Aero Engines

(According to the Syllabus Prescribed by Director General of Civil Aviation, Govt. of India)

FIRST EDITION

AERO ENGINES

Prepared by

L.N.V.M. Society Group of Institutes
* School of Aeronautics
(Approved by Director General of Civil Aviation, Govt. of India)

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Dedicated To

Shri. Laxmi Narain Verma
[Who Lived An Honest Life]

Preface

This book is intended as an introductory text on Aero Engine which is an essential part of General Engineering and Maintenance Practices of DGCA license examination.

It is intended that this book will provide basic information on principle, fundamentals and technical procedures in the subject matter areas relating to the Aero Engines.

The written text is supplemented with large number of suitable diagrams for reinforcing the key aspects.

In Einstein's word "Make things as possible but no simpler". No doubt he had textbook authors in mind. Only a few books find the narrow path between overwhelming the reader and wasting the reader's time. I believe that this is one of those rare books that find that path.

I acknowledge with thanks the contribution of this faculty and staff of L.N.V.M. Society Group of Institutions for their dedicated efforts to make this book Aero Engine a success.

I am also thankfull to our Director Mr. C.C. Ashoka for having faith on me in publishing this book.

I would very much appreciate criticism, suggestions for improvement and detection of errors from the readers, which will be gratefully acknowledged.

Arjun Singh

(Senior Instructor, School of Aeronautics)

L.N.V.M. Society Group of Institutes Dated : July, 2006

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CHAPTER: 1
PISTON ENGINE

PRINCIPLES OF OPERATION

A piston (or reciprocating) engine is a device for converting the heat energy of a fuel into mechanical energy, by internal combustion. The principles which govern the relationship between pressure, temperature. and volume. in a gas are stated in the laws of boyles' and Charles', and these principles are applicable to the operation of a piston engine.

In a piston engine, a fuel/air mixture is drawn or forced into a cylinder, compressed and ignited, thus increasing temperature and pressure; acts on a piston and forces it down in the cylinder. The linear movement of the piston is converted into rotary movement by the engine mechanism. Piston engines are designed to operate on a 2- stroke or 4- stroke cycle, but since the vast majority of aircraft engines operate according to the latter, this chapter deals solely with the 4 stroke or "otto" cycle which is named after in inventor (fig.1).

The movement of the piston from its highest to its lowest position in a cylinder is known as “stroke” and corresponds to one half of a revolution of its crank shaft. Two upward and two downward strokes make up the complete cycle, and purpose of each stroke is as follows:-

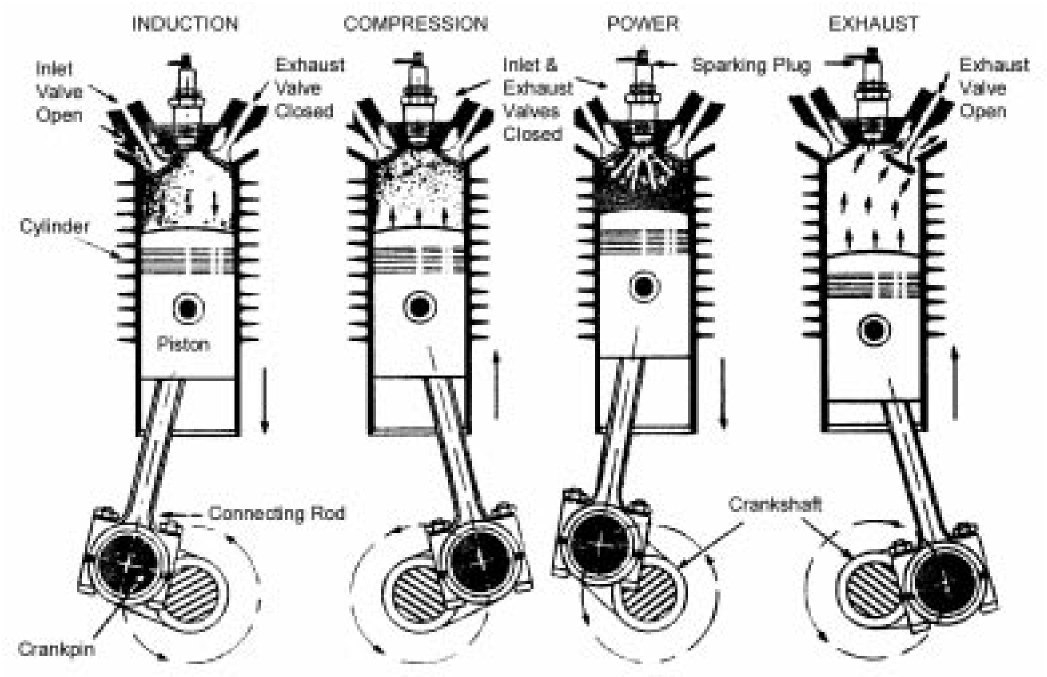


Fig. 1.Operation Of Four Stroke Cycle.

Induction Stroke

When the piston is at the top of its stroke, an inlet valve in the cylinder head is opened, and as the piston travels down to the bottom of its stroke, the combustible mixture of fuel and air is drawn into the cylinder. The valve closes when a piston reaches the bottom of the stroke.

Compression Stroke

As the piston travels up to the top of its stroke both the inlet valves and the exhaust valve are closed and the combustible gas is compressed in the cylinder.

Power Stroke

As the piston commences its second downward stroke the combustible mixture is electrically ignited (by means of a magneto and sparking plug) and gas expands thus building up pressure and forcing the piston down.

Exhaust Stroke

The exhaust valve in the cylinder head now opens, and as the piston continue its second upward stroke the burnt gases are forced out through the exhaust port to atmosphere. At the completion of this stroke exhaust valve is closed.

The theoretical 4- stroke cycle is very inefficient, for several reasons and must be modified, to produce acceptable power. The main factors which necessitate these modifications are inertia of the gases, burning rate of fuel/air mixture

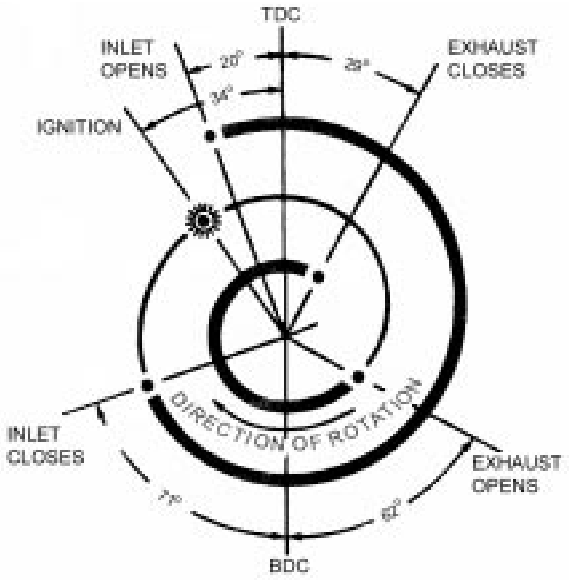


Fig. 2.Valve Timing Diagram.

and the ineffective crank angle, the last being defined as angular position of the crank shaft when, for large angular movement of the crankshaft at both ends of the stroke; the linear movement of the piston is small. Ideally best power will be produced by varying the valve timing (i.e. the times at which the valves open and close in relation to the crankshaft position) according to the rotational speed of the engine, but the mechanism necessary would result in such increased weight and complication that the valves of an a/c engine are usually timed to provide the greatest efficiency at cruising speed. The actual timing of the valves on a particular engine is often illustrated in the form of a dig known as valve timing Dig. shown in fig 2. The terms Top Dead Centre (T.D.C.) and Bottom Dead Centre (B.D.C.) are used to define the positions of the crankshaft when piston is exactly at the top or bottom of its stroke respectively.

For the induction stroke, the opening of the inlet valve is initiated before T.D.C. to ensure that it is partially open when the piston commences its downward stroke, so reducing the lag between the piston and the gases.

The inlet valve closes after B.D.C. to take advantage of the inertia of the incoming, gases and fill the cylinder as completely as possible. Movement of the piston for a short period after B.D.C. is in sufficient to oppose the incoming gases before the valve closes.

Although the fuel/air mixture burns quickly, combustion is not instantaneous. The ignition is therefore arranged to occur before T.D.C. at the end of the compression stroke, so that maximum pressure is achieved shortly after T.D.C. on the power stroke.

The exhaust valve opens before B.D.C. on the power stroke when most of the expansion due to combustion has taken place, and further useful work is limited by the ineffective crank angle residual gas pressure initiates scavenging of the burnt gases through the exhaust port.

The exhaust valve closes after T.D.C. to make use of the inertia of the outgoing gases to completely scavenge the cylinder and to assist in over coming the inertia of the incoming gases.

The number of degrees of crankshaft movement by which valve opening precedes B.D.C. or T.D.C. is known as "valve lead", and the number of degrees of crankshaft movement by which valve opening follows BDC or TDC is known as "Valve lag". The period when both inlet and outlet valve are open together is known as *Valve Over Lap.*

ENGINE LAYOUT

There are different arrangement of cylinders according to the requirements. Air cooled in line horizontally opposed and radial engines, are all widely used on civil a/c because of their general reliability and economy. Liquid cooled, Vee-engines were widely used on military a/c because of their high power output and low frontal area but are rarely found on civil a/c.

Radial Engine

A radial engine has an odd no of cylinders usually not more than nine arranged radially around the crank case. If greater power is required, two banks of cylinders are used, each cylinder in the rear row being located midway between two front row cylinders to ensure adequate cooling. The crankshaft of the radial engine has only one throw for each bank of cylinders, and all the connecting rods are attached to the single crankpin via a master rod. This fact also dictates

the firing order of the engine. On a seven cylinder engine a firing stroke is required every (360 x 2/7)^0 = $-\quad-$

of crankshaft movement, and since the angle between cylinders is $\left(- \right)$ the firing order can only be alternate

cylinders in the direction of rotation i.e. 1,3,5,7,2,4,6. To balance the heavy mass of the master rod assembly, counter weight and fitted to the crankshaft, and it is also usual to fit vibration dampers to minimize the effects of any residual vibration. On engine with two banks of cylinders, the crankshaft throws are arranged at 180^0 to each other.

(a) Except for sleeve valve engines, the valves are operated by a cam drum which is concentric with and driven by the crankshaft. The cam drum has two rows of cams, one for the inlet valves and one for the exhaust valves. On seven cylinder and nine cylinder engines , there are four equally spaced cams in each row, and the drum rotates at 1/8 engine speed ; on three cylinders and five cylinder engines, two equally spaced cams on each row, with the drum rotating at 1/4 engine speed would be suitable.

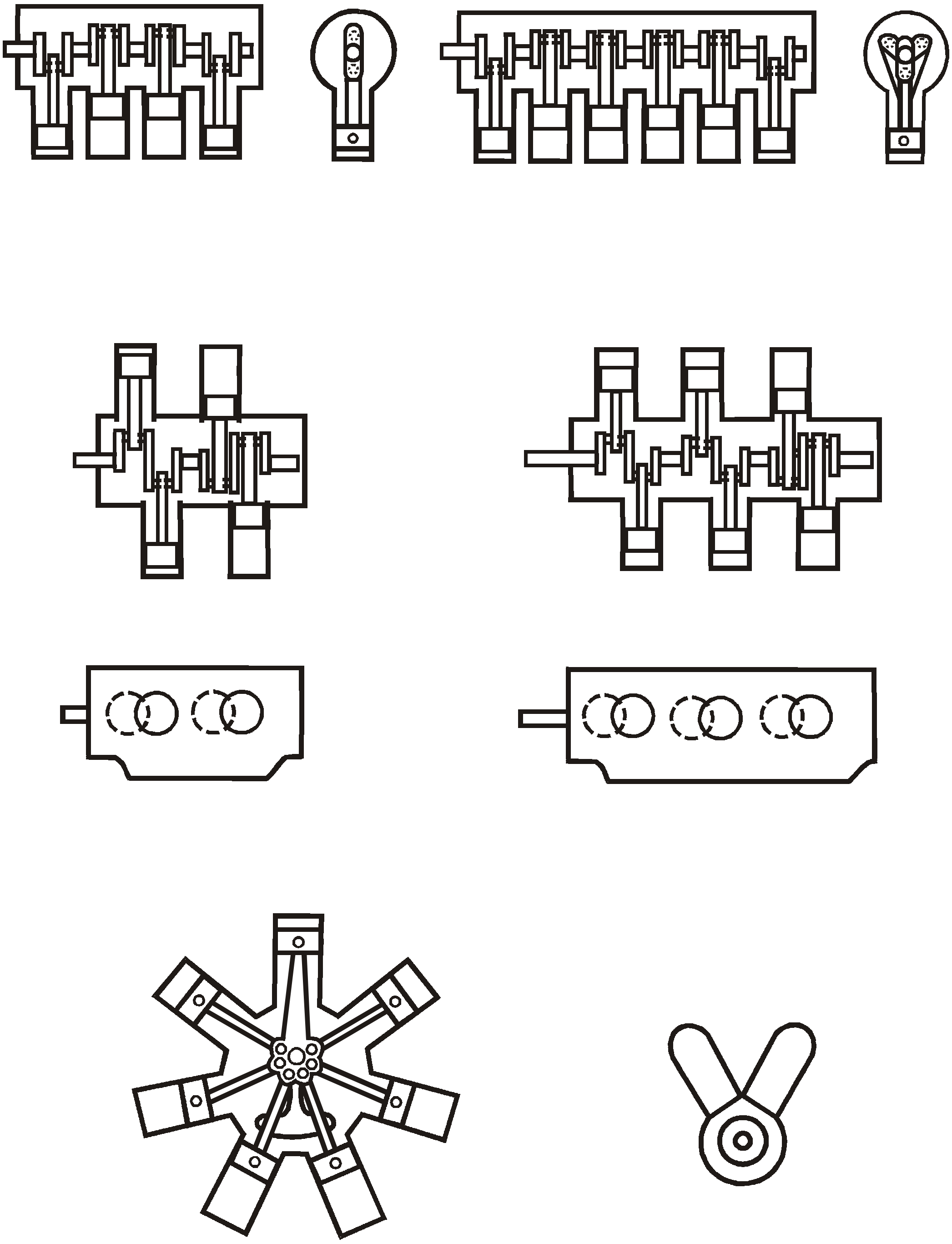


Fig.3. Engine Cylinder Arrangements.

(b) Taking a seven cylinder radial engine as example, when the inlet valve on No.1 cylinder is open, the next inlet valve to open is on No 3 cylinder (Since this is the next cylinder in the firing order).The cams are 90^0 apart and the drum must therefore rotate through an angle of $(12 \times 6/7)^0$ [the angle between No1 & No.3 cylinder is $(102\ 6/7)^0$] in the direction of rotation to open the required value on No.3 cylinder speed of rotation of the cam drum must be

— ÷ — = — engine speed (operation of cam drum on seven cylinder engine is shown in fig.4) On nine cylinder

engine the spacing of the cylinders is at 40^0 and successive valves open at every 80^0 of crankshaft movement. Since the cams are 90^0 apart, the cam drum must rotate in the opposite direction of rotation to the crankshaft, but still at 1/8 engine speed [(90-80]/80] =1/8

In-Line Engine

In line engines usually have four or six cylinders arranged in an upright or inverted row along the crankcase it is not usual to have more than six cylinders, because of the difficulty of cooling the rear cylinders and the length of the crankshaft which would be required. In a four cylinder engine, four power strokes occur every two revolutions of the crankshaft, and must be evenly spaced to provide smooth running with the firing order of 1,3,4,2 or 1,2,4,3. The camshaft which is a shaft having a cam for each valve in the engine, would be driven from the crankshaft at half engine speed and would operate the valves by means of push rods, and rockers. Each of the eight cams (two to each cylinders) would be located on the cam shaft to open and close an inlet or exhaust valve in relation to the particular firing order and valve timing prescribed for that engine. If the engine had six cylinders, there would be six power strokes every two revolutions of the crankshaft and a cylinder would have to fire every 120^0 of the crankshaft movement. This would necessitate a crankshaft with throws (i.e. the offset portions of the crankshaft containing the crankpins) arranged accordingly. Suitably arranged cams would be provided. On the camshaft, which would still be driven at half the engine speed. The firing orders of six cylinder engine is generally 1,4,2,6,3,5 but a different order could be used and the crankshaft would be arranged differently.

Horizontally Opposed Engines

The cylinders of a horizontally opposed engine (usually four or six) are arranged in horizontal banks on opposite sides of crankcase. Most engines have individual connecting rods operating on separate crankpins, thus the cylinders are staggered as shown in fig.3(c). A single camshaft is located either above or below the crankshaft, and is driven at half engine speed to operate the valves in both banks of cylinders. On some engines the inlet valve cams are shared by opposite cylinders, so that the camshaft of six cylinder engine may have a total of 9 cams, six separate exhaust cams and three shared inlet cams. To minimize the length of the engine, a four cylinder engine may have three main (crankshaft) bearing and a six cylinder engine may have four. Because six firing strokes occur every two revolutions of crankshaft of a six cylinder engine, the throws of the crankshaft must be arranged at 120^0 to each other. In the six cylinder engine shown in fig.3(d) the firing order would normally be 1,4,5,2,3,6, but different firing orders would be possible on engines with different crankshaft and cam arrangements.

V-Type

The V-type engine has the cylinders arranged on the crankcase in two rows or banks forming the letter V with an angle between the banks of 90, 60 or 45 degrees. There is always an even number of cylinders in each row.

Since the two banks of cylinders are opposite each other, two sets of connecting rods can operate on same crankpin, thereby reducing the weight as compared with the in-line engine. The frontal area is only slightly greater that of the in-line type, here the engine cowling can be streamlined to reduce drag. If the cylinders are above the crankshaft the engine is known as upright V-type, but if the cylinders are below the crankshaft, it is known as inverted V-type. Better pilot visibility and a short 1/a are possible if the engine is inverted.

ENGINE CYCLE

Otto Cycle

Otto cycle is the standard cycle for internal combustion engine (spark ignition (SI)). The sequence of process in the elementary operation of the S.I. engines is given below. With reference to fig. below where, the sketches of the engine and indicator diagram are given :-

Process 1-2 : Intake

The inlet valve is open, the piston moves to right admitting fuel-air mixture into the cylinder at constant pressure.

Process 2-3 : Compression

Both the valves are closed, the piston compresses the combustion to the minimum volume.

Process 3-4 : Combustion

The mixture is then ignited by means of a spark, combustion takes place and there is an increase in temperature and pressure.

Process 4-5 : Expansion

The products of combustion do work on the piston which moves to the right and the pressure and temperature of gases decrease.

Process 5-6 : Blow down

The exhaust valve opens and the pressure drops to the initial pressure.

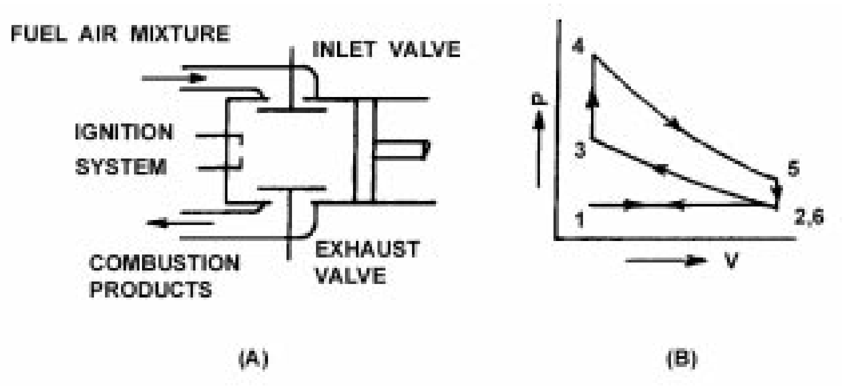


Fig.4. (a) S.I. Engine (b) Indicator Diagram.

Process 6-1 : Exhaust
With the exhaust valve open, and the piston moves inwards to expel the combustion product from the cylinder at constant pressure.

The series of processes as described above constitute a mechanical cycle, and not the thermodynamic cycle. The cycle is completed in four strokes. Fig. below shows a standard cycle (otto cycle) corresponding to I.C. engine. It consists of two reversible adiabatic and two reversible isochores.

Air is compressed in process 1-2 reversibly and adiabatically. Heat is then added to air irreversibly at constant volume in process 2-3. Work is done by air in expanding reversibly and adiabatically in process 3-4. Heat is then rejected by air reversibly at constant volume in process 4-1, and the system (air) comes back to its initial state. Heat transfer processes have been substituted for the combustion and blow down processes of the engine. The intake and exhaust processes of the engine cancel each other.

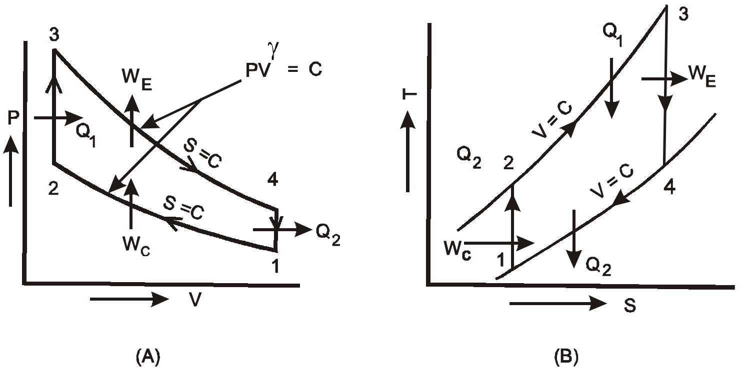


Fig. 5.Otto Cycle.

Let m be the fixed mass of air undergoing the cycle of operations as described above.

Heat Supplied : $Q_1 = Q_{2-3} = m\,c_v\,(T_3 - T_2)$

Heat Rejected : $Q_{4-1} = m\,c_v\,(T_4 - T_1)$

Efficiency $= 1 - (Q_2 / Q_1) = 1 - [m c_v (T_4 - T_1) / m\,c_v\,(T_3 - T_2)]$ ....(i)

$= 1 - [(T_4 - T_1) / (T_3 - T_2)]$

Process 1-2, $(T_2 / T_1) = (v_1 / v_2)\,(r-1)$

Process 3-4, $(T_3 / T_4) = (v_4 / v_3)^{\gamma-1} = (v_1 / v_2)^{\gamma-1}$

$(T_2 / T_1) = (T_3 / T_4)$ or $(T_3 / T_2) = (T_4 / T_1)$

$(T_3 / T_2) - 1 = (T_4 / T_1) - 1$ or $[(T_4 - T_1)/(T_1)] = [(T_3 - T_2) / T_2]$

$(T_4 - T_1) / (T_3 - T_2) = (T_1 / T_2) = (v_2 / v_1)^{\gamma-1}$ ....(ii)

Substituting the value of equation (ii) in equation (i)

$$\eta = 1 - (v_2 / v_1)^{\gamma-1}$$

or

$$= 1 - 1 / r_k^{(\gamma-1)}$$

where r_k is called the compression ratio and given by

r_k = Volume at the beginning of compression / Volume at the end of compression

$$r_k = v_1 / v_2$$

The efficiency of otto cycle is thus a function of the compression ratio only. The higher the compression ratio, the higher the efficiency. It is independent of the temperature levels at which the cycle operates. The compression ratio cannot, be increased beyond a certain point, because of a noisy and destructive combustion phenomenon, known as detonation. It also depends upon the fuel, the engine designs and operating conditions.

ENGINE EFFICIENCY

Mechanical Efficiency

The mechanical efficiency of an engine is measured by the ratio of the shaft output or brake horse power to the indicated horse power or power developed in cylinders. e.g. if the ratio of the bhp to ihp is 9:10, then the mechanical efficiency of the engines is 90%. In determining the mechanical efficiency only the losses suffered by the energy that has been delivered to the pistons is considered.

Thermal Efficiency

Thermal efficiency is a measure of the heat losses suffered in converting the heat energy of the fuel into the mechanical working. In fig below, the heat dispelled by the cooling system represents 25% the heat carried away by the exhaust gases represents 40%, the mechanical work on the piston to overcome friction and pumping losses represents 5% and the useful work at the propeller shaft represents 30% of the heat energy of the fuel. The thermal efficiency of air engine is the ratio of heat developed into the useful work to the heat energy of the fuel. It may be based on either bhp or ihp and is represented by a formula in this manner.

$$\text{Indicated thermal efficiency} = \frac{\text{ihp} \times 33000}{\text{weight of fuel} \times \text{Heat value burned per min. (Btu) } 788}$$

The formula for brake horse power is also same with the word “brake inserted in place of indicated on both sides of the formula.

Volumetric Efficiency

Volumetric efficiency is the ratio of the volume of fuel air charge, burned by the engine at atmospheric pressure and temperature to the piston displacement. If the cylinder of an engine draws in a charge of fuel and air having a volume at standard atmospheric pressure and temperature which is exactly equal to the piston displacement of the cylinder, the cylinder has a volumetric efficiency of 100%.

Volumetric efficiency may be expressed as a formula then;

$$\text{Volumetric efficiency} = \frac{\text{Volumetric charge at atmospheric pressure}}{\text{Piston displacement.}}$$

Factors which tend to decrease volumetric efficiency are improper timing of the valves fuel air manifolds having too small a diameter and many bends, the use of air which has been raised to a high temperature from any cause, two high a temperature in the c.c. incomplete scavenging of the burned gases during the exhaust stroke, and excessive speed. One or more of these factors may exist at various times.

Basically any condition which tends to slow or reduces the flow of air into the engine will reduce volumetric efficiency. Improper timing of the valves affects volumetric efficiency because the in take valve must be as wide open as possible when the piston starts the intake stroke. The exhaust valve must be closed precisely at the contact when the exhaust gases stop flowing out of the c.c.

At high engine rpm the volumetric efficiency of the engine decreases because of the friction produced by the intake, carburettor intake manifold, and valve ports. The effect of the friction increases as the air velocity increases. When the throttle is partially closed, volumetric efficiency decreases in accordance with the degree of closing.

A leak in the intake manifold would tend to increase volumetric efficiency because more air would be entering the engine, however it will also cause a lean mixture.

Maximum volumetric efficiency is obtained when the throttle is wide open and the engine is operating under a full load.

A naturally aspirated engine always has a volumetric efficiency of less than 100% on the other hand, the supercharged engine often is operated at a volumetric efficiency of more than 100% because the super charger compresses the air before it enters the cylinder. The volumetric efficiency of naturally aspirated is less than 100% for two principal reasons.

1) The bends, obstruction and surface roughness inside the intake system cause substantial resistance to the airflow, thus reducing air pressure below atmospheric in the intake manifold;
2) The throttle and the carburettor venturi provide restriction across which a pressure drop occurs.

ENGINE COOLING

Aircraft engines may be cooled either by air or by liquid; however, there are few liquid-cooled engines still in operation in the United States. We shall therefore devote most of our discussion to the air cooled types.

Excessive heat is undesirable in any internal combustion engine for three principal reasons

1) It adversely affects the behaviour of the combustion of the fuel-air charge.
2) It weakens and shortens the life of the engine parts, and
3) It impairs lubrication.

If the temperature inside the engine cylinder is too great the fuel mixture will be preheated and combustion will occur before the proper time. Premature combustion causes detonation, “knocking” and other undesirable conditions. It will also aggravate the over heated condition and is likely to result in failure of pistons and valves.

The strength of many of the engine parts depends on their heat treatment. Excessive heat weakens such parts and shortens their life. Also, the parts may become elongated, warped or expanded to the extent that they freeze or lock together and stop the operation of the engine.

Excessive heat “cracks” the lubricating oil, lowers its viscosity, and destroys its lubricating properties.

Air Cooling

In an air-cooled engine, thin metal fins project from the outer surface of the walls and heads of the engine cylinders. When air flows over the fins, it absorbs the excess heat from the cylinders and carries it into the atmosphere. Deflector baffles fastened around the cylinders direct the flow of air to obtain the maximum cooling effect. The baffles are usually made of aluminium sheet. They are called pressure baffles because they direct airflow caused by ram air pressure. The operating temperature of the engine can be controlled by movable cowl flaps located on the engine cowling. On some airplanes, these cowl are manually operated by means of a switch which controls an electric actuating motor. On other airplanes they can be operated either manually or by means of a thermostatically controlled actuator.

In the assembly of the engine baffling system, great care must be taken to see that the pressure baffles around the cylinders are properly located and secured. An improperly installed or loose baffle can cause a hot spot to develop with the result that the engine may fail. The proper installation of baffles around the cylinders of a twin-row radial engine. It will be observed that the baffling maintains a high-velocity airstream close to the cylinder and through the cooling fins. The baffles are attached by means of screws, bolts, spring hooks, or special fasteners.

Cylinder cooling is accomplished by carrying the heat from the inside of the cylinders to the air outside the cylinders. Heat passes by conduction through the metal walls and fins of the cylinder assembly to the cooling airstream which is forced into contact with the fins by the baffles and cowling. The fins on the cylinder head are made of the same material and are forged or cast as part of the head. Fins on the steel cylinder barrel are of the same metal as the barrel in most instances are machined from the same forging as the barrels. In some cases the inner part of the cylinder is a steel sleeve and the cooling fins are made as a part of a muff or sleeve, shrunk fitted on the outside of the inner sleeve. A large amount of the heat developed in an engine cylinder is carried to the atmosphere with the exhaust. This amount varies from 40 to 45 percent, depending upon the design of the engine. The proper adjustment of valve timing is the most critical factor in heat rejection through the exhaust.

In the operation of a helicopter, the ram air pressure is usually not sufficient to cool the engine, particularly when the craft is hovering. For this reason, a large engine driven fan is installed in a position to maintain a strong flow of air across and around the cylinders and other parts of the engine. Helicopters powered by turbine engines do not require the external cooling fan.

The principal advantages of air cooling are that

1) The weight of the air-cooled engine is usually less than that of a liquid-cooled engine of the same horsepower because the air-cooled engine does not need a radiator, connecting hoses and lines, and the coolant liquid;
2) The air-cooled engine is less affected by cold-weather operations:
3) The air-cooled engine in military airplanes is less vulnerable to gunfire. If an enemy bullet or bomb fragment strikes the radiator, hose, or lines of a liquid cooled engine, it is obvious that its cooling system will leak and soon cause a badly over heated engine.

Liquid Cooling

Liquid-cooled engines are rarely found in the United States aircraft today; however, the power plant technician should have some understanding of the principal elements of such systems.

A liquid cooling system consists of the liquid passages around the cylinders and other hot spots of the engine, a radiator by which the liquid is cooled, a thermostatic element to govern the amount of cooling applied to the liquid, a coolant pump for circulating the liquid, and the necessary connecting pipes and hoses. If the system is sealed, a relief valve is required to prevent excessive pressure and a sniffier valve is necessary to allow the entrance of air to prevent negative pressure when the engine is stopped and cooled off.

Water was the original coolant for liquid-cooled engines. Its comparatively high freezing point (32^{0}F) (0^{0}C) and its relatively low boiling point (212^0 F) (100^0 C), made it unsatisfactory for the more powerful engines used in military applications. The liquid most commonly used for liquid-cooled engines during world war II was ethylene glycol or a mixture of ethylene glycol and water. Pure ethylene glycol has a boiling point of about 350^{0}F (176^{0}C) and a slush-forming freezing point of about 0^{0}F (-17.78^0 C) at sea level. This combination of high boiling point and low freezing point made it a satisfactory coolant for aircraft engines.

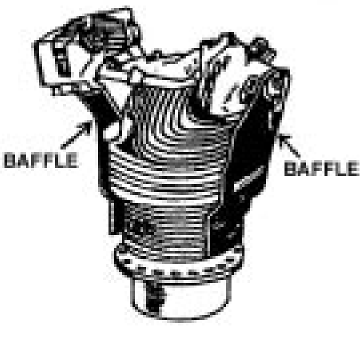


Fig.6. Cylinder with cooling baffles.

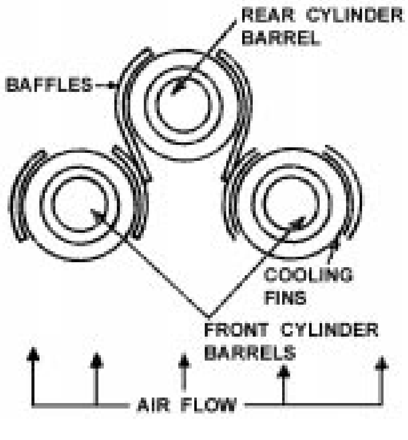


Fig.7. Baffles around the cylinder of a twin row radial engine.

FUEL USED IN PISTON ENGINES

There are two main types of fuel used in aircraft, aviation gasoline, which is used in piston engines, and aviation kerosene, which is used in turbo-jet and turbo-propeller engines. It is most important that the correct type and grade of fuel, as indicated in the appropriate maintenance manual, should be used.

Gasolene

Aviation gasoline (AVGAS) is the lighter of the two fuels, having a relative density of approximately 0.72. The only grade of AVGAS generally available is grade 100L, which has an octane rating of 100 and a low lead content. Where different grades of fuel were previously specified for use in a particular engine, the use of AVGAS 100L may necessitate additional checks and maintenance to be carried out. Automobile fuel must not be used instead of non-lead aviation fuel.

Gasoline has powerful solvent properties, and it is essential that it does not come into contact with certain components such as transparent panels and tyres. Personal contact may also result in skin infections, and it should be noted that some of the additives used in gasoline are poisonous.

ENGINE COMPONENTS

Bearings

Plain, ball or roller bearings may be used at various positions in an engine, depending on the magnitude and direction of the load which they are required to accept.

Plain bearings have a greater load-bearing capacity than either ball or roller bearings, and are generally used in a place where the radial load is high. A plain bearing usually consists of a pair of semi-circular steel shells which are lined with a non-ferrous alloy; this in turn may be faced with a white metal. In most cases each half of the bearing is pegged or otherwise located to prevent rotation in its support, and receives its oil supply through drilling in the supporting member. Some plain bearings, such as those fitted to the crankpins on radial engines, are completely circular and fully-floating, and oil is supplied to both sides of the bearing, thus providing two bearings faces. Although plain bearings are generally fitted in positions where the load is mainly radial, plain bearings can be made capable of accepting axial loads, and are sometimes used to transmit the propeller thrust. In these cases the bearing has a flange on each side, which forms a bearing face normal to the shaft axis, and limits axial movement. Plain bearings must be pressure lubricated in order to maintain an oil film between the mating parts, and prevent damage to their surfaces.

Ball bearings are used in many places where radial loads are light, and where axial positioning is important. Heavy roller bearings are used as main crankshaft bearings on radial engines, and ball bearings are frequently used as thrust bearings on propeller shafts and on the crankshafts of direct-drive engines Ball and roller bearings do not, generally, require pressure lubrication, and are frequently lubricated by splash; however, oil jets may be used in locations where lubrication is particularly critical.

Crankcases

The crankcase is, usually, the largest single component of an engine. It provides the mounting faces for the cylinders, reduction gear, sump, and accessories, supports the crankshaft, provides oil ways for the lubricating oil, and carries the mounting for attachment of the engine to the airframe. A crankcase is, therefore, of complicated shape, and it is usually cast from aluminium or magnesium alloys, which provide the strength and rigidity required, without unnecessary weight. Some crankcases are in two or more parts, which are bolted and dowelled together. A typical crankcase for a horizontally-opposed engine is illustrated in figure 8, which shows that the two halves are joined at a vertical plane passing through the crankshaft centre line. With radial engines the joint is on the plane normal to the crankshaft centre line and passing through the centres of all cylinders in one bank, each portion of the crankcase supporting one of the main bearings.

Studs are fitted to the crankcases for the attachment of all components, except that in the case of horizontally-opposed engines with staggered cylinders, the positions of some cylinder holding-down points coincide with the main bearing supports, and through-bolts are used at these locations.

The sump may be considered as part of the crankcase, and may be a casting in light alloy, or may be fabricated from sheet steel. The sump contains a drain plug, and may also house the scavenge filter. A dip-stick, housed in the crankcase, provides a means of checking the sump oil level.

All crankcase face joints are sealed to prevent oil leakage, but a vent at the top of the crankcase is ducted overboard to relieve internal pressure. In general, cylinder mounting flanges are sealed with an “O” ring, sump joint faces are sealed with a cork or composition gasket, and other joint faces are sealed with paper gaskets or jointing compound.

Crankshafts

The crankshaft is the heaviest single component of the engine and is usually forged from an alloy steel in order to resist the high stresses imposed during operation. The crankshafts of in-line and horizontally-opposed engines are machined from a single forging, with hollow crankpins and journals, and drilled webs to provide passageways for the lubricating oil. The crankshaft of a single-row radial engine is generally made from two forging, the separate parts being joined at the crankpins; this is because of the difficulty of providing a split bearing capable of accommodating all the connecting rods on a single crank pin. Typical crankshafts are illustrated in figure 9.

Lubricating oil is ducted from the oil pressure pump, through crankcase oil passages, to each of the crankshaft main bearing supports. This oil passes though holes in the bearings to lubricate the journals, and through radial holes in the journals into the hollow shaft. From there it flows through drilling in the webs to the connecting rod big-end bearings and then escapes from these bearings to be thrown by centrifugal force into the pistons and cylinders. On some engines, oil jets at the crankshaft main bearings spray oil into the cylinders. At its front end, a crankshaft may

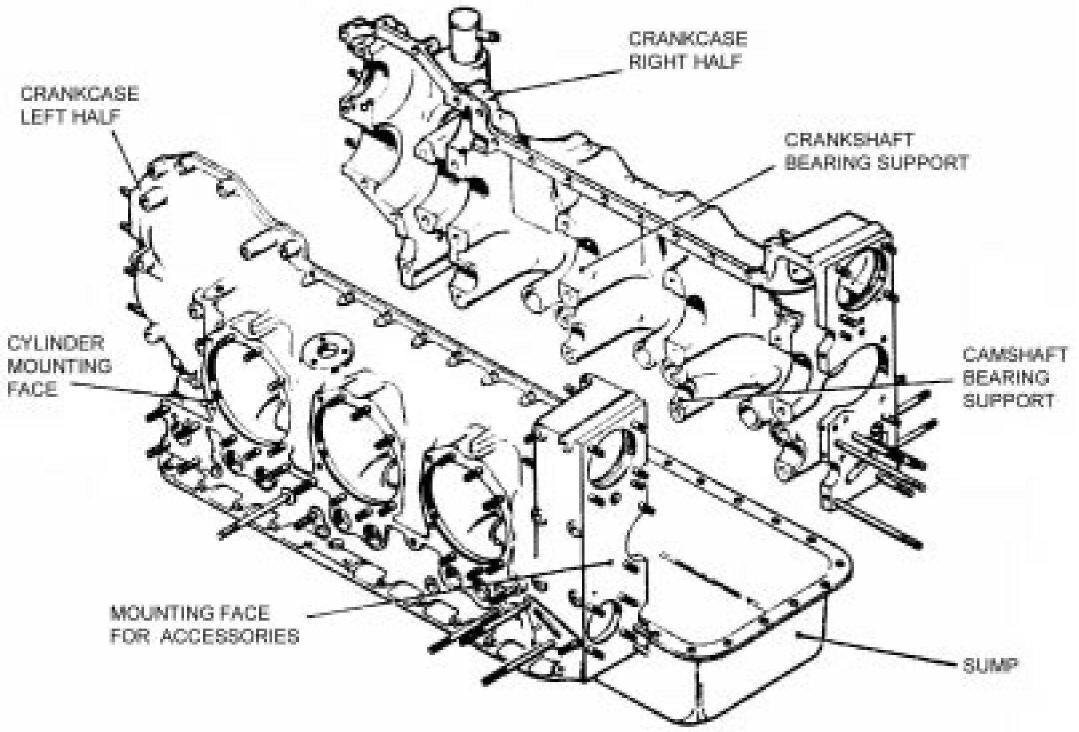


Fig. 8.Crankcase and Sump Of Horizontally Opposed Engine.

have a flange or splined portion to which the propeller is attached, or it may be internally splined in order to drive the propeller reduction gear through a quill shaft; the quill shaft is designed to twist under torsional loads so as to smooth out the power impulses. A gear or a quill shaft is generally attached to the rear end of the crankshaft, for the purpose of driving the camshaft and accessories, but some of these may be driven from the propeller reduction gear.

Cylinders

A cylinder must, generally, provide the hard bearing surface on which the piston slides, must be strong enough to resist the pressures produced by the combustion of the mixture, and must dissipate the heat produced in the combustion chamber. Aluminium alloy has god strength and have-dissipation properties and is generally used for cylinder heads, but its surface is not hard enough to resist abrasive wear, and therefore the cylinder barrels are generally made from a steel alloy. An exception is the sleeve valve engine, in which the piston operates inside a steel alloy sleeve, and aluminium alloy is used for the cylinder barrel. Poppet valve guides and rocker bearings fig 10., are

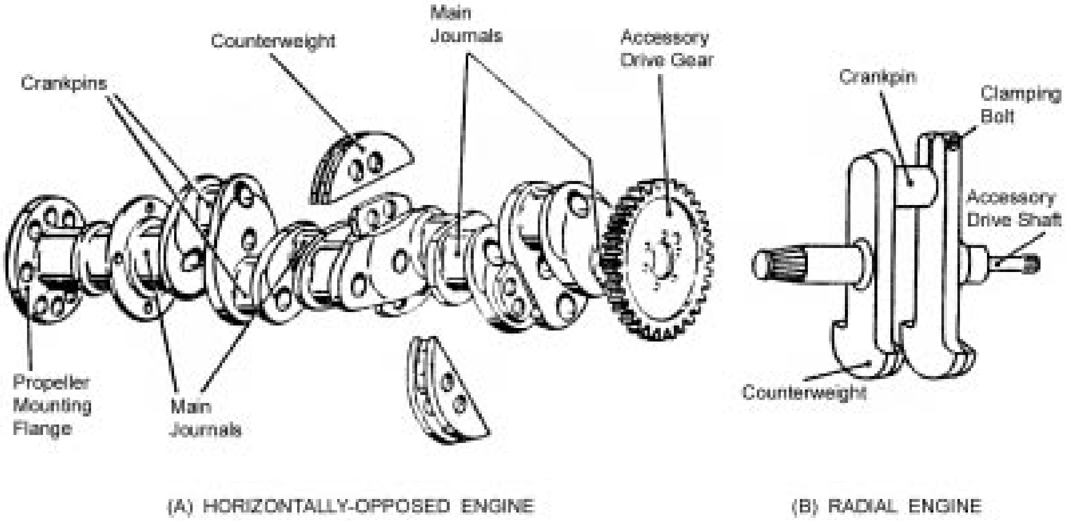


Fig.9. Typical Crankshafts.

made from bronze or similar material, and the valve seats are made from steel in order to resist the hammering of the valves. Sparking plugs may be fitted into bronze inserts, which are screwed and pegged into the cylinder head, but in some engines thread inserts are used, and are installed directly into the head.

On air-cooled engines, which invariably have individual cylinders, the cylinder head and barrel are finned to present a large cooling surface to the airflow, the spacing and size of the fins depending on the amount of heat which must be dissipated. The cylinder head is usually screwed and shrunk onto the barrel to make a permanent assembly, but on some engines the head may be removable and bolted to the cylinder barrel or secured by studs extending from the crankcase. A copper gasket between the head and barrel prevents gas leakage.

On water-cooled in-line engines, the one-piece aluminium-alloy cylinder block has a detachable head, and steel liners in which the pistons operate. The whole assembly is attached to the crankcase by studs or bolts which pass right through the head and block, a copper gasket preventing gas leakage between the liners and head, and a flexible seal round each liner preventing coolant leakage from the block. Coolant flowing round the liners, and through passageways in the head, absorbs and removes excess heat.

Lubrication of the cylinder bores is generally by oil mist and spray from the connecting rod bearings, but oil jets at the crankshaft bearings may be used. Cylinder bores are often honed in such a manner as to result in a pattern of microscopic grooves which permit the retention of small quantity of oil on the walls.

The rocker bearings (and, in the case of some in-line engines, the overhead camshaft bearings) are usually pressure-lubricated by oil ducted from the crankcase, and the splash oil released from these bearings is used to lubricate the valve stems, guides and springs. In some small engines the rocker arms oscillate in roller bearings which are hand lubricated at specified intervals, whilst on inverted engines the rocker cover may be partially filled with oil, to splash lubricate all the cylinder head components. A typical air-cooled cylinder is shown in figure.10.

Connecting Rods

Connecting rods convert the reciprocating motion of the pistons to the rotary motion of the crankshaft. They require considerable strength and rigidity, and are generally aluminium alloy or steel forging of "H" section. On horizontally opposed and in-line engines, the bearing at the crankpin end (big end) is usually a split plain bearing similar to those used at the crankshaft main bearings (figure 11.). The connecting rod small end is usually fitted with a bronze bush and attached to the piston with a hollow steel gudgeon pin. On radial engines only one connecting rod (the master rod) in each bank of cylinders is mounted directly on to the crankpin fig.12., and usually has a fully floating bearing. The connecting rods on the other cylinders (known as articulated rods) are connected to flanges on the master rod big-end by hollow steel wrist pins which are similar to the gudgeon pins at the connecting rod small end. Big end bearings are pressure lubricated through drilling in the hollow crankpins from the main oil pressure supply, and small-end (and wrist pin) bearings are usually lubricated by splash oil through holes in the connecting rods.

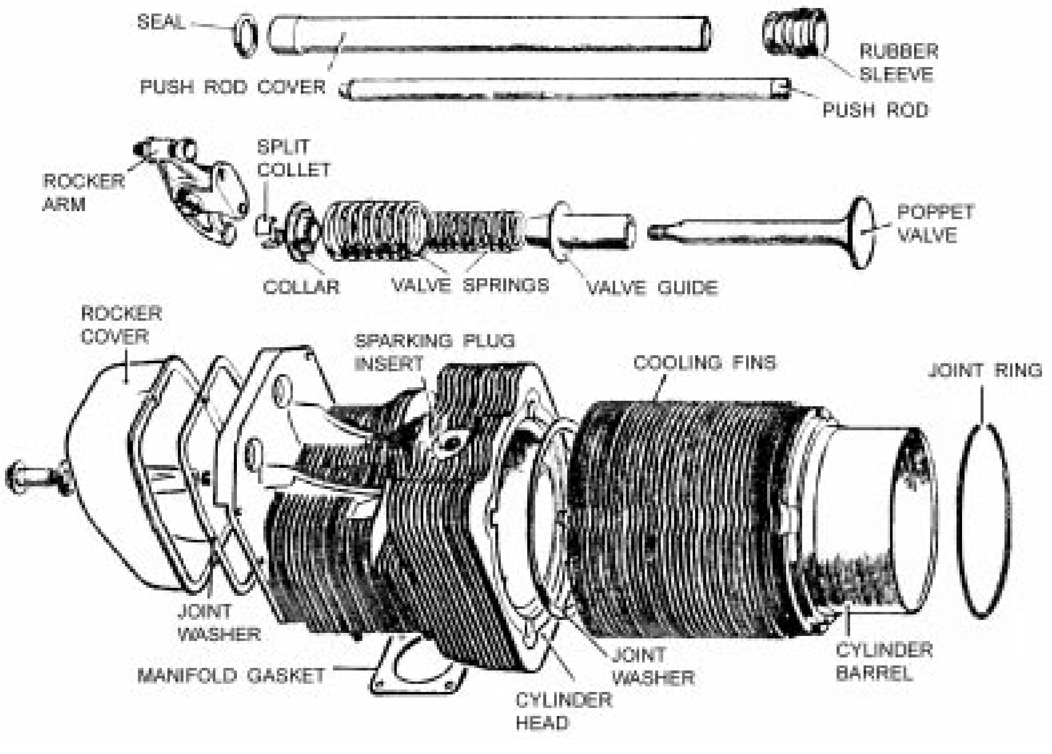


Fig.10. Cylinder Assembly.

Pistons

Pistons are subjected to high pressures and temperatures, and to rapid acceleration and deceleration. They must, therefore, be strong yet light, and capable of conducting away some of the heat generated in the combustion chamber; they are generally machined from forging of high strength aluminium alloy.

Pistons are attached to their connecting rods by means of a gudgeon pin, which is often free to rotate in both the piston and connecting rod, and may be supported in bronze bushes fitted internally on each side of the piston; axial movement of the gudgeon pin is usually prevented by a circlip fitted at each end, or by an end pad of soft metal, which bears against the wall of the cylinder.

Since a piston, being made from aluminium alloy, expands more than the cylinder barrel (which is normally steel alloy), a working clearance between these components is essential, and a number of piston rings are fitted into grooves in the piston. These rings are generally made from cast iron or alloy steel, are split to permit assembly, and have a gap between their ends to allow for expansion; a side clearance between the groove and ring is also essential. Rings are often free in their grooves, and are assembled with the gaps of alternate rings spaced 180° apart, but in some cases rotation is prevented by a peg in case the gas leakage from the combustion chamber, and are generally fitted above the gudgeon pin, whilst scraper rings (also known as oil control rings) are designed to remove oil from the cylinder walls, and are generally fitted below the gudgeon pin.

Piston heads may be flat or slightly domed for strength, or may be concave in order to provide a combustion chamber which is as nearly spherical as possible. In some cases it may also be necessary to have recesses in the head of the piston, to provide clearance for the open valves when the piston is at the top of the exhaust stroke.

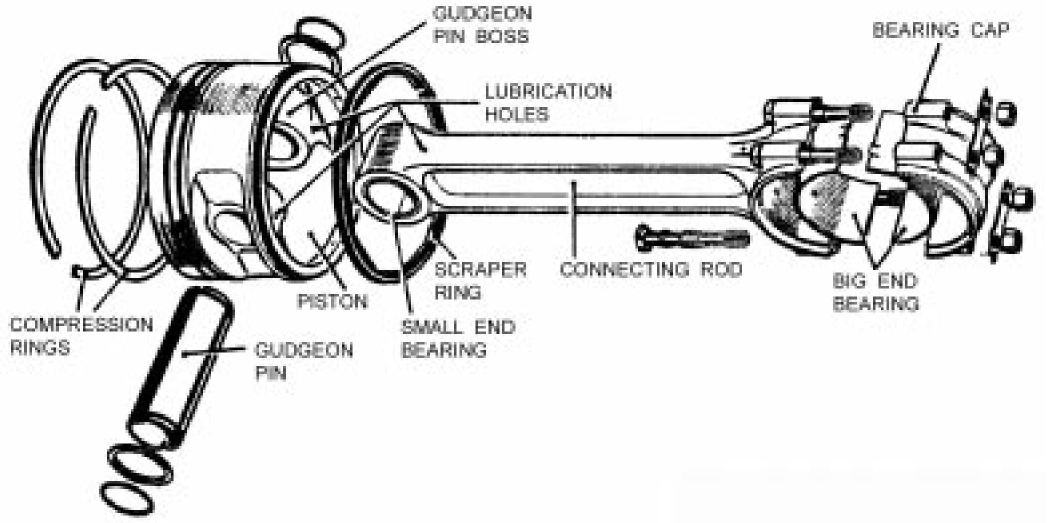


Fig.11. Connecting Rod And Piston Assembly.

Lubrication of the gudgeon pin bearings is provided by splash oil, through holes drilled in the gudgeon pin bosses, and drainage of the oil removed from the cylinder walls by the piston scraper rings, is provided by radial holes drilled through the piston from the base of the piston ring groves.

Valves

Sleeve Valves

On a few engines, the inlet and exhaust ports in the cylinder are opened and closed by means of a cylindrical sleeve fitted between the cylinder barrel and the piston. The sleeve, of hardened steel, is driven by a crank, which is geared to the crankshaft, and ports in the sleeve uncover the cylinder inlet and exhaust ports at the appropriate times. Timing of the opening and closing of the ports in the sleeve is set by manufacturer, and no adjustments are possible at field level. The main advantage of this method is reputed to be the increased volumetric efficiency resulting from the lack of obstruction to the incoming and out-going gases.

Poppet Valves

These valves are in fig.10. fitted to the majority of aircraft piston engines; they operate under arduous conditions and may be made from a variety of steel alloys. Exhaust valves, which are subjected to the highest temperatures, often have a larger diameter stem than inlet valves, the stem being hollow and partially filled with sodium to transfer heat away from the valve head. Valve heads are ground to form a face which mates with the valve seat and forms a gas-tight seal. The ends of the valve stems are grooved to secure a split collect, which holds the spring retaining collar in position, and are hardened at the tip to provide a bearing surface for the rocker arm. Each valve is closed by two or more coil springs, which are concentrically mounted and coiled in opposite directions; the fitting of two or more springs having different vibration frequencies prevents the valve from bouncing on its seat when it closes.

Valve stems slide in valve guides fitted in the cylinder head, which are generally lubricated by splash from the rocker gear. The inner ends of the valve guides are often fitted with a seal, to prevent the leakage of oil into the inlet and exhaust ports of the cylinder.

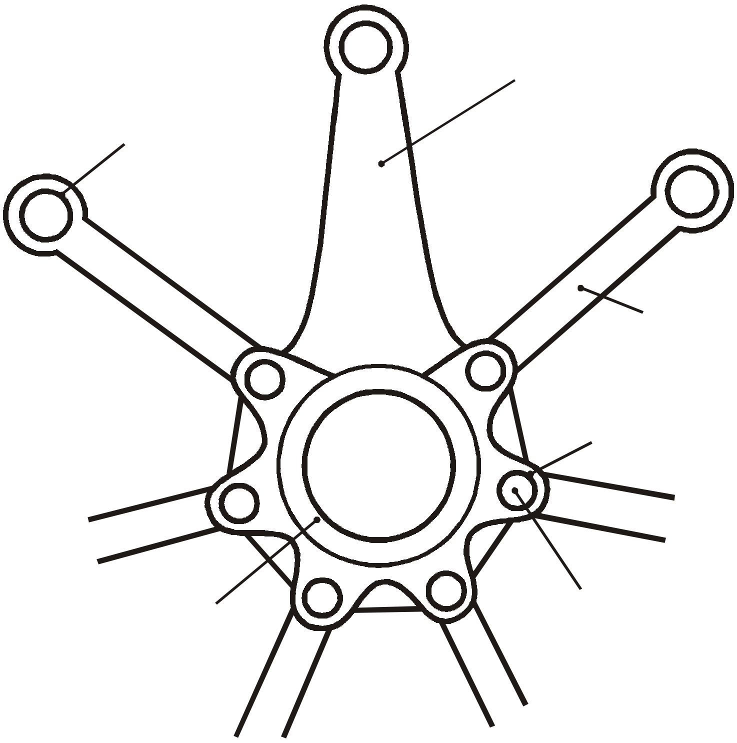


Fig. 12.Radial Engine Connecting Rods.

Valve Operating Mechanism

Poppet valves are opened by a mechanical linkage from the cam shaft or cam drum, and closed by the valve springs. As the appropriate cam is rotated, its lobe pushes a tappet, which in turn activates a push rod, which transmits movement to the rocker arm; the rocker arm pivots on its bearing and pushes on the end of the valve stem to open the valve. When the cam has passed its points of maximum lift, the valve springs return the mechanism to its original position and close the valve. This type of mechanism is generally used on horizontally-opposed and radial engines, and also on some in-line engines. On other in-line engines the camshaft is mounted on the cylinder heads, and operates directly on the rocker arms to open the valves; these are known as “overhead camshaft” engines.

Camshafts

Camshafts are fitted to all horizontally-opposed and inline engines, and are driven through spur or bevel gearing from the crankshaft, at half engine speed. They are made from alloy steel and are supported in plain bearings which are pressure lubricated from the engine oil system. The cams are shaped and positioned so as to open and close their associated valves at the correct time, and their faces are hardened to provide a good bearing surface.

Cam Drums

Cam drums are used in most radial engines, and have two rows of cams (one for the inlet valves and one for the exhaust valves). They are made from steel, and are mounted on a bearing around the front of the crankshaft and driven, by a gear train from the crankshaft, at the required speed and in the required direction of rotation. The cam drum bearing is generally pressure lubricated by the engine oil system.

Tappets

The purpose of a tappet is to transfer the motion of a cam to its associated push rod. Tappets may be fitted either directly into the crankcase or in bronze guides in the crankcase. They are often purely mechanical devices comprising a rod with a hardened pad or roller at the cam end, and a hardened socket at the push rod end. To ensure that the valves close properly when the engine is running, in spite of expansion of the cylinder, a means of adjustment is provided to enable a predetermined clearance to be maintained in the valve operating mechanism when the valve is closed; this is known as tappet clearance. Most modern light aircraft engines are fitted with hydraulic tappets. (fig.13). This type of tappet consists basically of a body and a plunger, with an internal spring and non return valve, and a push rod socket. During operation, pressure oil supplied to the tappet is picked up by a groove round the body when the tappet is near the outer end of its stroke. This oil lubricates the tappet bearing surface and enters the plunger reservoir through a port in the plunger wall; it then passes through the push rod socket and hollow push rod to lubricate the rocker mechanism. If clearance is present in the valve opening mechanism when the tappet is resting on the cam dwell, the spring in the tappet body pushes the plunger outwards to eliminate this clearance, the non-return valve opening to allow oil to pass into the body reservoir. As the cam lobe commences to push on the tappet, the non-return valve closes and a hydraulic lock is formed, transmitting motion to the push rod. In this way clearance is eliminated from the mechanism; valve closure is unaffected, since the force applied by the tappet spring is much less than that of the valve springs.

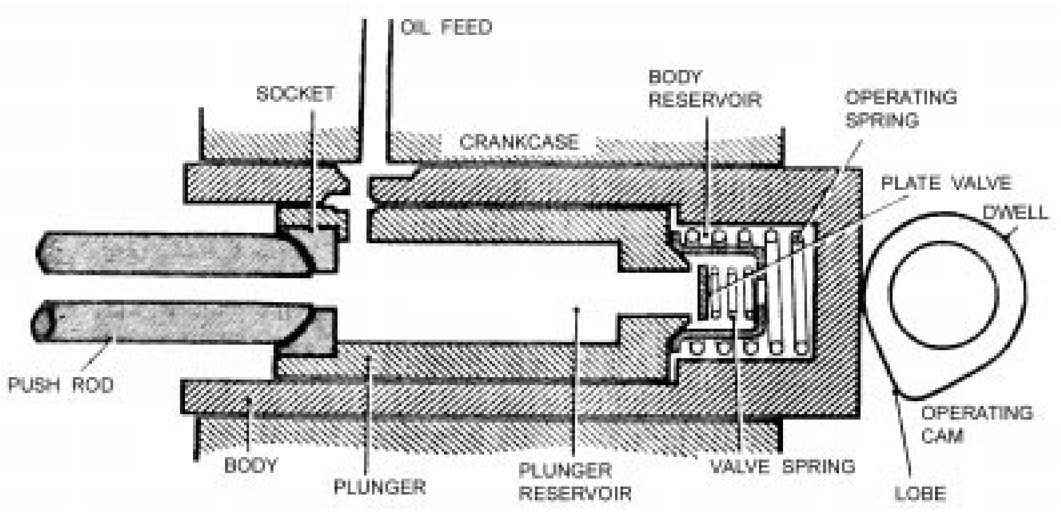


Fig.13. Hydraulic Tappet.

Push Rods

Push rods are usually steel tubes, with hardened steel fittings at each end to mate with the tappet and rocker arm. These fittings are usually drilled to allow lubricating oil to pass to the rocker arm. The push rods are surrounded by push rod covers, which may be steel or aluminium alloy tubes, and which are fitted with seals at the cylinder head and crankcase; the crankcase seal usually being spring-loaded to permit assembly.

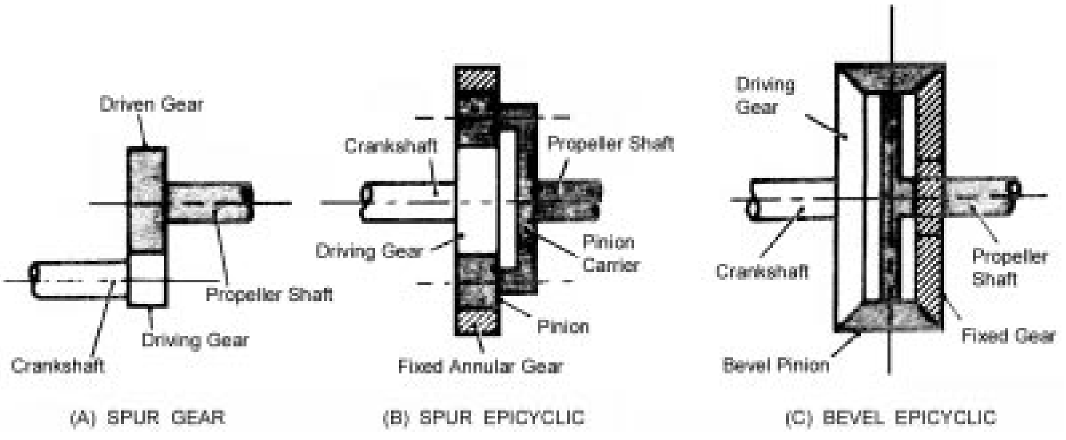
Rockers

A rocker arm pivots on a steel shaft, which may be held in mounting in the cylinder head or in pedestals which are bolted to the cylinder head. Rocker arms are generally made from alloy steel, with a hardened face at the valve end, and an adjusting screw with hardened socket at the push rod end. On some engines, mounting and adjustment are by means of a ball or roller pivot bearing, which is mounted in an eccentric bush. Oil from the hollow push rod is often fed through the drilling in the rocker arm to lubricate the rocker arm bearing. On other engines the rockers may be splash lubricated.

Propeller Reduction Gear

The purpose of a reduction gear is to reduce engine speed to a speed suitable for efficient operation of the propeller. The various types of reduction gears are illustrated in figure 14. Epicyclic (sometimes known as "planetary) reduction gears are always used on radial engines, and spur gear reduction gears are generally used on in-line engines, but either type may be fitted to horizontally-opposed engines.

A propeller shaft is normally supported in roller bearings, and propeller thrust is transferred to the engine by means



(A) SPUR GEAR (B) SPUR EPICYCLIC (C) BEVEL EPICYCLIC

Fig. 14. Reduction Gear Types.

of a ball thrust bearing. On some small engines, however, the propeller may be supported in plain bearings, the thrust being taken by a thrust washer placed between a flange on the propeller shaft, and one of the bearing supports.

Lubrication of plain bearings is by pressure feed from the normal engine lubrication system, and lubrication of ball and roller bearings, and of gears, is by oil spray nozzles and splash.

