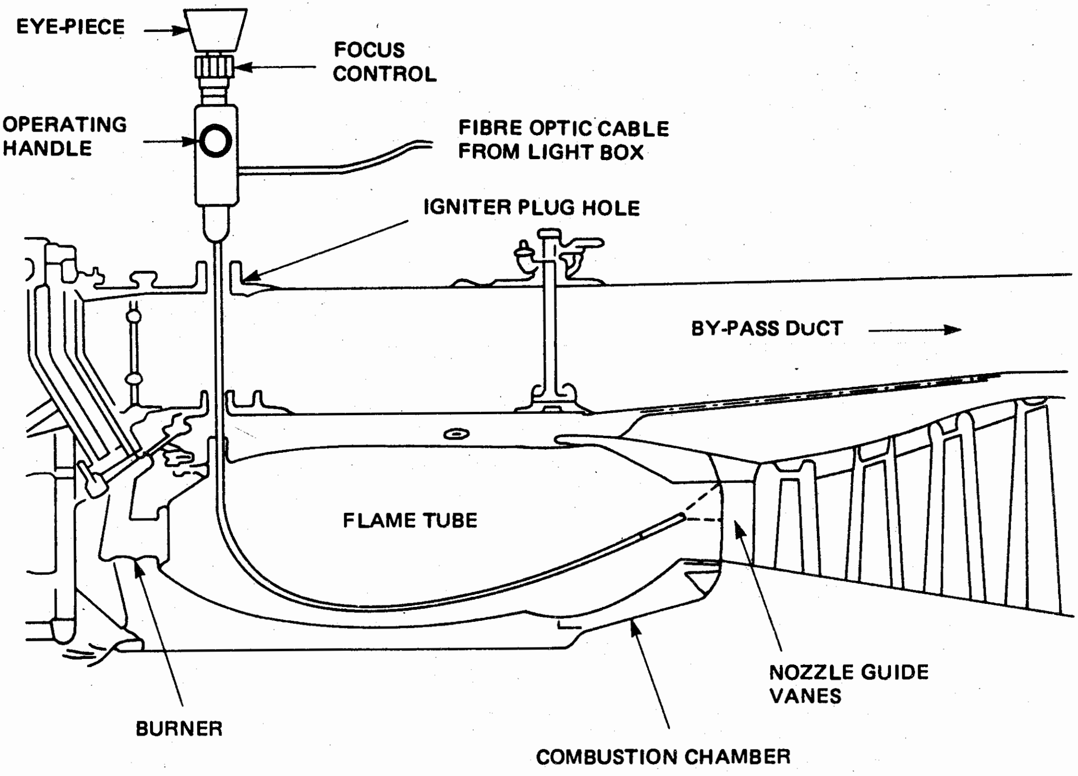

Figure 1 FLEXIBLE ENDOSCOPE INSPECTION EQUIPMENT

3 PREPARATIONS

3.1 **Precautions.** Consideration must be given to the potential hazards involved in the inspection of gas turbine engines while under ramp or first-line maintenance conditions, and special precautions should be taken because of the engineer's pre-occupation at the engine. A dangerous situation could occur in the event of the inadvertent operation of a starting system, ignition system, thrust reverser system or any mechanical or electrical controls; these systems should therefore be inhibited.

3.2 Other factors to be considered when inspecting engines under these conditions include:

(a) Dissipation of residual heat.
(b) Effect of windmilling.
(c) Endoscope equipment contamination.
(d) Electrical potential difference between the probe/light source and the aircraft structure.
(e) Fuel and oil leakage.

3.3 **Access.** Engines designed for endoscope inspections have access ports fitted with blanking plugs at various points in the casings, and the areas visible through these parts are detailed in the relevant Maintenance Manual. However, if specific access is not provided, a general knowledge of the layout of the engine together with the access provided by the removal of igniter plugs, temperature probes, pressure sensing lines, compressor bleed valves and other air off-takes enables useful condition assessments to be made. Forward view endoscopes can also be used to view through the air intake of an axial flow compressor or, to a more limited degree, through the turbine, the latter being restricted because of the greater curvature of nozzle guide vanes.

3.3.1 Access-port blanking plugs are subject to high temperatures and high rates of temperature change. This has the effect over a period of time of 'pinching' the blanking plugs to a higher torque than was applied at assembly. During removal, therefore, care must be taken to select a spanner which is a good fit on the plug and which will provide adequate leverage. Plugs which are fitted into blind holes in engine casings invariably have thread inserts and these, under high torque removal stresses, can become extracted with the plug and will require replacement.

3.3.2 The 'pinching' effect can be overcome to a certain extent by applying an anti-seize compound when fitting the blanking plugs. Manufacturers usually recommend the application of a graphite-based release agent which forms a dry film on the threads. Alternatively, a paste with metal or metal oxide content is applied. Neither paste nor dry film should be applied unless it can be established which of the compounds had been used previously, as any mixing will result in the formation of a hard-setting compound.

NOTE: In consideration of this 'pinching' effect, the initial torque settings for the blanking plugs must be those recommended in the relevant Maintenance Manual.

3.4 **Orientation.** Familiarity with the layout of an engine and experience in the use of endoscope equipment enables an engineer to recognise the area being viewed and the extent of inspection possible through a given access port.

NOTE: Parts frequently appear larger when viewed through an endoscope and damage can seem more extensive than it really is. Familiarisation with the size (height and width) of the item being viewed is therefore essential and ideally a spare part should be available to be held in the hand and viewed with and without an endoscope probe to ensure the item is correctly assessed.

3.5 Non-rotating assemblies cause few problems because major components such as burners and stators provide points of reference. Damage reporting on non-rotating components requires that burners, flame tubes, etc., be numbered to a standard form and that areas and components are named. An inspection report can then identify areas of damage by stating:

(a) Access port used.
(b) Direction of view.
(c) Area or component inspected (by name and/or number).
(d) Dimensions of and type of damage.

3.6 Components of rotating assemblies need to be identified for the same reasons. At overhaul, marks may be applied to the convex surface of turbine blades, together with the balance details normally applied, to number the blades consecutively around the disc. This procedure will enable positions to be fixed for the parts of the whole spool connected to that turbine. For instance, if HP turbine blades are numbered, HP compressor blades can be identified by stating:

(a) Compressor access port used.
(b) Direction of view.
(c) Details of damage.
(d) Turbine access port used.
(e) The turbine blade number visible at the centre of the field of view.

3.7 The number of blades in a particular compressor or turbine stage should be known and the blades counted while viewing to ensure that all blades in the stage are checked. When viewing large blades, such as early compressor stages, it will be necessary to make two or three passes to cover the complete blade length, i.e. view the outer third of the aerofoil, mid span section and inner third adjacent to the inner platform.

3.8 If damage is found on a rotating assembly which has no consecutive numbering of blades, point reference must be established by using an externally or internally recognisable point on the rotating assembly. Again, access ports must be stated and consecutive blades must be counted to locate the point of damage.

3.8.1 For ease of inspection, the HP shaft can be rotated (at a suitable speed to permit a satisfactory inspection) by an air-driven motor through the high-speed gearbox on engines with a drive facility; otherwise, hand-turning may be accomplished by using either a redundant component drive coupling or a standard socket fitting in the gearbox. Air-driven motor systems in general use have hand or foot controls to vary direction and speed; this is an advantage over using the hand-turning method which requires one person to turn the shaft while another performs the inspection.

3.8.2 LP shafts must be turned by hand, and to rotate an Intermediate Pressure shaft in a three-spool engine, without a gearbox, a locally-made tool may be required to turn the shaft through the IP intake.

4 INSPECTIONS One of the reasons for the increased use of endoscopes is the high cost involved in engine changes, either due to suspected internal damage or because of a Maintenance Schedule based on a "Hard Time Life" philosophy. It is, therefore, an advantage to allow the engines to remain in service until defects are revealed via performance analysis, oil analysis, endoscope inspection, or by repetitive monitoring of allowable damage.

4.1 **Scheduled Inspections.** Scheduled inspections are the regular ones which are carried out as part of an approved Maintenance Schedule. The frequency of such inspections is dependent upon either engine cycles or flight time and need not be concurrent with the aircraft's scheduled checks. The combustion section and the turbine blades are the primary concern during these inspections, due to the high stresses and temperatures encountered during service. All defects should be recorded, normally on a chart specific to the engine type, which after completion constitutes a record of any deterioration taking place within that particular engine. An assessment can then be made as to whether the engine may be allowed to continue in service until the next scheduled inspection, or that it may only continue in service subject to more frequent checks.

4.2 **Special Inspections.** Occasionally, experience gained by frequent endoscope inspections, in-service failures or inspection during overhaul highlights the development of particular defects which can be monitored using endoscopes while the engine continues in service. Normally only one or two access ports need be disturbed because it is only the area detailed by the special inspection which needs assessing. This again enables the engine either to continue in service or to be monitored even more frequently.

NOTE: Engines are often removed after scheduled or special inspections to prevent a primarily minor defect causing secondary damage, possibly leading to engine failure.

4.3 **Non-scheduled Inspections.** Endoscopes can be used to great effect when it is necessary to assess the damage caused by foreign object ingestion or engine surge, diagnose the cause of developed defects, and provide a means of establishing engine serviceability following excursions beyond the normal turbine temperatures or maximum power limits. Together with other basic visual techniques of inspection, the use of endoscopes may, under certain circumstances, provide the necessary evidence to permit an aircraft to fly back to base for repair when it would otherwise require an immediate engine change.

4.4 **Final Inspection.** On completion of an endoscope inspection, it is essential that all access plugs are refitted correctly and securely. Failure to do so could cause a gas leak and result in a fire warning, shut-down and turn-back or in some cases cause a failure due to blade flutter or loss of cooling air. Access panels must also be correctly refitted.

5 APPLICATION Components normally inspected with an endoscope, such as compressors, combustion sections and turbines, are subject to different types of damage and defects; therefore, actual limits and the specific forms of defects can only be found in the relevant Maintenance Manual.

5.1 **Compressors.** Endoscope inspections after such occurrences as foreign object damage (FOD), bird strikes or surge, must be systematic, not confined to single stages, and always preceded by a comprehensive external visual examination. In addition to the endoscope ports provided, it may be possible to use bleed valve apertures and air-sensing probe points to inspect the compressor.

5.1.1 The most common form of damage to compressors is FOD. Centrifugal compressors have proved to be fairly damage-resistant but axial compressors are not so resistant to FOD and are also subject to surge damage. Inspection of axial compressors and their blades should, therefore, always include a search for evidence of FOD in all its manifestations—nicks, dents, scratches, and the cracks which these defects may produce.

5.1.2 Surge damage may be in the form of trailing edge cracks at the blade root, rubbing marks on the blade platform or blade shroud, with perhaps damage to the spacer plates between the blades. Interference between tips or shrouds and the casing can occur during surge and may bend blade tips, cause cracks, etc. Interference between rotors and stators (clanging) is a more serious defect because of the likelihood of substantial deformation. Engine manufacturers normally know the type of damage which may be caused to their engines during surge, and the Maintenance Manual may, therefore, indicate which particular stage or stages need to be inspected and which defects are particularly indicative of surge damage.

5.1.3 Grime and oil deposits may form on the compressor blades over a period of time. Excessive oil deposits are usually an indication of front bearing oil leakage or general wear in the engine. Where engines are operated in sandy conditions, dust tends to stick on the rear of the compressor if there are oil deposits present, and such engines could benefit from compressor washing procedures.

5.1.4 Compressor blades which have mid-span shrouds (or clappered blades) are sometimes subject to wear at the point where the end of each shroud abuts its neighbour. On 1st stage LP or fan blades this wear is recognised and can be measured by taking up the total free play of the whole stage, by moving half the blades clockwise about their mounting pins and the other half anti-clockwise; this leaves a gap between one pair of blades which represents total shroud wear. Of course, this procedure will not be suitable for other than fans or 1st, and maybe 2nd, stage LP blades. Inspection of mid-span shroud wear through an endoscope is confined to a close and clear view of abutting shrouds. Shrouds which are wearing may be recognised by:

(a) Metallic streaking from the join.

(b) A wavy, uneven join line.

(c) Hammering (which is where the abutting faces deform, like chisel shafts under the effects of frequent hammer blows).

5.1.5 Whatever damage is found on compressor blades, its position on the blade will determine its seriousness. It is usual for the inner one-third of the blade to be classified as a 'no damage allowable' area, as are the areas on each side of mid-span shrouds.

5.2 **Combustion Section.** High temperature is the reason for most combustion section defects. Burning, cracking, distortion, and erosion of nozzle guide vanes (NGVs) are typical. The combustion section may be inspected with an endoscope either through the designated access ports or through the igniter plug holes or burner apertures. The components visible depend, of course, upon engine design and the position of the access ports, but the flame tubes or liners, burner flares and swirlers, tube interconnectors and the NGV leading edges are normally inspectable.

NOTE: In the combustion section, all defects must be assessed on the basis of the likelihood of the defect causing a breakaway of material. This could lead to greater damage occurring in the turbine.

5.2.1 **Burners.** The burners protrude into the forward face of the flame tube/liner through an aperture which is usually flared; this is sometimes called the burner flare. The burner must be concentric with this flare otherwise a loose flare or burner should be suspected. In an annular combustion chamber, the burners and flares are separated by blank segments, and these must be secure.

5.2.2 The burners may develop carbon deposits, which can be in the form of an irregularly-shaped protuberance from the burner face. In some engines this has a detrimental effect on starting, but when it breaks off it rarely causes any damage because it is usually soft. Hard carbon, however, can block the burner spray nozzle but does not grow large enough to cause break-off damage.

5.2.3 Swirlers (or swirl vanes) should be inspected for security and missing elements. All components should be inspected for cracks.

5.2.4 **Flame Tubes/Liners.** Flame tubes (or, in annular combustion chambers, the liners) contain the flame by directing air through holes or slots to the centre of the tube. The whole surface of the tube is peppered with cooling holes of varying sizes arranged in a regular pattern, and these are usually the starting points for cracks and sometimes determine the limits of cracks. For instance, the Maintenance Manual may state that axial cracks which extend rearward beyond the third row of cooling holes are unacceptable. The allowable limits for cracks can depend on both their position and length. To assess their length through an endoscope must at times be a matter of estimation. The engineer should, however, be aware of the general dimensions of the component being inspected (these are sometimes stated in the Maintenance Manual, otherwise familiarity with the components is required); from this a near estimate can be made of crack length. The flame tubes should be inspected for cracks and other damage as follows:

(a) **Cracks.** These start at holes or edges and may stop when they reach another hole or edge. Circumferential cracks can be more serious than axial cracks as they can result in pieces breaking off under the effect of airflow and flame impingement. Cracks around dilution chutes (scoops or nozzles into the airstream) are usually considered to be serious, since any distortion of the chute may create hot-spots which will accelerate deterioration and may cause torching of the flame onto the air casing.

(b) **Distortion.** Usually, defined limits give the allowable amount of distortion into the airstream and the length of cracks associated with it. The construction of a flame tube normally includes sections which overlap each other; these overlaps allow cooling air to flow near the surface of the tube. The sections are joined by a 'wigglestrip' (corrugated spacer) which allows air to flow through the overlap. The wigglestrips should be inspected for security because the welds can fail, causing distortion of the strips into the airstream of the tube. Limits for this damage are measured in numbers of adjacent or total wigglestrip pitches affected.

(c) **Burning and Hot Streaking.** The high temperature materials used for the flame tubes/liners sometimes change colour quite dramatically with heat, so coloured areas alone may not indicate serious burning. Burning is caused by the flame approaching the tube/liner and is recognised by the texture of the surface; this becomes rough and pitted, and a reduction of wall thickness is noticeable. Streaks of metallic particles sparkle under the high intensity light of the endoscope and are recognised this way. Edges of lips and overlaps are susceptible to burning and erosion. Burn limits depend upon position and area.

(d) **Holes.** These can be caused in three ways; (i) pieces breaking off, (ii) cracks allowing a section of metal to be lifted off and (iii) burning through. Holes in a flame tube/liner need not be a reason to reject an engine. However, the turbine should be inspected if the hole was caused other than by burning through. Carbon deposits produced at the burner can sometimes be mistaken for holes as the carbon is an intense black; the angle of view of the suspected hole should be changed if any doubt exists. If the suspected hole is a carbon deposit no detail of the edge of the 'hole' will be visible, neither will any detail through the 'hole'.

(e) **Nicks and Dents.** Inspection should be extended to the NGVs if this damage is found because these are evidence of broken-off particles or FOD.

5.2.5 **Nozzle Guide Vanes.** The NGVs are subject to very high thermal and mechanical stresses, and only the newest of engines do not show physical signs of this when inspected through an endoscope. If viewed from the igniter plug holes, the leading edges and some concave surfaces only will be visible. Access ports are required elsewhere to view the whole surface of NGVs as they are highly cambered. Rows of cooling-air holes are visible on most NGVs and these may be used to identify areas of the vane. Damage can be as follows:

(a) **Discoloration.** Slight discoloration is nearly always present and is not necessarily a defect. Heavy discoloration, however, is associated with burning.

(b) **Cracks.** These are allowable to a limited extent but if associated with lifting of the surface from the original contour they are not acceptable. Cracks are either axial (from leading edge to trailing edge) or radial (vertical) and their allowable length will depend on their direction; those which converge or are in convex surfaces may well necessitate engine rejection.

(c) **Burning and/or Erosion.** Erosion, although caused separately from burning, is usually found in the same areas as burning and is subject to the same limits. Erosion is the product of abrasion and looks like burning without the discoloration; that is, roughness and pitting with a noticeable reduction in skin thickness. Burning and erosion are most common on NGV leading edges and concave surfaces. They may penetrate the outer skin and are sometimes allowable, but again subject to position and size of area affected.

(d) **Dents and Nicks.** These are caused by FOD and further inspections should be carried out if they are found.

(e) **Tearing.** Tearing can occur in trailing edges and is allowable only within defined limits.

5.3 **Turbine Section.** Access for the endoscope inspection of turbine blades is either through the ports provided or sometimes through the igniter plug holes using a flexible endoscope (flexiscope). For this, a holding tool can be made which is fed through the igniter plug hole and fixed. The flexiscope is then inserted and the holding tool guides the tip through the NGVs to view the blades. Methods of identifying blades are explained in paragraph 3.6.

