EL/1-1

Issue 1.

14*th May*, 1976.

AIRCRAFT

ENGINES

PISTON ENGINE DESIGN AND CONSTRUCTION

1 INTRODUCTION This Leaflet is the first in a series of Leaflets which cover the principles of operation, design, construction and maintenance of aircraft piston engines, such as are used in civil aircraft throughout the world. This Leaflet deals with the general principles of operation, the design features and constructional details of typical aircraft engines.

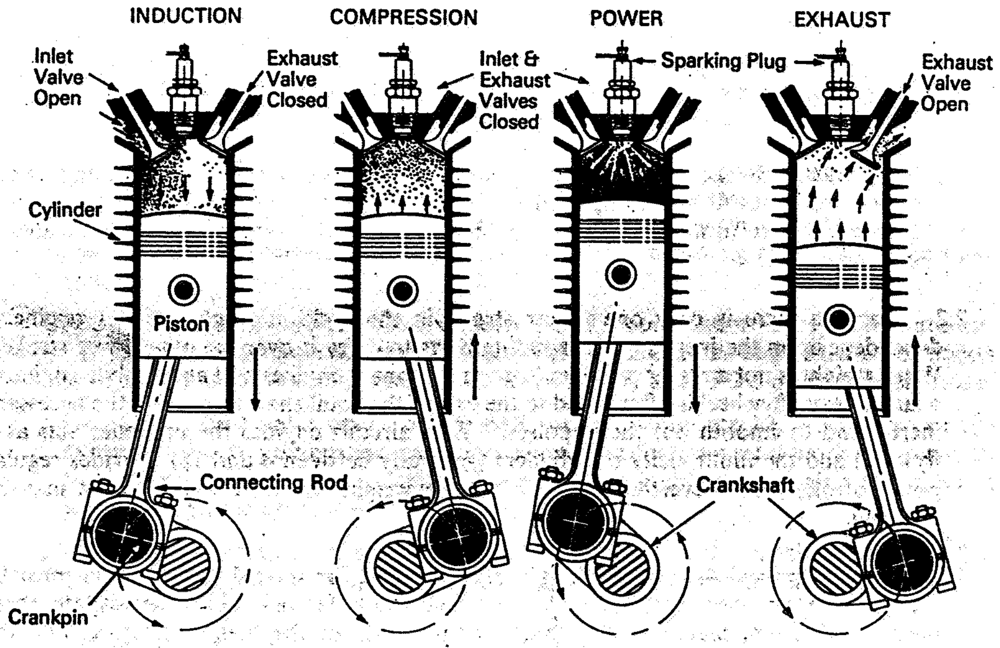


Figure 1 OPERATION OF FOUR-STROKE CYCLE

2 PRINCIPLES OF OPERATION A piston (or reciprocating) engine is a device for converting the heat energy of a fuel into mechanical energy, by internal combustion. The principles which govern the relationship between pressure, temperature and volume in a gas, are stated in the Laws of Boyle and Charles, and these principles are applicable to the operation of a piston engine. Boyle's Law states that, for a given mass of gas at constant temperature, the volume of the gas varies inversely as its pressure, and Charles' Law states that, at constant pressure the volume of a gas varies directly as its absolute temperature.

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

2.1 The movement of the piston from its highest to its lowest position in a cylinder is known as a "stroke", and corresponds to one half of a revolution of the crankshaft. Two upward and two downward strokes make up the complete cycle, and the purpose of each stroke, together with theoretical valve movement, is described below.

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

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

2.1.3 **Power Stroke.** As the piston commences its second downward stroke the combustible mixture is electrically ignited (by means of a magneto and sparking plug, see Leaflet **EL/3-9**) and the gas expands, thus building up pressure and forcing the piston down.

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

2.2 Because there is only one power stroke in the cycle, a single cylinder engine is dependent upon the inertia of the rotating parts to carry it over the other three strokes. When weight is not a major problem (e.g. on stationary engines and automobile engines), a large, heavy flywheel is often fitted to the end of the crankshaft to provide the necessary inertia and to smooth out the impulses. With aircraft engines the propeller acts as a flywheel and the multiplicity of cylinders (generally between 4 and 18) provides regular power strokes, but nevertheless small balance weights or vibration dampers may be required.

2.3 The theoretical 4-stroke cycle is very inefficient, for several reasons, and must be modified to produce acceptable power. The main factors which necessitate these modifications are, inertia of the gases, burning rate of the fuel/air mixture, and the ineffective crank angle, the last being defined as the angular position of the crankshaft when, for a large angular movement of the crankshaft at both ends of the stroke, the linear movement of the piston is small. Ideally, best power would be produced by varying the valve timing (i.e. the times at which the valves open and close in relation to the crankshaft position) according to the rotational speed of the engine, but the mechanism necessary would result in such increased weight and complication that the valves of an aircraft engine are usually timed to provide the greatest efficiency at cruising speed. The actual timing of the valves on a particular engine is often illustrated in the form of a diagram, known as a Valve Timing Diagram, such as is shown in Figure 2. The terms Top Dead Centre (TDC) and Bottom Dead Centre (BDC) are used to define the positions of the crankshaft when the piston is exactly at the top or bottom of its stroke, respectively.

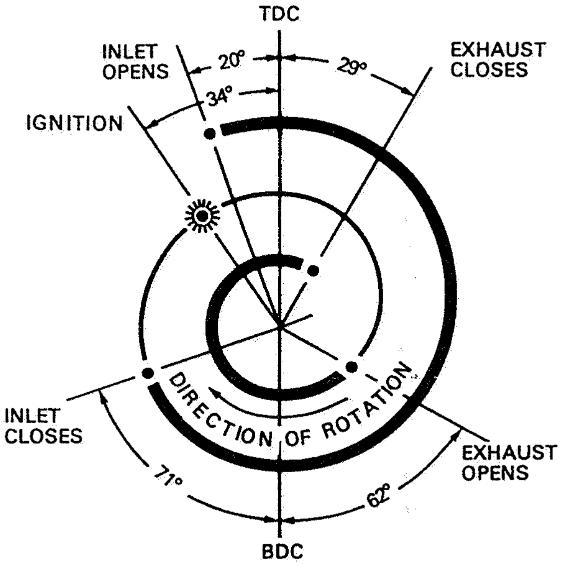


Figure 2 VALVE TIMING DIAGRAM

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

2.3.2 The inlet valve closes after BDC, to take advantage of the inertia of the incoming gases and fill the cylinder as completely as possible. Movement of the piston for a short period after BDC, is insufficient to oppose the incoming gases before the valve closes.

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

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

2.3.5 The exhaust valve closes after TDC, to make use of the inertia of the outgoing gases to completely scavenge the cylinder, and to assist in overcoming the inertia of the incoming gases.

2.3.6 The number of degrees of crankshaft movement by which valve opening precedes BDC or TDC is known as "valve lead", and the number of degrees of crankshaft movement by which valve opening follows BDC or TDC is known as "valve lag". The period when both inlet and exhaust valves are open together is known as "valve overlap".

NOTE: Although the valves are opened and closed at specific crankshaft positions, regardless of engine speed, it should be noted that the ignition timing may be varied according to engine speed and mixture strength. The ignition timing included on the Valve Timing Diagram represents the fully advanced position.

2.4 The main components of an engine are described in detail in paragraph 6 and are illustrated in Figures 4 to 13.

3 ENGINE DESIGN FEATURES The aims of an engine designer can be either to produce as much power as possible for a given engine size or weight, or to produce as small and light an engine as possible, with a given power output. In either case this means producing an engine with the best possible power/weight ratio, but reliability and cost are also very important factors to be considered. The power produced by an engine results from the burning of a fuel/air mixture in the cylinders, the greater the weight of mixture burnt the greater will be the amount of energy released. The power produced in the cylinders is initially used to overcome internal friction and to drive accessories such as pumps and generators, and the remainder is available to drive the propeller.

3.1 **Engine Power.** There are a number of ways of increasing the power output of an engine, but these may be resolved into three main methods. These are, increasing the volume of the cylinders, increasing combustion pressure, and increasing the engine speed. The strength and weight of the components used in an engine are the main factors limiting the power produced.

3.1.1 **Increased Volume.** The obvious way to increase the volume of the cylinders is to increase their actual size. However, increasing the size of the cylinders would also mean increasing the size, and therefore the weight, of the reciprocating and rotating parts of the engine, and a point will be reached when the forces on these parts will approach the limits of strength of the materials used. The rate of acceleration of the pistons, and their speed of movement, will increase as the length of stroke increases, and stresses will become very high. Inertia forces on the crankshaft will also increase with cylinder size. These factors place a physical limit on the size of the cylinders, and the method normally adopted to increase volume above this limit is to increase the number of cylinders. This method also has its limitations, however, resulting mainly from increased complexity, which may affect reliability.

3.1.2 **Increased Pressure.** There are two ways of increasing pressure in a cylinder. One method is to increase the compression ratio (i.e. the ratio of the total volume of the cylinder with the piston at BDC, to its volume with the piston at TDC). This produces a higher pressure in the cylinder at the end of the compression stroke, and the force exerted on the piston during combustion will also be greater. The second method is to increase the weight of charge drawn into the cylinder during the induction stroke. The weight of charge drawn into the cylinder during the induction stroke compared with the weight of charge which will fill the swept volume (i.e. the volume of the cylinder between the TDC and BDC positions of the piston) at standard temperature and pressure, is known as volumetric efficiency, and is expressed as a percentage. Volumetric efficiency may be increased by mechanically raising the pressure of the mixture fed to the inlet valve (i.e. supercharging), or, to a more limited extent, by careful design of the induction passages, ports and valves, so as to present as little hindrance as possible to the flow of gases. An increase in volumetric efficiency produces higher pressures in the cylinder throughout the complete cycle of operations; a greater weight of fuel/air mixture being burnt in a given time, and more energy being released by combustion. The extent to which compression ratio and manifold pressure (i.e. induction pipe pressure) can be raised, is limited by the strength of the materials used in the engine, and a factor known as detonation (paragraph 3.1.4).

3.1.3 **Increased Speed.** An increase in engine speed will also result in the burning of a greater weight of fuel in a given time, and will therefore result in the production of more power. However, the higher centrifugal forces, and other stresses set up in the engine, necessitate stronger components, with a disproportionate increase in weight. Again the strength of the materials is the limiting factor.

3.1.4 **Detonation.** In the normal combustion process, a flame front spreads out from the ignition point, and continues burning until all the combustible mixture is consumed. If the temperature of the gases prior to ignition is high, then depending on the characteristics of the fuel, the temperature may be raised sufficiently after ignition to a point where, instead of the mixture burning at a controlled rate, combustion spreads with almost explosive force. This is known as detonation, and produces a rapid rise in pressure within the cylinder, which is capable of causing physical damage to the cylinder, piston and connecting rod. The provision of fuels with good anti-detonation properties has permitted the use of higher compression and supercharger ratios, but, since the act of compressing a gas also raises its temperature, both these factors have to be limited. Alternatively, a means of cooling the mixture before it enters the cylinder may be used for operation at high power settings.

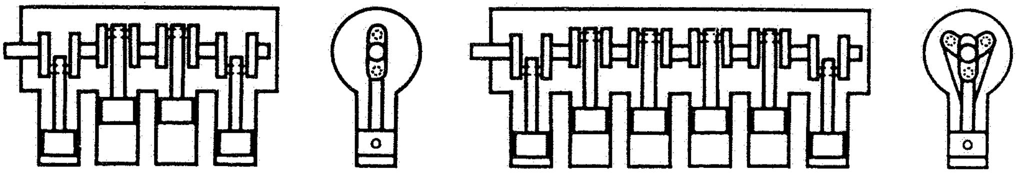
NOTE: A defect known as pre-ignition may also produce results similar to those caused by detonation. With pre-ignition, the gases in the combustion chamber are ignited by incandescent material such as carbon particles, or an overheated exhaust valve, before the proper spark is due to occur. This may cause gas pressure to be applied to the piston before it reaches TDC, and may result in damage to the piston or connecting rod.

3.1.5 **Thermal Efficiency.** The ratio of the power produced by an engine to the power theoretically available in the fuel, is known as the thermal efficiency. Whilst this can be improved by careful design of the combustion chamber, valves and ports, to obtain efficient combustion, its value is primarily dictated by the basic cycle and the compression ratio. In practice the thermal efficiency of an engine is approximately 30%, the remaining energy being lost through the exhaust, or wasted in heating the engine.

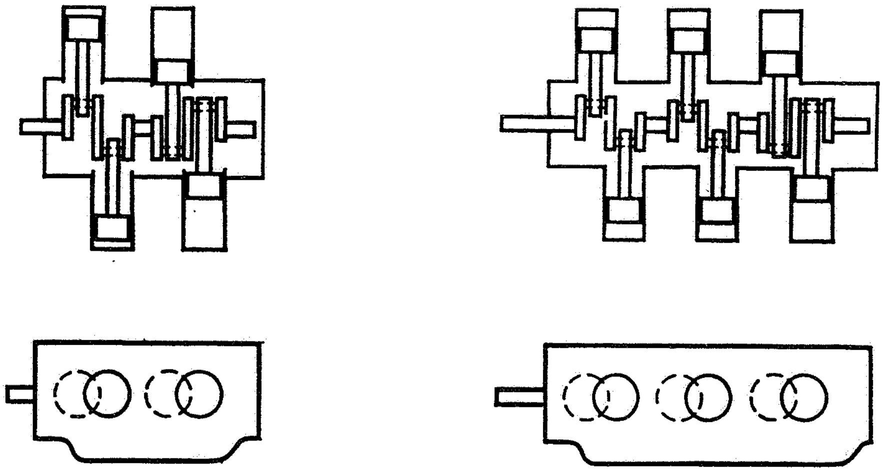
3.2 **Engine Layout.** Individual designers have adopted different methods of arranging the cylinders on an aircraft engine to achieve a particular power output. The different arrangements are illustrated in Figure 3, and are explained in paragraphs 3.2.1 to 3.2.3. Air-cooled in-line, horizontally-opposed, and radial engines, are all widely used on civil aircraft because of their general reliability and economy. Liquid-cooled Vee engines were widely used on military aircraft because of their high power output and low frontal area, but are rarely found on civil aircraft.

3.2.1 **In-line Engines.** In-line engines usually have four or six cylinders arranged in an upright or inverted row along the crankcase; it is not usual to have more than six cylinders, because of the difficulty of cooling the rear cylinders and the length of the crankshaft which would be required. In a four-cylinder engine, four power strokes occur every two revolutions of the crankshaft, and must be evenly spaced to provide smooth running. With the arrangement shown in Figure 3(A), the firing order could be 1,3,4,2 or 1,2,4,3. The camshaft, which is a shaft having a cam for each valve in the engine, would be driven from the crankshaft at half engine speed, and would operate the valves by means of push rods, and rockers as illustrated in Figure 7. Each of the eight cams (two to each cylinder) would be located on the camshaft to open and close an inlet or exhaust valve in relation to the particular firing order and the valve timing prescribed for that engine. If the engine had six cylinders, there would be six power strokes every two revolutions of the crankshaft, and a cylinder would have to fire every 120° of crankshaft movement. This would necessitate a crankshaft with throws (i.e. the offset portions of the crankshaft containing the crankpins) arranged as shown in Figure 3(B). Suitably arranged cams would be provided on the camshaft, which would still be driven at half engine speed. The firing order of a six-cylinder engine is generally 1,4,2,6,3,5, but a different order could be used, and the crankshaft throws could be arranged differently.