Accessories

A number of components such as magnetos, oil pumps, fuel pumps, starter and engine speed indicator drive, are required for normal operation of the engine, and , in addition, accessories such as hydraulic pumps, pneumatic pump and electrical generators may be required to power the aircraft systems. All these components are driven at a suitable speed by gearing from the engine crankshaft, and are generally attached to the engine crankcase. In some cases, however, the aircraft system components are fitted to a remotely mounted gearbox, which is driven by an extension shaft from the rear of the engine crankshaft. Accessories are often coupled to their driving gears by means of a quill shaft, which is designed to shear in the event of failure of the accessory, thus preventing damage to the engine. Lubrication of accessory drive plain bearings is generally by lubrication system pressure, through ductings in the crankcase, and of ball and roller bearings, by crankcase splash; remotely mounted gearboxes are generally self-contained, the casing being partially filled with oil, and lubrication effected by splash.

Pumps

Mechanically driven pumps may be used for a number of purposes on an engine; centrifugal pumps are used to circulate coolant, gear -type pumps are used to provide oil at high pressure for engine lubrication, and diaphragm pumps are sometimes used to supply fuel to the carburettor. Other types of pumps are used to power various aircraft systems.

Centrifugal Pumps

A centrifugal pump consists of an impeller, which is rotated inside a housing. The working fluid rotates with the impeller, and centrifugal forces acting on this fluid cause it to flow to the outside of the housing, and more fluid is drawn into the eye of the impeller. This provides a low pressure circulation through the system, and, since it is not a positive displacement pump, neither a pressure relief valve nor a by-pass is required.

Gear Pumps

These pumps consist of two meshing gears, which rotate in a close-fitting housing (fig.15). One gear is driven from the engine, and as it rotates it carries the other gear round with it, and fluid is carried round the casing between the gear teeth. These pumps are known as positive displacement pumps, a definite volume of fluid being delivered for each revolution of the gears. Any restriction in the delivery line (such as will normally be provided by the bearings) will result in a build-up of pressure, and a relief valve is required. Relief valves are adjusted to maintain a predetermined pressure on the delivery side of the pump, and any excess fluid is bypassed to the inlet side of the pump or to the sump; in some engines a second relief valve is fitted after the main pressure relief valve, to provide a low-pressure lubrication system for certain components. Engine oil pressure and scavenge pumps are generally driven by a common shaft and mounted in adjoining housings, the gears of the scavenge pump being longer than those of the pressure pump to ensure complete scavenging of the sump.

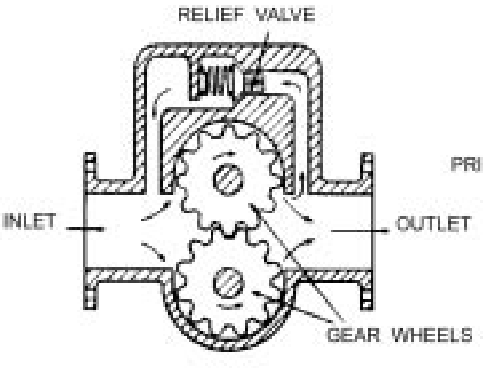


Fig.15. Gear Pump.

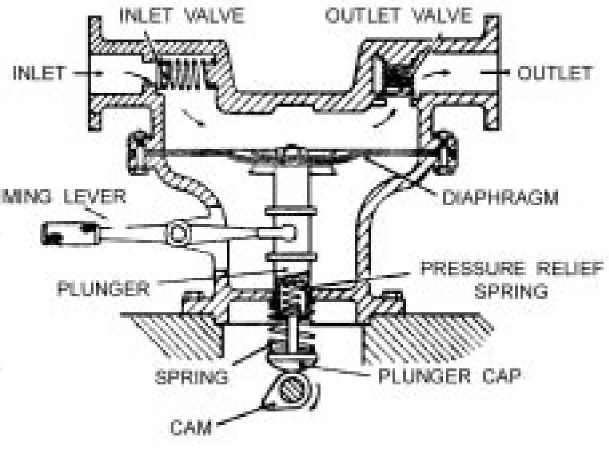


Fig.16. Diaphragm Pump.

Diaphragm Pumps

In a diaphragm pump, a rotating cam in the engine acts indirectly on a diaphragm (usually of rubberized fabric), and causes it to reciprocate. This motion , in conjunction with lightly spring-loaded inlet and outlet valves, can be used, for example, to pump fuel to the carburettor. In the pump illustrated in figure 16, a spring keeps the plunger cap in contact with the cam, and a second spring, inside the plunger, limits the delivery pressure by restricting the movement of the diaphragm. Construction of these pumps varies in detail, and in some pumps a filter bowl is suspended below the pump, the inlet valve being located inside the filter; in other pumps the plunger may be operated indirectly by a cranked lever.

POWER CALCULATION AND MEASUREMENT

Indicated Power

The power developed in an engine cylinder can be calculated from the cylinder dimensions and the average pressure on the piston during the power stroke. The force exerted on the piston will be the average pressure multiplied by the area of the piston, and the work done (force x distance) will be this force multiplied by the length of the stroke. The power developed in the cylinder can then be calculated by multiplying the work done by the number of power strokes (N) per unit time. In the case of single cylinder engine, "N" will be the crank shaft rotational speed divided by 2, and in the case of a multi-cylinder engine "N" will be the crankshaft rotational speed X no.of cylinders. When using Imperial units, power is usually quoted in horse power (hp) (1 hp = 33,000 ft lbf/min) and when using SI units, power is usually quoted in kilowatts (kw) (1 hp = 0.746 kw). Thus the Indicated Power of an engine can be calculated from the formula :-

$$\frac{PLAN}{33{,}000}\ \text{hp or}\ \frac{PLAN}{60{,}000}\ \text{kW}$$

where P = pressure on piston (lbf/in or N/m)
L = length of stroke (ft or m)
A = area of piston (in or m)
N = number of power strokes /min.

For any particular engine the cylinder capacity is fixed, so that a constant (k) could be used to replace all the invariable quantities in the formula for Indicated Power, which could then be simplified to :-

$$\frac{P \text{ X rev/min}}{k}$$

where k is $\frac{33{,}000}{\text{L X A X 1/2 no.of cylinders}}$ - or $\frac{60{,}000}{\text{L X A X 1/2 no.of cylinder}}$

as appropriate.

It can then be seen that Indicated Power for a particular engine varies directly as the cylinder pressure and engine speed, an increase in either giving an increase in Indicated Power.

Brake Power

The Brake Power, or shaft power, of an engine is the power actually delivered to the propeller, and represents the Indicated Power reduced in quantity by the power required to overcome friction and to drive the engine accessories. Power used internally is known as Friction Power, and the relationship between Brake Power and Indicated Power, expressed as a percentage, is known as the Mechanical Efficiency of the engine.

The output of an engine is obtained by measuring the torque of the propeller shaft. When calculating the work done on the piston, work was taken as force x distance (in a straight line); when measuring the work done by the propeller shaft, the torque can be thought of as a force "F" acting at a distance "r" from the axis of the shaft. If the system rotates once, the force can be regarded as having travelled one circumference of a circle of radius r,

i.e. work done per revolution = $F2\pi r$
or, as torque = Fr, then work = torque X 2π

Brake Power can then be calculated if the speed of rotation is known. Using Imperial units the Brake Power becomes :-

$$\frac{\text{torque (lbf ft) X } 2\pi \text{ X rev/min}}{33{,}000}\ \text{hp}$$

and using SI units it becomes :-

$$\frac{\text{torque (N-m) X } 2\pi \text{ X rev/min}}{60{,}000}\ \text{kW}$$

Again, using a constant (C) for the invariable quantities, Brake Power become $\frac{\text{torque X rev/min,}}{C}$ and it can be seen that it varies directly with torque and engine speed.

Mean Effective Pressure

The average pressure exerted on the piston during the power stroke is known as the Mean Effective Pressure (MEP). The actual pressures can be measured, and are generally reproduced on an Indicator Diagram similar to the one shown in figure17. The shaded areas represent work done on the piston during the induction and power strokes, and unshaded areas below the curve represent work done on the piston during the compression and exhaust strokes. The sum of the shaded areas, less the sum of the unshaded areas, represent useful work, and when this area is confined to the power stroke, the pressure coordinate becomes the Indicated MEP (IMEP), and may be used for calculating Indicated

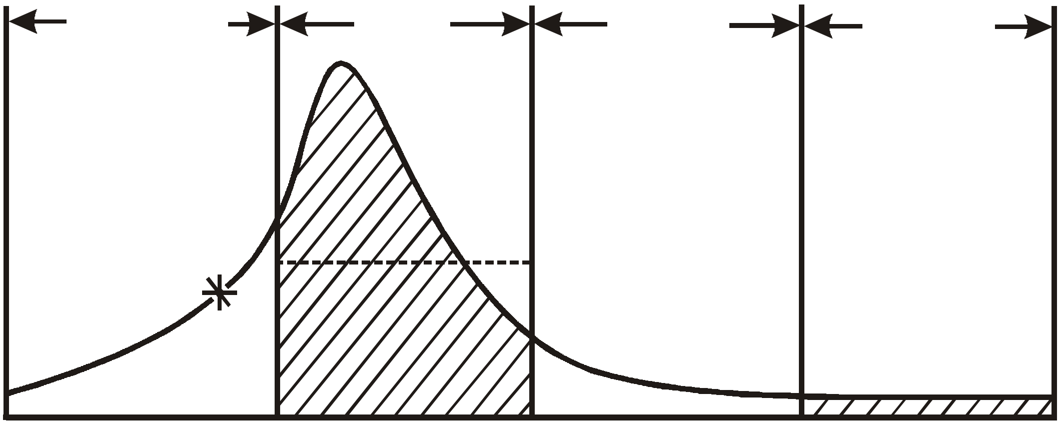


Fig.17. Indicator Diagram.

Power. IMEP, therefore, has a definite relationship to Indicated Power, and, in a similar way, is composed of components representing Friction Power and Bake Power. These components are known as Friction MEP (FMEP) and Brake MEP (BMEP), and can be used for calculating Friction Power and Brake Power respectively. Similarly, if Indicated Power and rev/min are known, IMEP can be calculated

$$\text{IMEP} = \frac{\text{k X Indicated Power}}{\text{rev/min}}$$

and if Brake Power and rev/min are known, then BMEP can be calculated

$$\text{BMEP} = \frac{\text{k X Brake Power}}{\text{rev/min}}$$

Power Control

Engine operation must be confined within cylinder pressure and crankshaft speed limitations, which are determined by the manufacturer. Various combinations of these parameters could be used to produce any particular power output, and the most economical would be the use of low rev/min to minimize friction and high cylinder pressure to produce the power required. On most engines, since cylinder pressure is related to manifold pressure, adequate control is provided by operating within prescribed manifold pressure and rev/min limitations, but on large engines where economy is particularly vital, closer control of cylinder pressure becomes necessary. IMEP is related directly to peak cylinder pressure and to Indicated Power, so that control of IMEP would ensure operating at safe cylinder pressures; however, Indicated Power is difficult to measure and other means must be used.

FMEP varies according to peak cylinder pressure and internal power requirements (different supercharger ratios, etc.), and can be measured throughout the engine speed range. The relationship between BMEP and IMEP can, therefore, be determined for any operating conditions, and since Brake Power can easily be measured by fitting a torque meter to the engine, operation at safe cylinder pressures can be achieved by imposing BMEP limitations for the various operating conditions. Manufactures conduct tests to ascertain the BMEP which is equivalent to the maximum safe cylinder pressure for any set of operating conditions, and also provide sets of tables showing the range of BMEP and rev/min setting which will give particular power outputs. The pilot may then select the power settings for the power output he requires, ensuring that the BMEP is within the limit prescribed for the particular operating conditions. Alternatively, using the formula

$$\text{BMEP} = \frac{\text{k X Brake Power}}{\text{rev/min.}}$$

the pilot may calculate the rev/min necessary to achieve the power he requires at maximum permissible IMEP.

Any rapid reduction in rev/min when operating at maximum BMEP, would result in the cylinder pressure limit being exceeded. When adjusting power, therefore, manifold pressure should be reduced before decreasing rev/min, and rev/min should be increased before raising manifold pressure.

TORQUEMETERS

Propeller shaft torque is generally measured at the reduction gear. As the crankshaft gear rotates, it drives the propeller pinions, and these exert a thrust on the fixed gear teeth, tending to rotate the fixed gear in the opposite direction to the crankshaft gear; this thrust is directly proportional to power output. To measure the thrust applied to the fixed gear, the gear is allowed to float, and is attached to the structure through pistons and oil-filled cylinders, as shown in figure. Engine oil pressure to these cylinders is boosted by a torque meter pump, and each cylinder is fitted with a bleed back to the engine oil system.

Operation

At low engine power, thrust on the “fixed” gear is at a minimum and the bleed port is fully open, resulting in a low oil pressure in the system and a low reading on the torque meter pressure gauge. As power is increased the thrust on the “fixed” gear increases, and the pistons are forced further into their cylinders. The bleed ports are reduced in size by movements of the pistons, and the oil pressure in the system increases to balance the thrust on the fixed gear. The torque meter gauge may be calibrated directly in BMEP, or in units of oil pressure.

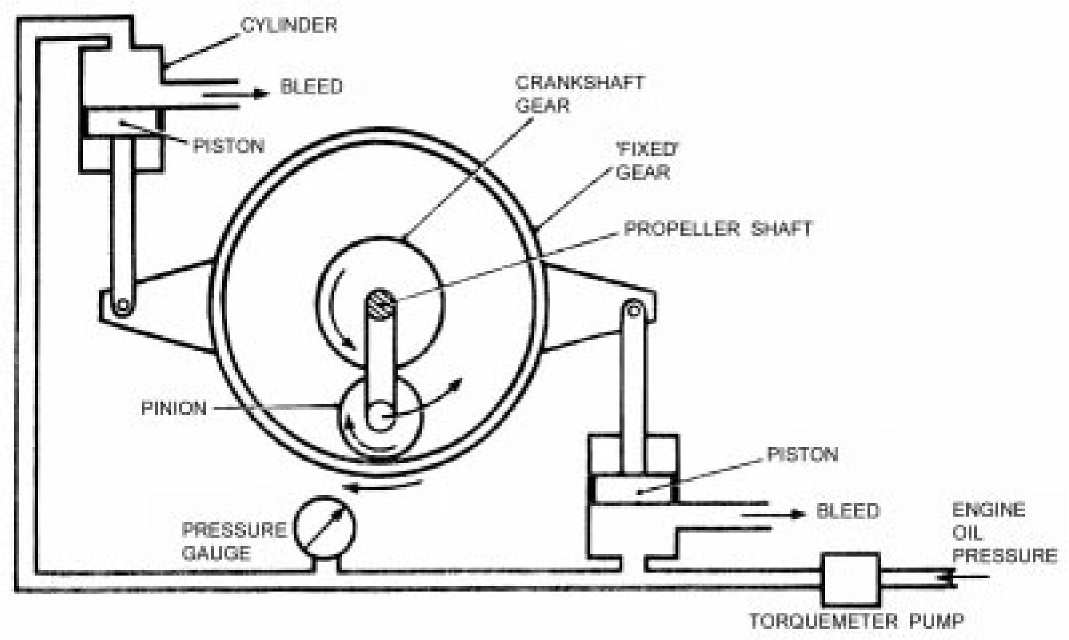


Fig. 18. Torquemeter System.

CHAPTER: 2
JET ENGINES

PRINCIPLE OF JET PROPULSION

Jet propulsion is a practical application of Sir Issac Newton's third law of motion which states that for every force acting on the body there is an opposite and equal reaction for aircraft propulsion, the "body" is atmosphere air that is caused to accelerate as it passes through the engine. The force required to give this acceleration has an equal effect in the opposite direction acting on the apparatus producing the acceleration. The jet engine produces thrust in a similar way to the propeller/engine combination, but where as the propeller gives a small acceleration to a large weight of air, the jet engines gives a large acceleration to small weight of air.

The familiar whirling garden sprinkler is a more practical example of this principle, for the mechanism rotates by virtue of the reaction to the water jets.

Jet reaction is definitely an internal phenomenon and does not, as is frequently assumed, result from the pressure of the jet on the atmosphere. In fact the jet propulsion engine, whether rocket, athodydes or turbojet is a piece of apparatus designed to accelerate a large stream of air and to expel it at an exceptionally high velocity. There are of course a number of ways of doing this but in all instances the resultant reaction or thrust exerted on the engine is proportional to the mass of air expelled by the engine and to the velocity change imparted to it. In other words, the same thrust can be provided either by giving a large mass of air a little extra velocity or a small mass of air, a large extra velocity.

METHODS OF JET PROPULSION

The types of jet engines, whether ram jet, pulse jet, rocket gas turbine, turbo/ram jet or turbo-rocket differ only in the way in which the thrust provider or engine, supplies and converts the energy into power for flight.

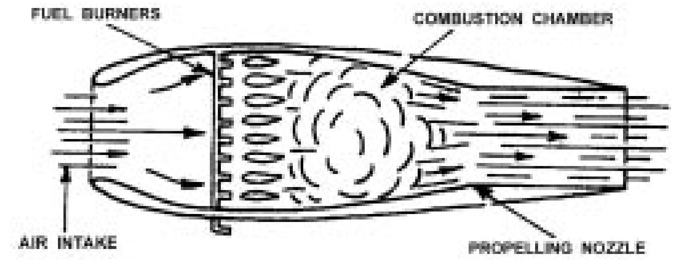


Fig.1. Ram Jet Engine.

Ram Jet

A Ram jet engine is an athodyde or aero-thermodynamic duct to give it its full name. It has no major rotating parts and consists of a duct with a divergent entry and a convergent or convergent-divergent exit. When forward motion is imparted to it from an external source, air is forced into the air intake where it loses velocity or kinetic energy and increases its pressure energy as it passes through the divergent duct. The total energy therefore, increased by the combustion of fuel, and the expanding gases accelerate to atmosphere through the outlet duct. A ram jet is often the power plant for missiles and target vehicles, but is unsuitable as an aircraft power plant because it requires forward motion imparting to it before any thrust is produced.

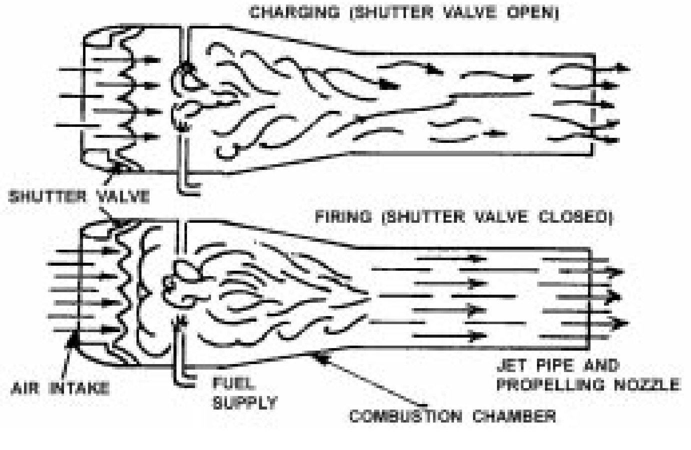


Fig. 2. Pulse Jet.

Pulse Jet

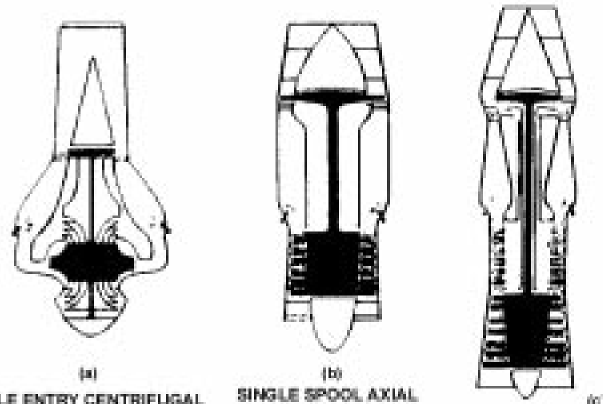
A pulse jet engine uses the principle of intermittent combustion and unlike the ram jet it can be run at a static condition. The engine is formed by an aerodynamic duct similar to the ram jet but due to higher pressure involved, it is of more robust construction. The duct inlet has a series of inlet valves that are spring loaded into the open position. Air drawn through the open valves passes into the combustion chamber and is heated by the burning of fuel injected into the chamber. The resulting expansion causes the rise in pressure, forcing the valves to close, and the expanding gases are therefore ejected rearwards. A depression created by the exhausting gases allows the valve to open and repeat the cycle. Pulse jets have been designed for helicopter rotor propulsion and some dispense with inlet valves by careful design of the ducting to control the changing pressure of the resonating cycle. The pulse jet is unsuitable as an aircraft power plant because it has a high fuel consumption and is unable to equal the performance of the modern gas turbine engine.

Rocket Engine

Although a rocket engine is a jet engine, it has in that it does not use atmosphere air as the propulsive fluid, stream. Instead it produces its own propelling fluid by the combustion of liquid or chemically decomposed fuel with oxygen, which it carries, thus enabling it to operate outside the earth's atmosphere. It is therefore only suitable for operation over short periods.

TYPES OF JET ENGINES (GAS TURBINE)

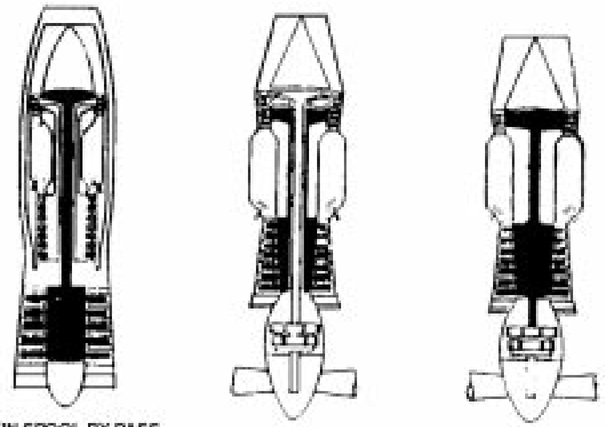
The gas turbine engine is basically of simple construction although the thermal and aerodynamic problems associated with its design are some what complex. There are no reciprocating components in the main assembly and the engine



(a) DOUBLE ENTRY CENTRIFUGAL COMPRESSORTURBO JET

(b) SINGLE SPOOL AXIAL FLOW TURBO JET

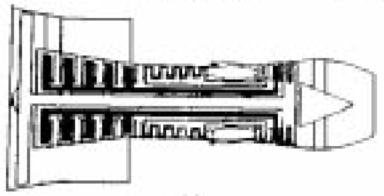
(c) TWIN-SPOOL TURBO-JET



(d) TWIN SPOOL BY PASS TURBO JET

(e) FREE TURBINE TURBO PROP

(f) DIRECT DRIVE TURBO PROP



(g) THREE SPOOL TURBO FAN

Fig. 3. Typical Variation In Gas Turbine Design.

is therefore essentially free from vibration. Power is produced in a continuous cycle by compressing the intake air and passing it to the combustion chamber where fuel is added and burnt to provide heat. The expansion of gases rearwards through the turbine produces the power necessary to drive, the compressor, the residual energy being used to provide jet thrust or in the case of turbo prop engines, to drive a propeller.

Propeller efficiency falls off rapidly above approximately 350 knots so that turbo prop engines are normally used to power comparatively low speed aircraft faster aircraft use turbo jet engines, by pass or turbo fan engines being favoured for high subsonic speeds because of their fuel economy and low noise level. After burning i.e. the burning of fuel in the jet pipe to provide additional thrust, is normally used only in military aircraft due to large quantities of fuel consumed, but it may be used on civil aircraft for take off and acceleration to supersonic flight.

LIMITATIONS

The power obtainable from the gas turbine engine is limited by the ability of the materials used in its manufacture to withstand the high centrifugal force and high gas temperature developed within engine. The life of components in the 'hot' sections of the engine, i.e. combustion chamber, turbine and jet pipes, is also influenced by the number of temperature cycles to which they are subjected. It is mainly the construction of the turbine which decides the operating speeds and temperature of the engines and although operation within these limits is often mechanically controlled, care must be taken to ensure that they are not exceeded either during ground running or in flight.

VARIATIONS IN GAS TURBINE DESIGNS

Fig. 3.shows a cutway of typical engines. Fig. (a) is a cutway of typical centrifugal flow turbojets. This particular engine has a double-sided, compressor rotor, which means that air is admitted on both sides of the compressor.

Fig. (b) shows a cutway of single spool axial flow turbo jet engine single spool means that there is only one spool of compressors which is the simplest type of turbojet engine.

Fig. (c) shows a cutway of Twin spool turbo jet engine. This type of engine has been used extensively in military fighter aircraft. It has separate turbines for both compressor spools.

Fig. (d) shows a cutway of twin spool by pass turbo jet, it has one turbine for fan and one spool of compressor where as separate turbine for one spool and another turbine for another spool of compressor. Where as part of air is by - passed over second spool after being compressed in first spool. Test flight with this engine indicate a remarkable specific fuel consumption and a excellent power/weight ratios.

Fig. (e) shows a cutway of free turbine turbo prop, which has got separate turbines for the propeller and the compressor and propeller.

Fig. (f) shows a cutaway of free turbine turbo prop, which has got separate turbines for the propeller and the compressor.

Fig. (g) shows a cutaway of three spool turbo fan engine which has got fan stage and two compressor stages, each of them having a separate turbine.

It will be noted from a study of the foregoing illustrations that a basic difference between the centrifugal-type engine and the axial-type engine is in the airflow through the engine. The airflow through the centrifugal engine follows a rather tortuous route as compared with the airflow through the axial-flow engine. Violent changes in direction of airflow remove some of the energy from the air, and this energy is lost.

DIFFERENCES BETWEEN VARIOUS TYPES OF ENGINES

FORWARD FAN	AFT FAN
1. Fan is fitted in an inlet fan section in front of the compressor.	1. Fitted in the exhaust section aft the main turbine at the rear of the engine (periphery of last turbine).
2. Tip efficiency by low pressure compressor turning.	2. Exhaust tip efficiency by better final velocity.
3. Cool air is drawn in from the front of combustion chamber.	3. Cool air drawn in after the combustion chamber.
4. Forms conventional inlet duct.	4. Efficient exhaust duct.
5. Fan is driven by the turbine through a shaft passing inside the engine.	5. Fan extended to the free turbine where entering gases passes through.
6. More than two fans for better acceleration.	6. Generally one turbine with blade
7. Fan air speeds out foreign matter	7. No provision to avoid foreign matter.
8. Front of the engine has a large diameter for casing and simple construction.	8. Rear of the engine has large diameter for casing and complicated construction.

DIFFERENCE BETWEEN TURBO JET AND TURBO PROP

TURBO JET	TURBO PROP
1. No propeller in front .	1. Propeller in front.
2. Thrust is due to the engine pressure variation and final velocity.	2. Thrust is due to the displacement of air.
3. Simple air intake.	3. Complicated air intake.
4. More noise to single or two turbine.	4. Less noise due to large diameter turbine.
5. Less air handled.	5. More air handled.
6. More weight.	6. Less weight.
7. No reduction gear.	7. Has reduction gear. 8. Turbine
drives compressor direct drive.	8. Turbine drives propeller through, splined shaft.
9. Efficient at high altitude.	9. Efficient at low altitude.
10. Ice formation at inlet position at high altitude.	10. No ice formation, aircraft flies at low altitude.

DIFFERENCE BETWEEN TURBO PROP AND TURBO SHAFT

TURBO PROP	TURBO SHAFT
1. Prop is fitted infront of the turbine section.	1. Shaft is fitted at the rear of the turbine section.
2. Prop shaft is separated from connecting torque shaft.	2. Shaft is bolted to the turbine.
3. Drives propeller in same engine axis or off set.	3. Drives the rotor shaft 90^0 to the engine axis.
4. Is driven through spur or bevel planetary gear.	4. The turbine speed is reduced through having bevel planetary.
5. Propeller throws the air towards the rear.	5. Rotor throws air towards top, bottom or at angle.
6. Speed of prop is more.	6. Speed of rotor shaft is less

CONSTRUCTIONAL DETAILS OF GAS TURBINE

MAJOR COMPONENTS OF GAS TURBINE ENGINES

In many types of turbine engines, it is not possible to list all the major components and have the list apply to all engines. There are several components and common to most turbine engines, however, and a knowledge of these will be helpful in developing a further understanding of aviation gas-turbine engines.

The operation of any gas-turbine engine requires that provision be made for three principal functions:

i) The compression of air
ii) The expansion of the air by burning fuel and
iii) The extraction of power from the jet stream of the engine for driving the compressor and accessories. Thus, we may say that gas-turbine engine comprises three main sections the compressor section, the combustion section and the turbine section.

In addition to these three main section, there are also component which serve to provide transition from one main functional section to another. The following is a list of all the major components, arranged as they would appear from the front of the turbine to the rear.

i) Inlet duct and guide vanes.
ii) The compressor.
iii) The diffuser, with or without air adaptor.
iv) The combustion chamber.
v) The nozzle diaphragm.
vi) The turbine.
vii) The exhaust cone.
viii) The after burners (if the engine is so equipped).
ix) The accessory section (which may be located at the front of the engine or further to the rear).

The Inlet Duct And Guide Vanes

Turbine engine inlet duct must furnish a relatively distortion free and high energy supply of air on the required quantity to the compressor, the uniform and steady air flow is necessary to avoid compressor stall and excessively high engine temperature at the turbines. The high energy enables the engine to produce an optimum amount of thrust. The air inlet duct is considered to be an air frame part. Inlet ducts has following functions.

(i) It must be able to recover, as much air as possible and deliver this pressure to the front of the engine with minimum pressure loss.

(ii) The duct must uniformly deliver air to compressor inlet with as little turbulence and pressure variations as possible.

There are two basic types of duct
(i) Single entry (ii) Divided entry.

Single Entry

This is the simplest and most effective because of the duct inlet is located directly ahead of the engine and the aircraft is in such a position that it scoops the undisturbed air. The duct can be built strong and straight with relatively gentle curvatures. In single engine aircraft installation the duct is necessarily is relatively curved and hence some pressure drop is possible by the long duct, but the condition is offset by smooth air flow characteristic, although a short inlet duct results in minimum pressure drop, the engine often suffer from inner turbulence specially at low air speed and high angle of attack.

Divided Entry Duct

The requirements of high speed single engine aircraft in which pilot seat is low in the fuselage and close to the nose render it a difficulty to employ a single entrance duct. Some types of divided duct which takes air from either side of the fuselage may be required. The divided ducts can be following types (i) Scoop (ii) Flush (iii) Wing root entrances.

Variable Geometry Duct

A super sonic inlet duct progressively decreases in area in the down streams, again it will follow the general configuration until the velocity of the incoming air is reduced to match 1 and below. The aft section of the duct will then commence to increase in area since this part must act as a subsonic diffuser.

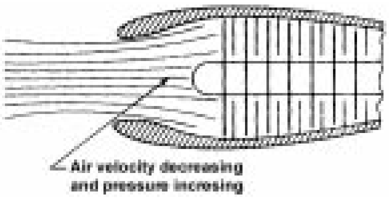
For very high speed aircraft, the inside area or configuration of duct will be changed by a mechanical device as the speed of the aircraft increases or decreases. The duct of this type is usually known as variable geometry inlet duct.

Two main methods used to diffuse the inlet air and reduce the inlet air velocity, at supersonic flight speed, one method is to vary the area of geometry of inlet duct either by using a movable restriction such as wedge inside the duct, another method is some short of variable air flow by pass arrangement which extracts part of inlet air flow from the duct ahead of the engine. Another method is by using a shock wave in the air stream, a shock wave is a thin region of discontinuity in a flow of air or gas during which velocity, density temperature of gas undergo a sudden change.

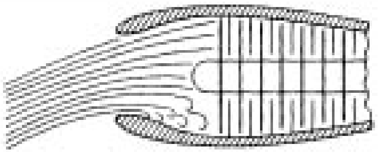
A shock wave is set up in a supersonic flow of air entering the duct by means of some restriction which automatically protrudes into the duct in high flight machine. The shock waves results in diffusion of this airflow which reduces the velocity of air. In some cases both shock waves method and variable geometry method of casing diffusion are used in combination.

Bell Mouth Air Inlet

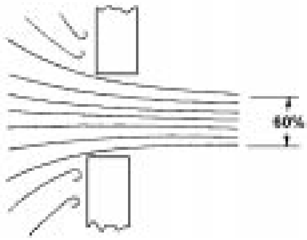
Bell mouth air inlet are convergent in shape and are used

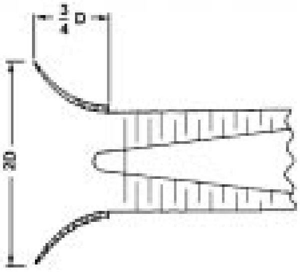


Normal airflow

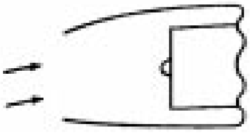


Distorted flow

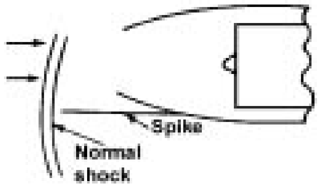




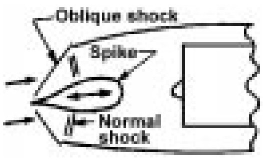
Bellmouth inlet



Subsonic duct



Transonic duct



Supersonic duct with variable geometry operating at design speed

Fig.4. Various types of air inlets.

on helicopter and slow moving aircraft which flies below ram recovery speed. This type of inlet reduces a large brake factor but drag is out weighed by high degree of Aerodynamic efficiency.

Engines being calibrated on ground run test, also utilizes bell mouth anti ingestion screen. Duct loss is slight in this design that it is considered to be zero. Engine performance data such as engine trimming while using a bell mouth engine inlet, aerodynamic efficiency and duct loss are shown in fig.3. It can be seen that rounded L.E. allows air stream to make use of total inlet cross section where as effective diameter of sharp edge orifice is greatly reduced.

Air Inlet Vortex Destroyer

When the jet engine operating on ground, the engine air inlet vortex can some times be formed between the air inlet and ground. This vortex can cause strong suction force capable of lifting foreign objects from the ground into the engine causing serious damage. To minimize the ingestion of debris, an inlet vortex destroyer is used. This destroyer is nothing but a small jet stream directed downwards from the lower L.E. of the nose cowling to the ground to destroy the vortex base. Bleed air from the engine is used as the vortex destroying stream, it is controlled by a valve located in the nose cowl. The control valve is a two position valve which is opened by a L/G weight switch. The valve closes when the aircraft leaves the ground and weight of aircraft is removed from the L/G.The valve opens when touches ground and when weight switch contact is made.

Foreign Object Damage

One of the major problems encountered in the operation of axial flow engines is foreign object damage. Rocks drawn into the air inlet during taxing cause considerable damage because they nick or scratch the compressor and turbine blades as they pass through the engines, which can lead to fatigue failure with the result that the engine may throw a blade in flight. This could result in loss of the aircraft or serious damage to the engine.

To prevent foreign object damage, the air inlet on the engine are screened. These screens are effective in removing large objects from the air stream, but they will not prevent small rocks from entering the engine. Small rocks, sand and grass can do a great amount of damage to the engine.

Air Inlet Icing

The air screen at the inlet of an axial flow engine is subject to icing, with the result that the engine may stop. The engine nose cowling nose dome and inlet guide vanes are subject to icing, however, and it is necessary to incorporate provisions in the engine nose cowlings to prevent the formation of ice. Jet engine anti icing system normally make use of a high temperature air from the diffuser section.

COMPRESSORS

In the gas turbine engine, compressor of the air before expansion through the turbine is effected by one of two basic types of compressor, one giving a centrifugal flow and the other an axial flow. Both types are driven by the engine turbine and are usually coupled direct to the turbine shaft.

The centrifugal flow compressor is a single or two stage unit employing an impeller to accelerate the air and a diffuser to produce the required pressure rise. The axial flow compressor is a multi stage unit employing alternate rows of rotating (rotor) blades and stationary (stator) blades to accelerate and diffuse the air until the required pressure rise is obtained.

With regards to the advantages and disadvantages of two types, the centrifugal compressor is usually more robust than the axial compressor and is also easier to develop and manufacture. The axial compressor, however, compresses more than a centrifugal compressor of the same frontal area and can also be designed for high pressure ratios much more easily. Since the air flow is an important factor in determining the amount of thrust, this means that the axial compressor engine will also give more thrust for the same frontal area.

The Centrifugal Flow Compressor

Have a single or double sided impeller and occasionally a two-stage, single sided impeller is used as on the Roll’s Royce Dart. The impeller is supported in a casing that also contains a ring of diffuser blades. If a double entry impeller is used, the airflow to the rear side is reversed in direction and a plenum chamber is required.

Principles Of Operation

The impeller is rotated at high speed by the turbine and air is continuously induced into the centre of the impeller. Centrifugal action causes it to flow radially outwards along the vanes to the impeller tip, thus accelerating the air and also causing a slight rise in pressure to occur. The engine intake duct may contain vanes that provides an initial whirl to the air entering the compressor.

The air on having the impeller, passes into the diffuser section where it passages from the divergent nozzles and converts most of the kinetic energy into pressure energy. In practice, it is usual to design the compressor so that about half of the pressure rise occurs in the impeller and half in the diffuser.

The air mass flow through the compressor and the pressure rise depend on the rotational speed of the impeller, therefore impellers are designed to operate at tip speed of up to 1600 ft per second. By operating at such high tip speeds, the air velocity from the impeller is increased. So that greater energy is available for conversion to pressure. Another factor influencing the pressure rise is the inlet air temperature, for the lower temperature of air entering the impeller the greater the pressure, the pressure rise for a given amount of work put into the air by the compressor, is a measure of the increase in the total heat of the air passing through the compressor.

To maintain the efficiency of the compressor, it is necessary to prevent excessive air leakage between the impeller and the casing, this is achieved by keeping their clearances as small as possible.

Construction

The construction of the compressor centres around the impeller diffuser and air intake systems. The impeller shaft rotates in ball and roller bearings and is either common to the turbine shaft or split in the centre and connected by a coupling, which is usually designed for case of detachments.

Impellers

The impeller consists of a forged disc with integral, radially disposed vanes on one or both sides forming divergent passages. The vanes may be swept back but for ease of manufacture straight radial vanes are usually employed. To ease the change of air flow from the axial to the radial direction, the vanes in the centre of the impeller are curved in the direction of rotation. The curved sections may be integral with the radial vanes, or formed separately for easier and more accurate manufacture.

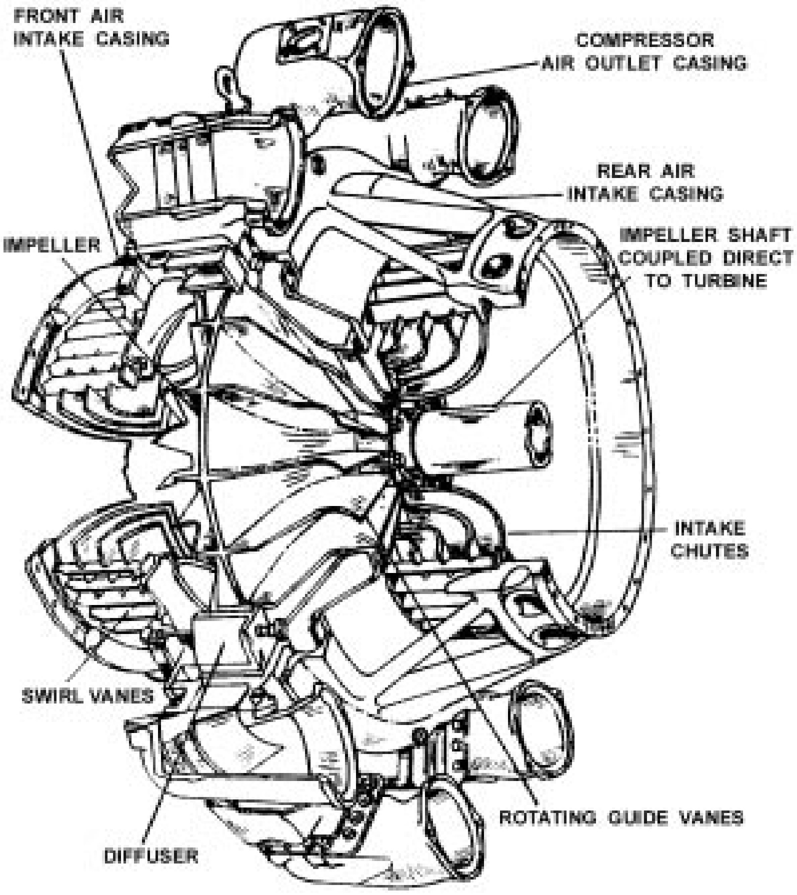


Fig. 5. A typical centrifugal flow compressor.

The choice of impeller is determined by the engine design requirements, but it is claimed that the single entry ducting allows the air to be fed into the compressor at the best all round efficiency. It is also claimed that the single entry ducting minimizes the chances of surging at altitude, because it makes more efficient use of the ram effect than, does the double entry ducting. A small amount of heating also occurs on the double entry ducting.

Diffusers

The diffuser assembly may be an integral part of the compressor casing or a separately attached assembly. In each instance it consists of a number of vanes formed tangential to the impeller, The vanes passages are divergent to convert the kinetic energy into pressure energy and inner edges of the vanes are in line with the direction of the resultant airflow from the impeller . The clearance between the impeller and the diffuser is an important factor, as too small a clearance will set up aerodynamic impulses that could be transferred to the impeller and create an unsteady airflow and vibration.

Axial Flow Compressor

An axial flow compressor consists of one or more rotor assemblies that carry blades of aerofoil section and are mounted between bearings in the casings in which are located the stator blades. The compressor is a multi stage unit as the amount of work done (pressure increase) in each stage is small, a stage consists of a row of rotating blades followed by a row of stator blades. Some compressors have an additional row of stator blades, known as intake or inlet guide vanes, to

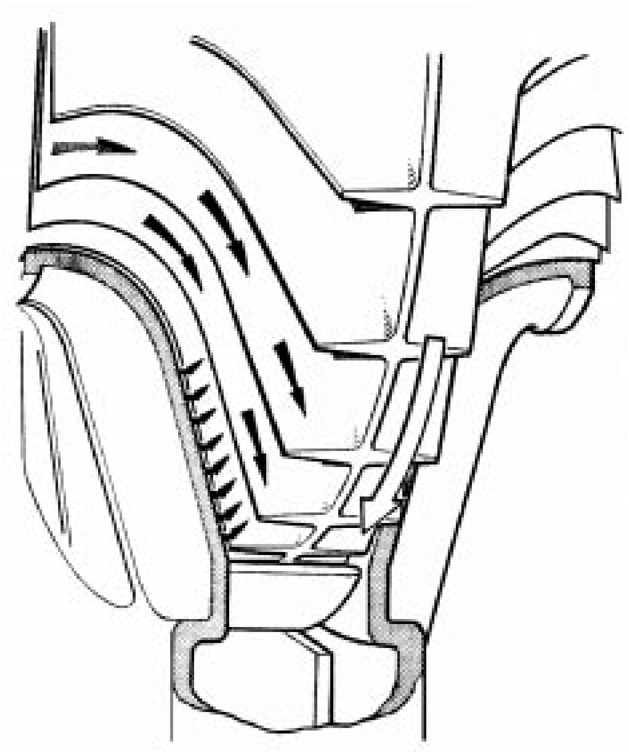


Fig. 6. Impeller working clearance and air leakage.

Fig7. Typical impeller for centrifugal compressor.

guide the air on to the first row of rotor blades. The angular setting of the vanes can be automatically controlled to suit the airflow requirements at various operating conditions.

From the front to the rear of the compressor, i.e. from the low to high pressure end, there is gradual reduction of the air annulus area between the rotor shaft and the stator casing. This is necessary to maintain the axial velocity of the air constant as the density increases through the length of the compressor. The convergence of the air annulus is achieved by the tapering of the casing or rotor. A combination of both is also possible, with arrangement being influenced by manufacturing problems and other mechanical design factors.

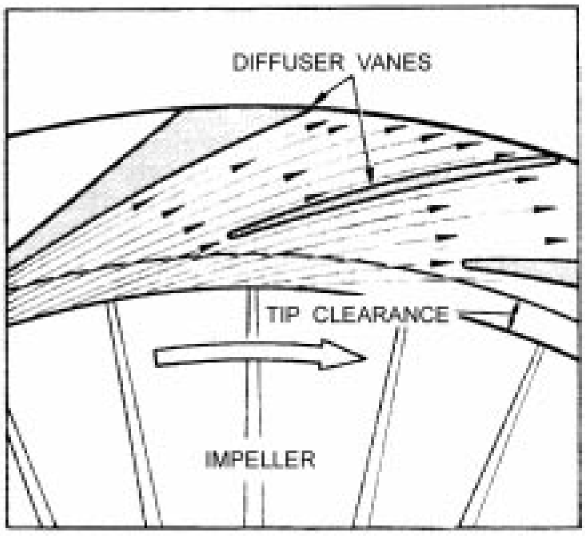
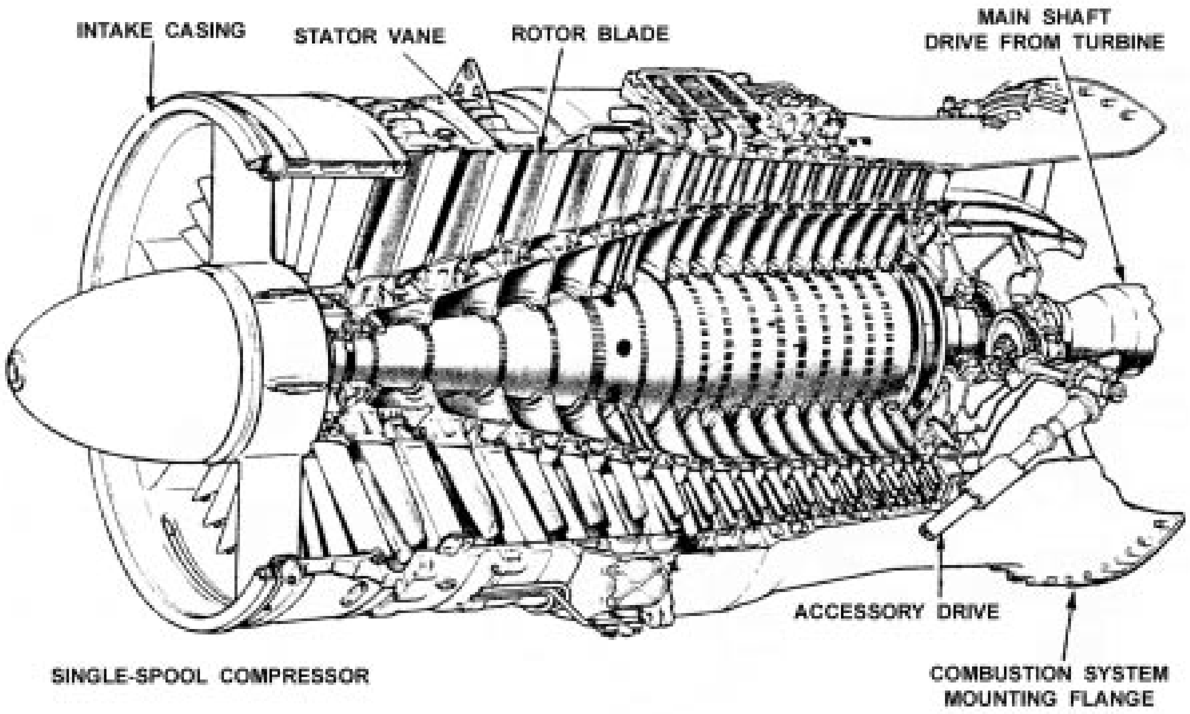
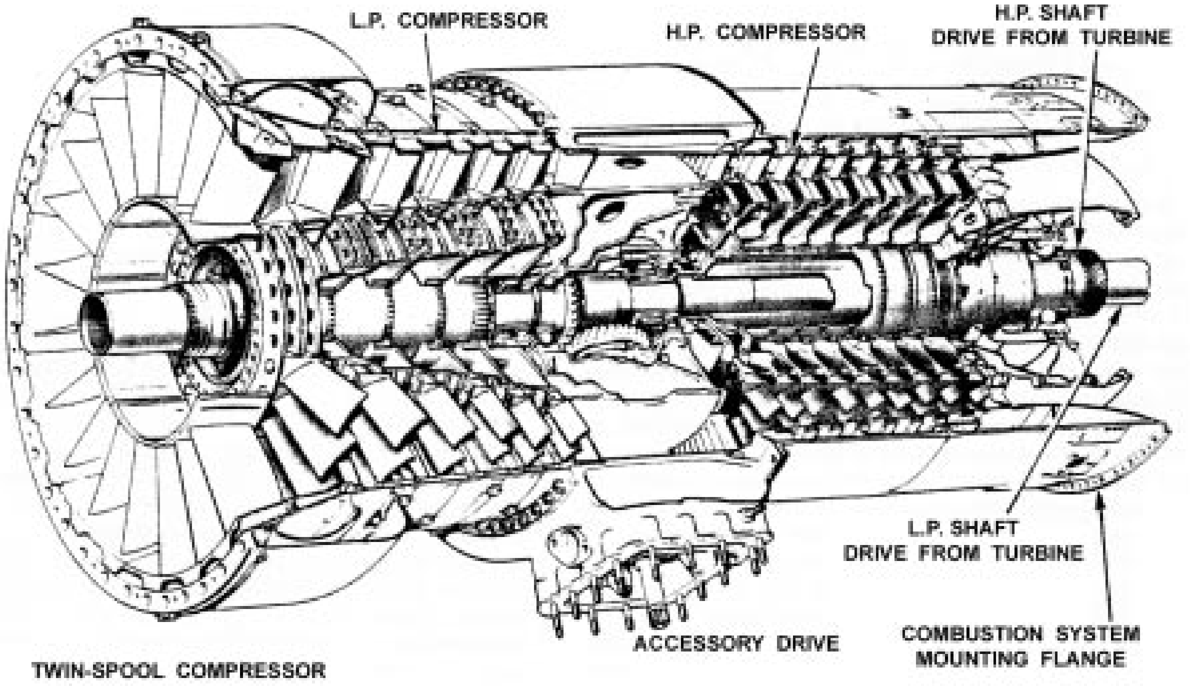


Fig.8. Airflow at entry to diffuser.



SINGLE-SPOOL COMPRESSOR



TWIN-SPOOL COMPRESSOR

Fig. 9. Typical Axial Flow Compressors.

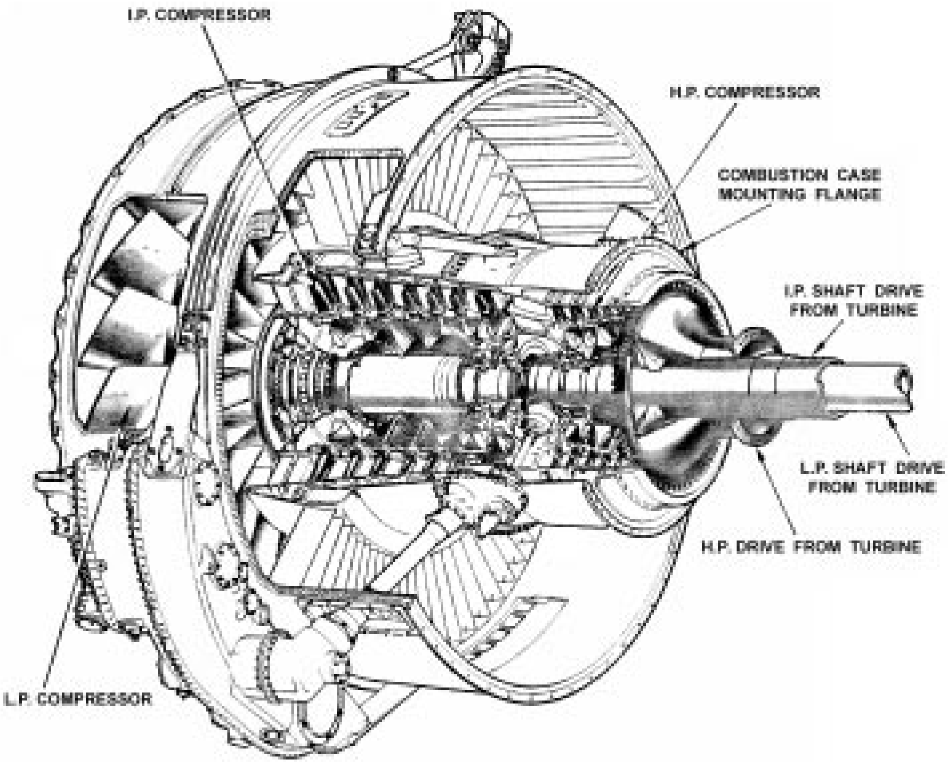


Fig.10. Typical Triple Spool Compressor.

A single spool compressor consists of one rotor assembly and stators with as many stages as necessary to achieve the designed pressure ratio, and all the airflow flow from the intake passes through the compressor. The multi spool compressor consists of two or more rotor assemblies, each driven by their own turbine at an optimum speed to achieve higher pressure ratio and to give greater operating flexibility.

Although a twin spool compressor can be used for a pure jet engine, it is most suitable for the by pass type of engine where the front or low pressure compressor is designed to handle a larger mass airflow than the high pressure compressor. Only a percentage of the air from the low pressure compressor passes into a high pressure compressor, the remainder of the air, the by pass flow is ducted around the high pressure compressor. Both flows mix in the exhaust system before passing to the propelling nozzle.

A fan may be fitted to the front of a single or twin spool compressor and on these types of engines the fan is driven at the same speed as the compressor to which it is fitted. On engines of the triple spool type, the fan is in fact the low pressure compressor and is driven by its own turbine separately from the intermediate pressure compressor and the high pressure compressor. The low pressure compressor has large rotor (fan) blades and stator blades is designed to handle a far larger mass airflow and the other two compressor, each of which has several stages of rotor blades. A large proportion of air from the lower part of the fan and known as the cold stream, by passes the other two compressors and is ducted to atmosphere through the cold stream nozzle. The smaller airflow, from the inner part of the fan and known as hot stream passes through the intermediate and high pressure compressor when it is further compressed before passing into the combustion system.

Principles Of Operation

During operation, the rotor is turned at high speed by the turbine, so that air is continuously induced into the compressor, where it is accelerated by the rotating blades and swept rearwards on the adjacent row of stator blades. The pressure rise in the airflow results from the diffusion process in the rotor blade passages and from a similar process in the stator blade passages; the latter also serves to correct the deflection given to the air by the rotor blades and to present the air at the correct angle to the next stage of rotor blades. The last row of stator blades usually act as “air straightner” to remove the whirl from the air so that it enters the combustion system at a fairly uniform axial velocity. The changes in pressure and velocity that occur in the airflow through the compressor are shown in fig.10. These changes are accompanied by a progressive increase in air temperature as density increases.

Across each stage, the ratio of the total pressures of the out going air and inlet air is quite small, being between 1:1 and 1:2. The reason for the small pressure increase through each stage is that the rate of diffusion and the deflection angles of the blades must be limited if losses due to air break away at the blades, and subsequent blade stall are to be avoided. The small pressure rise through each stage together with the smooth flow path of the air, does much to contribute to high efficiency of the axial flow compressor. For instance, the maximum air velocity through the axial compressor corresponds to a Mach number of about 0.9 and the flow is almost of thorough. On the other hand, the

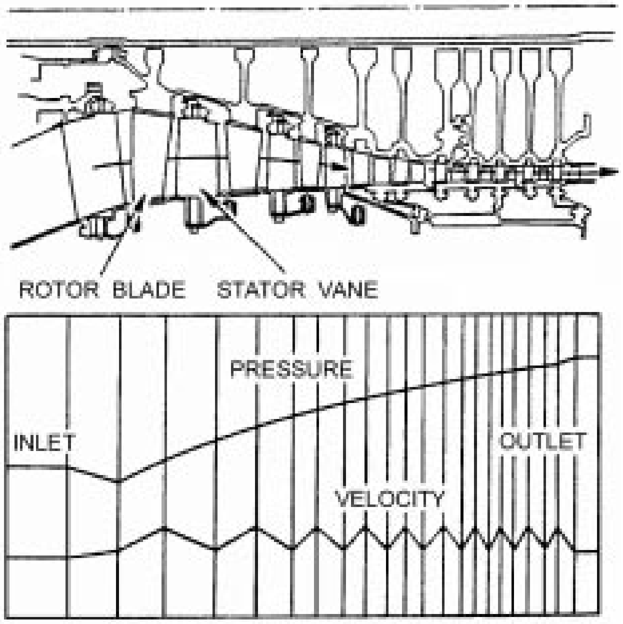


Fig.11. Pressure and velocity changes through an axial compressor.

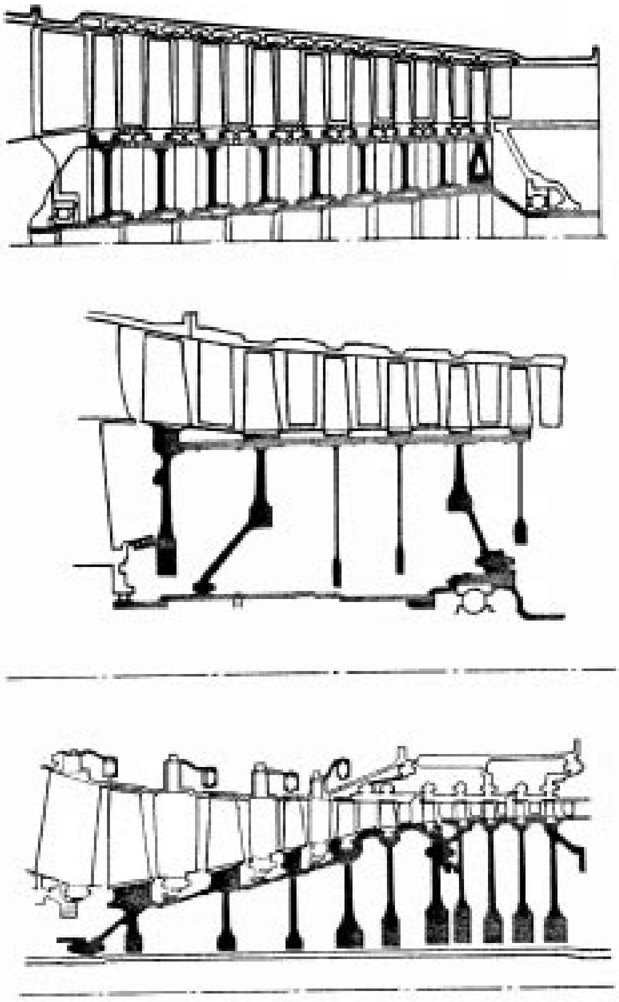


Fig.12. Rotars of drum and disc construction.

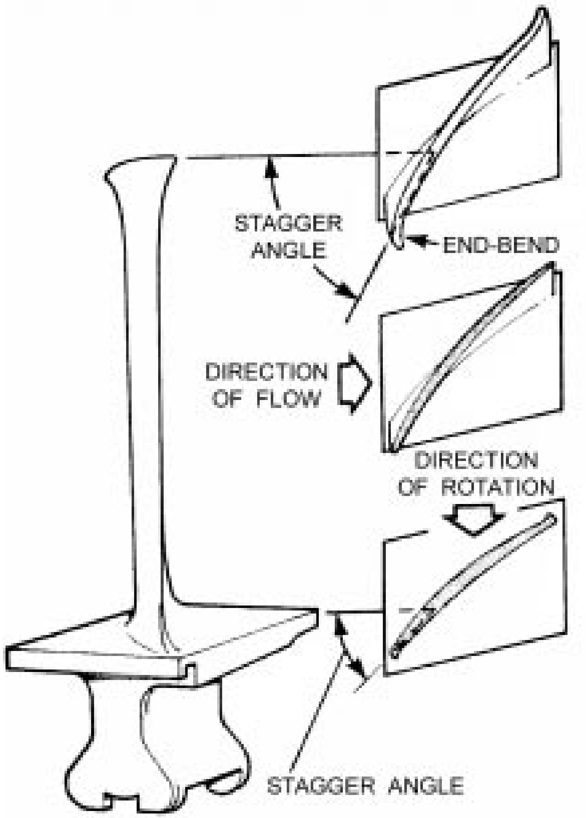


Fig. 13. A typical rotar blade showing twisted contour.

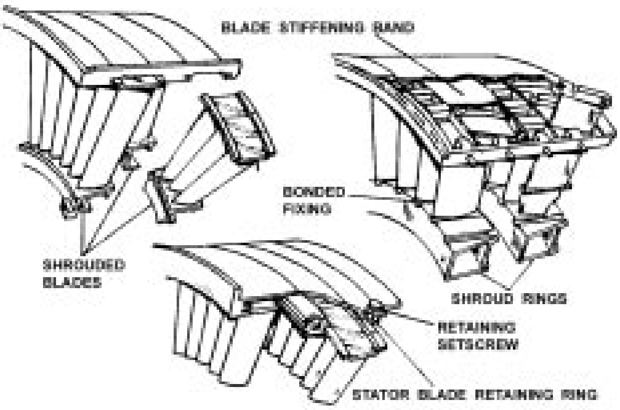


Fig.14. Methods of securing blades to compressor casing.

velocity through a centrifugal compressor is super sonic in places, reaching a Mach number of 1.2; the flow in this instance is tortuous culminating in a right angle bend at the outlet to the combustion chamber.

Because an axial flow compressor requires a large number of stages to produce a high compressor ratio, as the number of stages increases it becomes more difficult to ensure that each stage will operate efficiently over a engine speed range. An automatic system of airflow control is sometimes necessary to maintain compressor efficiency, but a more flexibly operated engine can be achieved by having more than one compressor with each compressor being an independent system, driven by separate turbine assemblies through coaxial shafts. The compressor, therefore be designed to operate more efficiently and with greater flexibility over a wide speed range.