NOTE: When viewing the aerofoil surface of a turbine blade, the end of the probe is located between the blades and must be withdrawn prior to engine rotation to avoid damaging the probe and blades.

5.3.1 Turbine blades are subject to the same types of damage and defects as NGVs. The limits for such damage are, however, more stringent. Blades can have some leading edge damage and cracking but still remain in service; trailing edge cracks, however, can propagate quite quickly due to tearing forces imposed by centrifugal force and the twist of the blade, and these cracks are not normally allowable. Dents on aerofoil surfaces of hollow turbine blades can initiate cracks on the cooling-air passage wall inside the aerofoil section which can propagate to form quite large internal cracks before breaking through and becoming visible.

5.3.2 Deposits can form on most internal parts of gas turbine engines. When airborne sand is ingested it usually accumulates on the NGV and turbine blade leading edges. It has a sandy colour and becomes baked on by the combustion process, and is not easily removed even at engine overhaul. It can cover some cooling holes but does not usually cover significant NGV or turbine blade defects. Its effect on inspections is therefore minimal, but its overall effect is to shorten engine life.

5.4 **Record of Damage.** When damage is found it must be recorded in the engine records. This is the case whether the inspection was routine or a special one. Increases in crack length, for instance, can then be assessed over a period of time, thus giving time to arrange for repairs or removal. Some operators have introduced inspection sheets for use when carrying out routine and special endoscope inspections. The sheets detail the preparation work necessary before inspection and also include drawings which depict blades or flame tubes; engineers then mark in observed defects and identify the drawings accordingly. These representations of the internal state of each engine then form part of the engine's records and can be used in future assessments of damage and the growth of existing damage. Photographic records may also be kept, using a still camera or video tape recording.

5.4.1 The Maintenance Manual will sometimes define a defect as acceptable for a finite number of flying hours or cycles. Engineers should, therefore, ensure that additional entries are made in log books and/or technical logs to limit engine operation to the periods allowed. If, however, inspection reveals that different defects exist which are related, each with a finite allowable number of flying hours, the engineer should consider certifying such defects as allowable only for a shorter time than the most restrictive of the allowances given.

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BASIC

HEAT-TREATMENT

WROUGHT ALUMINIUM ALLOYS

1 INTRODUCTION This leaflet gives guidance on the heat-treatment of wrought aluminium alloys. The recommendations apply only to those alloys which require solution treatment or precipitation treatment ; they do not refer to the non-heat-treatable alloys which achieve their strength through cold work.

1.1 Aluminium alloys of widely varying compositions and strengths are used in aircraft structures, and they each attain their optimum properties by a specific heat-treatment process. The process may consist of solution treatment followed by natural ageing, or solution treatment followed by precipitation treatment.

1.2 Except in special circumstances, e.g. when a drawing specifies a particular procedure, or when a special process for a specific batch is covered by endorsement of the Approved Certificate, the heat-treatment procedure prescribed in the relevant specification must be followed.

NOTE : The relevant specification may, in some instances, be a specification prepared by the aircraft constructor.

1.3 Heat-treatment is sometimes necessary to soften materials for manipulation purposes, and this is done either by annealing or by solution treatment, depending on the extent of the proposed manipulation. When material has been annealed, it is essential that its specified properties should subsequently be restored by the application of the full recommended heat-treatment process. Solution treatment of artificially aged alloys must be followed by precipitation treatment.

1.4 When it is foreseen that extensive manipulation will be necessary materials are sometimes ordered in the annealed or "as-manufactured" condition. Great care must be taken to ensure that such material is correctly heat-treated after fabrication.

1.5 If any delay is envisaged between the various operations of the heat-treatment process, e.g. between solution treatment and precipitation treatment, the material should be treated with a temporary protective to prevent the possibility of a corrosive attack.

2 SOAKING TIME The soaking time is the period during which the material is held at the required temperature, and is considered to commence when the temperature of the load (or charge) has reached the specified minimum. The time required to reach this condition will depend on the nature of the load and its spacing in the bath or furnace, but the aim should be to bring the load to the soaking temperature as quickly as possible. Typical soaking times for materials in various forms are given in Tables 1, 2 and 3, but actual times can only be determined by experience of the particular plant.

3 LIMITATION OF HEAT-TREATMENT Clad sheet should not be heat-treated more than three times, since the corrosion resisting properties of the material may be reduced due to diffusion through the cladding of copper from the core.

4 ANNEALING This process softens the material for manipulation purposes and consists of heating the material to a temperature some 100 to 200°C below that specified for solution treatment. The soaking period is followed by cooling in air at room temperature.

4.1 When materials, other than clad alloys, are required in a particularly soft condition, a "super-anneal" can be given. This consists of soaking the material at 400-425°C for at least one hour, followed by slow cooling at about 15°C per hour down to 320°C and finally cooling in air. In general, longer soaking times and slower cooling rates result in greater softening, but in no circumstances should materials be heat-treated by an unauthorised process.

4.2 Some age hardening will take place after the material has been annealed, and it is recommended that all severe manipulation should be completed within 24 hours of annealing.

4.3 Table 1 indicates typical soaking times for annealing wrought aluminium alloy forgings, bars and extrusions. The soaking time for sheet material of all thicknesses is usually about one hour.

4.4 Special care is necessary in the storage of material in the annealed condition to prevent the possibility of distortion.

TABLE 1

HEAT-TREATABLE WROUGHT ALUMINIUM ALLOYS
FORGINGS, BARS AND EXTRUSIONS

Size	*Time*
Bar up to ½ in. diameter	1 hour
Forgings up to 3 lb. and bar up to 1¼ in. diameter	1¼ hours
Forgings up to 1¼ in. max. section and bars up to 4 in. diameter	2—4 hours
Forgings up to 4 in. max. section and bars up to 8 in. diameter	4—8 hours
Large complex forgings	8 hours

5 SOLUTION TREATMENT For materials finally required in the naturally aged condition, the primary purpose of solution treatment is to alter the structure of the material so that an improvement of strength will occur during the ageing process. A similar situation exists for materials finally required in the precipitated condition.

5.1 The process consists of heating the material to a prescribed temperature (with the object of taking the alloying elements into solution) maintaining it at that temperature for a suitable period, and then immediately quenching it, usually into cold water, but sometimes, to reduce quenching stresses, into hot or even boiling water.

5.2 Solution treatment at a temperature lower than the specified minimum, or a delay in quenching, can result in the material having reduced mechanical properties. Conversely, treatment at a temperature in excess of the specified maximum is likely to cause burning or overheating, producing an impairment of the mechanical properties which cannot be restored by re-heat-treatment, resulting in the scrapping of the material. Guidance on the temperature control of heat treatment plants is given in paragraph 14.

5.3 Prolonged holding of clad alloys at solution treatment temperatures will affect the material in a manner similar to that described in paragraph 3.

5.4 When material is manipulated in the solution-treated condition, it is desirable that cold bending and similar work should be completed as soon as possible, but in any case within two hours of quenching. In instances where manipulation processes would exceed this period, the material should be annealed as described in paragraph 4.

5.5 **Solution Treatment of Sheet Metal.** Sheet material is usually solution treated in a salt bath, but a gas or electrically-heated muffle furnace of the fan-assisted, air circulation type is also suitable. Table 2 lists typical soaking times for sheet material of various thicknesses.

TABLE 2

Gauge	*Time*
26 S.W.G.	8 to 12 minutes
24 S.W.G.	11 to 15 minutes
22 S.W.G.	12 to 18 minutes
20 S.W.G.	14 to 20 minutes
18 S.W.G.	17 to 23 minutes
16 S.W.G.	20 to 26 minutes
14 S.W.G.	24 to 30 minutes
12 S.W.G.	30 to 36 minutes
10 S.W.G.	34 to 42 minutes
8 S.W.G.	43 to 49 minutes
3—6 S.W.G.	50 to 60 minutes

5.5.1 The requirements of British Standard L72, together with its allied standards L70, L71 and L73, are specific regarding the temperature range for solution treatment, and this governs treatment both by the material manufacturer and the user. However, experience has shown that the effects of the solution treatment of sheets in large batches, as practised by the material manufacturer, and the re-solution-treatment of the same material as individual pieces, or in small batches, by the user, may differ considerably. For example, the material manufacturer may use a temperature at the upper limit without difficulty, yet the same material solution-treated in small quantities at a similar temperature, may give rise to cracking troubles.

5.5.2 When re-solution-treatment of the material in small batches is necessary, it is recommended that a temperature towards the lower end of the temperature range should be used.

5.5.3 When material, and particularly thin sheet, is moved from the solution treatment plant to the quenchant, it is essential that it should be handled smoothly and carefully. Rough handling at this stage can in itself give rise to cracking troubles, irrespective of the heat treatment temperature.

5.6 **Solution Treatment of Bars, Extrusions and Forgings.** The solution treatment temperatures of some of the alloys used for such sections and components are critical, in particular L65, where even a short period in excess of the permitted maximum can be detrimental. Typical soaking times for bars, extrusions and forgings are given in Table 3.

TABLE 3

HEAT-TREATABLE WROUGHT ALUMINIUM ALLOYS
FORGINGS, BARS AND EXTRUSIONS

Size	*Time*
Bar up to ½ in. diameter	1 hour
Forgings up to 3 lb. and bar up to 1¼ in. diameter	2 hours
Forgings up to 1¼ in. max. section and bars up to 4 in. diameter	4 hours
Forgings up to 4 in. max. section and bars up to 8 in. diameter	6 hours
Large complex forgings	8 hours

5.7 **Rivets.** The procedure applicable to the solution treatment of rivets is given in Leaflet **AL/7-5.**

6 QUENCHING

On completion of the soaking period, the material should be quenched in water with as little delay as possible. To ensure correct cooling, the material should be left in the quenching tank until its temperature is the same as that of the quenchant. Where cold water quenchant is used, the temperature of the quenchant should not be allowed to rise above 20°C, and 30°C is regarded as an absolute maximum ; to ensure this, the quenching tank should contain an adequate quantity of water, preferably with provision for a continuous flow of fresh water.

6.1 The most critical problems in regard to solution treatment are concerned with quenching, particularly when treating dimensionally large extrusions and forgings. Parts manufactured of high strength aluminium alloys may be cracked by the high stresses induced by rapid quenching, as may also some parts manufactured of medium strength alloys.

6.2 When hot components are quenched, the outer layers are cooled more rapidly than the centre, so that they tend to shrink and may be compelled to yield plastically. As heat is conducted away from the centre, the inner material also endeavours to shrink, and thus becomes stressed in tension. This usually induces compressive stresses in the outer layers so that the final locked-up stress system is tri-axial tension at the interior and bi-axial compression just below the surface.

6.3 In view of the undesirability of such stress systems, parts are sometimes quenched into hot or even boiling water to slow the cooling rate, with the object of reducing the level of internal stress. However, it should be emphasised that an increase in quenchant temperature usually results in a reduction in the mechanical properties of the material and in some instances, a reduction in the resistance to corrosion.

6.4 When chromium bearing DTD.683 is quenched into boiling water, the presence of the chromium has the effect of making the material more sensitive to a slow rate of cooling, resulting in a loss of tensile strength proportional to the percentage of chromium. However, this may be considered preferable to the presence of a high residual stress system.

6.5 Residual stress, as mentioned in paragraph 6.2, in parts of constant cross-section, such as certain forgings, extrusions and rolled plate, can often be effectively reduced by stretching the material so that it sustains a plastic deformation of between 1-2 per cent, but this process can seldom be applied by the aircraft constructor, since components of constant cross-section are infrequently used. Stretching should be completed as soon as possible after solution treatment, or the available elongation of the material will be reduced.

6.6 There are advantages to be derived from machining components in the annealed condition to within a few thousandths of an inch of the final dimensions, since the adoption of this procedure, in conjunction with hot water quenching, reduces the risk of cracking induced by internal stress. The parts should not be machined to final dimensions, since small dimensional changes may occur during heat treatment. In some instances it may be more practicable to machine to within ⅛ in. or so of final size, any small or intermediate size forgings which are in the fully heat-treated condition, and then to re-solution-treat, using a hot water quenchant.

6.7 If material is solution-treated after anodising, the presence of the anodic film may cause a more rapid rate of cooling than would occur if the material was not anodised. This practice is not recommended, since greater distortion or, if distortion cannot occur, a higher residual stress system, would result.

6.8 **Correction of Distortion.** Apart from the introduction of an internal stress system quenching may also cause distortion which, if unacceptable, must be corrected as soon as possible after heat treatment, because the process of ageing commences immediately after solution treatment. It is recognised that the correction of distortion is often difficult and, in some instances, may leave high local stresses in the material; it is essential therefore that such work should not be carried out without the prior knowledge of the design department.

6.9 **Quenching Extrusions and Forgings.** Such components should normally be quenched vertically to minimise the risk of distortion and, with tapered extrusions, the thickest end should, where possible, be entered into the quenchant first. However, where vertical furnaces are used, it is often impracticable to suspend the extrusion from the thinnest end, since this may introduce undesirable dimensional changes during heat treatment, and suspension from the thick end must be employed.

6.10 **Quenching Hollow Sections, Tubes, and Components of Complex Shape.** Great care should be taken when quenching such items after salt bath treatment, since entrapped molten salt solution may be ejected violently from one end as the other is plunged into the quenchant. In addition, trapping of the quenchant, either as water or steam, may reduce cooling rates and locally affect the mechanical properties of the material.

6.11 **Final Cleaning.** When material has been solution treated in a salt bath, it should be washed immediately after quenching to remove all traces of the corrosive salt deposits. Washing should be done in a bath other than that used for quenching, unless the latter is large by comparison with the load quenched and is fed with a continuous supply of fresh water. Forgings are usually cleaned with sawdust, or with water and detergents.

7 AGEING The natural ageing of aluminium alloys occurs at room temperature, and has the effect of bringing about a change in the mechanical properties of the material, e.g. increase in strength and hardness. The Al/Zn/Mg alloys show natural ageing curves very different from those of the Al/Cu alloys, since hardening continues to take place over several years, whereas the Al/Cu alloys are fully aged in a few days. For alloys to be used in the naturally aged condition, the specifications always quote the minimum period which must elapse before the material is suitable for use and reference should be made to these in all instances.

8 PRECIPITATION TREATMENT With some high strength alloys, the specified properties are secured by precipitation treatment. The process is usually effected in a furnace, but salt baths containing solutions having a sufficiently low melting point may also be used.

8.1 The process consists of heating the material within the prescribed ranges of time and temperature, and then cooling it slowly in air or, more rarely, in water. No attempt should be made to accelerate the ageing of material for which no precipitation procedure is prescribed in the specification.

8.2 With alloys of the Al/Zn/Mg type, the mechanical properties of the material are improved if precipitation treatment follows solution treatment within two hours. However, if this is not possible it should be noted that the properties of some high strength alloys are adversely affected if the precipitation treatment is delayed for a period of some months after the solution treatment has been carried out. It is essential that the precipitation process should be carefully controlled if the full mechanical properties of the material are to be obtained.

9 REFRIGERATION Natural ageing can be suspended by storing the material at a sub-normal temperature, immediately after solution treatment, in a refrigerator or cold storage plant maintained within a temperature range of —15°C to —20°C, or 0°C to —5°C.

9.1 When the former temperature range is used, the maximum storage period is limited to 150 hours, and with the latter range to 45 hours.

9.2 Any manipulation which may be necessary must be performed within two hours of removal from the refrigeration plant, since natural ageing occurs somewhat quicker after refrigeration. After this time, re-heat-treatment will be necessary, as will also be the case on expiry of the maximum storage period, but the limitations given in paragraph 3 regarding the number of times the clad alloys should be re-treated must be borne in mind.

9.3 When material is to be dried before refrigeration, this should be done as quickly as possible and the drying temperature should not exceed 60°C.

10 STOVE ENAMELLING The precipitation mechanism of artificial ageing after natural ageing produces an initial drop in strength, followed by a marked rise, and eventually a further drop. The aim in artificial ageing is to achieve the maximum properties, and the time has to be selected to obtain this.

10.1 Stove enamelling has the effect of commencing the precipitation process, but the temperature and time are normally such as to take the mechanism only to the stage where the drop in properties occur.

10.2 Some recovery of mechanical properties may occur over a period after completing the stoving process, but this cannot be relied upon to restore to the specified values any material which fails to give these values immediately after stoving.

10.3 Only low temperature stoving enamels, complying with specification DTD.235, should be used with alloys which have been solution treated, and it is recommended that a temperature of 125°C should not be exceeded.

11 BATH LOADING Prior to solution treatment, the material should be cleansed free of dirt, oil, grease, paint, etc., otherwise local overheating may occur, causing blistering or partial melting of the metal. The trichlorethylene process detailed in Leaflet **BL/6-8** is suitable for this purpose. Where water has been used in conjunction with chemical cleaners, care must be taken to ensure that the material is perfectly dry before immersion into the solution bath to prevent the possibility of a violent reaction.

11.1 The bath should not be overloaded nor should the free circulation of the solution be restricted. To reduce distortion to a minimum, all material, including tubes and light sections, should be suspended in the bath as nearly vertical as possible, but with strip material, it is preferable that this should be rolled before treatment and subsequently straightened.

11.2 It is essential that the whole of the material should be immersed ; treatment in part is not permitted in any circumstances. The material must not be allowed to touch the sides or bottom of the bath.

11.3 Small articles may conveniently be treated in perforated containers which permit the free circulation of the solution.

12 SALT BATH OPERATION AND MAINTENANCE A suitable mixture for salt bath operation consists of 90 per cent nitrate of soda and 10 per cent sodium nitrite, but other compositions are sometimes used.

12.1 **Storage of Salts.** Nitrate of soda is usually supplied in jute bags and sodium nitrite in metal drums. The salts should be stored in a dry, cool room, care being taken to ensure that they are not placed near sources of heat (such as steam pipes) or near electrical wiring. The salts, when mixed with any combustible matter, are easily ignited and it is essential that naked lights should not be permitted in the store.

12.2 **Starting Up the Bath.** Dry salts only should be used and these should be well mixed, in the correct proportions, ensuring that no combustible matter is introduced into the mix. The salts should be melted slowly, and when the required temperature is reached, the grids or perforated liner should be placed in the bath.

12.3 **Operating the Bath.** Precautions should be taken to prevent the accumulation of foreign matter, such as metal pieces, sludge and scale in the bath, since this may lead to the formation of local "hot-spots" which, in addition to overheating certain parts of the load, may result in a serious explosion.