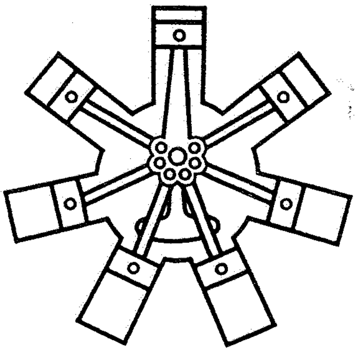
NOTE: The cylinders of British engines are usually numbered commencing from the propeller end of the engine, but engines of American manufacture are often numbered in the opposite direction.



(A) FOUR CYLINDER INVERTED IN-LINE (B) SIX CYLINDER INVERTED IN-LINE



(C) FOUR CYLINDER HORIZONTALLY-OPPOSED (D) SIX CYLINDER HORIZONTALLY-OPPOSED



(E) SEVEN CYLINDER RADIAL

Figure 3 ENGINE CYLINDER ARRANGEMENTS

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

3.2.3 **Radial Engines.** A radial engine has an odd number of cylinders (usually not more than nine) arranged radially around the crankcase (Figure 3(E)). If greater power is required, two banks of cylinders are used, each cylinder in the rear row being located midway between two front row cylinders to ensure adequate cooling. The crankshaft of a radial engine has only one throw for each bank of cylinders, and all the connecting rods are attached to the single crankpin via a master rod (Figure 9); this fact also dictates the firing order of the engine. On a seven-cylinder engine a firing stroke is required every $\frac{360^\circ \times 2}{7} = 102\frac{6}{7}^\circ$ of crankshaft movement, and since the angle between cylinders is $51\frac{3}{7}^\circ$, the firing order can only be alternate cylinders in the direction of rotation, i.e. 1,3,5,7,2,4,6. To balance the heavy mass of the master rod assembly, counterweights are fitted to the crankshaft, and it is also usual to fit vibration dampers to minimize the effects of any residual vibration. On engines with two banks of cylinders, the crankshaft throws are arranged at 180° to each other.

(a) Except for sleeve-valve engines (paragraph 6.7.1) the valves are operated by a cam drum (Figure 4), which is concentric with, and driven by, the crankshaft. The cam drum has two rows of cams, one for the inlet valves and one for the exhaust valves. On seven-cylinder and nine-cylinder engines, there are four equally-spaced cams in each row, and the drum rotates at $\frac{1}{8}$ engine speed; on three-cylinder and five-cylinder engines, two equally spaced cams on each row, with the drum rotating at $\frac{1}{4}$ engine speed, would be suitable.

(b) Taking a seven-cylinder radial engine as an example, when the inlet valve on No. 1 cylinder is open, the next inlet valve to open is on No. 3 cylinder (since this is the next cylinder in the firing order). The cams are 90° apart and the drum must, therefore, rotate through an angle of $12\frac{6}{7}^\circ$ (the angle between No. 1 and No. 3 cylinder is $102\frac{6}{7}^\circ$) in the direction of rotation to open the required valve on No. 3 cylinder. Speed of rotation of the cam drum must be $12\frac{6}{7} \div 102\frac{6}{7} = \frac{1}{8}$ engine speed (operation of the cam drum on a seven-cylinder engine is illustrated in Figure 4). On a nine-cylinder engine the spacing of the cylinders is 40°, and successive valves open every 80° of crankshaft movement. Since the cams are 90° apart, the cam drum must rotate in the opposite direction of rotation to the crankshaft, but still at $\frac{1}{8}$ engine speed $\left(\frac{90 - 80}{80} = \frac{1}{8}\right)$.

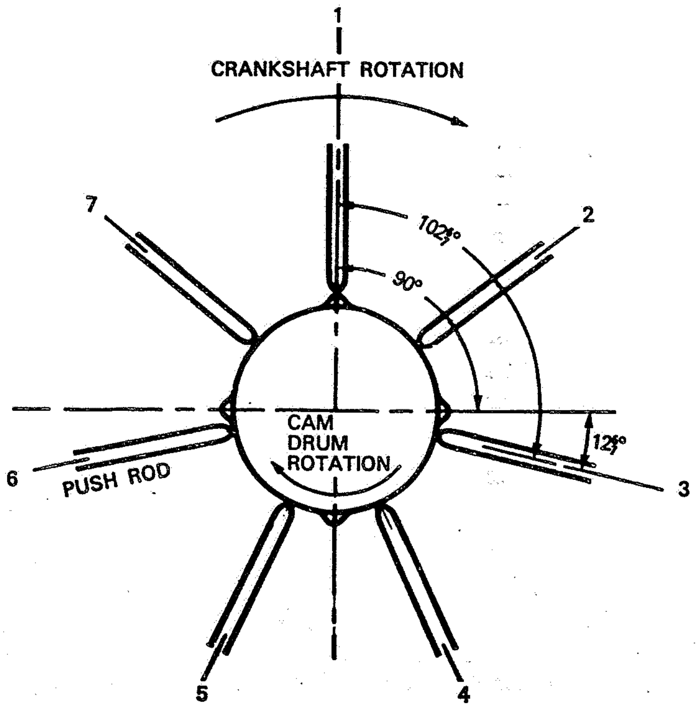


Figure 4 RADIAL ENGINE CAM DRUM OPERATION

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

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

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

5 LUBRICATION Where there is movement between parts which are in contact (e.g. rotary or reciprocating motion), a film of oil is provided between the surfaces to reduce wear and to minimize friction. Crankshaft, camshaft and other plain bearings in the engine are fed with oil under pressure from an engine-driven pump; oil escaping from these bearings, or sprayed through oil nozzles, is directed onto the underside of the pistons to provide lubrication and cooling of the pistons and cylinder walls; other parts of the engine are lubricated by the oil mist which exists inside the crankcase. On most engines the valve rocker mechanism is pressure lubricated, but on some the rocker bearings are greased by hand at pre-determined intervals, and on certain inverted engines the rocker covers are filled with oil, to splash-lubricate the mechanism. The methods of providing lubrication to individual components are described in paragraph 6.

5.1 In some light aircraft engines the oil required for lubrication is housed in a sump, which is attached directly to the bottom of the crankcase. The pressure pump draws its supply through a tube, the open end of which is in the bottom of the sump, and the oil, after circulation through the engine, drains back into the sump. In some engines the supply from the pump passes through an oil cooler, whilst on others the sump is finned on the outside, and cooling air is directed over it. This method of lubrication is known as a "wet sump" system.

5.2 In other engines the oil is stored in a separate tank, which may be fixed to the engine, or mounted on the engine bulkhead. Oil is supplied through rigid and flexible pipes to the pressure pump, and, after circulating round the engine, drains into a small sump. A separate engine-driven scavenge pump empties this sump, and returns the oil, via an oil cooler, to the tank. The capacity of the scavenge pump is greater than that of the pressure pump, so that the sump is kept empty and the oil in the tank is maintained at a satisfactory level. This method of lubrication is known as the "dry-sump" system.

5.2.1 With a dry-sump system, the scavenge pump, being of greater capacity than the pressure pump, will draw in air with the oil in the sump, and this may result in frothing in the tank. If this air were drawn in by the pressure pump, inefficient lubrication of the bearings would result, and steps are usually taken to prevent this from happening. By passing the oil across a de-aerator tray in the tank, or, in some instances by pressurizing the tank, frothing is reduced to a minimum. Air separates further as the oil stands in the tank before being drawn out by the pressure pump.

5.3 **Filters.** During its passage through the engine, the lubricating oil picks up minute particles of metal resulting from engine wear, and carbon particles resulting from the combustion process and heating of the engine. These particles could cause damage to the bearing surfaces if they were not removed from the pressure oil supply, and filters are fitted to keep the oil in a clean condition. A pressure filter is fitted between the pressure pump and the engine, and usually consists of a container, which houses a paper or cloth filter element through which the oil must pass. This filter is changed at regular intervals. A scavenge filter is usually a coarse wire-mesh type filter, fitted in the sump to prevent large metallic particles from damaging the pumps. In addition, a wire mesh filter is often fitted to the tank filler opening, to exclude foreign matter when the oil tank is being replenished.

6 ENGINE COMPONENTS

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

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

6.1.2 Ball bearings are used in many places where radial loads are light, and where axial positioning is important. Heavy roller bearings are used as main crankshaft bearings on radial engines, and ball bearings are frequently used as thrust bearings on propeller shafts and on the crankshafts of direct-drive engines (see Leaflet **BL/6-14** for the various types of rolling bearings). Ball and roller bearings do not, generally, require pressure lubrication, and are frequently lubricated by splash; however, oil jets may be used in locations where lubrication is particularly critical.

6.2 **Crankcases.** The crankcase is, usually, the largest single component of an engine. It provides the mounting faces for the cylinders, reduction gear, sump, and accessories, supports the crankshaft, provides oilways for the lubricating oil, and carries the mountings for attachment of the engine to the airframe. A crankcase is, therefore, of complicated shape, and it is usually cast from aluminium or magnesium alloys, which provide the strength and rigidity required, without unnecessary weight. Some crankcases are in two or more parts, which are bolted and dowelled together. A typical crankcase for a horizontally-opposed engine is illustrated in Figure 5, which shows that the two halves are joined at a vertical plane passing through the crankshaft centreline. With radial engines the join is on the plane normal to the crankshaft centreline and passing through the centres of all cylinders in one bank, each portion of the crankcase supporting one of the main bearings.

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

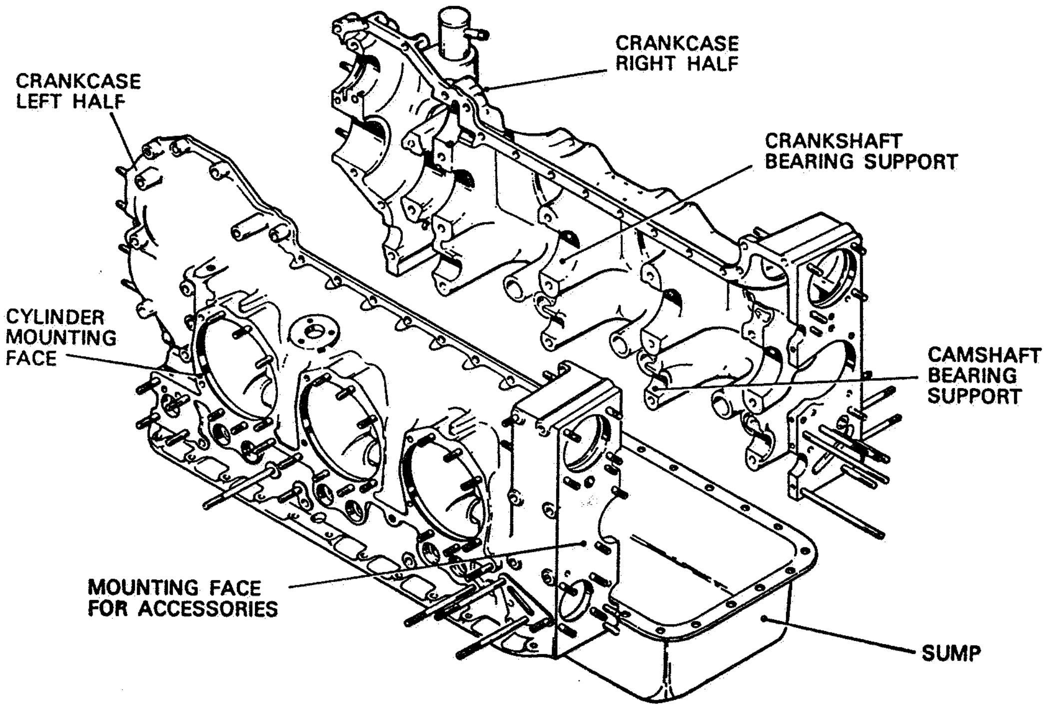


Figure 5 CRANKCASE AND SUMP OF HORIZONTALLY-OPPOSED ENGINE

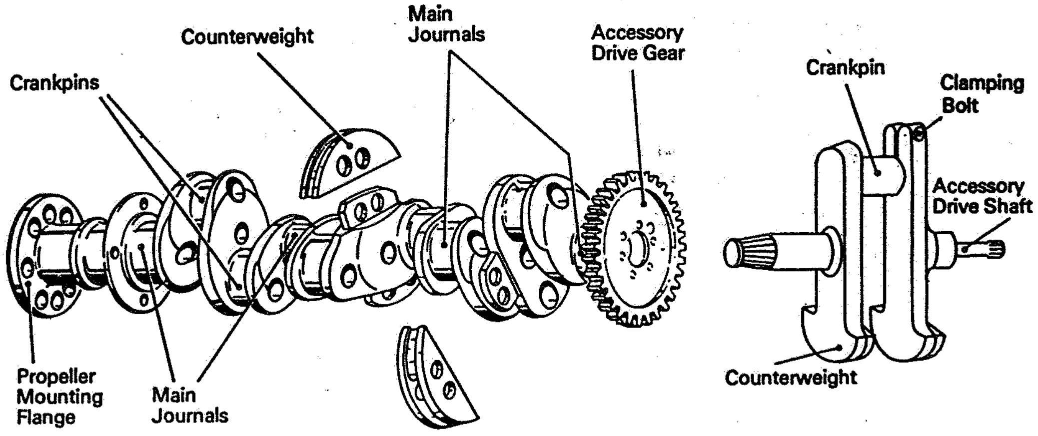
6.2.2 The sump may be considered as part of the crankcase, and may be a casting in light alloy, or may be fabricated from sheet steel. The sump contains a drain plug, and may also house the scavenge filter. A dip-stick, housed in the crankcase, provides a means of checking the sump oil level.

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

6.3 **Crankshafts.** The crankshaft is the heaviest single component of the engine, and is usually forged from an alloy steel in order to resist the high stresses imposed during operation. The crankshafts of in-line and horizontally-opposed engines are machined from a single forging, with hollow crankpins and journals, and drilled webs to provide passageways for the lubricating oil. The crankshaft of a single-row radial engine is generally made from two forgings, and that of a two-row radial engine from three forgings, the separate parts being joined at the crankpins; this is because of the difficulty of providing a split bearing capable of accommodating all the connecting rods on a single crank pin. Typical crankshafts are illustrated in Figure 6.

6.3.1 Lubricating oil is ducted from the oil pressure pump, through crankcase oil passages, to each of the crankshaft main bearing supports. This oil passes through holes in the bearings to lubricate the journals, and through radial holes in the journals into the hollow shaft. From there it flows through drillings in the webs to the connecting rod big-end bearings, and then escapes from these bearings to be thrown by centrifugal force into the pistons and cylinders. On some engines, oil jets at the crankshaft main bearings spray oil into the cylinders. At its front end, a crankshaft may have a flange or splined portion to which the propeller is attached, or it may be internally splined in order to drive the propeller reduction gear through a quill shaft; the quill shaft is designed to twist under torsional loads so as to smooth out the power impulses. A gear or a quill shaft is generally attached to the rear end of the crankshaft, for the purpose of driving the camshaft and accessories, but some of these may be driven from the propeller reduction gear.