A by pass engine invariably has a spool compressor with the low pressure compressor supplying sufficient air for both the by pass system and the high pressure compressor. Still greater flexibility can be obtained and higher maximum compression ratios reached by using an automatic airflow control system for high pressure compressor, this method is used on the Rolls Royce spey series of engines. Although an engine may have a front or an aft fan, the front fan is favoured by most manufactures as giving greater reliability, due to the fan operating in the cold section of the engine. The fan can have one or more stages of large blades, both rotor and stator. The rotor blades can be fitted to the front of a compressor or be part of a complete compressor driven by its own turbine. The air accelerated by the outer portion of the blades forms a by pass or secondary airflow that is ducted to atmosphere, the main airflow from the inner portion of blade passes through the remainder of the compressor and into the combustion systems. Only one stage of blades is used on the fan of triple spool engines, because the blades are designed to operate at transonic tip speeds. This permits the desired compression ratio to be achieved and not only reduces the weight of engine but also its noise level.

Construction

The construction of the compressor centres around the rotor assembly and casings. The rotor shaft is supported in ball and roller bearings and is coupled to the turbine shaft. The casing assembly consists of a number of cylindrical casings some of which are in two halves to facilitate engine assembly and inspection, these are bolted together to completely house the rotor.

Rotors

The rotor assembly may be of a disc construction (in fig) or of drum, or a combination of both types may be used. The drum type rotor consists of a one or two piece forging on to which are secured the rotor blades. The disc type rotor has the rotor blades attached to separate discs, which are then splined to the rotor shaft and separated by integral or individual spacer rings. In the former type axial thrust and radial load both are taken by the drums where as in disc type radial load is taken by the disc and axial thrust by the black platform and spacer rings. The accumulated end thrust is taken by the end of the or the end discs.

Rotor Blades

The rotor blades are of aerofoil section (in fig) and are usually designed to give a pressure gradient their length to ensure that the air maintains a fairly uniform axial velocity. The higher pressure towards the tip balances out the centrifugal action of the rotor on the airstream. To obtain thrust condition, it is necessary to twist the blade from root to tip to give the correct angle of incidence at each point. The length of the blades varies from front to rear, the front or low pressure blades being the longest.

Stator Blades

The stator blades are again of aerofoil section and are secured into the compressor casing or into stator blade retaining ring, which are themselves secured to the casings. The blades are often mounted in packs in the front stages and may be shrouded at their tips to minimize the vibrational effect of flow variation on the longer blades. It is also necessary to lock the stator blades in such a manner that they will not rotate around the casings.

Operating Conditions

Each stage of a multi-stage compressor processes certain airflow characteristics that are dissimilar from those of its neighbour: thus, to design a workable and efficient compressor, the characteristics of each stage must be carefully matched. This is a relatively simple process to carry out for one set of conditions (design mass flow, pressure ratio and rotational speed), but is much more difficult if reasonable matching is to be retained when the compressor is operating over a wide range of conditions such as an aircraft engine encounters.

Outside the design conditions, the flow around the blade tends to degenerate into violent turbulence when the smooth flow of air through the compressor is disturbed. Although the two terms ‘stall ‘ and ‘ surge ‘ are often used synonymously, there is a difference which is mainly a matter of degree. A stall may affect only one stage or even a group of stages, but a compressor surge generally refers to a complete flow breakdown through the compressor.

Compressor blades are designed to produce a given pressure rise and velocity increase over the engine speed range. If something should disturb the pressure, velocity, rotational speed relationship the airflow across the blade profile will break away and create eddies until eventually the blade ‘ stalls ‘. This could occur if the airflow was reduced due to icing or a flight manoeuvre, or if the fuel system scheduled too high a fuel flow; damage due to ingestion could, of course, create a similar condition.

If the stall condition of a stage or group of stages continues until all stages are stalled, then the compressor will surge . The transition from a stall to a surge could be so rapid as to be unnoticed; on the other hand, a stall may be so weak as to produce only a slight vibration or poor acceleration or deceleration characteristics.

At low engine speeds or 'off design' speeds, a slight degree of blade stalling invariably occurs in the front stages of the compressor, even though a system of airflow control may be used. This condition is not harmful or noticeable on engine operation.

A more severe compressor stall is indicated by a rise in turbine gas temperature, vibration or 'coughing' of the compressor. A surge is evident by a bang of varying severity from the engine and a rise in turbine gas temperature.

The value of airflow and pressure ratio at which a surge occurs is termed the 'surge point'. This point is a characteristic of each compressor speed, and a line which joins all the surge points called the ' surge line ' defines the minimum stable airflow that can be obtained at any rotational speed. A compressor is designed to have a good safety margin between the airflow and the compression ratio at which it will normally be operated and the airflow and compression ratio at which a surge will occur.

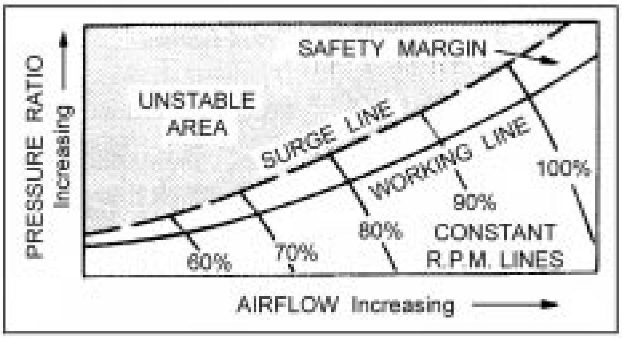


Fig.15. Limits of stable airflow.

THE DIFFUSER AND AIR ADAPTOR

Diffusers

The function of the diffuser assembly is to direct air from the compressor to the combustion chambers and to change air pressure and velocity as required for best fuel combustion.

The air discharge from a centrifugal impeller enters equally spaced diffuser passages, and at the end of each is a Wrist type of elbow containing four vanes which turn the air 90^{o} into the compressor discharge. The diffuser has boxed type of single casting, with elbows and turning vanes cast integrally. Fig.15. below illustrates at typical diffuser for a centrifugal-flow engine.

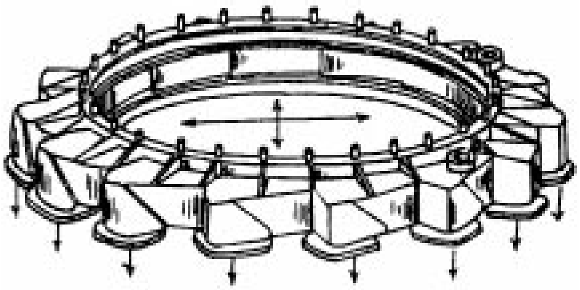


Fig. 16.Diffuser for centrifugal flow turbo jet engine.

The diffuser for an axial-flow engine serves to carry the air from the compressor to the combustion chambers. For an engine equipped with individual "can" type combustion chambers, the diffuser must have a separate outlet shaped to fit the inlet of each combustion chamber. In some axial-flow engines, the diffuser section is called the midframe. It not only contains the diffuser but also provides support for the mid bearing and mountings for the fuel-nozzle assemblies.

Air Adapters

Air adapters on a centrifugal-flow engine carry the air from the diffuser to the combustion chambers. They also provide attachment for the fuel nozzles, domes or end caps of the combustion chambers, air adapters aid in slowing the air velocity and increasing the pressure as is desirable at this point of the thermodynamic cycle.

On axial-flow engines, the air adapter is actually the outlet of the diffuser section. Usually this portion of the assembly is not even named as the air adapter.

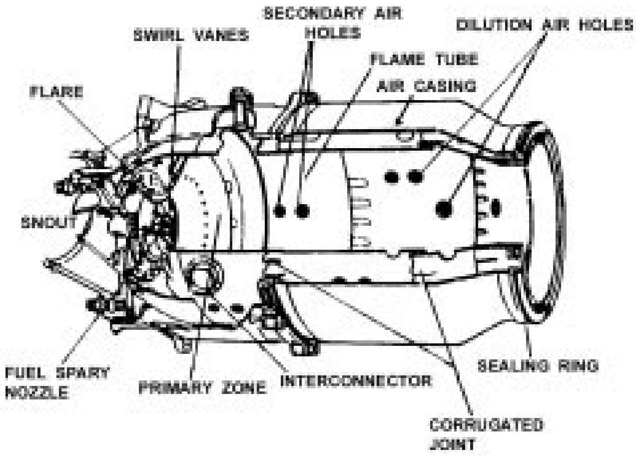


Fig.17.A typical combustion chamber.

COMBUSTION CHAMBER

Introduction

The amount of fuel added to the air will depend upon the maximum temperature rise required and, as this is limited by the materials from which the turbine blades and nozzles are made, the rise must be in the range of 700 to 1200^{0}C because the air is already heated by the work done during compressor, the temperature rise required at the combustion chamber may be between 500 and 800^{0}C. Since the gas temperature required at the turbine varies with engine speed and in the case of turbo-prop engine upon the power required, the comb. Chamber must also be capable of maintaining stable and sufficient combustion over a wide range of engine operating condition.

Combustion Process

Air from the engine compressor enters the combustion chamber at a very high velocity which is further diffused and static pressure increased in the combustion chamber, this is done because the burning of kerosine at normal mixture ratio is only few fts/sec, and any fuel which is burnt at high velocity will be blown off or away. A region of low axial velocity has therefore to be created in the chamber so that the flame will remain alight throughout the range of energy separating conditions.

In normal operation the over all air/fuel ratio of a combustion chamber can vary between 45% and 30% kerosene however will only burn efficiently at or close to a ratio of 15:1 so the fuel must be burnt with only part of the air entering the chamber, in what is called a primary combustion zone. This is achieved by means of a flame tube (combustion liner) that has various devices for metering the airflow distribution along the chamber.

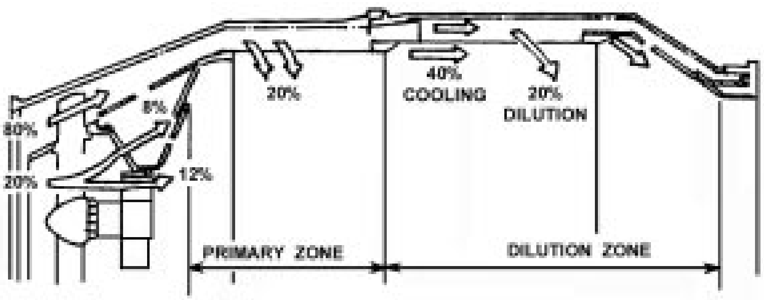


Fig. 18. Apportioning the air flow.

Approx. 18% of the air mass flow is taken in by the snout or entry section. Immediately down stream of the snout, are swirl vanes and a perforated flare, through which air passes into the primary combustion zone. The swirling air induces a flow upstream of the centre of the flame tube and promotes the desired recirculation. The air not picked up by the snout flows into the annular space between the flame tube and the air casing.

Through the wall of the flame tube body, adjacent to the combustion zone, are a selected number of holes through which a further 10 to 15% of the main flow of air passes into the primary zone. The air from the swirl vanes and that from the primary air holes inter acts and creates a region of low velocity recirculation. This takes a form of a toroidal vortex similar to a smoke ring and has the effect of stabilizing and anchoring the flame. The recirculating gases hasten the burning of freshly injected fuel droplets by rapidly bringing them to ignition temperature.

It is arranged so that the conical fuel spray from the burner, intersects the recirculation vortex at the centre. This action, together with the general turbulence in the primary zone, greatly assists in bringing up the fuel and mixing it with the incoming air.

The temperature of the combustion gases released by the combustion zone is about 1,800 to 2000^{0}C which is far too hot for entry to the nozzle guide vanes of the turbine. The air not used for combustion, which is therefore introduced progressively into the flame tube. Approx. half of this is used to lower the gas temperature before it enters the turbine and the other half is used for cooling the walls of the flame tube. Combustion should be completed before the dilution air enters the flame tube, otherwise the incoming air will cool the flame and incomplete combustion will result.

An electric spark from an igniter plug initiates combustion and the flame is then self sustained.

Types Of Combustion Chamber

There are three main types of combustion chamber in use, they are multiple chamber, the turbo annular chamber and the annular chamber.

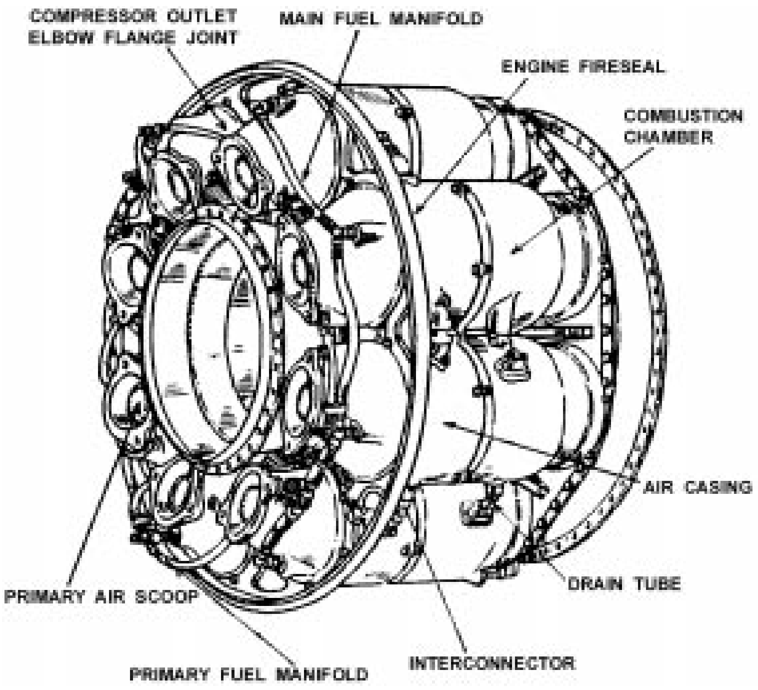


Fig.19. Multiple combustion chamber.

Multiple Combustion Chamber

This type of combustion chamber is used on centrifugal compressor engines and the earlier types of axial flow compressor engines. It is a direct development of the earlier type of whittle combustion chamber. The major difference is that whittle chamber had a reverse flow, but as this created a considerable pressure loss, the straight through multiple chamber was developed by Joseph Lucas ltd.

The chambers are disposed around the engine (fig. 19.) and compressor delivery air is directed by ducts to pass into the individual chamber. Each chamber has an inner flame tube around which, there is an air casing. The air passes through the flame tube snout, and also between the tube and the outer casing.

The separate flame tubes are all interconnected. This allows each tube to operate at the same pressure and also allows combustion to propagate around the flame tubes during engine starting.

Turbo Annular Combustion Chamber

The turbo annular C.C is a combination of the multiple and annular types. A number of flame tubes are fitted inside a common air casing. The

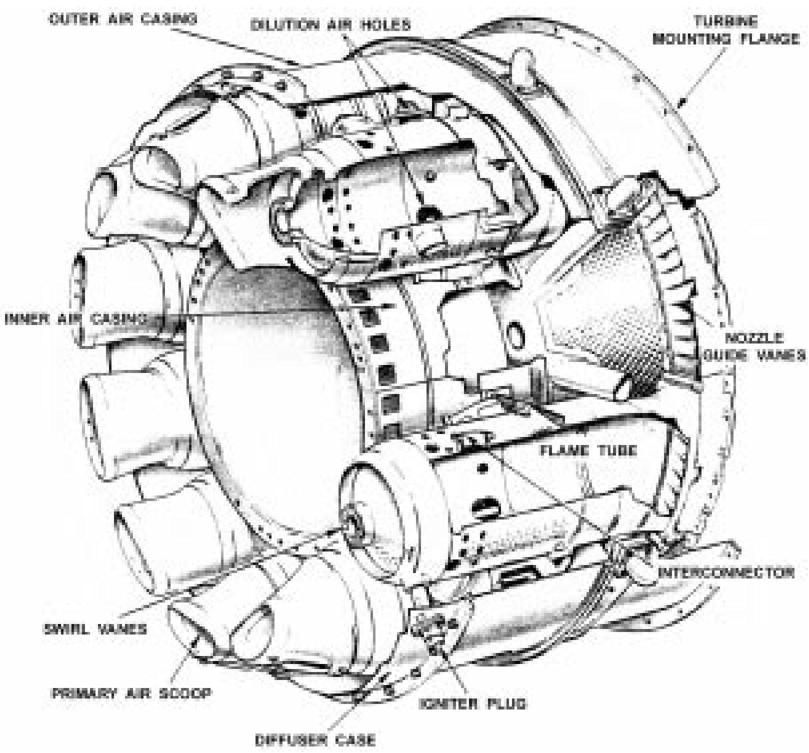


Fig.20. Turbo-annular combustion chamber.

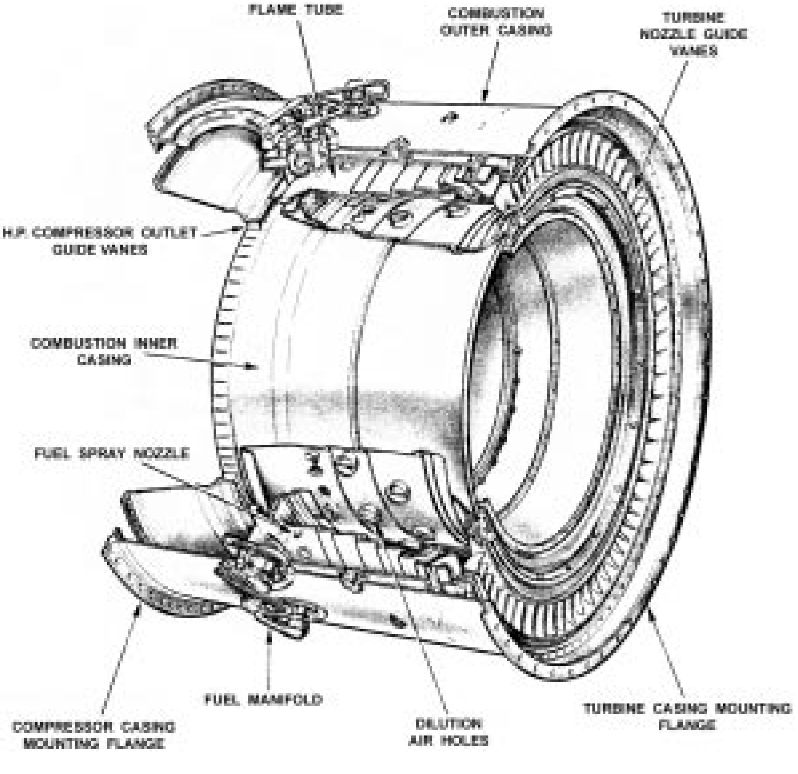


Fig.21. Annular combustion chamber.

airflow is similar to that already described and this arrangement, embodies the case of overhaul and testing of the multiple system with the compactness of annular system. (fig. 20).

Annular Combustion Chamber

This type of combustion chamber consists of a single flame tube, completely annular in form, which is contained in an inner and outer casing (fig 21). The air flow through the flame tube is similar to that previously, described, the chamber being open at the front to the compressor and at the rear to the turbine nozzles.

The main advantage of annular chamber is that, for the same power output, the length of the chamber is only 75% of that of a turbo annular system for an engine of the same diameter, resulting in considerable saving of weight and production cost. Another advantage is that because inter connection are not required the propagation of combustion is improved.

In comparison with a turbo annular combustion system, the wall area of a comparable annular chamber is much less; consequently the amount of cooling air required to prevent the burning of the flame tube wall is less, by approx. 15%. This reduction in cooling air raises the combustion efficiently to virtually eliminate unburnt fuel, and oxidizes the carbon monoxides to non toxic carbon dioxide, thus reducing air pollution.

A high by pass ratio engine will also reduce air pollution since for a given thrust the engine burns less fuel.

Turbine Nozzle And Nozzle Diaphragm

This diaphragm consists of a group of nozzle vanes welded, between two shroud rings. In the typical nozzle diaphragm, the inner and outer bands contains punched holes to receive the ends of nozzle vanes. The nozzle vanes are usually constructed of high temperature alloy, and they must be highly heat resistant.

In many engines the nozzle vanes are hollow and are formed from stainless steel sheet. They are then welded and ground smooth before being installed between the shroud rings. When there is more than one turbine wheel, additional nozzle diaphragms are installed to direct the hot gases from one wheel to the next. Second third and fourth stage nozzle vanes are often constructed of solid steel alloy. These may be either forged or precision cast.

Purpose

The purpose of nozzle diaphragm is two fold : (i) it increases the velocity of the hot gases flowing past this point and (ii) it

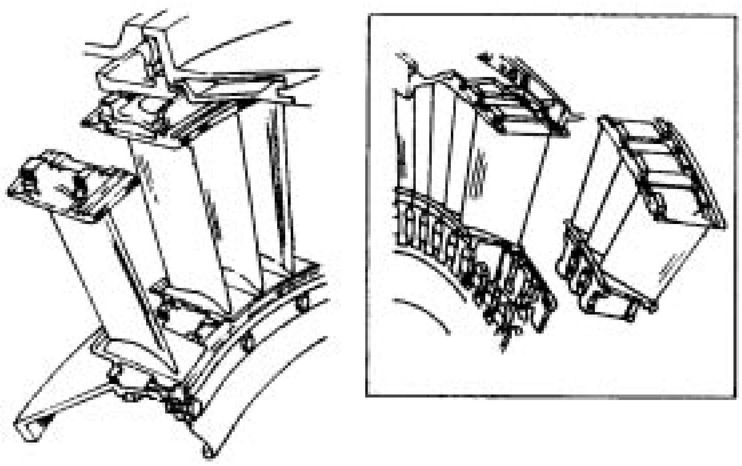


Fig. 22. Typical nozzle guide vanes showing their shape and location.

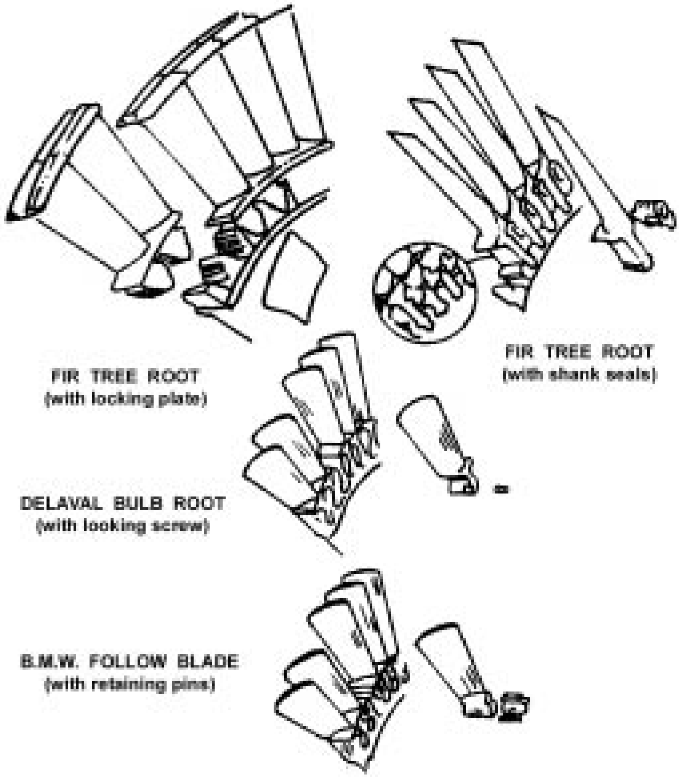


Fig.23. Methods of attaching blades to turbine discs.

directs the flow of gases to strike the turbine buckets at the desired angle. The gases flowing through the nozzle diaphragm attain their highest velocity at this point.

The blades or vanes in the nozzle diaphragm are of aerofoil design. In the pure reaction type design, the nozzle blades resemble turbine blades closely. This is particularly true of the nozzle or stator blades (vanes) between the turbines wheels in multi stage turbine assemblies.

TURBINE

Introduction

The turbine has the task of providing the power to drive the compressor and accessories and, in the case of engines which do not make use solely of jet for propulsion, of providing shaft power for a propeller or rotor. It does this by extracting energy from the hot gases released from the combustion system and expanding them to a lower pressure and temperature. High stresses are involved in this process, and for efficient operation, the turbine blade tip may rotate at speeds up to 1300 feet per second.

To produce the driving torque, the turbine may consists of several stages, each employing one row of stationary nozzle guide vanes and one row of moving blades. The no. of stages depends on whether the engine has one shaft or two and on the relation between the power required from the gas flow, the rotational speed at which it must be produced and the diameter of turbine permitted.

The number of shafts varies with the types of engine, high compression ratio engines usually have two shafts, driving high and low pressure compressors. On high bypass ratio fan engines that feature an intermediate pressure system, another turbine is inter posed between the high and low pressure turbine thus forming a triple spool system. On some propeller or shaft engines, driving torque is derived from a free power turbine. The shaft driving the propeller or the output shaft to the rotor blade of a helicopter, through a reduction gear, may be mechanically independent of other turbine and compressor shafts.

The bypass engine enables a smaller turbine to be used than in a pure jet engine for a given thrust output and it operates at a higher gas inlet temperature, there by obtaining important thermal efficiency and power/weight ratio.

The design of the nozzle guide vanes and turbine blade passages is based broadly on aerodynamic considerations, and to obtain optimum efficiency compatible with compressor and combustion design, the nozzle guide vanes and turbine blades are of a basic aerofoil shape. The relationship and juxtaposition of these shapes are such that the turbine functions partly under impulse and partly under reaction condition, that is to say, the turbine blades experience an impulse force caused by the initial impact of the gas on the blades and a reaction force resulting from the expansion and acceleration of the gas through the blade passages. Normally gas turbine engines do not use either pure impulse or pure reaction turbine blades. With an impulse turbine, the total pressure drop across each stage occurs in the fixed nozzle guide vanes and the effect on the turbine, blades is one of momentum only ; where as with a reaction turbine, the total pressure drop occurs through the turbine blade passages. The proportion of each principle incorporated in the design of a turbine is therefore largely dependant on the type of engine in which the turbine is to operate, but in general it is about 50% impulse and 50% reaction. Impulse type turbines are used for cartridges and air starters.

Construction

The basic components of the turbine are the combustion discharge nozzles, the nozzle guide vanes, the turbine discs and turbine blades. The rotating assembly is carried on roller bearings mounted to a compressor shaft or connected to it by a self aligning coupling.

Nozzle Guide Vanes

Are of aero foil shape, the passages between adjacent vanes forming a convergent duct. The vanes are located in the turbine casing in a manner that allows for expansion.

The nozzle guide vanes are usually of hollow form and be cooled by passing compressor delivery air through them to reduce the effects of high thermal stresses and gas load.

Turbine Disc

The turbine disc is a machine forging with an integral shaft or with a flange on to which the shaft may be bolted. The disc also has around its perimeter provision for the attachment to the turbine blades.

To limit the effect of heat conduction from the turbine blades to the disc a flow of cooling air is passed across both sides of each disc.

Turbine Blades

The turbine blades are of an aerofoil shape. The main air is to provide passages between adjacent blades that gives a steady acceleration of the flow up to the throat where the area is smallest and the velocity reaches that required at exit to produce the required degree of reaction.

High efficiency demands thin trailing edges to the sections but a compromise has to be made so as to prevent the blades cracking due to temperature changes during engine starting and stopping.

The method of attaching the blades to the turbine disc is of considerable important, since the stress in the disc around the fixing or in the blade root has an important bearing on limiting rim speed. Various methods of blade attachment are

(1) Fir tree Root (with locking plate)
(2) Fir tree Root (with shank seals).
(3) De laval By it Root (with locking screw).
(4) B.M.W.hollow blade (with retaining pins).

Now a days majority of gas turbine use fir tree root type attaching method.

To reduce the loss of efficiency due to gas leakage, across the blade tips, a shroud is often fitted this is formed by forging small segment at the tip of each blade, so that when all the blades are fitted to the disc, the segment form a peripheral ring around the blade tips.

On a fan engine, where the fan is aft (rear) mounted the blade forming the fan present an additional thermal problem. This is because the outer portion of each blade operation is in a duct through which passes a cool air stream, while the inner portion operates in the normal gas stream to extract the energy for accelerating the fan airflow.

THE EXHAUST CONE

The exhaust cone is located directly behind the turbine wheel and its main function is to collect discharge gases from the turbine wheel and expel then at the correct velocity. The exhaust cone consists of a stainless steel outer shell and central cone supported from the shell by four stream lined struts or fins is to straighten out the airflow from approx. 45% to an axial direction. Air flowing through this section decreases in velocity and increases in pressure.

The outer surface of the exhaust cone is insulated in most installations and many different types of insulation are used. A typical arrangement consists of four layers of A1 foil, each separated from the next by a layer of bronze screening. The insulation reduces the heat losses that would normally escape through the exhaust cone. The insulation also protects adjacent aircraft structures and equipment from damage caused by heat.

When the gas-turbine engine is delivered by the manufacturer to the ultimate consumer, the exhaust cone is the terminating component of the basic engine. In order to operate the engine and obtain the required performance, however, it is necessary to use a tail pipe and exhaust nozzle. The length of the exhaust pipe or tail pipe varies with each airplane installation, and therefore, by necessity, the pipe must be manufactured by the air-frame manufacturer.

THE THRUST REVERSER

Jet engines installed in jet airlines are equipped with thrust reversers to provide a braking action after the airplane has landed. The thrust reverser blocks gas flow to the rear and directs it forward to produce reverse thrust up to 5,000 lb. or more. The reverse thrust is produced when the air baffle doors or " clamshells " are moved into the gas stream by actuating cylinders controlled by the reverse thrust lever in the cockpit. Fig.24. below is a drawing of a typical thrust reverser unit designed for use with the General Electric CJ805 jet engine.

ACCESSORIES SECTION

Locations

Early type of engines usually had the accessory drive sections located at the nose of the engine, where it had the effect of limiting the available area for air intake. This was particularly true on axial flow engines.

Present designs place the main accessory drive section at the bottom of the engine, and fitted closely against the case. The accessory drive is geared to the shift of the high pressure compressor.

Engine Driven Accessories

Includes the accessories needed for engine operation and also those required for the operation of a/c. The following is a list of accessories commonly driven by the engine and mounted on the accessory section.

i) Engine starter (connected to the engine during starting).
ii) Generator
iii) Fuel Pump
iv) Emergency fuel pump
v) After burner fuel pump
vi) Techo meter generator
vii) Fuel control unit
viii) Air bleed governor
ix) Oil pump and scavenge pump
x) Hydraulic pump.

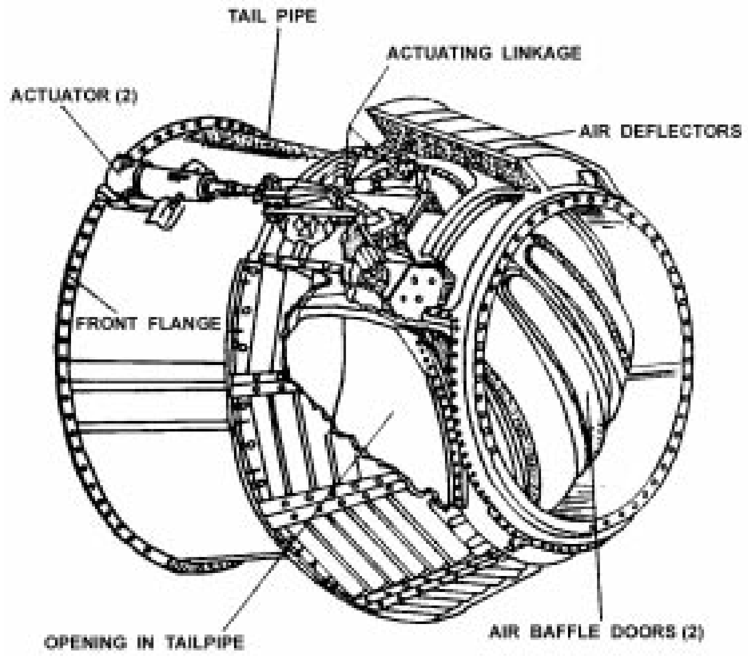


Fig. 24. Thrust reverser unit. (General Electric Company)

Some gas-turbine engines have one accessory power section, while others may have more. For example, one modern engine drives most of the accessories from a power takeoff at the bottom of the engine but also has an auxiliary accessory driven at the front of the engine. Two or threeof the smaller accessories are driven from this front accessory section.

AFTERBURNING

After burning (or reheat) is a method of augmenting the basic thrust of an engine to improve the aircraft-take off, climb and (for military aircraft) combat performance. The increased power could be obtained by the use of a larger engine, but as this would increase the weight, frontal area and specific fuel consumption, after burning provides the best method of thrust augmentation for sort periods.

After burning consists of the introduction and burning of fuel between the engine turbine and the jet pipe propelling nozzle utilizing the unburned oxygen in the exhaust gas to support combustion. The resultant increase in the temperature of the exhaust gas gives an increased velocity of the jet leaving the propelling nozzle and therefore increases the engine thrust.

As the temperature of the after burning flame can be in excess of 1700 deg. C., the burners are usually arranged so that the flame is concentrated around the axis of the jet pipe. This allows a proportion of the turbine discharge gas to flow along the wall of the jet pipe and thus maintain the wall temperature at a safe value.

The area of the after burning jet pipe is large than a normal jet pipe would be for the same engine, to obtain a reduced velocity gas stream. To provide for operation under all conditions, an after burning jet pipe is fitted with wither a two-position or a variable-area propelling nozzle. The nozzle is closed during non-after burning operation, but when after burning is selected the gas temperature increases and the nozzle opens to give an exit area suitable for the resultant increase in the volume of the gas stream. This prevents any increase in pressure occurring that would affect the functioning of the engine and enables after burning to be used over a wide range of engine speeds.

The thrust of an after burning engine, without after burning in operation, is slightly less than that of a similar engine not fitted with after burning equipment; this is due to the added restrictions in the jet pipe. The overall weight of the power plant is also increased because of the heavier jet pipe and after burning equipment.

After burning is achieved on bypass engines by mixing the bypass and turbine streams before the afterburner fuel injection and stabilizer system is reached so that the combustion takes place in the mixed exhaust stream. An alternative method is to inject the fuel and stabilize the flame in the individual bypass and turbine streams, burning the available gasses up to a common exit temperature at the final nozzle. In this method, the fuel injection is scheduled separately to the individual streams and it is normal to provide some form of interconnection between the flame stabilizers in the hot and cold streams to assist the combustion processes in the cold bypass air.

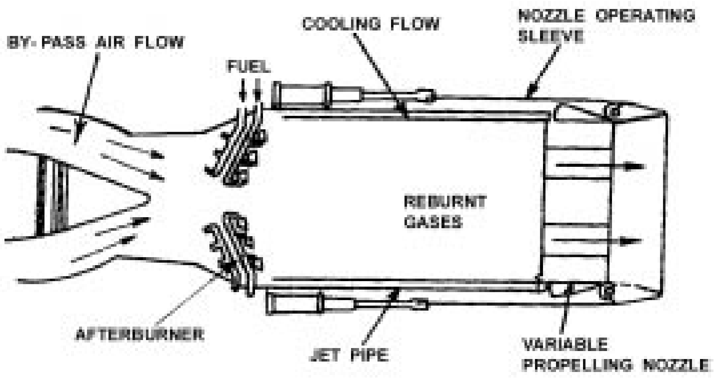


Fig. 25. Principle of after burning.

Operation of Afterburning

The gas stream from the engine turbine enters the jet pipe at a velocity of 750 to 1200 feet per seconds, but flow is diffused before it enters the afterburner combustion zone, i.e. the flow velocity is reduced and the pressure is increased. However, as the speed of burning kerosene at normal mixture ratios is only a few feet per second., any fuel lit even in the diffused air stream would be blown away. A form of flame stabilizers is, therefore, located downstream of the fuel burners to provide a region in which turbulent eddies are formed to assist combustion in operation.

An atomized fuel spray is fed into the jet pipe through a number of burners, which are so arranged as to distribute the fuel evenly over the flame area. Combustion is then initiated by a catalytic igniter which creates a flame as a result of the chemical reaction of fuel/air mixture being sprayed on to a platinum-based element by an igniter plug adjacent to the burner, or by a hot streak of flame that originates in the engine combustion chamber; this latter method known as hot shot ignition. Once combustion is initiated the gas temperature increases and the expanding gases accelerated through the enlarged area propelling nozzle to provide the additional thrust.

In view of the high temperature of the gases entering the jet pipe from the turbine, it might be assumed that the mixture would ignite spontaneously. This is not so, for although cool flames form at temperatures up to 700 deg. C., combustion will not take place below 800 deg C. If , however, the conditions were such that spontaneous ignition could be effected at sea level, it is unlikely that it could be effected at altitude where the atmospheric pressure is low. The spark or flame that initiates combustion must be of such intensity that a light-up can be obtained at considerable altitudes.

For smooth functioning of the system, a stable flame that will burn steadily over a wide range of mixture strengths and gas flows is required. The mixture must also be easy to ignite under all conditions of flight, and combustion must be maintained with the minimum loss of pressure.

Thrust Increase

The increase in thrust due to after burning depends solely upon the ratio of the absolute jet pipe temperatures before and after extra fuel is burnt. For example, neglecting small losses due to the afterburner equipment and gas flow momentum changes, the thrust increase may be calculated as follows.

Assuming a gas temperature before after burning of 640 deg. C (913 deg K) and with after burning of 1269 deg. C (1542 deg. K) then the temperature ratio = (1542/913) = 1.69

The velocity of the jet stream increases as the square root of the temperature ratio. Therefore, the jet velocity 1.69 = 1.3. Thus, the jet stream velocity is increased by 30 percent and the increase in static thrust, in its instance, is also 30%.

Static thrust increases of up to 70% are obtainable from bypass engines fitted with after burning equipment, and at high forward speeds several times this amount of thrust boost can be obtained. High thrust boosts can be achieved on by pass engines because of the large amount of exhaust oxygen in the gas stream and the low initial temperature of the exhaust gases.

It is not possible, however, to go on increasing the amount of fuel that is burnt in the jet pipe so that all the available oxygen is used, because the jet pipe would not withstand the high temperatures that would be incurred.

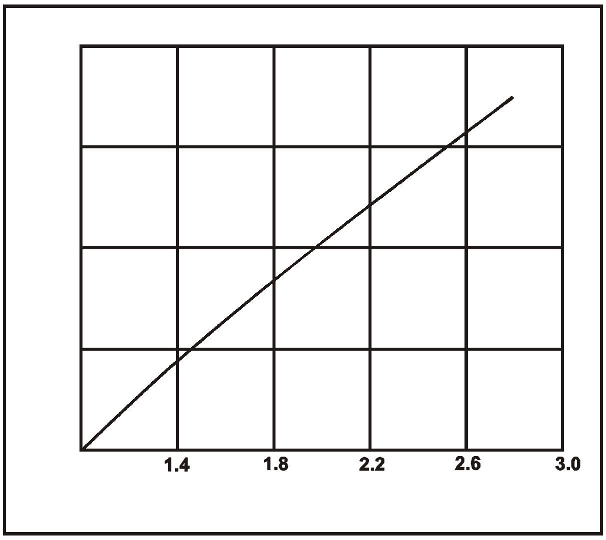


Fig. 26. Thrust increase and temperature ratio.

MATERIAL FOR GAS TURBINE ENGINES

Chemical Elements

The most commonly used elements in the manufacture of metals and alloys for gas turbine engines are listed here with their symbols : Carbon (C); Silicon (Si); Manganese (Mn); Chromium (Cr); Nickel (Ni); Cobalt (Co); Molybdenum

(M)Tungsten (W); Colombian (Cb); Titanium (Ti); Nitrogen (N); Copper (Cu); Iron (Fe); Aluminium (Al).

This list is not meant to include all possible elements used in high-temperature alloys, but it indicates the types of elements required.

The three characteristics that metallurgists search for in the metals for high-temperature applications are Oxidation resistance, high-temperature strength, and corrosion resistance. Probably the most vital of these three characteristics is the capacity to resist oxidation, because structural strength is useless if a metal rapidly burns away. At jet-engine operating temperature, ordinary steel burns like paper; and tungsten, molybdenum ; and Colombian oxidize quickly, as do most high-melting-point metals.

For years manufacturers have worked closely with the steel mills in developing research data that would serve as a guide to the evolution of new alloys. Today, at least 20% high-temperature alloys are used in the fabrication of components for power plants. These metals may be classified into four groups;

(1) Chrome-nickel steels,
(2) Chrome steels,
(3) Nickel-base alloys and
(4) Cobalt-base alloys.

Chrome-Nickel Steels

The chrome-nickel steels contain these elements in approximately 18:8 ratios and are commonly referred to as “austenitic steels”. This description refers to their crystalline structure, in which the ingredients are said to be in solid solution so that each crystal is composed of an intimate mixture of the constituents.

This group of steels is most widely used for high-temperature applications because of its good characteristics of oxidation and corrosion resistance and of high strength at elevated temperatures. These steels have about six times the electrical resistance of ordinary steels and respond readily to welding techniques. However, since they expand 50 percent faster than plain steels and conduct heat only half as fast, they require special care during welding to prevent distortion. They do not need heat-treatment after welding to develop maximum physical strength.

These steels are nonmagnetic and cannot be hardened by heat-treatment. They may be hardened by cold-working, and then they become slightly magnetic. Cold-working enhances their structural strength at the cost of ductility. They are difficult to machine unless they contain added amounts of sulphur or selenium.

When subjected to temperatures above 800^0 F, they tend to precipitate carbides in their grain boundaries, thus lowering their resistance to corrosion. The corrosion resistance may be restored by heating them to 1850 to 1900^0F and cooling them quickly, or they may be protected against the formation of harmful carbide precipitation by the addition of Colombian or titanium to their formulas.

Chrome Nickel steels are suitable for parts such as high-pressure compressor casings, combustion casings, turbine casings, and similar parts where extreme temperatures are not encountered. High-temperature stainless steels are also employed for compressor blading, compressor disks, turbine disks, exhaust cones, thrust reversals afterburner casings, and miscellaneous sheet metal parts. The principal disadvantage of chrome-nickel stainless steels is the weight. For this reason, titanium alloys are often used where the temperature is not excessive for the material.

Chromium Steels

The straight alloys, containing no nickel, are either martenstic or ferritic in crystalline structure, depending upon their hardening characteristics. Those containing upto 14% chromium harden intensely if they are allowed to cool rapidly from high temperatures, forming a hard, relatively brittle substance called martensite. Because these alloys respond to heat-treatment, they are capable of being given a wide range of mechanical properties such as tensile strength and hardness.

Those chromium steels containing from 17 to 30 percent chromium do not respond to heat-treatment or cooling and remain essentially ferritic at all times. The intermediate types, containing between 14 and 17 percent chromium, behave in a manner that depends upon their exact chromium and carbon contents.

Chromium contents up to 4 percent do not increase corrosion resistance. Amounts from 4 to 10 percent improve resistance to corrosion appreciably. Chromium percentages from 10 to 30 percent are designated when oxidation resistance at high temperatures is required.

The steels with chromium contents of 5 to 30 percent are magnetic in all conditions. They exhibit distinctly inferior creep resistance compared with the chrome-nickel stainless steels. The 17 percent chromium steels have excellent oxidation and corrosion resistance and may be used at temperatures up to 1500^0F. The 25% chromium content steel is designated for severe heat and corrosion applications and is good for applications where temperatures reach 2000^0 F.

All the straight chrome steels are more difficult to weld than the chrome-nickel types because the welding heat leaves them in a brittle condition. They have about the same coefficients of expansion as ordinary steel, with several times the electrical resistance and slightly lower melting points. They tend to become brittle from welding heat in two ways : by slow cooling from around the 1200^0 F range, and by grain growth produced by holding them over 1650^0 F. The first type of embrittlement may be eliminated by quick cooling from above 1200^0F. The second type cannot be remedied but may be avoided by careful welding techniques.

From straight chrome steel, jet- engine case weldments and bearing-housing assemblies are built for Pratt & Whitney turbojet engine. These are fabricated from welded alloys of Type 410. Additional jet-engine detail fittings and components are built from Type-415 and used in applications where temperature is not a critical factor.

Nickel Base Alloys

The nickel-base alloy contain between 70 and 80 percent nickel and cannot properly be called "steels" because of their small quantities of iron. In this group of alloys, many of which are called "super alloys", are the Nimonics, M-252, GMR-235, the Hastelloys, Nichrome, Rex 400, K42 B the Inconels, Waspalloy, Rene 41, Multi-alloy, Refract alloy 26, the Udimets, and Unitemp 1735. These alloys have been tailored for high-temperature and some offer excellent oxidation and corrosion resistance at temperatures of over 2100^0F.

Inconel

These alloys can be cold-worked, hot-worked, or forged without difficulty and can also be welded and machined. Various types of the Inconel alloys are used for combustion chambers, transition liners, turbine nozzle parts, and turbine buckets.

The Nimonic

The nimonic alloys, numbered 75, 80, 80A and 90, are of British manufacture and contain a major percentage of nickel, with chromium as the next most important element. Nimonic 90 utilizes a large percentage of cobalt as an alloying element. The Nimonic alloys are largely used for the hot parts of gas-turbine engines, such as combustion chambers and turbine nozzles.

GMR-235

GMR-235 contains about 55 percent nickel, 15.5% chromium and 10 percent iron with smaller portions of molybdenum aluminium, and titanium. It is of low strategic-alloy content, that is, it contains neither cobalt nor Colombium; hence it can be manufactured even though these metals are not available. GMR-235 was developed by the General Motors Corporation primarily for gas turbine wheels, buckets, and nozzle vanes operating at temperatures in excess of 1400^0 F. An improvement of this alloy, GMR-235, contains increased amounts of aluminium and titanium, and less iron.

The Hastelloys

Designated A, B, C, R-235. W, and X, are nickel-base alloys developed and manufactured by the Haynes Stellite Company, a Division of the Union Carbide Company. These alloys contains large % of molybdenum. These alloys are used in various applications where high temperature and corrosion resistance are desirable.

Waspalloy

Waspalloy was originally developed by the Pratt & Whitney Aircraft Division of United Aircraft Corporation for use in the manufacture of turbine buckets. It is traditional super alloy suitable for use in the 1200 to 1600°F range although it retains good strength at higher temperatures. This alloy is also used for turbine disks and other heavy forging in jet engines.

The Udimet

Alloy, manufactured by special metals, Incorporated are super alloys of high strength, corrosion resistance, and high temperature resistance. Udimet 500 is used for turbine buckets and small integral gas turbines. Udimet 700 is suitable for the 1400 to 1800°F range and can be used for a short time upto 2000°F. It is used for turbine buckets and for turbine disks in advanced jet engines. Udimet N-115 is one of the strongest wrought super alloys and is used for turbine buckets in applications requiring extended service upto 1850^0F.

Cobalt Base Alloys

Cobalt-base alloys, also called super alloys, are designated for use where high-temperature strength and corrosion resistance are important. These alloys usually contain substantial amounts of tungsten, nickel, chromium, and molybdenum in addition to cobalt. Some of the alloys contain either tungsten or molybdenum but not both.

Haynes Stellite No.25 (HS-25) is used to build the eyelid assemblies for afterburners and afterburner flame holders. It has excellent strength and resistance to oxidation at high temperatures. It also exhibits good ductility and can be worked both hot and cold. It has oxidation and carburization resistance for service upto 1900^0 F.

Haynes Stellite Alloy no.21 (HS-25) is resistant to oxidizing and reducing atmospheres upto 2100^0F. It has excellent strength which is maintained through a wide range of temperatures and thermal shock conditions. Haynes Stellite No.31 (HS-31) is a casting alloy, and has good creep, endurance, and stress-rupture properties.

Another cobalt-base alloy manufactured by the Haynes Stellite Company is Alloy No.151. This alloy has excellent properties at high temperatures and is suitable for turbine blade applications upto 1800^0F.

Variations In Alloy Properties

It must be emphasized that the properties of high-temperature alloys are not imparted merely by the mixing of various metallic elements. The elements are most important ; however, the type of heat treatment and working applied to the alloy is also essential.

Among some of the treatments employed for developing desired characteristics in the super alloys are solution heat treating, precipitation hardening, strain hardening, cold-working and hot-working. Some of these processes are time-consuming and complicated, hence they add to the cost of the material. It is important to note, however, that without the required treatment a particular alloy will not give the specified service.

Sintered Mesh Porous Media

A rather new material in its applications to jet engines is a sintered mesh sheet constructed of two or more layers of mesh manufactured from high-temperature alloys N-155 or L-605 and sinter bonded. This material is used primarily for transpiration cooling in high temperature zones.

Transpiration cooling, as the name implies, is the cooling which results from passing a fluid, either liquid of gas, through a porous media to remove heat from the porous surface. The porous media must have a large internal surface area for heat transfer to permit an efficient heat removal with a minimum of coolant.

The major application in the aircraft field are found in turbojet engines. Afterburner liners as well as the liners of combustion chambers have been fabricated media.

Another important application in turbojet engines is the fabrication of transpiration-cooled turbine blades from porous media.

COMPARATIVE ADVANTAGES AND DISADVANTAGES OF GAS TURBINE ENGINES

In its present forms, the gas turbine, either propeller-drive or pure jet, has numerous attractive features that have been mentioned frequently. These may be reviewed briefly as follows.

Advantages

Freedom From Vibration

This permits lighter propeller sections and mounting structure. Vibration is reduced by the elimination of reciprocating parts such as connecting rods and pistons.

Simplicity Of Control

Only one lever is required for controlling the speed and power of the unit.

No Spark Plugs Required Except For Starting

Such surfaces add weight and drag. Very small coolers for lubricating oil are used on large jet engines and turboprop engines.

Negligible Cooling Air Required

Conventional engines require from five to eight times as much air for cooling as is required for power production. The acceleration of this air to airplane speed represents an appreciable loss of power, particularly in climb, even though much of this may be recovered later by the use of carefully designed radiators.

No Spark Plugs Required Except For Starting

After combustion is once established, it is self supporting.

No Carburettors

Hence there is no carburettor icing and no mixture controls. There is some question as to this advantage, since large gas turbines do require very complex fuel-control units. The automatic features of these units compensate for their complexity, however.

Available Supply Of Compressed Air

This air is used for driving cabin superchargers and small turbines and for anti-icing purposes.

Decreased Fire Hazard

Fuels used for gas turbines are usually less volatile than the high-octain fuels used in reciprocating engines.

Lower Specific Weight

A gas turbine may develop several times as much power as a reciprocating engine of the same weight.

Lower Oil Consumption

DISADVANTAGES

HIGH SPECIFIC FUEL CONSUMPTION AT LOW AIRSPEEDS

This applies chiefly to pure jet engines. Turboprop engines have performance comparable to reciprocating engines in some instances, since they have attained specific fuel consumption as low as 0.40 lb per hp per hr.

Inefficient Operation At Low Power Levels

Slow Acceleration From Minimum Speed

This condition applies chiefly to turbojet engines. Turboprop and turbofan engines are able to accelerate quite rapidly.

High Starting Power Requirements

Starting large gas-turbine engines has been a problem in the past; however, starters have been developed within the past few years which make it relatively simple.

High Cost Of Manufacture

Although the gas turbine is much simpler in operation than the piston engine, the special materials and manufacturing processes needed make the cost of the gas turbine much higher.

Susceptibility To Damage By Foreign Material

Such material is rapidly drawn into the air inlet.

BASIC DIFFERENCES - GAS TURBINE V/S RECIPROCATING ENGINE

The basic differences between the gas-turbine engine and the reciprocating engine may be classified into five main groups.

Aerodynamic (Advantages)

Smaller nacelles possible; negligible cooling power required; highspeed jet is a more efficient propulsive means than propeller at high flight speeds.

Disadvantages

A high speed jet is a less efficient propulsive means than a propeller at lower flight speeds and during takeoff. The development of turboprop and turbofan engines has made it possible to combine the advantages of the turbine engines with the efficiency of the propeller for lower speeds and for takeoff.

Weight (Advantages)
Turbine engines are considerably lighter than reciprocating engines for the same power output. Turbojet engines have been developed with a weight/power ratio of less than 0.13 lb. per lb. of thrust. Turboprop engines have attained 0.39 lb. per equivalent shaft horsepower (eshp) in comparison with reciprocating engines which usually have a weight/power ratio of approximately 1.0 lb. per hp or more.

Fuel Consumption (Neutral Characteristics)
Best specific fuel consumption occurs near maximum output. (Best specific fuel consumption reciprocating engines occurs at about one-half maximum power.) At a given flight speed, specific fuel consumption of the turbojet engine tends to decrease with altitude. The specific fuel consumption for turboprop engines is comparable to that of the best reciprocating engines. It is likely that continued development will produce a turboprop engine with much better specific fuel consumption than any reciprocating engine. Turbojet engines have been developed to a point where specific fuel consumption is excellent, at operating speeds and altitudes, they are more efficient than of 1:2:1 and have brought about specific fuel-consumption figures of less than 0.70 lb. per pound of static thrust.

Disadvantages
Best fuel consumption is in general is poorer for the turbojet engine; however this disadvantage appears to be decreasing rapidly.

Output
Operation of the gas turbine engine at varying altitudes is somewhere between that of an unsupercharged and supercharged reciprocating engine. That is, the turbine engine is more adaptable to varying altitudes than the unsupercharged engine and perhaps a little less adaptable than the supercharged reciprocating engine.

General (Advantages)
Low power plant vibration, relatively constant speed over a wide range of output.

Disadvantages
High engine speed (advantageous for generator drive)

PERFORMANCE COMPARISON
A comparison of the performance of aircraft powered by reciprocating turboprop, and turbojet engines indicates that for a cruising altitude of 35,000 ft :

1) Aircraft with top speeds below 335 mph achieve their maximum range when powered by reciprocating engines.
2) Aircraft with top speeds above 610 mph achieve their maximum range when powered by turbojet engines.
3) Aircraft with speeds between those specified in the foregoing statements in general achieve their maximum range when powered by turboprop or turbofan engines.

Axial Flow V/S Centrifugal Flow
Within the classification of turbojet engines, some engines have advantages over other. At the present stage of development of these engines, the axial-flow type has the following advantages over the centrifugal-flow type:

Lower Specific Fuel Consumption
This advantage is quite important, since turbine powered aircraft are now designed to fly vast distances without refuelling. The lower fuel consumption is accomplished with the axial-flow engine because the axial compressor makes possible higher pressure ratio. This is particularly true of the turbofan engines.

Smaller Diameter Or Frontal Area
This characteristic makes the axial-flow engine more suitable for wing installation.

The following are some of the advantages of the centrifugal flow engine over the axial-flow type :

Simple Manufacture And Fewer Parts
This reduces initial cost and maintenance.

Lower Specific Weight
A centrifugal engine with an equivalent compression ratio may be lower in weight for the amount of thrust.

Faster Installation And Removal
No close fitting ducts to engine are necessary.

More Effective Water Injection
On this type of engine the water can be injected directly into the compressor, where as in an axial flow engine, water is injected into the C.C.

Faster Acceleration Of The Rotor Section

The advantages of higher compressor ratios possible with the axial flow engines will make this type of engine more desirable, especially for high performance a/c.

Turbofan or by pass engines increase air mass flow by feeding additional air into the jet stream directly to the rear of the turbine. This results in thrust augmentation because a greater mass of air is accelerated than would be the case with the simple jet engine.

PERFORMANCE OF GAS TURBINE ENGINES

The performance of the turbojet engine is measured in thrust produced at the propelling nozzle or nozzles, and that of the turbo-propeller engine is measured in shaft horsepower (s.h.p.) produced at the propeller shaft. However, both types are in the main assessed on the amount of thrust or s.h.p. they develop for a given weight, fuel consumption, and frontal area.

Since the thrust or s.h.p. developed is dependent on the mass of air entering the engine and the acceleration imparted to it during the engine cycle, it is obviously influenced, as subsequently described, by such variables as the forward speed of the aircraft, altitude, and climatic conditions. These variables influence the efficiency of the air intake, the compressor, the turbine, and the jet pipe; consequently, the gas energy available for the production of thrust or s.h.p. also varies.

In the interest of fuel economy and aircraft range, the thrust or s.h.p. per unit weight should be at its maximum with the fuel consumption as low as possible. This factor, known as the specific fuel consumption (s.f.c.), is expressed in pounds of fuel per hour per pound of net thrust of s.h.p and is determined by the thermal and propulsive efficiency of the engine.

Whereas the thermal efficiency is often referred to as the internal efficiency of the engine, the propulsion efficiency is referred to as the external efficiency.

The thermal and propulsive efficiency also influence, to a large extent, the size of the compressor and turbine thus determining the weight and diameter of the engine for a given output.

ENGINE THRUST ON THE TEST BENCH

The thrust of the turbojet engine on the test bench differs somewhat from that during flight. On the test bench the thrust is mainly the product of the mass of air passing through the engine and the jet velocity at the propelling nozzle; whereas in flight it is mainly the product of the mass of air passing through the engine, and the jet velocity less the forward speed of the aircraft. Algebraically, the thrust of the stationary engine is expressed as wvj/g

where

W = mass of air (lb.per.sec.)

v_j = jet velocity at propelling nozzle (ft.per.sec.)

g = gravitational constant 32.2.

Engine running under choked nozzle condition drive additional thrust from the excess pressure acting over the propelling nozzle and this is expressed as (p - Po) A, where

p = static pressure at propelling nozzle (lb.per.sq.in)

Po = atmospheric pressure (lb.per.sq.in.)

A = area of propelling nozzle (sq.in.)

Thus, the total thrust $F = (p-Po)\,A + Wvj/g$

From the formula it will be seen that the thrust of the engine can be increased either by increasing the mass of air passing through the engine or by increasing the jet velocity. Increase in mass airflow may be obtained by using water injection and increase in jet velocity by using after burning.

As the air density changes, mass of air entering the engine for a given engine speed changes. Thus, when comparing the performance of similar engines, a correction to the observed readings is required for any variation from the I.S.A. conditions.

The correction for a turbojet engine is :

$$\text{Thrust (lb.) (corrected)} = \text{thrust (lb.) (observed)} \times \frac{29.99}{po}$$

where Po = atmospheric pressure in Hg (observed).

The observed performance of the turbo-propeller engine is also corrected to I.S.A. conditions, but due to the rating being different. For example,

$$\text{s.h.p. (corrected)} = \text{s.h.p. (observed)} \times \frac{29.99}{Po} \times \frac{273+15}{273+To}$$

where Po = atmospheric pressure in Hg (observed).

To = atmospheric temperature deg C. (observed).

In practice there is always a certain amount of jet thrust in the total output of the turbo-propeller engine and this must be added to the s.h.p.

The total equivalent horsepower is denoted by t.e.h.p. and is the s.h.p. plus the s.h.p equivalent to the net jet thrust.

$$\text{t.e.h.p.} = \text{s.h.p.} + \frac{\text{jet thrust lb.}}{2.6}$$

COMPARISON BETWEEN THRUST AND HORSEPOWER

Because the turbojet engine is rated in thrust and the turbo-propeller engine in s.h.p. no direct comparison between the two can be made without a power conversion factor. However, since the turbo-propeller engine receives its thrust mainly from the propeller, a comparison can be made by converting the horsepower developed by the engine to thrust or the thrust developed by the turbojet engine to t.h.p., that is, by converting work to force or force to work. For this purpose, it is necessary to take into account the speed of the aircraft.

The t.h.p. is expressed is FV/ 550 ft.per.sec.
where F = lb.of thrust.
V = aircraft speed (ft.per.sec.)

Since one horsepower is equal to 550 ft.lb.per.sec. and 550 ft.per.sec. is equivalent to 375 miles per hour, it can be seen from the above formula that one lb.of thrust equals one t.h.p. at 375 m.p.h. It is also common to quote the speed in knots (nautical miles); one knot is equal to 1.1515 m.h.p. or one pound of thrust is equal to one t.h.p. at 325 knots.

Thus if a turbojet engine produces 5,000 lb. of net thrust at an aircraft speed of 600 m.p.h. the t.h.p. would be

$$\frac{5{,}000 \text{ X } 600}{375} = 8{,}000$$

However, if the same thrust was being produced by a turbo-propeller engine with a propeller efficiency of 55 per cent at the same flight speed of 600 m.p.h., then the t.h.p. would be

$$\frac{8{,}000 \text{ X } 100}{55} = 14{,}545$$

ENGINE THRUST IN FLIGHT

Since reference will be made to gross thrust, momentum drag, and net thrust it may be helpful at this stage to define these terms.

The gross or total thrust is the reaction to the momentum of the jet velocity, expressed as (p -Po) A + Wvj. The momentum or intake drag is the drag due to the momentum of the air passing into the engine relative to aircraft velocity, expressed as WV/g .

The net thrust or resultant force acting on the aircraft in flight is the difference between the gross thrust and the momentum drag.

It was stated that the thrust of a stationary engine is mainly the product of the mass of air passing through the engine and the jet velocity at the propelling nozzle. This is expressed algebraically as (p - Po) A +Wvj/g i.e. gross or total thrust. Under flight conditions, momentum drag must be taken into account and subtracted from gross thrust. Therefore, simplifying, net thrust can be expressed as (p - Po) A + W (vj -V)/g.

EFFECT OF AFTER BURNING ON ENGINE THRUST

At take-of conditions, the momentum drag of the air flowing through the engine is negligible, so that the gross thrust can be considered to be equal to the net thrust. If after burning is selected, an increase in takeoff thrust in the order of 30 per cent is possible with the pure jet engine and considerably more with the bypass engine. This augmentation of basic thrust is of greater advantage for certain specific operating requirements.

Under flight conditions, however, this advantage is even greater, since the momentum drag is the same with or without after burning and, due to the ram effect, better utilization is done of every pound of air pumped through the engine.

Assuming an aircraft speed of 600 m.p.h. (880ft.per sec.,then,
momentum drag $\frac{880}{32.2}$ = 27.5 lb. (approximately).

This means that very pound of air per second pumped through the engine and accelerated up to the speed of the aircraft caused a drag of about 27.5 lb.

Suppose each pound of air pumped through the engine gives a gross thrust of 77.5 lb. Then the net thrust given by the engine per lb. of air per second is 77.5 - 27.5 =50 lb.

When after burning is selected, the gross thrust will be 1.3 X 77.5 = 107.5 lb. Thus, under this condition, the net thrust per pound of air per second swill be 107.5 - 27.5 = 80 lb. Therefore the ratio of net thrust due to after burning is 80 = 1.60. In other words, a 30 percent increase in thrust under static conditions becomes a 60 percent increase in thrust at 600 m.p.h.

This larger increase in thrust is invaluable for obtaining higher speeds and higher altitude performance. The total and specific fuel consumption are high, but not unduly as for such as increase in performance.