12.3.1 The mixture should be topped up from time to time to replace that lost by "drag-out" and at monthly intervals a sample of the mixture should be taken for analysis of the nitrite content, which should not be allowed to fall below 8 per cent.

12.3.2 When the bath is loaded, the temperature of the load lags behind that of the bath, the extent and duration of the difference depending largely on the mass of the load in relation to the size of the bath. Although typical soaking times are given in Tables 1-3, actual treatment times can only be determined by experience of a particular plant.

12.3.3 Information on temperature control is given in paragraph 14.

12.4 **Shutting Down the Bath.** When shutting down the bath, it is preferable to reduce the temperature to 300-350°C, rather than to cut off the heat altogether and let the mixture solidify. The subsequent re-heat of a solidified mixture may overstress the container and there is a possibility that the expansion of the liquid under the solid crust may cause a mishap.

12.5 **General.** Water should never be used to extinguish fires in the neighbourhood of heat-treatment baths where molten salt mixtures are used. The fires should be extinguished by the use of dry sand.

13 AIR FURNACES When an air furnace is used for solution treatment, it is essential that the material should be properly cleaned and dried before treatment. Every effort should be made to exclude water vapour from the furnace, since its presence may cause the surface of the material to blister.

13.1 Furnaces should be large enough to preclude the necessity of placing the material in the cool zone near the door and the material should be stacked in such a way that the circulation of the air is unrestricted.

13.2 Instances have occurred where material has been overheated by direct radiation from the walls of the furnace, although pyrometer readings were within the permitted tolerance. Care must be taken to prevent this possibility by the use of suitable shields to protect the material from excessive radiation, or by improving the rate of heat transfer through the material to keep the temperature of the whole mass uniform.

14 TEMPERATURE CONTROL The degree of temperature uniformity of a furnace or salt bath should be thoroughly investigated before either is put into operation. This should be done by taking readings in as many different positions as may be necessary to prove that the whole of the effective space is at a uniform temperature. It is preferable that the suitability of the plant should be finally confirmed by cut-up tests on large samples treated in the plant.

14.1 Where a grid is used in a salt bath to prevent the material touching the sides or bottom of the bath, the pyrometer couple, or couples, should be placed within it and not between it and the sides of the bath.

14.2 The temperature of the plant should be registered by one or more pyrometers, one of which must be of a recording type. A record must be kept showing the times at which the treatment of each batch began and ended, so that, by comparison between this and the pyrometer chart, the thermal conditions relating to the part or material can be subsequently ascertained.

14.3 The accuracy of the temperature control equipment must be checked regularly and the results recorded for reference purposes. Normally it is sufficient to check pyrometers once monthly, but where temperature limitations are critical, a weekly check should be made.

14.4 Since there are several types of pyrometers in use, each varying slightly from the other, it is not possible to detail the necessary checks for accuracy, therefore the instrument manufacturers' instructions should be carefully followed in each instance. Every effort should be made to reproduce normal working conditions whilst the checks are being made.

14.5 The thermo-couple wiring should be checked periodically for soundness of insulation and connections, and for cleanliness and corrosion.

14.6 A portable "standard-couple" should be kept for checking purposes and this should be used in conjunction with a proprietary indicator supplied by the pyrometer manufacturer. In some plant the cold junction is compensated electrically, but where direct reading instruments are used, the setting should be checked at least once daily.

15 CONTROL TESTING Although every care might be taken in the control of the heat-treatment process, it cannot be guaranteed that the finally heat-treated parts will automatically comply with the requirements of the specifications, therefore some mechanical testing is necessary to ascertain the actual properties obtained. For this purpose a system of control sampling, such as that outlined in the following paragraphs, should be used. This procedure does not apply to forgings or stampings, for which the test procedures contained in the relevant material specifications must be followed.

15.1 The control test samples should, where possible, be prepared from material of the same batch as that to be heat-treated, and in instances where the characteristics of the material are not well known, this is essential. It is common practice to cut the control samples from the sheet or extrusion after full heat-treatment rather than before. The samples of sheet or strip material should be prepared as prescribed in British Standard L100, Section 1, Paragraph 5.4. Where the plant is used only for intermittent treatment of batches, a control sample should be treated with each batch, but where the plant is in continuous use, two samples per day are sufficient.

15.2 If prepared before heat treatment, the control samples should be wired to the material which they represent, and should be heat-treated and quenched with it. After ageing, the control samples should be hardness-tested and the sample showing the lowest hardness number in each batch should be subjected to tensile testing.

15.3 When materials are to be precipitation treated, the samples should follow through the complete heat-treatment sequence with the parts they represent, and should be tested on completion of the process. A system for recording the results of the tests must be maintained.

15.4 It should be noted that control testing is not intended primarily as a method of sentencing heat-treated parts, but as a means of verifying that the heat-treatment operation has been carried out with consistent correctness. An isolated failure of a control test sample to give the specified test values requires immediate investigation into the application of the heat-treatment process. Where recurrent failures are experienced, or where investigation made as a result of an isolated failure gives cause for anxiety, the matter should be investigated immediately. Further treatment should be suspended until the fault has been ascertained and rectified, and consideration should be given to the suitability of the parts heat-treated with the batch in question.

16 IDENTIFICATION OF HEAT-TREATMENT CONDITIONS Immediately after the material has been heat-treated, it should be marked with the appropriate symbol denoting the treatment to which it has been subjected, since serious risk would attend the use of materials in one heat-treatment condition which were thought to be in a different condition.

16.1 There are two identification systems in general use, i.e. that recommended in British Standards 1470 to 1477 and that recommended by the Ministry of Supply in SP4089. Both systems are acceptable to the Board and details of both are given below.

16.2 **Identification System Recommended in British Standards 1470 to 1477.**

O	Material in the annealed condition.
M	Material in the "as-manufactured" condition, e.g. as rolled, as extruded, straight and/or drawn to size, or as forged, without subsequent heat treatment of any kind.
OD	Material which has been annealed and lightly drawn (at present applicable only to rivet, bolt and screw stock).
T	Material which has been solution-treated and requires no precipitation treatment.
W	Material which has been solution-treated and will respond effectively to precipitation treatment.
WP	Material which has been solution-treated and precipitation-treated.
WD	Material which has been drawn after solution treatment (at present only applicable to wire).
P	Material which has been precipitation-treated only.

16.3 **Identification System Recommended in SP4089.**

A	Material and parts which have been annealed.
N	Material and parts which have been solution-treated and which do not require precipitation treatment.
W	Material and parts which have been solution-treated and which require subsequent precipitation treatment.
WP	Material and parts which have been solution-treated and precipitation treated.

16.4 **General.** The symbol must be applied in the manner prescribed in the appropriate drawing.

BL/10-3

Issue 2.

15*th June*, 1970

BASIC

TESTING OF MATERIALS AND CHEMICAL SOLUTIONS

TESTING OF METALLIC MATERIALS

1 INTRODUCTION

1.1 This Leaflet gives guidance on the testing of metallic materials. It should be read in conjunction with the latest issue of British Standard A4, entitled "Test Pieces and Test Methods for Metallic Materials for Aircraft", with the latest issues of British Standards L100, S100, S500, T100 and TA100 (which deal with the inspection and testing procedures for aluminium and its alloys, steel, steel sheet and strip, steel tubes and titanium alloys respectively), and with the relevant material specifications.

1.2 Information on tensile testing, previously contained in Issue 1 of this Leaflet, and on bend testing, previously contained in Leaflet **BL/10-4**, has been brought up to date and included in Issue 2 of this Leaflet.

1.3 The topics discussed in this Leaflet are as follows:—

Paragraph	*Topic*
2	General
3	Tensile Tests
4	Ductility Tests
5	Hardness Tests
6	Impact Tests

2 GENERAL

2.1 The particular tests called for in material specifications are designed to ensure that the material will be satisfactory for the purpose for which it is required. The range of tests will therefore vary considerably between materials and between different forms of the same material. A tensile test at room temperature is always a requirement and in addition one or more of the ductility, hardness or impact tests are usually specified.

2.2 At the present time most British testing laboratories are using machines calibrated in British units (i.e., pounds, inches, foot pounds force, etc.) and many material specifications still require results to be notified in these units. The introduction of International Standards (S.I.) units into the aircraft industry will result in a gradual changeover from the British system, and current material specifications are being issued quoting only S.I. units. Testing equipment will also be brought into line with this International Standard.

2.3 The S.I. units applicable to the testing of metallic materials are as follows:—

mass : kilogram (kg)
force : newton (N)
stress : hectobar (hbar)
work, energy : joule (J)
dimensions : millimetre (mm)

NOTE: It should be noted that the units 'N', 'J' and 'hbar' are not related to the force of gravity and this must be taken into consideration when making calculations. 1 hbar = $10N/mm^2$, = $1.02 kgf/mm^2$, $=0.65 tonf/in^2$.

3 TENSILE TESTS

3.1 General

3.1.1 Tensile tests are normally carried out at room temperature (10 to 30°C) and this paragraph deals mainly with the procedures and test pieces employed with this type of test. Certain materials, however, are manufactured specifically for use in regions of high temperature (e.g. turbine engines or external surfaces of high speed aircraft) and additional tests are necessary to ensure that these materials meet the requirements for such a use. While the methods used to carry out these tests are basically similar to those used for tensile tests at room temperature, certain differences exist and these are discussed in paragraph 3.11.

3.1.2 The principles of tensile testing are applied in the determination of certain data relating to the properties of materials and these include tensile strength, proof stress, percentage elongation, percentage reduction in area and Young's Modulus of elasticity. Definitions of this data are given in subsequent paragraphs.

3.1.3 When a tensile test piece (Figure 1) is subjected to a steadily increasing load, it will extend proportionally to the load until a point is reached (varying with different metals) after which the extension increases at a progressively greater rate than loading and failure by fracture occurs. The tensile strength of the material is the maximum load obtained on the sample divided by the original cross-sectional area.

3.1.4 Samples of the material to be tested are often cut from the parent metal and accompany it through all stages of heat treatment. In other instances, for example with small castings, a percentage of the items is selected for test purposes. It is from these samples that the test pieces are manufactured. A system of cast and/or batch code markings (see Leaflet **BL/2-2**) should be used to identify the sample with the parent metal or particular cast so that the samples are known to be truly representative of the material to which they belong.

3.1.5 The results of tensile tests may be affected by a number of factors, e.g. gauge length in relation to the cross-sectional area and the type of material from which the specimen is machined. These factors are taken into consideration in the specification.

3.1.6 Local unsound areas may occur in cast materials, especially in areas subject to shrinkage or porosity, so that small test pieces cut from a normal test sample may give unduly low results. Conversely, unduly high results may be obtained if the test piece includes part of a chilled zone of a test sample.

3.1.7 Steel samples of large cross-section may, due to heat treatment, exhibit non-uniform properties through the section; bright drawn material may also exhibit non-uniform mechanical properties through its cross-section. The difference in tensile strength or proof stress, measured at different positions within a sample, may amount to several hectobars.

3.1.8 Certain aluminium alloys possess natural age hardening qualities (Leaflet **BL/9-1**). It is therefore essential to allow sufficient time for the natural precipitation to take place before carrying out the tests, otherwise low tensile and unduly high ductility properties will be indicated.

3.2 Test Pieces

3.2.1 General Requirements

(i) The form and dimensions of standard round and flat test pieces, and of strips cut from tubes, are specified in BS A4. These test pieces are illustrated in Figure 1 and the dimensions listed in Tables 1 and 2.

NOTE: The gauge lengths specified in Tables 1 and 2 are used for measurement after fracture and should not be confused with the extensometer gauge length which is used for measuring extensions during testing. Extensometers are manufactured in the sizes 25 mm and 50 mm.

(ii) Care must be taken during machining to avoid overheating, bending and surface distortion, special care being necessary with small specimens. A good finish is essential, since a rough surface finish or tool marks on the gauge length of the test piece may result in low mechanical test properties, particularly with materials of low ductility.

(iii) Material specifications normally stipulate the standard size of test piece to be used and this is mandatory provided that the sample is of sufficient size. When the material is too small, i.e. a small casting or bar, the largest practical size of test piece selected from Tables 1 or 2, as appropriate, should be used.

(iv) Certain specifications permit testing to full section and the extent of machining should be only sufficient to remove scale or give a symmetrical form. It is particularly important in this case to select a length of material which is free from bends or kinks as these faults will make it very difficult to achieve accurate results.

(v) It is necessary to maintain the dimensions over the gauge length as these have a considerable effect on the results obtained from a test. The parallel portion must not vary in diameter or width by more than 0.03 mm and measurement must be accurate to within 0.2 per cent or 0.005 mm, whichever is the greater.

(vi) Material specifications state the position from which the test sample should be taken, and in some cases as many as three samples are required so that the effect of grain flow or direction of rolling can be judged.

3.2.2 Proportional Test Pieces

(i) These test pieces are round in section and have a specific relationship of gauge length to diameter of 5:1. The gauge length is important when measuring elongation due to the "waisting" of the test piece when under load. If, for example, the waisting affects 10 mm of the parallel portion of the test piece the *percentage* elongation over a 50 mm gauge length would be vastly different from that over a 100 mm gauge length. An international standard has been agreed of 5.65 $\sqrt{}$ cross-sectional area (i.e. 5 × diameter). If a test piece is manufactured to dimensions other than those shown in Table 1 then the geometric proportions must be maintained.

(ii) The gripped ends of the test piece must be co-axial with the parallel portion and suitably shaped for the holders of the testing machine. Threaded or shouldered ends are normally used.

3.2.3 Non-proportional Test Pieces

(i) For material less than 10 mm thick a flat test piece may be used, the standard size being 12.5 mm wide and normally the full thickness of the material. Table 2 gives the dimensions of test pieces of this type and it should be noted that the gauge length/cross-sectional area ratio varies considerably. Accurate measurement and calculation of the cross-sectional area is necessary as this determines the load to be applied to achieve a particular stress. For material more than 10 mm thick a proportional test piece should be used.

(ii) When flat test pieces are produced by means of a press tool, sufficient material must be left along the gauge length to permit machining to the final width.

3.2.4 **Test Pieces for Tubes.** Tensile test pieces for tubes may consist of either a length of tube (which is tested in full section), a strip cut from the tube or, for thick walled tubes, a round test piece turned from the wall of the tube.

(i) **Full Section Test Pieces.** For these test pieces the tubular section should be plugged at the ends to facilitate gripping in the test machine, but care must be taken to ensure that the tube is not cold worked during this operation. The length of the tube between the inner ends of the plugs should be at least 50 mm more than the gauge length. Elongation should normally be measured over a 50 mm gauge length unless otherwise required by the material specification.

NOTE: **Plugs should be parallel over the gripping length and at least as strong as the tube.**

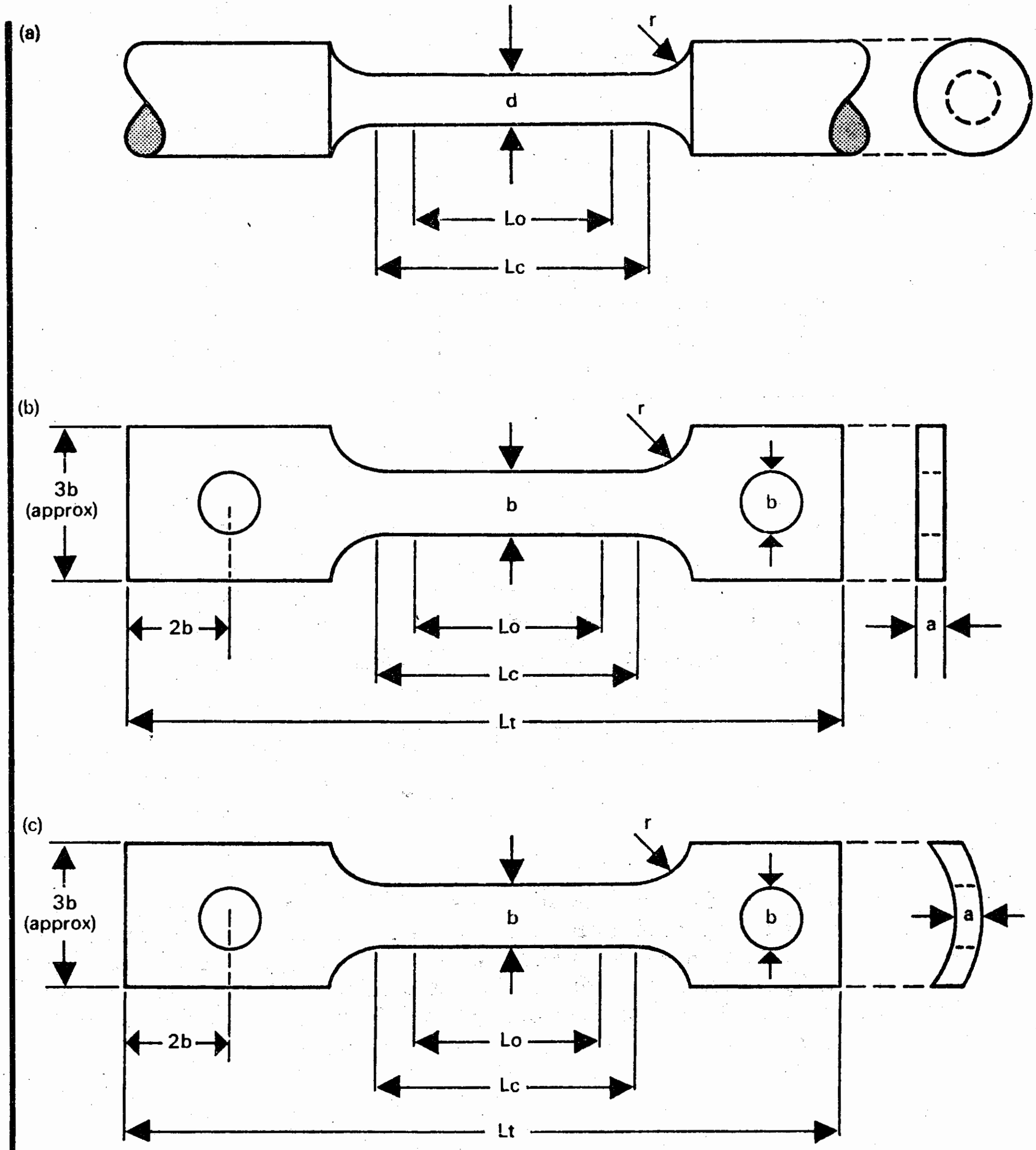
(ii) **Test Pieces Cut from Tube.** These test pieces are illustrated in Figure 1 (c) and the dimensions are those given in Table 2. The first listed should be considered as the standard size. The strip may not be flattened over the gauge length but the gripping ends may be flattened as required to fit the holders. For the purposes of calculation, for tubes of more than 100 mm outside diameter, the cross-sectional area may be taken as 'ab' (Figure 1c), but for smaller tubes the formula

$ab\,(1 + \frac{lb^2}{6Dd})$ should be used.