6.4 **Cylinders.** A cylinder must, generally, provide the hard bearing surface on which the piston slides, must be strong enough to resist the pressures produced by the combustion of the mixture, and must dissipate the heat produced in the combustion chamber. Aluminium alloy has good strength and heat-dissipation properties and is generally used for cylinder heads, but its surface is not hard enough to resist abrasive wear, and therefore the cylinder barrels are generally made from a steel alloy. An exception is the sleeve-valve engine, in which the piston operates inside a steel alloy sleeve, and aluminium alloy is used for the cylinder barrel. Poppet valve guides and rocker bearings (Figure 7) are made from bronze or similar material, and the valve seats are made from steel in order to resist the hammering of the valves. Sparking plugs may be fitted into bronze inserts, which are screwed and pegged into the cylinder head, but in some engines thread inserts are used, and are installed directly into the head.



(A) HORIZONTALLY-OPPOSED ENGINE

(B) RADIAL ENGINE

Figure 6 TYPICAL CRANKSHAFTS

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

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

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

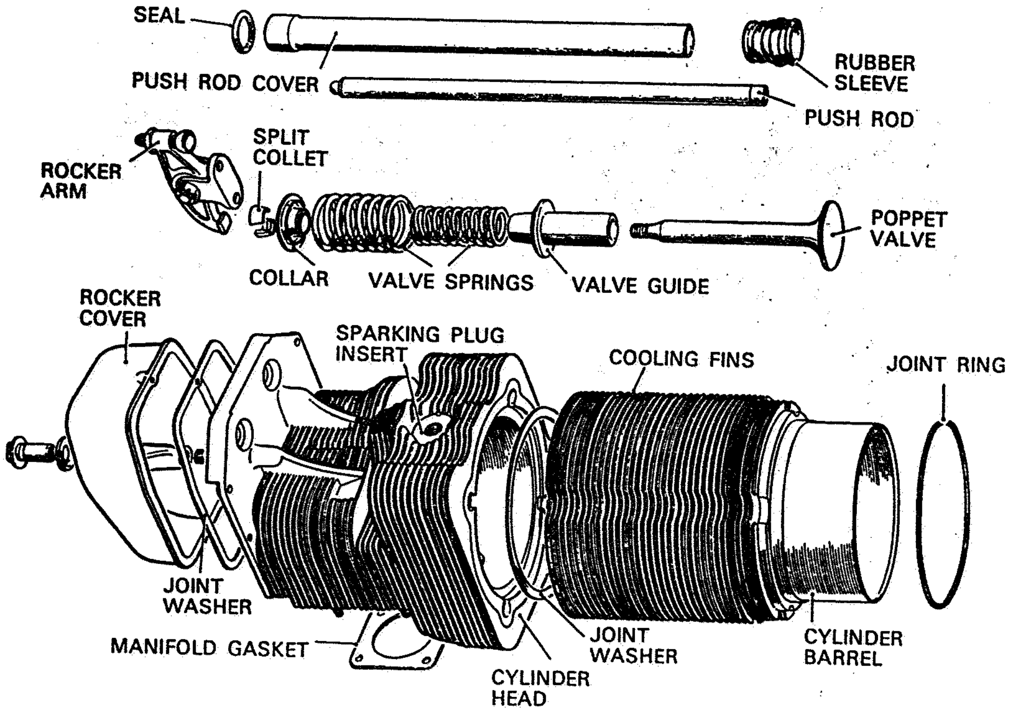


Figure 7 CYLINDER ASSEMBLY

6.4.4 The rocker bearings (and, in the case of some in-line engines, the overhead camshaft bearings) are usually pressure-lubricated by oil ducted from the crankcase, and the splash oil released from these bearings is used to lubricate the valve stems, guides and springs. In some small engines the rocker arms oscillate in roller bearings which are hand lubricated at specified intervals, whilst on inverted engines the rocker cover may be partially filled with oil, to splash lubricate all the cylinder head components. A typical air-cooled cylinder is shown in Figure 7.

6.5 **Connecting Rods.** Connecting rods convert the reciprocating motion of the pistons to the rotary motion of the crankshaft. They require considerable strength and rigidity, and are generally aluminium alloy or steel forgings of "H" section. On horizontally-opposed and in-line engines, the bearing at the crankpin end (big end) is usually a split plain bearing similar to those used at the crankshaft main bearings (Figure 8). The connecting rod small end is usually fitted with a bronze bush and attached to the piston with a hollow steel gudgeon pin (Figure 8). On radial engines only one connecting rod (the master rod) in each bank of cylinders is mounted directly on to the crankpin (Figure 9), and usually has a fully-floating bearing (paragraph 6.1.1). The connecting rods on the other cylinders (known as articulated rods) are connected to flanges on the master rod big-end by hollow steel wrist pins, which are similar to the gudgeon pins at the connecting rod small end. Big-end bearings are pressure lubricated through drillings in the hollow crankpins, from the main oil pressure supply, and small-end (and wrist pin) bearings are usually lubricated by splash oil through holes in the connecting rods.

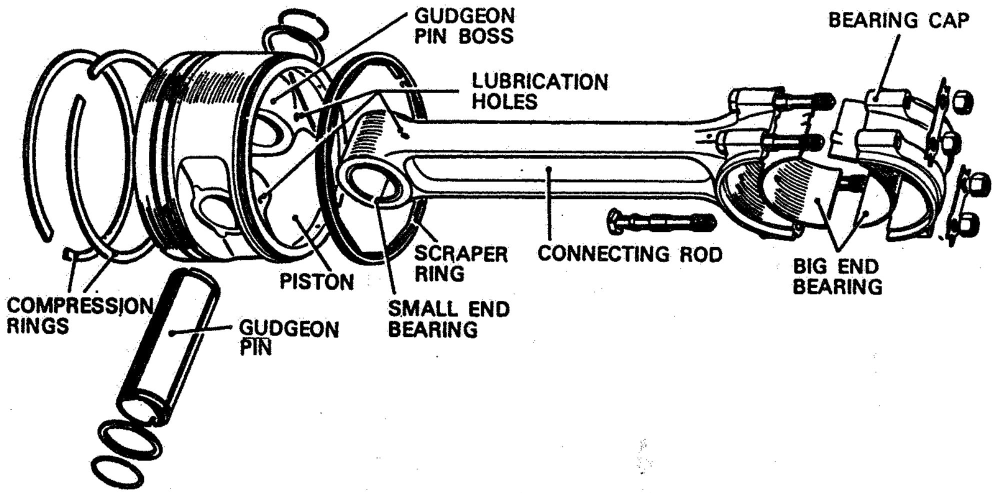


Figure 8 CONNECTING ROD AND PISTON ASSEMBLY

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

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

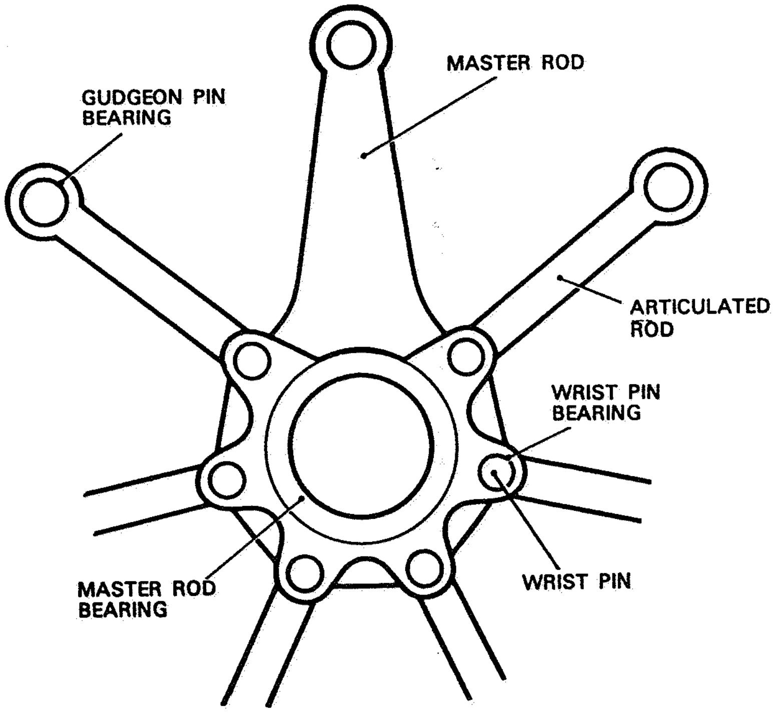


Figure 9 RADIAL ENGINE CONNECTING RODS

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

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

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

6.7 Valves

6.7.1 **Sleeve Valves.** On a few engines, the inlet and exhaust ports in the cylinder are opened and closed by means of a cylindrical sleeve fitted between the cylinder barrel and the piston. The sleeve, of hardened steel, is driven by a crank, which is geared to the crankshaft, and ports in the sleeve uncover the cylinder inlet and exhaust ports at the appropriate times. Timing of the opening and closing of the ports is fixed by the gear train and the position and shape of the ports in the sleeve, and no adjustments are possible. The main advantage of this method is reputed to be the increased volumetric efficiency resulting from the lack of obstruction to the incoming and outgoing gases.

6.7.2 **Poppet Valves.** These valves (Figure 7) are fitted to the majority of aircraft piston engines; they operate under arduous conditions and may be made from a variety of steel alloys. Exhaust valves, which are subjected to the highest temperatures, often have a larger diameter stem than inlet valves, the stem being hollow and partially filled with sodium to transfer heat away from the valve head. Valve heads are ground to form a face which mates with the valve seat and forms a gas-tight seal. The ends of the valve stems are grooved to secure a split collet, which holds the spring retaining collar in position, and are hardened at the tip to provide a bearing surface for the rocker arm. Each valve is closed by two or more coil springs, which are concentrically mounted and coiled in opposite directions; the fitting of two or more springs having different vibration frequencies prevents the valve from bouncing on its seat when it closes.

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

6.8 **Valve Operating Mechanism.** Poppet valves are opened by a mechanical linkage from the cam shaft or cam drum, and closed by the valve springs. As the appropriate cam is rotated, its lobe pushes a tappet, which in turn activates a push rod, which transmits movement to the rocker arm; the rocker arm pivots on its bearing and pushes on the end of the valve stem to open the valve. When the cam has passed its point of maximum lift, the valve springs return the mechanism to its original position and close the valve. This type of mechanism is generally used on horizontally-opposed and radial engines, and also on some in-line engines (Figure 7). On other in-line engines the camshaft is mounted on the cylinder heads, and operates directly on the rocker arms to open the valves; these are known as "overhead camshaft" engines.

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

6.8.2 **Cam Drums.** Cam drums are used in most radial engines, and have two rows of cams (one for the inlet valves and one for the exhaust valves). They are made from steel, and are mounted on a bearing around the front of the crankshaft and driven, by a gear train from the crankshaft, at the required speed and in the required direction of rotation (paragraph 3.2.3). The cam drum bearing is generally pressure lubricated by the engine oil system.

6.8.3 **Tappets.** The purpose of a tappet is to transfer the motion of a cam to its associated push rod. Tappets may be fitted either directly into the crankcase or in bronze guides in the crankcase. They are often purely mechanical devices comprising a rod with a hardened pad or roller at the cam end, and a hardened socket at the push rod end. To ensure that the valves close properly when the engine is running, in spite of expansion of the cylinder, a means of adjustment is provided to enable a predetermined clearance to be maintained in the valve operating mechanism when the valve is closed; this is known as tappet clearance. Most modern light aircraft engines are fitted with hydraulic tappets (Figure 10). This type of tappet consists basically of a body and a plunger, with an internal spring and non-return valve, and a push rod socket. During operation, pressure oil supplied to the tappet is picked up by a groove round the body when the tappet is near the outer end of its stroke. This oil lubricates the tappet bearing surface and enters the plunger reservoir through a port in the plunger wall; it then passes through the push rod socket and hollow push rod to lubricate the rocker mechanism. If clearance is present in the valve operating mechanism when the tappet is resting on the cam dwell, the spring in the tappet body pushes the plunger outwards to eliminate this clearance, the non-return valve opening to allow oil to pass into the body reservoir. As the cam lobe commences to push on the tappet, the non-return valve closes and a hydraulic lock is formed, transmitting motion to the push rod. In this way clearance is eliminated from the mechanism; valve closure is unaffected, since the force applied by the tappet spring is much less than that of the valve springs.

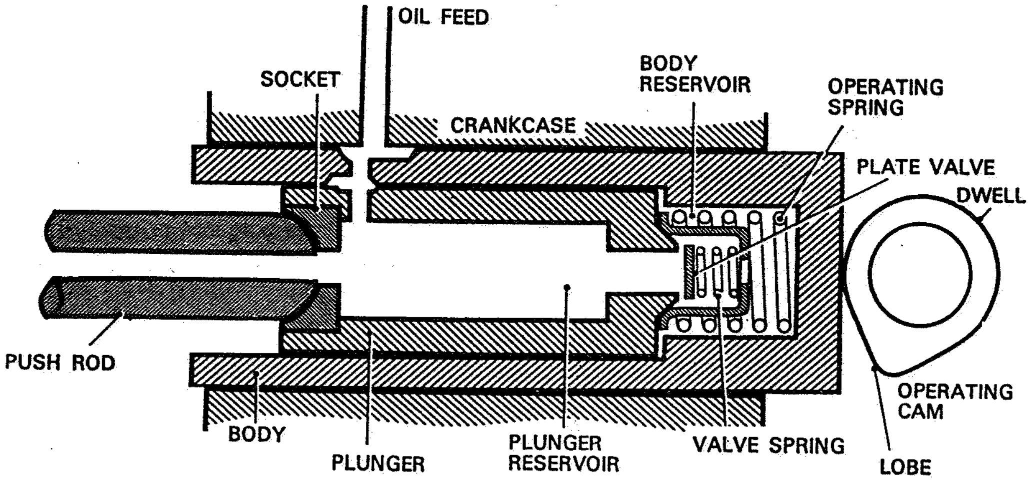


Figure 10 HYDRAULIC TAPPET

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

6.8.5 **Rockers.** A rocker arm pivots on a steel shaft, which may be held in mountings in the cylinder head or in pedestals which are bolted to the cylinder head. Rocker arms are generally made from alloy steel, with a hardened face at the valve end, and an adjusting screw with hardened socket at the push rod end. On some engines, mounting and adjustment are by means of a ball or roller pivot bearing, which is mounted in an eccentric bush. Oil from the hollow push rod is often fed through the drillings in the rocker arm to lubricate the rocker arm bearing. On other engines the rockers may be lubricated as described in paragraph 5.

6.9 **Propeller Reduction Gear.** The purpose of a reduction gear is to reduce engine speed to a speed suitable for efficient operation of the propeller. The various types of reduction gears are illustrated in Figure 11. Epicyclic (sometimes known as "planetary") reduction gears are always used on radial engines, and spur gear reduction gears are generally used on in-line engines, but either type may be fitted to horizontally-opposed engines.