The limit to the obtainable thrust is determined by the after burning temperature and the oxygen in the exhaust gas stream. Because no previous combustion heating takes place in the duct of a bypass engine, these engines with their large residual oxygen surplus are particularly suited to after burning and static thrust increases, of upto 70 percent are obtainable. At high forward speeds several times this amount is achieved.

EFFECT OF FORWARD SPEED

Ram Ratio

Ram ratio is the ratio of the total air pressure at the engine compressor entry to the static air pressure at the air intake entry.

Mach Number

Mach number is an additional means of measuring speed and is defined as the ratio of the speed of a body to the local speed of sound. Mach 1.0 therefore represents a speed equal to the local speed of sound.

From the thrust equation

$$T = (p-Po) A + W (v_j - V)$$

It is apparent that if the jet velocity remains constant, independent of aircraft speed, then as the aircraft speed increases the thrust would decrease in direct proportion. However, due to the 'ram ratio' effect from the aircraft forward speed, extra air is taken into the engine so that the mass airflow and also the jet velocity increase with aircraft speed. The effect of this tends to offset the extra intake momentum drag due to the forward speed so that the resultant net thrust is partially recovered as the aircraft speed increases. A typical trend curve illustrating this point is shown in fig.27. Obviously, the 'ram ratio' effect, or the return obtained in terms of pressure rise at entry to the compressor in exchange for the unavoidable intake drag, is of considerable importance to the turbojet engine, especially at high speeds. Above speeds of Mach 1.0 and as a result of the formation of shock waves at the air intake, this rate of pressure rise will rapidly decrease unless a suitably designed air intake is provided with an efficient air intake, ram ratio effect at supersonic speeds can be significantly increased.

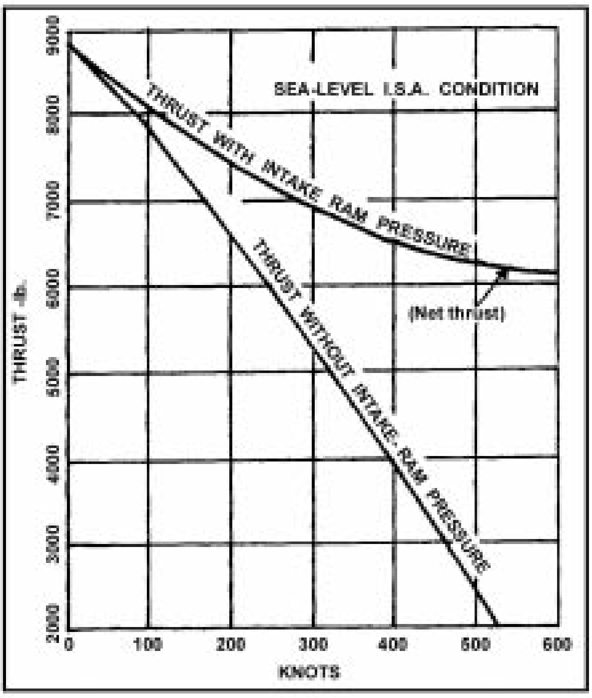


Fig.27.

As aircraft speed increases into the supersonic region, the ram air temperature rapidly rises consistent with the basic gas laws. This temperature rise effects the compressor delivery air temperature proportionately and, in consequence, to maintain the required thrust, the engine must be subjected to higher turbine entry temperature. Since the maximum permissible turbine entry temperature is determined by the temperature limitations of the turbine materials and the cooling techniques of blades and stators are increasingly involved.

With an increase in forward speed, the increased mass airflow due to the 'ram ratio' effect must be matched by the fuel flow and the result is an increase in fuel consumption. Because the net thrust tends to decrease with forward speed the end result is an increase in specific fuel consumption, as shown by the trend curves for a typical turbojet engine.

At forward speeds at low altitudes the 'ram ratio' effect causes very high stresses on the engine and, to prevent over stressing, the fuel flow is automatically reduced to limit the engine speed and airflow.

In the case of turboprop engine, the net jet thrust decreases, s.h.p. increases due to the 'ram ratio' effect of increased mass flow and matching fuel flow. Because it is standard practice to express the s.f.c. of a turbo-propeller engine relative to s.h.p. an improved s.f.c. is exhibited. However, this does not provide a true comparison with the curves, for a typically turbojet engine, as s.h.p. is absorbed by the propeller and converted into thrust and, irrespective of an increase in s.h.p, propeller efficiency and therefore, net thrust deteriorates at high subsonic forward speeds. In consequence, the turbo-propeller engine s.f.c. relative to net thrust would, in general comparison with the turbojet engine, show an improvement at low forward speeds but a rapid deterioration at high speeds.

EFFECT OF ALTITUDE

With increasing altitude the ambient air pressure and temperature are reduced. This affects the engine in two interrelated ways :

The fall in pressure reduces the air density and hence the mass airflow into the engine for a given engine speed. This causes the thrust or s.h.p to fall. The fuel control system adjusts the pump output to match the reduced mass airflow, so maintaining a constant engine speed.

The fall in air temperature increases the density of the air, so that the mass of air entering the compressor for a given engine speed is greater. This causes the mass airflow to reduce at a lower rate and so compensates to some extent for the loss of thrust due to the fall in atmospheric pressure.

EFFECT OF CLIMATE

On a cold day the density of the air increases so that the mass of air entering the compressor for a given engine speed is greater, hence the thrust or s.h.p is higher. The denser air does, however, increase the power required to drive the compressor or compressors; thus the engine will require more fuel to maintain the same engine speed or will run at a reduced engine speed if no increase in fuel is available.

On a hot day the density of the air decreases, thus reducing the mass of air entering the compressor and, consequently, the thrust of the engine for a given r.p.m. Because less power will be required to drive the compressor, the fuel control system reduces temperature, as appropriate; however, because of the decrease in air density, the thrust will be lower. Some sort of thrust augmentation, such as water injection are sometimes used.

PROPULSIVE EFFICIENCY

Performance of the jet engine is not only concerned with the thrust produced, but also with the efficient conversion of the heat energy of the fuel into kinetic energy, as represented by the jet velocity, and the best use of this velocity to propel the aircraft forward, i.e. the efficiency of the propulsive system. A turbo-propeller engine gives a small acceleration to a large mass of air, whereas a pure turbojet gives a large acceleration to a small mass of air.

The efficiency of conversion of fuel energy to kinetic energy is termed the thermal or internal efficiency and, like all heat engines, is controlled by the cycle pressure ratio and combustion temperature.

The efficiency of conversion of kinetic energy to propulsive work is termed the propulsive or external efficiency and this is affected by the amount of kinetic energy wasted by the propelling mechanism. Waste energy displaced in the jet wake, which represents a loss, can be expressed as($1\backslash 2\ mv^2$)/g where V is the waste velocity (v_j - V). It is therefore, apparent that at the aircraft lower speed range the pure jet stream wastes considerably more energy than a propeller system and consequently is less efficient over this range. However, this factor changes as aircraft speed increases, because although the jet stream continues to issue at a high velocity from the engine its velocity relative to the surrounding atmosphere is reduced and, in consequence, the waste energy loss is reduced.

Briefly, propulsive efficiency may be expressed as:

$\eta_{\text{Propulsive}}$ = work done on the aircraft / Energy imparted to engine airflow or simply
$\eta_{\text{Propulsive}}$ = work done / Work done + work wasted in exhaust

Work done is the net thrust multiplied by the aircraft speed.

Propulsive efficiency =

$$[v \{ (p-po) A + w (v_j - v)/g \}] / [v \{ (p-Po) A + w (v_j -v)/g \}+\{ \tfrac{1}{2}w(v_j - v)^2 /g\}]$$

In the instance of an engine operating with a non choked nozzle the equation become :

$$[WV (vj -v)] /[WV (v_j - v) + \tfrac{1}{2} (v_j - v)^2] \qquad \text{Simplified to: } 2v / V+ v_j$$

e.g. assuming an aircraft speed (V) of 375 m.p.h. and a jet velocity (v_j) of 1,230 m.p.h. the efficiency of a turbojet is:

$$\eta = \quad 2x375/ 375 + 1{,}250 = \text{approx 47 per cent}$$

On the other hand, at an aircraft speed of 600 m.p.h. the efficiency is :

$$\eta = \frac{2X\ 600\ .}{600+1230} = \text{approx 66 per cent.}$$

propeller efficiency at these values of V is approximately 82 and 55 percent.

The disadvantage of the propeller at the higher aircraft speeds is its rapid fall off in efficiency, due to shock waves created around the propeller as the blade tip speed approaches Mach 1.0.

To obtain good propulsive efficiency without the use of a complex propeller system, the bypass principle is now used in various forms. With this principle, some part of the total output is provided by a jet stream other than that which passes through the engine cycle and this is energized by a fan or a varying number of L.P. compressor stages. This bypass air is used to lower the main jet temperature and velocity either by exhausting through a separate propelling nozzle, or by mixing with the turbine stream to exhaust through a common nozzle.

The propulsive efficiency equation for a high bypass ratio engine exhausting through separate nozzles is given below, where W_1 and vj_1 relate to the bypass function and W_2 and vj_2 to the engine main function.

Propulsive efficiency = $[W_1 V (vj_1-v) + W_2V (vj_2-v)]/[W_1 V (vj_1-v) + W_2V (vj_2-v) + \tfrac{1}{2}W_1 (vj_1 - V)^2 + \tfrac{1}{2} W_2(vj_2-v)^2]$

A graph illustrating the various propulsive efficiency with aircraft speed is shown in fig. 28.

FUEL CONSUMPTION AND POWER-TO-WEIGHT RELATIONSHIP

Primary engine design considerations, particularly for commercial transport duty, are those of low specific fuel consumption and weight. Considerable improvement has been achieved by use of the bypass principle, and by advanced mechanical and aerodynamic features, and the use of improved materials. With the trend towards higher bypass ratios, in the range of 5:1, the triple-spool engine enables the pressure and bypass ratios to be achieved with short rotors, using fewer compressor stages, resulting in a lighter and more compact engine.

S.f.c. is directly related to the thermal and propulsive efficiency; that is, the overall of the engine. Theoretically, to provide a high thermal efficiency only a high pressure ratio is required, although in practice normal inefficiencies in the compression and expansion processes also necessitate a high turbine entry temperatures. In a pure turbojet engine this increase in temperature would increase the jet velocity and consequently lower the propulsive efficiency. However, by using the bypass principle, high thermal and propulsive efficiency can be effectively combined by bypassing a proportion of the L.P. compressor or fan delivery air to lower the mean jet temperature and velocity. With advanced technology engines of high bypass and overall pressure ratios, a further pronounced improvement in s.f.c. is obtained.

The turbines of the pure jet engine are heavy because they deal with the total airflow, whereas the turbines of the bypass engine deal only with part of the flow; thus the H.P. compressor, combustion chambers and turbines, can be

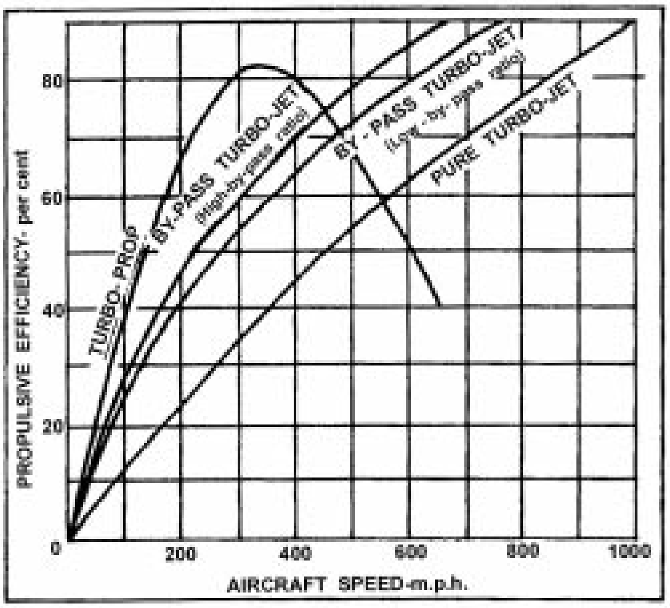


Fig. 28.Propulsive efficiencies and aircraft speeds.

scaled down. The increased power per lb. of air at the turbines, to take advantage of their full capacity, is obtained by the increase in pressure ratio and turbine entry temperature. It is clear that the bypass engine is lighter, because not only has the diameter of the pressure rotating assemblies been reduced but the engine is shorter for a given power output. With a low bypass ratio engine, the weight reduction compared with a pure jet engine is in the order of 20 per cent for the same air mass Flow.

With a high bypass ratio engine of the triple spool configuration, a further significant improvement in specific weight is obtained. This is derived mainly from advanced mechanical and aerodynamic design, which, in addition to permitting a significant reduction in the total number of parts, enables rotating assemblies to be more effectively matched and to work closer to optimum conditions, thus minimizing the number of compressor and turbine stages for a given duty. The use of higher strength lightweight materials is also a contributory factor.

For a given mass flow, however, less thrust is produced by the bypass engine due to the lower exit velocity. Thus, to obtain the same thrust, the bypass engine must be scaled to pass a larger total mass airflow than the pure turbojet engine. The weight of the engine, however, is still less because of the reduced size of the H.P. section of the engine. There, in addition to the reduced specific fuel consumption, an improvement in the power-to-weight ratio is obtained.

BRAYTON CYCLE

A simple gas turbine power plant is shown in fig.29. Air is first compressed adiabatically in process a-b, it then enters the combustion chamber where fuel is injected and burned essentially at constant pressure in process b-c, and then the products of combustion expand in the turbine to the ambient pressure in process c-d and are thrown out to the surroundings. The cycle is open. The state diagram on the p-v coordinates is shown in fig.

The Brayton cycle is the air standard cycle for the gas turbine power plant. Here air is first compressed reversibly and adiabatically, heat is added to it reversibly at constant pressure, air expands in the turbine reversibly and adiabatically and heat is then rejected from the air reversibly at constant pressure to bring it to the initial state. The Brayton cycle, therefore, consists of

Two reversible isobars and two reversible adiabatics.

The flow, p-v, and T-s diagrams are shown in fig below for m kg of air.

Q_1 = heat supplied = $mc_p(T_3-T_2)$
Q_2 = heat rejected = $mc_p(T_4-T_1)$

Therefore Cycle efficiency = $1 - Q_2/Q_1 = [1-\{(T_4-T_1)/(T_3-T_2)\}]$
Now $T_2/T_1 = (p_2/p_1)^{(\gamma-1)/\gamma} = T_3/T_4$ (Since $p_2 = p_3$ and $p_4 = p_1$)
$[(T_4/T_1)-1] = [(T_3/T_2)-1]$
or $[(T_4-T_1)/(T_3-T_2)] = [T_1/T_2] = (p_1/p_2)^{\gamma-1/\gamma} = (v_2/v_1)^{\gamma-1}$

if r_k = compression ratio $= v_1/v_2$, the efficiency becomes
$\eta = 1-(v_2/v_1)^{\gamma-1}$
or $\eta_{\text{brayton}} = 1-1/r_k^{\gamma-1}$

if r_p = pressure ratio $= p_2/p_1$ the efficiency may be expressed in the following form also
$h = 1-(p_1/p_2)^{(\gamma-1)/\gamma}$
or $\eta_{\text{brayton}} = 1-1/(r_p)^{(\gamma-1)/\gamma}$

The efficiency of the Brayton cycle, therefore, depends upon either the compression ratio or the pressure ratio. For the same compression ratio, the Brayton cycle efficiency is equal to the Otto cycle efficiency.

COMPARISON BETWEEN BRAYTON CYCLE AND OTTO CYCLE

Brayton and Otto cycles are shown superimposed on the p-v and T-s diagrams. For the same r_k and work capacity, the Brayton cycle (1-2-5-6) handles a larger range of volume and a similar range of pressure and temperature than does the Otto cycle (1-2-3-4).

In the reciprocating engine field, the Brayton cycle is not suitable. A reciprocating engine cannot efficiently handle a large volume flow of low pressure gas, for which the engine size $\pi/4\ D^2L$ becomes large, and the friction losses also become more. So the Otto cycle is more suitable in the reciprocating engine field.

In turbine plants, however, the Brayton cycle is more suitable than the Otto cycle. An internal combustion engine is expressed to the highest temperature (after the combustion of fuel) only for a short while, and it gets time to become cool in the other processes of the cycle. On the other hand, a gas turbine plant, a steady flow device, is always exposed to the highest temperature used. So to protect material, the maximum temperature of gas that can be used in a gas turbine plant cannot be as high as in an internal combustion engine. Also, in the steady flow machinery, it is more difficult to carry out heat transfer at constant volume than at constant pressure. Moreover, a gas turbine can handle a large volume flow of gas quite efficiently. So we find that the Brayton cycle is the basic air standard cycle for all modern gas turbine plants.

ROCKET ENGINES

A rocket is a reaction engine used for thrust buildup, energy source and working medium source installed on the vehicle to be propelled.

The main advantage of the rocket engine over the air-breathing jet engine is its ability to work and develop thrust at any speed and at any flight altitude. Rocket engine thrust remains constant during a change in flight velocity and is little affected by the altitude of the flight.

The rocket engine is usually used in aviation as an auxiliary engine for different types of aircraft. It is widely used in rocket technology and is the basic type of engine in modern cosmonautics.

At the present time heat rocket engines are used in aviation, rocket technology and cosmonautics, using the chemical energy of a liquid or solid propellant. In the first case the engine is called liquid-propellant rocket engine, in the second a solid-propellant rocket engine.

LIQUID-PROPELLANT ROCKET ENGINE & SOLID-PROPELLANT ROCKET ENGINE

The main element of the liquid-propellant rocket engine is the chamber, consisting of head, combustion chamber , nozzle, cooling jacket and flame igniter (device for ignition) .

In the chamber there takes place combustion of the propellant being fed into it (with the aid of a pump or pressure feed system) from tanks and considerable part of the enthalpy of the combustion products is converted into kinetic energy.

During the expansion of the combustion products in the nozzle the pressure is lowered and the speed substantially increases. With gas velocity increase at the nozzle exit and economy of the engine improves. The greater the velocity and the mass of gas exiting from the nozzle per unit of time the higher the thrust of the liquid-propellant rocket engine.

To obtain a high velocity of combustion products at the nozzle exit a propellant is required to possess large calorific value and a considerable effective pressure ratio in the nozzle. Therefore, in the combustion chamber a fairly high pressure is maintained. The engine operates on a propellant consisting of liquid oxygen (oxidizer) and hydrocarbon fuel.

In liquid-propellant rocket engines we frequently use a hydrocarbon fuel as kerosene. More effective is hydrogen, which in burning liberates almost three times the heat from the same quantity of kerosene by weight .

For engines that operate on a propellant consisting of liquid oxygen and liquid hydrogen the gas velocity at the nozzle exit in flight at a great distance from the earth reaches approximately 4.2 to 4.4 km/sec.

As for the aircraft gas turbine engine, or a liquid-propellant rocket engine, during operation a flame igniter is not required. The flame in the combustion chamber created when starting the engine is maintained by a continuous feed of propellant components into the chamber. To light a flame for starting we use a pyrotechnic or electric flame igniter and other means.

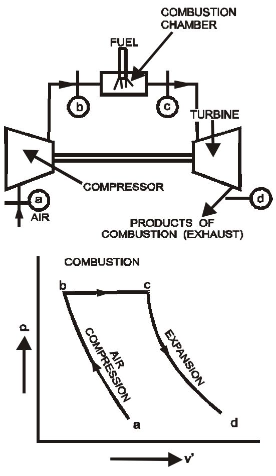


Fig. 29.

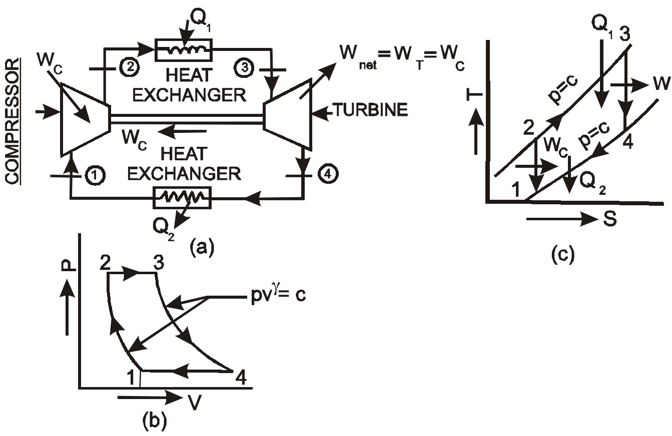


Fig. 30.

Some liquid-propellant rocket engine, including some space engines, operate on a hypergolic propellant, i.e. on a propellant that ignites on contact between oxidizer and fuel is a result of the chemical reaction developed by their interaction. In this case a flame igniter is not required.

Cooling of the engine chamber, necessary because of the high temperature of the combustion products ($3,000^0$C and above), is usually achieved with the aid of one of the propellant components. It first cools the chamber walls from the outside and then enters the combustion chamber through the head. Frequently the chamber walls cool not only from the outside but also from the inside. For this we lower the temperature of the layer of combustion products near the wall by same means or other. Some other methods of cooling the engine chamber are also used.

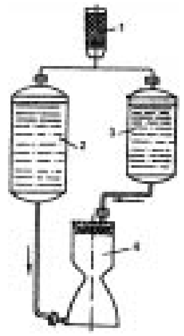


Fig. 31.

The main elements of solid-propellant rocket engine are combustion chambers, the propellant charge 3 placed in it, nozzle 2 and igniter 4.

The construction of a solid-propellant rocket engine and its maintenance during operation and storage are simpler than for liquid-propellant rocket engines. Its special advantage is constant readiness for operation and simplicity of starting. By Comparison with the liquid-propellant rocket engine the solid-propellant rocket engine makes possible a big reduction in the time needed to prepare the rocket for starting. It allows storage of rockets charged with propellant and ready for launching for a long time and at the same time considerably lowers the cost.

The main disadvantages of the solid-propellant rocket engine are a lower specific thrust by comparison with the liquid-propellant rocket engine and also severe difficulties in control of the engine thrust value. The specific thrust (or specific impulse) of a rocket engine using chemical propellant is consumption per second.

Of great interest is the sectional solid-propellant rocket engine. It consists of parts (sections) separately manufactured, controlled and transported to the launching pad.
The front (nose) section is the front part of the combustion chamber of the engine, the rear (tail) section terminates with a jet nozzle, and the intermediate standard sections are interchangeable.

The engine can be assembled for the front, rear and a variable number of intermediate sections, which makes it possible in a simple way to change the total (sum) impulse of the engine and parameters of the flight vehicle within wide limits, for example the range or payload.

The total impulse of a solid-propellant rocket engine is the product of the average thrust (during the engine's operating time) it develops and the time of operation of the engine, corresponding to complete burn-up of the propellant charge.

Liquid-propellant rocket engines and solid-propellant rocket engines are able to develop very high thrust force with low weight and small overall size. Under terrestrial static conditions and especially in flight at altitudes over 10 to 20 km the specific weight of these engine is many times less than for a turbojet engine.

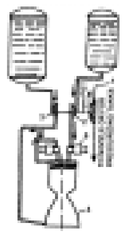


Fig. 32.

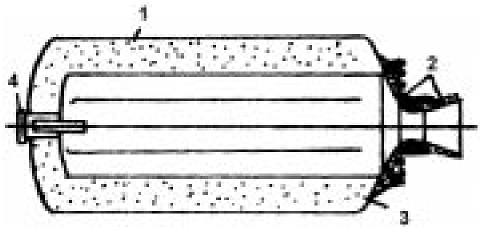


Fig. 33. Solid Propellent Rocket.

They have great advantages over the turbojet engine with respect of the thrust being developed in one unit, its invariability with change in flight speed, small change during climb and lightness and small size. However, their service life is such shorter and the fuel economy at the speeds and altitudes of contemporary aviation is much worse than for turbojet engine.

□ □ □

CHAPTER: 3

STARTING AND IGNITION SYSTEMS

(TURBINE ENGINES)

INTRODUCTION

Two separate systems are required to start a turbine engine, a means to rotate the compressor turbine assembly and a method of igniting the air/fuel mixture in combustion chamber. Ideally the process is automatic after the fuel supply is turned on and the starting circuit brought into operation.

METHODS OF STARTING

The starting procedure for all jet engines is basically the same, but can be achieved by various methods. The type and power source for the starter varies in accordance with engine and aircraft requirements. Some use electrical power, others use gas, air, or hydraulic pressure, and each has its own merits. For example, a military aircraft requires the engine to be started in the minimum time and, when possible to be completely independent of external equipment. A commercial aircraft, however, requires the engine to be started with the minimum disturbance to the passengers and by the most economical means.

The starter motor must produce a high torque and transmit it to the engine rotating assembly in a manner that provides smooth acceleration from rest upto a speed at which the gas flow through the engine provides sufficient power for the engine turbine to take over.

Electric

Electric starting is used on some turboprop and turbojet engines. The starter is usually a direct current (D.C.) electric motor coupled to the engine through a reduction gear and ratchet mechanism or clutch, which automatically disengages after the engine has reached a self-sustaining speed.

The electrical supply may be of a low or high voltage, and it is passed through a system of relays and resistance to allow the full voltage to be progressively built up as the starter gains speed. It also provides the power for operation of the ignition system. The electrical supply is automatically cancelled when the starter load is reduced after the engine has satisfactorily started or when the time cycle is completed.

Cartridge

Cartridge starting is sometimes used on military engines and provides a quick independent method of starting. The starter motor is basically a small impulse-type turbine that is driven by high velocity gases from a burning cartridge. The power output of the turbine is passed through a reduction gear, and an automatic disconnect mechanism to rotate the engine. An electrically fired detonator initiates the burning of the cartridge charge. As a cartridge charge provides the power supply for this type of starter, the size of the charge required may well limit the use of cartridge starters.

Iso-Propyl Nitrate

Iso-propyl-nitrate starting provides a high power output and gives rapid starting characteristics, but is dependent upon supplies of iso-propyl-nitrate.

This starter motor also has a turbine that transmits power through a reduction gear to the engine. In this instance, the turbine is rotated by high pressure gasses resulting from the combustion of iso-propyl-nitrate. This fuel is mono-fuel i.e., it requires no air to sustain combustion. The fuel is sprayed into a combustion chamber which forms part of the starter, where it is electrically ignited by a high-energy ignition system. A pump supplies the fuel to the combustion chamber from a storage tank, and an air pump scavenges the combustion chamber of fumes before each start Operation of the fuel and air pumps, ignition systems, and cycle cancellation, is electrically controlled by relays and time switches.

Air Starter

Air starting is used on most modern commercial and some military jet engines. It has many advantages over other starting systems, as it is comparatively light, simple and economical to operate.

An air starter motor has a turbine rotor that transmits power through a reduction gear and clutch to the starter output shaft that is connected to the engine.

The starter turbine is rotated by air pressure taken from an external ground supply, from an auxiliary power unit (A.P.U.) carried in the aircraft, or from an engine that is running. The air supply to the starter is controlled by an electrically operated control and pressure reducing valve that is opened when an engine start is selected and is automatically closed at a predetermined starter speed. The clutch also automatically disengages as the engine accelerates upto idling r.p.m. and the rotation of the starter ceases.

A combustion starter is sometimes fitted to an engine incorporating an air starter, and is used to supply power to the starter when an external supply of air is not available. The starter unit has a small combustion chamber into which high pressure air, from an aircraft-mounted storage bottle, and fuel, from the engine fuel system, are introduced. Control valves regulate the air supply, which pressurizes a fuel accumulator, to give sufficient fuel pressure for atomization, and also activates the continuous ignition system. The fuel/air mixture is ignited in the combustion chamber, and the resultant gas is directed on to the turbine of the air starter. An electrical circuit is provided to shut off the air supply, which in turn terminates the fuel and ignition systems on completion of the starting cycle.

Some turbojet engines are not fitted with starter motors, but use air impingement onto the turbine blades as a means of rotating the engine. The high pressure air is obtained from an external source or from an engine that is running, and is directed, through non-return valves and nozzles, onto the turbine blades.

Gas Turbine

A gas turbine starter is used for some jet engines and is completely self-contained. It has its own fuel and ignition system, starting system (usually electric or hydraulic) and self-contained oil system. This type of starter is economical to operate and provides a high power output for a comparatively low weight.

The starter consists of a small, compact gas turbine engine, usually featuring a turbine-driven centrifugal compressor, a reverse flow combustion system, and a mechanically independent free-power turbine. The free-power turbine is connected to the main engine via a two-stage epicyclic reduction gear, automatic clutch and output shaft.

On initiation of the starting cycle, the gas turbine starter is rotated by its own starter motor unit it reaches self-sustaining speed, when the starting and ignition systems are automatically switched off. Acceleration than continues upto a controlled speed of approximately 60,000 r.p.m. At the same time as the gas turbine starter engine is accelerating, the exhaust gas is being directed, via nozzle guide vanes, onto the free turbine to provide the drive to the main engine. Once the main engine reaches self-sustaining speed, a cutout switch operates and shuts down the gas turbine starter. As the starter runs down, the clutch automatically disengages from the output shaft, and the main engine accelerates upto idling r.p.m. under its own power.

Hydraulic

Hydraulic starting is used for starting some small jet engines. In most applications, one of the engine-mounted hydraulic pumps is utilized and is known as a pump/starter, although other applications may use a separate hydraulic motor. Methods of transmitting the torque to the engine may vary, but a typical system would be a reduction gear and clutch assembly. Power to rotate the pump/starter is provided by hydraulic pressure from a ground supply unit, and is transmitted to the engine through the reduction gear and clutch. The starting system is controlled by an electrical circuit that also operates hydraulic valves so that on completion of the starting cycle the pump/starter functions as a normal hydraulic pump.

IGNITION OF THE JET ENGINES

The ignition system of a turbine engine must provide the electrical discharge necessary to ignite the air/fuel mixture in the combustion chamber during starting and must also be capable of operating independently from the starter system in the event of flame extinction through adverse flight conditions. (fig 1)

The electrical energy required to ensure ignition of the mixture varies with atmospheric and flight conditions, more power being required as altitude increases. However, under certain flight conditions, such as icing or take off in heavy rain or snow, it may be necessary to have the ignition system continuously operating to give an automatic relight should flame extinction occur. For this conditions, a low volt output (e.g. 3 to 6) is favourable because it results in longer life of the ignition plug and ignition unit. Two independent 12 joule systems are normally fitted to each engine to provide a positive light up during starting but some engines have now 12 joule and 3 joule system. The 3 joule system is kept in continuous operation to provide automatic relighting.

Where continuous operation of one system is not desirable, a glow plug is sometimes fitted in the combustion chamber where it is heated by the combustion process and remains incandescent for a sufficient period of time to ensure automatic re-ignition.

HIGH ENERGY IGNITION UNIT

A 12 joule unit receives electrical power from the aircraft d.c. supply either in conjunction with starter operation or independently through the “relight” circuit. An induction coil or transistorized H.T. generator repeatedly charges a capacitor in the unit until the capacitor voltage is sufficient to break down a sealed discharge gap. The discharge is conducted through a choke and H.T. lead to the igniter plug where the energy is released in a flashover on the semi-conducting face of the plug. The capacitor is then recharged and the cycle repeated approximately twice every second. A resistor connected from the output to earth ensures that the energy stored in the capacitor is discharged when the d.c. supply is disconnected.

NOTE: A 3 joule unit is usually supplied with LT alternating current but its function is similar to that described above.

The electrical energy stores in the high energy ignition unit is potentially lethal and even though the capacitor is discharged when the d.c. supply is disconnected, certain precautions are necessary before handling the components. The associated circuit breaker should be tripped, or fuse removed as appropriate, and at least one minute allowed to elapse before touching the ignition unit, high tension lead or igniter plug.

Ignition units are attached to the aircraft structure by anti-vibration mounting and the rubber bushes should be checked for perishing at frequent intervals. It is also important that the bonding cable is securely attached, making good electrical contact and of sufficient length to allow for movement of the unit on its mounting.

At the intervals specified in the appropriate Maintenance Schedule the unit should be inspected for signs of damage, cracks or corrosion. Bonding leads securely attached and locked.

IGNITER PLUG

The igniter plug consists of a central electrode and outer body, the space between them being filled with an insulating material and terminating at the firing end in a semi-conducting pellet. A spring-loaded contact button is fitted at the outer end of the electrode. During operation a small electrical leakage from the ignition unit is fed through the electrode

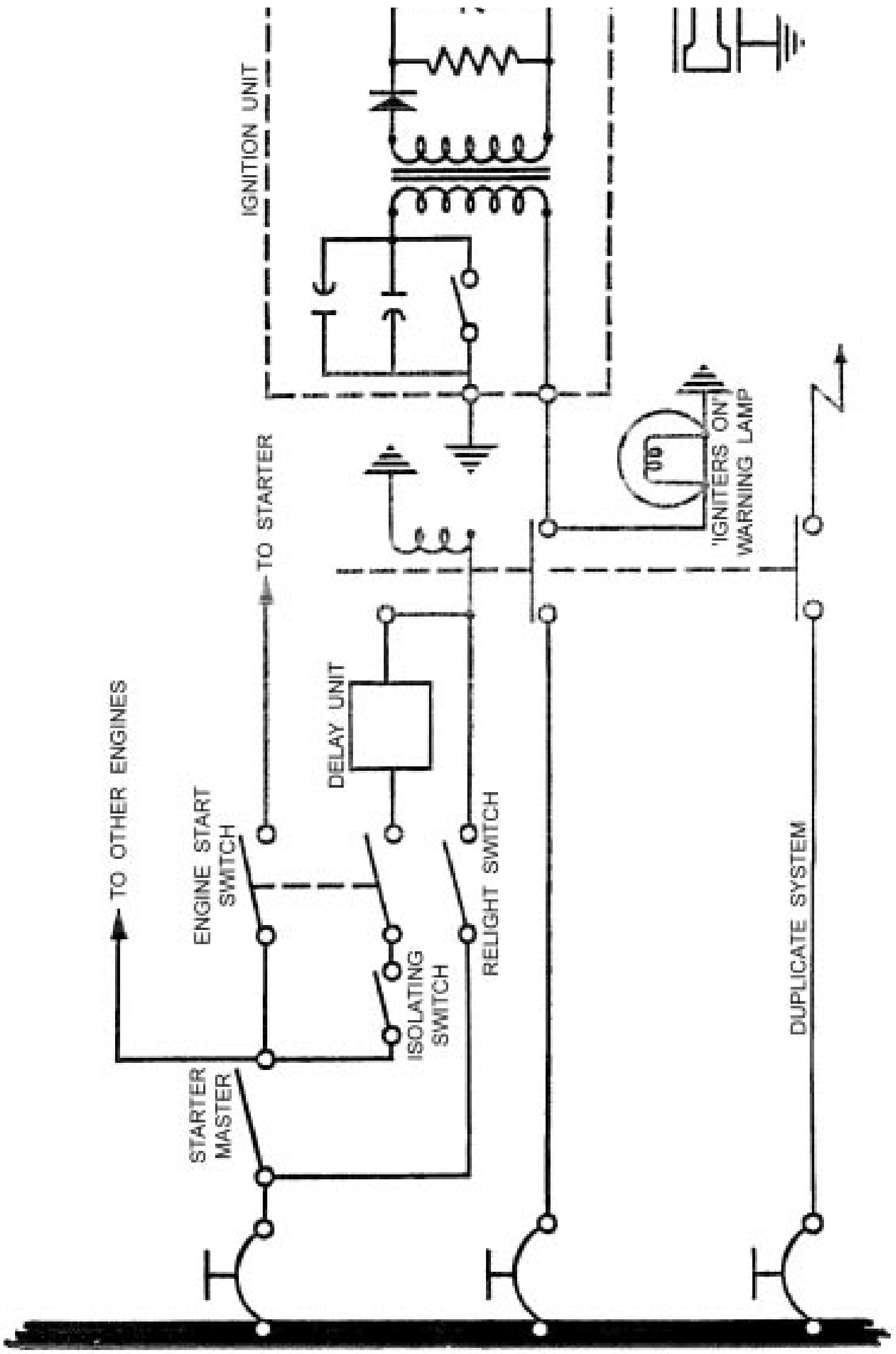


Fig.1. Typical ignition system.

to the plug body and produces an ionized path across the surface of the pellet. The high intensity discharge takes place across this low-resistance path.

IGNITION LEAD

The high energy ignition lead is used to carry the intermittent high voltage outputs from the ignition unit to the associated igniter plug. A single insulated core is encased in a flexible metal sheath and terminates in a spring-loaded contact button at each end. The end fittings usually incorporate a self locking attachment nut.

RELIGHTING

The jet engine requires facilities for relighting should the flame in the combustion system be extinguished during flight. However, the ability of the engine to relight will vary according to the altitude and forward speed of the aircraft. A typical relight envelope, showing the flight conditions under which an engine will obtain a satisfactory relight, is shown in Fig.3. Within the limits of the envelope, the airflow through the engine will rotate the compressor at a speed satisfactory for relighting; all that is required therefore, provided that a fuel supply is available, is the operation of the ignition system. This is provided for by a separate switch that operates only the ignition system.

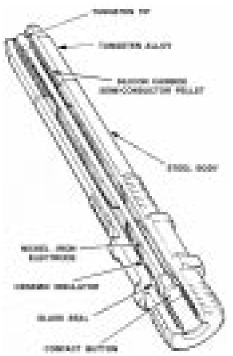


Fig.2. Igniter Plug.

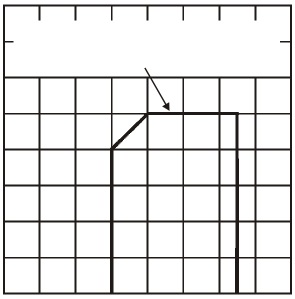


Fig.3. A typical flight relight envelope.

SEQUENCE OF STARTING OF A GAS TURBINE ENGINE

GROUND RUNNING

The life of a turbine engine is affected both by the number of temperature cycles to which it is subjected and by operation in a dusty or polluted atmosphere. Engine running on the ground should therefore be confined to the following occasions:

a. After engine installation.
b. To confirm a reported engine fault.
c. To check an aircraft system.
d. To prove an adjustment or component change.
e. To prove the engine installation after a period of idleness.

Safety Precautions

Turbine engines ingest large quantities of air and eject gases at high temperature and high velocity, creating danger zones both in front of and behind the aircraft. The extent of these danger zones varies considerably with engine size and location and this information is given in the appropriate aircraft Maintenance Manual. The danger zones should be kept clear of personnel, loose debris and equipment whenever the engines are run. The aircraft should be positioned facing into wind so that the engine intakes and exhausts are over firm concrete with the jet efflux directed away from other aircraft and buildings. Silencers or blast fences should be used whenever possible for runs above idling power. Additional precautions, such as protective steel plates or deflectors, may be required when testing thrust reversers or jet lift engines, in order to prevent ground erosion.

Air intakes and jet pipes should be inspected for loose articles and debris before starting the engine and the aircraft main wheels chocked fore and aft. It may be necessary to tether vertical lift aircraft if a high power check is to be carried out.

Usually on large aircraft one member of the ground crew is stationed outside the aircraft and provided with a radio headset connected to the aircraft intercom system. This crew member is in direct communication with the flight deck and able to provide information and if necessary warnings on situations not visible from inside the aircraft. Due to the high noise level of turbine engines running at maximum power, it is advisable for other ground crew members to wear ear muffs.

A suitable CO_2 or foam fire extinguisher must be located adjacent to the engine during all ground runs. The aircraft fire extinguishing system should only be used in the event of a fire in an engine which is fully cowled.

Starting

There are many different types of turbine engine starters and starting systems, therefore it is not possible to give a sequence of operations exactly suited to all aircraft. The main requirements for starting are detailed in the following paragraphs.

An external electrical power supply is often required and should be connected before starting. Where a ground/ flight switch is provided this must be set to 'ground' and all warning lights checked for correct operation.

Where an air supply is required for starting this should be connected and the pressure checked as being sufficient to ensure a start.

NOTE: If the electrical and air supplies are not adequate for starting purposes it is possible for a light-up to occur at insufficient speed for the engine to accelerate under its own power. This could result in excessive turbine temperatures and damage to the engine.

The controls and switches should be set for engine starting, a check made to ensure that the area both in front of and behind the engine is clear and the starter engaged. When turbine rotation becomes apparent the HP cock should be opened and the engine instruments monitored to ensure that the starting cycle is normal. When light-up occurs and the engine begins to accelerate under its own power, switch off the starter. If it appears from the rate of increase in exhaust or turbine gas temperature that starting limits will be exceeded the HP cock should be closed immediately and the cause investigated (see under 'Trouble Shooting' in the appropriate Maintenance Manual).

Once engine speed has stabilised at idling, a check should be made that all warning lights are out, the external power supplies disconnected and the ground/flight switch moved to 'flight'.

Testing

When a new engine has been installed a full ground test is necessary, but on other occasions only those parts of the test necessary to satisfy the purpose of the run need be carried out. The test should be as brief as possible and for this reason the aircraft Maintenance Manual specifies a sequence of operations which should always be observed. Records of the instrument readings obtained during each test should be kept to provide a basis for comparison when future engine runs become necessary.

Each aircraft system associated with engine operation should be operated and any warning devices or indicators in the cockpit checked against physical functioning. It may be necessary in certain atmospheric conditions to select engine anti-icing throughout the run and this should be ascertained from the minimum conditions quoted in the Maintenance Manual.

The particular tests related to engine operation are idling speed, maximum speed, acceleration, and function of any compressor airflow controls which may be fitted. Adjustments to correct slight errors in engine operation are provided on the engine fuel pump, flow control unit, and airflow control units. Observed results of the tests must be corrected for ambient pressure and temperature, tables or graphs being provided for this purpose in the aircraft Maintenance Manual. Adjustments may usually be carried out with the engine idling unless it is necessary to disconnect a control. In this case the engine must be stopped and a duplicate inspection of the control carried out before starting it again. An entry must be made in the engine log book quoting any adjustments made and the ambient conditions at the time.

Stopping

After completion of the engine run the engine should be idled until temperatures stabilise and then the HP cock closed. The time taken for the engine to stop should be noted and compared with previous times, due allowance being made for wind velocity (e.g. a strong head wind will appreciably increase the run-down time). During the run-down fuel should be discharged from certain fuel component drains and this should be confirmed. A blocked drain pipe must be rectified. When the engine has stopped, all controls and switches used for the run must be turned off and the engine inspected for fuel, oil, fluid and gas leaks.

After a new engine has been tested the oil filters should be removed and inspected and after refitting these items the system should be replenished as necessary.

* * *

CHAPTER: 4
STARTING AND IGNITION SYSTEMS
(PISTON ENGINES)

TYPES OF STARTING SYSTEMS

Types of starting system in piston engines are

(1) Direct hand cranking
(2) Direct cranking, either hand or electrical
(3) Hand inertia
(4) Combination hand and electric inertia.

First two may be described as direct cranking systems and second two may be referred to as inertia type cranking systems.

DIRECT CRANKING SYSTEMS

Direct Hand Cranking Starter

The direct hand-cranking starter is sometimes described as a hand-turning gear-type starter. It consists of a worm-gear assembly that operates an automatic engaging and disengaging mechanism through an adjustable-torque overload - release clutch. It has an extension shaft that may be either flexible or rigid, depending on the design. To prevent the transmission of any reverse motion to the crank handle in case the engine “kicks” backward while it is being cranked, a ratchet device is fitted on the hand crankshaft.

This type of starter can be used with a gear ratio of 6:1 for any engine rated at 250 hp or less. It has a comparatively low weight, and it is simple to operate and maintain. It was extensively used on early airplanes which had low horsepower engines and no source of electric power for starting. On seaplanes, where it was very difficult to start the engine by swinging the propeller, it was especially popular. However, it has been entirely supplanted by more efficient design.

Direct Cranking Electric Starter

When the direct-cranking method is used, there is no preliminary storing of energy in the flywheel as there is in the case of the inertia-type starters. The starter of the direct type, when electrically energized, provides instant and continuous cranking. The starter fundamentally consists of an electric motor, reduction gears, and an automatic engaging and disengaging mechanism, which is operated through an adjustable torque overload-release clutch. The engine is therefore cranked directly by the starter.

The motor torque is transmitted through the reduction gears to the adjustable torque overload-release clutch, which actuates a helically splined shaft. This, in turn, moves the starter jaw outward, along its axis, and engages the engine-cranking jaw. Then, when the starter jaw is engaged, cranking starts.

When the engine starts to fire, the starter automatically disengages. If the engine stops, the starter automatically engages again if the current continues to energize the motor.

The automatic engaging and disengaging mechanism operates through the adjustable torque overload-release clutch, which is a multiple-disk clutch under adjustable spring pressure. When the unit is assembled, the clutch is set for a predetermined torque valve. The disks in the clutch slip and absorb the shock caused by the engagement of the starter dogs. They also slip if the engine kicks backward. Since the engagement of the starter dog is automatic, the starter disengages when the engine speed exceeds the starter speed.

The most prevalent type of starter used for light and medium engines is a series electric motor with an engaging mechanism. In all cases, the gear arrangement is such that there is a high gear ratio between the starter motor and the engine. That is, the starter motor turns many times the rpm of the engine.

INERTIA STARTERS

There are two types of inertia starters :

(1) The hand-cranking type, commonly called the hand inertia starter, in which the flywheel is accelerated by hand only ; and
(2) The electric type, commonly called the combination inertia starter and sometimes referred to as the combination of hand and electric inertia starter. In which the flywheel is accelerated by either a hand crank or an electric motor.

Principles Governing The Operation Of The Inertia Starter.

Newton’s first law states : Every body continues in its state of rest or uniform motion in a straight line unless it is compelled to change that state by some external force. This is also known as a statement of the property of inertia.

The cranking ability of an inertia starter for airplane depends on the amount of energy stored in a rapidly rotating flywheel. The energy is stored in the flywheel slowly during the energizing process, and then it is used very quickly to crank the engine rapidly, thus obtaining from the rotating flywheel a large amount of power in a very short time.

Under ordinary conditions, the energy obtained from the flywheel is great enough to rotate the engine crankshaft three or four times at a speed of 80 to 100 rpm. In this manner, the inertia starter is used to obtain the starting torque needed to overcome the resistance imposed upon the cranking mechanism of the engine by reason of its heavy and complicated construction.

The speed at which the engine crankshaft is rotated may be less than the coming-in speed for the magneto, which is the minimum crankshaft speed at which the magneto will function satisfactorily. Therefore, if the engine uses magnetos for ignition, as practically all modern engines do, an ignition booster of some type must be provided. It is usually installed on or near the engine and operated while the inertia starter is cranking the engine.

Hand Inertia Starter

In using the hand inertia starter, when a hand crank is placed in the crank socket and the crank rotated, a gear relationship between the crank and the flywheel makes it possible for a single turn of the hand crank to cause the flywheel to turn many times. For example, one revolution of the hand crank may cause the flywheel to revolve 100 or more times, depending on the make, model, etc., of the starter. The speed of all movable parts is gradually increased with each revolution of the hand crank, and most of the energy imparted to the crank is stored in the rapidly rotating wheel in the form of kinetic energy.

Fig.1. is a sectional diagram of a hand inertia starter. The crank socket, flywheel, engaging lever, mounting flange, starter driving jaw, torque overload-release clutch, springs, disks, and barrel are shown.

One type of clutch consists of one set of disks fastened to the shaft and another set of disks, made of a different kind of metal, fastened to the barrel. The disks are pressed together by springs. The retaining ring compresses the springs and can be adjusted to set the value of the slipping torque. This feature is important because the normal operation of the clutch is to slip momentarily after the starter and engine jaws are meshed. During the process of slipping, a torque is exerted on the crankshaft until the initial resistance of the engine is overcome and the clutch is again able to hold. The maximum holding torque is called the break away. This break away and the slipping torque depend on the size of the engine being cranked.

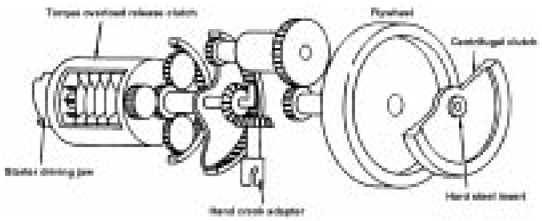


Fig.1. Hand Inertia Starter.

Combination Hand And Electric Inertia Starters

A combination hand and electric inertia starter may consist of a hand inertia starter with an electric motor attached, and the gear and clutch arrangement may be like that of the hand inertia starter. The flywheel may be accelerated by either a hand crank or the electric motor. When the starter is energized by hand cranking, the motor is mechanically disconnected and no longer operates. When the motor is operated, a movable jaw on a helically splined shaft engages the motor directly to the inertia starter flywheel in one type of inertia starter called a jaw = type starter motor-engaging mechanism, illustrated in figure.2.

On some starters of this general type, the starter jaw tends to remain at rest when the motor armature starts to rotate, but as the shaft turns, the jaw moves forward along the splined shaft until it engages the flywheel jaw. Ordinarily, there is no trouble with this type of mechanism, but if the jaw binds on the shaft, it will not engage the flywheel, and thus the motor races. When the engine fails to start, the operator must not continue to attempt cranking otherwise, the teeth may be stripped on either the flywheel for the motor jaw or both. The correct procedure is to wait until the starter flywheel comes to rest before energizing the motor in a second attempt to crank. This avoids both the racing of the motor and the stripping of the teeth.

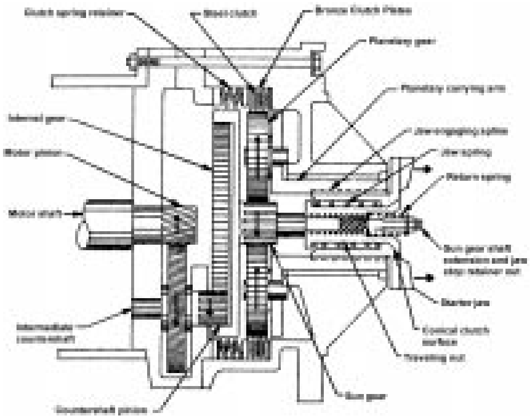


Fig.2. Starter engaging jaw and mechanism.

Electric Motors For Inertia Starters

The typical electric motor used on inertia starter are series motors operated on 12 or 24 V D.C. and with a low resistance winding. It was a low resistance, because there is a great amount of current flow in order to provide a powerful starting torque. When the motor gain speed, the induced electromotive force (emf) in a reverse direction causes the smaller amount of current to flow i.e. a counter emf is established when the motor gain speed.

An inertia starter motor is never operated at full voltage unless there is a load imposed upon it. If there is no load, and if the motor has a small amount of internal friction, it will race and the armature may fly apart ("burst") because of the centrifugal stresses.

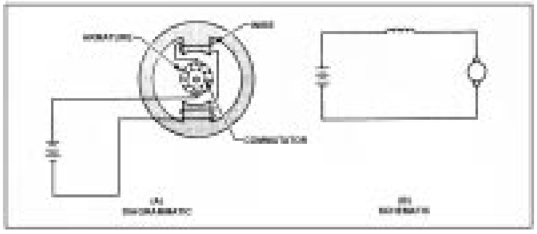


Fig.3. Schematic diagram of a series motor circuit.

Fig. 3. is a simple schematic diagram of a series motor. The field coils are connected in series with the armature. Since all the current used by the motor must flow through both the field and the armature it is apparent that the flux of both the armature and the field will be strong.

The greatest flow of current through the motor will take place when the motor is being started; hence, the starting torque is high. Series-wound motors are used wherever the load is continually applied to the motor and is heavy when the motor first starts. In addition to starting motors, motors used to operate landing gear, cowl flaps, and similar equipment are of this type.

IGNITION SYSTEM FOR PISTON ENGINES

During ignition event of a piston engine, the electric spark jumps between the electrodes (points) of a spark plug that is installed in the cylinder head or combustion chamber of the engine cylinder. The ignition system furnishes sparks periodically to each cylinder at a certain position of piston and valve travel.

Essential Parts Of An Ignition System

The essential parts of an ignition system for a reciprocating engine are a source of high voltage, a timing device to cause the high-voltage source to function at the set position of piston travel, a distributing mechanism to route the high voltage to the various cylinders in the correct sequence, spark plugs to carry the high voltage into the cylinders of the engine and ignite the fuel air mixture, control switches, and the necessary wiring. The source of the high voltage may be either a magneto driven by the engine or an induction coil connected to a battery or a generator.

All parts of the aircraft ignition system are enclosed in either flexible or rigid metal covering called shielding. This metal covering “receives” and “grounds out” radiation from the ignition system, which would otherwise cause interference (noise) in the radio receiving equipment in aircraft.

Magneto Ignition

Magneto ignition is superior to battery ignition because it produces a hotter spark at high engine speeds and it is a self contained unit, not dependent on any external source of electric energy. Magneto produces electric current in pulsations of high voltage for purpose of ignition. When an aircraft engine is started, the engine turns over too slowly to permit the magneto to operate; hence, it is necessary to use a booster coil, vibrating interrupter (induction vibrator), or impulse coupling for ignition during starting.

When two magnetos fire at the same or approximately the same time through two sets of spark plugs, this is known as double or dual, magneto ignition system. The principle advantage of dual magneto ignition are as follows :-

(1) If one magneto or any part of one magneto system fails to operate, the other magneto system will furnish ignition until the disabled system functions again.

(2) Two sparks, igniting the fuel-air mixture in each cylinder simultaneously at two different places, give a more complete and quick combustion than a single spark; hence, the power of the engine is increased.

On radial engines, it has been a standard practice to use the right-hand magneto for the front set of spark plugs and the left-hand magneto for the rear set of spark plugs.

Dual-ignition spark plugs may be set to fire at the same instant (synchronized) or at slightly different intervals (staggered). When staggered ignition is used, each of the two sparks occurs at a different time. The spark plug on the exhaust side of the cylinder always fires first because the slower rate of burning of the expanded and diluted fuel-air mixture at this point in the cylinder makes it desirable to have an advance in the ignition timing.

POLARITY OR DIRECTION OF SPARKS

Fundamentally the magneto is a special form of AC generator, modified to enable it to deliver the high voltage required for ignition purposes. The high rate of change of flux linkages are responsible for the high voltage which produces the strong spark. Flux change are in downward and upward direction, alternating in direction at each opening of the contacts. Since the direction of an induced current depends on the direction of the flux change which produced it, the sparks produced by the magneto are of alternate polarity, that is, they jump one way and then the other.

HIGH-TENSION IGNITION SYSTEM

Figure4. illustrates a complete high-tension ignition system for a four-cylinder aircraft engine.

One end of the primary winding is grounded to the magneto, and the other and is connected to the insulated contact point. The other contact point is grounded. The capacitor is connected across the contact points.

The ground terminal on the magneto is electrically connected to the insulated contact point. A wire called the P lead connect the ground terminal on each magneto with the switch. When the switch is in the OFF position, this wire provides a direct path to the ground for the primary current, that is, the breaker points are short-circuited. Therefore, when the contact points open, the primary current is not interrupted, thus preventing the production of high voltage in the secondary winding.

One end of the secondary winding is grounded to the magneto, and the other and terminates at the high-tension insert on the coil. The high-tension current produced in the secondary winding is then conducted to the central insert of the distributor finger and across a small air gap to the electrodes of the distribution block. High-tension cables in the distributor block then carry it to the spark plugs where the discharge occurs in the engine cylinder.

The distributor

The distributor finger of fig 4 is secured to the large distributor gear which is driven by a smaller gear located on the drive shaft of the drive shaft of the rotating magnet. The ratio between these gears is always such that the distributor finger is driven at one-half engine-crankshaft speed. The ratio of the gears ensures the proper distribution of the high-tension current to the spark plugs in accordance with the firing order of the particular engine.

In general, the distributor rotor of the typical aircraft magneto is a device that distributes the high-voltage current to the various connections of the distributor block. This rotor may be in the form of a finger, disk, drum, or other shape, depending on the judgement of the magneto manufacturer. In addition, the distributor rotor may be designed with either

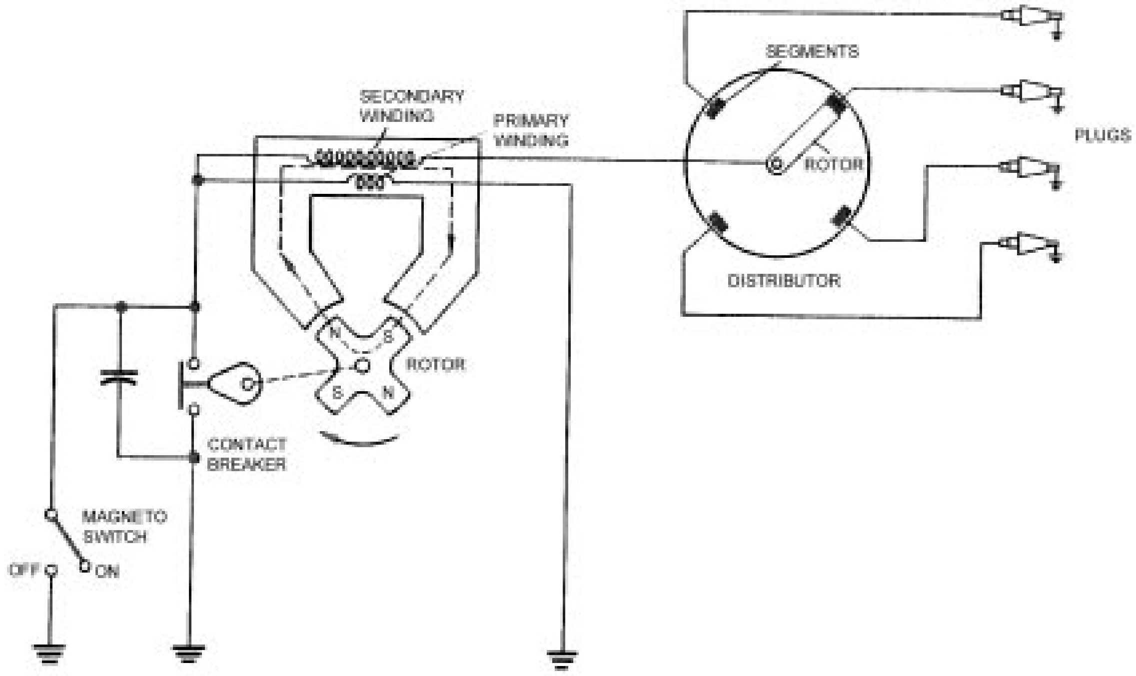


Fig. 4. High tension ignition system.

One or two distributing electrodes. When there are two distributing electrodes, the leading electrode, which obtains high voltage from the magneto secondary, makes its connection with the secondary through the shaft of the rotor, while the trailing electrode obtains a high-tension voltage from the booster by means of a collector ring mounted either on the stationary distributor block or on the rotor itself.

Distributor with the trailing finger are used on older aircraft. The modern engines utilizes booster magnetos or high tension booster coil to provide a strong spark when starting the engine.

Magneto sparking order

Almost all piston-type aircraft engines operate on the four-stroke five-event-cycle principle. For this reason, the number of sparks required for each complete revolution of the engine is equal to one-half the number of cylinders in the engine. The number of sparks produced by each revolution of the rotating magnet is equal to the number of its poles. Therefore the ratio of the speed at which the rotating magnet is driven to the speed of the engine crankshaft is always one half the number of cylinders on the engine divided by the number of poles on the rotating magnet.

The numbers on the distributor block show the magneto sparking order and not the firing order of the engine. The distributor-block position marked 1 is connected to no 1 cylinder and no 2 to no 2 cylinder and so on.

Some distributor blocks or housing are not numbered for all high tension leads. In these cases the lead socket for the no. 1 cylinder is marked and the others follow in order according to direction of rotation.

Coming in speed of magneto

To produce sparks, the rotating magnet must be turned at or above a specified number of revolutions per minute, at which speed the rate of change in flux linkages is sufficiently high to induce the required primary current and the resultant high-tension output. This speed is known as the coming-in speed of the magneto; it varies for different types of magnetos but averages about 100 to 200 rpm.

Harness assembly

Harness assembly consists of flexible shielding from the magneto housing to the rigid manifold that is suitably installed on the crankcase of the engine and flexible shielded leads from the manifold to the spark plugs. Thus the complete system is shielded to prevent the emanation of electromagnetic waves which would cause radio interference.

In a system of this type, the lower extremities of the manifold must be provided with drain holes to prevent the accumulation of moisture. In some systems, the manifold is completely filled with a plastic insulating material after the ignition cables are installed. This seals the cables completely away from any moisture.

Ignition harnesses for opposed engines consist of individual high-tension leads connected to the distributor plate or cap and routed to each spark plug in proper order.

Ignition switch and the primary circuits

The usual electric switch is closed when it is turned ON. The magneto ignition switch is closed when it is turned OFF. This is because the purpose of the switch is to short-circuit the breaker points of the magneto and prevent collapse of the primary circuit required for production of a spark.

The ignition switches for modern aircraft have the appearance of automobile starter switches mounted on the dash board. The aircraft switch is operated by a key and has positions for OFF, RIGHT, BOTH and START. The switch has a connection for battery power which is used in the START position to actuate the starter contactor or relay. In some cases, the start-ignition switch also includes the master power switch for the aircraft.

TYPES OF MAGNETO

Types of magnetos are (1) low tension, high tension (2) rotating-magnet or inductor-rotor, (3) single or double and (4) base-mounted or flange-mounted.

Low tension and high tension magnetos

A low-tension magneto delivers current at a low voltage by means of the rotation of an armature, wound with only one coil, in the field of a permanent magnet. Its low-voltage current must be transformed into a high tension (high-voltage current by means of a transformer.

A high tension magneto delivers a high voltage and has both a primary winding and a secondary winding. An outside induction coil is not needed because the double winding accomplishes the same purpose. The low voltage generated in the primary winding induces a high-voltage current in the secondary winding when the primary circuit is broken.

Rotating magnetos and inductor rotor magnetos

In a magneto of the rotating-magnet type, the primary and secondary winding are wound upon the same iron core. This core is mounted between two poles, or inductor, which extend to “shoes” on each side of the rotating magnet. The rotating magnet is usually made with four poles, which are arranged alternately north and south in polarity.

The inductor-rotor type of magneto has a stationary coil (armature) just as the rotating-magnet type does. The difference lies in the method of inducting a magnetic flux in the core of the coil. The inductor-rotor magneto has a stationary magnet or magnets. As the rotor of the magneto turns, the flux from the magnets is carried through the segments of the rotor to the pole shoes and poles, first in one direction and then in the other.