'D' and 'd' are the outside and inside diameters of the tube respectively.

(iii) **Proportional Test Pieces.** The preparation of test pieces machined from the wall of a tube should be identical to the procedure recommended in paragraph 3.2.2.

3.2.5 **Test Pieces for Wire.** For the purpose of tensile testing, a length of wire, unmachined and in full section, is used as a test piece. If the determination of percentage elongation is required the gauge length is stated in the material specification, but if tensile strength only is required the length is not important. Results must be discounted if obtained when the wire breaks at one of the grips.



Key: Lt = total length of test piece
Lo = original gauge length
Lc = minimum parallel length
r = blend radius
a = thickness of test section
b = width over gauge length
d = diameter of test section

Figure 1 STANDARD TENSILE TEST PIECES

Table 1 DIMENSIONS OF PROPORTIONAL ROUND TEST PIECES

Gauge length = $5.65 \sqrt{So}$

Nominal Cross-Sectional Area (So)	*Diameter* (d)	*Gauge Length* (Lo)	*Minimum Parallel Length* (Lc)	*Minimum Radius (r)*	
				Wrought Metals and Cast Steel	*Other Cast Metals*
mm^2	mm	mm	mm	mm	mm
150	13.82	69	76	13	26
100	11.28	56	62	10	20
50	7.98	40	44	8	16
25	5.64	28	31	5	10
12.5	3.99	20	22	4	8

Table 2 DIMENSIONS OF RECTANGULAR SECTION TEST PIECES

Width (b)	*Gauge Length* (Lo)	*Minimum Parallel Length* (Lc)	*Minimum Radius* (r)	*Total Length* (Lt)
mm	mm	mm	mm	mm
12.5	50	63	25	200
6	24	30	12.5	100
3	12	15	6	50

3.3 **Percentage Elongation and Percentage Reduction in Area.** Knowledge of the ductility of a material can be obtained from the ordinary tensile test by measuring, after fracture, the percentage elongation which has occurred over a specified length of the test piece, and by the percentage reduction in cross-sectional area at the position where the fracture occurs. Ductility is also measured by different types of test and these are described in paragraph 4.

3.3.1 Percentage Elongation

(i) Unless otherwise permitted by the relevant testing procedure or material specification, percentage elongation results should be determined wherever practicable on standard test pieces conforming with the dimensions specified in BS A4. If samples are tested in full section, the elongation should be determined on the gauge length specified in the appropriate material specification.

(ii) The elongation of the test piece is normally in two distinct phases, i.e., the uniform elongation which takes place over the whole gauge length, and the additional stretching which occurs at the waist formed at the point of fracture (see Figure 2).

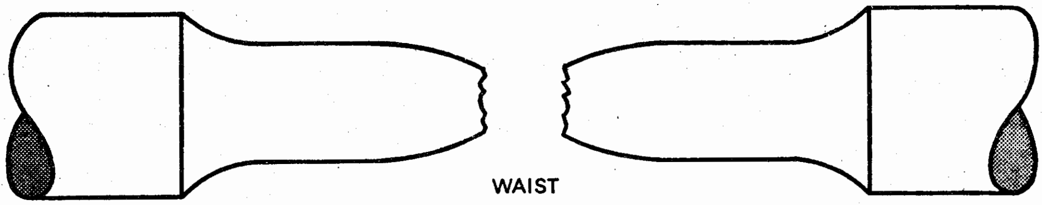


Figure 2 FRACTURED TEST PIECE SHOWING WAISTING

(iii) The extent of elongation depends on the form of the test pieces, and comparable figures can only be obtained from test pieces in which the gauge length bears a fixed ratio to the square root of the cross-sectional area, as is the case with all proportional test pieces.

(iv) The practice of marking two or more alternative gauge lengths in different positions on rod or wire test pieces is advisable so that, should a fracture occur towards one end of the test piece, the whole of the elongation associated with the waisting can be measured between the points selected.

(v) For certain copper alloys and materials where a fracture is likely to occur through a deeply incised mark, a suitable quick-drying paint or lacquer should be applied to the test piece and the gauge length lightly marked with dividers. A lacquer suitable for this purpose may be prepared by dissolving 10 grams of Nigrosene (spirit soluble) and 25 grams of Shellac in one litre of methylated spirit.

(vi) Where the specified minimum elongation is 5 per cent or more the gauge length should be marked on the test piece by scratches or light centre-pops before commencing the test and the distance between the marks measured after fracture.

(vii) Where the specified minimum elongation is less than 5 per cent, one end of the gauge length should be marked by two crossed scribe lines and the other end by an arc of gauge length radius struck from the crossed lines. After fracture, the broken test specimen should be placed in a suitable fixture and axial pressure applied (preferably by means of a screw), to a degree just sufficient to hold the broken pieces firmly together during measurement. A second arc of the same radius should then be struck from the original centre, the distance between the two arcs being measured by a suitable instrument, e.g. a Brinell microscope.

(viii) The percentage elongation can be determined by the formula:—

$$\text{Percentage elongation} = \frac{\text{Lu-Lo}}{\text{Lo}} \times 100 \text{ where:—}$$

Lo = Original gauge length, and

Lu = Gauge length after fracture.

(ix) Any statement of results of this test must include information on the type of test piece, its section and gauge length.

3.3.2 **Percentage Reduction in Area.** There appears to be no definite relationship between the percentage elongation and percentage reduction of area for most materials, and it is essential that both measurements are taken in order to assess correctly the ductility of any particular material. For example, certain steels exhibit a considerable reduction of cross-section area with only moderate elongation, whilst others behave in the reverse manner.

(i) The percentage reduction of area can be determined by the formula:—

$$\text{Percentage Reduction in Area} = \frac{\text{So–Su}}{\text{So}} \times 100 \text{ where:—}$$

So = Original cross-sectional area, and

Su = The minimum cross-sectional area obtained by measurement of the fractured test specimen.

(ii) In practice the reduction in area is usually determined by means of an adjustable caliper from which the percentage reduction in area may be read directly.

3.4 **Limit of Proportionality.** The limit of proportionality is the stress (load divided by the cross-sectional area of the test piece) at which the strain (elongation divided by original gauge length) ceases to be proportional to the stress.

3.5 **Yield Point.** The yield point is the stress at which a substantial amount of plastic deformation takes place under constant or reduced load. This sudden yielding is characteristic of low carbon and annealed steels, but in other metals plastic deformation begins gradually and its incidence is indicated by measuring the proof stress (paragraph 3.7).

3.6 **Young's Modulus of Elasticity.** Young's Modulus, referred to as a constant 'E' is $\frac{\text{stress}}{\text{strain}}$, where stress $= \frac{\text{load}}{\text{area}}$ and strain is extension per unit length.

3.6.1 For steel the constant 'E' is approximately 20000 hectobar (200 kN/mm^2). Thus a stress of 1 hbar will produce an extension or contraction of 1/20000 of the original length. The working stress for mild steel under steady load conditions is approximately 10 hbar and the strain produced by this stress will be 10/20000 mm per mm length of specimen.

3.6.2. The constant 'E' may be found for a particular metal by comparing the extensions produced by two different loads within the elastic range.

3.7 **Proof Stress**

3.7.1 **General Considerations.** For design purposes it would be convenient to know the highest stress that a material could withstand without deformation. The limit of elasticity (proportionality) is a very difficult point to determine however, particularly with materials which have no definite yield point, and proof stress has been chosen as a value which can be reproduced with accuracy. Proof stress is defined as the stress which is just sufficient to produce, under load, a non-proportional elongation equal to a specified percentage of the gauge length.

(i) In specifying proof stress the non-proportional elongation quoted in most specifications is either 0.1% or 0.2% and this figure should always be included in the results of proof stress measurement.

(ii) According to BS A4, and unless otherwise stated in the relevant material specification, the primary method of proof stress determination is by means of an accurately determined stress/strain diagram (see paragraph 3.7.2). The extensions corresponding to suitable increasing values of stress are measured by an extensometer (see paragraph 3.10) and are plotted in appropriate units of extension to form a stress/strain curve as illustrated in Figure 3. This may be done either autographically or manually.

(iii) Where permitted by the relevant testing procedure or specification, alternative methods of proof stress determination, such as the Four-Point Method and the Three-Point Method described in BS A4 may be used. In these instances also the extensions must be measured by a suitable extensometer.

(iv) The tensile properties of the test piece are unaffected by loading and unloading within the limit of proportionality, but if the test piece is loaded beyond this limit, then unloading and reloading will result in an incorrect proof stress value being obtained. To obviate unnecessary loading and unloading every care should be taken in the early stages of the test to ensure that the testing machine grips (paragraph 3.8) are correctly aligned.

(v) It is also necessary to ensure that the extensometer is securely mounted and that bending or twisting of the specimen during mounting is avoided. The weight of the extensometer is usually disregarded, but for very thin sheet specimens or thin-walled tubes, it may be necessary to support the instrument, preferably by a system of light springs.

(vi) Tests should be carried out at room temperature (i.e. 10 to 30°C) unless otherwise specified. The speed at which the load is applied is unimportant within the elastic range, but BS A4 recommends that strain rate should be 0.001 to 0.005 per minute in the plastic range.

3.7.2 **Stress/Strain Diagram Method.** As indicated in paragraph 3.7.1 (ii) the stress/strain diagram method is the primary method of proof stress determination. A typical stress/strain diagram is illustrated in Figure 3.

(i) The magnitude of the initial tensioning stress OA will depend on the limit of proportionality of the material under test. Generally, this should be as high as practicable (although not more than 20 per cent of the anticipated proof stress) to obviate the possibility of machine factors (e.g. backlash) adversely affecting the accuracy of the stress/extension readings in the early stages of the test.

(ii) However, since certain high strength aluminium alloys, magnesium alloys and austenitic steels have relatively low limits of proportionality, it is good practice to employ a low initial tensioning stress, and thereafter increments of approximately 1 hectobar where the operator is not familiar with the stress/extension characteristics of the material under test. If too low a tensioning stress is applied, the initial points on the graph may be scattered and should be ignored.

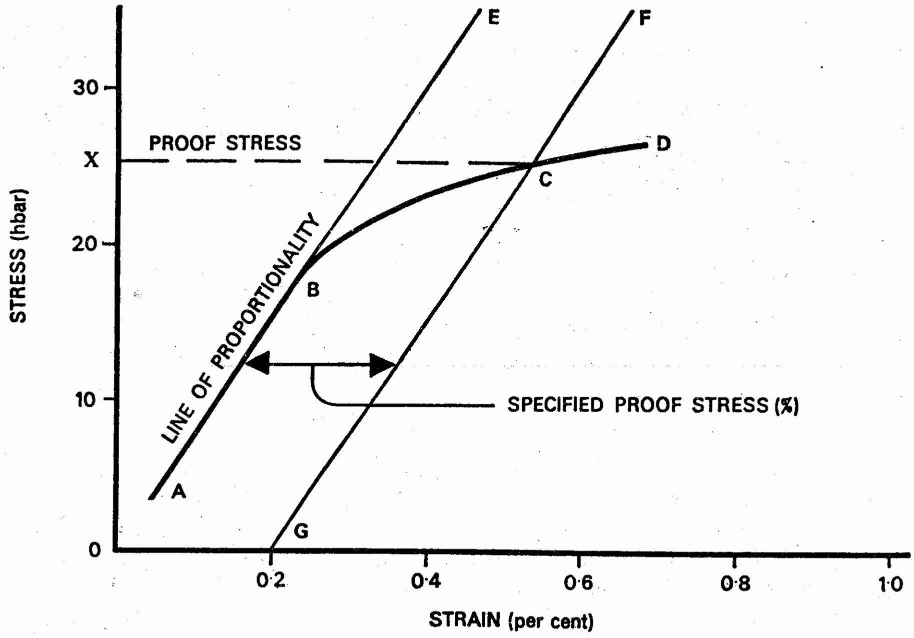


Figure 3 TYPICAL STRESS/STRAIN DIAGRAM

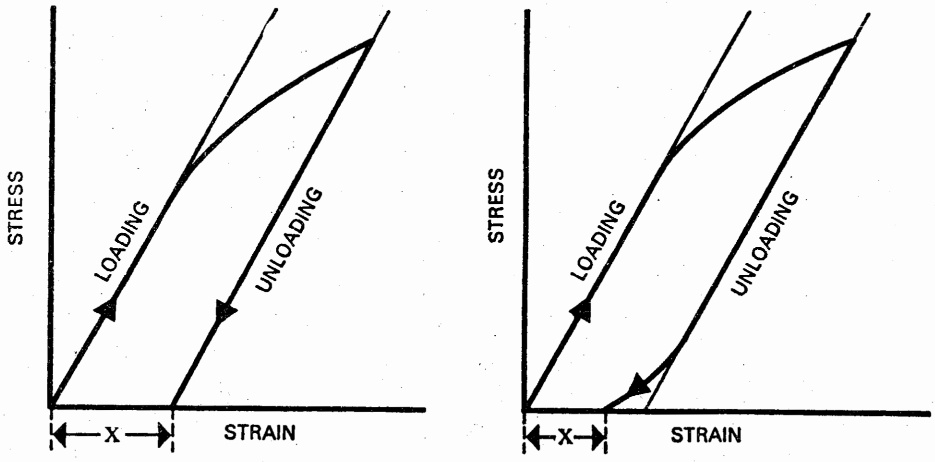
(iii) The value of Young's Modulus of a given material is reasonably constant, thus the theoretical extension of any given increment of stress within the limit of proportionality may be readily calculated. If the extensions are calculated for the increments of stress used in plotting that portion of the stress/extension diagram between A and B of Figure 3, it is possible to verify that the test is proceeding satisfactorily by comparing the calculated values with those actually obtained. A difference of more than 0.002 mm between the calculated and actual extension for a stress increment of 5 hbar for non-ferrous, or of 10 hbar for ferrous materials, is usually an indication of some abnormality in either the testing apparatus or the specimen which should be investigated before proceeding with the test.

(iv) The stress/strain diagram should be plotted on the longest convenient scale. On the horizontal ordinate, 100 mm should represent not more than 0.2 mm extension. The line GF is drawn parallel to the extended straight line of proportionality ABE and distant from it by an amount representing the specified percentage of the extensometer gauge length (e.g. 0.1 mm for a 0.2 per cent proof stress on a gauge length of 50 mm). The proof stress is the stress OX corresponding to the point of intersection of the curve ABCD by the line GF.

(v) When testing clad materials such as L72 it will be found that a double slope is produced. The change of slope occurs when the cladding materials extends plastically.

3.7.3 **Four-Point Method.** In general the four-point method should only be used when the stress/strain diagram of the material under test conforms to the general shape of the diagram shown in Figure 3.

(i) This method is based on the knowledge that proportional elongation of a test piece continues on the line of proportionality up to the point of fracture, and is always proportional to the stress. In other words, at any specified stress the elastic extension is always greater than it would be at a lower stress. This can be proved by applying proof stress to a test piece and measuring the total extension. Subsequent unloading will leave a permanent extension and the difference between this and the total extension will be seen to be equal to the elastic extension at proof stress. This statement is true for all metals except magnesium, from which a certain amount of non-proportional extension is regained; hence, in the case of magnesium, non-proportional extension cannot properly be called "permanent" extension (see Figure 4). It is also assumed that if an appropriate length of the stress/strain curve is taken to be a straight line, an approximate value for proof stress can quickly be found. In practice the error is seldom greater than 0.3 hectobar.



(a) Normal material

(b) Magnesium

(X= permanent extension)

Figure 4 LOADING AND UNLOADING DIAGRAMS

(ii) In general, the range of readings adopted, either specified or selected, should not be more than about a quarter of the specified minimum proof stress, thus the range employed for a material of 24 hectobar minimum specified proof stress should not exceed 6 hectobar.

(iii) **Conducting the Test.** The following example is included to illustrate the requirements of BS A4 and should be studied in conjunction with that specification and Figure 5.

Material : Aluminium alloy
Gauge length : 40 mm
Extensometer gauge length : 50 mm
Diameter of test piece : 7.98 mm
Cross-sectional area : 50 mm^2
Specified minimum stress : 24 hbar
Assumed maximum stress : 28 hbar
Specified proof stress : 0.2 per cent (0.1 mm)
Young's Modulus : 70 kN/mm^2 (7000 hbar)

Procedure:—

(a) Set up the test piece in the testing machine and attach an extensometer over the gauge length.

(b) Apply a tensioning stress of 4 hbar (OA) and set the extensometer at zero.

NOTE: 4 Hbar is equivalent to a load of 204 kgf for this size test piece (i.e. $4 \times 50 \times 1.02$).

(c) Apply a further stress of 4 hbar (selected because 4 divides easily into both 24 hbar and 28 hbar) and carefully measure the extension 'x'. Check this extension by a calculation using Young's Modulus.
Answer = 0.03 mm.