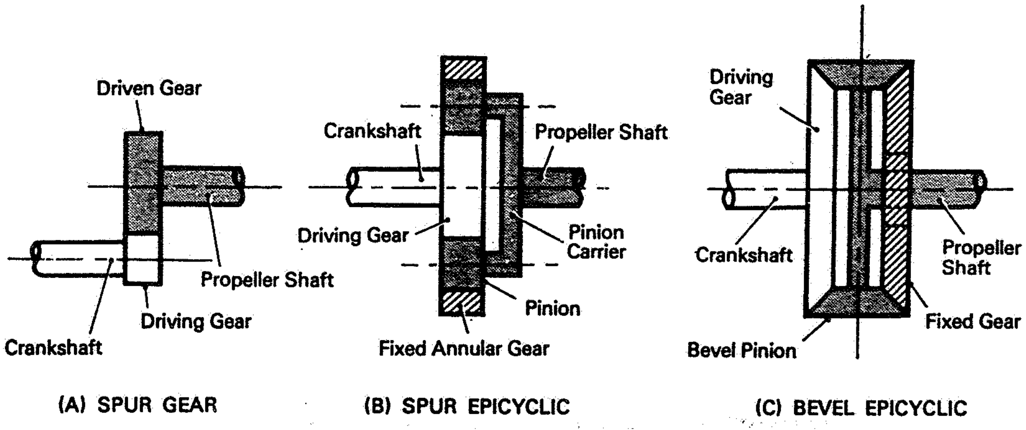


Figure 11 REDUCTION GEAR TYPES

6.9.1 A propeller shaft is normally supported in roller bearings, and propeller thrust is transferred to the engine by means of a ball thrust bearing. On some small engines, however, the propeller may be supported in plain bearings, the thrust being taken by a thrust washer placed between a flange on the propeller shaft, and one of the bearing supports.

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

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

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

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

6.11.2 **Gear Pumps.** These pumps consist of two meshing gears, which rotate in a close-fitting housing (Figure 12). One gear is driven from the engine, and as it rotates it carries the other gear round with it, and fluid is carried round the casing between the gear teeth. These pumps are known as positive displacement pumps, a definite volume of fluid being delivered for each revolution of the gears. Any restriction in the delivery line (such as will normally be provided by the bearings) will result in a build-up of pressure, and a relief valve is required. Relief valves are adjusted to maintain a predetermined pressure on the delivery side of the pump, and any excess fluid is by-passed to the inlet side of the pump or to the sump; in some engines a second relief valve is fitted after the main pressure relief valve, to provide a low-pressure lubrication system for certain components. Engine oil pressure and scavenge pumps are generally driven by a common shaft and mounted in adjoining housings, the gears of the scavenge pump being longer than those of the pressure pump to ensure complete scavenging of the sump.

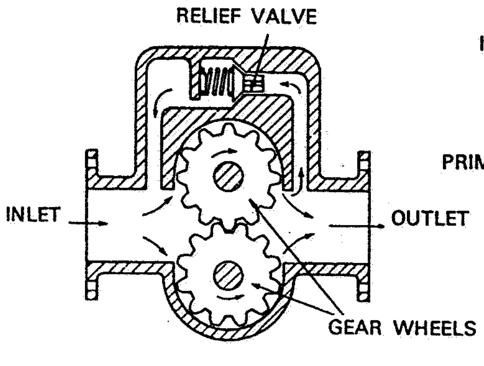


Figure 12 GEAR PUMP

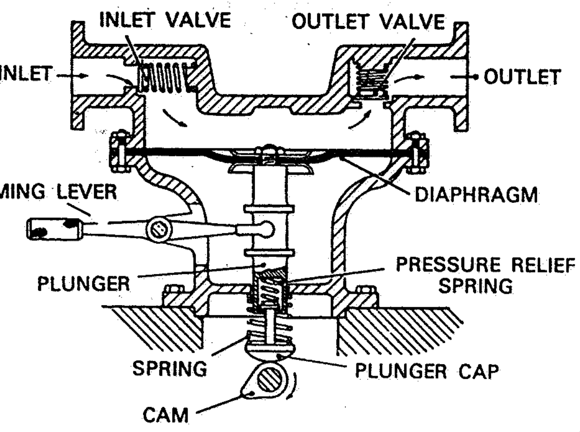


Figure 13 DIAPHRAGM PUMP

6.11.3 **Diaphragm Pumps.** In a diaphragm pump, a rotating cam in the engine acts indirectly on a diaphragm (usually of rubberized fabric), and causes it to reciprocate. This motion, in conjunction with lightly spring-loaded inlet and outlet valves, can be used, for example, to pump fuel to the carburettor. In the pump illustrated in Figure 13, a spring keeps the plunger cap in contact with the cam, and a second spring, inside the plunger, limits the delivery pressure by restricting the movement of the diaphragm. Construction of these pumps varies in detail, and in some pumps a filter bowl is suspended below the pump, the inlet valve being located inside the filter; in other pumps the plunger may be operated indirectly by a cranked lever.

7 POWER CALCULATION AND MEASUREMENT

7.1 **Indicated Power.** The power developed in an engine cylinder can be calculated from the cylinder dimensions and the average pressure on the piston during the power stroke. The force exerted on the piston will be the average pressure multiplied by the area of the piston, and the work done (force x distance) will be this force multiplied by the length of the stroke. The power developed in the cylinder can then be calculated by multiplying the work done by the number of power strokes (N) per unit time. In the case of a single cylinder engine, "N" will be the crankshaft rotational speed divided by 2, and in the case of a multi-cylinder engine "N" will be the crankshaft rotational speed $\times \frac{\text{no. of cylinders}}{2}$.

When using Imperial units, power is usually quoted in horsepower (hp) (1 hp = 33,000 ft lbf/min) and when using SI units, power is usually quoted in kilowatts (kW) (1 hp = 0·746 kW). Thus the Indicated Power of an engine can be calculated from the formula:—

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

where P = pressure on piston (lbf/in² or N/m²)
L = length of stroke (ft or m)
A = area of piston (in² or m²)
N = number of power strokes/min.

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

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

where k is $\frac{33{,}000}{\text{L} \times \text{A} \times \frac{1}{2}\text{ no. of cylinders}}$ or $\frac{60{,}000}{\text{L} \times \text{A} \times \frac{1}{2}\text{ no. of cylinders}}$ as appropriate.

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

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

7.2.1 The output of an engine is obtained by measuring the torque of the propeller shaft. When calculating the work done on the piston (paragraph 7.1) work was taken as force x distance (in a straight line); when measuring the work done by the propeller shaft, the torque can be thought of as a force "F" acting at a distance "r" from the axis of the shaft (Figure 14). If the system rotates once, the force can be regarded as having travelled one circumference of a circle of radius r, i.e. work done per revolution = F × 2 πr or, as torque = Fr, then work = torque × 2π. Brake Power can then be calculated if the speed of rotation is known. Using Imperial units the Brake Power becomes:—

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

and using SI units it becomes:—

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

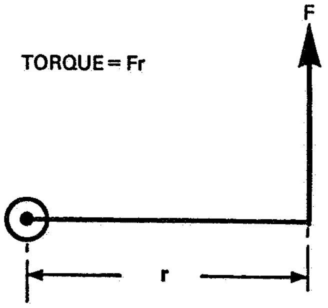


Figure 14 TORQUE MEASUREMENT

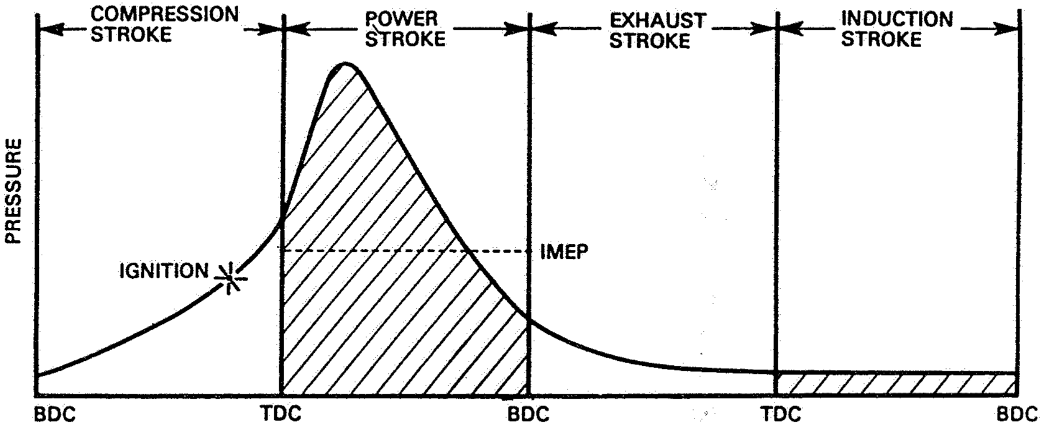
Again, using a constant (C) for the invariable quantities, Brake Power becomes $\frac{\text{torque} \times \text{rev/min}}{C}$, and it can be seen that it varies directly with torque and engine speed.

7.3 **Mean Effective Pressure.** The average pressure exerted on the piston during the power stroke is known as the Mean Effective Pressure (MEP). The actual pressures can be measured, and are generally reproduced on an Indicator Diagram similar to the one shown in Figure 15. The shaded areas represent work done on the piston during the induction and power strokes, and the unshaded areas below the curve represent work done by the piston during the compression and exhaust strokes. The sum of the shaded areas, less the sum of the unshaded areas, represents useful work, and when this area is confined to the power stroke, the pressure co-ordinate becomes the Indicated MEP (IMEP), and may be used for calculating Indicated Power (paragraph 7.1). IMEP, therefore, has a definite relationship to Indicated Power, and, in a similar way, is composed of components representing Friction Power and Brake Power. These components are known as Friction MEP (FMEP) and Brake MEP (BMEP), and can be used for calculating Friction Power and Brake Power respectively. Similarly, if Indicated Power and rev/min are known, IMEP can be calculated

$$\left(\text{IMEP} = k \times \frac{\text{Indicated Power}}{\text{rev/min}}\right),$$

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

$$\left(\text{BMEP} = k \times \frac{\text{Brake Power}}{\text{rev/min}}\right).$$



CRANKSHAFT ANGLE

Figure 15 INDICATOR DIAGRAM

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

7.4.1 FMEP varies according to peak cylinder pressure and internal power requirements (different supercharger ratios, etc.), and can be measured throughout the engine speed range. The relationship between BMEP and IMEP can, therefore, be determined for any operating conditions, and since Brake Power can easily be measured by fitting a torquemeter (paragraph 7.5) to the engine, operation at safe cylinder pressures can be achieved by imposing BMEP limitations for the various operating conditions.

7.4.2 Manufacturers conduct tests to ascertain the BMEP which is equivalent to the maximum safe cylinder pressure for any set of operating conditions, and also provide sets of tables showing the range of BMEP and rev/min setting which will give particular power outputs. The pilot may then select the power settings for the power output he requires, ensuring that the BMEP is within the limit prescribed for the particular operating conditions. Alternatively, using the formula

$$\left(\text{BMEP} = k \times \frac{\text{Brake Power}}{\text{rev/min}}\right),$$

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

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

7.5 **Torquemeters.** Propeller shaft torque is generally measured at the reduction gear. As the crankshaft gear rotates, it drives the propeller pinions, and these exert a thrust on the fixed gear teeth, tending to rotate the fixed gear in the opposite direction to the crankshaft gear; this thrust is directly proportional to power output. To measure the thrust applied to the fixed gear, the gear is allowed to float, and is attached to the structure through pistons and oil-filled cylinders, as shown in Figure 16. Engine oil pressure to these cylinders is boosted by a torquemeter pump, and each cylinder is fitted with a bleed back to the engine oil system.

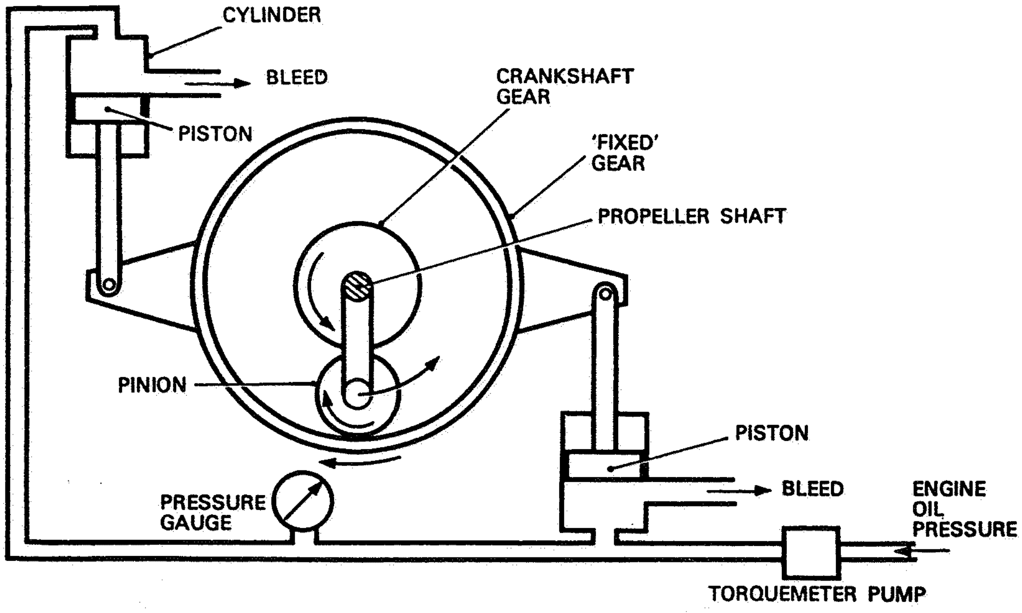


Figure 16 TORQUEMETER SYSTEM

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

EL/1-2

Issue 1.

3rd December, 1976.

AIRCRAFT

ENGINES

PISTON ENGINE CARBURATION SYSTEMS

1 INTRODUCTION This Leaflet deals with piston-engine fuel requirements, and the methods used to provide a satisfactory supply of combustible mixture to the cylinders under all operating conditions. The storage of fuel and the supply of fuel to the engine are dealt with in Leaflets **AL/3-15** and **AL/3-17**, respectively.

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

2.1 The most important qualities required in a fuel are outlined in paragraphs 2.1.1 to 2.1.4 below.

2.1.1 **Anti-knock Rating.** This is an indication of the resistance afforded by the fuel to the onset of detonation. It is explained in Leaflet **EL/1-1**, that an increase in power can be obtained by increasing cylinder pressure, but that this can cause detonation. It is important, therefore, that the fuel has good resistance to detonation in order to enable satisfactory engine power to be developed.

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

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

2.1.4 **Corrosive Effects.** A fuel must not be corrosive to any components in the engine or fuel system.

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

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

3.1 Although the chemically-correct mixture strength would theoretically produce the highest temperature, and therefore power, in practice mixing and distribution are less than perfect and this results in some regions being richer and others being weaker than the optimum strength; this variation may exist between one cylinder and another. A slight excess of fuel does not have much effect on power since all the oxygen is still consumed and the excess of fuel simply serves to reduce slightly the effective volumetric efficiency; in fact its cooling effect can be to some extent beneficial. Weak mixtures, however, rapidly reduce power since some of the inspired oxygen is not being utilized, and this power reduction is much greater than that resulting from slight richness. It is, therefore, quite common to run engines (when maximum power rather than best fuel economy is the objective) at somewhat richer than chemically-correct mixtures (e.g. about 12·5 : 1) to ensure that no cylinder is left running at severely reduced power from being unduly weak.