Single and double type magnetos

Two single type magnetos are commonly used on piston type engines. The single-type magneto is just what its name implies-one magneto.

The double-type magneto is generally used on different models of several types of engines, when made for radial engines, it is essentially the same as the magneto made for in-line engines except that two compensated cams are employed.

The double type magneto is essentially two magnetos having one rotating magnet common to both. It contains two sets of breaker points, and the high voltage is distributed either by two distributors mounted elsewhere on the engine or by distributors forming part of the magneto proper.

Base mounted and flange mounted magnetos

A base-mounted magneto is attached to a mounting bracket on the engine by means of cap screws, which pass through holes in the bracket and inter tapped holes in the base of the magneto.

A flange-mounted magneto is attached to the engine by means of a flange on the end of the magneto. The mounting holes in the flange are not circular; instead, they are slots that permit a slight adjustment, by rotation, in timing the magneto with the engine.

The single-type magneto may be either base-mounted or flange-mounted. The double-type magneto is always flange mounted.

IGNITION BOOSTERS

It is impossible under certain conditions to rotate the engine crankshaft fast enough to produce the coming-in speed of the magneto, a source of external high-tension current is required for starting purposes. The various devices used for this purpose are called ignition boosters.

An ignition booster may be in the form of a booster magneto, a high-tension coil to which primary current is supplied from a battery, or a vibrator which supplies in intermittent direct current from the battery directly to the primary of the magneto. Another device used for increasing the high-tension voltage of the magneto for starting is called a impulse coupling. It gives a momentary high rotational speed to the rotor of the magneto during starting.

THE BOOSTER COIL

A booster coil is a small induction coil. Its function is to provide a shower of sparks to the spark plugs until the magneto fires properly. It is usually connected to the starter switch. When the engine has started the booster coil and the starter are no longer required; hence they can be turned off together.

When voltage from a battery is applied to the booster coil, magnetism is developed in the core until the magnetic force on the soft-iron armature mounted on the vibrator overcomes the spring tension and attracts the armature toward the core. When the armature moves toward the core, the contact points and the primary circuit are opened. This demagnetizes the core and permits the spring again to close the contact points and complete the circuit. The armature vibrates back and forth rapidly, making and breaking the primary circuit as long as the voltage from the battery is applied to the booster coil.

Booster coils were used on older aircraft. Most of the modern aircraft employ the induction vibrator or an impulse coupling.

THE INDUCTION VIBRATOR

A circuit for an induction vibrator is used with a high tension magneto is shown in figure5. This circuit applies to one engine only, but it is obvious that a similar circuit would be used with each engine of a multi engine airplane. The induction vibrator is energized from the same circuit which energizes the starting solenoid. It is thus energized only during the time that the engines are being started.

One advantage of the induction vibrator is that it reduces the tendency of the magneto to “flash over” at high altitudes, since the booster finger can be eliminated. The function of this induction vibrator is to supply interrupted low voltage for the magneto primary coil, which induces a sufficiently high voltage in the secondary for starting.

The vibrator sends an interrupted battery current through the primary winding of the regular magneto coil. The magneto coil then acts like a battery ignition coil and produces high tension impulses, which are distributed through the distributor rotor and distributor block, and cables to the spark plugs. These high-tension impulses are produced during the engine time that the magneto contact points are open. When the contact points are closed, sparks cannot be generated, although the vibrator continues to sand interrupted current impulses through the magneto contact points without harm to the vibrator or any part of the circuit.

When the ignition switch is in the ON position and the engine starter is engaged, the current from the battery is sent through the coil of a relay which is normally open. The battery current causes the relay points to close, thus completing the circuit to the vibrator coil and causing the vibrator to produce a rapidly interrupted current.

The rapidly interrupted current produced by the vibrator is sent through the primary winding of the magneto coil. By induction, high voltage is created in the secondary winding of the magneto coil, and this high voltage produces high-tension sparks which are delivered to the spark plugs through the magneto distributor-block electrodes during the time that the magneto contact points are open.

The process is repeated each time that the magneto contact points are separated, because the interrupted current once more flows through the primary of the magneto coil. The action continues until the engine is firing because of the regular magneto sparks, and the engine starter is released. It should be understood that the vibrator starts to operate automatically when the engine-ignition switch is turned to the ON position and the starter is engaged. The vibrator stops when the starter is disengaged.

LOW-TENSION IGNITION

Reasons for development of low tension ignition

There are several very serious problems encountered in the production and distribution of the high-voltage electricity used to fire the spark plugs of an aircraft engine. High voltage electricity causes corrosion of metals and deterioration of insulating materials. It also has a marked tendency to escape from the routes provided for it by the designer of the engine.

There are four principal causes for the troubles experienced in the use of high-voltage ignition systems: (1) Flashover, (2) Capacitance, (3) Moisture, and (4) High-voltage corona.

Flashover:

Is a term to describe the jumping of the high voltage inside a distributor when an airplane ascends to a high altitude. The reason for this is that the air is less dense at high altitudes and hence has less dielectric, or insulating, strength.

Capacitance

Is the ability of a conductor to store electrons. In the high-tension ignition system, the capacitance of the high-tension leads from the magneto to the spark plugs causes the leads to store a portion of the electric charge until the voltage is built sufficiently to cause the spark to jump the gap of a spark plug. When the spark has jumped and established a path across the gap, the energy stored in the leads during the rise of voltage is dissipated in heat at the spark-plug electrodes since this discharge of energy is in the form of a relatively low voltage and high current, it causes burning of the electrodes and shortens the life of the spark plug.

Moisture

Whenever it exists, increases conductivity. Thus it may provide new and unforeseen routes for the escape of high-voltage electricity.

High voltage corona

Is a phrase often used to describe a condition of stress which exists across any insulator (dielectric) exposed to high voltage. When the high voltage is impressed between the conductor of an insulated lead and any metallic mass near the lead, and electrical stress is set up in the insulation. Repeated application of this stress to the insulation will eventually cause failure.

Operation of low tension ignition system

The low tension ignition system consists of (1) a low tension magneto (11) a carbon brush distributor and (111) a transformer for each spark plug.

During the operation of the low-tension system, surges of electricity are generated in the magneto generator coil. The peak surge voltage is never in excess of 350V and probably is nearer 200 V on most installations. This comparatively low voltage is fed through the distributor to the primary of the spark-plug transformer.

At the instant of opening of the breaker contacts which are connected across the magneto generator coil, a rapid flux change takes place in the generator coil core, causing a rapid rise of voltage in this coil. As has already been

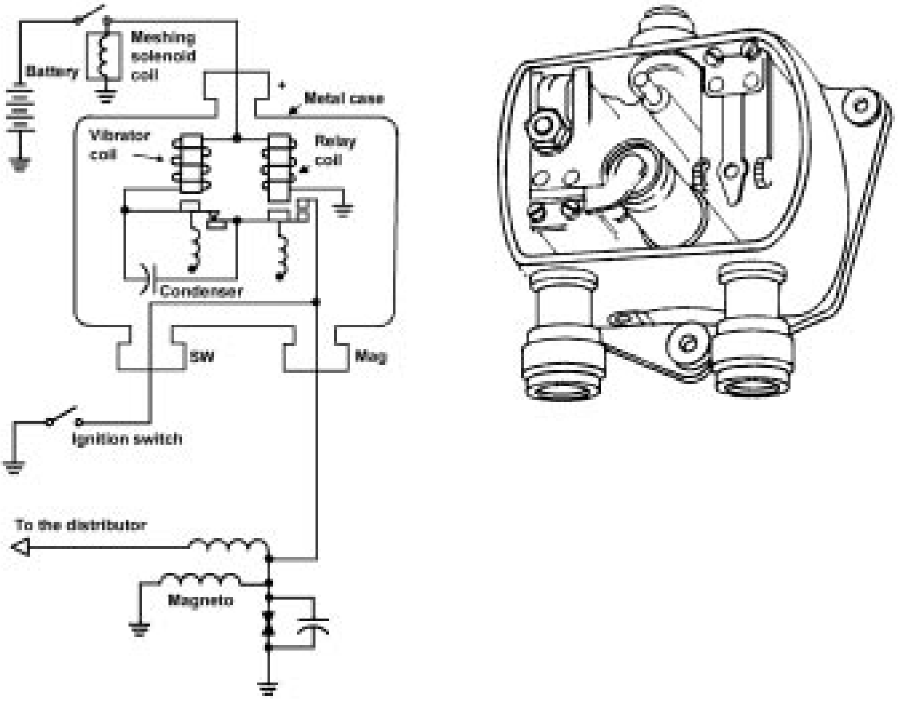


Fig.5. Circuit for induction vibrator.

explained, it is the capacitor connected across the breaker points which actually stops the flow of current when the breaker opens.

The primary capacitor and magneto generator coil of a low-tension system are connected through the distributor directly across the primary winding of the transformer coil, Therefore, during the time that the voltage across the primary capacitor is rising, as the breaker points open, the natural tendency is for current to start flowing out through the distributor and the primary of the transformer coil.

When this condition has been achieved, we have the situation of a primary capacitor charged to nearly 2000V connected across the primary of the transformer. The result in a very rapid rise of current in the primary, accomplished by a very rapid change in flux linkages (magnetic field) in both coils. The rapid change in the flux linkages in the secondary induces the voltage which fires the spark plug. As soon as the spark gap has been "broken down" (broken through and ionized), current also starts to flow in the secondary circuit.

Duration of the spark in a high-tension system is several times that of a comparable low-tension system. The high resistance of the transformer primary winding, which is characteristic of all low-tension transformer coils, helps to bring the primary current to a stop after the spark has been produced.

It should be clear that the spark voltage is produced by the growth of magnetic field in the transformer core and not by the collapse of the field as is the case in conventional ignition coils. This fact sometimes raises the question about why the subsequential collapse or decay of the field in the transformer does not produce a second spark at the spark plug. The reason for this is that the rate of decay of the magnetic field in the transformer is determined by the rate decay of the primary current. It has already been pointed out that the primary current results from the discharge of the primary capacitor and that this current tapers off at a rather slow rate after the secondary current stops. Since the rate of decay of the magnetic field is the same as that of the primary current, it is too slow to produce enough voltage for a second spark at the plug.

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CHAPTER: 5

LUBRICATION SYSTEM : GAS TURBINE ENGINE

INTRODUCTION

The lubrication requirements of an aircraft gas turbine engine are generally not too difficult to meet, because the oil does not lubricate any parts of the engine that are directly heated by combustion. Because of this, the loss of oil from the system is small compared with that from a piston engine.

The requirements of a turbo-propeller engine are a little more-severe than those of a turbojet engine, because of the heavily loaded propeller reduction gears and the need for a high pressure oil supply to operate the propeller pitch control mechanism.

Most gas turbine engines use a self-contained recirculatory oil system, in which the oil is distributed and returned to the oil tank by pumps. Some turbojet engines, however, use another system known as the total loss or expendable system in which the oil is spilled overboard after the engine has been lubricated. Recirculatory are divided into two types they are (i) Pressure Relief Valve (ii) Full flow systems, the major difference between them being in the control of the oil flow to the bearings.

LUBRICATION SYSTEMS

Recirculatory system

Pressure relief valve system

In pressure relief valve system the oil flow to the bearings of the rotating assemblies is controlled by limiting the maximum pressure in the feed line. This is achieved by a system relief valve in which feed oil pressure is opposed by a spring pressure plus atmospheric pressure via the oil tank. On some installations bearing housing pressure or an equivalent of this is used in place of atmospheric pressure. Above a specific engine speed, feed oil pressure overcomes the opposing pressure and the excess oil spills back to the tank, thus maintaining the pressure and flow to the bearings constant at higher engine speeds.

Operation

The pressure pump draws the oil from the tank through strainer which protects the pump gears from any debris which may have entered the tank. Oil is then delivered through a pressure filter to a relief valve (system relief valve) that controls the maximum pressure of the oil flow to the rotating assemblies. On some engines an additional relief valve (pump relief valve) is fitted at the pressure pump out let. This valve is set to open at a much higher pressure than the system relief valve and opens only to return the oil to the inlet side of the pump should the system become blocked. To prevent oil starvation when the oil is very cold or the pressure filter is partially blocked, a bypass valve that operates at a preset pressure difference is fitted across the inlet and outlet of the pressure filter.

On the turbojet system the pressure oil from the relief valve is delivered, through transfer tubes and passages, to lubricate the bearings and gears. Twin-spool engines are provided with a separate metering pump that supplies a controlled amount of oil to the front bearing of the low pressure compressor. This prevents flooding during the initial stage of the starting cycle when only the high pressure compressor is rotating. As the low pressure compressor starts to rotate, oil is supplied to the front bearing, the flow being centred in relationship to compressor speed.

On the turbo-propeller system, the pressure oil is divided after leaving the relief valve, to feed the rotating assembly bearings, propeller pitch control supply system, reduction gear and torque-meter system.

The rotating assembly bearings and some of the heavier loaded gears in the gearboxes are lubricated by oil jets and these are often protected by thread-type filters. The remaining bearings and gears are splash lubricated. Bearings at ‘hot’ end of the engine receive the maximum oil flow because, in addition to lubricating the bearings, the oil assists in heat dissipation.

On some engines, to minimize the effect of the dynamic loads transmitted from the rotating assemblies to the bearing housing, ‘squeeze film’ type bearings are used. These have a small clearance between the outer track of the bearing and the housing, the space being filled with feed oil. The film modifies the radial motion of the rotating assembly and the dynamic loads transmitted to the bearing housing, thus reducing the vibration level of the engine and the possibility of damage by fatigue.

To prevent the flooding of the bearing housing, it is necessary to use more than one pump to return or scavenge it to the oil tank. This is achieved by using a pack of pumps, each of which returns the oil from a particular section of the engine. To protect the pump gears, each return pipe is provided with a strainer that, during inspection, can reveal the failure or impending failure of a component.

Centrifugal breather

To separate the air from the oil returning to the tank, a de-aerating device and a centrifugal breather are incorporated. The return air/oil mixture is fed on to the de-aerator where partial separation occurs, the remaining air/oil mist then passes into the centrifugal breather for final separation. The rotating vanes of the breather centrifuge the oil from the mist and the air is vented overboard through the hollow drive shaft.

Oil coolers

On all engines using the recirculatory type of oil system, heat is transferred to the oil from the engine and it is, therefore, common practice to fit an oil cooler. The cooling medium may be fuel or air and, in some instances, both fuel-cooled and air-cooled coolers are used.

If fuel is used as a cooling medium, either low pressure or high pressure fuel may be used, for in both instances the fuel temperature is much lower than the oil temperature. Whether the cooler is located in the feed side or the return side of a lubrication system depends upon the operating temperature of the bearings.

A turbo-propeller engine may be fitted with an oil cooler that utilizes the external airflow as a cooling medium. This type of cooler, however, incurs a large drag factor and, as kinetic heating of the air occurs at high forward speeds, it is unsuitable for turbojet engines.

Magnetic plugs

Magnetic plugs or chip detectors be fitted in the return oil side of a system to provide a warning of impending failure without having to remove and inspect the scavenge strainers. Some of these detectors are designed so that they can be removed for inspection without oil loss occurring; others may be checked externally by a lamp and battery or even connected to a crew compartment warning system to give an in-flight indication.

FULL FLOW SYSTEM

The full flow system is different from a pressure relief valve system, in that the flow of oil to the bearings is determined by the speed of the pressure pump, the size of the oil jets and the pressure in each bearing housing. The system also incorporates a metered spill of feed oil back to the tank and this spill, together with the oil jets, is calibrated to match the pump output. This arrangement ensures that the oil flow requirements of the bearings are met at all engine speeds. The function of the relief valve in the relief valve system to the open only to prevent excessive oil pressure occurring in the feed side of the system.

A pressure filter bypass valve is not normally fitted, but the pressure drop across either the filter or the system is sensed by a differential pressure switch. An increase in the pressure difference is shown on the indicating system, thus giving advance warning of a blocked filter.

The full flow system, like the pressure relief valve system, draws oil from a tank and delivers it in a similar way, via a pressure filter, to various parts of the engine from where it is returned by scavenge pumps, via oil coolers, to the tank. Likewise, air is separated from the oil by a de-aerator and centrifugal breather. Magnetic chip detectors are also fitted in the return oil lines, and squeeze film bearings are used to reduce engine vibration; indications of pressure and temperature are also displayed in the crew compartment. On some engines an anti-syphon jet is provided to prevent oil in the feed line draining through the pressure pump into the gearbox when the engine is stationary, the oil being diverted into the oil tank.

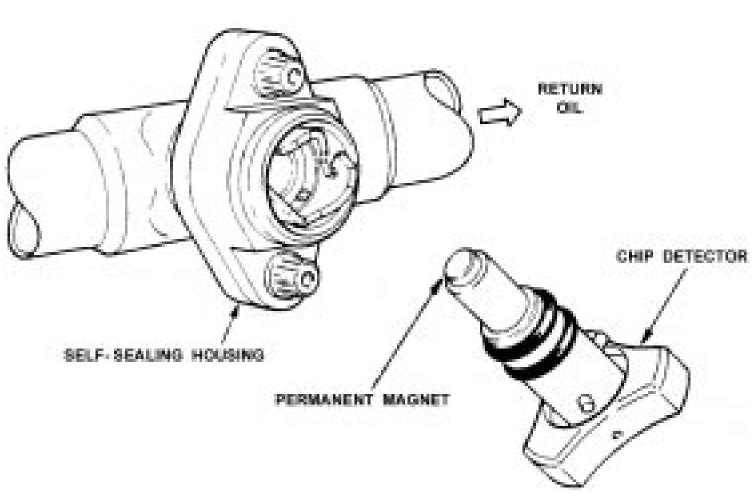

Fig.1. A magnetic chip detector.

TOTAL LOSS (EXPENDABLE) SYSTEM

The total loss oil system is generally used only on engines that run for periods of short duration, such as vertical lift and booster engines. The system is simple and incurs low weight penalties, because it requires no oil cooler, scavenge pump or filters. On some engines oil is delivered in a continuous flow to the bearings by a plunger type pump, indirectly driven from the compressor shaft; on others it is delivered by a piston-type pump operated by fuel pressure. On the latter, the oil supply is automatically selected by the high pressure shut-off valve (cock) during engine starting and is delivered as a single shot to the front and rear bearings. On some engines provision is made for a second shot to be delivered to the rear bearing only, after a predetermined period.

After lubricating the fuel unit and front bearings., the oil from the front bearing drains into a collector tray and is then ejected into the main gas stream through an ejector nozzle. The oil that has passed through the rear bearing drains into a reservoir at the rear of the bearing where it is retained by centrifugal force until the engine is shut down. This oil then drains overboard through a central tube in the exhaust unit inner cone.

TYPICAL LUBRICATION SYSTEM OF A TURBO FAN ENGINE: P&W JT 8D ENGINE

The JT8D gas turbine engine has a ‘hot tank’ system. The term refers to the technique of returning hot secavanged oil directly from bearing compartments to the de-areator located in the oil tank.

In a cold tank system, the secavanged oil is passed through the oil cooler before being returns to oil tank. The advantage of ‘hot tank’ system is more efficient removal of entrapped air.

Pressure system

The oil is gravity fed from the tank to the main oil pump by a transfer tube and cored passage in the accessories gear box. Pump discharge pressure is then directed to main oil filter. A by pass valve provided in filter provides oil if main filter becomes obstructed.

External pressure taps are provided to sense before and after filter. This permits in-flight monitoring of main oil filter via a differential pressure switch and annunciator light on flight deek.

Oil from filter, regulated to provide operating pressure after the fuel oil cooler, directed to oil cooler and further delivered to engine bearings, components and accessories gear box at desired pressure and temperature.

Pressure regulated valve is located in a cored passage and regulate oil pressure. The surface area of oil cooler is adequate to provide sufficient cooling when flow is the mid to high range, thus, the thermostat control is eliminated. The higher oil temperature at prolonged idling can be controlled by moving the power lever to higher speed periodically.

Secavange System

After the oil has lubricated the engine and accessories box bearings, it is returned to oil tank by the secavange system.

The main collection points for secavanging oil located in the Numbers. 1,4,5,and 6 bearings compartment and accessories gear box. A gear type of pump is located in each compartment. Secavange oil from No.1 bearing is returned directly to gear box, number 2 and 3 secavange to gear box by gravity and breather flow throw tower shaft housing. Gear box lube oil along with the oil secavanged from 1,2 and 3 supports is returned to oil tank by gear box secavange pump.

Secavange oil from No.6 bearing area is pumped to no 4(1/2) bearing area through transfer tubes located in low pressure turbine shaft. Centrifugal force causes the oil to be ejected from the no 4(1/2) bearing out through the high pressure turbine shaft secavanging holes to No 4 and 5 bearing compartments. The secavange pump located in No.4 and 5 bearing compartment directly return the oil to the oil tank.

Breather System

To ensure proper oil flow and to maintain satisfactory secavange pump performance, the pressure in the bearing cavities is controlled by the breather system. The breather air from all the main bearings is vented to the accessory gear box as follows:-

a The No.1 bearing breather air is vented to the accessories box via external tubing.
b. The No.2 and 3 bearings are vented internally to the accessory gear box through tower shaft housing.
c. The No. 4(1/2) and 6 bearing breath through the secavange system into No. 4 and 5 collection point.
d. The combined breather air from No. 4, 4(1/2), 5 and 6 bearings is vented to the accessory gear box through an external line. A de-oiler located in the accessory gear box serves to remove oil particles from in the breathing air before it is discharged into airframe waste tube.

Magnetic plugs and chip detectors are located in oil system to indicate the presence of metallic chips in lubricating oil in subsequence of any internal failure of bearings.

TYPICAL LUBRICATION SYSTEM OF A TURBO PROPELLER ENGINE: ALLISON 501-D13

For this engine, oil storage and cooling provisions are made in aircraft and provides independent oil supply for power section and reduction gear assembly.

Power Section Lubrication System

It contain an independent lubrication system with the exception of airframe furnished parts common to power section and reduction gear.

Main Oil Pump

It includes the pressure pump, a secavange pump and the pressure regulating valve

Oil Filter

It houses a check valve, filter element and the by pass valve for the filter is located in gear box housing.

Three Secavange Pumps

Located in diffusor, turbine inlet casing and turbine rear bearing support

Secavange Relief Valve

Located in the accessory drive housing assembly

Breather

Located on top of the air inlet housing.

Oil is supplied from the aircraft tank to the inlet of the pressure pump, after pressurisation flows through the filter, the system pressure is regulated to 50 to 70 psi by the pressure regulating valve. A by pass valve provide oil supply in the event of blockage of filter and a check valve prevents oil flow when engine is stoped.

The secavange pump which is incorporated in the main oil pump and the three independent secavange pumps are so located that they will secavange oil from the power section in any normal attitude of aircraft flight.

The secavange pump located in the main oil pump, secavange oil from the accessory gear box, the other three secavanges oil from diffuser and front and rear side of turbine. The out put of diffuser and front turbine secavange pump join that of the main secavange pump.

The out put of the rear turbine secavange pump is delivered to the interior of the turbine to compressor tie bolts and compressor rotor tie bolt. This oil is directed to the splines of turbine coupling shaft assembly and to the splines for extension shaft of compressor. Thus the out put of rear turbine secavange pump must be resecavanged by the other three secavange pumps.

A secavange relief valve is located, so that it will prevent excessive pressure build up in the power section secavange system. The combined flows of secavanged oil from the power section and reduction gear secavange system must be cooled and returned to supply tank.

A magnetic plug is located on the bottom of accessory gear box and another on secavange line on the forward side of gear box.

Reduction Gear Lubricating System

The reduction gear lubricating system includes the following:

Pressure Pump

Located on left rear side of reduction gear.

Filter

Located in pump body assembly alongwith by - pass valve and check valve.

Two Secavange Pumps

One located in the bottom of the rear case, the other in the front case below the propeller shaft.

Two Pressure Relief Valves

One for the pressure system and other for secavange system.

Oil flows from the pressure pump through a filter and to all parts with in the reduction gear that requires lubrication. In addition the oil pressure is also used as hydraulic pressure in propeller brake assembly. By pass valve ensures continuous oil supply in the event of filter get contaminated and check valve stops oil flow to reduction gear when engine is stoped. Relief valve limits pressure to 250 psi.

The out put of secavange pumps returns the oil to oil tank by common outlet to the aircraft system. A relief valve limits the secavange pressure, as system pressure, and limits to 250 psi.

A magnetic plug located on the bottom rear of the reduction gear assembly provides a means of draining it.

LUBRICATION OILS

Gas turbine engines use a low viscosity (thin) synthetic lubricating oil that does not originate from crude oil. The choice of a lubricating oil is initially decided by the loads and operating temperatures of the bearings and the effect that the temperature will have on the viscosity of the oil. Special laboratory and engine tests are then done to prove the suitability of a particular oil for a specific engine and assess the extent to which it deteriorates and the corrosive effects it may have on the engine.

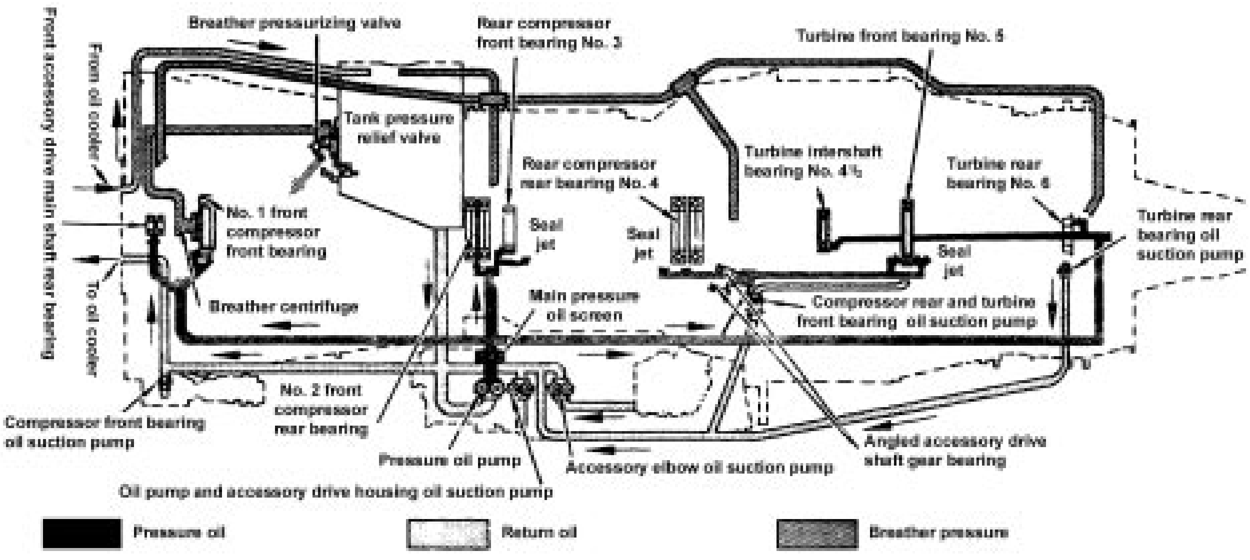

Fig.2. Turbo Jet Lubrication.

The viscosity of a fluid is its resistance to flow and is measured in stokes, a hundredth part of which is a centistoke. This measurement gives a relationship between the specific gravity of the fluid and the force required to move a plane surface of one square centimetre area over another plane surface at the rate of one centimetre per second, when the two surface are separated by a layer of the test fluid one centimetre thick.

The turbojet engine is able to use a low viscosity oil due to the absence of reciprocating parts and heavy duty gearing. This reduces the power requirement for testing, particularly at low temperatures.

Turbo-propeller engines, however, require a slightly higher viscosity oil due to the reduction gear and propeller pitch change mechanism.

All gas turbine oils must retain their lubricating properties and be resistant to oxidation at high temperatures. There are many types of synthetic gas turbine oil and these are manufactured to rigid specifications, but only those specified by the engine manufacturer must be used .

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CHAPTER: 6
PISTON ENGINE LUBRICATION SYSTEM

CLASSIFICATION OF LUBRICANTS

Definition

A lubricant is any natural or artificial substance having greasy or oily properties which can be used to reduce friction between moving parts or to prevent rust and corrosion on metallic surfaces, lubricants may be classified according to their origins as animals, vegetable, minerals or synthetic.

Animal lubricants

Examples of Animal lubricant oil are tallow oil, lard oil, spermoil and porpoise jaw oil. These are highly stable at normal temperature, so that they can be used to lubricate fire arms, and other light machinery and devices. Animal lubricant cannot be used for internal combustion engines because they produce fatty acids at high temperature.

Mineral lubricants

Mineral lubricants are used to a large extent in the lubrication of aircraft internal combustion engines they may be classified as solids, semisolids and fluids.

Solid lubricants, such as mica, soapstone and graphite are fairly satisfactory in a finely powered form on slow speed machines, but they do not dissipate heat rapidly enough for high speed machines. They fill the low spots in the metal on atypical bearing surface to form a perfect smooth surface, and at the same time they provide a slippery film that reduces friction. When a solid lubricant is finely powdered and is not too hard it may be used as a mild abrasive to smooth the surface previously roughened by excessive wear or by machine operation in a factory. Some solid lubricants can carry heavy loads, and hence they are mixed with certain fluid lubricants to reduce the wear between adjacent surfaces subjected to high unit pressures.

Synthetic lubricants

Because of high temperature required in the operation of gas turbine engines, it becomes necessary for the industry to develop lubricants which would retain their characteristics at temperature that will cause petroleum lubricants to evaporate and break down into heavy hydro carbons. These new lubricants are called synthetic because they are not made from natural crude oil. Typical synthetic lubricants are Type I, alkly diester oils (MIL-L-7808) and Type II poly-ester oil (MIL-L-23699).

Semisolid lubricants

Extremely heavy oils and greases are examples of semi solid lubricants. Grease is a mixture of oil and soap. It gives good service when applied periodically to certain units, but its consistency is such that it is not suitable for circulating or continuous-operating lubrication systems.

Fluid lubricants

Fluid lubricants (oil) are used as the principal lubricant in all types of internal combustion engines because they can be pumped easily and sprayed readily and because they absorb and dissipated heat quickly and provides a good cushioning effect.

LUBRICANT REQUIREMENTS AND FUNCTIONS

Characteristic of aircraft lubricating oil

1. It should have the proper body (viscosity) at the engine operating temperature usually encountered by the airplane in which it is used; It should be distributed readily to the lubricated parts and it must resist the pressure between the various lubricated surfaces.
2. It should have high anti friction characteristics to reduce the frictional resistance of the moving parts when separated only by boundary films. An ideal fluid lubricant provides a strong oil film to prevent metallic friction and to create a minimum amount of oil friction or oil drag.
3. It should have maximum fluidity at low temperature to ensure a ready flow and distribution when starting at low temperature. Some grades of oil become practically solid in cold weather, causing high oil drag and impaired circulation.
4. It should have minimum changes in viscosity with changes in temperature to provide uniform protection where atmosphere temperature very widely. The viscosity of oils is greatly affected by temperature changes. e.g. at high operating temperature, the oil may be so thin that the oil film is broken and the moving parts wear rapidly.
5. It should have high anti wear properties to resist the wiping action that occurs wherever microscopic boundary film are used to prevent metallic contact. The theory of fluid lubrication by an oil film, is as long as oil film is not broken, the external friction (fluid friction) of the lubricants takes place of the metallic sliding friction which other wise would exists.
6. It should have maximum cooling ability to absorb as much heat as possible from all lubricated surfaces and especially from the piston head and skirt. One of the reasons for long using liquid lubricants is that they are

effective in absorbing and dissipating heat. Another reason is that liquid lubricant can be readily pumped or sprayed. Many engine parts, especially those carrying heavy load with high rubbing velocities are lubricated by oil under direct pressure. Where direct-pressure lubrication is not practical a spray or mist of oil provides the required protection. Regardless of the method of application, the oil absorbs the heat and later dissipates it through the coolers.

7. It should offer maximum resistance to oxidation thus minimizing harmful deposits on the metal parts.
8. It should be non corrosive to the metals in the lubricated parts.

Functions

1. It lubricates, thus reducing the friction between moving parts.
2. It cools the various parts of the engine.
3. It tends to seal the combustion chamber by filling the walls, thus preventing the loss of compression past the piston rings.
4. It tends to clean the engine by carrying sludge and residue away from the moving engine parts and depositing them in the oil filter.

COMPONENTS AND CHARACTERISTICS OF LUBRICATING SYSTEMS

The lubrication oil is distributed to the various moving parts of a typical internal combustion engine by one of three methods:- (1) Pressure (2) Splash (3) A combination of pressure and splash.

Pressure lubrication

In a typical lubrication system, a mechanical pump supplies oil under pressure to the bearings. The oil flows into the inlet or suction side of the pump, usually located higher than the bottom of the oil sump so that sediment which falls into the sump will not be drawn into the pump. The pump may by either the eccentric vane type or the gear type, but the gear type is most commonly used. It forces oil into an oil manifold, which distributes the oil to the crankshaft bearings. A pressure relief valve is usually located near the outlet side of the pump.

Oil flows into the main bearings through holes drilled in crankshaft to the lower connecting rod bearings. Each of these holes through which the oil is fed is located so that the bearing pressure at that point will be as low as possible.

Oil reaches a hollow camshaft through a connection with the end bearings or the main oil manifold and then flows out of the hollow camshaft to the various camshaft bearings and cams.

The engine cylinder surfaces receive oil sprayed from the crankshaft and also from the crankpin bearings. Since oil seeps slowly through the small crankpin clearances before it is sprayed on the cylinder walls, considerable time is required for enough oil to reach the cylinder walls, especially on a cold day when oil flow is more sluggish. This situation is one of the chief reasons for diluting the engine oil with engine fuel for starting in very cold weather.

SPLASH LUBRICATION AND COMBINATION SYSTEM

Pressure lubrication is the principle method of lubrication used on all aircraft engines. Splash lubrication may be used in addition to pressure lubrication on aircraft engines, but it is never used by itself. Hence aircraft engine lubrication system are always of either the pressure type or the combination pressure-and-splash type.

Principle components of a lubrication system

An aircraft engine lubrication system includes pressure oil pump, an pressure relief valve, an reservoir/either as part of the engine or separate from the engine) an oil pressure gauge, and oil temperature gage, oil filters, and the necessary piping and connections. In addition many lubrication system include oil coolers and/or temperature regulating devices. Oil dilution system are included when they are deemed necessary for cold weather starting.

Typical lubrication system

In this system, oil is contained in a separate tank and is forced under pressure from a pressure pump through a hollow crankshaft to lubricate the engine, the oil is then drained into the sump from which it is pumped by a scavenge pump, which has a 20% greater capacity then a pressure pump, to ensure that the oil does not accumulate in the engine and it passes through an oil cooler and is returned to the tank.

The by pass around the filter is provided to prevent damage in case of failure to clean the filter. In this event dirty oil is considered definitely a lesser evil than no oil at all. The by pass is also a safety device allowing the oil to return to the tank without damaging the parts such as the filter in case the pressure should become excessive. The pressure relief valve provides a means of regulating the oil pressure, the oil pressure is monitored by the means of an oil pressure gage on the instrument panel of the aircraft.

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CHAPTER: 7
VENTILATION AND COOLING SYSTEM

PISTONENGINE

Aircraft engines may be cooled either by air or by liquid, Excessive heat is undesirable in any internal-combustion engine for three principal reasons: (1) It adversely affects the behaviour of the combustion of the fuel-air charge, (2) it weakens and shortens the life of the engine parts, (3) it impairs lubrication.

If the temperature inside the engine cylinder is too great, the fuel mixture will be preheated and combustion will occur before the proper time. Premature combustion causes detonation “knocking,” and other undesirable conditions. It will also aggravate the overheated condition and is likely to result in failure of pistons and valves.

The strength of many of the engine parts depends on their heat treatment. Excessive heat weakness such parts and shortens their life. Also, the parts may become elongated, warped, or expanded to the extent that they sieze or lock together and stop the operation of the engine.

Excessive heat “cracks” the lubricating oil, lowers its viscosity, and destroys its lubricating properties.

COOLING

Approximately one third of the energy produced by burning fuel in the engine cylinders manifests itself as heat which is not converted to power. If this heat were not dissipated failure of some of the engine components indirect contact with the combustion process would take place, and the engine would fail. Some of the heat is rejected with the exhaust gases but the remainder must be dissipated so as to maintain the working parts of the engine at a temperature which will ensure that the materials are not adversely affected. However a minimum temperature must be maintained to assist proper lubrication and to provided good fuel evaporation. There are two main methods of cooling, by liquid or by air, but some internal parts are also cooled by heat transfer through the medium of the lubricating oil.

Liquid cooling

In liquid cooled engines the cylinders are surrounded by a water jacket, through which liquid (normally a mixture of ethylene glycol and water) is passed to absorb and remove excess heat. The jackets are parts of a closed system, which also includes an engine driven pump and a radiator which projects into the airstream. Some systems are provided with thermostatically controlled radiator shutter, by means of which a suitable coolant temperature is maintained during flight. Liquid cooling has been used mainly on military aircraft engines, but a few examples may still be for on civil aircraft.

Air cooling

With air cooled engines, all those parts of the engine which needs to be cooled (mainly the cylinders) are provided with fins, the purpose of which is to present a larger cooling surface to the air flowing round them. The size of the fins is related directly to the quantity of heat to be dissipated, thus the fins on the cylinder head gave a greater area than those on the cylinder barrel. Baffles and deflecters are fitted round the cylinders to ensure that all surfaces are adequately cooled and the whole engine is cowled to direct airflow past the cylinder to reduce drag. The exit path from the cowling is generally provided with gills or flaps, by means of which the mass air flow may be adjusted to control cylinder temperature. Because air cooling is simple and little maintenance is required, air cooled engines are used in the majority of piston engine aircraft.

AIR-COOLINGOFTURBINEENGINES

Introduction

An important feature in the design of a gas turbine engine is the need to ensure that certain parts of the engine, and in some instances certain accessories, do not absorb heat from the gas stream to an extent that is detrimental to their safe operation. This is achieved by allowing a controlled amount of air from the compressors to flow around these components. The internal cooling airflow is also used to cool the oil, and to pressurize the main bearing housing and various drive shaft seals to maintain the efficiency of the lubrication system by preventing oil leakage. External cooling of the engine power plant is also essential to prevent the transfer of heat to the aircraft structure.

Internal cooling

The heat transferred by the turbine blades from the main gas stream to the turbine discs, the bearings of the rotating assemblies, and the engine main casings, is absorbed and dispersed by directing a flow of comparatively cool air over these components. High and low pressure airflows are provided by taking air from both compressors; on completion of its function, the air is either vented overboard or joins the exhaust gas flow.

On the type of engine shown in figure, low pressure (L.P.) air is directed forward to cool the L.P. compressor shaft, and rearward to cool the high pressure (H.P.) compressor shaft L.P. air is also taken from the by-pass duct and fed to the rear of the engine to cool the turbine shafts; the separate L.P. airflows then mix and are ducted overboard after cooling the outer surface of the H.P. turbine shaft. An intermediate H.P. compressor flow is used to cool the rear half of the H.P. compressor shaft and the rear face of the final compressor disc before passing through tubes into the bypass duct.

The H.P. compressor outlet air is directed rearwards onto the turbine discs and, because the flow moves outwards across the discs into the exhaust gas flow, the hot exhaust gases, being of a lower pressure, are prevented from the

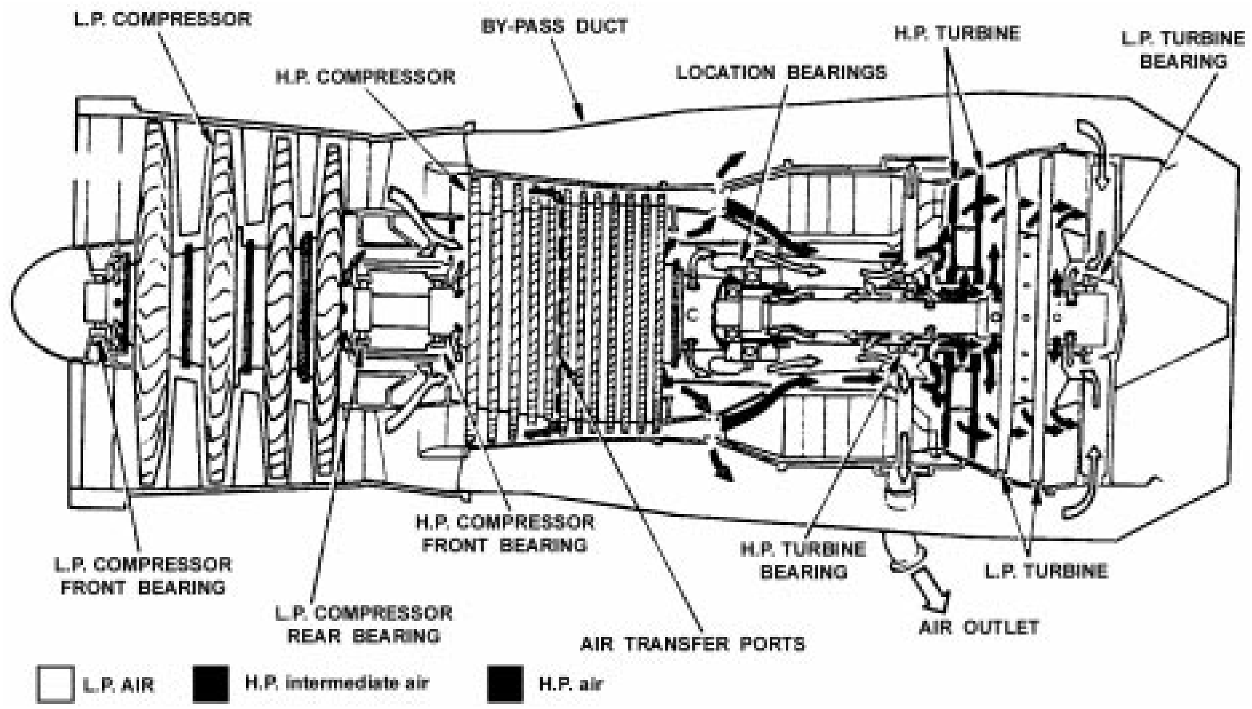

Fig. 1. General internal airflow pattern.

flowing inwards. The outward flow of cooling air is controlled by inter stage air seals of multi-groove construction that provide the faces of the turbine discs with an adequate cooling airflow. The inter stage air seals are formed in two sections; the front section forms the least restriction, the pressure difference across it being less than that across the rear section. This prevents any inward flow of exhaust gases across the seals.

Due to the high temperature of the gas stream at the turbine inlet, it is often necessary to provide internal air cooling of the nozzle guide vanes and, some instances, the turbine blades. Turbine blade life will depend not only on the form of the cooled blade, but also the method of cooling; therefore, the flow design of the blade internal passages is important. Recent development of turbine blade cooling is to provide an efficient axial flow of cooling air directly into the blade instead of a pressure feed through the inter stage; this is known as pre-swirl feed.

A variation in temperature of the cooling air will give some indication of engine distress, either by a thermal switch operating a warning indicator at a predetermined temperature of through a thermocouple system to a temperature gauge.

Accessory cooling

A considerable amount of heat is produced by some of the engine accessories, of which electrical generator is an example, and these may often require their own cooling circuit. Air is sometimes ducted from intake louvres in the engine cowlings or it may be taken from a stage of the compressor.

When an accessory is cooled during flight by atmospheric air passing through louvres, it is usually necessary to provide an induced circuit for use during static ground running, when there would be no external air flow. This is achieved by allowing compressor delivery air to pass through nozzles situated in the cooling air outlet duct of the accessory. The air velocity through the nozzles creates a low pressure area which forms an ejector, so inducting a flow of atmospheric air through the intake louvres. To ensure that the ejector system operates only during ground running, the flow of air from the compressor is controlled by a pressure control valve. This valve is electrically opened by a switch that is operated when the weight of the aircraft is supported by the undercarriage.

External cooling and ventilation

The engine bay or pod is usually cooled by atmospheric air being passed around the engine and then vented over board. Conventional cooling during ground running may be provided by using an internal cooling outlet vent as an ejector system. An important function of the cooling air flow is to purge any inflammable vapours from the engine compartment.

By keeping the airflow minimal, the power plant drag is minimized and, as the required quantity of fire extinguishant is in proportion to the zonal airflow . Any fire outbreak would be of low intensity.

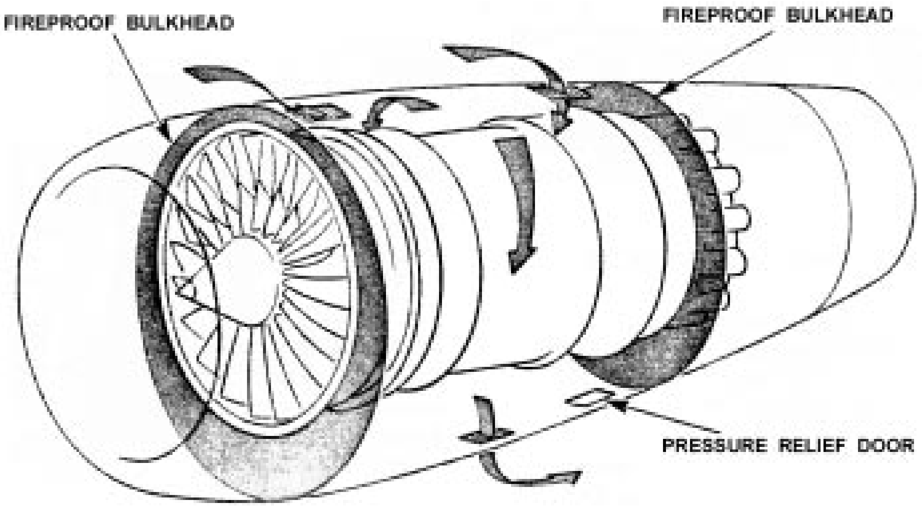

Fig.2. A typical cooling and ventilation system.

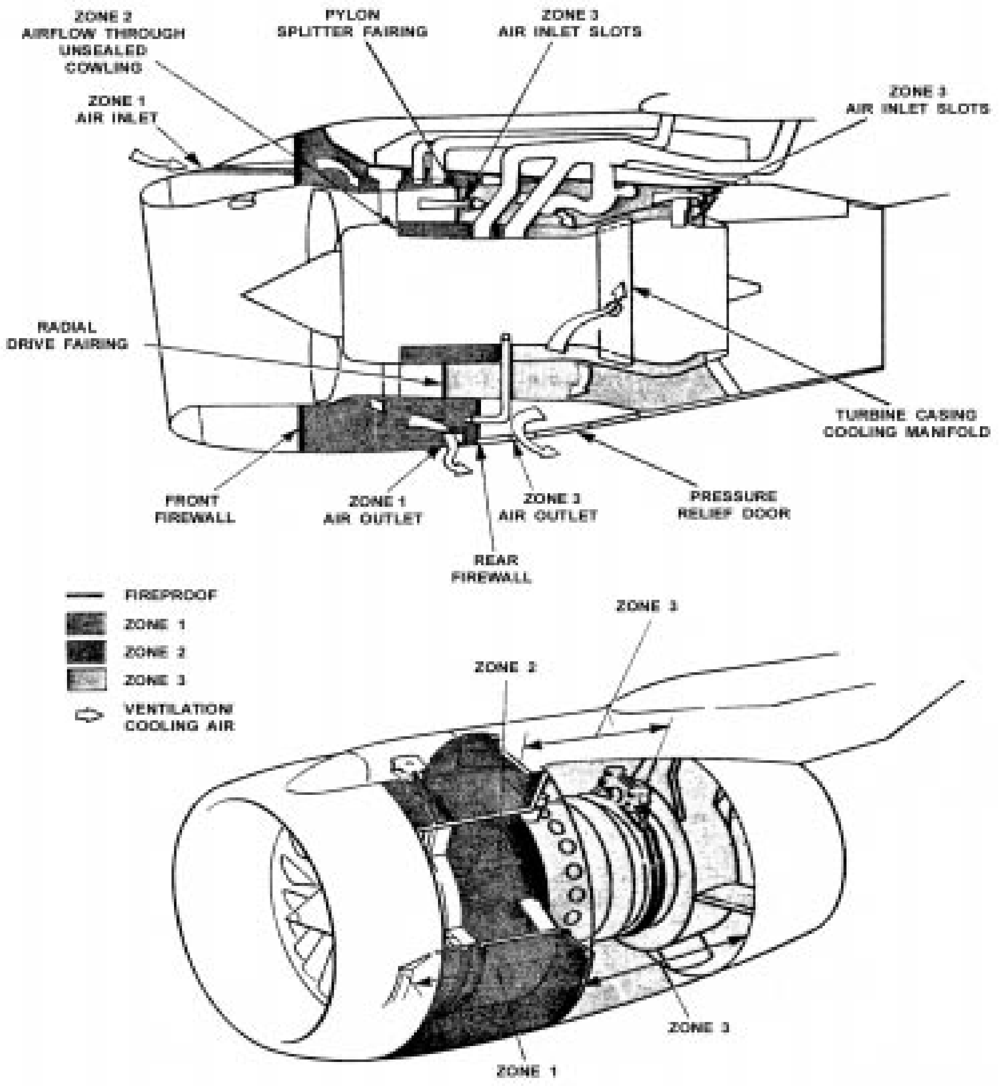

Fig. 3.Cooling and ventilation-fan engine.

A fireproof bulkhead is also provided to separate the ‘cool’ area or zone of the engine, which contains the fuel, oil, hydraulic and electrical systems, from the ‘hot’ area surrounding, the combustion, turbine and exhaust sections of the engine. Differential pressures can be created in the two zones by calibration of the inlet and outlet apertures to prevent the spread of fire from the hot zone.

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CHAPTER: 8
PISTON ENGINE CARBURATION SYSTEM

INTRODUCTION

This Chapter deals with piston-engine fuel requirements, and the methods used to provide a satisfactory supply of combustible mixture to the cylinders under all operating conditions.

FUEL

The fuel used in piston engines is a hydrocarbon fuel, with a composition of approximately 85% carbon and 14% hydrogen by weight. When the fuel is mixed in suitable proportions with air, and ignited, the carbon and hydrogen combine with the oxygen in the air and form carbon dioxide and water vapour; the nitrogen in the air, being an inert gas, is chemically unchanged, but performs the useful function of slowing down the combustion process and maintaining acceptable combustion temperatures.

The most important qualities required in a fuel are outlined in paragraphs to below.

Anti-Knock Rating

This is an indication of the resistance afforded by the fuel to the onset of detonation. It is explained earlier, that an increase in power can be obtained by increasing cylinder pressure, but that can cause detonation. It is important, therefore, that the fuel has good resistance to detonation in order to enable satisfactory engine power to be developed.

Calorific Value

This is a measure of the amount of heat which can be obtained from a given weight of fuel. This is important in an aircraft, since the weight of fuel carried will limit the payload. The calorific value of a given volume of fuel is also of significance, as in some cases the fuel tank capacity may be a limiting factor.

Volatility

This is the tendency of a fuel to evaporate. Volatility should be high enough to permit easy starting under cold atmospheric conditions, but not so high that vapour will form in the pipelines and pumps at high temperatures and/ or low pressures, and interrupt fuel flow or upset the metering system.

Corrosive Effects

A fuel must not be corrosive to any components in the engine or fuel system.

Although fuels of various grades have been available in the past, and have been specified for use in particular engines, there is a tendency for fuel companies to reduce the number of grades available, to standardize on Grade 100L (dyed green) or Grade 100LL (dyed blue), which both contain a small quantity of tetraethyl lead to assist in preventing detonation and are covered by Specifications D Eng RD 2485 and 2475 respectively. The problems associated with the use of these fuels in engines which were designed for use with non-leaded fuel, or fuel with a lower lead content, are outlined in CAA Airworthiness Notice No. 70.

MIXTURE REQUIREMENTS

Air and fuel vapour will burn if mixed in the ratios of between approximately 8:1 and 20:1 by weight. However, complete combustion will only occur at a ratio of approximately 15:1 (i.e. all the hydrogen and carbon in the fuel, and all the oxygen in the air will be used up), and this is known as the chemically-correct, or stoichiometric, mixture, which produces the highest combustion temperatures. With weaker mixtures (i.e. those containing less fuel), and richer mixtures (i.e. those containing more fuel), the excess air or fuel will absorb some of the heat of combustion and lower the temperature of the burning gases.

Although the chemically-correct mixture strength would theoretically produce the highest temperature, and therefore power, in practice mixing and distribution are less than perfect and this results in some regions being richer and others being weaker than the optimum strength; this variation may exist between one cylinder and another. A slight excess of fuel does not have much effect on power since all the oxygen is still consumed and the excess of fuel simply serves to reduce slightly the effective volumetric efficiency; in fact its cooling effect can be to some extent beneficial. Weak mixtures, however, rapidly reduce power since some of the inspired oxygen is not being utilized, and this power reduction is much greater than that resulting from slight richness. It is, therefore, quite common to run engines (when maximum power rather than best fuel economy is the objective) at somewhat richer than chemically-correct mixtures (i.e. about 1205:1) to ensure than no cylinder is left running at severely reduced power from being unduly weak.

A mixture which is weaker than the chemically-correct mixture, besides burning at lower temperatures, also burns at a slower rate (because of the greater proportion of inert gas in the cylinder). Power output thus decreases as the mixture is weakened, but, because of the increase in efficiency resulting from cooler burning, the fall in power is relatively less than the decrease in fuel consumption. Thus the specific fuel consumption (i.e. the weight of fuel used per horsepower per hour) decreases as mixture strength is weakened below 15:1. For economical cruising at moderate power, air/fuel ratios of 18:1 may be used, an advance ignition timing being necessary to allow for the slower rate of combustion.

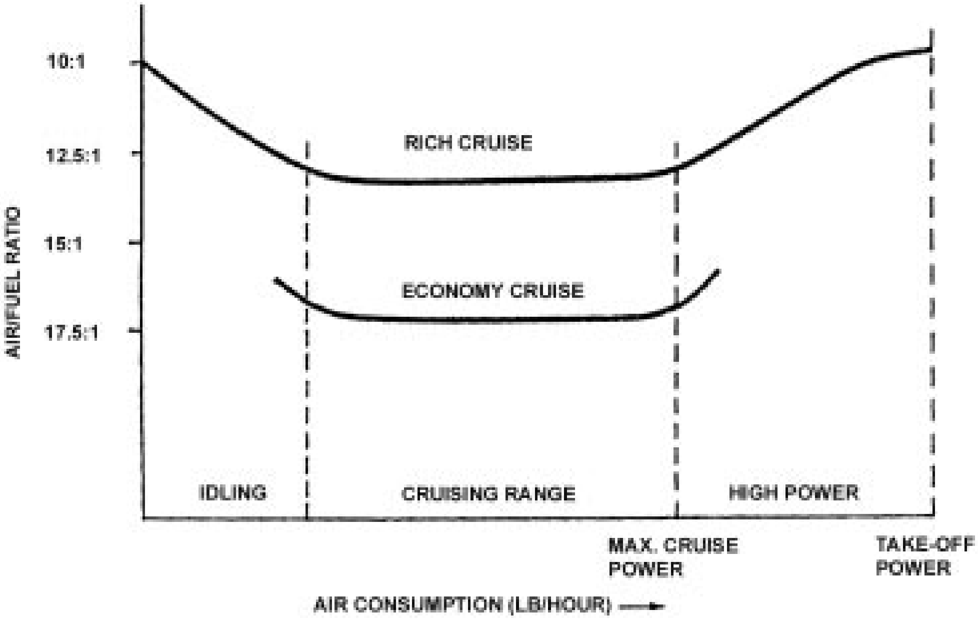

Fig.1. Typical Mixture Requirements.

At high power settings, the increase in engine speed and cylinder pressure results in an increase in mixture temperature, and this could lead to detonation. Cooling may be provided by using excess fuel, an air/fuel ratio as low as 10:1 often being used at maximum power. The excess fuel, other than acting as a coolant, is otherwise wasted, because there is no oxygen available to burn it.

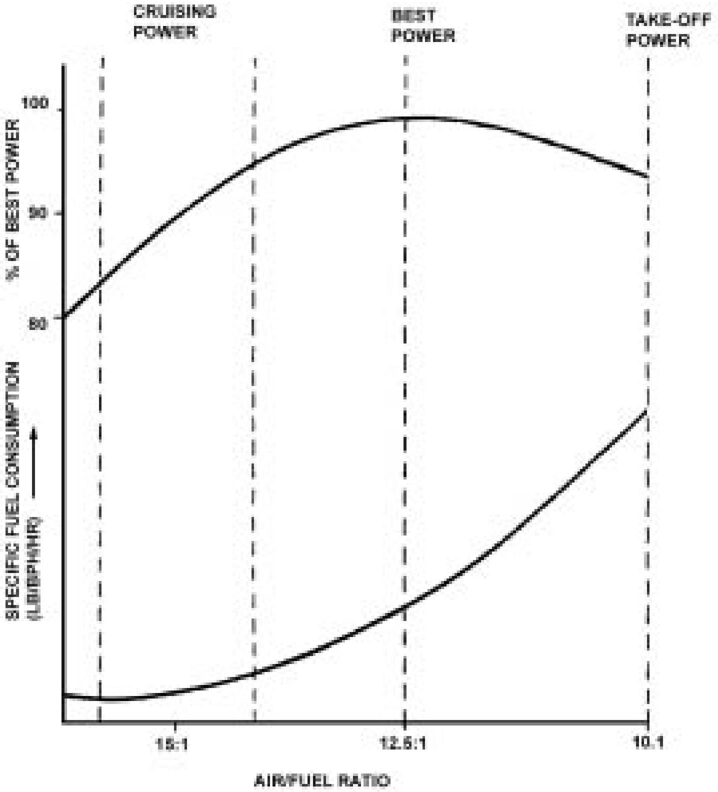

Fig.2. Fuel Consumption and Power.

A richer mixture is also required at low engine speeds. The valves are timed to provide efficient operation at high engine speeds, and at low speeds the exhaust gas velocity is much less, with the result that exhaust gases are left in the cylinder during the period of valve overlap. This residual gas results in dilution of the incoming mixture, which must be progressively enriched as speed is decreased, in order to maintain smooth running.

The mixture requirement is, therefore, dependent upon engine speed and power output. A typical air/fuel mixture curve is shown in Fig.1, and Fig.2 illustrates the relationship between fuel consumption and power.

Fuel is supplied to the engine as a liquid, but must be burnt as a mixture of fuel vapour and air; a number of engine and carburettor design features are, therefore, aimed at producing thorough atomization and mixing of the charge.

Initial atomization of the fuel in a float-chamber carburettor is achieved in a diffuser or discharge nozzle, by mixing the air and fuel before they pass into a venturi, but in other carburation systems the fuel is forced through a discharge nozzle under positive pressure, and better atomization is achieved.

Vaporization is often assisted by warming the induction passages, by designing the engine so that much of the induction manifold is either submerged in hot oil in the engine sump, or is surrounded by an exhaust-heated jacket.

On some engines the fuel/air mixture passes through a distribution impeller, which is attached to the crankshaft and rotates at engine speed. This has the effect of thoroughly mixing the fuel and air, and assisting in vaporization.

The carburation system must control the air/fuel ratio in response to throttle setting, at all selected power outputs from slow-running to full throttle, and during acceleration and deceleration ; it must function at all altitudes and temperatures in the operating range, must provide for ease of starting and may incorporate a means of shutting off the fuel to stop the engine. The float-chamber carburettor is the cheapest and simplest arrangement and is used on many light aircraft; it is very prone to carburettor icing, however, and may be affected by flight manoeuvres. The injection carburettor is a more sophisticated device and meters fuel more precisely, thus providing a more accurate air/fuel ratio ; it is also less affected by flight manoeuvres, and is less prone to icing. The direct- (or port-) injection system provides the best fuel distribution and is reputed to be the most economical ; it is unaffected by flight manoeuvres and is free from icing.

Any of these carburettor types may be fitted with a manual mixture control, by means of which the most economical cruising mixture may be obtained. However, in order to assist the pilot in selecting the best mixture, some aircraft are fitted with fuel flowmeters, exhaust gas temperature gauges or exhaust gas analysers.

FLOAT-CHAMBER CARBURETTORS

In a float-chamber carburettor (Fig.3), airflow to the engine is controlled by a throttle valve, and fuel flow is controlled by metering jets. Engine suction provides a flow of air from the air intake, through a venturi in the carburettor, and thence to the induction manifold ; this air speeds up as it passes through the venturi, and a drop in pressure occurs. Fuel is contained in a float chamber, which is supplied by gravity, by an electrical booster pump or by an engine-driven fuel pump, and a constant level is maintained in the chamber by the float and needle-valve. Where fuel pumps are used, a fuel pressure gauge is included in the system to provide an indication of pump operation. Air intake or atmospheric air pressure acts on the fuel in the float chamber, which is connected to a fuel discharge tube located in the throat of the venturi. The difference in pressure between the float chamber and the throat of the venturi, provides the force necessary to discharge fuel into the airstream. As airflow through the venturi increases so the pressure drop increases, and a higher pressure differential acts on the fuel to increase its flow in proportion to the airflow. The size of the main jet in the discharge tube determines the quantity of fuel which is discharged at any particular pressure differential, and therefore controls the mixture strength. The simple carburettor illustrated in Fig.3 contains all the basic components necessary to provide a suitable air/fuel mixture over a limited operating range. A number of alterations are necessary, however, in order to provide for all the requirements of an aircraft engine, and these are discussed in following paragraph.

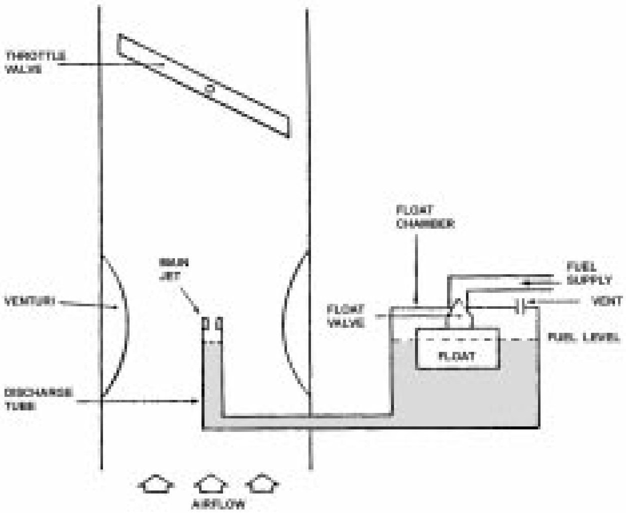

Fig.3. Simple Carburettor.