(d) From 'x' calculate and record the extensions at points 'C' and 'B' thus;
at minimum proof stress of 24 hbar the total extension should be,

$$x\left(\frac{24-4}{4}\right) + 0.1 \text{ mm} = 0.03\ (5) + 0.1 \text{ mm} = 0.15 + 0.1 = 0.25 \text{ mm};$$

and at maximum proof stress of 28 hbar the total extension should be,

$$x\left(\frac{28-4}{4}\right) + 0.1 \text{ mm} = 0.03\ (6) + 0.1 \text{ mm} = 0.18 + 0.1 = 0.28 \text{ mm}.$$

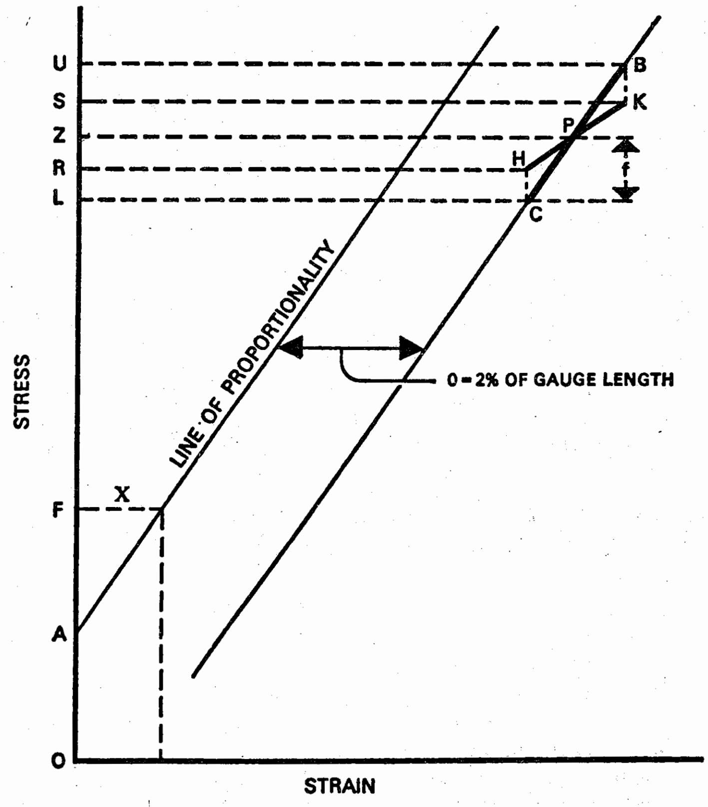


Figure 5 FOUR-POINT METHOD

(e) Load the test piece until the extension calculated for 'C' (0.25 mm) is obtained. If the total load applied (OR) is equivalent to a stress of more than 24 hbar the material satisfactorily exceeds the minimum stress requirement. A stress in excess of 24 hbar means that a proportional extension in excess of 0.15 mm has taken place and therefore the non-proportional extension must be less than 0.1 mm (0.2 per cent).

(f) Load the test piece further until the extension calculated for 'B' (0.28 mm) is indicated. If the total load applied is equivalent to a stress of less than 28 hbar then the material does not exceed the assumed maximum proof stress. A stress lower than 28 hbar indicates that a proportional extension of less than 0.18 mm has taken place and therefore the non-proportional extension is greater than 0.1 mm (0.2 per cent).

(g) The approximate proof stress may be obtained by plotting the points shown in Figure 5. 'HK' represents part of the stress/strain curve, and 'CB' part of the 0.2 per cent proof stress line. The proof stress is indicated by the intersection of these lines at 'P'.

(h) In practice it is not necessary to draw a graph, proof stress being calculated from the formula:—

$$\text{Proof Stress (OZ)} = \text{OL} + \text{f where f} = \frac{(\text{OR–OL}) \times (\text{OU–OL})}{(\text{OR–OL}) + (\text{OU–OS})}$$

the figures being obtained from the calculations in the steps outlined above.

(j) Maximum stress may be obtained by removing the extensometer and loading until fracture of the test piece occurs.

3.7.4 **Three-Point Method.** In certain circumstances, for example when it is required to check the effectiveness of a heat treatment, it may only be necessary to determine that the test sample meets a minimum proof stress requirement. The three-point method is a convenient way of carrying out this check.

(i) The procedure adopted is the same as for the four-point method except that only the minimum proof stress calculation is made, the test piece being loaded until this extension is achieved. If the total load is equivalent to a stress greater than the minimum proof stress then the material is satisfactory.

3.7.5 **Beaumont Determinator Method.** The main advantage of this method is that accurate proof stress values may be determined without the need for plotting a stress/extension diagram. The determinator consists of an instrument employing special charts for various materials which are related to the load indicator of the testing machine. The proof load is indicated on a dial gauge.

3.8 **Methods of Gripping.** Some of the various types of mechanisms used for gripping the test pieces are described in the following paragraphs.

3.8.1 **Pin Grips.** For sheet and strip standard test pieces (e.g. item 'b' of Figure 1) pin grips are mostly used, the pins fitting into the holes provided in the test piece.

3.8.2 **Wedge Grips.** A cross-sectional view of a typical wedge-grip arrangement is shown in Figure 6. The wedges are manufactured of hardened steel, the surface adjacent to the test piece being roughened to provide a positive grip, whilst the remaining surfaces have a smooth finish to facilitate the sliding of the wedges down the shackle adaptor. By this method the test piece is gripped progressively tighter as the load increases.

(i) Wedge grips are used for flat test pieces and, when arranging the grips in the shackle holders, at least two-thirds of the length of each pair of grips should hold the test piece, otherwise the grips will tend to tilt.

(ii) Before inserting the grips in the holders, the sliding surfaces should be coated with graphite grease. Should the wedges be too tightly fixed after a test piece has fractured to be removed normally, a tube should be applied under pressure to the lower end of the grips until they are freed.

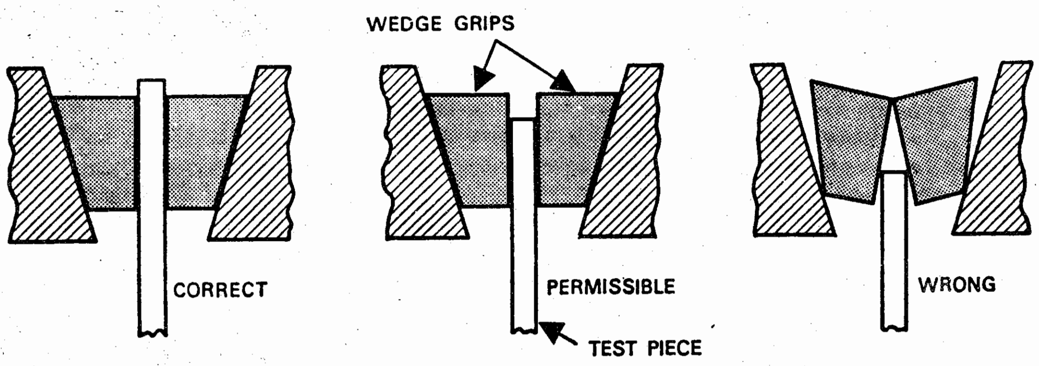


Figure 6 ARRANGEMENT OF WEDGE GRIPS

3.8.3 **Threaded Shackles.** Shackles of this type are used to accommodate the screwed ends of round test pieces.

3.8.4 **Split Collet.** A cross-sectional view of a typical split collet type gripping mechanism is shown in Figure 7. Grips of this type are used for testing shouldered test pieces.

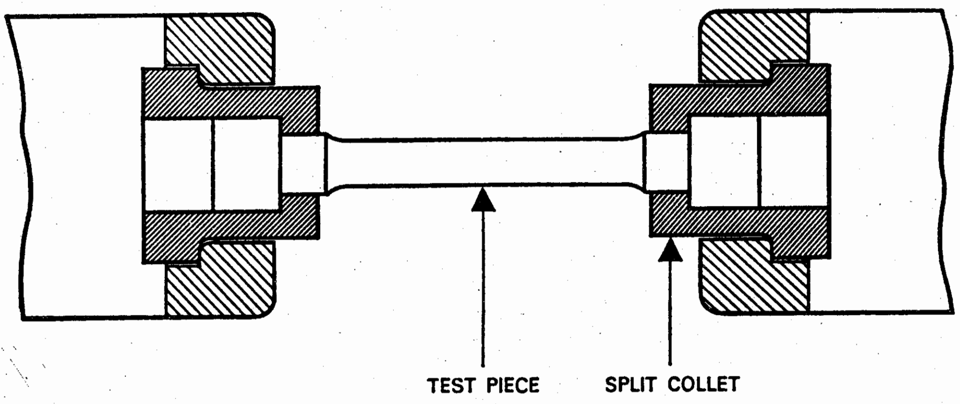


Figure 7 SPLIT COLLET GRIPS

3.9 **Tensile Testing Machines.** Except for machines operating hydraulically, most tensile testing machines load the test piece by means of weights and a system of levers. The value of the load is altered by varying either the weight or the effective leverage and most machines are designed to record automatically the load applied. In hydraulically operated machines (Figure 8), the pressure of oil in the straining cylinder is measured by a dynamometer which operates a lever mechanism to indicate the load on a dial.

3.9.1 On early machines it was necessary to have two operators to carry out a tensile test; one to apply the stress and balance the weighing head whilst the other recorded load and extension readings for the stress/strain graph. Most modern machines are fitted with autographic devices for measuring both load and extension, the most accurate results being obtained by the use of transducers attached to the extensometer and load recording mechanism. Signals from the transducers are amplified to drive a pen, and a graph is produced from which proof stress, tensile stress and extension may be readily determined.

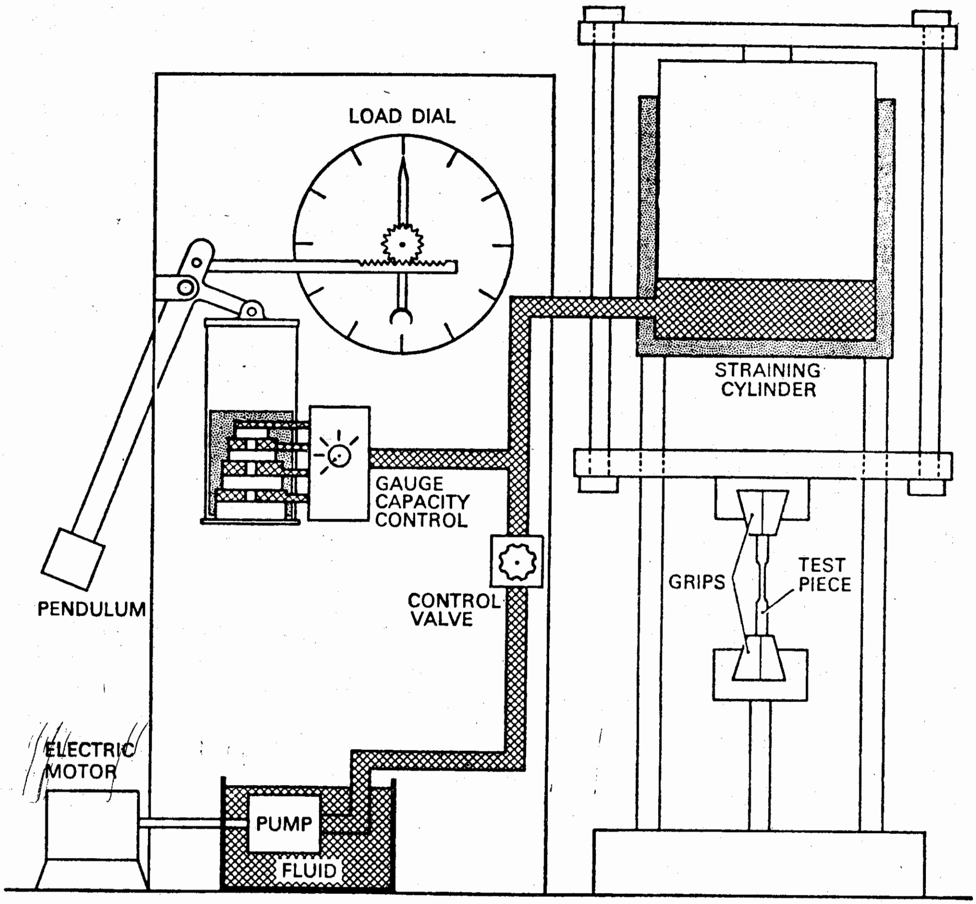


Figure 8 HYDRAULICALLY OPERATED TENSILE TESTING MACHINE

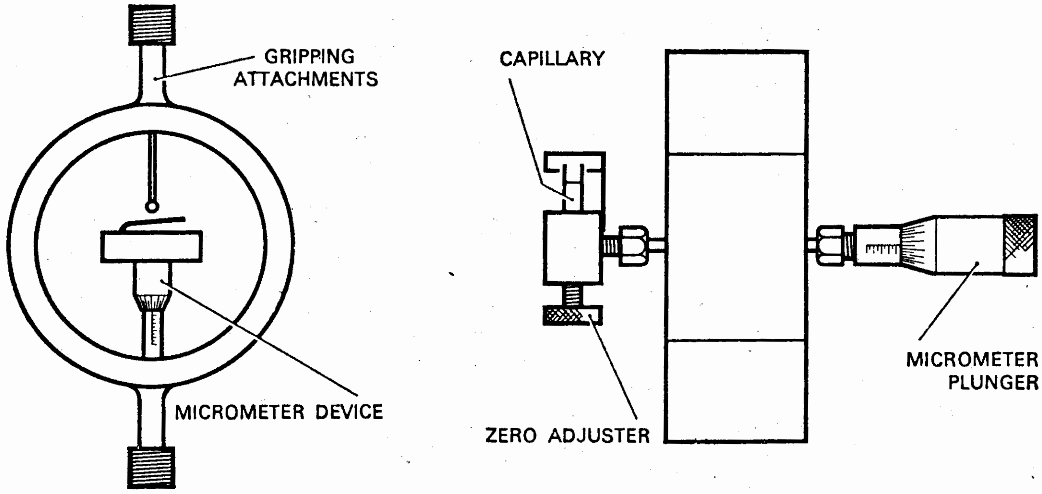
3.9.2 Tensile testing machines must be verified periodically to ensure that their accuracy is maintained. BS 1610 lays down the acceptable methods of verification and the limits of error permitted for various types of test. The methods are discussed briefly in the following paragraphs.

(i) **Dead Weights.** The simplest method of load verification is to hang certified weights from the upper specimen grips. This is only practicable with small capacity machines, due to the handling and transportation difficulties involved.

(ii) **Proving Levers.** Certified levers and weights are used with this method in order to increase the effective force acting on the machine. Larger capacity machines may be verified by this method, but again handling and transportation of the equipment present difficulties.

(iii) **Proving Rings.** (Figure 9 (a)). These are portable alloy steel rings each fitted with a micrometer across the internal diameter. The distortion produced at various stresses is noted during calibration and provides a scale for subsequent machine verification. The rings are manufactured in various capacity ranges and mounted in the testing machine in the same way as a test piece. By using two or more rings together verification of large capacity machines is possible.

(iv) **Standardising Boxes.** (Figure 9 (b)). These are hollow steel cylinders, filled with mercury and completely closed. A capillary tube and micrometer plunger are connected separately to the inside of the cylinder. When carrying out a test, the level of mercury in the capillary is first adjusted to a datum mark by setting the micrometer at zero and rotating the zero adjuster. Application of a compression load will expel mercury from the cylinder into the capillary and the level may be reset to the datum mark by unscrewing the micrometer plunger. The reading shown on the thimble is then converted into units of stress from tables engraved on the box.



(a) Proving Ring

(b) Standardising Box

Figure 9 METHODS OF LOAD VERIFICATION

3.10 **Extensometers.** Extensometers are used for measuring extension over the gauge length of a test piece during a tensile test. Strains within the elastic limit are extremely small, e.g., in a mild steel test piece of 50 mm gauge length the total amount of elastic extension is about 0.05 mm. To measure such small lengths the extensometer must be extremely accurate.

NOTE: BS 3846 details the methods of calibration of extensometers and also lists the limits of error acceptable for various types of tensile test.

3.10.1 Mechanically operated extensometers use leverage to amplify strain and the extension is measured by means of a dial gauge or micrometer attachment. Another type makes use of small mirrors attached to rollers in the extensometer, the change in angle when the test piece is strained being viewed on a large scale by means of a telescope.

3.10.2 Most modern extensometers have provision for the attachment of a transducer, which converts extension into an electric current. This is led to a milliammeter from which extension may be read directly without the need for measurement.

3.11 **High Temperature Tests.** High temperature tensile testing is often necessary with modern aircraft materials and may be a simple tensile test similar to those carried out at room temperature, or a prolonged test to determine creep strain.

3.11.1 **Equipment.** The testing machines used are similar to those required for tests at room temperature except for the addition of a heating furnace. This is lowered over the test piece and grips to increase the temperature to that required by the material specification. Special extensometers are used so that the actual measurement can be taken outside the furnace at room temperature on each side of the test piece. A minimum temperature soaking time of one hour is required to ensure that thermal expansion does not affect test readings.

3.11.2 **High Temperature Tensile Test.** After heating the test piece to the required temperature, a normal tensile test is carried out. A stress/strain graph must be drawn, either by manual or autographic means and used to determine the proof stress, Young's Modulus, tensile strength or elongation as required by the material specification. BS A4, Part 1, Section 2, details the procedures to be used and lays down the limits on stress and temperature.

3.11.3 **Creep and Rupture Tests.** When a metal is subjected to both stress and high temperature over a long period, continuous and permanent elongation takes place and this is termed "creep", the final fracture due to creep being known as "rupture". This phenomenon occurs within the normal limits of proportionality and must be studied when a metal is to be used in a high temperature environment in order to determine working clearances and component life. Figure 10 shows the effect of time on creep strain and it can be seen that the use of a material beyond the secondary stage would lead to rapid failure.

(i) Experimental tests of up to 30000 hours duration are frequently conducted in order to determine the creep characteristics of a material, but tests of this length are neither necessary nor desirable for routine testing purposes. Tests of 100 hours duration are typical of current material specifications and determination of percentage strain at a specified temperature and stress is normally sufficient to prove a batch of material. In some cases "time to rupture" is also required and this may extend the duration of the test.

(ii) Creep characteristics vary with changes in temperature making it essential to control the temperature of the furnace to within close tolerances. The tolerances specified in BS A4 are less than 1 per cent and to achieve this accuracy rare metal thermocouples (platinum/platinum-rhodium) are often used in controlling the furnace electronically. The thermocouples are calibrated frequently by comparison with the freezing points of pure metals.

(iii) Creep testing machines are fitted with a load maintaining device to ensure that the specified stress is maintained throughout the test.

(iv) The test pieces used for creep testing may be identical to those described in paragraph 3.2, but some material specifications require the use of a notched test piece and this is fully described in BS A4, Part 1, Section 3.