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

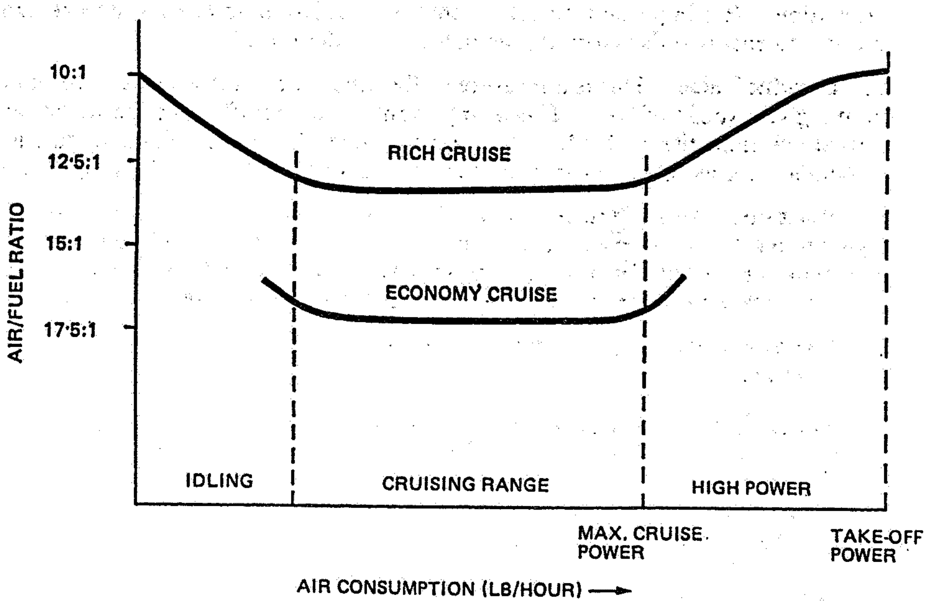


Figure 1 TYPICAL MIXTURE REQUIREMENTS

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

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

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

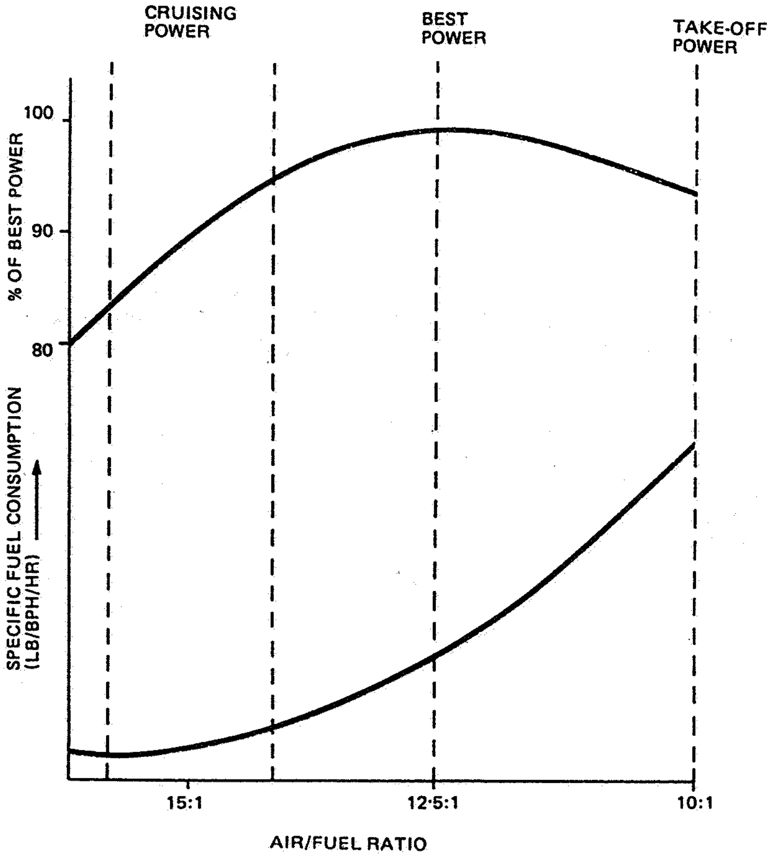


Figure 2 FUEL CONSUMPTION AND POWER

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

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

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

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

3.7 The carburation system must control the air/fuel ratio in response to throttle setting, at all selected power outputs from slow-running to full throttle, and during acceleration and deceleration; it must function at all altitudes and temperatures in the operating range, must provide for ease of starting and may incorporate a means of shutting off the fuel to stop the engine. The float-chamber carburettor (paragraph 4) is the cheapest and simplest arrangement and is used on many light aircraft; it is very prone to carburettor icing, however, and may be affected by flight manoeuvres. The injection carburettor (paragraph 5) is a more sophisticated device and meters fuel more precisely, thus providing a more accurate air/fuel ratio; it is also less affected by flight manoeuvres, and is less prone to icing. The direct- (or port-) injection system (paragraph 6) provides the best fuel distribution and is reputed to be the most economical; it is unaffected by flight manoeuvres and is free from icing.

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

4 **FLOAT-CHAMBER CARBURETTORS** In a float-chamber carburettor (Fig. 3), airflow to the engine is controlled by a throttle valve, and fuel flow is controlled by metering jets. Engine suction provides a flow of air from the air intake, through a venturi in the carburettor, and thence to the induction manifold; this air speeds up as it passes through the venturi, and a drop in pressure occurs. Fuel is contained in a float chamber, which is supplied by gravity, by an electrical booster pump or by an engine-driven fuel pump, and a constant level is maintained in the chamber by the float and needle-valve. Where fuel pumps are used, a fuel pressure gauge is included in the system to provide an indication of pump operation. Air intake or atmospheric air pressure acts on the fuel in the float chamber, which is connected to a fuel discharge tube located in the throat of the venturi. The difference in pressure between the float chamber and the throat of the venturi, provides the force necessary to discharge fuel into the airstream. As airflow through the venturi increases so the pressure drop increases, and a higher pressure differential acts on the fuel to increase its flow in proportion to the airflow. The size of the main jet in the discharge tube determines the quantity of fuel which is discharged at any particular pressure differential, and therefore controls the mixture strength. The simple carburettor illustrated in Fig. 3 contains all the basic components necessary to provide a suitable air/fuel mixture over a limited operating range. A number of alterations are necessary, however, in order to provide for all the requirements of an aircraft engine, and these are discussed in paragraphs 4.1 to 4.5.

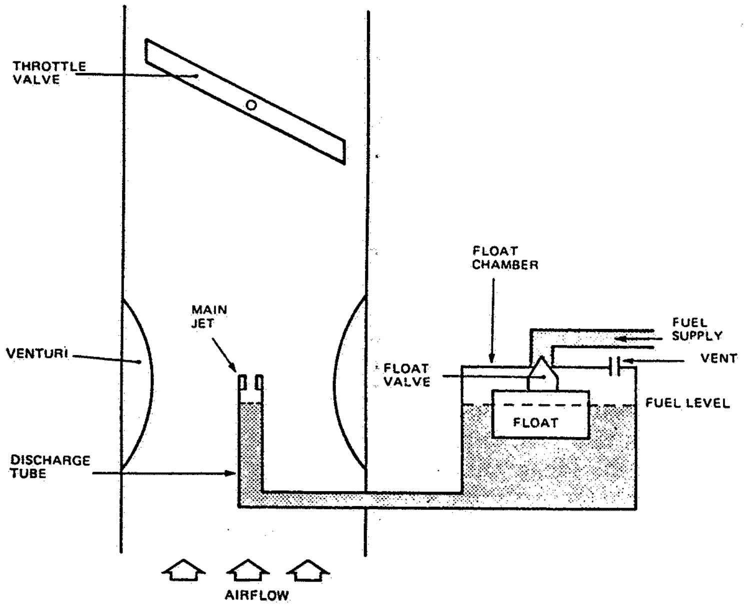
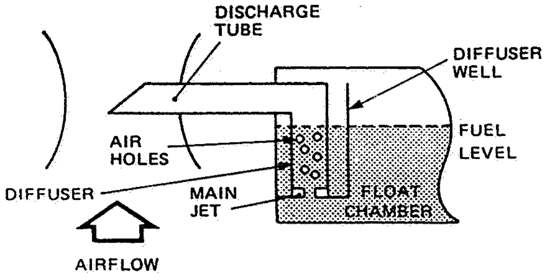


Figure 3 SIMPLE CARBURETTOR



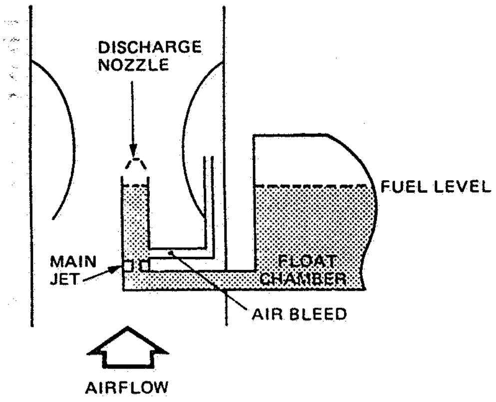


Figure 4 DIFFUSER

Figure 5 AIR BLEED

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

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

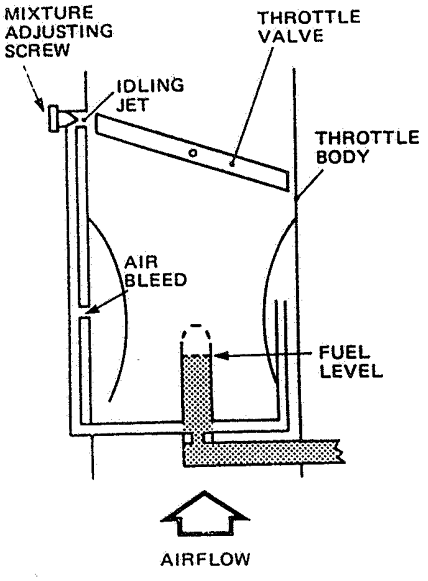


Figure 6 IDLING SYSTEM

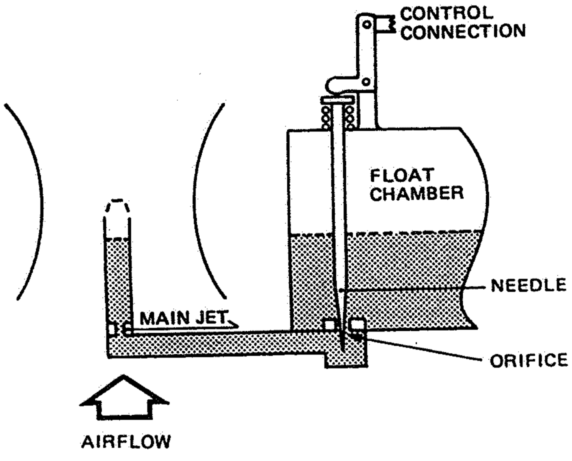


Figure 7 NEEDLE-TYPE MIXTURE CONTROL

4.3 **Mixture Controls.** The pressure drop at the venturi is a measure of air mass flow and is proportional to d × 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 × V^2 (where D is fuel density and V is fuel velocity). At constant density therefore, v^2 and V^2 are both proportional to the pressure drop, and changes in fuel mass flow will be proportional to changes in air mass flow (engine speed), except as noted in paragraph 4.1. At constant air velocity however, the pressure drop in the venturi is directly proportional to changes in air density, whilst fuel mass flow, being of constant density, remains proportional to $\sqrt{\text{pressure drop}}$; changes in air density therefore, produce less than proportional changes in fuel flow. This results in a progressive increase in richness with increased altitude, which would be unacceptable for economic operation. Float-chamber carburettors are normally fitted with a manual mixture control, which is used for correcting the enrichment resulting from decreased air density, and also for leaning (weakening) the mixture for economical cruising. The carburettors fitted to some large engines have automatic mixture control for altitude.