Main Metering System

As engine speed and airflow through the venturi increase, the proportion of fuel to air rises as a result of the different flow characteristics of the two fluids. To overcome this effect, some carburettors are fitted with a diffuser such as is illustrated in Fig.4. As engine speed is progressively increased above idling, the fuel level in the diffuser well drops, and progressively uncovers more air holes. These holes allow more air into the discharge tube, and by reducing the pressure differential prevent enrichment of the air/fuel mixture. The process of drawing both air and fuel through the discharge tube also has the effect of vaporizing the fuel more readily, particularly at low engine speeds. On carburettors not fitted with a diffuser, air at atmospheric pressure is bled into the discharge tube, and produces similar results ; the air bleed method is illustrated in Fig.5.

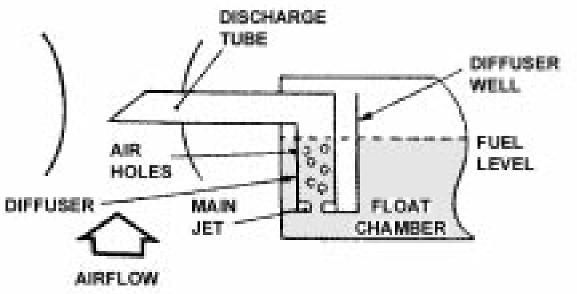

Fig.4. Diffuser.

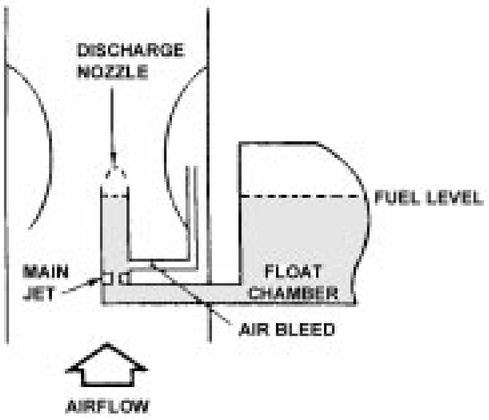

Fig.5. Air Bleed

Idling

When the engine is idling, the air velocity through the venturi is too low to provide an adequate discharge of fuel. However, the air passing through the gap between the throttle valve and the wall of the throttle body has sufficient velocity to provide the necessary reduction in pressure. One or more small holes are drilled through the wall at this position, and ducted to the float chamber ; an air bleed is in-corporated in this duct, to provide a mixture of air and fuel to an idling jet. On some carburettors the idling mixture is adjusted by varying the total quantity of mixture discharged into the airstream, whilst on others a fuel metering jet is placed in the idling duct, and adjustment is obtained by varying the air bleed. A cut-off valve may be fitted to the duct, to enable the engine to be stopped. A typical idling system is shown in Fig.6.

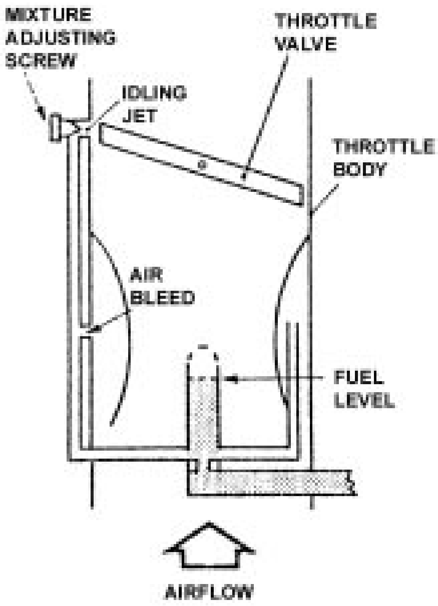

Fig.6. Idling System.

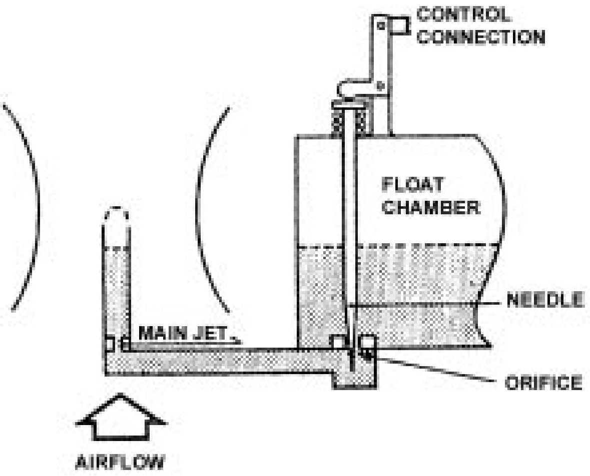

Fig.7. Needle-Type Mixture Control.

Mixture Controls

The pressure drop at the venturi is a measure of air mass flow and is proportional to $d \times v^2$ (where d is air density and v is air velocity). Fuel mass flow resulting from the pressure drop in the venturi is proportional to $D \times V^2$ (Where D is fuel density and V is fuel velocity). At constant density therefore, v^2 and V^2 are both proportional to the pressure drop, and changes in fuel mass flow will be proportional to changes in air mass flow (engine speed), except at idling. At constant air velocity however, the pressure drop in the venturi is directly proportional to changes in air density, whilst fuel mass flow, being of constant density, remains proportional to pressure drop ; changes in air density therefore, produce less than proportional changes in fuel flow. This results in a progressive increase in richness with increased altitude, which would be unacceptable for economic operation. Float-chamber carburettors are normally fitted with a manual mixture control, which is used for correcting the enrichment resulting from decreased air density, and also for leaning (weakening) the mixture for economical cruising. The carburettors fitted to some large engines have automatic mixture control for altitude.

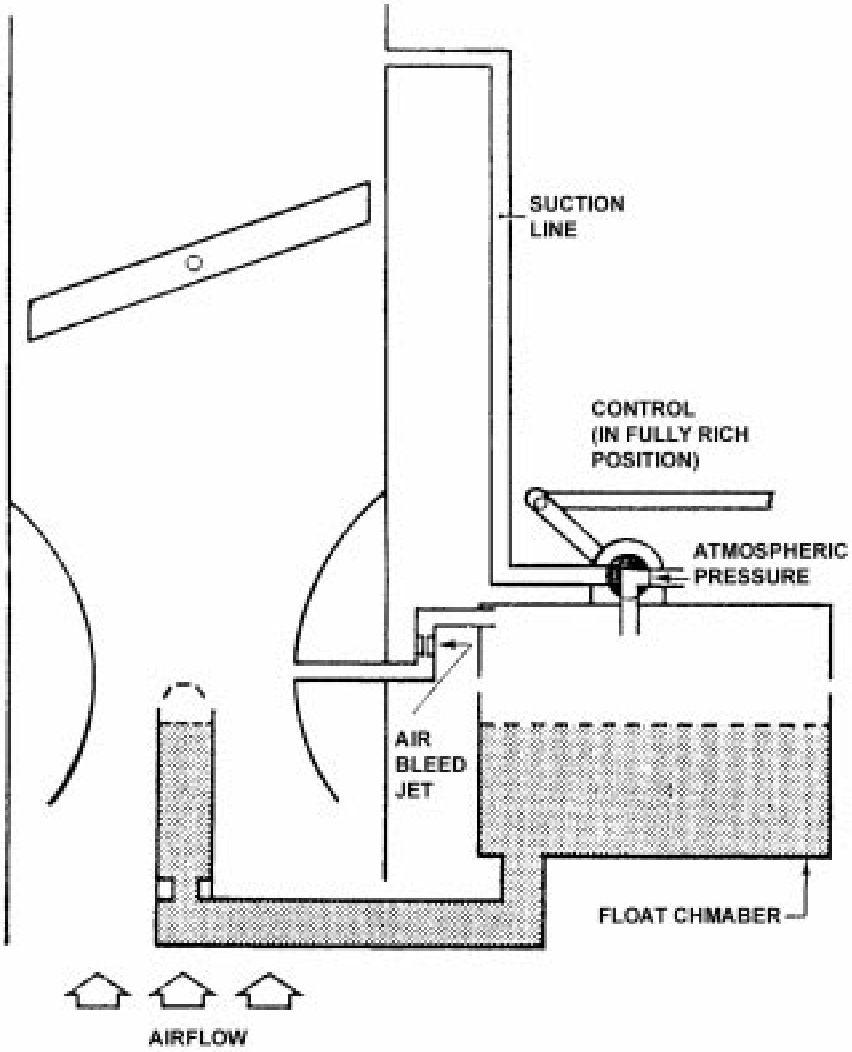

Fig.8. Air Bleed Mixture Control.

With a needle-type mixture control, such as is illustrated in Fig.7, a cockpit lever is connected to a needle valve in the float chamber. Movement of the cockpit lever raises or lowers the needle and varies fuel flow through an orifice to the main jet. The position of the needle, therefore, controls the mixture strength, and in the fully-down position will block fuel flow to the main jet, thus providing a means of stopping the engine.

The mixture control shown in Fig.8 operates by controlling the air pressure in the float chamber, thus varying the pressure differential acting on the fuel. A small air bleed between the float-chamber and the venturi tends to reduce air pressure in the float-chamber, and a valve connected to a cockpit lever controls the flow of air into the float chamber. When this valve is fully open the air pressure is greatest, and the mixture is fully rich ; as the valve is closed the air pressure decreases ; thus reducing the flow of fuel and weakening the mixture. In the carburettor illustrated the valve also includes a pipe connection to the engine side of the throttle valve ; when this pipe is connected to the float-chamber by moving the cockpit control to the ‘idle cut-off’ position, float-chamber air pressure is reduced and fuel ceases to flow, thus stopping the engine.

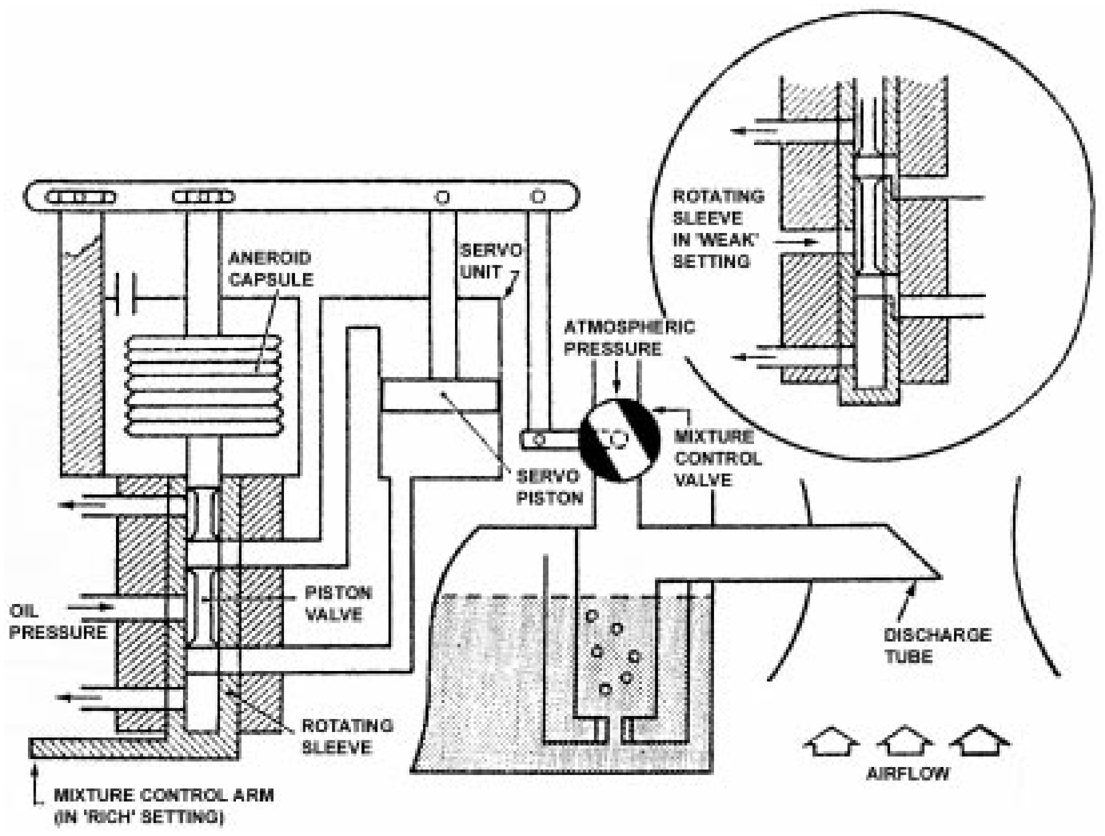

Fig.9. Automatic Mixture Control.

An automatic mixture control usually consists of an aneroid capsule, which controls the position of a valve admitting atmospheric pressure into the mixture discharge tube; this action alters the pressure difference between the venturi and the float-chamber, thus varying fuel flow. Fig.9. illustrates a mixture control which uses engine oil pressure to position the mixture control valve according to atmospheric pressure. The aneroid-capsule chamber is open to atmosphere, and, as altitude increases, the capsule expands and lowers the piston valve. The piston valve directs oil to the lower side of the servo piston, which moves upwards in the servo unit; oil from above the servo piston returns through the piston valve to the scavenge line. The servo piston is connected to the mixture control valve and to the top of the aneroid capsule, and while opening the control valve also raises the aneroid capsule and piston valve, until the piston valve regains its neutral position and blocks oil flow to the servo unit. The reverse situation occurs as atmospheric pressure increases. The linkage is set by the manufacturer so that movement of the servo piston is proportional to changes in atmospheric pressure, and opening of the mixture control valve is proportional to fuel flow requirements.

In this system, the mixture normally supplied is in accordance with the rich curve shown in Fig.1. Economical cruising is obtained by resetting the neutral position of the piston valve, so that the servo piston adopts a higher position in the servo unit, irrespective of altitude. A sleeve around the piston valve is provided with two sets of holes, so that when the sleeve is rotated 90^0 (by movement of a two-position cockpit control), a second pair of holes is brought into line with the ducts leading to the servo unit. These holes are so formed that when their outlet points are lined up with the servo unit ducts, their inlet points (inside the sleeve) are situated higher up the sleeve, as shown in the small sketch in Fig.9. The piston valve must, therefore, be moved to a higher position before it can block the servo unit ducts, and this results in an upward movement of the servo piston, which alters the position of the mixture control valve to give a weaker mixture.

The cockpit controls are so arranged that, as power is increased above the cruising range, the mixture lever is automatically moved to the rich setting.

Power Enrichment

At power settings above the cruising range, a richer mixture is required to prevent detonation. This rich mixture may be provided by an additional fuel supply, or by setting the carburettor to provide a rich mixture for high power and then bleeding off float-chamber pressure to reduce fuel flow for cruising.

Fig.10. illustrates a carburettor with an additional needle valve, which may be known as a power jet, enrichment jet, or economizer. The needle valve, which is connected to the throttle control, is fully closed at all throttle settings below that required to give maximum cruising power at sea-level, but as the throttle is opened above this setting the needle

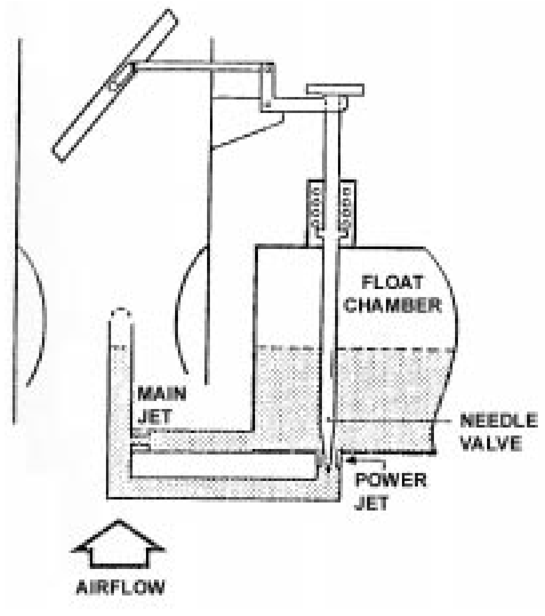

Fig.10. Power Jet.

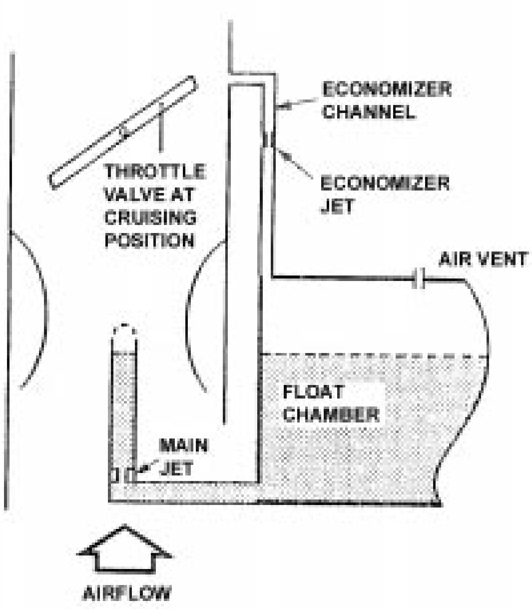

Fig.11. Back-Suction Economizer.

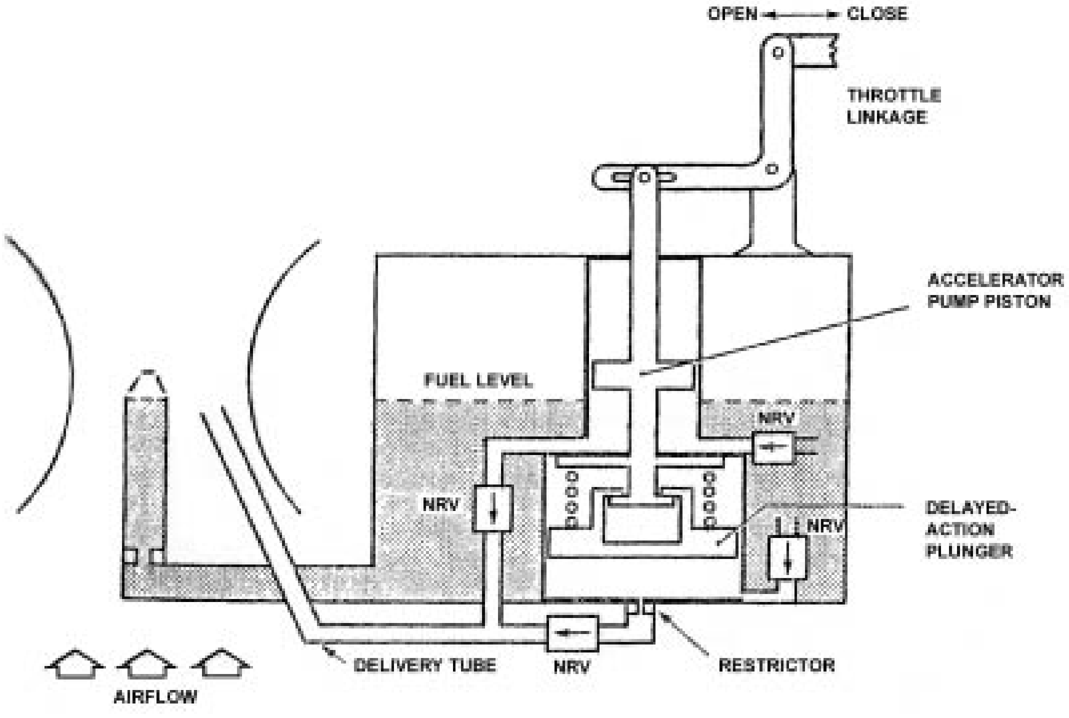

Fig.12. Accelerator Pump.

valve opens progressively until, at full throttle, it is fully open. On some engines the power jet is operated independently of the throttle, by means of a sealed bellows which is actuated by manifold pressure. In this way high-power enrichment is related to engine power rather than to throttle position.

An air-operated economizer (known as a back-suction economizer) is illustrated in Fig.11. When the throttle valve is at a high power setting, the pressure of air flowing past the valve is only slightly below atmospheric pressure, and will have little effect on air pressure in the float chamber; thus a rich mixture will be provided. As the throttle is closed to the cruising position, air flowing past the throttle valve creates a suction, which is applied to the float-chamber through the economizer channel and air jet. The reduced float-chamber pressure reduces fuel flow through the main jet to provide the economical mixture required for cruising.

Acceleration

If the throttle valve is opened quickly, airflow responds almost immediately and a larger volume of air flows through the carburettor. The fuel metering system, however, responds less quickly to the changing conditions, and a temporary weakening of the mixture will occur before fuel flow again matches airflow. This condition is overcome by fitting an accelerator pump, which is linked directly to the throttle and forces fuel into the venturi whenever the throttle is opened. In some pumps a controlled bleed past the pump piston allows the throttle to be opened slowly without passing fuel to the engine; in other pumps an additional delayed-action plunger is incorporated to supply an additional quantity of fuel to the engine for a few seconds after throttle movement has ceased. The latter type of pump is illustrated in Fig.12.

INJECTION CARBURETTORS

These carburettors do not have a vented float-chamber, and do not rely on venturi suction to discharge fuel into the airstream; they provide a pressurized, closed system, which meters fuel according to airflow and mixture strength requirements, and sprays it into the induction manifold, downstream of the throttle valve. The various components in the system normally include an air throttle valve, an engine-driven pump, a pressure regulator, a fuel control unit, an automatic mixture control, an accelerator pump and a discharge nozzle; these components combine to provide for all the air/fuel mixture requirements of the engine. A typical injection carburettor is illustrated in Fig.13.

Throttle Body

This unit contains the throttle valve, discharge nozzle, accelerator pump, venturis and automatic mixture control, and provides various connections to the regulator and fuel control unit.

Throttle Valve

Unlike the throttle valve on a float-chamber carburettor, the throttle valve on an injection carburettor controls only the airflow to the engine. Since no fuel passes the throttle valve, there is less likelihood of carburettor icing.

Discharge Nozzle

The discharge nozzle contains a spring-loaded valve and diaphragm. The valve opens when metered fuel pressure acting on the diaphragm is sufficient to overcome spring pressure, and acts as a relief valve to hold the pressure in the discharge line relatively constant, regardless of fuel flow.

Accelerator Pump

The accelerator pump is automatic in operation, and supplies additional fuel during rapid throttle opening.

Venturis

The throttle body contains two venturis, the smaller, or ‘boost’, venturi discharging into the throat of the main venturi. This arrangement provides a larger pressure drop than could be obtained with a single venturi. A number of impact tubes are arranged around the top of the main venturi, and provide air-intake pressure to the regulator. The purpose of the venturis is to measure airflow through the throttle body.

Automatic Mixture Control

This unit contains a sealed bellows, which responds to changes in air pressure and temperature. It is connected to a tapered needle in the duct supplying air intake pressure to the regulator, and provides the means of automatically varying fuel flow with changes in air density.

Fuel Pumps

The engine-driven fuel pump is generally a positive-displacement type pump, with a capacity in excess of the maximum fuel requirements of the engine. Since the carburettor relies on fuel being supplied at a positive pressure, an electrically-operated booster pump is also included in the fuel system, both to supply fuel in the event of failure of the engine-driven pump and for use during engine starting. A fuel pressure gauge is fitted to provide an indication of pump operation.

Regulator

The regulator is attached to the throttle body, and is designed to regulate the pressure drop across the jets in the fuel control unit according to airflow through the throttle body. It consists of two pairs of chambers, each pair being separated by a flexible diaphragm. Referring to Fig.13, chamber A is ducted to air-intake pressure, chamber B is ducted to boost-venturi suction, chamber C is ducted to metered fuel pressure and chamber D is supplied by unmetered fuel pressure. The air and fuel diaphragms, and the sealing diaphragm between chambers B and C, are all attached to the stem of the fuel valve, which is opened or closed by the air and fuel forces in the four chambers. Fuel is delivered from the fuel pump to chamber E of the regulator, which also contains a filter and vapour vent valve. The vent valve allows any vapour in the fuel to escape and return to the aircraft tanks, thus preventing it from upsetting the balance of the carburettor.

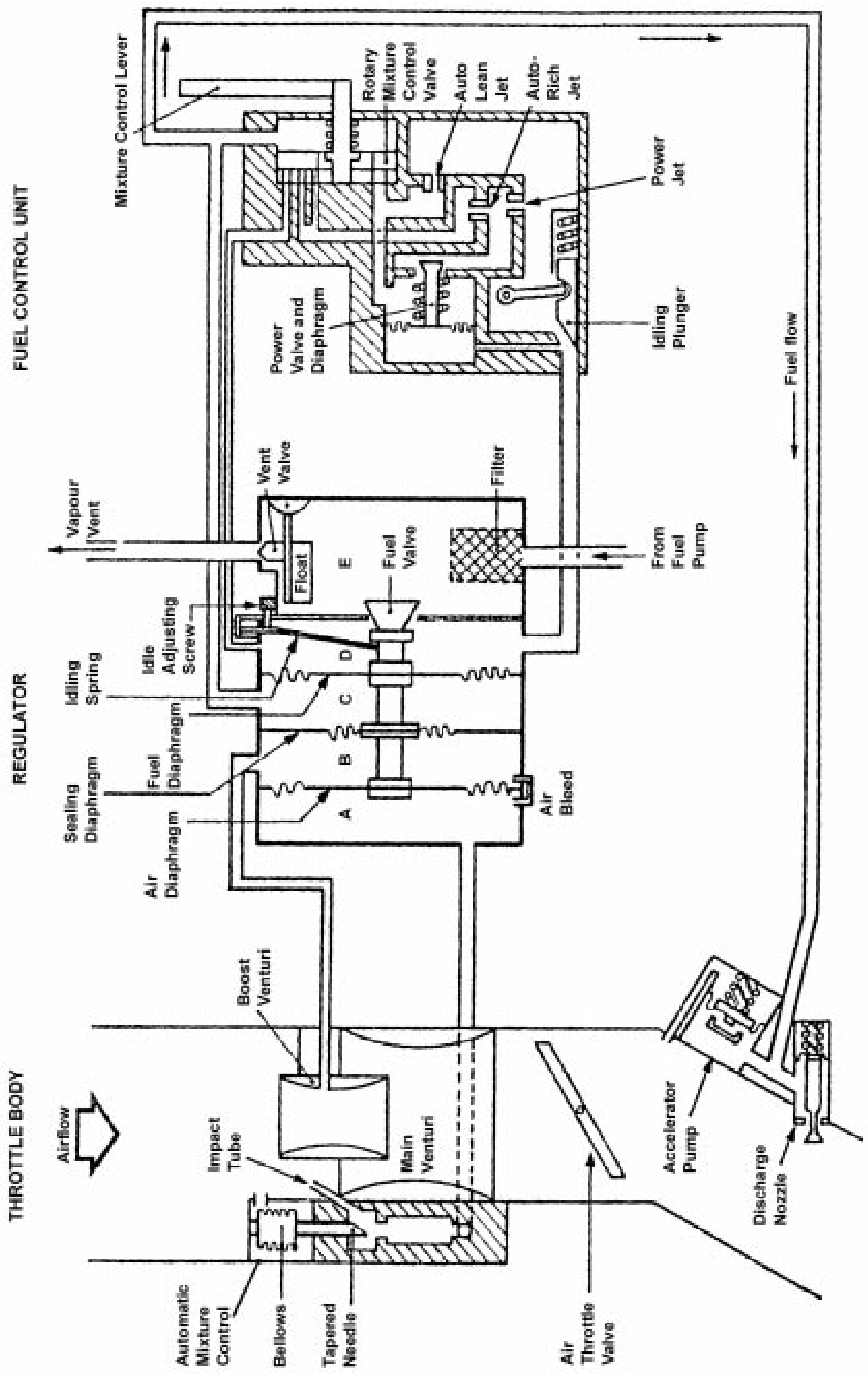

Fig.13. Typical Injection Carburettor.

Fuel Control Unit

The fuel control unit is attached to the regulator, and contains all the metering jets and valves. The manual mixture-control lever is connected to a rotary mixture-control valve, which determines which jets are in operation. The valve consists of a stationary member, with ducts leading to the auto-rich and auto-lean jets, and a rotating member which covers or uncovers the ducts according to its position. A pressure-operated valve opens the passage from the power jet, and a plunger connected to the pilot's throttle, adjusts fuel flow in the idling range. It should be noted that if two holes or jets are connected in series, it is the smaller jet or hole which, combined with the pressure drops across the jets, controls fuel flow. Operation of the mixture control is illustrated in Fig.14.

With the manual mixture control lever in the 'idle cut-off' position, all the fuel passages in the rotary valve are blocked, and no fuel flows to the engine.

With the manual mixture control lever set to 'auto-lean', the largest passage in the rotary valve is partially uncovered, and fuel flows past the idling plunger, through the auto-lean jet and mixture control valve to the discharge nozzle. Fuel flow depends on the size of the auto-lean jet, and on the difference in pressure between the metered and the unmetered fuel.

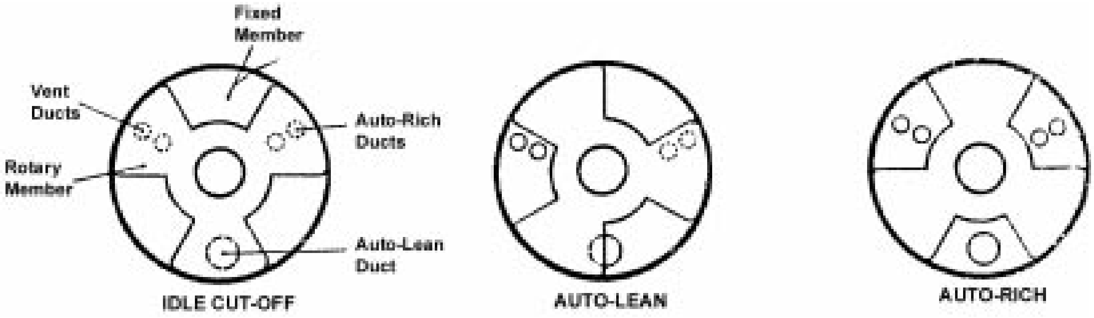

Fig.14. Rotary Mixture Control Valve.

With the manual mixture control lever set in the 'auto-rich' position, all the fuel passages through the mixture control valve are uncovered, and fuel flows past the idling plunger, through both the auto-lean and auto-rich jets, through all holes in the rotary valve and to the discharge nozzle. When the power valve is opened, additional fuel flows through the power jet and the large hole in the mixture control valve. Fuel flow in this setting depends on which jets are in operation, and on the difference in pressure between the metered and unmetered fuel.

Basic Operation

The difference in pressure between chambers A and B in the regulator, is dependent upon the difference between intake pressure and boost-venturi suction. This pressure difference will increase with airflow through the engine, and will result in movement of the air diaphragm and opening of the fuel valve. With the fuel valve open, fuel will flow into chamber D, through the metering jets in the fuel control unit, back to chamber C in the regulator, and thence to the discharge nozzle. When pressure in chamber C and the discharge line reaches a predetermined value, the discharge nozzle valve will open and fuel will be discharged into the induction manifold. The unmetered fuel pressure in chamber D will always be greater than the metered fuel pressure in chamber C, because of the restriction of the jets, and the fuel diaphragm will move in opposition to the air diaphragm to close the fuel valve. However, the pressure in chamber D will decrease as the fuel valve closes, and a balanced condition will be reached when air and fuel forces are equal. In this condition, fuel flow through the jets will be in proportion to the difference in pressure between chambers C and D. Since the pressure difference across the fuel diaphragm is equal to the pressure difference across the air diaphragm, fuel flow will be proportional to, and governed by, the airflow through the throttle body, and the engine will be supplied with correct basic air/fuel mixture at all engine speeds.

Alteration of the mixture control setting will change the fuel flow, and alter the pressure drop across the jets. The diaphragm and fuel valve assembly will reposition to maintain the pressure drop established by the particular airflow, resulting in a change in mixture strength according to the size of the jets in operation. Similarly, any change in fuel pump pressure or fuel pressure at the discharge nozzle would affect the balanced condition of the diaphragm assembly and would be followed by a corrective movement of the fuel valve.

Idling

At very low engine speeds, airflow through the throttle body is insufficient to provide an effective pressure drop through the boost venturi, and is unable to regulate fuel flow. To overcome this problem, a spring is attached to the fuel valve stem in chamber D, and holds the fuel valve off its seat at idling speeds. Fuel may then flow through chamber D to the fuel control unit, where the idling plunger, which is connected to the pilot's throttle, meters fuel flow for the first few degrees of throttle opening. At larger throttle openings the idling plunger is withdrawn from the fuel passage and has no effect on fuel flow.

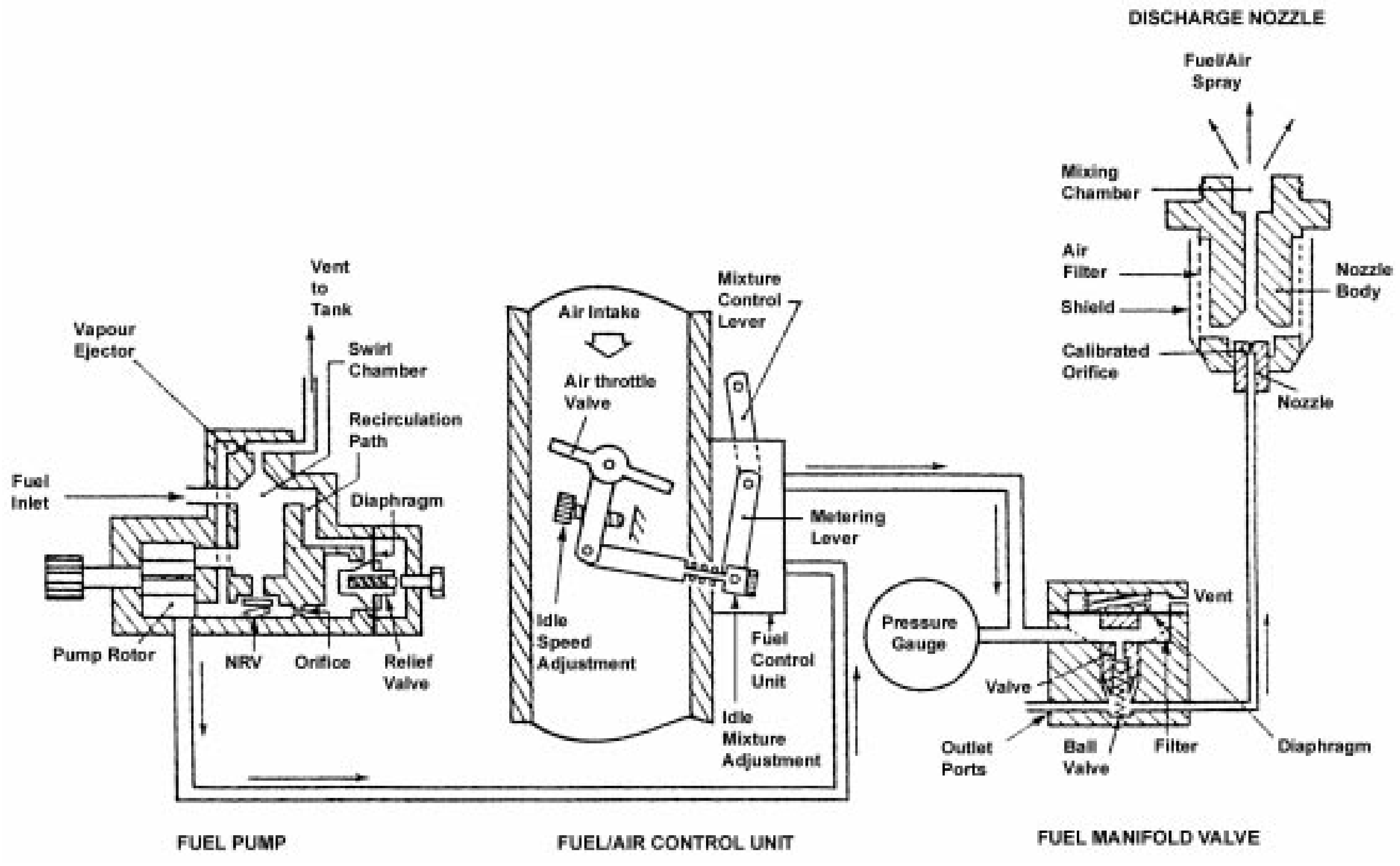

Fig.15. Fuel Injection System.

Mixture Control

The manually-operated mixture control varies fuel flow according to engine operating conditions and was described earlier. Automatic correction of fuel flow for changes in air density (temperature and pressure) is provided by the automatic mixture control. A small air bleed between chambers A and B in the regulator causes a slight but continuous flow of air from the impact tubes to the boost venturi, thus providing the means of controlling the pressure in chamber A, and thereby regulating fuel flow. At sea level the bellows is fully compressed and the tapered needle is withdrawn from the air passage leading to chamber A ; full intake pressure acts on the air diaphragm, so that fuel valve opening and fuel flow are at the maximum for the particular airflow condition. As the aircraft climbs and atmospheric pressure decreases, the bellows expands and inserts the tapered needle into the air passage, thus restricting the flow of air into chamber A, and reducing the differential pressure across the air diaphragm. As a result the fuel valve closes slightly and fuel pressure is adjusted to match air pressure, thus reducing fuel flow through the jets to maintain the required mixture strength.

Acceleration

A number of different fully-automatic accelerator pumps may be used with injectors; a single-diaphragm pump is illustrated in Fig.13, and operation of this type is explained below.

Air pressure on the engine side of the throttle valve varies according to throttle position, being lowest when the throttle is at the idling position and progressively increasing as the throttle is opened. This air pressure is ducted to the rear of the accelerator-pump diaphragm. At small throttle openings air pressure and fuel discharge-nozzle pressure are sufficient to overcome the force of the spring and withdraw the diaphragm, allowing the pump fuel chamber to fill. When the throttle is opened, the air pressure increases and the spring is able to force the diaphragm forward, discharging fuel to the nozzle. This fuel, added to the normal metered fuel flow, is sufficient to overcome any temporary weakening of the mixture.

DIRECT FUEL INJECTION

Direct fuel injection is often employed on aircraft piston engines, but is of the low-pressure, continuous-flow type rather than the intermittent-flow type commonly used on diesel engines, in which calibrated quantities of fuel are injected into the cylinders at a particular time in the operating cycle. In the low-pressure, continuous-flow method, fuel is sprayed continuously into the inlet port of each cylinder; the advantages claimed for the method are low operating pressure, good fuel distribution, freedom from icing problems and the ability to use a pump which does not have to be timed to the operating cycle. Some fuel injectors operate on similar principles to the injection carburettor described earlier, with a distribution system replacing the discharge nozzle, but a different method of operation is used on some engines, and this latter method is described in paragraphs below.

In this system, the size of a variable orifice is controlled according to the position of the air throttle valve, and the pressure of fuel passing through this orifice is controlled according to engine speed. Mixture strength is varied by a manually-operated control, which adjusts the fuel pressure for altitude or operating conditions, as necessary. Because of the method of operation of the injector, no special idling arrangements are required and a separate priming system for engine starting is unnecessary. The main components in the system are a fuel pump, a fuel/air control unit, a fuel manifold (distribution) valve, and discharge nozzles for each cylinder. In addition, a normal throttle valve controls airflow to the engine, and a fuel pressure gauge is fitted to enable mixture adjustments to be made. The system is illustrated in Fig.15.

Fuel Pump

The fuel pump is a positive-displacement, vane-type pump, which is driven by gearing from the engine crankshaft; total pump output is, therefore, proportional to engine speed. The pump supplies more fuel than is required by the engine, and a recirculation path is provided; a calibrated orifice and relief valve in this path ensure that the pump delivery pressure is also proportional to engine speed. Fuel enters the pump through a swirl chamber in which vapour is separated from liquid fuel; the vapour is ejected from the pump by a jet of pressurized fuel, and returned to the fuel tank. When the pump is not operating, a spring-loaded valve in the base of the swirl chamber allows fuel under positive pressure to by-pass the pump, so allowing an electrically-operated booster pump to be used for engine starting and in an emergency. The booster pump is often a two-speed pump, providing a low pressure for normal back-up use, and a high pressure for use in the event of main fuel pump failure.

Fuel/Air Control Unit

This unit is mounted on the intake manifold and contains three control elements.

The air throttle assembly contains the air throttle valve, which is connected to the pilot's throttle lever and controls airflow to the engine. The intake manifold has no venturi or other restriction to airflow.

The fuel control unit is attached to the air throttle assembly, and controls fuel flow to the engine by means of two rotary valves. One valve, the metering valve (Fig.16), is connected to the air throttle, and by means of a cam-shaped end face controls fuel flow to the fuel manifold valve according to the position of the air throttle; thus fuel flow is proportioned to air flow and provides the correct air/fuel ratio. The second valve, the mixture valve (Fig.17), is connected to the pilot's mixture control lever, and by means of a contoured end face, bleeds off fuel pressure applied to the metering valve. Thus the air/fuel ratio can be varied from the basic setting of the metering valve, as required by operating conditions. A fuel pressure gauge in the system indicates metered fuel pressure, and, by suitable calibration, enables

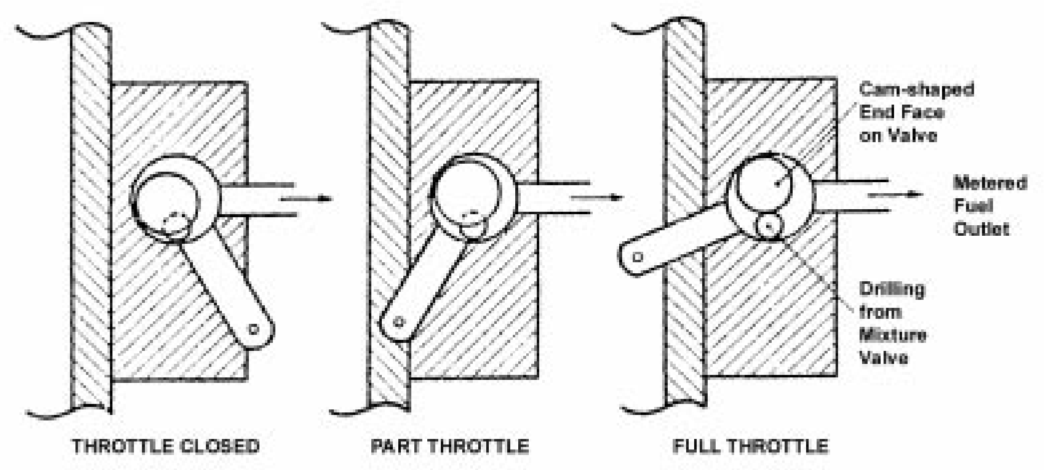

Fig.16. Metering Valve.

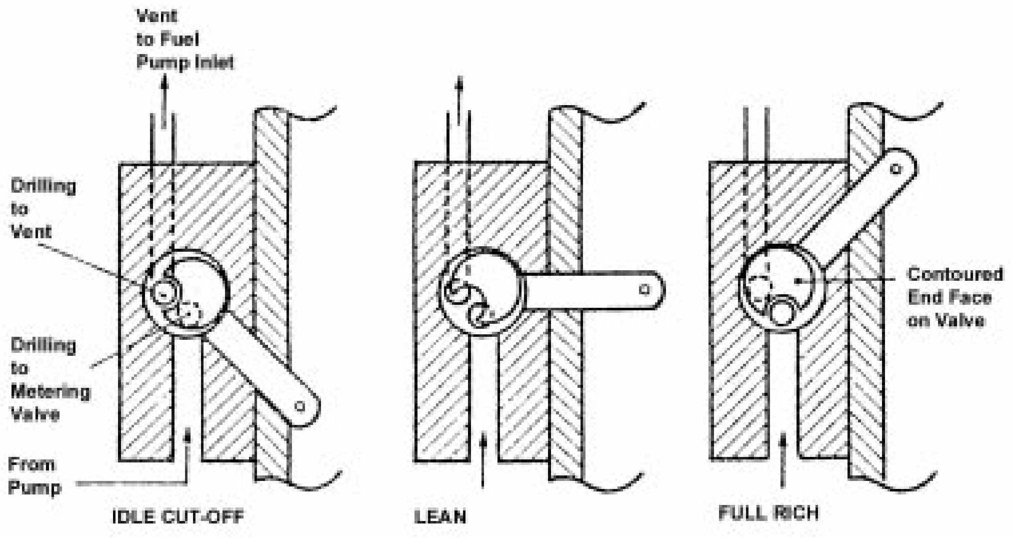

Fig.17. Mixture Valve.

the mixture to be adjusted according to altitude and power setting.

Fuel Manifold Valve

This valve is located on the engine crankcase, and is the central point for distributing metered fuel to the engine. It contains a spring-loaded diaphragm to which a valve is attached. When the engine is stopped, the spring forces the diaphragm down, and seats the valve in the bore of the valve body; all the outlet ports are closed, and no fuel can flow to the engine. As fuel pressure builds up (as a result of engine rotation or booster pump operation) and overcomes spring force, the valve lifts and opens all the ports to the discharge nozzles simultaneously. The ball valve ensures that the ports are fully open before fuel starts to flow.

Discharge Nozzle

A fuel discharge nozzle is located in each cylinder head, with its outlet directed into the inlet port. A nozzle, with a calibrated orifice, fits into the nozzle body and directs fuel through a central bore. Radial holes in the body allow air to be drawn in through a cylindrical filter which surrounds the body (at ambient air pressure on a normally-aspirated engine and at manifold pressure on a supercharged engine), and this air is mixed with the fuel before it sprays into the inlet port. Nozzles are calibrated in several ranges, and are fitted to individual engines as a set, each nozzle in a set having the same calibration.

Pressure Gauge

A pressure tapping is taken from the metered fuel pressure line to operate a fuel pressure gauge. Since the mixture strength depends on the pressure of the fuel passing through the metering valve, the gauge reading is proportional to fuel flow and may be used when adjusting mixture strength to suit flight conditions.

Fig.18 illustrates a fuel pressure gauge which is marked for use with a normally-aspirated engine, and has two ranges of pressures. The take-off segment is used for take-off and climb, and is calibrated in thousands of feet of altitude; the cruise segment is marked with maximum and minimum lines for each of a range of power settings. The fuel pressure is adjusted by means of the mixture control lever, and during take-off is set according to the airfield height, and this compensates for reduced air density. During cruising flight, fuel pressure is first set to the highest line for the power being used, and this gives best power; when engine temperatures have stabilized, the fuel pressure is then reduced to the minimum line, and this increases the air/fuel ratio to give economical cruising. For ground running, the mixture lever is left in the fully-rich position.

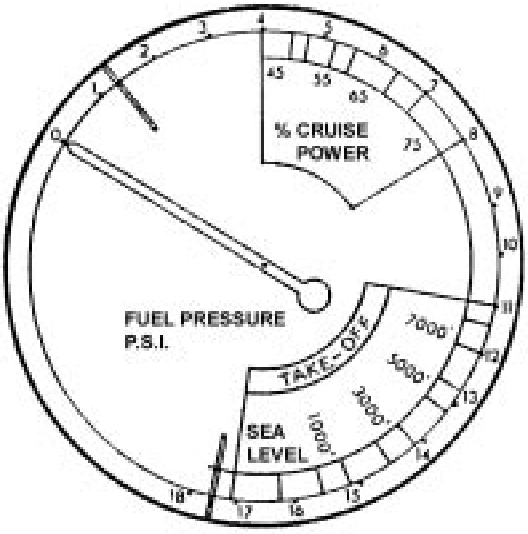

Fig.18. Fuel Pressure Gauge.

With a turbocharged engine, fuel flow at any particular power setting remains constant at all altitudes, so that the fuel pressure gauge is calibrated solely in units of pressure or flow. The correct mixture strength is obtained by adjusting the mixture control to give the fuel pressure or flow recommended for the particular flight conditions.

ENGINE ICING

Icing encountered on aircraft piston engines may be classified into two distinct types, impact icing and carburettor icing. These are formed in different ways but may occur in ambient temperatures between + 25°C and - 15°C; below - 15°C any ice which forms is too dry to adhere to the intake or throttle-body wall. Engine icing may be encountered when an aircraft is flying in cloud, rain or snow, or even in clear air provided that the humidity is sufficiently high; it may also be encountered when running an engine on the ground in similar atmospheric conditions. An air-intake temperature gauge is often fitted to provide a warning of icing conditions.

Impact Icing

This is caused by water droplets freezing on impact with the intake, throttle-body wall or impact tubes, and is most likely to occur at temperatures of 0^oC to -7^oC. Ice can build up round the air intake and disturb airflow to the carburettor, thus upsetting the air/fuel ratio and causing loss of power and even complete stoppage of the engine. Protection against this form of icing is provided by fitting a gapped ice-guard, or by providing an alternative air intake which is sheltered from the direct airflow.

A gapped ice-guard consists of a coarse wire-mesh screen mounted in front of the air intake, the gap between the screen and intake providing a passage for air should the screen become blocked with ice or snow.

Where a permanent mesh screen or air filter is fitted in the intake an alternative intake is usually provided. This may be manually operated or in the form of a spring-loaded door in the intake duct, which opens into the engine compartment. If the intake or filter becomes blocked with ice, engine suction opens the door automatically, and warm air is drawn into the engine.

Carburettor Icing

The restriction to airflow caused by the venturi and throttle valve, by increasing the velocity and reducing the pressure of the air, also reduces its temperature (Boyles Law). In addition, vaporization of the fuel also cools the air and throttle-body walls, and further reduces the temperature. When the temperature of the air passing through the carburettor is reduced below 0^oC, any moisture in the air forms into ice and builds up on the venturi and throttle valve. This ice further reduces the area through which the air must pass, and thus worsens the situation. Rough-running, loss of power, jamming of the throttle valve and eventual stoppage of the engine may result. Carburettor icing may develop in any type of carburettor in air temperatures below $+25^oC$, but is less likely to occur with direct fuel injectors since the fuel is injected downstream of the throttle valve and venturi. Protection against carburettor icing is usually effected by supplying warm air to the carburettor, or by heating the carburettor.

A hot-air intake may be provided, through which air, taken from regions adjacent to heated parts of the engine, e.g. an exhaust muff, is ducted to the carburettor. The pilot's control may be a two-position control selecting the source of air, or may be a multi-position control which progressively bleeds more hot air into the intake duct.

On some earlier carburettors, the throttle-body wall and throttle valve are hollow, and form passages through which engine oil is pumped. This warms the carburettor sufficiently to prevent icing, and assists in fuel vaporization.

Use of a manually-selected hot-air intake is usually restricted to operation below 80% power; the prolonged use of hot air at higher power settings could result in detonation.

AIR FILTERS

Dust and grit in the atmosphere could cause serious damage to a piston engine by entering the engine through the air intake and being drawn into the cylinders, thus causing excessive wear to the cylinder walls and pistons. Dust and grit could also collect in the carburettor and upset the air/fuel mixture by clogging air and fuel passages. To prevent this from happening, most engines have an air filter in the air intake, through which all air is drawn during normal operation. Air drawn in through the alternative air intake in icing conditions is not filtered, but because of the sheltered position of the intake, the air is less likely to be contaminated.

On some older aircraft the normal engine air intake has no filter, so that full advantage may be taken of ram effect to increase engine power. In these cases a separate filtered intake may be provided, and is used during flight at low altitude to prevent dust and grit from affecting the engine. A flap in the intake duct controls the source of air and is operated by a control in the cockpit.

PRIMING SYSTEM

To avoid unnecessary cranking when starting a cold engine, a quantity of neat fuel is supplied to the induction manifold so that a rich fuel/air mixture is drawn into the cylinders as soon as the engine begins to rotate. The fuel may be supplied in a number of ways, depending on the type of carburettor.

Some carburettors are fitted with a means of overfilling the float chamber, and this often takes the form of a manually-operated plunger, which presses down on the float. This action allows the fuel level to rise, and results in fuel flowing from the discharge nozzle into the induction manifold.

On carburettors which are fitted with a throttle-operated accelerator pump (Fig.12), the action of opening the throttle will result in fuel being sprayed into the induction manifold, thus priming the engine.

In many cases separate priming system is installed on the engine. This comprises a priming pump (hand-or electrically-operated), which draws fuel from one of the fuel tanks, and discharges it through a system of priming pipes and nozzles to a number of points in the induction manifold.

With fuel injection systems no separate priming system is generally required. By switching on the fuel booster pump, fuel is sprayed into the cylinder inlet ports as soon as the mixture lever is moved out of the idle cut-off position.

In order to avoid flooding an engine with neat fuel, a drain is fitted to the lowest point in the induction manifold or supercharger casing, to drain off any surplus fuel which may have collected.

PISTON ENGINE SUPERCHARGERS

GENERAL

The power output of an engine depends basically on the weight of mixture which can be burnt in the cylinders in a given time, and the weight of mixture which is drawn into each cylinder on the induction stroke depends on the temperature and pressure of mixture in the induction manifold. On a normally aspirated engine the pressure in induction manifold at full throttle is slightly less than atmospheric pressure because of intake duct losses, and the manifold pressure decreases with any increase in altitude. Power output, therefore, decreases with altitude, although some of the loss is recovered in better scavenging of the cylinders as a result of reduced back pressure on the exhaust. In order to increase engine power for take-off and initial climb, and/or to maintain engine power at high altitude, the manifold pressure must be raised artificially, and this is done by supercharging.

Where supercharger is used to increase sea-level power, rather than to maintain normal power up to a high altitude the engine will need to be strengthened, in order to resist the higher combustion pressure. For superchargers capable of producing maximum power at high altitude, a control system is necessary to prevent excessive pressure being generated within the engine at low altitude.

Centrifugal impellers (fig.19) are used for superchargers on aircraft engines and may be driven by either internal or external means; in some installations a combination of both is used. Internally-driven superchargers are driven by gearing from the engine crankshaft, and externally-driven superchargers (known as turbo-superchargers or turbochargers) are driven by a turbine which is rotated by the exhaust gases. The methods of operation and control of these two types are quite different, and are dealt with separately.

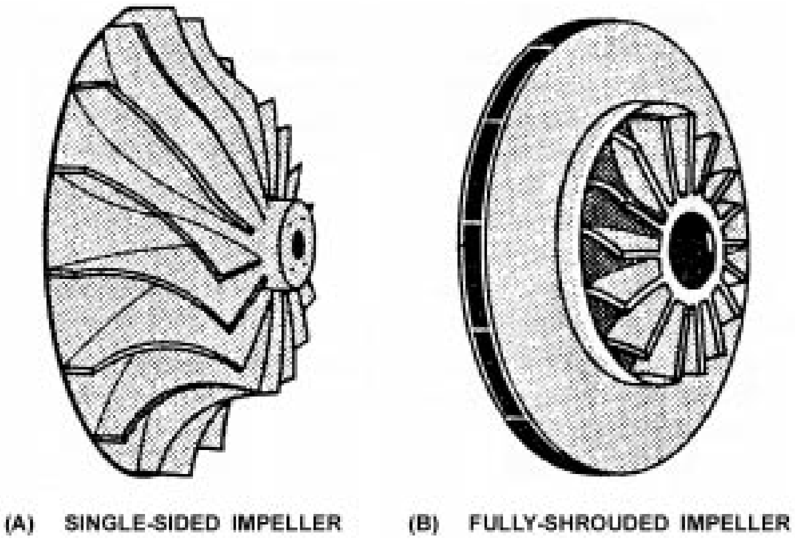

Fig.19. Supercharger Impellers.

CENTRIFUGAL IMPELLERS

Centrifugal impellers are used because they are comparatively light, are able to run at high speed, will handle large quantities of air, and are reliable.

A centrifugal impeller, is in effect, a fan which, when rotated at high speed, causes the air between the vanes to be flung outwards under centrifugal force. The air receives kinetic energy as it flows outwards between the vanes, and, as the cross-section of its path increases some of this energy is converted into pressure energy. The proportion of pressure gained in the impeller depends on the impeller's diameter, speed of rotation, and the shape of the vanes. The air leaves the impeller with considerable tangential and radial velocity and passes into a diffuser, which consists of a number of vanes fixed between the walls of the supercharger casing. The angle of the diffuser vanes is initially parallel to the path taken by the air leaving the impeller and the curvature of the vanes guides the air into a volute casing, or manifold ring, in such a way as to minimize turbulence, which would impede the flow and increase temperature. The diffuser vanes form divergent passages, which decreases the velocity and increase the pressure of the air passing through them.

The action of compressing the air rapidly increases its temperature, and reduces some of the increase in density which results from the increased pressure; this loss of density may be partially recovered either by passing the air through a heat exchanger or by spraying the fuel into the eye of the impeller so that vaporization will reduce air temperature. Other losses are caused by friction, air leakage, and buffet at the inlets to the impeller and diffuser. Friction losses may be reduced by using a shrouded impeller (fig.19B) and buffet losses may be reduced by using curved inlet vanes on the impeller, and by careful design of impeller tip clearance to suit the impeller's speed of rotation. Air leakage is causes by the pressure difference across the impeller tending to produce a reverse flow of air; this is minimized by ensuring that clearances between stationary and rotating parts are kept as small as possible, but leakage cannot be completely eliminated.

At a particular speed of rotation a centrifugal supercharger increases the pressure of air passing through the impeller in a definite ratio. Physical constraints limit the speed of rotation and size of an impeller, and so limit the compression ratio and , consequently, the power output or maximum operating altitude of the engine to which it is fitted. Compression ratios between 1.5:1 and 3:1 are generally obtainable, and any further compression necessary would have to be obtained by fitting two impellers in series.

INTERNALLY-DRIVEN SUPERCHARGERS

Internally-driven superchargers are generally used on medium and high-powered piston engines (approximately 250 bhp and above), and are fitted downstream of the throttle valve. In the past the superchargers of high-powered engines have often been driven at two speeds in order to save power at low altitudes, and have also been fitted with two impellers working in series in order to raise the over all compression ratio; some of these engines are still in use, but current engines generally employ a single impeller driven at a fixed ratio to the crankshaft (usually between 6:1 and 12:1). This type of supercharger is usually capable of maintaining sea level manifold pressure up to an altitude of 5000 to 10,000 feet, depending on the gear ratio, at Rated Power settings, In Fig.20 the power curves of a single-speed,single-stage supercharged engine are compared with a normally-aspirated but otherwise identical engine.

The power developed by the normally-aspirated engine is at a maximum at sea-level and progressively decreases as altitude is increased. The power developed by the supercharged but otherwise identical engine, at the same speed and manifold pressure, is less than that of the normally-aspirated engine at sea-level and this power loss represents the power required to drive the supercharger. However, as height is increased, the power developed by the supercharged engine at constant throttle setting increases as a result of the decreased temperature of the atmosphere. The decreased temperature increases the density of the air, and thus a greater weight of air is pumped into the cylinders for the same manifold pressure. Decreased air pressure also causes less back pressure on the exhaust, thus improving scavenging of the cylinders.

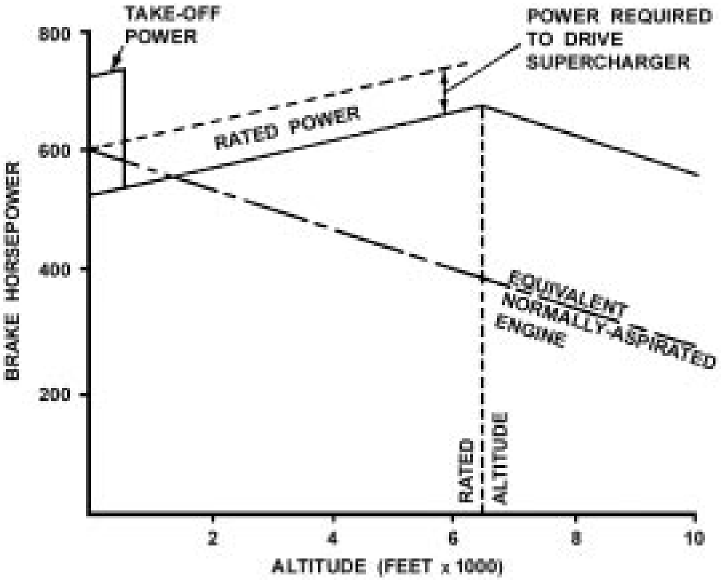

Fig.20. Power curves single speed supercharger.

At sea-level the throttle valve in the supercharged engine must be partially closed, so as to restrict manifold pressure and prevent excessive cylinder pressures, but as the aircraft climbs the throttle valve must be progressively opened (either manually or automatically) to maintain this manifold pressure. Eventually a height is reached where the throttle is fully open, and this is known as full-throttle height, above this height power will fall off as with the normally aspirated engine. Since the effect of super charger depends on the speed of rotation of the impeller, each power setting will have a different full throttle height according to the engine speed and manifold pressure used; the full-throttle height at Rated power settings is known as Rated Altitude.

Supercharger Drives

A shaft, splined into the rear of the crankshaft, provides the initial drive to the supercharger impeller and often also drives a number of accessories and transmits the drive from the starter motor to the engine. Such a shaft may incorporate a spring-driven unit, which transmit the drive through intermediate gears to the impeller pinion, and the impeller pinion may also include a centrifugal clutch.

Supercharger controls

Since a supercharger is designed to compress air and provide sea-level pressure, or greater, in the induction manifold when atmospheric pressure is low, excessive manifold pressures could be produced when atmospheric pressure is high. It is necessary therefore, to restrict throttle opening below full throttle height, and, to relieve the work load on the pilot, this is often done automatically.

An aneroid capsule, which expands or contracts under varying pressure, is normally used in any system designed to control manifold pressure. The capsule (or in some cases a stack of individual capsules) is enclosed in a chamber connected to supercharger outlet pressure, and is attached to a servo valve to control the flow of pressure oil to a servo piston. The servo piston is connected to the throttle linkage so as to adjust throttle valve opening and thus control and limit manifold pressure.