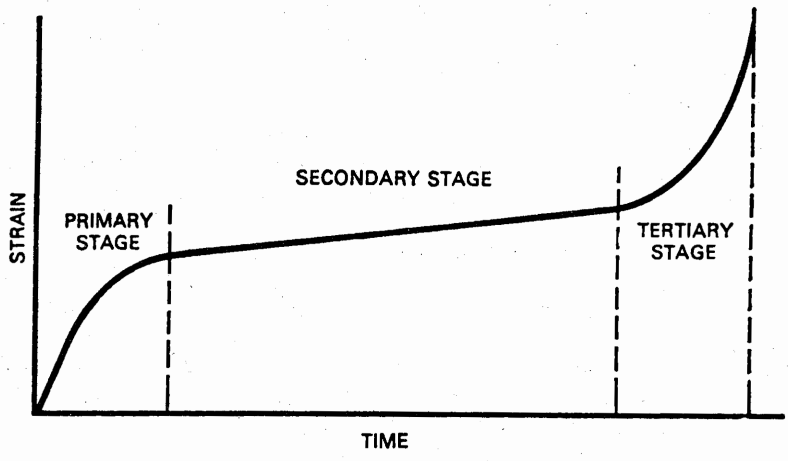


Figure 10 CREEP STRAIN/TIME DIAGRAM

4 DUCTILITY TESTS The ductility of a material is usually determined by means of a simple bend test, but other tests are often specified when a material is required for a particular use, i.e. wire, rivets or tubes. Information on the bend test requirements for weld test specimens is given in Leaflet **BL/6-4.**

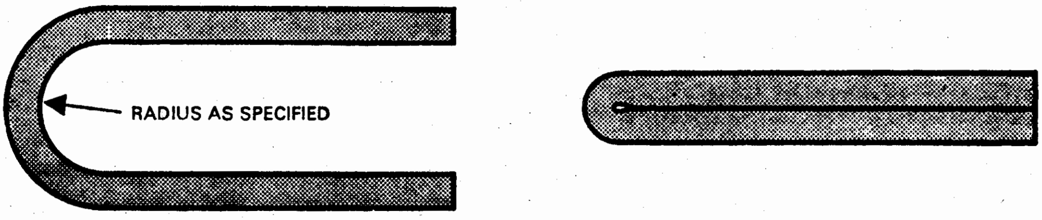
4.1 **Simple Bend Test.** The term "simple bend test" refers to a test in which a straight solid test piece of round or rectangular section is submitted to appreciable plastic deformation (without reversing the direction of flexure during the test) for the purpose of assessing the ductility of the material represented by the test piece. In some instances bend testing is considered to be an alternative or useful additional test to tensile testing and sometimes (but not often) it is used as an alternative test to the flattening test normally specified for tubular sections.

4.1.1 The capacity of a material to withstand deformation in a particular direction without cracking, or other specified forms of failure can be assessed by a simple bend test. The severity of the test is governed by the width/thickness ratio of the test piece for a given final internal radius. Experiments have shown that the test is less severe for a test piece of round section than for one of square section of equal thickness.

4.1.2 Where prescribed in the relevant specification, the simple bend test on sheets and strips used for aircraft purposes should, according to BS A4, be carried out on test pieces of 12.5 mm width, the edges of which should be smoothed and chamfered until approximately semi-circular in form. Such test pieces must be cut from the material in the direction relevant to the direction of rolling, as prescribed in the appropriate specification. The test should be made by bending the test piece through the angle (usually 180°) and over the radius prescribed in the specification, either by means of a former applied at mid-span (see paragraph 4.1.5), or by bending the test piece round a mandrel having the required radius (see paragraph 4.1.6).

4.1.3 During the bending of the test piece, it is often difficult to avoid a local decrease in the radius (a defect known as "peaking") but it should be noted that this may prevent comparison with results obtained by a different method of testing.

4.1.4 Where the standard or specification makes reference to a "close bend test" this indicates that the test piece should be bent through 180°, and that the "U" bend thus formed should subsequently be closed until the inner surfaces are in general contact. Examples of open and closed test pieces are illustrated in Figures 11 (a) and 11 (b) respectively.



(a) (b)

Figure 11 OPEN AND CLOSED TEST PIECES

4.1.5 Where thin materials are to be tested, the recommended method of producing the bend is by pressing the test piece into a block of soft lead using a former, as illustrated in Figure 12. To avoid damaging the test piece by excessive pressure, it should be pressed into the lead until it assumes an angle of about 90°, after which it should be bent around the former with the fingers or with a mallet until it assumes the standard "U" shape. During this later stage of manipulation, pressure on the former should not be increased.

NOTE: This method must be used when it is doubtful whether the metal will satisfy the bend test requirements.

4.1.6 A method of forming the test piece by means of a special bending machine is illustrated in Figure 13. Other methods of producing bends with formers used in conjunction with rollers, radiused supports or vee-blocks are given in BS 1639, and suitable methods of applying force to test pieces bent around mandrels are also given. Equipment for making bend tests is supplied with most of the universal testing machines.

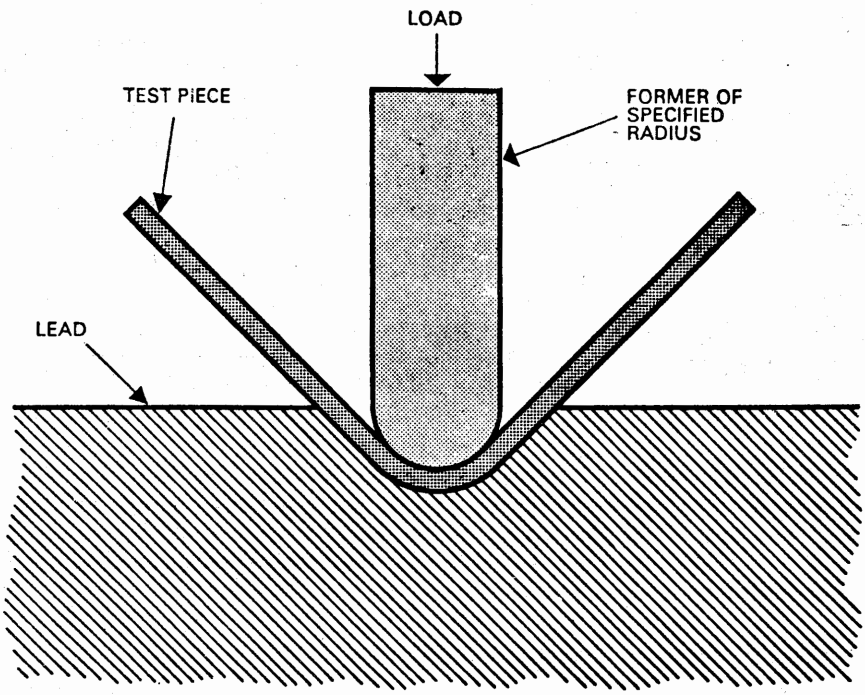


Figure 12 FORMING BEND TEST PIECE WITH LEAD BLOCK AND FORMER

4.1.7 When a test piece manufactured of ductile material is gradually bent from its original straight form through 180°, the "fibres" on the outer surface are stretched through the elastic limit and beyond to the yield point or even further, depending on the type of material and its physical condition. For a test to be satisfactory, the outer surface of the test piece must, after bending, be free from cracks visible to the naked eye, except that small cracks at the edges may be disregarded.

4.2 **Reverse Bend Test.** This test is specified for steel wire used for the manufacture of springs.

4.2.1 To make the test, one end of the test piece should be placed between suitable formers with inner edges rounded to a radius of 3 times the diameter or thickness of the material, the assembly being secured in a vice or testing machine.

4.2.2 The projecting end of the test piece should then be bent at right angles to the fixed end, first to one side and then the other (Figure 14), until the test piece breaks.

4.2.3 The number of bends the material should withstand without fracture is stated in the material specification.

4.2.4 As with the simple bend test, peaking (paragraph 4.1.3) is difficult to avoid and the results obtained by different methods of making the test are only approximate. If there is any doubt about the ability of a material to withstand the test, it must be tested in a machine which is reproducible in action, and which applies a component of axial tension sufficient to prevent peaking the test piece during the test.

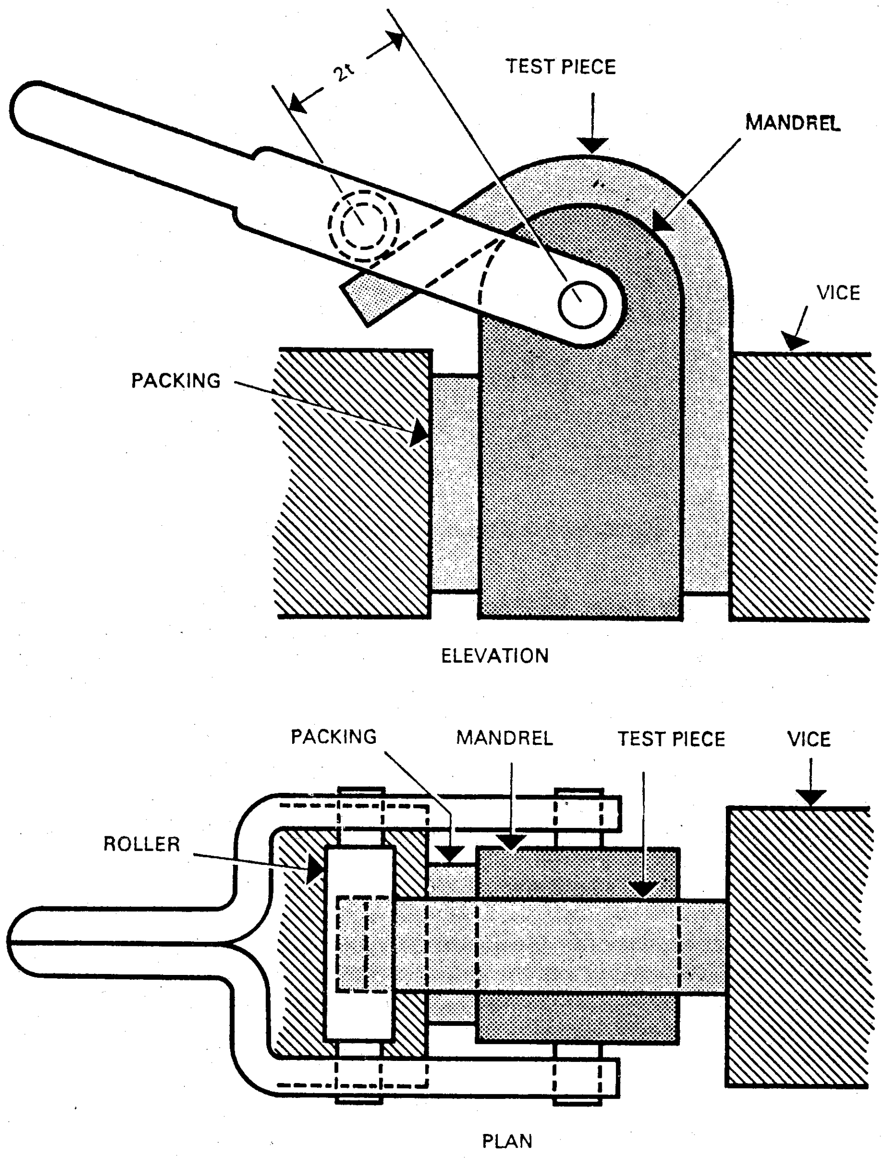


Figure 13 MACHINE FOR BENDING TEST PIECES

4.2.5 For a test to be considered satisfactory, the test piece must withstand the number of bends required by the specification without showing cracks visible to the naked eye, except that small cracks at the edges may be disregarded.

4.3 **Wrapping Test.** This test is sometimes specified for wire. The wire is wrapped around a former of the same diameter a specified number of times (usually 8) and then unwound. It must withstand this test without cracking.

4.4 **Torsion Tests.** These tests are also specified for wire, particularly that used for the manufacture of rivets, cables or bolts. There are two forms of tests.

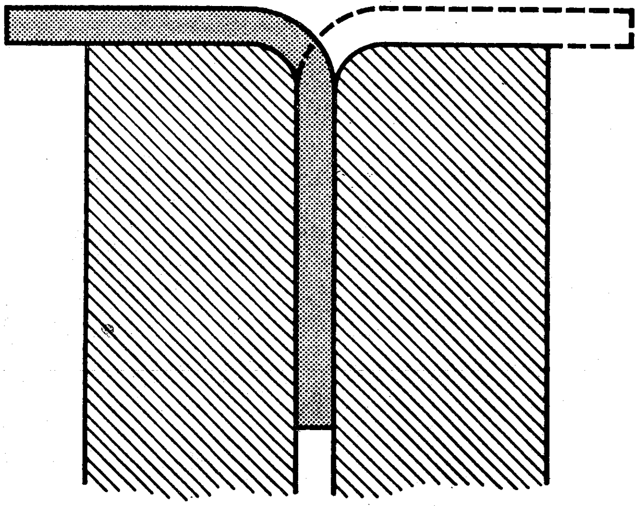


Figure 14 REVERSE BEND TEST

4.4.1 **Normal Torsion Test.** In this test a length of wire is selected (usually 100 × diameter) and twisted in a torsion machine which holds one end of the wire in a vice and rotates the other end at a speed of up to 60 revolutions per minute. The number of turns specified for steel wire is usually 15, but the test is continued until fracture occurs so that an examination of the fractured surface can be made.

4.4.2 **Reverse Torsion Test.** This is a test normally specified for wire from which bolts or rivets are manufactured. The test sample is gripped in two jaws which are a specified distance apart, one jaw being fixed and the other free to rotate. The free jaw is rotated a specified number of times in one direction and then turned back to the original position. No defects must be visible in the wire after test.

4.5 **Proof Bend Test.** This test is specified in some material specifications, usually for circular steel tubes, and as an alternative to a hardness test, on circular, solution-treated aluminium alloy tubes. It is only applied to tubes which are more than 12·5 mm diameter and which are neither too short nor too heavy for the testing machine (a length of approximately 1.5 m of tube is required to carry out the test).

4.5.1 The test procedure specifies that the test specimen shall be supported at two points and loaded at a third. This may be achieved by means of either a cantilever machine (Figure 15) or a beam machine on which the load is applied in the centre.

4.5.2 The particular material specification will state the 0.2 per cent proof stress figure to be used in calculating the bending moment to be applied to the machine. The bending moment is calculated from the formula:—

$$M = S \times \frac{(D^4 - d^4)}{32D \times 100}$$

Where M = Bending moment (Nm).
S = Specified proof stress (hbar).
D = Outside diameter of tube (mm).
d = Inside diameter of tube (mm).

4.5.3 **Testing Machine.** Figure 15 shows a typical approved testing machine of the cantilever type. A beam 'D' is pivoted at 'B' and loaded to give the required moment. The specimen 'T' is supported at 'A' and 'B' by suitably shaped blocks ('A' above and 'B' below) and a force 'F' is applied to raise the beam off the stop 'S'. Bending of the tube is recorded on the dial gauge 'G' at point 'C'.

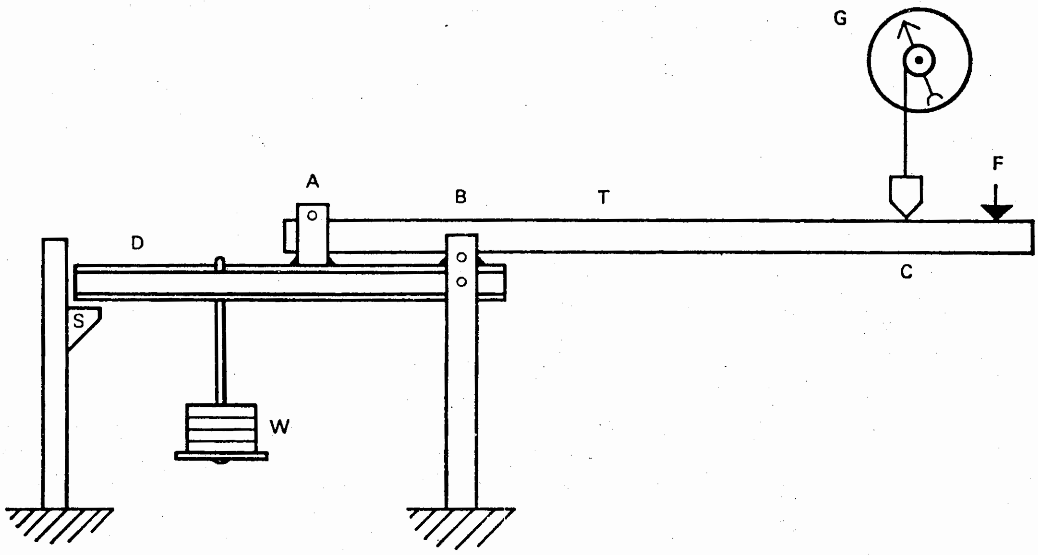


Figure 15 CANTILEVER PROOF BEND TESTING MACHINE

4.5.4 **Test Procedure**

(i) With the beam loaded to give the moment about its pivot which was calculated from the material specification and the formula given in paragraph 4.5.2, the tube is mounted between blocks A and B, and the dial gauge set to zero.

(ii) The force F is then applied to the tube until the beam is just lifted from its support. This force is maintained for 15 seconds and the dial gauge reading noted to record the elastic deflection of the tube.

NOTE: The elastic deflection may be calculated, if desired, from formulae quoted in the relevant testing instructions (e.g. BS T100 or L100). but in this case the distances AB and BC must be fixed.

(iii) Removal of the force will leave a permanent set in the tube and this will be shown on the dial gauge. Unless otherwise stated in the material specification, this reading must not exceed 5 per cent of the elastic deflection.

4.6 **Flattening Test.** This test may be applied to tubes of any shape or size, the selected test specimens being required to withstand, without cracking, flattening to a dimension stipulated in the appropriate material specification. Flattening is effected between flat surfaces by hammer blows or by pressure, a distance piece being placed inside the tube to limit the degree of flattening. Square or streamlined tubes are flattened across their diagonal or major axis as appropriate.

4.7 **Bend Test.** This test may be used as an alternative to the flattening test. A strip is cut transversely from the tube and bent 180° over a former of specified radius in such a way that the bore of the tube is at the inside of the bend. The strip must withstand this treatment without cracking.

4.8 **Drifting Test.** This test is applied particularly to light alloy tubing. The specimen must be cut at 90° to the longitudinal axis and all sharp edges removed. The drift is in the shape of a cone with (normally) an included angle of 30°, and is forced into the tube under steady pressure until the specified increase in tube diameter is obtained at the cut edge. The specimen must withstand drifting without any signs of cracking.