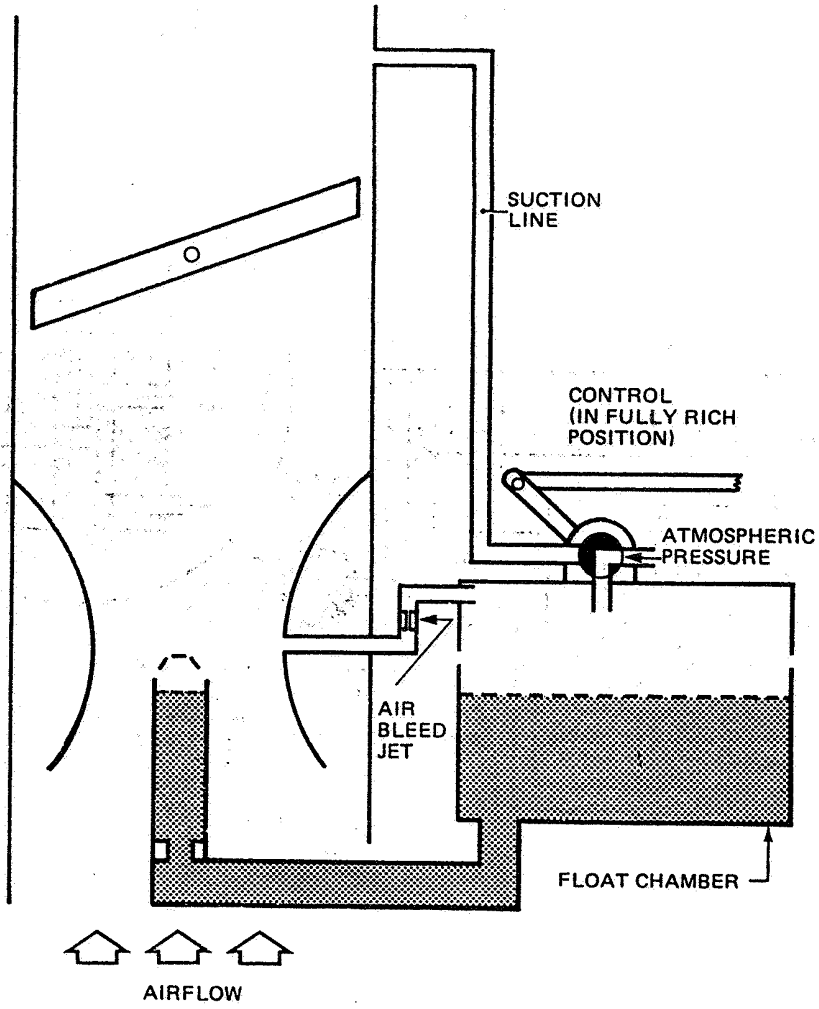


Figure 8 AIR BLEED MIXTURE CONTROL

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

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

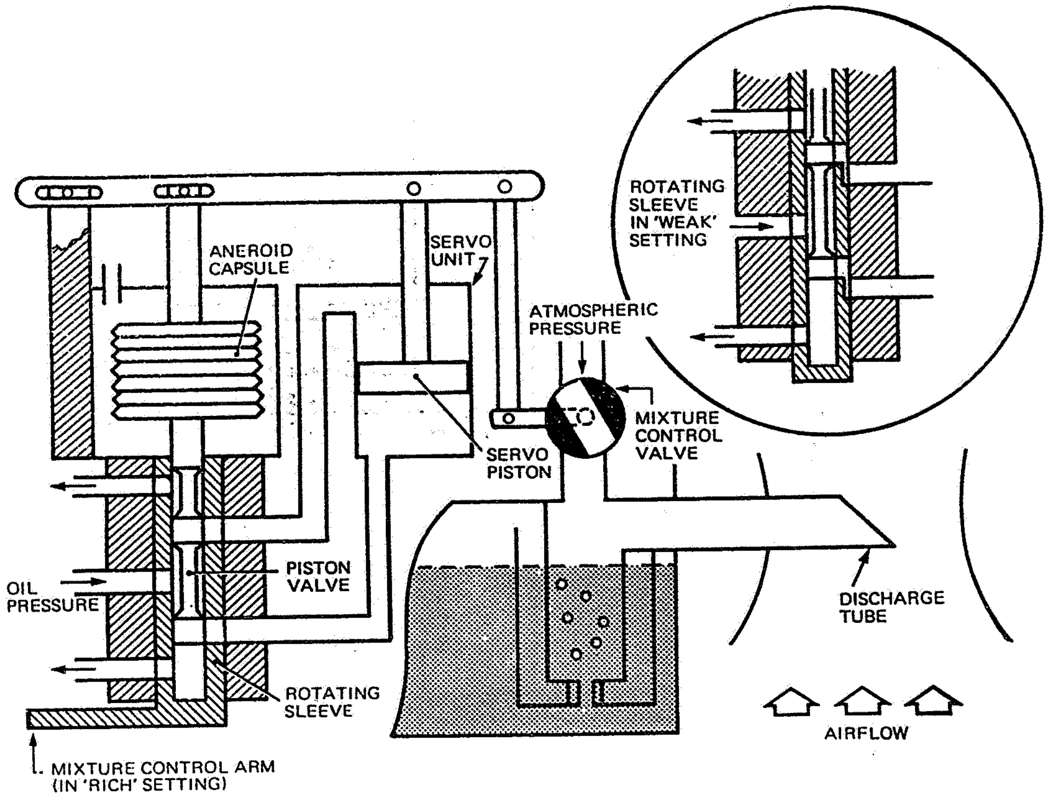


Figure 9 AUTOMATIC MIXTURE CONTROL

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

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

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

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

4.4.1 Fig. 10 illustrates a carburettor with an additional needle valve, which may be known as a power jet, enrichment jet, or economizer. The needle valve, which is connected to the throttle control, is fully closed at all throttle settings below that required to give maximum cruising power at sea-level, but as the throttle is opened above this setting the needle valve opens progressively until, at full throttle, it is fully open. On some engines the power jet is operated independently of the throttle, by means of a sealed bellows which is actuated by manifold pressure. In this way high-power enrichment is related to engine power rather than to throttle position.

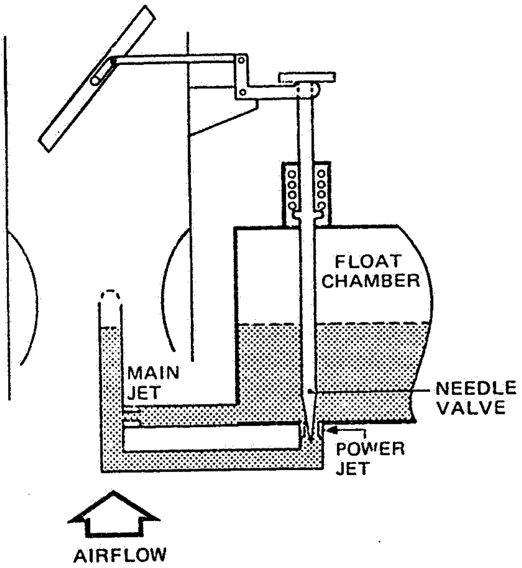


Figure 10 POWER JET

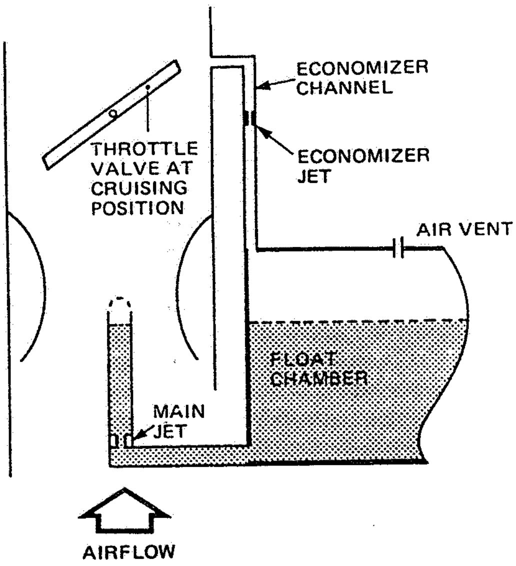


Figure 11 BACK-SUCTION ECONOMIZER

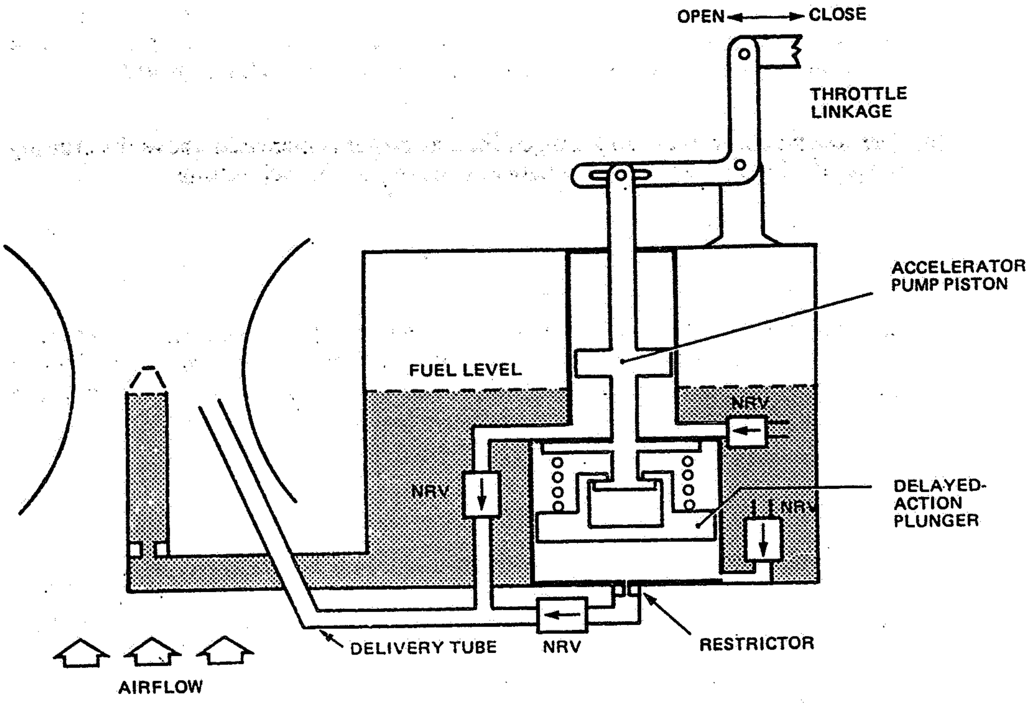


Figure 12 ACCELERATOR PUMP

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

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

5 INJECTION CARBURETTORS

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

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

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

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

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

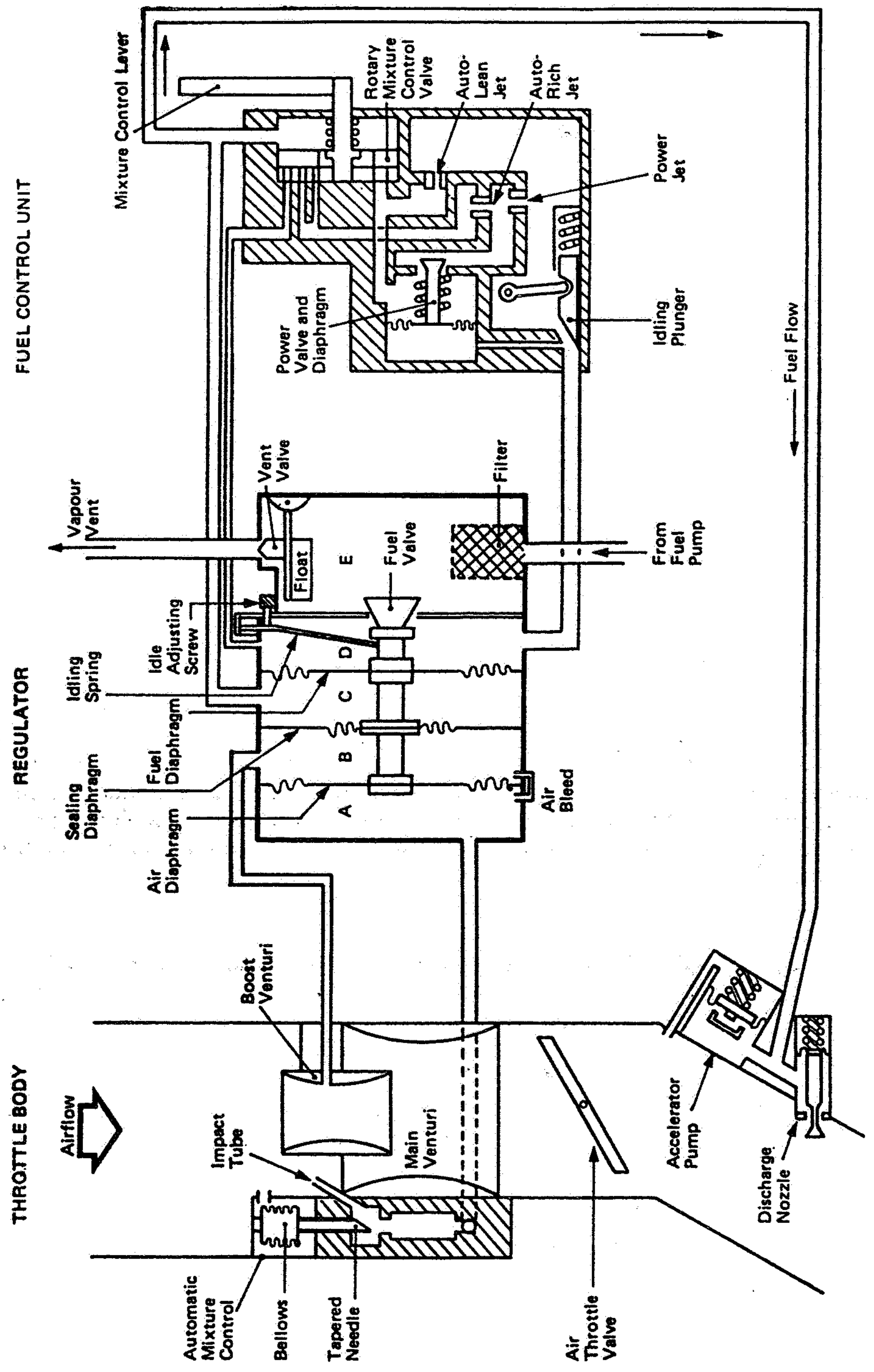


Figure 13 TYPICAL INJECTION CARBURETTOR

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

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

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

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

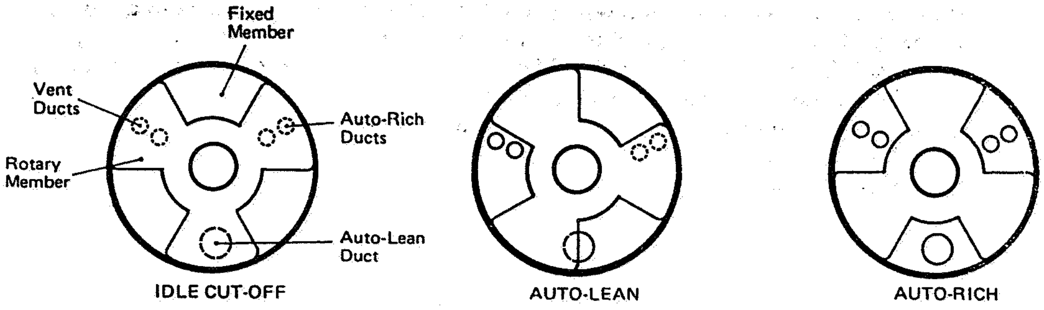


Figure 14 ROTARY MIXTURE CONTROL VALVE

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

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

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

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

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

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

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

5.7 **Mixture Control.** The manually-operated mixture control varies fuel flow according to engine operating conditions and was described in paragraph 5.4. Automatic correction of fuel flow for changes in air density (temperature and pressure) is provided by the automatic mixture control. A small air bleed between chambers A and B in the regulator causes a slight but continuous flow of air from the impact tubes to the boost venturi, thus providing the means of controlling the pressure in chamber A, and thereby regulating fuel flow. At sea level the bellows is fully compressed and the tapered needle is withdrawn from the air passage leading to chamber A; full intake pressure acts on the air diaphragm, so that fuel valve opening and fuel flow are at the maximum for the particular airflow condition. As the aircraft climbs and atmospheric pressure decreases, the bellows expands and inserts the tapered needle into the air passage, thus restricting the flow of air into chamber A, and reducing the differential pressure across the air diaphragm. As a result the fuel valve closes slightly and fuel pressure is adjusted to match air pressure, thus reducing fuel flow through the jets to maintain the required mixture strength.

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

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

6 DIRECT FUEL INJECTION Direct fuel injection is often employed on aircraft piston engines, but is of the low-pressure, continuous-flow type rather than the intermittent-flow type commonly used on diesel engines, in which calibrated quantities of fuel are injected into the cylinders at a particular time in the operating cycle. In the low-pressure, continuous-flow method, fuel is sprayed continuously into the inlet port of each cylinder; the advantages claimed for the method are low operating pressure, good fuel distribution, freedom from icing problems and the ability to use a pump which does not have to be timed to the operating cycle. Some fuel injectors operate on similar principles to the injection carburettor described in paragraph 5, with a distribution system replacing the discharge nozzle, but a different method of operation is used on some engines, and this latter method is described in paragraph 6.1 to 6.6.