A fixed-datum control, such as is illustrated in fig. 21 is designed to prevent manifold pressure exceeding the Rated Power setting. When the engine is started, the throttle valve is only slightly open and manifold pressure is low; the capsule expands, lowering the servo valve and directing pressure oil to the underside of the servo piston which moves to the top of its cylinder. As the throttle lever is advanced, the manifold pressure rises until the capsule has contracted sufficiently to lift the servo valve and coincides with Rated Power. If the throttle lever is advanced, the manifold pressure rises until the capsule has contracted sufficiently to lift the servo valve and block the flow to the servo piston; this is the neutral position of the valve and coincides with Rated Power . If the throttle lever is advanced further, the manifold pressure will increase and the capsule will contract, lifting the servo valve and directing pressure oil to the top of the servo piston. This action moves the servo piston downwards, closing the throttle valve until manifold pressure has returned to the Rated Power settings, the decreasing atmospheric pressure results in a lower supercharger outlet, pressure and the capsule gradually expands, progressively opening the throttle valve until full-throttle height is reached. In order to enable maximum power to be obtained during take-off, a means of overriding the control unit is required; this is often in the form of a calibrated leakage from the capsule chamber which is activated by linkage to the throttle lever. The main disadvantages of the fixed-datum system is that it has no effect on the throttle valve at power settings below Rated Power, and the throttle lever must be continually adjusted when climbing or descending at a lower power. There is also some “lost motion” of the throttle lever, which is greatest at sea level and decreases with altitude, and this means that the mixture enrichment required at high-power settings must be obtained by pressure controlled devices rather than by the use of jets which are controlled by throttle movement.

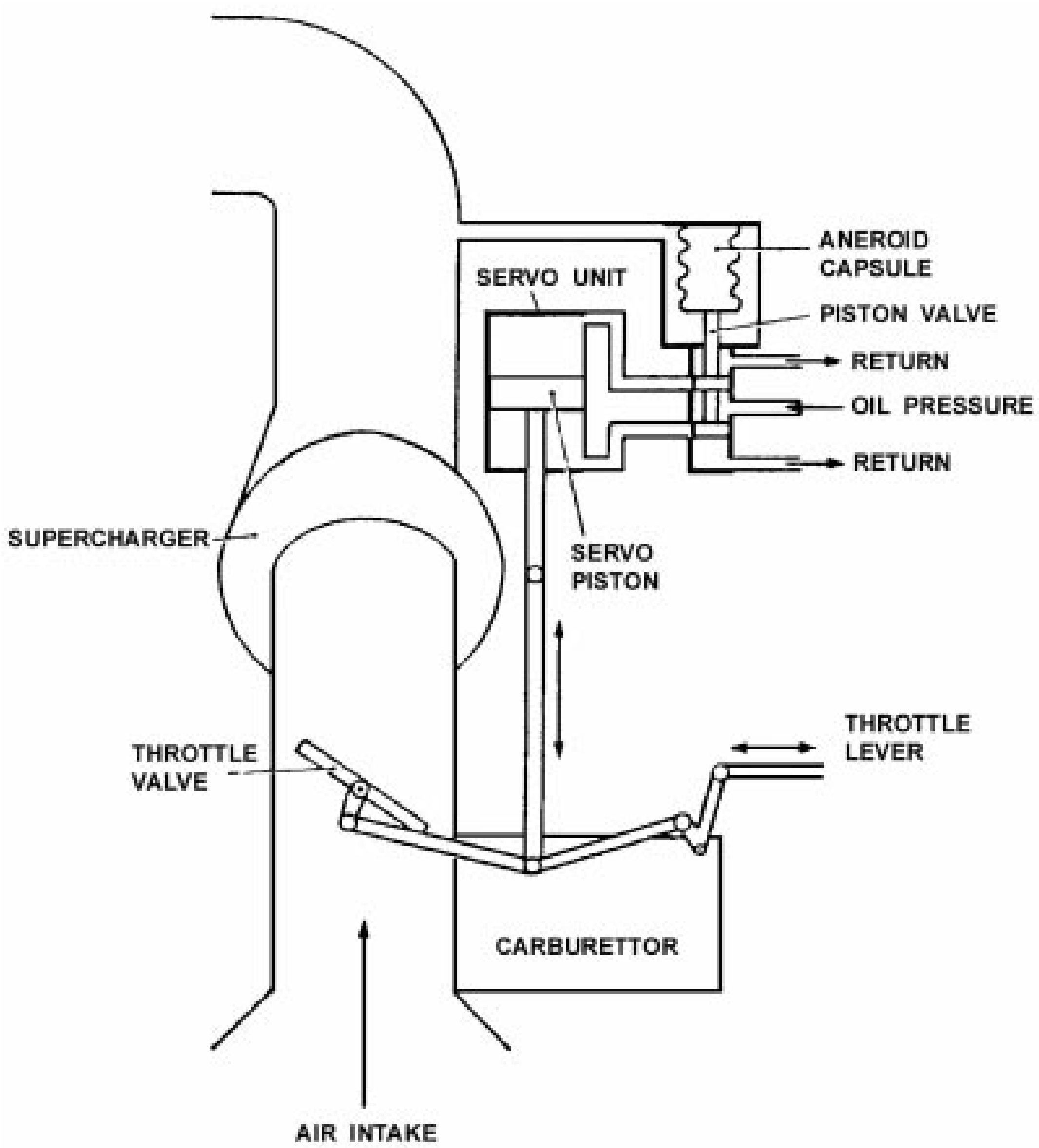

Fig. 21. Manifold pressure control.

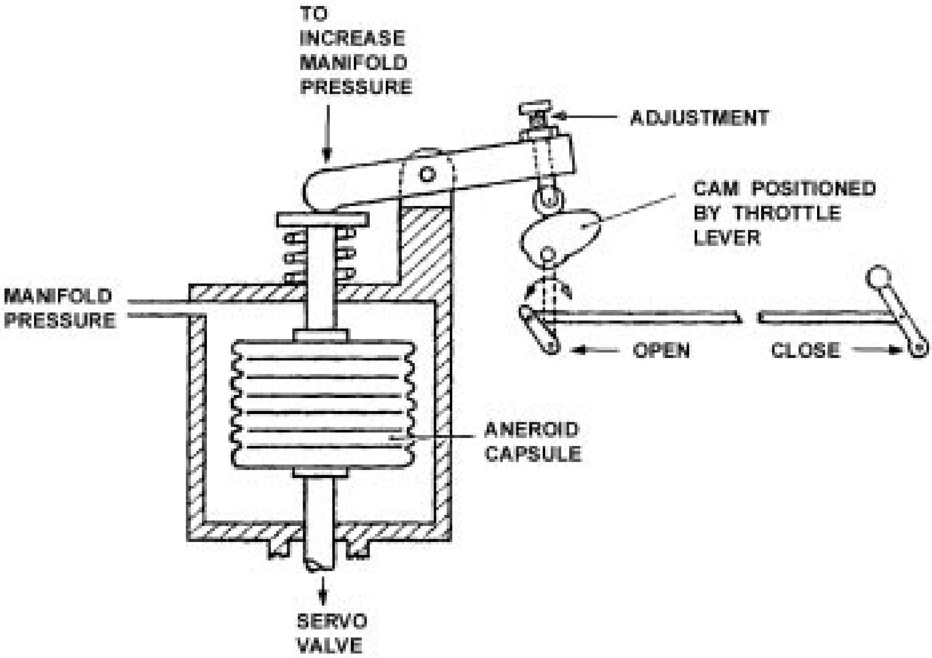

Fig. 22. Variable Datum Control.

A method used to overcome the deficiencies of the system described in the fixed datum control, is the variable datum control which is illustrated in Fig.22, A cam connected to the throttle lever controls the datum setting of the aneroid capsule; as the throttle lever is closed from the fully-open position, the cam rotates and allows the capsule to rise under spring pressure. Thus the neutral position of the servo valve varies according to throttle lever position, and enables the capsule to exercise control at whatever manifold pressure is selected by the throttle lever. There is no lost motion in the throttle lever, and adjustment on the throttle valve to compensate for changes in atmospheric pressure, is carried out automatically at any selected by the throttle lever.

When an engine is operating in the idling range the induction pressure is very low, and a reversal of flow may occur in which air or exhaust gases are drawn into the induction manifold during the period of valve overlap. This would produce an increase in pressure in the manifold, which would be communicated to the capsule chamber and, on engines fitted with a variable-datum control, would have the effect of closing the throttle valve. This would effectively prevent any acceleration, and with this type of control the cam is so contoured and adjusted that the throttle lever is the sole means of controlling the throttle valve in the idling range.

EXTERNALLY-DRIVENSUPERCHARGERS

The main differences between the an internally-driven and an externally-driven supercharger are in the method of driving the impeller and, in fact that the latter delivers compressed air to the throttle and carburettor. Externally-driven superchargers are powered by the energy of the engine exhaust gases and do not directly lower the power output of the engine they are generally known as turbo-superchargers or turbochargers. Some turbochargers are designed to maintain approximately sea-level air pressure in the engine air intake up to a high altitude, and are known as altitude turbo charger others are designed to provide an intake pressure which is higher than sea-level pressure, and thus produce a higher power output at all altitudes than would be available from an unsupercharged engine, and these are known as Ground Boosted Turbochargers. The former type may be fitted without significant engine design changes to normally-aspirated engines in order to maintain sea level power up to a high altitude but the latter may only be fitted to engines which are designed to withstand the higher stresses imposed by the higher combustion pressure.

A few large engines with internally-driven superchargers are also fitted with a turbocharger, which is used to increase the altitude at which a given power can be developed; because of the increased air temperature arising from the two stages of compression; it may be necessary to fit an inter cooler between the turbocharger and the carburettor.

A turbocharger consists of a turbine wheel and an impeller fitted on a common rotor shaft, the bearings for which are contained within a bearing housing and are lubricated by oil from the engine. The turbine and compressor casings are attached to the bearing housing and are connected to the exhaust and intake systems respectively; the compressor is shielded from the heat of the turbine, and intake or external air is ducted between the two casings to remove excess heat. The turbocharger is not necessarily an integral part of engine, but may be mounted on the engine or on the fireproof bulkhead, and shielded from combustible fluid lines in the engine bay. A typical turbocharger is illustrated in Fig. 23 and a turbo charged engine installation is illustrated in Fig.24 below.

Exhaust gases are ducted to the turbine casing, where they pass through nozzles and impinge on vanes on the turbine wheel, causing it to rotate; the gases then pass between the vanes are exhausted overboard. Since the impeller is

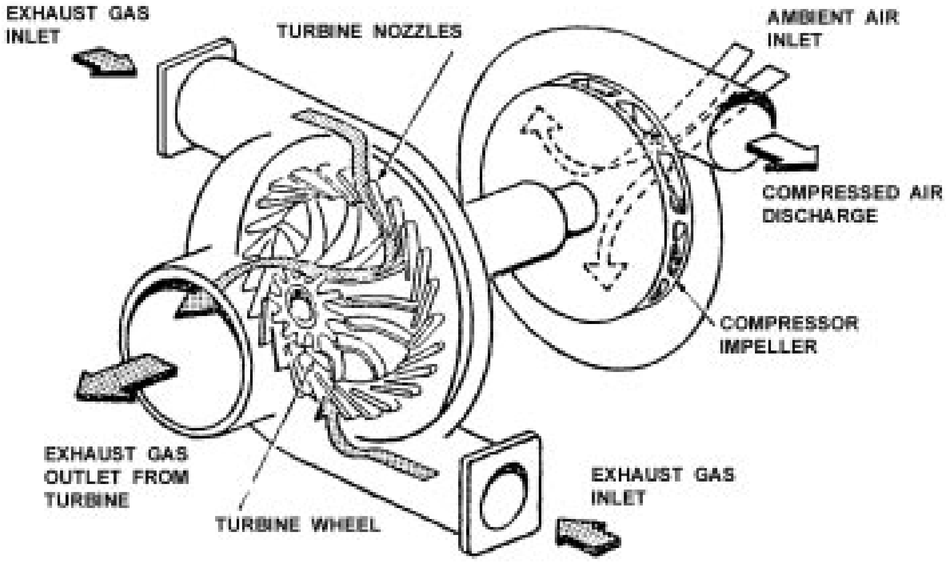

Fig. 23.Typical Turbocharger.

attached to the same shaft as the turbine wheel it also rotates, drawing in air from the intake duct and throwing it outwards at high velocity through diffuser vanes in the compressor casing; these vanes convert the velocity energy into pressure energy, and the compressed air is delivered to the engine.

For any particular power output the turbocharger delivers a fixed weight of air to the engine in a given time, and since the density of air decreases with altitude, a greater volume of air is compressed and the impeller rotates faster at high altitude than it does at low altitude. Therefore, some form of control over compressor output must be provided, and this is done by varying the quantity of exhaust gas passing to the turbine. A turbine bypass, in the form of an alternative exhaust duct, is fitted with a valve (known as a waste gate) which shuts or regulates the degree of opening of the bypass. When the waste gate is fully open nearly all the exhaust gases pass directly to atmosphere, but as the waste gate closes gases are directed to the turbine, and the maximum rotor speed is achieved when the waste gate is fully closed. The waste gate may be controlled manually by the pilot, but in most turbocharger systems automatic controls are fitted to prevent over-boosting the engine.

In an automatic control system, the waste gate is mechanically connected to an actuator (fig.25), the position of which depends on the opposing forces of a spring and engine oil pressure. Spring force tends to open the waste gate and

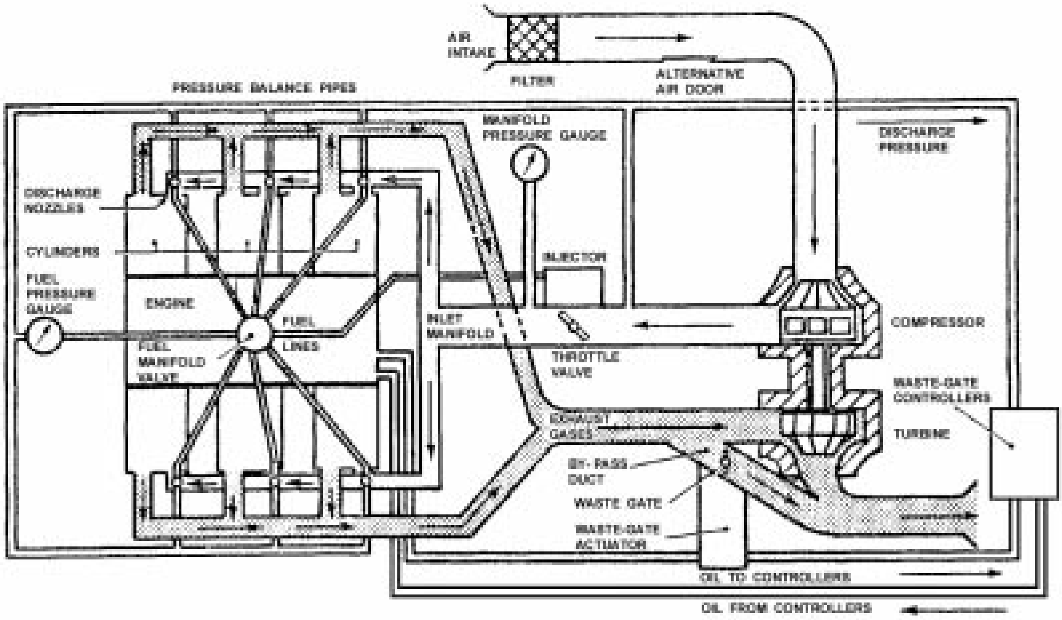

Fig. 24. Turbocharger Installation.

oil pressure tends to close it. Engine oil pressure is fed to the actuator through a restrictor, and the waste gate controllers are placed in the return line. When a controller opens the return line, oil follows through the actuator and controller back to the engine pump, and pressure in the actuator falls. The extent to which the oil pressure will fall depends on the size of the restrictor and the size of the bleed through the controllers; the larger the bleed the lower the oil pressure will drop. Thus oil pressure in the actuator is controlled to regulate the position of the waste gate according to engine requirements. Various types of controllers may be used to vary waste-gage actuator oil pressure.

Some simple turbocharger systems use a single controller, called an Absolute Pressure Controller, which is designed to prevent supercharger outlet pressure from exceeding a specified maximum; this type of controller is illustrated in Fig. 26. At low power settings full oil pressure is applied to the waste gate actuator, which closes the waste gate and diverts all exhaust gases through the turbine. As the throttle is opened engine speed increases, and more exhaust gas passes through the turbine; this results in an increase in the speed of rotation of the turbine and impeller, and produces a higher supercharger outlet pressure which is communicated to the capsule chamber in the Absolute Pressure Controller. When the controlling supercharger outlet pressure is reached, the capsule is compressed sufficiently to open its bleed valve and thus to bleed of oil pressure from below the waste-gate actuator piston. The piston moves down under spring pressure and starts to open the waste gate, diverting exhaust gas from the turbine and reducing its speed. Thus at high power settings at low altitude the waste gate is almost fully open, but as the aircraft climbs and more air has to be compressed it is gradually closed until, at critical altitude (equivalent to Rated Altitude on an internally-driven supercharger) it is fully closed. Above this height both manifold pressure and power output will decrease, even though the turbocharger is operating at its maximum speed.

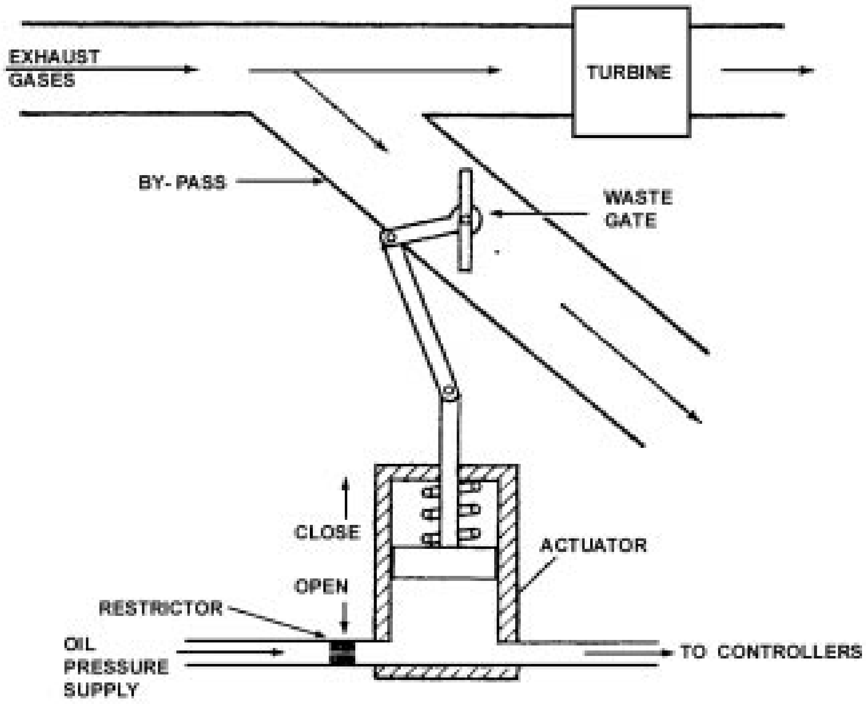

Fig.25. Operation of waste gate.

A variation of the single controller is the Variable Pressure Controller (fig.27), which is similar in operation to the variable datum control described for internally-driven superchargers, A cam, operated by linkage to the throttle control lever, adjusts the datum of the valve in the Variable Pressure Controller, so controlling the degree of opening of the waste gate and producing manifold pressure which is related to the power selected by the throttle lever. Operation of this system is otherwise similar to the operation of the Absolute Pressure Controller.

On some Ground Boosted Turbocharger a dual-unit control system is used to adjust waste-gate actuator oil pressure; the units are the Density Controller and the Differential Pressure Controller, which are installed as shown in Fig.28.

(a) The Density Controller is designed to prevent the supercharger output from exceeding the limiting pressure; it regulates oil pressure only at full throttle and up to the turbocharger's critical altitude. The capsule is filled with dry nitrogen and is sensitive to both temperature and pressure changes contraction and expansion of the capsule varies the quantity of oil bled from the waste-gate actuator and repositions the waste gate, thus maintaining a constant density at full throttle.

(b) The Differential Pressure Controller controls the waste gate at all positions of the throttle other than fully open. A diaphragm divides a chamber which has supercharger outlet pressure on one side and inlet manifold pressure on the other side, thus responding to the pressure drop across the throttle valve. The bleed valve is fully closed at full throttle, when the pressure drop is least, and gradually opens as the throttle is closed and the pressure

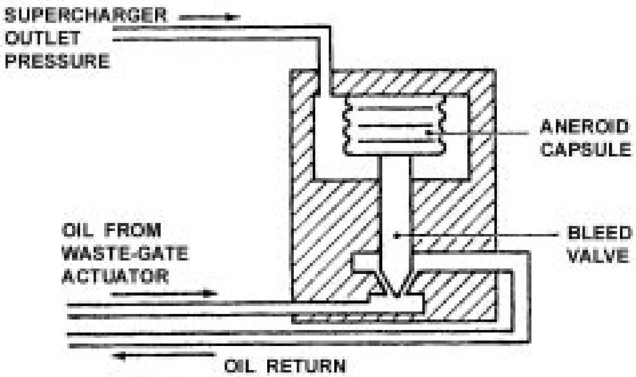

Fig.26. Absolute pressure controller.

drop increases. The controller thus opens the waste gate as the throttle is closed and the pressure drop increases. The controller thus opens the waste gate as the throttle is closed, and reduces supercharger outlet pressure in accordance with the power selected.

Any variation in power caused by slight changes in temperature or engine speed will result in a change in exhaust gas flow which will affect turbine speed. This may produce an unstable condition, known as 'boot strapping' or hunting, of the manifold pressure as the control system attempts to reach a state of equilibrium. This condition is smoothed out by the Differential Pressure Controller, which reacts quickly to changes in the pressure drop across the throttle valve, and reduces the effects of small power changes.

On some Ground Boosted Turbochargers three separate controllers are used; two of these control the waste gate up to the turbocharger's critical altitude and the third controls the waste gate above critical altitude. This system is illustrated in Fig.29.

(a) An Absolute Pressure Controller is used to control the supercharger outlet pressure below critical altitude. Operation of this unit is as described before.

(b) A Rate Controller is fitted to control the rate at which supercharger outlet pressure will increase, thus preventing over boosting the engine initially when the throttle is opened. Both sides of a diaphragm in the unit are connected to supercharger outlet pressure, but the opening to the lower chamber is fitted with a

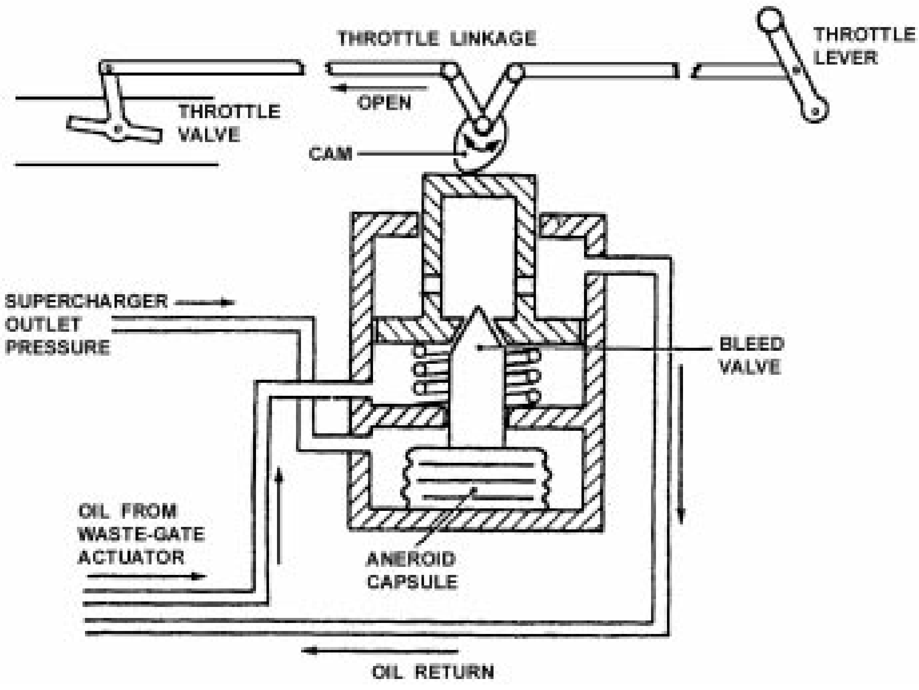

Fig. 27. Variable pressure controller.

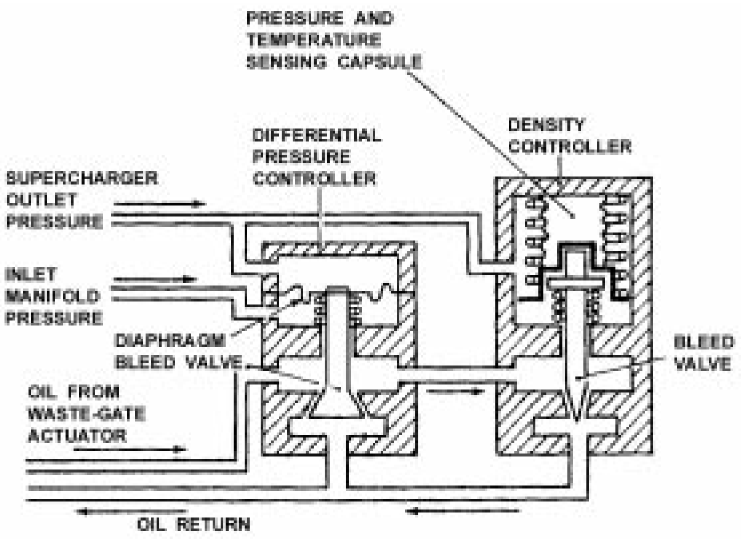

Fig.28. Dual unit control system.

restrictor. If supercharger outlet pressure increases at too high a rate, air pressure will increase more quickly above the diaphragm than it does below it, because of the presence of the restrictor. The downward force on the diaphragm opens the bleed valve, bleeding oil pressure from the waste-gate actuator and opening the waste gate. Thus the rate of increase of supercharger outlet pressure is controlled, regardless of the rate of acceleration of the engine.

(c) As altitude is increased, the supercharger has to rotate faster and compresses more air to maintain maximum power, and this results in the increase in the temperature of the air delivered to the engine. This rise in temperature could eventually reach a point where detonation would occur, and is controlled by placing limits on the maximum manifold pressure which can be used above a specified altitude (often 16,000 ft) whilst it is possible to operate within these limitations, by retarding the throttle lever above the specified altitude, a Pressure ratio Controller can be fitted to limit supercharger outlet pressure automatically. This controller contains a chamber which is open to atmospheric pressure, at the specified altitude a capsule in the chamber will have expanded sufficiently to contact the stem of a bleed valve. As the aircraft climbs above this altitude the valve is opened by an increasing amount, and gradually increases the bleed form the waste-gate actuator to reduce supercharger outlet pressure as a set ratio to the atmospheric pressure.

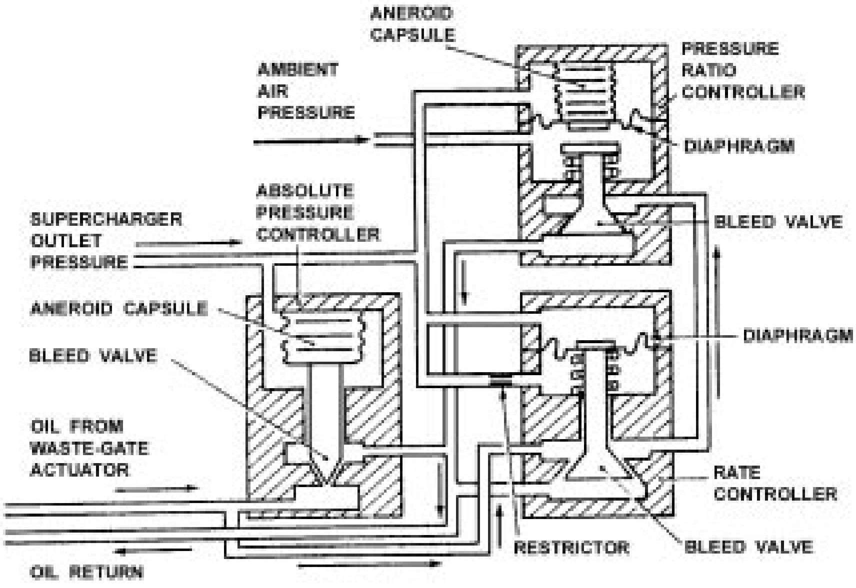

Fig.29. Triple unit control system.

On some aircraft a manifold pressure relief valve is fitted in the compressor discharge duct, to prevent over boosting of the engine during rapid acceleration, and in the event of failure of the controllers or sticking of the waste gate. The valve is usually a simple poppet type valve, which is adjusted to relieve the supercharger discharge pressure to atmosphere whenever the controlled maximum pressure is exceeded. A manifold pressure relief valve is usually fitted in conjunction with an Absolute Pressure Controller or a Variable Pressure Controller.

Turbocharger systems are very sensitive to changes in exhaust gas flow and automatic controls take time to reach a state of equilibrium. It is important, therefore, that the throttle and propeller controls are operated slowly and that time is allowed for the control system to settle down.

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CHAPTER: 9
FUEL SYSTEM TURBINE ENGINES

INTRODUCTION

The functions of the fuel system are to provide the engine with fuel in a form suitable for combustion and to control the flow to the required quantity necessary for easy starting acceleration and stable running, at all engine operating conditions, to do this, one or more fuel pumps are used to deliver the fuel to the fuel spray nozzles, which inject it into the combustion system in the form of an atomized spray because the flow rate must vary according to the amount of air passing through the engine to maintain a constant selected engine speed or pressure ratio, the controlling devices are fully automatic with the exception of engine power selection, which is achieved by a manual throttle or power lever. A fuel shut-off valve (cock) control lever is also used to stop engine, although in some instances these two manual controls are combined for single-lever operation.

It is also necessary to have automatic safety controls that prevent the engine gas temperature, compressor delivery pressure, and the rotating assembly speed, from exceeding their maximum limitations.

With the turbo-propeller engine, changes in propeller speed and pitch have to be taken into account due to their effect on the power output of the engine. Thus, it is usual to interconnect the throttle lever and propeller controller unit, for by so doing the correct relationship between fuel flow and airflow is maintained at all engine speeds and the pilot is given single-lever control of the engine. Although the maximum speed of the engine is normally determined by the propeller speed controller, over speeding is ultimately prevented by a governor in the fuel system.

Fuel system also provides oil cooling for lubricating system of various engine parts.

There are two types of fuel control i.e. Automatic and Manual. Automatic control system is divided into 3 parts they are : (i) Pressure Control System (ii) Flow control system (iii) Acceleration and speed control.

Some engines are fitted with an electronic system of control and this generally involves the use of electronic circuits to measure and translate changing engine condition to automatically adjust the fuel pump output. On helicopters powered by gas turbine engines using the free power turbine principle, additional manual and automatic controls on the engine govern the free power turbine and consequently aircraft rotor speed.

FUEL CONTROL SYSTEMS

Typical high pressure (H.P.) fuel control systems for a turbo-propeller engine and a turbojet engine are shown in simplified form in figure 1, each basically consisting of an H.P. pump, a throttle control and a number of fuel spray nozzles, In addition, certain sensing devices are incorporated to provide automatic control of the fuel flow in response to engine requirements. On the turbo-propeller engine, the fuel and propeller systems are coordinated to produce the appropriate fuel/r.p.m. combination.

The usual method of varying the fuel flow to the spray nozzles is by adjusting the output of the H.P. fuel pump. This is effected through a servo system in response to some or all of the following :

(1) Throttle Movement.
(2) Air, temperature and pressure.
(3) Rapid acceleration and deceleration.
(4) Signals of engine speed, engine gas temperature and compressor delivery pressure.

FUEL PUMP

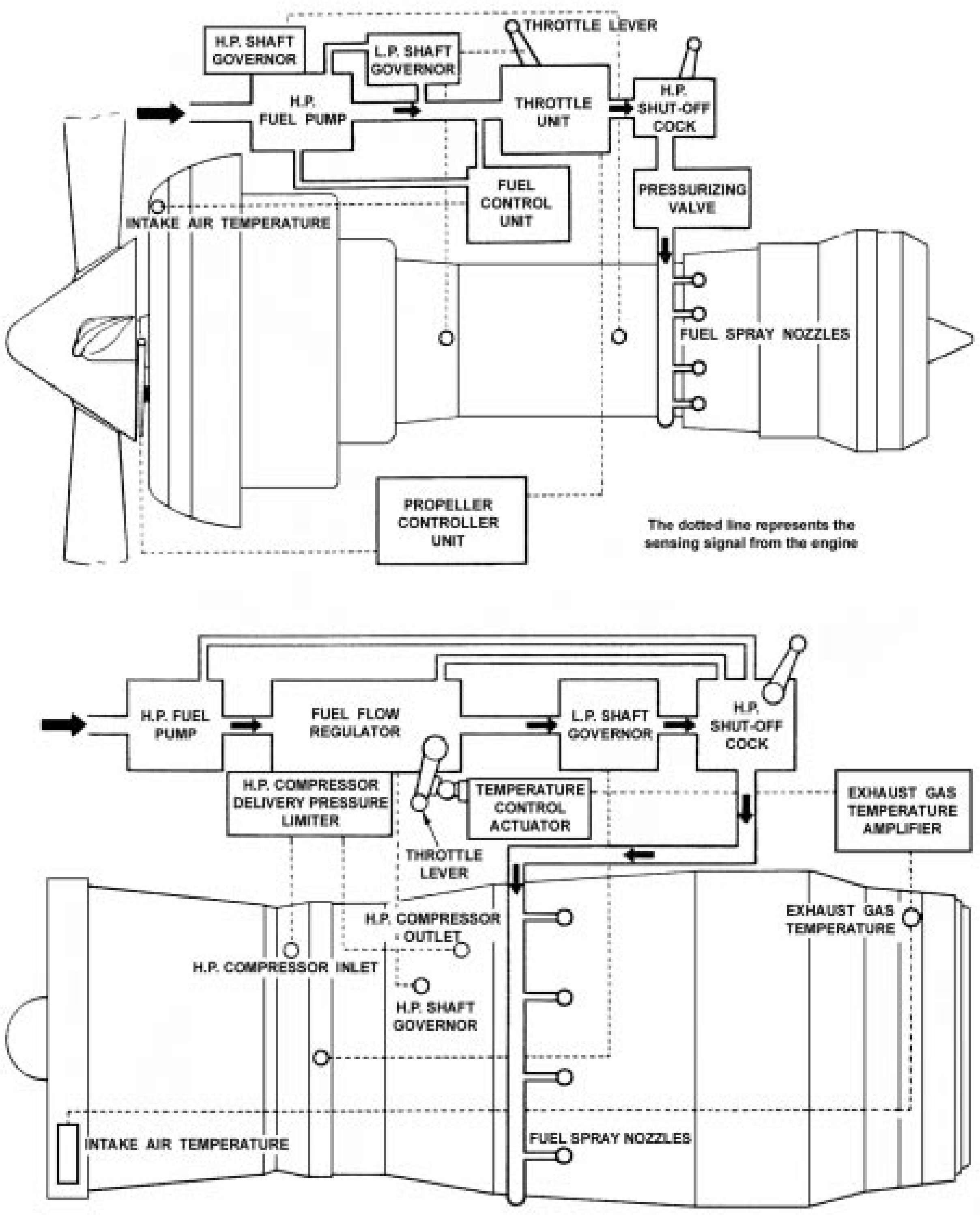
On some early turbine engines a constant displacement pump was used, the design of which ensured that pump delivery was always in excess of engine requirements. Excess fuel was bled back to the fuel tanks by means of unit called a Barostat which was sensitive to changes in air intake pressure. Most modern British systems employ a pump of the variable stroke (swash-plate) type, a dual pump often being fitted on large engines to obtain high delivery rates.

The variable stroke pump is driven directly from the engine and consists of rotating cylinder block in which a number of cylinders are arranged around the rotational axis. A spring-loaded piston in each cylinder is held against a non-rotating cam plate so that rotation of the cylinder block results in the pistons moving up and down in their respective cylinders. Conveniently placed ports in the pump body allow fuel to be drawn into the cylinders and discharged to the engine. The angle of the cam plate determines the length of stroke of the piston and, by connecting it to a servo mechanism, delivery may be varied from the nil to maximum pump capacity for a given pump speed.

The servo piston operates in a cylinder and is subjected to pump delivery pressure on one side and the combined forces of reduced delivery (servo) pressure and a spring on the other. A calibrated restrictor supplies pump delivery fuel to the spring side of the piston and this is bled off by the control system to adjust the piston position and hence the angle of the cam plate.

FUEL PUMP CONTROL SYSTEMS

Some engines are fitted with a control system which uses electronic circuits to sense changing fuel requirements and adjust pump stroke. Most engines however, use hydro-mechanical systems, with an electromechanical element to control maximum gas temperature and these are discussed in the following paragraphs.



The dotted line represents the sensing signal from the engine

Fig. 1. Simplified fuel system for turbo propeller and turbo jet engines.

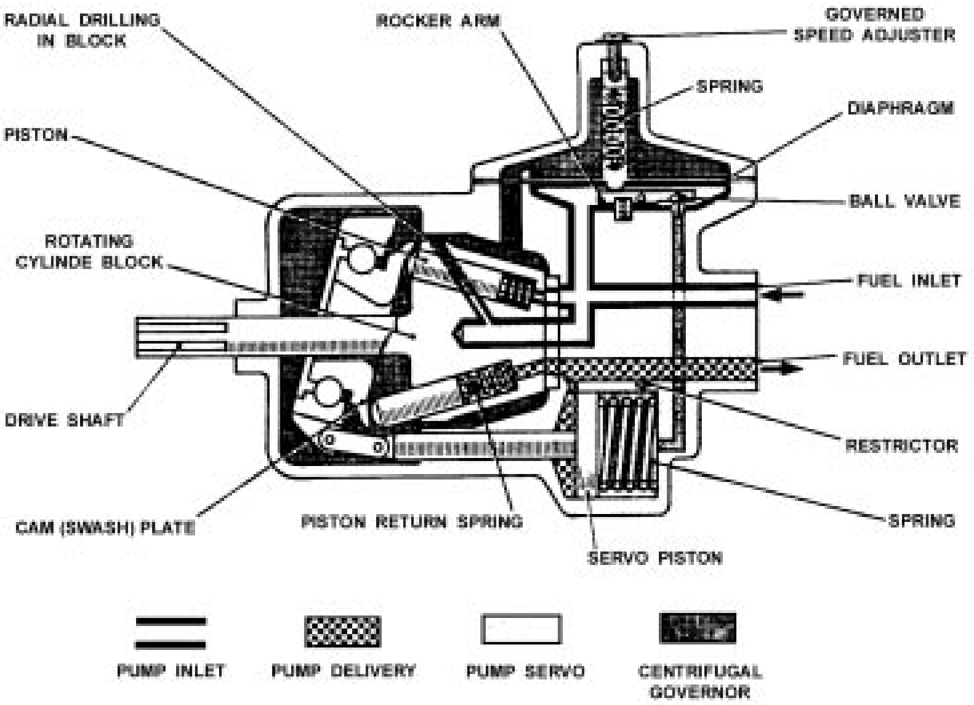


Fig.2. Fuel pump.

Pressure controller

The quantity of fuel passing through a restrictor (the throttle valve may be varied by increasing or decreasing the fuel pressure. In the pressure control system (fig.3.) fuel pressure is varied in relation to air intake pressure, decreasing with decreased mass air flow through the engine, Spill valves in the Barometric Pressure Control (B.P.C), Acceleration Control Unit (A.C.U.) and pump governor, bleed off servo pressure to control pump stroke.

Under steady running conditions below maximum governed speed only the B.P.C. spill valve is open. A capsule subject to air intake pressure, contained in the B.P.C., controls the extent to which the spill valve is open. The bleed is arranged to increase as intake pressure decreases thus reducing servo pressure, pump stroke and fuel delivery pressure as altitude increases.

When the throttle is opened slowly, reduced throttle inlet pressure is transmitted to the B.P.C. and the spill valve

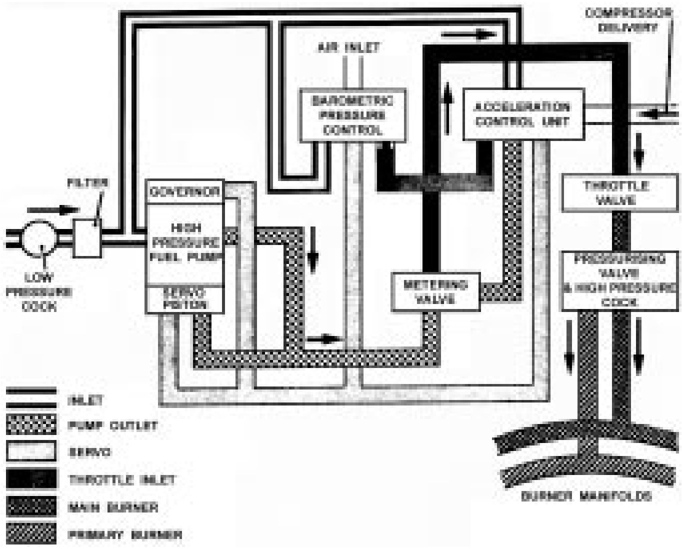


Fig.3. Pressure control system.

closes to increase servo pressure and pump stroke. As pressure to the throttle is restored the B.P.C. spill valve again takes up its controlling position, and pump stroke, combined with increased pump speed, stabilises to give the output for the new throttle position. If the aircraft is in level flight the increasing speed will increase intake pressure and act on the B.P.C. capsule to further increase fuel flow to match the increasing mass air flow.

During rapid throttle opening, the action of the B.P.C. spill valve closes, increased fuel flow creates an increased pressure drop across the Metering Valve which is sensed by the A.C.U. fuel diaphragm. Movement of this diaphragm opens the A.C.U. spill valve to reduce servo pressure and limit over fuelling to the maximum amount which can be tolerated by the engine. As the engine accelerates, increasing compressor delivery pressure acting on the A.C.U. air diaphragm gradually closes the spill valve to permit greater acceleration at higher engine speeds.

Radial drilling in the fuel pump rotor direct fuel under centrifugal force to one side of a spring loaded diaphragm in the governor unit. When centrifugal force reaches a predetermined value the diaphragm flexes sufficiently to open its spill valve and reduce servo pressure, thus limiting the amount of fuel delivered to the engine and so controlling engine speed.

Flow control

In this system fuel pump delivery is controlled to maintain a constant pressure drop across the throttle valve regardless of engine speed A common variation of the system is one in which a small controlling flow (proportional flow) is created with the same characteristics as the main flow and is used to adjust the main flow. A different type of spill valve known as a “kinetic” valve is used which consists of opposing jets of fuel at pump delivery pressure and servo pressure; a blade moving between the jets alters the effect of the high pressure on the low pressure. When the blade is clear of the jets, servo pressure is at maximum and moves the fuel pump to maximum stroke but as the blade comes between the jets servo pressure reduces to shorten pump stroke. The control elements which are housed in a single unit called the Fuel Control Unit (F.C.U.) and throttle, which sometimes also functions as a shut-off (H.P.) cock. the system is illustrated in figure.4

Under steady running conditions below governed speed, flow through two P.V.U. restrictors is proportional to flow through the throttle valve and the P.V.U. diaphragm is held open by spring pressure, allowing fuel to flow through the A.S.U. back to the pump inlet. The A.S.U. adjusts servo pressure in relation to this proportional flow by means of a kinetic spill valve.

When the throttle is opened slowly the pressure drop across and throttle valve and P.V.U. restrictors decreases and the P.V.U. diaphragm adjusts its position to reduce proportional flow through the A.S.U. This results in the A.S.U. spill valve closing slightly to increase servo pressure and therefore pump stroke, thus restoring the pressure difference across the throttle and P.V.U. restrictors.

Variation in air intake pressure are sensed by a capsule in the A.S.U. which adjusts its spill valve to decrease or increase servo pressure as required. The resulting change in proportional flow returns the A.S.U. spill valve to its controlling position.

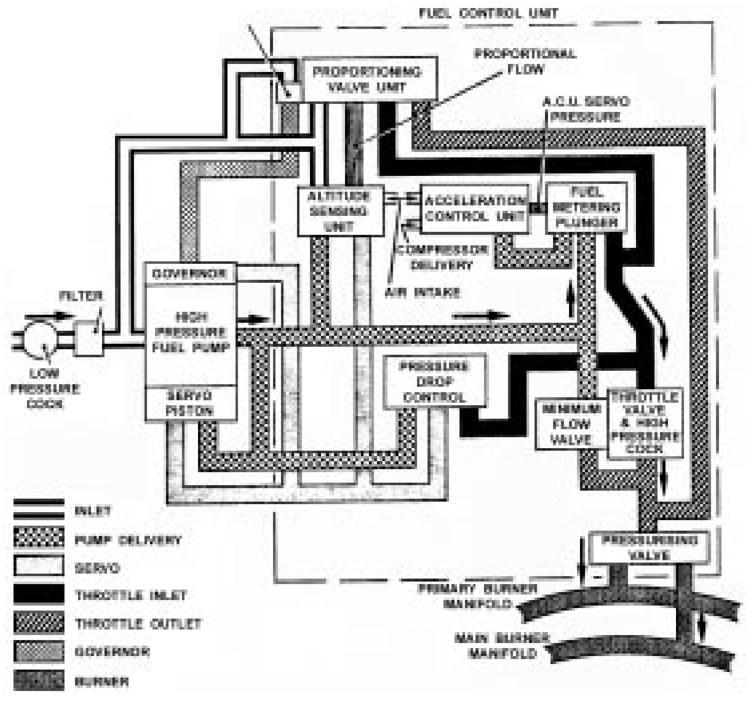


Fig.4. Flow control system.

During rapid throttle opening the sudden decrease in pressure drop across the throttle is sensed by the A.S.U. which closes its spill valve to increase pump stroke. The rapid increase in fuel flow, which would cause over fuelling, is restricted by means of a pressure drop diaphragm and metering plunger. This diaphragm is sensitive to the pressure drop across the metering plunger, the latter being located in the main fuel line to the throttle valve. Rapid throttle opening increases the pressure drop across the plunger and at a fixed rate of over fuelling the pressure drop diaphragm flexes sufficiently to open its spill valve and override the A.S.U. , maintaining a fixed pressure drop across the metering plunger. The metering plunger is, in effect, a variable area orifice and by means of a capsule in the A.C.U. sensitive to compressor delivery pressure, its position is controlled, over fuelling and engine speed increase, the pressure drop across the throttle valve is gradually restored until the proportional flow reaches a controlling value once more and the A.S.U. spill valve controls pump stroke.

Fuel under centrifugal force from the fuel pump also acts on a diaphragm in the P.V.U. to adjust the position of one of the restrictions and maintain proportional flow at a value suitable for idling.

Combined acceleration and speed control

This fuel pump control system is contained within a single unit called a Fuel Flow Regulator, the fuel pump servo piston being operated by fuel pump delivery pressure opposed by main burner pressure and a spring. The system is illustrated in figure.5.

Two rotating assemblies, each with a hollow valve and centrifugal governor, are driven from the engine by a gear train in the regulator and are known as the Speed Control Unit and the Pressure Drop Unit. The speed control valve is given axial movement by a capsule assembly under compressor delivery pressure and has a triangular hole known as the Variable Metering Orifice (V.M.O.). A non rotating governor sleeve round this valve is given axial movement by the governor unit and restricts fuel flow through the V.M.O. Fuel from the pump outlet flows from the regulator body through the V.M.O. to the inside of the speed control valve and passes through the hollow valve to the pressure drop unit. The pressure drop valve is in the form of a hollow piston, moving axially under the force of fuel from the V.M.O. and governor flyweights, has an unrestricted outlet through the regulator body for primary burner fuel and a triangular outlet known as the Pressure Drop Control Orifice (P.D.C.O.) through which fuel flow to the main burners is restricted by the axial movement of the pressure drop valve.

Under steady running conditions the position of the speed control valve is fixed by the capsule assembly and the governor sleeve is held in a fixed axial position, the drop valve which adjusts its position and the exposed area of the P.D.C.O. to supply the correct quantity of fuel in relation to engine speed.

When the throttle is opened slowly, spring loading on the speed control governor increases to move the governor sleeve and increase the V.M.O. area. Pressure drop across the V.M.O. decreases and this is sensed by the pressure drop valve which moves to increase the size of the P.D.C.O. the reduced system pressure difference acting on the pump servo piston

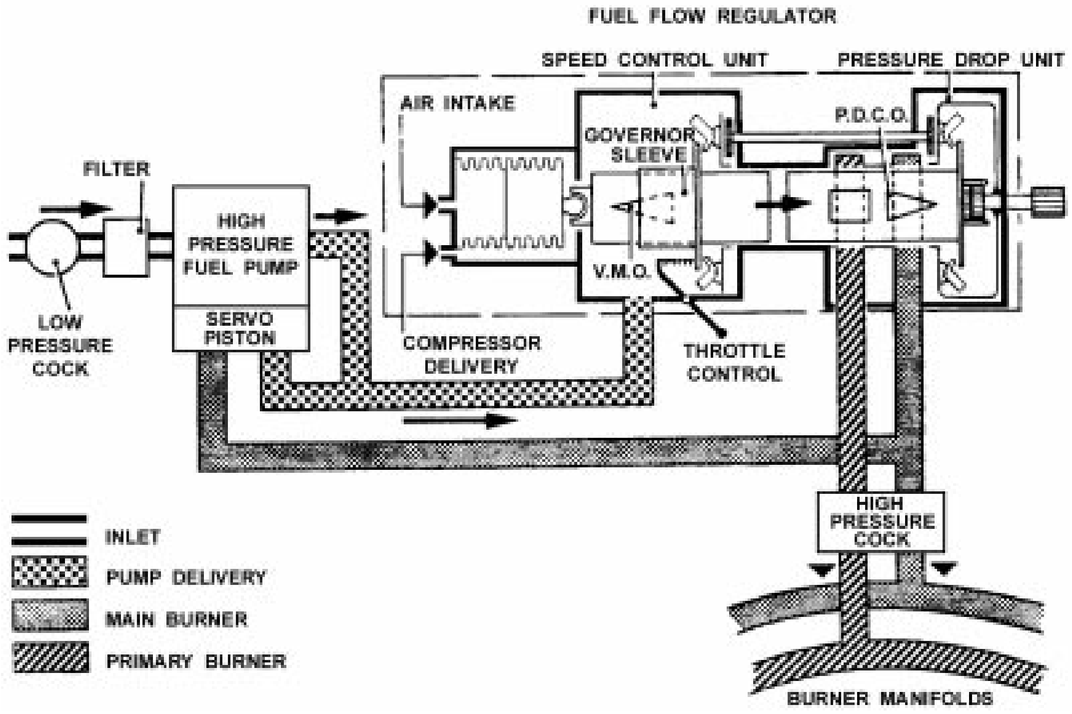


Fig.5. Combined acceleration and speed control.

to increase fuel flow to the engine. As the engine accelerates, the capsule in the speed control unit is compressed due to compressor delivery pressure and moves the speed control valve to further increase the size of the V.M.O. Balance is restored when centrifugal force acting on the speed control governor moves the governor sleeve to restore the system pressure difference.

The effect to rapid throttle movements is restricted by mechanical stops acting on the governor sleeve.

Changes in altitude or forward speed affect the capsule of the speed control unit which adjusts the position of the speed control valve to correct fuel flow.

BURNERS

The purpose of the burners is to provide fuel to the engine in a suitable form for combustion. A burner with a single spray nozzle, although used on some early engines, is not suitable for large modern engines due to the widely varying fuel flow requirements for different flight conditions.

If the orifice were of the size suitable for atomising fuel at low rates of flow the pressure required at take-off would be tremendously high, flow through an orifice being proportional to the square of the pressure drop across it.

One of the methods used to overcome this problem is the provision of a dual spray burner. The central orifice provides the fuel for low flow rates and a second annular orifice is used in addition for high flow rates. Distribution between the primary (low flow) manifold and the main (high flow) manifold is normally controlled by a pressure operated valve. In the case of the Fuel flow Regulator, fuel flowing through the rectangular outlet from the pressure drop valve is always at a higher pressure than fuel flowing through the outlet from the P.D.C.O. and is used to supply the primary burner manifold.

Another method used on some engines is known as the Vaporising Burner. Fuel is injected at low pressure into one end of a hollow “U” shaped tube located in the combustion chamber. It mixes with the primary air flow, is vaporised by the heat in the chamber and ejected upstream into the combustion zone. In this system a separate burner is necessary for engine starting.

ADDITIONAL CONTROLS

In addition to, the system usually is provided to prevent the engine from exceeding operating limitations.

Turbine gas temperature control

Control of the maximum permitted turbine gas temperature is often exercised electrically. Signals from the T.G.T. thermocouples are amplified to either actuate a solenoid operated valve in the fuel system or reset the throttle linkage to reduce fuel flow to the burners. On engines which have different T.G.T. limitations for climb and take-off, a switch on the flight deck pre-sets the T.G.T. signal reference datum.

Compressor control

In certain circumstances such as high forward speed and low ambient temperature it is possible to produce maximum power/thrust at less than maximum engine speed. Under these conditions the engine could sustain damage due to high compressor delivery pressures and fuel flow is restricted by providing a bleed from the A.C.U. capsule, chamber to atmosphere when compressor delivery pressure exceeds a predetermined value.

To prevent the low pressure compressor from exceeding its design speed a centrifugal governor driven from the low pressure shaft is often included in the fuel system. If design speed is exceeded the low pressure governor restricts the fuel flow in the main burner line and reduces both high and low pressure compressor speeds.

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CHAPTER: 10
CONSTRUCTION AND OPERATION OF PROPELLERS

GENERAL

A propeller is a means of converting engine power into propulsive force. A rotating propeller imparts rearward motion to a mass of air, and the reaction to this is a forward force on the propeller blades.

Each propeller blade is of aerofoil cross-section. As the blade moves through the air, forces are produced, which are known as thrust and torque, and which may be regarded as roughly equivalent to the forces of lift and drag produced by an aircraft wing. Thrust is the propulsive force, and torque the resistance to rotation, or propeller load. The magnitude of the thrust and torque forces produced will depend on the size, shape and number of blades, the blade angle, the speed of rotation, the air density and the forward speed.

Since each blade is of aerofoil cross-section, thrust will be produced most efficiently at a particular angle of attack, that is the angle between the chord line at a particular blade section and the relative airflow. This angle varies both with operating conditions and with the design camber of the blade sections, but for a given blade and given in flight condition, it will be found to be relatively constant along the length of the blade. The rotational speed of particular cross-section of a blade will increase with its distance from the axis of rotation, and, since the forward speed of all parts of the blade is the same, the relative airflow will vary along the blade, and it is, therefore, necessary to provide a decreasing blade angle from root to tip. The various terms relating to propeller operation are illustrated in fig 1. This is a simplified diagram omitting inflow angles for clarity, but in practical designs these angles can not be ignored.

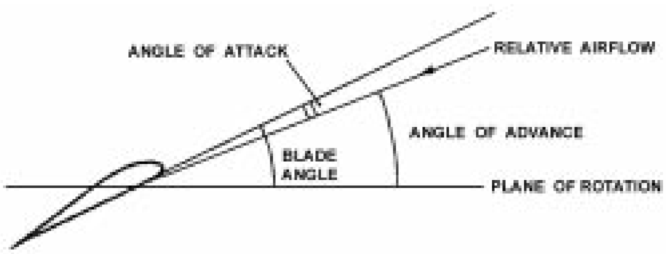

Fig. 1. Showing propeller terms.

The geometric pitch of a propeller is the distance which it should move forward in one revolution without slip; it is equal to $2\pi r \tan\theta$ where r is the radius of the particular cross section and θ is the blade angle at that point. Fixed pitch propellers are usually classified by their diameter and pitch, the pitch being related to the blade angle at 3/4 radius, or other nominated station.

Centrifugal, bending, and twisting forces act on a propeller during flight, and can be very severe at high rotational speeds. Propellers must be both strong enough to resist these forces, and rigid enough to prevent flutter. The main forces experienced are as follows :-

a) Centrifugal forces which induce radial stress in the blades and hub, and, when acting on material which is not on the blade axis, also induce a twisting moment. Centrifugal force can be resolved into two components, in the plane of rotation one is a radial force parallel to the blade axis, and the other a force at 90° to the blade axis; the former produces radial stress, and the latter tends to turn the blade to a finer pitch. The turning effect is referred to as centrifugal twisting moment, and is illustrated in figure.2; the wider the blade, the greater will be the twisting moment.

b) Thrust forces which tend to bend the blades forward in the direction of flight.

c) Torque forces which tend to bend the blades against the direction of rotation.

d) Air loads which normally tend to oppose the centrifugal twisting moment and coarsen blade pitch.

The diameter of a propeller, and the number and shape of its blades, depend on the power it is required to absorb, on the take-off thrust it is necessary to produce, and on the noise-level limits which have to be met. High tip speeds absorb greater power than low tip speeds, but if the tip speed approaches the speed of sound, efficiency will fall, and this consideration limits practical diameter/ rotational speed combinations. High tip speed is also the main source of propeller noise. Large diameters normally result in better performance than small diameters, and blade area is chosen to ensure that blade lift coefficients are kept in the range where the blade sections are efficient. Wide chord blades and/or large diameters lead to heavy propellers; increase in number of blades increases cost but reduces noise. The design of any propeller is, therefore, a compromise between conflicting requirements, and the features

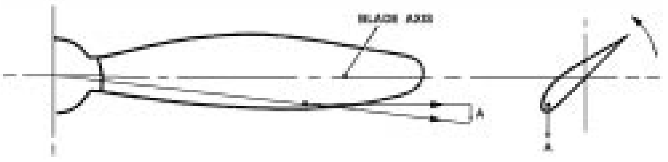

Fig.2. Centrifugal twisting moment.

which are given prominence will vary from one application to another. Small two-bladed propellers, of suitable profile, are satisfactory for low-powered piston engines, but for high-powered piston or turbine engines, three, four, or five bladed, or contra-rotating, propellers are used, and are driven through a reduction gear to enable high engine power to be used at efficient propeller speeds.

PROPELLER BALANCE

A propeller is a rotating mass, and if not correctly balanced can produce unacceptable vibration. An unbalanced condition may be caused by uneven weight distribution, or by uneven air loads or centrifugal forces on the blades when the propeller is rotating. Even weight distribution is known as static balance; this is checked by mounting the propeller on a shaft between knife edges; or by use of a single plane precision balancing machine. An unbalanced condition can be corrected by adding weight to the lighter blade (s) and/or removing weight from the heavier blade (s). Material may easily be removed from wooden propellers, but metal propellers are usually balanced by attaching weights to the blade hub or by adding lead wool to the hollow blade roots. If there are significant differences in form or twist between the blades on a propeller, vibration can result because the thrust and or torque produced by the blades is uneven. Procedures for evaluating such differences, and for achieving aerodynamic balance, are often available for large propellers. In their absence, careful checking of the blade profiles and adjustment of any deviations, may often eliminate vibration. It is possible for a propeller to be in perfect static and aerodynamic balance, but still suffer from dynamic unbalance when rotating. The cause of such unbalance is non-symmetrical disposition of mass within the propeller, or non-symmetrical mounting of the propeller. Such unbalance can be corrected by adding balance weights, but this may be a lengthy procedure, involving repeated runs with the propeller installed on the aircraft. Propellers are balanced after manufacture, and whenever repairs, or overhaul, have been carried out, or vibration has been reported.

TYPES OF PROPELLERS

The various types of propellers are described briefly in this paragraph. The construction and operation of the main types of propellers in common use.

Fixed pitch propellers

Because of its lightness, cheapness and simplicity, a fixed-pitch propeller is often fitted to a single engine aircraft. The pitch selected for any particular engine/airframe combination will always be a compromise, since the angle of attack will vary with changes in engine speed and aircraft attitude. Too coarse a pitch would prevent maximum engine power from being used during take-off and climb, and too fine a pitch would prevent economical cruising, and would lead to over speeding of the engine in a dive.

Variable pitch propellers

With this type of propeller the blade angle may be varied in flight, so that engine power may be fully utilized. Variable-pitch propellers were originally produced with two blade-angle settings; a fine pitch to enable full engine speed to be used during takeoff and climb, and a coarse pitch to enable an economical engine speed to be used for cruising. The introduction of an engine driven centrifugal governor enabled the blade angle to be altered automatically (within a predetermined range), in order to maintain any engine speed selected by the pilot, regardless of aircraft speed or attitude.

Feathering propellers

If an engine failure occurs, the wind milling propeller may cause considerable drag, and adversely affect controllability of the aircraft. In order to reduce this drag, the blades of most constant speed propellers fitted to multi-engine aircraft are capable of being turned past the normal maximum coarse-pitch setting into line with the airflow. This is known as the ‘feathered’ position. Feathering the propeller not only reduces drag, but also minimizes engine rotation, thus preventing any additional damage to the engine.

Reversible pitch propellers

On some aircraft, the propeller blades may be turned past the normal fine-pitch setting, to a pitch which will produce thrust in the opposite direction (reverse thrust). On selection of reverse pitch by the pilot, the blades may be turned to a fixed reverse-pitch angle, but on some installations the pilot has control of blade angle, and can select any angle within a given range on each propeller individually, Reversible-pitch propellers provide braking during the landing run, and facilitate aircraft ground manoeuvring.

FIXED PITCH PROPELLERS

Fixed-pitch propellers normally have two blades, and are manufactured from either wood or aluminium alloy; they are generally only fitted to single-engine light aircraft.

Wooden propellers

Wooden propellers are made up from a number of planks glued together. The wood used is usually either birch or mahogany, and is specially selected and seasoned for the purpose. After gluing and a further short seasoning period to equalise moisture content in the planks, the block is cut to shape and finished. An abrasion resistant coating of either canvas or cellulose is applied to the blades, and a metal sheath is normally screwed on to the leading edges and blade tips to protect the wood from being damaged by stones. The propeller is then given several coats of varnish or cellulose paint to protect it from atmospheric conditions.

If the engine shaft has an integral flange, the propeller is clamped between this flange and a separate steel faceplate. If the shaft is splined, the propeller is mounted on a steel hub, which is internally splined to fit the shaft and has an integral rear flange an detachable front flange between which the propeller is mounted. In either case, a large clamping area is required so as to minimize damage to the wood fibres when the attachment bolts are tightened.

Hubs fitted to parallel splined shafts are mounted between a front and rear cone, the purpose of which is to ensure that the propeller is concentric with the shaft. The shaft is threaded to receive a large nut, which is tightened against the front face of the front cone. Hubs fitted to tapered shaft are similarly attached, but may not be mounted on cones.