5 HARDNESS TESTS

5.1 General Requirements

5.1.1 Hardness is the resistance of a material to indentation and by pressing a suitably shaped indenter into the surface of the material being tested a comparison of hardness values can be made. Hardness values are normally required by the material specification and tests are also conducted to ascertain the effectiveness of case hardening, hardening and tempering, and heat treatment at the various stages of manufacture.

5.1.2 The surface hardness of a material is not always consistent and this is most evident in forgings and castings where irregular shape has led to uneven cooling. Similar conditions may be obtained by excessive grinding or machining which heat the surface, or by other manufacturing processes which may cause work hardening. Material specifications take these factors into account and require several impressions to be made and the mean value taken to calculate the hardness number. In other cases it may be necessary to make the test in a specified position (for example, on a portion of a casting which will be a bearing surface) and this will be stated on the relevant drawing.

5.1.3 Methods of measuring the size of the impression made by the indenter vary, but for the measurement of absolute (as opposed to comparative) hardness values, British Standards 240 and 427 stipulate that the surface area of the impression must be calculated, and the load applied to make the impression, divided by this area to give the hardness number. For production testing, and for checking the effectiveness of heat treatments, however, this is not essential and sufficiently accurate comparisons can be made by measuring the depth of the impression.

5.1.4 When test methods are used which require accurate measurement of the impression, the condition of the surface of the material is important and it is usually necessary to polish the test sample with fine grade emery cloth to obtain a satisfactory impression. This applies particularly when the indenter is lightly loaded. If direct readings are taken from the movement of the indenter, surface conditions are not so important; the only effect of a rough surface is the negligible difference in resistance offered to penetration of the indenter.

5.1.5 The rate of application of load to the indenter is specified in the relevant British Standard and is usually controlled automatically. In cases where the rate of application is controlled manually it should be remembered that rapid loading will induce a measure of kinetic energy and result in a deeper impression and lower hardness number.

5.1.6 The three main methods of carrying out hardness tests are outlined in BS A4 and described in the subsequent paragraphs. Other types of machine may be used but the type of indenter, load applied, and methods of measuring the impression, must comply with the appropriate standard. Material specifications normally stipulate the Brinell test for hardness measurement, but if this is unsuitable for any reason the Vickers test may be used. The relative values of hardness numbers derived from these two tests are shown in BS 860. For comparative measurement the Rockwell test is permitted.

5.2 **Brinell Test.** In the Brinell test a spherical indenter is used and a specified load applied by means of a press. The hardness number is obtained by dividing the force used by the spherical area of the impression.

5.2.1 The size of the impression is determined by measurement of the diameter, and the spherical area calculated from the formula:—

$$\frac{\pi D}{2}\left[D - \sqrt{(D^2 - d^2)}\right]$$

Where D = diameter of ball.
d = diameter of impression.

The measurement is made by means of a microscope engraved with a suitable graticule.

5.2.2 It would be possible to calculate the spherical area of the impression from measurement of the depth, but this is not done for three reasons:—

(i) The lip formed round the edge of the impression is not consistent but varies with different metals. Measurement from the normal surface would be difficult.

(ii) Elastic recovery after removal of the indenter is proportionally much greater in depth than in diameter and would yield larger errors.

(iii) The depth of the impression is much less than the diameter, and errors in measurement would be proportionally greater.

5.2.3 Originally the diameter of the Brinell indenter was 10 mm and the force employed 3000 kgf. The size of the impression made thus limited the method to the testing of large pieces, and was impracticable for testing soft metals or thin sheets. Furthermore, the results obtained were not proportional due to the shape of the indenter; the diameter (d) varied in relation to the spherical area.

5.2.4 In order to obtain comparable results and permit the use of the Brinell test on all types of metal a method was determined which produced a geometric similarity in all cases. It was found that if a d/D ratio of 0.25 to 0.5 was maintained, comparable results were achieved. It was also found that if the ratio of pressure $(P)/D^2$ was kept constant for a particular metal then different sized balls could be used and would give the same hardness number. This constant (P/D^2) is listed in BS 240 for various metals; examples being, steel: 30, aluminium alloy: 10, copper: 5, lead: 1. Ball diameters are standardised at 1, 2, 5 and 10 mm. Thus when testing steel with an indenter of 5 mm diameter, a force of $D^2 \times 30$, i.e. $5^2 \times 30 = 750$ kgf must be used. For a material not listed it would be necessary to carry out a series of tests using different loads until an impression giving a d/D ratio near to 0.375 was obtained. The constant P/D^2 could then be calculated for this material for future reference.

5.2.5 The accuracy of the results obtained by the Brinell test depend on the formation of an accurate impression and it has been found that, when testing hard steel, deformation of the ball indenter leads to inconsistent results. Steel balls are satisfactory up to hardness values of approximately 500, and this can be extended to about 630 by use of a work-hardened ball. Above this value, results, although satisfactory for purposes of comparison, are not proportional to those obtained on softer materials. This means that the Brinell hardness number (written HB) 300 is twice as hard as HB 150, but HB 800 is not twice as hard as HB 400.

5.2.6 **Brinell Machine**

(i) The standard Brinell machine operates hydraulically. A handpump is used to increase pressure in the operating cylinder and a form of dead-weight control ensures application of the correct force. When pressure in the cylinder reaches the correct value a proportional weight lifts and remains "floating" for as long as the correct force is being applied to the indenter.

(ii) A number of similar machines are manufactured which are used for carrying out Brinell tests, the main improvements being in the rapidity of testing. All must use a ball indenter and load calculated in accordance with the Brinell method however, and measurement of the diameter of the impression must be made in order to comply with BS 240.

(iii) Measuring microscopes with a graticule scale are often used to measure the mean diameter of the impression but in some machines the image is projected onto a ground glass screen for direct reading.

(iv) To obviate the need to make the calculation $\text{HB} = \dfrac{P}{\frac{\pi D}{2}\left[D - \sqrt{(D^2 - d^2)}\right]}$, tables are provided in BS 240 from which the hardness number may be read directly by entering the mean diameter of the impression. It should be noted that these tables provide for d/D ratios outside the range to 0.25 to 0.5 which means that hardness values obtained from the extremities of the tables will not be proportional.

5.2.7 **Test Blocks.** In order to check the accuracy of the machine being used, test blocks of a specified hardness are provided by the manufacturer. A normal hardness test carried out on these blocks will verify readings obtained on the machine. The hardness number of the test block used should approximate to that of the material to be tested.

5.2.8 **Testing Precautions.** In order to ensure satisfactory results from a test the following precautions should be observed:—

(i) Surface of material should be smooth. If circumstances permit, it is advisable to polish lightly with fine emery paper to remove any surface defects.

(ii) The impression should not be near an edge. BS 240 states that the minimum distance from the edge is 2½ × diameter of impression.

(iii) The thickness of the material to be tested must be at least 10 × depth of impression. BS 240 contains a table showing the minimum thickness of material to be used in tests with standard balls at various loads.

(iv) The test specimen should be adequately supported and square to the ball holder.

(v) Load should be applied for 15 seconds.

(vi) Diameter of impression should be measured in two places at right angles and the mean value taken to find the hardness number.

(vii) When quoting results of the Brinell test the ball diameter and load should also be quoted, e.g. HB 10/3000 = 240.

5.3 **Vickers Test.** The Vickers hardness test is similar to the Brinell in that an impression is made by applying a load to an indenter and the hardness number is derived from measurement of the impression.

5.3.1 In the Vickers test a diamond in the shape of a square based pyramid is used and the measurement is made across the diagonal (d) of the impression. The hardness number is derived from the formula:—

$$HV = \frac{2P \sin \theta/2}{d^2}$$

Where P = load (kg).
d = diagonal of impression (mm).
θ = included angle between faces of pyramid.
HV = Vickers hardness number.

5.3.2 The included angle between opposite faces of the pyramid is 136° and is derived from the ideal form of Brinell impression (d/D = 0.375). This ensures that hardness numbers on the Vickers and Brinell scales coincide approximately until increased pressure on the ball indenter causes distortion and divergence from the true scale. By using a diamond indenter of this shape, geometric similarity is assured and a proportional scale of hardness numbers is achieved. As no distortion of the indenter occurs, much higher values of hardness may be tested by this method.

5.3.3 As the Vickers system gives a constant angle of indentation, any change of load will be accompanied by a proportional change in the size of impression, so that the hardness number for a given material will always be the same, regardless of the load applied. The advantage of this is that the load can be altered to suit the material under test; a small load would be used on thin sheet or a finished product. Standard loads of 5, 10, 20, 30, 50, 100 and 120 kg are used whenever possible, but it is recommended that the largest practicable load be used to reduce the effects of surface irregularities, and to minimise errors in measurement.

5.3.4 **Measurement.** The square impression made by the diamond pyramid has distinct advantages over the circular impression with regard to measurement. The lip formed by the indenter is confined to the sides of the square impression, thus errors in measurement are less and arise only from the slight difference in area between the form of the impression and a true square. Measurement across the points is also much easier and more accurate than measurement of a circular impression.

5.3.5 **Vickers Machine** (Figure 16). In this machine the load is applied directly by weights, the rate and duration of loading being controlled automatically to that required by BS 427. Proportional weights are hung on a scale pan at the rear of the machine to give the required force on the indenter. Leverage on the arm operating the indenter is 20:1 so that only small weights are required and these may be selected according to the type of test being undertaken.

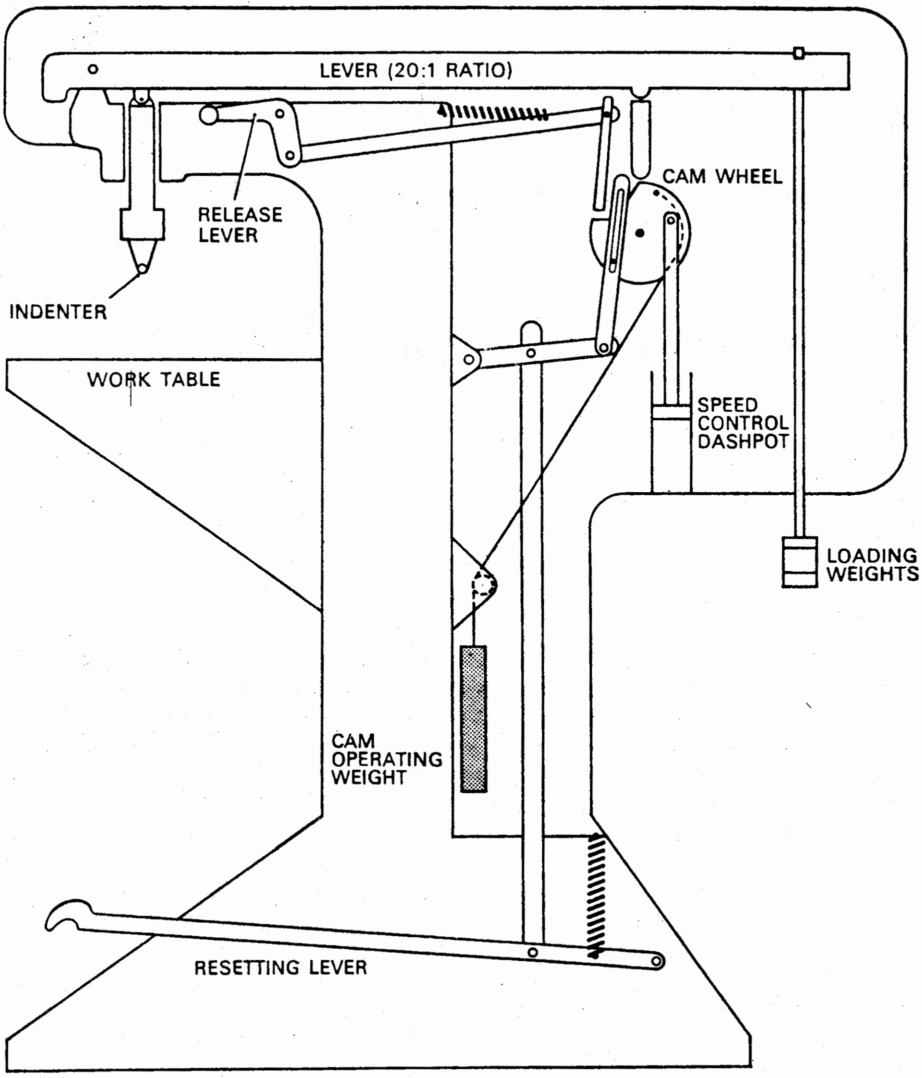


Figure 16 VICKERS HARDNESS TESTING MACHINE

5.3.6 **Optical Microscope.** The measuring microscope is an integral part of the machine and is mounted alongside the indenter. The test sample is attached to a sliding table and may be moved into the range of the microscope immediately after an impression is made.

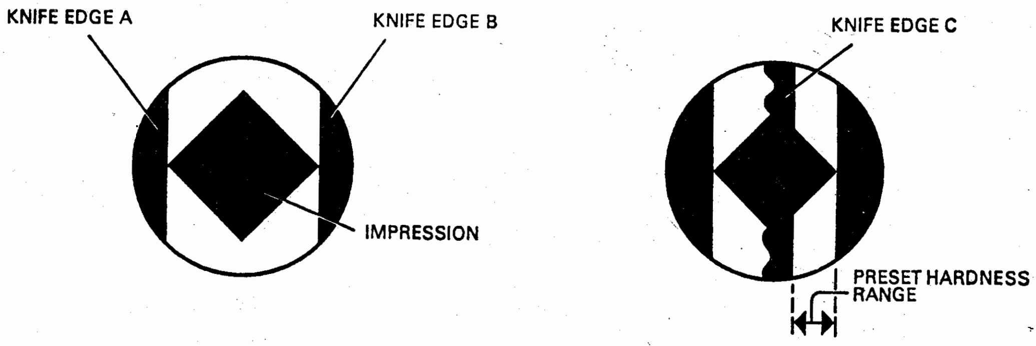
(i) The eyepiece incorporates knife edge adjusters for measurement of the impression as shown in Figure 17. The adjuster for 'A' is the datum adjuster and moves all knife edges together, while the adjuster for 'B' is connected to a digital counter for easy reading of the diagonal dimension (in mm).

(ii) A normal reading is made in the following manner:—

- (a) 'A' is set against the left-hand corner of the impression.
- (b) 'B' is adjusted until it touches the right-hand corner of the impression and the reading noted.
- (c) The microscope is swung through 90° and steps (a) and (b) repeated for the other diagonal.
- (d) The mean diagonal dimension is entered in the appropriate table in BS 427 to find the Vickers hardness number.

(iii) On some machines a third knife edge 'c' is incorporated in the microscope and is used for rapid production testing when the hardness is required to be within a stipulated range. In this case the procedure is as follows:—

- (a) Set knife edge 'B' to the reading which gives the maximum hardness value.
- (b) Bring 'C' up to 'B'.
- (c) Reset 'B' to the reading which gives the minimum specified hardness value.
- (d) Carry out a test, then line up knife edge 'A' with the left-hand corner of the impression.
- (e) If the hardness of the material is satisfactory then the right-hand corner of the impression will be between knife edges 'B' and 'C' as shown in Figure 17(b).



(a) NORMAL USE

(b) CHECKING WITHIN RANGE

Figure 17 MEASUREMENT OF VICKERS IMPRESSION

5.3.7 General Observations.

(i) The Vickers machine may be verified by use of test blocks of known hardness as described in paragraph 5.2.7.

(ii) In view of the small size of the impression made by the Vickers test, the condition of the surface of the test sample is of more importance than with the Brinell test and should be either ground or polished to ensure accurate results.

(iii) When testing case hardened materials several impressions should be made at increasingly lighter loads until two identical readings are obtained. This is necessary due to the effect of the softer core on the thin case-hardened layer.

(iv) When reporting the results of Vickers hardness tests the load used should also be included, e.g. HV/5 = 550, indicates a Vickers hardness number of 550 using a 5 kg load.

(v) Tables of Vickers hardness numbers for various standard loads will be found in BS 427.

5.4 **Rockwell Test.** The Rockwell method differs from the previously discussed tests in that the depth of penetration of the indenter is gauged mechanically and indicated directly to the operator. No physical measurement is necessary.

5.4.1 Because of the method of measurement, the Rockwell test is not suitable for the measurement of absolute hardness numbers and is not normally permitted by material specifications. The scale of hardness numbers is proportional to the depth of penetration of the indenter and not to the hardness of the material (1 scale unit = 0.002 mm penetration). It is a very useful method of making rapid hardness tests during the manufacture of a material however, as preparation of the surface is usually unnecessary.

5.4.2 Two types of indenter are used; a steel ball for use with unhardened steel and soft metals, and a spherical tipped diamond cone known as a 'Brale' indenter for use with harder materials.

5.4.3 The method of forming the impression is as follows:—

(i) A light (minor) load is applied to the indenter and the dial gauge set to zero.

(ii) A heavier (major) load is applied to the indenter and released when the dial needle has settled.

(iii) The hardness number is then read directly from the dial gauge with the minor load still applied.

5.4.4 This method ensures that the machine is under the same stress when the dial is set and when the reading is taken thereby taking into account machine factors and backlash. The elasticity of the material is of no importance as it does not enter into the hardness reading.

5.4.5 A number of different dial scales may be used in the Rockwell machine depending on the particular tests being carried out. The scales 'B' and 'C' are most used, and are included on a single dial. The 'B' scale is used with a 1.588 mm ($\frac{1}{16}$ inch) diameter ball indenter and major load of 90 kg, while the 'C' scale is used with a 'Brale' indenter and major load of 140 kg. A 10 kg minor load is used in each case. Scale units are identical but the 'C' scale zero coincides with the 'B' scale 30. Other scales are used for special purposes, e.g. thin sheet material, very soft metals or very hard metals.

5.4.6 Because of the different scales available with this method of hardness testing it is necessary to specify which was used for a particular test, e.g. HR/C40 indicates a Rockwell hardness number of 40 on the 'C' scale.

5.4.7 **Standard Rockwell Machine.** In the working of this machine, the minor load is applied by raising the test specimen to the indenter and continuing upward movement until the required load is indicated by a small pointer on the dial gauge. The major load is provided by a lever and proportional weight and applied by means of a release lever, rate of application being controlled by a dashpot to ensure consistent readings. BS 891 describes the use of this machine.