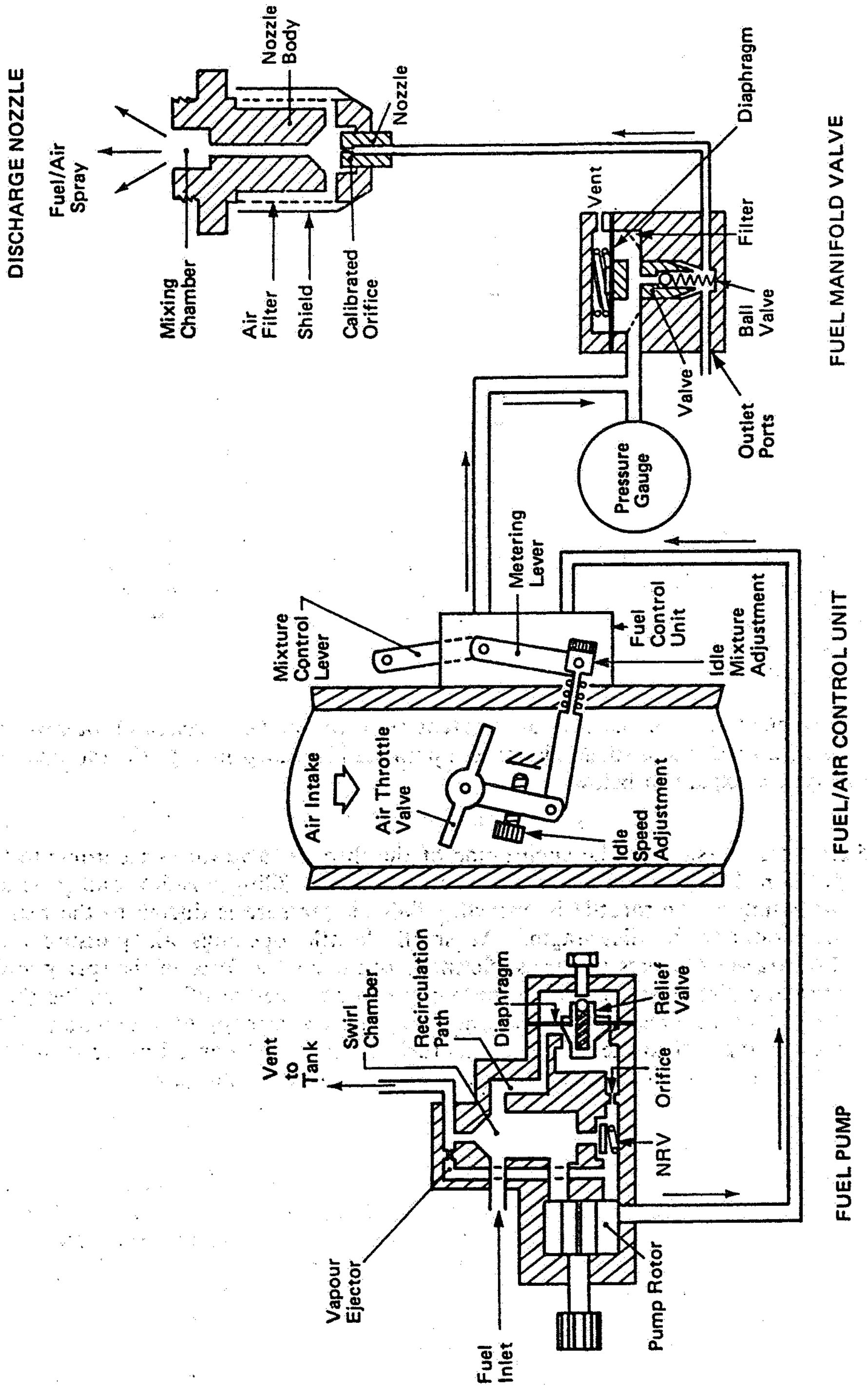


Figure 15 FUEL INJECTION SYSTEM

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

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

6.3 **Fuel/Air Control Unit.** This unit is mounted on the intake manifold and contains three control elements.

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

6.3.2 The fuel control unit is attached to the air throttle assembly, and controls fuel flow to the engine by means of two rotary valves. One valve, the metering valve (Fig. 16), is connected to the air throttle, and by means of a cam-shaped end face controls fuel flow to the fuel manifold valve according to the position of the air throttle; thus fuel flow is proportioned to air flow and provides the correct air/fuel ratio. The second valve, the mixture valve (Fig. 17), is connected to the pilot's mixture control lever, and by means of a contoured end face, bleeds off fuel pressure applied to the metering valve. Thus the air/fuel ratio can be varied from the basic setting of the metering valve, as required by operating conditions. A fuel pressure gauge in the system indicates metered fuel pressure, and, by suitable calibration, enables the mixture to be adjusted according to altitude and power setting (paragraph 6.6).

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

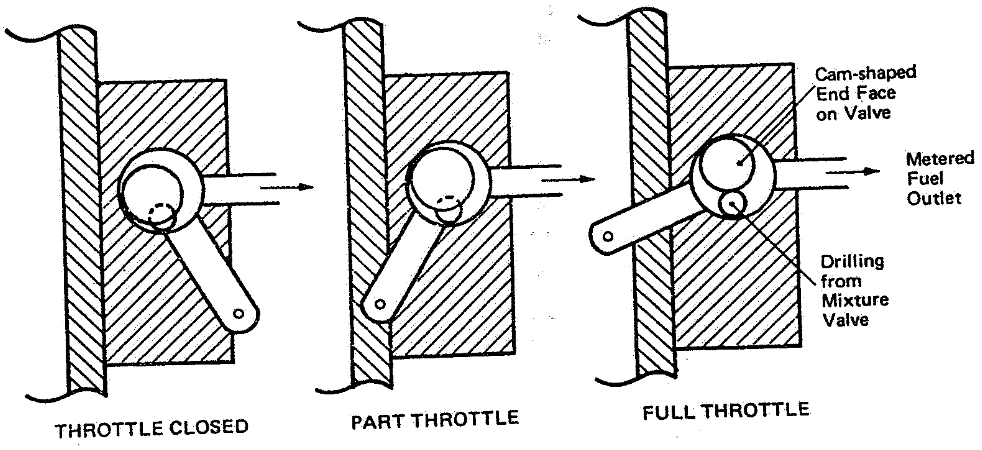


Figure 16 METERING VALVE

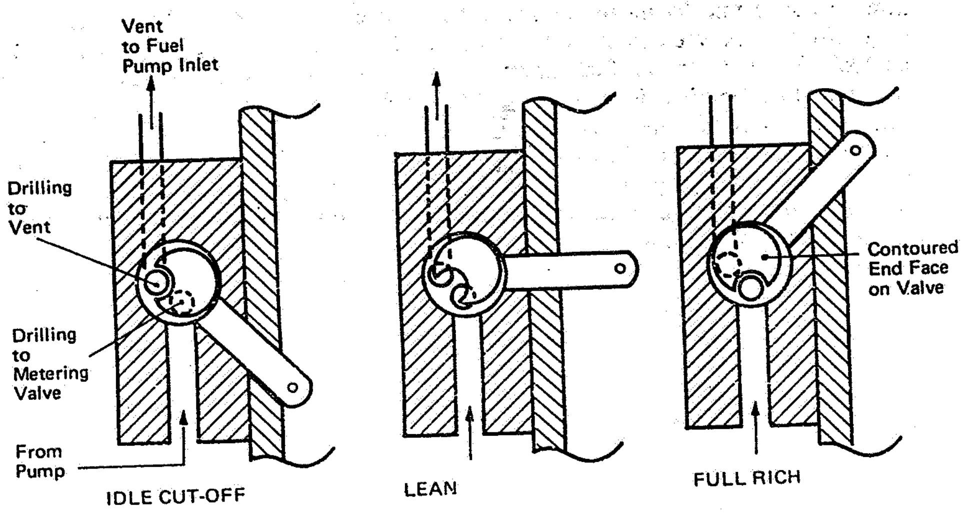


Figure 17 MIXTURE VALVE

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

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

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

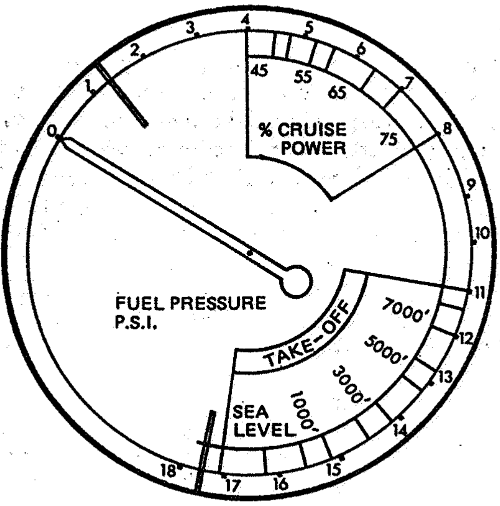


Figure 18 FUEL PRESSURE GAUGE

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

10 INSPECTION AND MAINTENANCE Because of the many variations within the three main types of carburettors, the inspection and maintenance requirements may vary considerably. However, sophisticated test rigs are usually required to set-up a carburettor over its complete range of operation, and, therefore, adjustments without the rigs are usually limited to those affecting the idling speed, idling mixture strength, fuel pressure, and the mechanical connections between the carburettor and the pilot's controls. Individual components in some carburettor systems may be removed for cleaning or repair, and in some cases the renewal of damaged diaphragms in a regulator, accelerator pump or manifold valve may be permitted.

10.1 **Routine Inspections and Maintenance.** Routine inspections and maintenance are intended to check the security of the carburettor and its components, the correct operation of the operating controls, the cleanliness of the air and fuel passing through the carburettor, and the supply of a correct mixture to the cylinders.

10.1.1 The cleanliness of the air and fuel is of the utmost importance to the satisfactory operation of a carburettor. Dust in the air could build up on the venturi, impact tubes and air passages, and affect the metering action of the carburettor; similarly, any contamination of the fuel could restrict or block fuel jets and again affect proper metering. Cleanliness of the air and fuel filters is of the utmost importance, therefore, and regular inspection and cleaning are specified in the appropriate Maintenance Schedules. However, depending on the operating environment of the aircraft, more frequent checks may be advisable.

10.1.2 A further cause of incorrect mixture may be leakage at the inlet manifold joints or at the joint between the carburettor and the inlet manifold. On a supercharged engine such leakage may be evident by signs of blowing at the leakage points, and on a normally-aspirated engine by excessively weak mixtures at low engine speeds.

10.1.3 Air leakage into the intake system upstream of the carburettor will not directly affect the mixture, although it may allow dirt to enter with the airstream, but leakage of hot air into the normally cold intake will affect engine power. In this latter respect alternative air intake flaps with magnetic catches are particularly prone to unsatisfactory operation, through failure to remain positively in the intended position.

10.1.4 To ensure continued satisfactory operation, and depending on the carburettor type, the routine checks prescribed in an approved Maintenance Schedule, will normally include the following:—

(a) Check carburettor or injector components for fuel leakage and security, and for tightness and locking of attaching bolts and nuts.

(b) Check all connections on fuel, priming and vent pipes, for security and freedom from leaks, and ensure that the pipes are securely clipped and free from damage.

(c) Check inlet manifold for leaks or damage, and for tightness and locking of attaching nuts and bolts.

(d) Check intake duct seals for condition and proper fit, and alternative air flap for fit, wear, security and positive action.

(e) Check intake duct for damage, and for satisfactory connection to carburettor.

(f) Check all engine controls for full and free movement, locking, security and correct operation.

(g) Remove float chamber drain plug, and flush out sediment by operation of the electrical booster pump or gravity feed, as appropriate.

(h) Check that intake or supercharger drains are clear.

(j) Remove and clean air filter.

(k) Remove and clean fuel filters in the carburettor and fuel pump.

(l) Refit, tighten and lock any parts removed during maintenance work.

(m) Check idling mixture and engine speed.

(n) Check operation of priming pump, and connections for security and freedom from leaks.

(o) Open the drain tap in the fuel filter bowl, drain off a quantity of fuel into a glass jar and inspect for water and sediment. If excessive free water is found, proceed as outlined in Leaflet AL/3—17.

10.2 Cleaning of Filters

10.2.1 **Dry Air Filters.** A dry filter element should be carefully removed from its casing, and shaken or tapped on a hard surface to remove all loose dirt; the casing should be cleaned by wiping with a lint-free cloth moistened in solvent, and should be dried before refitting the element. On no account should the element be washed in any liquid. If any damage is found, the element should be discarded and a new element should be fitted.

10.2.2 **Oil-wetted Air Filters.** A filter of this type should be thoroughly washed in solvent to remove all oil and dirt, then checked for satisfactory condition. When completely dry, the filter should be immersed for a few minutes in oil of the recommended grade, then allowed to drain thoroughly before refitting it to the engine.

10.2.3 **Fuel Filters.** Fuel filters in the carburettor and fuel pump should be cleaned by flushing in solvent, then dried with dry compressed air. Brushes and rags should not be used for cleaning filters.

10.3 **Idling Adjustment.** Because of small changes in compression and ignition which may affect engine operation, the idling mixture and speed may occasionally require adjustment. This adjustment is also important to operation outside the idling range, since fuel may still be drawn through the idling jet at power settings in the cruising range. An excessively rich idling mixture will result in sooting of the plugs, whilst an excessively weak idling mixture will prevent satisfactory acceleration. Most carburettors are adjusted to provide an idling mixture which is slightly richer than the 'best power' mixture, but some injector systems are adjusted to the 'best power' mixture, or slightly weaker.

10.3.1 In order to adjust the idling mixture and speed, the engine should be warmed up until the oil and cylinder (or coolant) temperatures are in the normal operating range, and the ignition should be checked at the power setting recommended for the particular engine to ensure that the engine is operating satisfactorily; where appropriate, the propeller should be in fully fine pitch and the mixture set to fully rich. In some instances it may be advisable to withdraw the idling-speed stop to adjust the mixture, and set the required speed with the throttle lever; this will save the need for continual adjustment of speed after a change of idling mixture. Between adjustments the engine should be run for a short period at a moderate power setting, to prevent oiling of the plugs.

10.3.2 On a float-chamber carburettor, the throttle should be closed to give normal idling speed, and the idling mixture screw turned to richen the mixture until the engine runs roughly or 'rolls' from over-richness. The screw should then be turned in the opposite direction until the engine runs roughly from leanness, and this will show the range of adjustment within which the best-power mixture and idling mixture lie. From the lean position the screw is then turned to richen the mixture until just after the position at which maximum engine speed is obtained. The setting should then be checked after increasing power to clear the engine, and the throttle stop should be adjusted to give the specified engine idling speed. Several alterations to the mixture screw may be necessary before the idling mixture is correct, and each alteration of the mixture will affect the idling speed.

10.3.3 On a carburettor fitted with a mixture control and cut-off lever, a different method of adjustment may be used. With the engine idling at the correct speed, the mixture lever should be moved smoothly into the idle cut-off position, and any changes in engine speed or manifold pressure should be noted. With a correct idling mixture, an initial increase in engine speed (5 to 60 rev/min, depending on the installation) and decrease in manifold pressure (approximately ¼ in.Hg) will occur as the mixture becomes leaner, before the engine stops firing. A larger rev/min increase indicates that the mixture is too rich, and a smaller increase, or no increase, indicates that the mixture is too lean. Care must be taken during the check to ensure that the mixture lever is returned to the fully-rich position as soon as engine speed starts to fall and manifold pressure starts to rise. As with the float-chamber carburettor, a number of adjustments may be necessary before the correct mixture strength is obtained and it will usually be necessary to re-adjust the idling speed.

10.3.4 With an injection system the idling mixture is altered by adjusting the length of the linkage between the air throttle valve and the metering valve. Idling speed should be set first then the method described in paragraph 10.3.3 should be used to adjust the idling mixture. With an injection system the mixture supplied to the cylinders may be affected by the condition of the air filters in the discharge nozzles, and if difficulty is experienced in setting the idling mixture these filters should be examined and, if necessary, cleaned by washing in solvent.

10.3.5 If idling is erratic, the throttle linkage should be checked for play, and it should be ensured that the idling speed adjusting-screw contacts the throttle stop on the carburettor before the throttle lever reaches its fully-closed position. If the idling mixture is excessively lean, the induction manifold joints, sealing gaskets, and priming connections should be checked for signs of damage or leakage.