Metal propellers

Metal propellers are usually aluminium alloy forging, and are anodised and painted for protection. They are usually bolted directly on to a shaft with an integral flange, but if they are fitted to a splined shaft they are mounted on a hub which is similar to that used for wooden propellers, but without a front flange.

VARIABLE PITCH PROPELLERS

Variable-pitch propellers consist of a number of separate blades mounted in a central hub, and a mechanism to change the blade angle according to aircraft requirements. The blades and hub are often aluminium alloy forging, but the hub on a large propeller may be constructed from steel forging because of the high centrifugal forces which it has to contain. The blades are mounted in the hub in ball or tapered roller bearings, and the pitch-change mechanism is attached to the hub and connected to each blade through rods, yokes or bevel gears. Operation and control of the pitch change mechanism varies considerably, and three main types are discussed in this paragraph.

Single acting propellers

A single-acting propeller is illustrated in fig.3 it is a constant-speed feathering type, and is typical of the propellers fitted to light and medium sized twin-engine aircraft. A cylinder is bolted to the front of the hub, and contains a piston and piston rod which move axially to alter blade angle. On some propellers, oil under pressure, fed through the hollow piston rod to the front of the piston, moves the piston to the rear to turn the blades to a finer pitch; on other propellers the reverse applies. When oil pressure is relieved, the counterweights and feathering spring move the piston forward to turn the blades to a coarser pitch. Counterweights produce a centrifugal twisting moment but, because they are located at 90 degree to the chord line, they tend to move the blades to a coarser pitch. Counterweights must be located far enough from the blade axis, and must be heavy enough to overcome the natural twisting moment of the blade, but since weight and space are limiting factors, they are generally only used with blades of narrow chord.

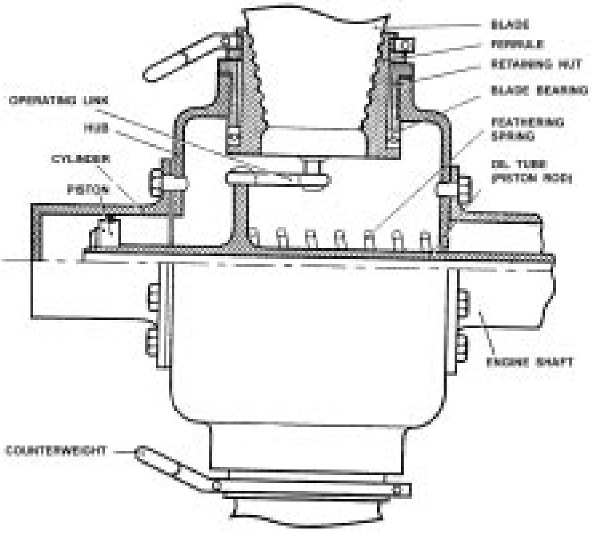

Fig.3.Single acting propellers.

Propeller Control

Blade angle is controlled by a constant-speed unit which comprises a centrifugal governor, a governor valve, and an oil pump to boost engine oil pressure sufficiently for the operation of the propeller control mechanism. The governor is driven from the engine shaft, and movement of the governor weight under centrifugal force is opposed by a control spring, the loading of which is set by means of the pilot's control lever. The position of the governor valve is determined, therefore, by engine speed and the force exerted by the spring; when these forces balance, the oil line to the propeller is blanked off, and oil is trapped in the cylinder of the pitch change mechanism.

a) When the pilot's control lever is set to the maximum rev/min position, and the throttle is at a low power setting, the governor valve will be fully down, and oil from the pump will be directed through the hollow piston rod to turn the propeller blades to fully fine pitch. As the throttle is opened and rev/min are increased, centrifugal force on the governor weights will raise the valve, until a position is reached where maximum rev/min are obtained and the oil line to the propeller is blanked off. Any further increase in power will tend to increase rev/min and result in the governor valve being lifted; oil will drain from the propeller and produce a coarser blade pitch to maintain the specified maximum rev/min.

b) During flight, rearward movement of the pilot's control lever will reduce control spring loading, and allow the governor weights to lift the valve; this will result in a coarser blade angle, and the increased load on the engine will reduce engine speed until the spring force is balanced by centrifugal force on the governor weights,. Forward movement of the pilot's control lever will increase spring loading, and result in a finer propeller pitch and higher engine speed.

c) If propeller load decreases in flight, or power is increased, the engine will begin to speed up, the governor weights will raise the valve, and propeller pitch will coarsen to maintain the set engine speed; conversely an increase in propeller load, or a decrease in engine power, will result in a finer propeller pitch, to maintain the set engine speed.

Feathering is accomplished by moving the pilot's control lever to the appropriate position, which is normally obtained by moving the lever through a gate in the quadrant. This action raises the governor valve fully, allowing oil to drain from propeller, and the blades to turn to the fully coarse (feathered) position under the action of the counterweights and feathering spring.

In order to unfeather the propeller, a separate source of oil under pressure is required; on light aircraft this is usually provided by an accumulator which is charged during normal operation. To unfeather, the pilot's control lever is moved into the constant speed range, thus lowering the governor valve, and the unfeathering button is pressed, releasing oil from the accumulator and allowing it to flow to the propeller. This action commences unfeathering, and once the propeller starts to windmill the normal oil supply completes the operation.

When the engine is stopped on the ground, oil pressure in the cylinder is gradually relieved by leakage through the constant speed unit (CSU), and this would enable the propeller blades to turn to the feathered position under action of the feathering springs. This condition would result in unacceptable loads on the engine during starting, and a centrifugal latch is fitted to prevent forward movement of the propeller piston when the engine is stopped. Fig.5. below shows the operation of a centrifugal latch; it is disengaged by centrifugal force at all speeds above ground idling, thus enabling the propeller to function normally during flight, but below this speed centrifugal force is overcome by the return spring, and the piston can only move forward a short distance, equivalent to approximately 5^o of blade angle. When the engine is started, oil pressure builds up to move the blades to fully fine pitch, and centrifugal force disengages the latch.

Because of the predominance of single-acting propellers on light aircraft, only a simple propeller has been described. However, there is a wide variety of propeller/engine installations, some of the safety features attributed to double acting propellers will also be found on particular single-acting propellers.

DOUBLE-ACTING PROPELLER

This type of propeller is normally fitted to larger engines and, because of engine requirements, is more complicated then the propellers fitted to smaller engines, Construction is similar to that of single-acting propeller, the hub supporting the blades, and the cylinder housing the operating piston. In this case, however, the cylinder is closed at both ends, and the piston is moved in the both directions by oil pressure. In one type of mechanism, (Fig.6.) links from the annular piston pass through seals in the rear end of the cylinder, and are connected to a pin at the base of each blade. In another type of mechanism, the piston is connected by means of pins and rollers to a cam track and bevel gear, the bevel gear meshing with a bevel gear segment at the base of each blade; axial movement of the piston causes rotation of the bevel gear, and alteration of blade angle. Operating oil is conveyed to the propeller mechanism through concentric tubes in the bore of the engine reduction gear shaft.

NORMAL OPERATION

In a turbo-propeller installation the power control lever is often connected to both the fuel control unit and the propeller

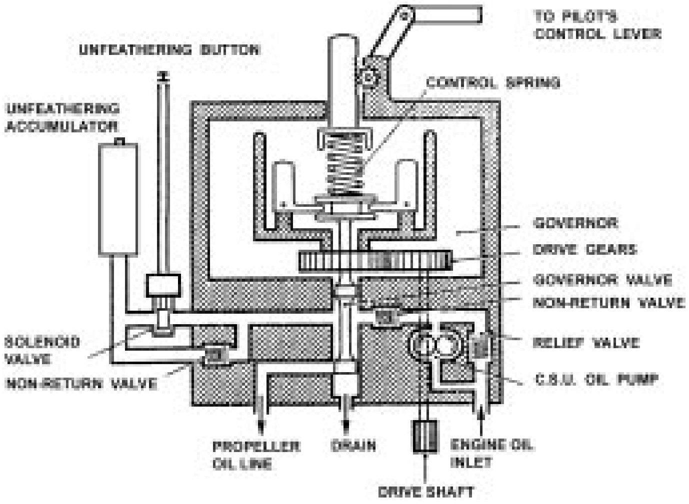

Fig.4. Constant Speed Unit.

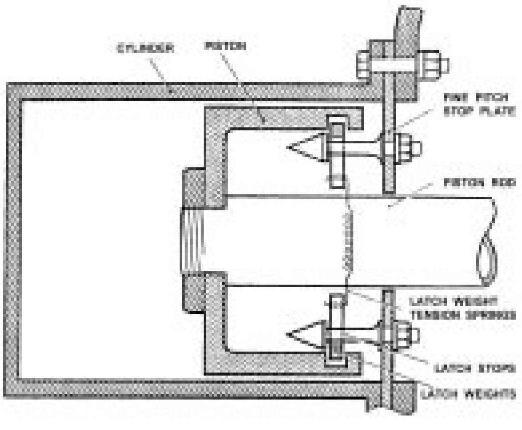

Fig.5. Centrifugal latch.

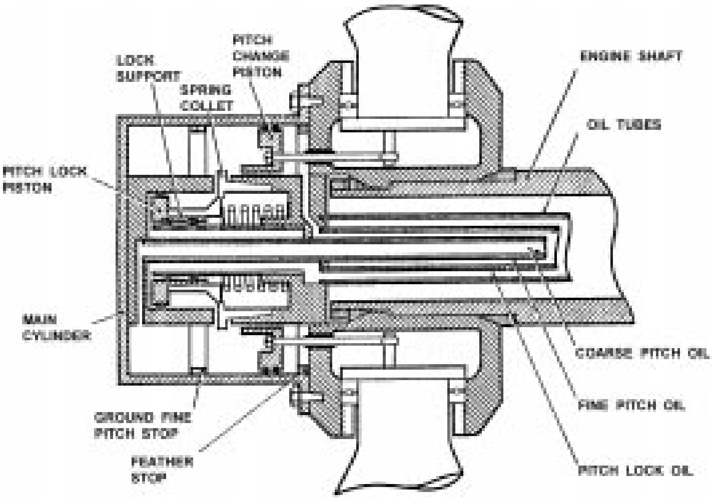

Fig.6. Double acting propeller.

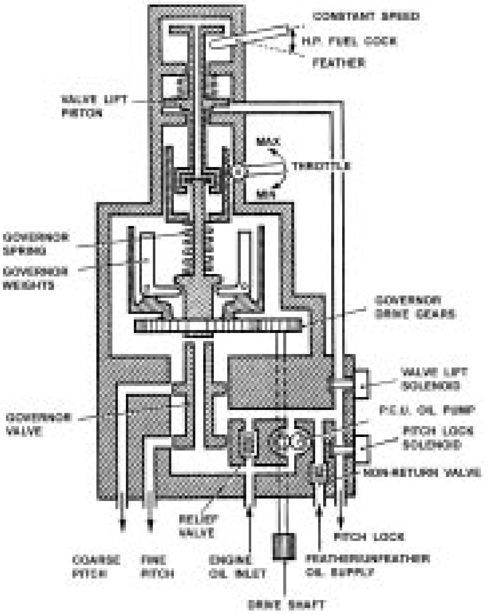

Fig.7.Propeller control Unit.

control unit (PCU), so that fuel flow and engine speed are selected at the same time. The PCU is basically CSU as illustrated in Fig.7, but the PCU includes a number of additional features. Constant speed operation is controlled in a similar manner to that on the single-acting propeller; the governor weights opposing control spring force to raise or lower the governor valve, and to supply oil to the appropriate side of the pitch change piston, whenever engine speed varies from the speed selected. Fig.7 illustrates the PCU.

(a) In the 'on speed' condition, centrifugal force on the flyweights balances the force of the control spring, and the governor valve traps oil in both sides of the pitch change cylinder.

(b) In the 'under speed' condition, control spring force is greater than the centrifugal force on the flyweights, and the governor valve is lowered, supplying oil to the rear of the pitch change cylinder, and providing a drain for oil from the front of the cylinder. Blade angle decreases, and the engine speeds up until centrifugal force on the flyweights balances the force of the control spring, and the governor valve is returned to the 'on speed' condition.

(c) In the 'overspeed' conditions, control spring force is less than the centrifugal force on the flyweights, and the governor valve is raised, directing oil to the front of the pitch change cylinder, and providing a drain for oil in the rear of the cylinder. Blade angle increases, and the engine speed decreases because of the added load, until the flyweights and control spring are once more in balance.

FINE PITCH STOPS

During starting and ground running, a very fine propeller pitch may be required, to minimize propeller load, and to prevent engine overheating; however, during flight, this very fine pitch would lead to engine over speeding, and excessive drag if the PCU were to fail. To cater for both these requirements, the pitch change piston on the type of propeller illustrated in figure 6 is provided with two fine pitch stops, the flight fine pitch stop being withdrawn for starting and ground operations. The flight fine pitch stop is in the form of a spring collet, the prongs of which are designed to spring inwards. When the collet is operating as a stop, the pitch-lock piston is held in the forward position by a spring, forcing the spring collet open, and preventing the pitch change piston from moving forward further than the flight fine pitch position. When ground fine pitch is required, a solenoid in the PCU is energized (normally by operation of both a stop withdrawal lever and a throttle-operated switch) and oil pressure is ducted through the third oil line to the front of the pitch lock piston; as the piston moves rearwards, support for the collet is withdrawn and the prongs spring inwards, allowing the pitch change piston to move fully forward, to the ground fine pitch position. The pitch lock solenoid is disarmed when the throttles are moved forward for takeoff, and, when the propeller has coarsened in to the constant speed range, the pitch lock piston moves forward under spring pressure and opens the spring collet to form the flight fine pitch stop.

NOTE : The term 'pitch lock' is used, in the above paragraph, to describe a means of holding the fine pitch stop in a prescribed position. Some manufacturers use the term to describe a device which locks the blades at whatever angle they happen to be, should failure of the pitch change mechanism occur.

(a) The entire power-unit and the aircraft must be safeguarded in the event of the failure of the pitch-lock unit to operate, and a safety system is incorporated in the PCU. If, during flight, the propeller blades move to a pitch finer than flight fine pitch, a switch fitted to one blade closes, and completes the circuit through an isolating switch to a solenoid in the PCU. This solenoid directs oil pressure to a valve-lift piston, which lifts the governor valve and directs oil to the front of the pitch change piston. This action coarsens the propeller blade angle, and breaks the circuit to the valve-lift solenoid. If the pitch-change piston does not latch over the spring collet as it moves rearwards, the sequence will be repeated as the blades fine-off past flight fine pitch again. An isolation switch prevents operation of this safety system when ground-fine pitch is purposely selected.

FEATHERING

Facilities for the manual feathering of the propeller are provided on all large piston and turbo-propeller engines. With some turbo-propeller installations, however, the drag from a wind milling propeller in the fine pitch could be very dangerous, particularly with a twin engine aircraft, and for these aircraft automatic feathering is also provided.

(a). Manual feathering of the propeller on a piston engine is normally carried out by movement of the propeller control lever to the 'feather' position, and operation of the feathering pump. These actions raise the governor valve, and supply oil under pressure to the appropriate side of the pitch-change piston. On a turbo-propeller installation, manual feathering is carried out by an interconnection between the PCU and the high pressure fuel cook. When the fuel cook is moved to the 'feather' position, linkage to the PCU lifts the governor valve independently of governor control, and oil is directed to the front of the pitch change piston to turn the blades fully coarse. Since the oil pump in the PCU is driven by the engine, the oil supply may be insufficient to feather the propeller completely, and the operation of the electrically-driven feathering pump may be necessary.

(b). Automatic feathering is initiated by means of a torque switch. Whenever the power levers are positioned above the idling range, and the engine torque falls below a specified amount, the torque switch closes and completes a circuit to the feathering pump and the valve-lift solenoid in PCU. The solenoid direct oil to the valve lift piston which raises the governor valve, and opens the oil ports from the feathering pump to the front of the pitch change piston, thus feathering the propeller.

UNFEATHERING

On turbo-propeller engines, when the high pressure fuel cock is open and the power levers closed, the governor valve is in a suitable position to direct oil from the feathering pump to the rear of the pitch change piston. Selection of feathering pump switch (which is often incorporated in the fire control handle), supplies oil to the PCU and thence to the propeller, and activates the engine ignition system. When the propeller blades have turned from the feathered position, the airstream commences to wind will the propeller and rotate the engine, and normal oil pressure builds up to complete the unfeathering operation.

REVERSING

In a reversing propeller, the propeller mechanism includes a removable ground fine pitch stop, which enables the propeller to fine-off to a negative pitch when certain actions have been taken and certain condition are fulfilled. Various safeguards are incorporated to prevent selection during flight. The means of achieving negative pitch vary considerably, but operation of a typical hydraulically operated propeller is described in the following paragraphs.

(a) Electrical control is exercised by throttle-mounted switches, weight contact switches on the landing gear, and a master switch or lever to arm the circuit. With the throttle levers closed beyond normal idling to a datum position, 'reverse' selected, and the weight of the aircraft on its wheels, electrical power is supplied to a pitch-stop withdrawal solenoid, and oil pressure is directed to withdraw the fine-pitch stop and move and pitch-change piston forward to the reverse stop, where it is held by hydraulic pressure. Operation of the 'reverse' lever also changes the sense of operation of the throttle levers., which are pulled further back to increase power in reverse pitch.

(b) Indication of stop withdrawal, and movement of the blades to negative pitch, is provided by hub-mounted switches, which illuminate appropriate warning lamps on the flight deck.

(c) Re-selection of positive blade angle is achieved by moving the throttle into the normal idling range, and by moving the master lever out of the reverse position. Oil is ducted to the front of the pitch change piston, and the blades move to a positive angle; the stop returns to normal operation once the blades have moved past the ground fine pitch angel.

'BETA' CONTROL

On some gas turbine engines, a form of control known as 'beta', or blade angle control, is used or ground operations, and may be applied to either, single-acting or double-acting propellers. With this system, the throttle (usually known as power lever) operate in a gated quadrant. During flight these levers cannot be closed below the 'flight idle' gate, and the CSU operates normally to maintain any pre-selected propeller speed, In the ground idling and reversing range, the power lever control propeller speed, and the governor mechanism is overridden. An overspeed sensor, and mechanical pitch stop, prevent operation in the ground (fine pitch) range during flight. In the beta range, the pitch stop is withdrawn, and movement of a power lever rotates a setting cam in the associated CSU, which raises or lowers the governor valve according to whether a coarser or finer pitch is required. A mechanical feedback mechanism, operated by linkage from the propeller blades, resets the governor valve via a follow-up cam, and pitch change ceases when the angle scheduled by the power lever is achieved.

ELECTRICALLY OPERATED PROPELLERS

As with other types of variable-pitch propellers, a hub is mounted on the engine reduction gear shaft, the individual blades are fitted into the hub, and the pitch change mechanism is fitted to the front of the hub. In this type, however, the pitch change mechanism consists of a reversible electric motor, driving a bevel gear through a gear train with a very high reduction ratio. The bevel gear meshes with a bevel gear segment attached to the root of each blade, and, when rotates, turns the blades to alter propeller pitch. Electric power to the motor is provided through a brush and slip-ring arrangement at the rear of the hub. A motor brake is provided to prevent overrun, and normally consists of two friction discs, one fixed to the rotating motor shaft, and the other keyed to the stationary motor casing. The brake is applied (discs held together) by spring pressure, and released by means of a solenoid whenever a pitch change in initiated.

Some electrically operated propellers are controlled by an engine-driven CSU, and switches are also provided which enable propeller pitch to be controlled manually. The CSU is similar to those fitted to hydraulically operated propellers, but the governor valve supplies oil to the appropriate side of a piston contained in the CSU, which is connected to the central contact of a switch unit. Movement of this piston in either direction completes a circuit to the pitch change motor, and alters blade angle as required.

On some multi-engines aircraft an electrical control system is used. A single propeller pitch level controls the speed of a master electric motor, which is used as a reference for engine speed, and which drives the stator of a contactor unit for each engine. Each engine drives an alternator, which supplies three-phase alternating current to the stator winding of the appropriate contactor, the frequency being proportional to engine speed. During operation , a magnetic field is built up round the stator with a phase rotation opposite to a that of the stator. If the stator speed and alternator speed are the same, the magnetic field will, therefore, be stationary; any variation in alternator speed will result in rotation of magnetic field, the direction of rotation depending on whether the alternator is rotating faster or slower than the stator. Rotation of the magnetic, field influences a concentric rotor, which rotates with it, and closes a pair of contacts to complete the circuit to the appropriate winding in the propeller pitch change motor. Switches are normally provided to enable pitch changes and feathering to be carried out manually.

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CHAPTER: 11
ANTI ICING OF GAS TURBINE ENGINE

INTRODUCTION

This Chapter gives general guidance on the installation and maintenance of the thermal systems employed for the anti-icing of the air intakes of turbine engine. It should be read in conjunction with the installation drawings, Maintenance Manuals and approved Maintenance Schedules for the engine and aircraft concerned.

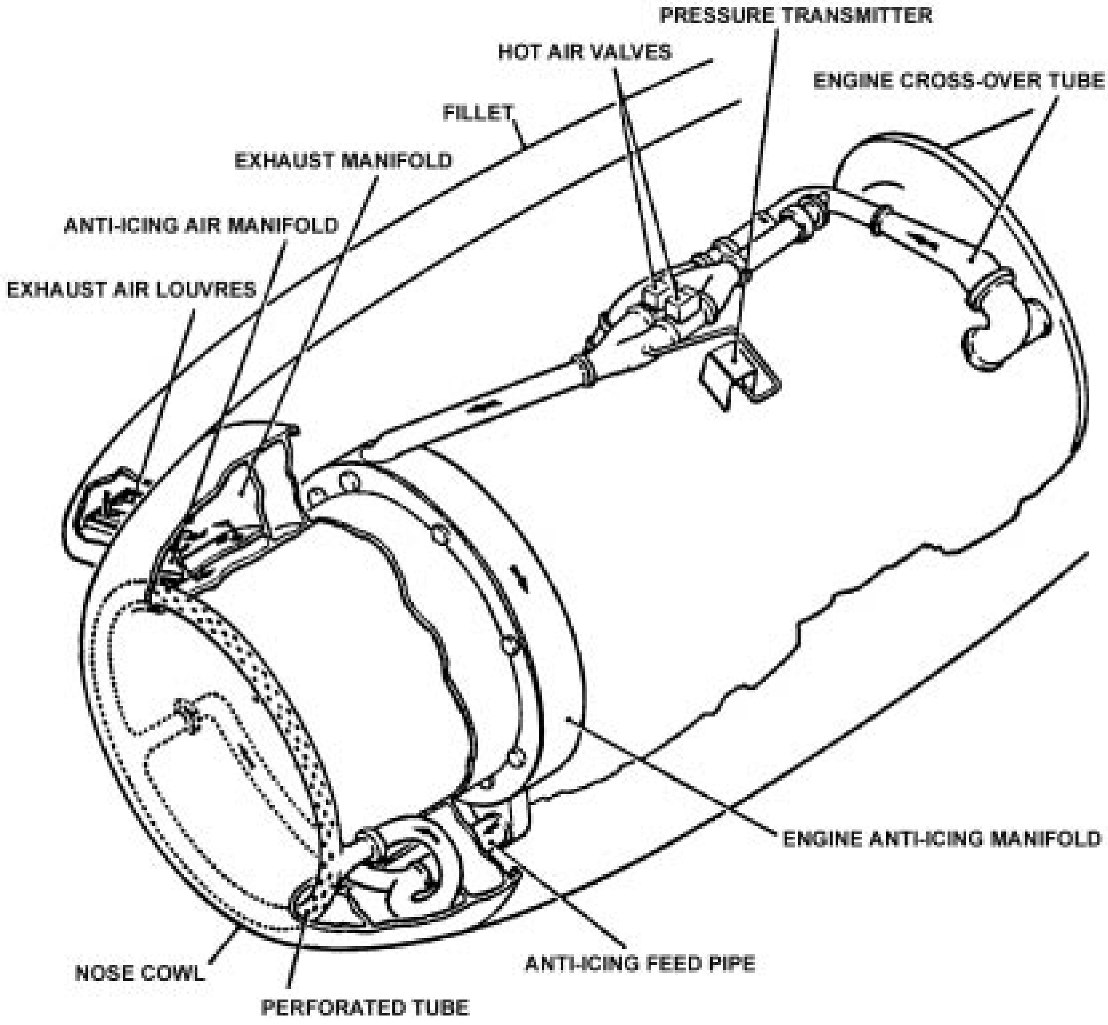

Fig.1. Typical Hot Air Anti-Icing System.

General

A gas turbine engine presents a critical icing problem and therefore requires protection against ice formation particularly at the air intake, nose bullet or fairing, and inlet guide vanes. Icing of these regions can considerably restrict the airflow causing a loss in performance and, furthermore, cause damage to the compressor as a result of ice breaking away and being ingested by the compressor. There are two thermal systems in use for air intake anti-icing; a hot air bleed system and an electrical resistance heating system, and although the latter is usually chosen for turbo propeller engines to provide protection for the propeller, there are some examples where both systems are used in combination.

Hot Air System

In a hot air system the air is bled from the compressor and is fed via ducting into the air intake nose cowl, through the inlet guide vanes of the engine and also, in some engines, through the nose bullet. A typical system is illustrated in

Fig. 1. After circulating the intake cowl and guide vanes, the air is exhausted either to atmosphere or into the engine air intake. The flow of hot air is regulated by electrically operated control valves which are actuated by control switches on a cockpit panel. An air temperature control system is not usually provided in a hot air system.

Electrical Heating System

In an electrical heating system, heating elements either of resistance wire or sprayed metal, are bonded to the air intake structure. The power supply required for heating is normally three-phase alternating current. The arrangement adopted in a widely used on turbopropeller engine is illustrated in Figure 2 as an example. The elements are of the resistance wire type and are formed into an overshoe which is bonded around the leading edge of the air intake cowl and also around the oil cooler air intake. Both anti-icing and de-icing techniques are employed by using continuously heated and intermittently heated elements respectively. The elements are sandwiched between layers of glass cloth impregnated with resin. In some systems the elements may be sandwiched between layers of rubber. The outer surfaces are, in all cases, suitably protected against erosion by rain, and the effect of oils, greases, etc. The power supply is fed directly to the continuously heated elements, and via a cyclic time switch unit to the intermittently heated elements and to the propeller blade elements. The cyclic time switch units control the application of current in selected time sequences compatible with prevailing outside air temperature conditions and severity of icing. The time sequences which may be selected vary between systems. For the system shown in Figure 2 the sequences are 'Fast', giving one complete cycle (heat on/heat off) of 3 minutes at outside air temperature between –6°C and + 10°C, and 'Slow', giving one complete cycle of 6 minutes at outside air temperatures below –6°C. An indicator light and, in some cases, an ammeter, are provided on the appropriate cockpit control panel to indicate correct functioning of the time switch circuit.

INSTALLATION AND MAINTENANCE

Full details of the methods of installation and check necessary for the inspection and maintenance of systems and associated components will be found in the relevant aircraft and engine Maintenance Manuals and approved Maintenance Schedules; reference must therefore be made to such documents. Reference should also be made for guidance on the installation of electric cables and testing of circuits. The information given in the following paragraphs is intended only as a general guide to the installation and maintenance procedures normally required.

Hot Air System

The installation and maintenance of components of hot air systems is, in general, a straightforward procedure which only requires checks to ensure security of attachments to appropriate parts of the aircraft structure, security of duct

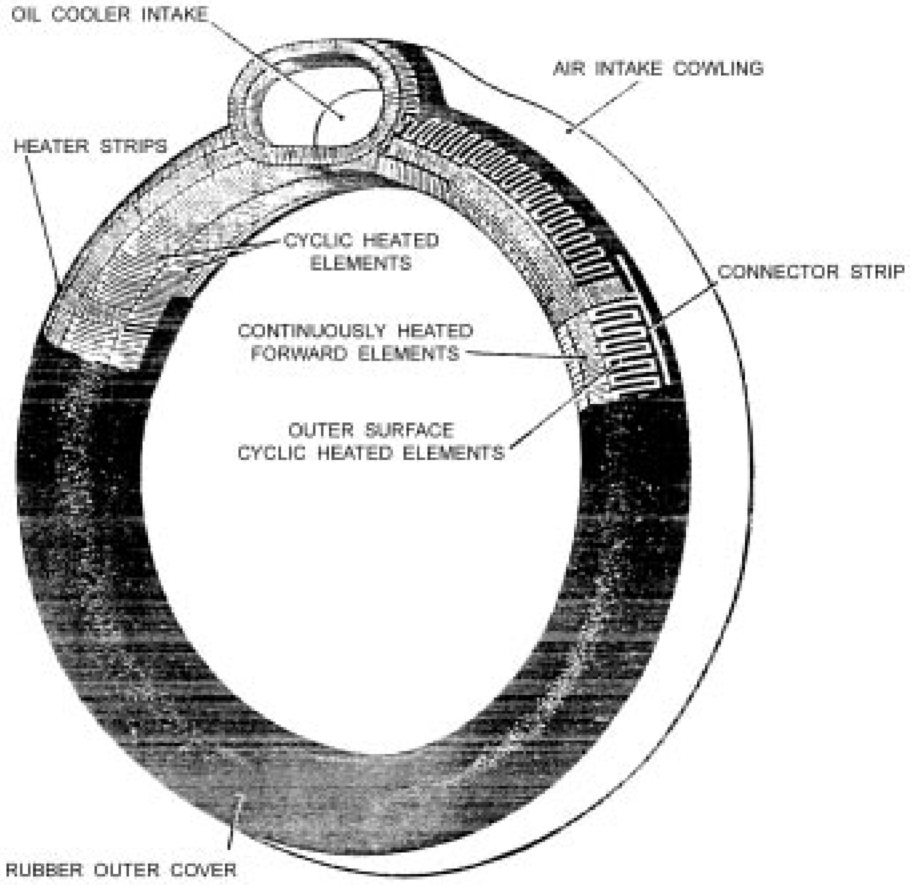

Fig.2. Typical Electrical Anti-Icing System.

connections and wirelocking, where necessary. After installation of a component and at the periods detailed in the aircraft approved Maintenance Schedule, a system should be tested to ensure proper functioning and checks made for leakage at the areas disturbed. Some important aspects common to installation and maintenance procedures are given in the following paragraphs.

Ducts should be inspected externally and internally for cleanliness, signs of damage and security of end fittings.

During installation, ducts must be adequately supported at all times, and must not be allowed to hang from a joint or other component. There must be adequate clearance between ducts and adjacent structure and components.

In general, new seals should be fitted between jointing faces of end fittings of ducts and components such as control valves. This is also essential whenever a joint is broken down for any reason. The jointing faces should also be checked for excessive ovality or gaping.

Whenever possible ducting should be removed by disconnecting at a point where band-type vee-clamps are used. On some engines bolted spherical connections are employed and , unless it is absolutely necessary, the ducts should not be disconnected at these points since the connections will require special refitting.

Band-type vee-clamps should be lubricated with the dry-film lubricant specified in the Maintenance Manual and torque-tightened to the loads specified. The clearance between the flanges of fittings should be checked in order to ensure that the seal between the jointing faces of duct end fittings has been sufficiently compressed.

Expansion bellows type joints should be checked for full and free movement.

All sections of ducting should be properly aligned with each other and with other associated components. In most cases ducting passes through confined spaces and requires considerable care to ensure stress-free alignment at the joints before finally securing in place. Ducting should not be drawn into alignment by means of flange attachment devices. On some types of engine alignment is facilitated by locating a dowel in a hole. On others alignment is by means of coloured flashes painted on the ducts and components.

If a section of ducting or a component is removed and refitting is not being effected immediately, suitable blanks must be fitted to the open ends of ducts or other connections to prevent the ingress of foreign matter.

Where specified, ducts should be tested for leaks in the manner prescribed in the relevant aircraft and engine Maintenance Manuals. The test pressure and rate of leakage should not exceed the limits quoted.

Note: Adequate safety precautions must be taken when inspecting duct sections under pressure.

Control valves should be inspected for cleanliness, signs of damage and their insulation resistance and solenoid resistance values measured to ensure that they are within the limits specified in the Maintenance Manual. When installing valves particular care is necessary to ensure that they are positioned in correct relation to the air flow as indicated by an arrow on the body of the valve.

Cables interconnecting appropriate electrical components must be of the rating specified by the manufacturer. All connections should be checked against the relevant wiring diagrams, and plugs, sockets and terminal screws properly secured.

On completion of the installation of a duct section or component, and the periods specified in the approved Maintenance Schedule, an in-situ functional test should be carried out. Any limitations as to the duration of the test and other precautions during engine ground running, must be strictly observed. A functional test consists principally of checking the air pressure supplied to the system at a specified engine speed, and checks on the function of associated controlling and indicating devices. Such checks and tests should be performed to a prescribed test schedule.

Electrical Heating Systems

In systems of this type, the overshoes are bonded to the air intake cowls, therefore removal and installation procedure are related to the cowls as combined units. The procedures are straightforward involving only the removal and refitting of setscrews which secure cowls to engine air intake casings, and the making and breaking of the electrical connections. In some cases the procedures also involve the connection and disconnection as appropriate, of fire extinguisher system spray pipes and oil cooler pipes and couplings at the rear face of the air intake cowl. Set-screws pass through steel insert and rubber bush assemblies and care should be taken to avoid losing these during removal. The bushes should be examined for wear and deterioration and renewed as necessary. Where specified, the clearance between the cowl diaphragm and engine air intake casing must be checked before finally securing the cowl, to ensure that it corresponds to the value specified in the engine Maintenance Manual. If the correct clearance cannot be obtained, the complete cowl assembly or diaphragm should be replaced by a serviceable item. Some important aspects common to inspection and maintenance procedures are given in the following paragraphs. These should be read in conjunction with the aircraft and engine Maintenance Manuals and approved Maintenance Schedules.

Cowls and electrical leads should be inspected for security and the overshoes inspected for blisters, gashes, exposure of the heating elements, signs of overheating and general deterioration.

NOTE: Overheating or a complete ‘burn-out’, can be caused through impact damage to the overshoe, defects in the heating elements or malfunction of the aircraft’s electrical power supply to the heating elements.

The lacquer film on rubber covered overshoes should be examined for damage or deterioration and if either is evident the film should be touched-up or completely renewed as necessary, by using repair kit supplied by the relevant manufacturer.

Checks on the continuity and resistance of the heating elements, and insulation resistance checks of the complete cowl assembly, must be carried out whenever an assembly has been change or repair effected and also at the prescribed inspection periods.

NOTE: The metal or air cowls is normally anodised and it is necessary to bare a small area to effect the 'earth' connection. On completion of the electrical checks, this area must be reprotected against corrosion.

Functional testing of a complete system must be carried out at the check periods specified in the approved Maintenance Schedule, when a system malfunction occurs, after replacement of an intake cowl or a system component such as a cyclic time switch, and also after any repairs to an overshoe. A functional test consists principally of checking that heating current is applied to the heater elements at the periods governed by the operation of the cyclic time switch and, as indicated by the system indicator light, and ammeter where applicable, to the systems. Tests and checks must be performed to a prescribed test schedule paying particular attention to any limitations on system operation and engine speeds during ground running.

NOTE: The power supply control circuit is usually routed through landing gear shock-strut micro switches so that on the ground the power is automatically reduced to prevent overheating. Therefore, whenever the aircraft is on jacks, or the micro switches are otherwise rendered inoperative, power should not be applied to the heating elements.

If blisters, gashes, exposure of the heating elements, general deterioration and lack of adhesion of either rubber or glass cloth covering is evident, the covering should be carefully cut open to permit examination of the heating elements. If the elements are not fractured or cracked and the rubber or glass cloth below the elements has not deteriorated, the areas may be repaired as a minor repair.

The heating element system is made up of a number of sections or pads and if any one of the sections has been fractured due to a localised burn-out or mechanical damage, a repair can be made by welding a portion of element in the appropriate section.

NOTE: The number or repairs in a section or pad is normally limited to one since the weld causes an increase in element resistance.

The repair methods to be adopted, and the nature of the work involved, depends largely on the extent of damage and also on the type of overshoe construction, i.e. glass cloth or rubber laminate. Repair schemes are therefore devised for each type and are usually classified according to the level of the repairs required, i.e. minor repairs which can be carried out in the normal overhaul workshops, or major repairs to be carried out by the manufacturer. Full details of these schemes are given in the Maintenance Manuals and Overhaul Manuals for the relevant type of engine and reference must always be made to these documents.

An air intake cowl assembly which has been damaged or has deteriorated to an extent outside repair standards specified in the Maintenance Manuals and Overhaul Manuals should be removed and replaced by a serviceable assembly.

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CHAPTER: 12
ROUTINE AND NON-ROUTINE MAINTENANCE OF PISTON ENGINE

Engine Testing

Before starting an engine the cowlings should be fitted, the aircraft should be faced into wind and securely chocked, the brakes should be applied, and suitable fire extinguishers should be made available. When starting a new engine it is advisable to use an external power supply rather than the aircraft batteries, and this should be connected to the aircraft. The method of starting will vary according to the type of carburettor and the engine installation, and the procedure recommended by the aircraft manufacturer should be followed. Engine speed should be kept as low as possible until the oil pressure has built up to a prescribed value in a given time. If the minimum oil pressure is not achieved within the specified time the engine must be stopped and the cause determined. The engine should then be warmed up until the recommended minimum cylinder and oil temperatures are reached. At this power setting the magnetos should be checked for a dead cut (by momentarily switching off both magnetos), then the engine should be stopped and inspected for fuel and oil leaks. The engine cowlings should then be refitted, the engine started, and the following checks carried out as appropriate and in accordance with the manufacturer's instructions.

a. Exercise the propeller several times by operation of the pitch control lever, to ensure that it is filled with oil and is operating properly.
b. Check the operation of the magnetos at the recommended power settings.
c. Carry out an engine power check.
d. Open up to full power and check the maximum engine speed. Correct by means of the constant speed unit adjustment as necessary.
e. Check the carburation over the full power range.
f. Check operation of the supercharger.
g. Check operation of all engine-operated systems. This may include checking battery-charging rate, hydraulic pressure and system operation, pneumatic pressure and system operation, vacuum pressure, and operation of the instruments and de-icing boots. The maintenance of the correct fuel pressure over the full power range should also be checked, to ensure correct operation of the engine-driven pump.
h. Close the throttle and check the idling speed and mixture strength.
i. Cool the engine by running it at approximately 1000 rev/min for a short period, or until the cylinder head temperature is within limits, then close it down.

NOTE: Prolonged ground running at high power settings must be avoided, since the cylinders are not adequately cooled when the aircraft is stationary.

After the ground run, the engine should be inspected for gas, fuel or oil leaks, and any adjustments found necessary during the run should be carried out. It will usually also be found necessary to replenish the oil system, since some of the oil from the tank will now occupy the sump and pipelines.

The results of the engine run, including the manifold pressure and engine speed obtained during the power check, and the drop in engine speed obtained during the magneto checks, together with any adjustments carried out, should be recorded in the engine log book.

ROUTINE MAINTENANCE

In order to guard against malfunction or failure of an engine and its associated equipment, a programme of inspection and maintenance is carried out in accordance with a approved schedule. The engine and component manufacturers stipulate the work which should be carried out to maintain their particular products in a satisfactory condition, and the combined inspection and maintenance requirements for the complete engine installation are included in the Maintenance Schedule for the particular aircraft. The bulk of the items will normally be repeated at intervals of 100 flying hours, but some items may be carried out more frequently and some less frequently. The following paragraphs indicate the work required for a typical light-aircraft engine installation.

Lifed Items

The engine itself must be removed for overhaul after a specified number of flying hour (see Airworthiness Notice No. 35), the time depending on its proven reliability; a new type of engine normally has an initial overhaul life which is capable of being extended as experience is gained during its operation. Some components (such as the alternator) may also have to be removed for overhaul after a specified time, but these "lives" are usually arranged to coincide with the engine life. Other components may have to be replaced at more frequent intervals, depending on their condition.

General Condition of Engine

The general condition of an engine should be checked after each routine inspection, by carrying out an engine run as outlined in earlier Chapter. At less frequent intervals a compression check should be carried out on all cylinders, to determine the condition of the cylinders, pistons and valves. Various methods of carrying out this check are outlined but the particular manufacturer's recommendations should be followed. If any particular cylinder shows excessive loss of compression, that cylinder should be replaced with a serviceable component; it is not normally necessary to change the engine because of cylinder unserviceability.

Basic Engine

The crankcase, sump and reduction gear casing, should be inspected for damage, cracks, corrosion and oil leaks, and the security and locking of attaching parts. The cylinders should be checked for damaged fins, corrosion, cracks, security and locking of attaching parts, oil leaks at the cylinder base, rocker covers, and push-rod covers, and gas leaks at the barrel/head joint and at the inlet and exhaust pipe flanges. Any apparent gas/oil leaks at the barrel/head joints should be checked carefully, to ensure that they result from oil seepage and are not the beginning of barrel/head separation. Any damaged paintwork should be repaired according to the manufacturer's instructions, and oil leaks should be rectified as appropriate.

Cowlings and Baffles

Cowlings should be cleaned and checked for cracks, distortion, condition of any rubbing strips attached to them, and loose or unserviceable fasteners. The interior of the cowlings should be inspected for evidence of chafing against engine structure, accessories or baffles; the cowlings should be repaired as necessary, and adjustments should be made to the chafing parts, to provide clearance. Baffles should be checked for cracks, security, and condition of any sealing strips attached to them. Cracks may normally be repaired by welding or patching, but temporary repairs may be effected by drilling the ends of the cracks. Fasteners which are not fully effective should be renewed. Paintwork should be made good in accordance with the manufacturer's instructions and the particular paint scheme.

Engine Mountings

The engine mounting framework should be carefully inspected for cracks, corrosion, distortion, and security of attachment to the airframe. The flexible mountings should be inspected for condition and security; some sag may occur during service, and if this reduces the clearance between engine parts and the structure below the minimum figure specified, it is usually permitted to add spacers to restore the clearance. Damage to the mounting frame and paintwork must be repaired.

Intake Duct

The ducting to the carburettor or injector air intake should be inspected for cracks, corrosion and security, and the condition of the seals at the air filter, carburettor, and, where fitted, the hot-air flap. Any controls provided for filtered air or hot air should be checked for correct operation and for full and free movement, and the connections in the control run should be checked for wear and correct locking. Alternative air flaps which are operated by differential air pressure and are held in position by magnetic catches, should be inspected carefully, as they are more prone to wear and failure, particularly when the magnetic catches lose their effectiveness. The air filter should be cleaned regularly.

Exhaust System

Because of its operating environment, cracking and wear of parts of the exhaust system are inevitable, and frequent inspections are usually specified in the relevant Maintenance Schedule. All parts of the exhaust system should be inspected for security, warping, cracks, dents, and evidence of gas leakage, particularly at slip joints, V-clamps, bellows and heater muffs. Damage may often be repairable by welding, but when carrying out such repairs, extreme caution is necessary to maintain the original contour, since any disruption to the smooth flow of exhaust gas will result in a hot spot, and lead to early failure at that point. Renewal of damaged parts is preferable to repair, and new gaskets or seals should always be fitted.

Attention is drawn, in Airworthiness Notice No. 40, to the dangers inherent in the use of heating systems which employ an exhaust heat-exchanger to heat the air entering the cabin. A thorough inspection of these systems should be carried out at the specified intervals, whenever carbon monoxide contamination is suspected. In some cases the heating jacket on the muffler is detachable, and can be completely removed to enable a thorough inspection to be made for signs of leakage from the exhaust section of the muffler. In other cases a pressure test may be recommended, and this is carried out by blanking the outlet from the heater jacket and applying air pressure through the inlet; with the air supply shut off, there should be no leakage from the heater jacket.

Oil System

Internal lubrication of the engine is of vital importance, and the oil quantity should be checked daily or prior to each flight. Oil should be changed regularly (usually at 50 or 100 hour intervals) by draining the sump and tank (preferably when the oil is hot) and refilling the system with new oil to the correct specification. Oil screens (wire-mesh filters) should be cleaned and filter elements changed at the specified intervals, but on removal, should be inspected for the presence of metal particles, which would indicate internal failure in the engine. The oil-cooler air passages should be checked for blockage and cleaned as necessary, and all parts of the oil system should be checked for cracks, security, chafing, leaks and damage during the routine inspection.

Engine Fuel System

The fuel system in the engine bay, including flexible pipes, injector distribution pipes, carburettor, pump, and filter, should be checked for leakage under pressure, and should be inspected for security, chafing and damage; some engine fuel components also have tell-tale drains from shafts, seals and diaphragms which facilitate checks for internal failure.

The main fuel filter should be drained before flight, daily, or after refuelling, as specified in the relevant Maintenance Schedule, in order to remove sediment and to drain off any water which may have accumulated. A small amount of water will often be removed from the filter or tank drains, but if the amount is excessive the fuel system should be checked according to prescribed method.

All filters associated with the fuel system should be removed and cleaned at the specified intervals, and when required by unsatisfactory engine operation. Fuel filters should be cleaned by washing in solvent and blowing dry with compressed air, but the air filters fitted to injector nozzles may not be detachable and are often cleaned with the nozzle, by ultrasonic methods.

Throttle and mixture controls should be checked for full and free movement, for correct locking, and for signs of play or lost motion resulting from excessive wear.

Operation of the engine fuel system should be checked during engine runs. Any adjustments found to be necessary should be carried out.

Electrical System

All major components in the electrical system should be checked for condition and security. The generator and starter brushes should be checked for wear, their bearings for play, and their connections for security and locking as appropriate; the alternator drive belt, where fitted, should be checked for condition and tension. The magneto timing and contact breaker gap should be checked and the cam pad should be lubricated. Ignition switch leads should be checked for condition and security, and the sparking plugs should be removed, cleaned and tested. All wiring harnesses and conduits should be checked for security and condition.

Pipes

Rigid pipes should be inspected for security of attachment to the airframe or engine, for cracks, dents, corrosion and chafing, and for signs of leakage. Bonding strips fitted across hose joining rigid pipes should be checked for condition and security. All flexible hoses should be inspected for deterioration, kinks, chafing, security and correct installation, without twists or unnecessary bends. The life of flexible hoses should also be checked, and they must be rejected at the end of this time regardless of their apparent condition. Firesleeves such as are fitted to flexible fuel and oil hoses, should be checked for deterioration, and should be renewed if they are cut, chafed or frayed, or have become impregnated with fuel or oil.

Lubrication

A diagram is provided in most light-aircraft Maintenance Manuals, indicating the method and frequency of lubrication of various parts of the aircraft, and the types of lubricant to be used. As far as the engine installation is concerned, lubrication is generally confined to the application of oil or grease to the various working parts. These include the lever pivots, rod ends and bearings in the throttle, mixture, air filter, and cabin-heat control linkages, and the links and hinges on filter doors, hot-air intake doors, and cooling-air exit flaps. In addition, the rocker covers of some inverted engines may need filling with engine oil, whilst the rocker bearings of some radial engines may require lubrication by means of a grease gun. Dirt, grit and old lubricant should be wiped off before applying the new oil or grease, and any excess should be removed.

Fireproof Bulkhead

Damage to a fireproof bulkhead, or ineffective sealing of pipes, mounting structure or controls passing through the bulkhead, could result in exhaust fumes passing into the wing or fuselage, and in the case of an engine fire, in the spreading of the fire to the airframe structure, with possible catastrophic results. The fireproof bulkhead should be examined very carefully for cracks and other damage, and for signs of ineffectiveness of the seals or sealing compound used; any faults should be corrected in accordance with the relevant Maintenance Manual.

NON-ROUTINE INSPECTIONS

Operating limitations on the rotational speed and manifold pressure of an engine are imposed to ensure that the engine is operated within design parameters. There are times, however, when these limitations may be exceeded, through either a mechanical fault or mishandling, and the engine must be inspected to determine whether it is still satisfactory for continued operation. The inspections necessary following overspeeding or overboosting of the engine, and also after a shock-loading of the engine. The inspections which are required following a lighting strike or static discharge damage are carried out as specified.

Overspeeding

Operation at engine speeds higher than the rated speed (or take-off engine speed when this is specified), can cause rapid wear of highly-stressed parts, and, if the speed is high enough, serious damage or failure can occur. The inspections required by the engine manufacturer are normally contained in the Maintenance Manual or in Service Bulletins, but the inspections outlined in paragraphs below are typical of those required on light-aircraft engines.

Momentary Overspeed up to 2%

No special inspections are normally required for a momentary overspeed of 2% of the rated engine speed, but the cause should be determined and corrected, and an entry should be made in the engine log book.

Overspeeding Up to 5%

The following inspections should be carried out following an overspeed of up to 5% of rated speed, and if satisfactory the engine may be returned to service.

a. Drain all oil from the engine lubrication system, remove all filters and inspect for metal particles.
b. Carry out a cylinder compression check.
c. Using a suitable inspection instrument (e.g. a boroscope), examine the cylinder walls for scoring, which may have been caused by broken piston rings.

Overspeeding between 5% and 10%

Repeated momentary overspeeds or short periods of operation at 5% to 10% higher than rated speed may produce excessive wear in the valve train. A routine 100 hour inspection should be carried out, and the following checks should also be made. Any parts which are found to be unserviceable must be renewed before the engine is returned to service.

a. Check all filters for metal particles.
b. Using a suitable inspection instrument, examine the cylinder walls for scoring, and the valves and seats for distortion or damage.
c. Examine the rockers, valves, valve guides and springs for condition.
d. Rotate the engine by hand to check the full and free movement of all parts in the valve train.
e. On a turbocharged engine, inspect the turbine wheel and compressor for damage, and the bearings for excessive wear.

Overspeed higher than 10%

Any overspeed in excess of 10% above rated speed will require removal of the engine for overhaul in accordance with the manufacturer's instructions.

Overboosting

On a supercharged engine, overboosting is possible through a mechanical fault (in the control system) or through mishandling, and may result in excessive pressures in the cylinders and overstressing of the working parts of the engine. The inspections which are generally required by engine manufacturers, following over-boosting, are outlined as below.

Overboosting not exceeding 2 inHg (1 lbf/in^2)

A momentary overboost which does not exceed 2 inHg does not require any special inspections, but the cause should be determined and corrected, and the relevant details should be entered in the engine log book.

Overboosting not exceeding 5 inHg [2(1/2) lbf/in^2]

An overboost not exceeding 5 inHg which is of short duration (i.e. less than 10 seconds) will require a routine 50 hour inspection to be carried out, and the following checks to be made. Provided that no damage is found, the engine may be returned to service.

a. Inspect cylinders for cracks around base flange, the sparking plug holes and in the head.
b. Examine oil filters for metal particles.
c. Inspect sparking plugs for cracks, and for loose or damaged electrodes.

Overboosting exceeding 5 inHg [2(1/2) lbf/in^2]

If the overboosting exceeds 5 inHg, or is of long duration, the engine must be removed from the aircraft, and overhauled in accordance with the manufacturer's instructions.

Shock-loading

When sudden stoppage of an engine occurs, through, for example, the propeller striking the ground, damage to the engine is likely to occur. The extent of the damage is very difficult to assess, however, and may bear no relationship to engine speed or to the forward speed of the aircraft; damage is most likely to be incurred by the propeller shaft, the engine bearers, the crankshaft counterweights and the crankcase bearing webs. The propeller shaft and engine bearers can be examined for damage, and a limited inspection of the internal parts of an engine can be made by removing one or more cylinders, but satisfactory crack detection is not possible with the engine assembled. Most manufacturers, therefore, recommend that any incident of sudden engine stoppage is sufficient to warrant removal of the engine for complete disassembly and inspection.

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CHAPTER: 13
STORAGE OF PISTON AND GAS TURBINE AERO ENGINE

INTRODUCTION

Under normal operating conditions the interior parts of an engine are protected against corrosion by the continuous application of lubricating oil, and operating temperatures are sufficient to dispel any moisture which may tend to form; after shutdown the residual film of oil gives protection for a short period. When not in regular service, however, parts which have been exposed to the products of combustion, and internal parts in contact with acidic oil, are prone to corrosion. If engines are expected to be out of use for an extended period they should be ground run periodically or some form of anti-corrosive treatment applied internally and externally to prevent deterioration.

The type of protection applied to an engine depends on how long it is expected to be out of service, if it is installed in an aircraft, and if it can be turned.

This Chapter gives guidance on the procedures which are generally adopted to prevent corrosion in engines but, if different procedures are specified in the approved Maintenance Manual for the particular engine, the manufacturer's recommendations should be followed.

The maximum storage times quoted in this Chapter are generally applicable to storage under cover in temperate climates, and vary considerably for different storage conditions. Times may also vary between different engines, and reference must be made to the appropriate Maintenance Manual for details.

INSTALLED PISTON ENGINES

If it is possible to run a piston engine which is installed in an aircraft and expected to be out of service for a period of up to one month, sufficient protection will be provided by running the engine every seven days, but if the period of inactivity is subsequently extended, continued periodic ground running would result in excessive wear and the engine should be placed in long term storage. The run should be carried out at low engine speed (1000 to 1200 rev/min), exercising the engine and propeller controls as necessary to ensure complete circulation of oil, until normal working temperatures are obtained. If the engine cannot be run for any reason, the manufacturer may recommend that it should be turned by hand or motored by means of an external power supply, but generally it will be necessary to inhibit the engine as described below.

Long Term Storage

When a piston engine is likely to be out of service for a period in excess of one month it must be treated internally and externally with a corrosion inhibitor. The treatments described below are normally considered satisfactory for six months but this may be extended to twelve months in ideal storage conditions. At the end of this period the engine should be prepared for service, given a thorough ground run and re-protected or, alternatively, removed from the aircraft and stored as described in following paragraphs.

Internal Protection

(I) American Method

a. Drain the oil sump and tank and refill with storage oil as prescribed by the manufacturer.
b. Run the engine at low speed (1000 to 1200 rev/min) until normal operating temperatures are obtained.
c. Spray cylinder protective into the induction system until white smoke issues from the exhaust, then switch off the engine but continue spraying until rotation has ceased.
d. Drain the oil sump and remove the filters.
e. Remove the sparking plugs and spray a fixed quantity of cylinder protective into each cylinder while the engine is turned by hand. A further quantity should then be sprayed into the cylinders with the engine stationary.
f. Fit dehydrator plugs in each cylinder and replace oil filters.
g. Place a quantity of desiccant in the intake and exhaust and blank off all openings.

(II) British Method

a. Drain the oil sump and tank and refill with the storage oil recommended by the manufacturer.
b. Run the engine at low speed (1000 to 1200 rev/min) until normal operating temperatures are obtained.
c. Drain all oil from the system and remove filters.
d. Remove sparking plugs and spray the specified quantity of cylinder protective into each cylinder while the piston is at the bottom of its stroke, at the same time spraying the valve springs and stems with the valves closed, and the valve heads and ports with the valves open. Also spray the valve rocker gear.
e. Turn the engine at least six revolutions by hand, then spray half the previously used quantity of cylinder protective into each cylinder with the engine stationary.
f. Replace oil filters and fit dehydrator plugs.
g. Blank off all openings into the engine (intake, exhaust, breathers, etc.).
h. Replenish oil tank to normal level with storage oil as specified.

(III) Special Requirements

a. Coolant systems should be drained and thoroughly flushed unless an inhibited coolant is used.
b. Fuel system components such as fuel pumps, injectors, carburettors or boost control units also require inhibiting. This is done by draining all fuel and oil as appropriate, and refilling with storage or mineral oil as recommended by the manufacturer. Blanking caps and plugs should then be fitted to retain the oil.
c. Auxiliary gearboxes should also be inhibited. The normal lubricating oil should be drained and the gearbox refilled with storage oil.
d. If the propeller is removed the propeller shaft should be sprayed internally and externally with cylinder protective and correct blanks fitted.

External Protection

Exterior surfaces of the engine should be thoroughly cleaned with an approved solvent such as white spirit, by brushing or spraying, and dried with compressed air. Any corrosion should be removed, the area re-treated in accordance with the manufacturer's instructions and chipped or damaged paintwork renewed. The following actions should then be taken :-

I All control rods should be liberally coated with a general purpose grease.
II Magneto vents should be covered.
III Sparking plug lead ends should be fitted with approved transport blanks, exposed electrical connections masked and rubber components covered with waxed paper or mouldable wrap.
IV Spray holes in fire extinguisher pipes should, if possible, be blanked off, using polythene sleeving or waxed paper suitably secured.
V An approved preservating (normally lanolin or external air drying varnish) should be sprayed over the whole engine, in a thin even film.

INSTALLED TURBINE ENGINES

Installed turbine engines which are to be out of use for a period of up to seven days require no protection apart from fitting covers or blanks to the intake, exhaust and any other apertures, to prevent the ingress of dust, rain, snow, etc. A turbine engine should not normally be ground run solely for the purpose of preservation, since the number of temperature cycle to which it is subjected is a factor in limiting its life. For storage periods in excess of seven days additional precautions may be necessary to prevent corrosion.

Short-term Storage

The following procedure will normally be satisfactory for a storage period of up to one month.

Fuel System Inhibiting

The fuel used in turbine engines usually contains a small quantity of water which, if left in the system, could cause corrosion. All the fuel should therefore be removed and replaced with an approved inhibiting oil by one of the following methods:

Motoring Method

This should be used on all installed engines where it is convenient to turn the engine using the normal starting system. A header tank is used to supply inhibiting oil through a suitable pipe to the engine. A filter and an on/off cock are incorporated in the supply pipe, which should be connected to the low pressure inlet to the engine fuel system and the aircraft LP cock closed. After draining the engine fuel filter a motoring run should be carried out bleeding the high pressure pump and fuel control unit, and operating the HP cock several times while the engine is turning. Neat inhibiting oil will eventually be discharged through the fuel system and combustion chamber drains. When the motoring run is complete the bleeds should be locked, the oil supply pipe disconnected and all apertures sealed or blanked off.

Pressure Rig Method

This may be used on an engine which is installed either in the aircraft or in an engine stand. A special rig is used which circulates inhibiting oil through the engine fuel system at high pressure. The fuel filter should be drained and, where appropriate, the aircraft LP cock closed. The inlet and outlet pipes from the rig should be connected to the high pressure fuel pump pressure tapping and the system low pressure inlet respectively, and the rig pump turned on. While oil is flowing through the system the components should be bled and the HP cock operated several times. When neat inhibiting oil flows from the combustion chamber drains the rig should be switched off and disconnected, the bleed valves locked and all apertures sealed or blanked off.

Gravity Method

This is used when the engine cannot be turned. A header tank similar to the one used in the motoring method is required but in this case the feed pipe is provided with the fittings necessary for connection at several positions in the engine fuel system. The fuel filter should first be drained then the oil supply pipe connected to each of the following positions in turn, inhibiting oil being allowed to flow through the adjacent pipes and components until all fuel is expelled:

a. High pressure fuel pump pressure tapping.
b. Fuel control unit pressure tapping.
c. Burner Manifold.
d. Low pressure inlet pipe.

Components should be bled at the appropriate time and the HP cock operated several times when inhibiting the fuel control unit. All bleeds and apertures should be secured when the system is full of inhibiting oil.

Lubrication Systems

Some manufacturers recommend that all lubrication systems (engine oil, gearbox oil, starter oil, etc.) of an installed engine should be drained, and any filters removed and cleaned, while others recommend that the systems should be filled to the normal level with clean system oil or storage oil. The method recommended for a particular engine should be ascertained from the appropriate Maintenance Manual.

External Treatment

Exterior surfaces should be cleaned as necessary to detect corrosion, then dried with compressed air. Any corrosion should be removed, affected areas re-treated, and any damaged paintwork made good in accordance with the manufacturer's instructions. Desiccant or vapour phase inhibitor should be inserted in the intake and exhaust, and all apertures should be fitted with approved covers or blanks.

Long-term Storage

For the protection of turbine engines which may be in storage for up to six months, the short-term preservation should be applied and, in addition, the following actions taken :-

I Grease all control rods and fittings.

II Blank-off all vents and apertures on the engine, wrap greaseproof paper round all rubber parts which may be affected by the preservative and spray a thin coat of external protective over the whole engine forward of the exhaust unit.

At the end of each successive six months storage period an installed engine should be re-preserved for a further period of storage. Alternatively, the engine may be removed from the aircraft and preserved in a moisture vapour proof envelope.

UNINSTALLED ENGINES (PISTON AND TURBINE)

Engines which have been removed from aircraft for storage, or uninstalled engines which are being returned for repair or overhaul, should be protected internally, and sealed in moisture vapour proof (MVP) envelopes. This is the most satisfactory method of preventing corrosion, and is essential when engines are to be transported overseas.

A piston engine should be drained of all oil, the cylinders inhibited as described in above paragraphs, drives and inside of crankcase sprayed with cylinder protective, and all openings sealed.

A turbine engine should be drained of all oil, fuel system inhibited, oil system treated as recommended by the manufacturer, and blanks fitted to all openings.

Particular care should be taken to ensure that no fluids are leaking from the engine, and that all sharp projections, such as locking wire ends, are suitably padded to prevent damage to the envelope.

The MVP envelope should be inspected to ensure that it is undamaged, and placed in position in the engine stand or around the engine, as appropriate. The engine should then be placed in the stand, care being taken not to damage the envelope at the points where the material is trapped between the engine attachment points and the stand bearers.

Vapour phase inhibitor or desiccant should be installed in the quantities and at the positions specified in the relevant Maintenance Manual, and a humidity indicator should be located in an easily visible position in the envelope. The envelope should then be sealed (usually by adhesive) as soon as possible after exposure of the desiccant or vapour phase inhibitor.

The humidity indicator should be inspected after 24 hours to ensure that the humidity is within limits (i.e. the indicator has not turned pink). An unsafe reading would necessitate replacement of the desiccant and an examination of the MVP envelope for damage or deterioration.

After a period of three years storage in an envelope the engine should be inspected for corrosion and re-preserved.

INSPECTION

Engines in storage should be inspected periodically to ensure that no deterioration has taken place.

Engines which are not preserved in a sealed envelope should be inspected at approximately two-weekly intervals. Any corrosion patches should be removed and the protective treatment re-applied, but if external corrosion is extensive a thorough inspection may be necessary.

Envelopes on sealed engines should be inspected at approximately monthly intervals to ensure that humidity within the envelope is satisfactory. If the indicator has turned pink the envelope should be unsealed, the desiccant renewed and the envelope resealed.

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