5.4.8 **Rockwell Superficial Hardness Tester.** This machine operates on the same principles as the standard machine, but is only used for the 'N' and 'T' scales. The minor load is only 3 kg and major loads used are 15, 30 and 45 kg. One scale unit is equal to a movement of 0.001 mm, therefore the scale is more accurate than on the standard machine. The machine is ideally suited for testing very thin metal sheet or finished products where a small indentation is essential. BS 4175 deals with the methods to be used for Rockwell superficial hardness tests.

5.5 **Care of Equipment.** Proper maintenance of the equipment is essential if consistent results are to be obtained. This is particularly important when light loads are used and the effects of friction become more pronounced.

5.5.1 Pivots and bearings should be examined periodically and particular attention paid to knife edges which support heavy loads.

5.5.2 Damage to indenters may occur, and will usually be noticed on the Brinell and Vickers test when the impression is viewed under the measuring microscope. The impressions made by the Rockwell indenters are not viewed, however, and these indenters should be examined for damage at frequent intervals.

5.5.3 Measuring microscopes should be checked by means of a calibrated scale to ensure that the focus is correct.

6 IMPACT TESTS Impact tests are necessary as a check of the impact resistance qualities of a metal and to ensure that temper brittleness has not been introduced during heat treatments. There are two types of machine used for testing aircraft materials, both of which use a pendulum weight to fracture the specimen. The energy absorbed by the specimen is measured from the angle through which the pendulum swings after causing the fracture. The Izod test is quoted in the majority of British material specifications but when there is a requirement for testing at sub-ambient or elevated temperatures the Charpy test is recommended. This is because of the difficulties associated with mounting the test piece in the Izod machine and completing the test within the stipulated 6 seconds after removal from the heating/cooling bath. The Izod machine is illustrated in Figure 18.

NOTE: Perusal of BS 131 will show that pendulum energy is still quoted in ft lb and that test results should include this unit. It will also be noted that while the standard square test pieces are dimensioned in millimetres the Izod round test piece is demensioned in inches. The S.I. unit being introduced as the unit of energy is the joule (J) and this will be stipulated in some material specifications. 1 ft lb = 1.356J.

6.1 **Test pieces.** The standard impact test pieces are illustrated in Figure 19. Subsidiary test pieces are permitted when the test specimen is too small to permit manufacture of the standard test piece, but it should be noted that no reliable relationship has been established between results obtained with test pieces of different sizes. Results obtained with identical test pieces on different types of machine are also difficult to correlate, so that comparisons should only be made between tests on similar machines using identical test pieces.

6.1.1 Test pieces are notched to concentrate stress and may have one, two or three notches depending on the test requirements of the particular material. The position of the notch in relation to the direction of rolling is most important and should always be at right angles to the grain flow. With small bar specimens the test piece can only be prepared in this way but with larger material it may be possible for the notch to be cut ***with*** **the grain** flow and this would result in very low impact test result

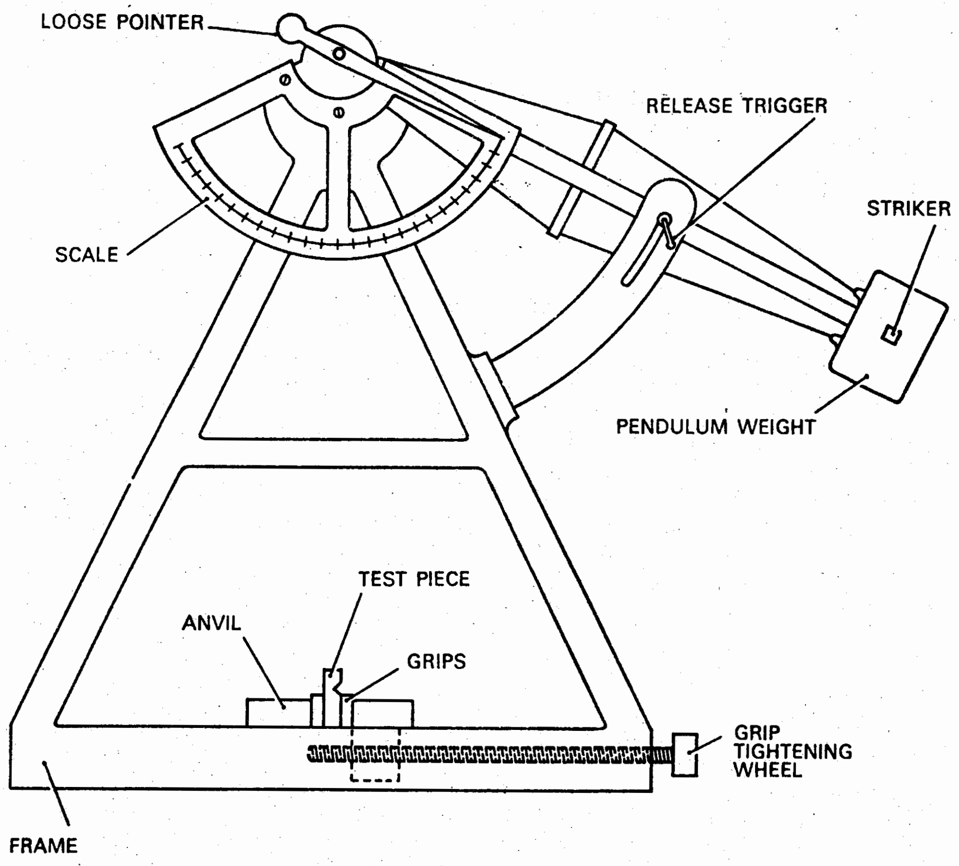
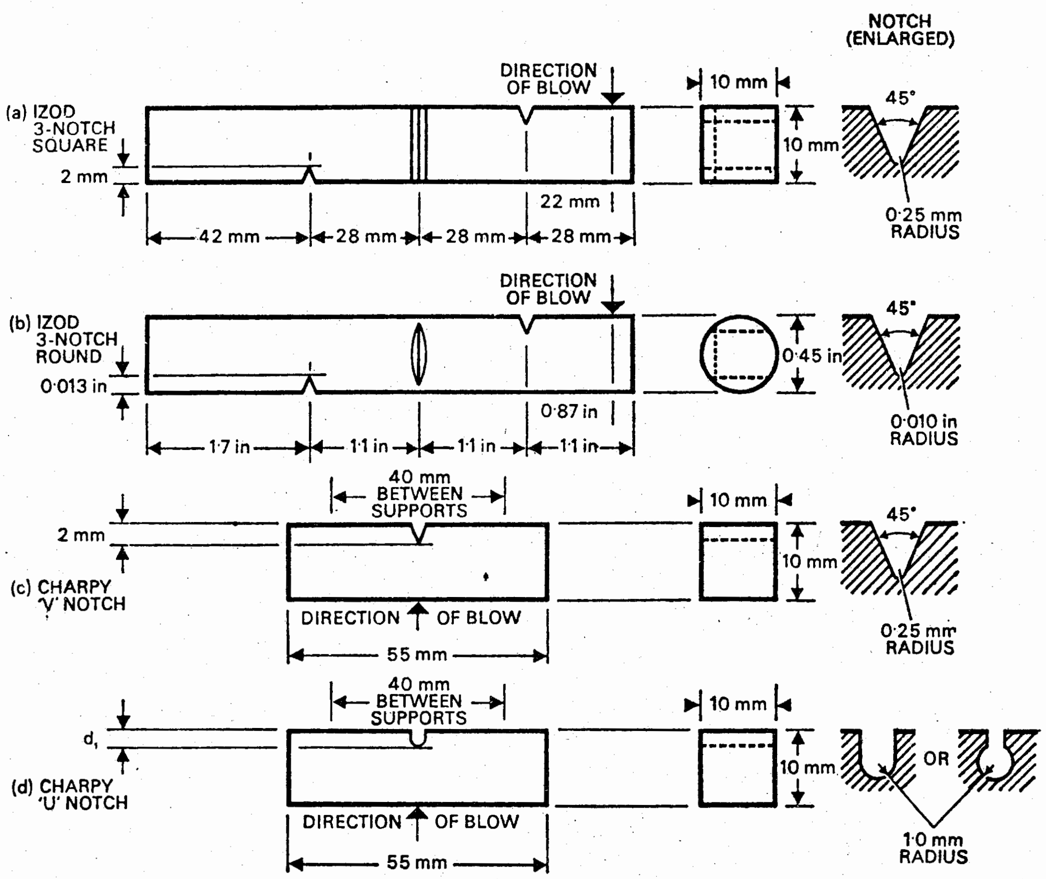


Figure 18 IZOD IMPACT TESTING MACHINE

6.1.2 BS 131 stipulates that test pieces shall be machined all over to ensure accurate results. The condition of the notch is particularly important with some materials and the relevant specification may require it to be formed in a certain way; otherwise it may be cut by any suitable machining operation which will provide a smooth contour. Reference should be made to this British Standard for details of dimensional tolerances.

6.2 **The Izod Test.** This test is carried out on a machine with a striking energy of, normally, 120 ft lb (163J) although smaller machines of 20 ft lb (27J) and 60 ft lb (81J) energy are sometimes used for testing materials of low energy absorption. A cantilever type of test piece, mounted in a vice at the base of the machine, is fractured by means of a striker attached to a pendulum weight.

6.2.1 A trigger mechanism is used to release the pendulum from the 'cocked' position and it then falls through an angle of 60° to strike the test piece at a distance of 22 mm above the notch. As the pendulum continues its swing it carries with it a loose pointer which stops at the maximum angle reached by the pendulum. The energy absorbed by the test piece is recorded on a scale located behind the pointer.



NOTE: depth of notch (d_1), for 'U' notch is 2, 3 or 5 mm and for 'keyhole' notch 3 or 5 mm. Required depth is stated in material specification.

Figure 19 STANDARD IMPACT TEST PIECES

6.2.2 It is important that the test piece is gripped in the vice so that the notch is level with the surface of the rear jaw and facing the striker. A simple gauge is provided with the machine to assist in achieving this position.

6.3 **The Charpy V-Notch Test.** BS 131 states that this test should be carried out on a machine with a striking velocity of 4.5 to 6.0 m/s and also specifies two striking energies; 100 to 120 ft lb (136 to 163J) and 200 to 240 ft lb (272 to 326J). The Charpy machine satisfies these requirements by using a pendulum fitted with detachable weights. The angle through which the pendulum falls is 160° in both cases. The machine may also be adapted for making Izod tests by changing the pendulum head and fitting a cantilever test piece attachment.

6.3.1 The test piece used for normal tests is illustrated in Figure 19 (c), and is mounted horizontally on the machine with the notch facing away from the pendulum and in line with the striker. It rests on supports 40 mm apart, and because of the ease of mounting tests may be performed quickly. For this reason the Charpy machine is ideal for conducting tests at sub-ambient or elevated temperatures.

6.3.2 Thc method of measuring the energy absorbed by the test piece is the same as on the Izod machine, but in this case a triple scale is employed from which the maximum rise of the pendulum may be read in degrees, in kgm or in kg/mm^2.

6.3.3 For normal use the pendulum is held by a trigger stop at an angle of 160° from the test piece, but a second stop is sometimes provided from which the pendulum may be released when carrying out a test to Izod requirements.

6.3.4 The size of pendulum weights to be used will normally be dictated by the material specification and will generally be such that a striking force of 100 to 120 ft lb (136 to 163J) is applied only to materials with impact values less than 50 ft lb (68J).

6.4 **The Charpy U-Notch Test.** This test is carried out on a standard Charpy machine but uses the test piece shown in Figure 19 (d). The shape of the notch has no significant effect on the test and, for ease of manufacture, may be chosen from either of those shown in the illustration. The depth of notch to be used will be stated in the relevant material specification (usually 5 mm).

6.5 **Care of Equipment.** Impact testing machines are initially calibrated by direct measurement of the weights, angles and dimensions involved, and these should not require alteration. The nature of the test is such, however, that considerable shocks are transmitted to the machine and the following periodical checks are recommended to ensure continued accuracy:—

(i) Check that the machine is vertical by means of a spirit level placed on the vice or test piece supports as appropriate.

(ii) Operate the machine normally but without a test piece and ensure that the loose pointer registers zero.

(iii) Hang the pendulum vertically and ensure that the appropriate energy is indicated on the scale.

(iv) Inspect the striker and the vice or test piece supports for signs of dents, cracks or other damage which could affect test results.

(v) Lubricate the pendulum bearing and vice operating mechanism in accordance with the manufacturer's instructions.

BL/10-9

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BASIC

TESTING OF MATERIALS AND CHEMICAL SOLUTIONS

PERFORMANCE TESTING OF PENETRANT TESTING MATERIALS

1 INTRODUCTION This leaflet gives guidance on tests devised to show whether materials used for the penetrant inspection processes described in Leaflet **BL/8-2**, Penetrant Dye Processes, and Leaflet **BL/8-7**, Fluorescent Penetrant Processes, are in a satisfactory condition for further use.

1.1 The tests described in this leaflet (there are other equally satisfactory methods) consist of comparing the performance of materials in use with samples of unused materials which are known to be in a condition as received from the manufacturer. The tests should be carried out at regular intervals as specified by the manufacturers and should also be made if it is suspected that the materials may have become contaminated.

1.2 In order to provide for the tests, a one-pint sample of all new batches of penetrants and emulsifiers should be taken and stored in airtight glass containers, protected from extremes of temperature and direct sunlight, and suitably identified to show the batch of materials to which they belong.

1.3 A metallic specimen containing cracks the location of which are known is necessary to enable the comparison to be made between samples. The preparation of a suitable test piece is described in paragraph 2.

2 THE TEST PIECE The most suitable type of specimen is the "demountable" type test piece which can be dismantled between tests for cleaning but a suitable alternative is an aluminium alloy block, as illustrated in Figure 1, containing known fine defects.

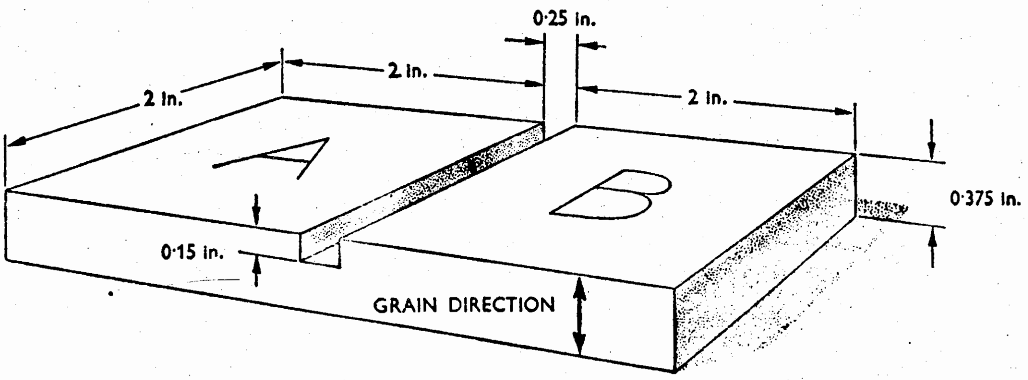

Figure 1 TEST PIECE

2.1 The test piece should be cut from 24ST rolled aluminium plate to the dimensions and in the grain direction shown in Figure 1. All excessive markings should be removed from the working face and the test piece cracked by heat-treating in the following manner.

2.2 The test piece should be heated over an open flame so controlled that a temperature of 525°C. is reached in not less than four minutes, after which the test piece should be quenched in cold water and then heated gently over a flame to ensure that it is completely dry.

2.3 A slot of the dimensions given in Figure 1 should be made in the working face and the two 2 in. square surfaces thus obtained should be identified by lightly etching the surface with suitable symbols, e.g. "A" and "B".

2.4 A record of the surface markings of the test piece should be made for subsequent reference in the following manner. The penetrant process should be applied to the test piece by hand under ideal conditions and using materials of a known standard and of the same type as those for which the test piece will be used. After allowing the defect indications to develop for a period of 15 minutes, the test piece should be photographed. Finally the test piece should be cleaned by the method described in paragraph 4.

3 USE OF TEST PIECE A test piece prepared for use with dye penetrants must not be used for testing fluorescent penetrants and vice versa. In this way the risk of contamination, which would give a false indication of the quality of the material being tested, is considerably reduced.

3.1 The test piece should be used by dipping surface "A" into a sample of unused material and surface "B" into a sample of the material under test. The test piece should then be allowed to drain for not less than 20 minutes, care being taken to ensure that the penetrants cannot mix.

3.2 After draining, both halves of the test piece should be washed simultaneously by the normal process method (see Leaflets **BL/8-2** or **BL/8-7**, as applicable), notice being taken of the ease with which each half is cleaned. The test piece should then be dried and developed by the normal process method and allowed to stand for 15 minutes.

NOTE : Where the recommendations given above would not be suitable for a particular process, the general principle should be followed but adapted as necessary.

3.3 The two halves of the test piece should be compared one with the other and with the record of the initial test for the following :—

(a) vividness of indications

(b) definition of indications

(c) extent to which very fine defects are revealed

(d) ability to retain indications in wider cracks

(e) background contamination.

3.4 After making the comparisons described above it should be possible to arrive at one of the following conclusions.

3.4.1 If both halves of the test piece compare favourably with each other and with the record of the initial test, it can be concluded that the material under test and the process used are satisfactory.

3.4.2 If the half of the test piece treated with unused material is comparable with the record of the initial test but the half treated with used material is not, this suggests that the used penetrant has become contaminated or has otherwise deteriorated and should be discarded.

3.4.3 If both halves of the test piece compare favourably one with the other but not with the record of the initial test, this suggests that the whole or some part of the process is at fault and should be investigated. However, the possibility of the test piece having become contaminated should not be overlooked. Possible faults with the process include incorrect temperatures, excessive washing and incorrect development techniques.

4 RESTORATION OF TEST PIECE On completion of each test the test piece should be thoroughly cleaned to remove all traces of contamination. This can be effected by degreasing in a trichloroethylene vapour plant (Leaflet **BL/6-8**) for two cycles of 15 minutes each (allowing the test piece to cool after each cycle) followed by immersion in a bath containing acetone, benzene or toluene for not less than 24 hours.

4.1 After cleaning the test piece should be stored in an airtight container in a mixture of 50 per cent trichloroethylene and 50 per cent toluene until required for further use.

4.2 It should be borne in mind that the useful life of a test piece depends entirely on the effectiveness of the restoration process.