10.3.6 When the idling adjustments have been completed and rechecked, any locking which has been disturbed should be renewed, and any cowlings or panels which have been removed to obtain access should be refitted.

10.4 **Removal and Installation.** It may occasionally be necessary to remove and refit a carburettor or some of the separate components in a carburation system, because of damage, excessive wear or incorrect operation. Individual installations will vary in detail and the particular requirements of each installation will be included in the approved Maintenance Manual for the aircraft concerned, but the procedures and precautions to be observed will generally be similar to those outlined in paragraphs 10.4.1 to 10.4.4.

10.4.1 **Carburettor Removal.** Before removing a carburettor, the fuel supply cock should be closed and suitable containers should be made available to prevent major spillage of fuel into the engine compartment when the fuel pipes are disconnected. Any electrical circuits to the engine should be made safe by tripping the circuit breakers or removing the fuses, as appropriate. Precautions must also be taken during removal of the carburettor (particularly a down-draught carburettor), to prevent any foreign material from entering the induction manifold, intake duct or supercharger, since this could result in physical damage to the engine. The following procedure should normally be adopted:—

(a) Disconnect throttle and mixture control linkage at the carburettor and, where appropriate, the linkage to the supercharger control unit. In some cases it may be advisable to secure these control linkages to adjacent structure, so as to prevent interference with carburettor removal and refitting.

(b) Disconnect the fuel inlet pipe, vapour return pipe and pressure gauge connection, as appropriate. If a new carburettor is not being fitted immediately, these pipes should be suitably blanked and any spilled fuel should be mopped up.

(c) Secure the throttle valve in the closed position, then disconnect the intake duct from the carburettor and remove the intake air screen.

(d) Remove the nuts and washers securing the carburettor to the engine, then carefully remove the carburettor and joint gasket. A protective cover should immediately be secured over the mounting flange on the engine, to prevent the entry of foreign matter.

10.4.2 **Carburettor Installation.** A new or replacement carburettor should be examined before being fitted to an engine, to ensure that it is the correct type for the particular engine, that it is undamaged, and that all locking is correctly fitted and secure. The throttle valve operating lever may have to be positioned to suit the particular installation, and should be temporarily secured in the closed position to prevent the entry of foreign matter into the engine. The carburettor should then be fitted as follows:—

(a) Remove protective cover from the engine mounting flange and inspect the induction passages for foreign matter.

(b) Place the joint gasket in position, ensure that any bleed holes in the flange match up with corresponding holes in the gasket, then position the carburettor and tighten the attaching nuts to the prescribed torque.

(c) Remove the blanks from the fuel and vent pipes, inspect the threads for condition and connect to the carburettor. Only fuel-soluble oil should be used on the threads of the connections; the use of hard-drying sealants should be avoided.

(d) Remove the temporary restraint from the throttle valve and check the throttle and mixture levers on the carburettor for full and free movement. Reconnect the control linkage to the carburettor and check operation (paragraph 10.4.3).

(e) Flush the carburettor by selecting the fuel cock on, switching on the booster pump, and opening the mixture control valve until fuel, free from preservative oil, is discharged from the manifold or supercharger drain. Carburettors in which flexible diaphragms are used to control fuel flow should be allowed to stand for at least eight hours before running the engine, in order to soak the diaphragms and make them more flexible; to save time, this procedure may be carried out before installing the carburettor on the engine.

(f) Lock all controls and connections as required.

(g) Check operation of carburettor by running the engine (paragraph 10.5) and adjust the idling mixture as necessary (paragraph 10.3). After closing down the engine, inspect the installation for leaks and rectify as necessary.

10.4.3 **Control Settings.** When the control linkage to a carburettor is reconnected, its adjustment must be checked to ensure correct operation of the engine.

(a) The throttle valve must have full movement between the stops on the carburettor which limit its movement at the idling and fully-open positions. To make sure that this occurs, the pilot's throttle lever must have clearance at both ends of the quadrant in which it operates; this clearance is often referred to as 'spring-back' and ensures that vibration of the engine does not affect the position of the throttle valve. On most light aircraft the linkage should be adjusted so that there is an equal clearance at both ends of the quadrant, but on aircraft with long control runs the positions of the various pulleys and levers may be set by rigging pins or angular markings, and the rods and cables should be adjusted to suit these positions. The controls should be checked for full and free movement, and any looseness or excessive play in the linkage should be corrected by adjustment or renewal of parts. When connected and checked, the adjustments and connections should be locked in the appropriate manner.

(b) Mixture controls which do not have marked positions should be adjusted in the same way as throttle controls, to give clearance in the quadrant at the fully-rich and fully-lean positions. Mixture controls which have detents on the carburettor and marked positions on the quadrant, should be adjusted so that the position of the mixture valve agrees with the position of the control lever. Mixture controls should be checked for looseness or play, and faults should be corrected in the appropriate manner. Locking should be renewed as appropriate.

(c) On carburettors fitted with a separate idling cut-out control, the linkage is usually in the form of a cable, which is spring-loaded to the 'running' position. The cable should be adjusted so that a small movement of the control is necessary before the cut-out begins to operate.

(d) On those carburettors which have linkage from the throttle valve to a supercharger control unit, the linkage to this unit will not normally have been altered. Where necessary, the setting-up procedure will be specified in the approved Maintenance Manual, and any adjustments necessary should be carried out during engine runs.

10.4.4 **Individual Components.** Removal and installation of individual components such as injector nozzles, accelerator pumps, fuel pumps, priming pipes, etc., is usually permitted by the manufacturer, and is generally straightforward. Care is necessary to prevent damage to rigid pipes and couplings when making or breaking connections, and blanks should be used whenever a component is removed. After replacement of a component, the engine should be run to check the satisfactory operation of the carburation system (paragraph 10.5), and inspected for fuel leakage. In some instances adjustments may be necessary (e.g. adjusting fuel pressure after changing a fuel pump) and these should be carried out in accordance with the manufacturer's instructions.

10.5 Whenever a carburettor, injector, or major component in the system is changed, an engine run should be carried out to verify correct fuel metering. The following should be confirmed:—

(a) The engine should start smoothly when hot or cold.

(b) At normal operating temperatures, idling should be smooth and steady.

(c) Rapid acceleration and deceleration are prohibited on some engines, but acceleration and deceleration within the limitations of the particular engine should be checked as being smooth, and without hesitation or any tendency to stop or run roughly.

(d) The engine should run smoothly at any power setting likely to be encountered in flight.

(e) Any interconnection between the throttle and mixture controls, or between the throttle and the alternative air intake controls, should function as intended.

(f) A full-power check or reference power check (see Leaflet EL/3-15) should be carried out to confirm that normal power is being produced.

NOTES: (1) Excessive ground running should be avoided since the engine will not be adequately cooled when the aircraft is stationary.

(2) Running at those engine speeds at which engine/propeller resonant vibrations may occur, and concerning which there may be cockpit placards or warnings in the Flight Manual, should be avoided.

10.6 **Storage.** A carburettor which has been removed from an engine, should be protected from deterioration before being placed in storage. All fuel should be drained out, and the fuel chambers and passages should be filled with preservative oil; the carburettor should then be rocked and rotated to distribute the oil over all the internal surfaces. Injection carburettors should be filled with oil by connecting an oil supply line to the fuel inlet and pumping in oil under pressure with the throttle valve fully open and the mixture control fully rich; on no account must the maximum permitted pressure be exceeded. After draining out surplus oil, all openings should be securely blanked and the throttle valve should be locked in the closed position. The carburettor should then be wrapped in greaseproof paper, and packed in a suitable carton or crate to protect it from damage. A label should be affixed to the carton, giving details regarding type of carburettor, reason for and date of removal, and any other details relevant to it.

EL/1-3

Issue 1.

3rd *December*, 1976.

AIRCRAFT

ENGINES

PISTON ENGINE SUPERCHARGERS

1 INTRODUCTION This Leaflet deals with the methods used to increase the power of a piston engine, or to increase the altitude at which sea-level power can be maintained.

2 GENERAL The power output of an engine depends basically on the weight of mixture which can be burnt in the cylinders in a given time, and the weight of mixture which is drawn into each cylinder on the induction stroke depends on the temperature and pressure of the mixture in the induction manifold. On a normally-aspirated engine the pressure in the induction manifold at full throttle is slightly less than atmospheric pressure because of intake duct losses, and the manifold pressure decreases with any increase in altitude. Power output, therefore, decreases with altitude, although some of the loss is recovered in better scavenging of the cylinders as a result of reduced back pressure on the exhaust. In order to increase engine power for take-off and initial climb, and/or to maintain engine power at high altitude, the manifold pressure must be raised artificially, and this is done by supercharging.

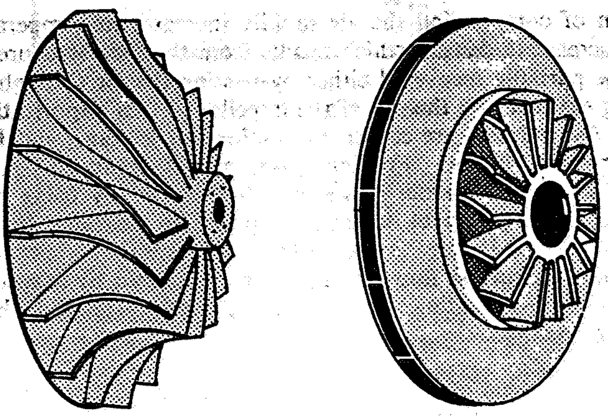

(A) SINGLE-SIDED IMPELLER (B) FULLY-SHROUDED IMPELLER

Figure 1 SUPERCHARGER IMPELLERS

2.1 Where a supercharger is used to increase sea-level power, rather than to maintain normal power up to a high altitude, the engine will need to be strengthened in order to resist the higher combustion pressure. For superchargers capable of producing maximum power at high altitude, a control system is necessary to prevent excessive pressure being generated within the engine at low altitude.

2.2 Centrifugal impellers (Fig. 1) are used for superchargers on aircraft engines and may be driven by either internal or external means; in some installations a combination of both is used. Internally-driven superchargers are driven by gearing from the engine crankshaft, and externally-driven superchargers (known as turbo-superchargers or turbochargers) are driven by a turbine which is rotated by the exhaust gases. The methods of operation and control of these two types are quite different, and are dealt with separately in this Leaflet.

3 CENTRIFUGAL IMPELLERS Centrifugal impellers are used because they are comparatively light, are able to run at high speed, will handle large quantities of air, and are reliable.

3.1 A centrifugal impeller is, in effect, a fan which, when rotated at high speed, causes the air between the vanes to be flung outwards under centrifugal force. The air receives kinetic energy as it flows outwards between the vanes, and, as the cross-section of its path increases, some of this energy is converted into pressure energy. The proportion of pressure gained in the impeller depends on the impeller's diameter, speed of rotation, and the shape of the vanes.

3.2 The air leaves the impeller with considerable tangential and radial velocity and passes into a diffuser, which consists of a number of vanes fixed between the walls of the supercharger casing. The angle of the diffuser vanes is initially parallel to the path taken by the air leaving the impeller, and the curvature of the vanes guides the air into a volute casing, or manifold ring, in such a way as to minimize turbulence, which would impede the flow and increase temperature. The diffuser vanes form divergent passages, which decrease the velocity and increase the pressure of the air passing through them.

3.3 The action of compressing the air rapidly increases its temperature, and reduces some of the increase in density which results from the increased pressure; this loss of density may be partially recovered either by passing the air through a heat exchanger or by spraying the fuel into the eye of the impeller so that vaporization will reduce air temperature. Other losses are caused by friction, air leakage, and buffet at the inlets to the impeller and diffuser. Friction losses may be reduced by using a shrouded impeller (Fig. 1 (B)), and buffet losses may be reduced by using curved inlet vanes on the impeller, and by careful design of impeller tip clearance to suit the impeller's speed of rotation. Air leakage is caused by the pressure difference across the impeller tending to produce a reverse flow of air; this is minimized by ensuring that clearances between stationary and rotating parts are kept as small as possible, but leakage cannot be completely eliminated.

3.4 At a particular speed of rotation a centrifugal supercharger increases the pressure of air passing through the impeller in a definite ratio. Physical constraints limit the speed of rotation and size of an impeller, and so limit the compression ratio and, consequently, the power output or maximum operating altitude of the engine to which it is fitted. Compression ratios between 1·5 : 1 and 3 : 1 are generally obtainable, and any further compression necessary would have to be obtained by fitting two impellers in series.

4 INTERNALLY-DRIVEN SUPERCHARGERS Internally-driven superchargers are generally used on medium- and high-powered piston engines (approximately 250 bhp and above), and are fitted downstream of the throttle valve. In the past the superchargers of high-powered engines have often been driven at two speeds in order to save power at low altitudes, and have also been fitted with two impellers working in series in order to raise the overall compression ratio; some of these engines are still in use, but current engines generally employ a single impeller driven at a fixed ratio to the crankshaft (usually between 6 : 1 and 12 : 1). This type of supercharger is usually capable of maintaining sea-level manifold pressure up to an altitude of 5000 to 10,000 feet, depending on the gear ratio, at Rated Power settings. In Fig. 2 the power curves of a single-speed, single-stage supercharged engine are compared with a normally-aspirated but otherwise identical engine.

NOTE: Rated Power, or Maximum Continuous Power, is the maximum power at which continuous operation is permitted. Take-off Power, and in some instances Climbing Power, may have a time limitation.

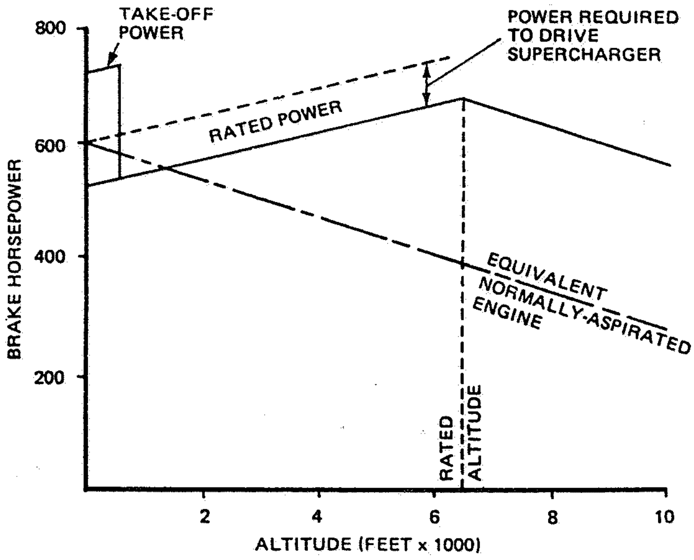


Figure 2 POWER CURVES—SINGLE-SPEED SUPERCHARGER

4.1 The power developed by the normally-aspirated engine is at a maximum at sea-level, and progressively decreases as altitude is increased. The power developed by the supercharged but otherwise identical engine, at the same speed and manifold pressure, is less than that of the normally-aspirated engine at sea-level, and this power loss represents the power required to drive the supercharger. However, as height is increased, the power developed by the supercharged engine at constant throttle settings, increases as a result of the decreased temperature of the atmosphere. The decreased temperature increases the density of the air, and thus a greater weight of air is pumped into the cylinders for the same manifold pressure. Decreased air pressure also causes less back-pressure on the exhaust, thus improving scavenging of the cylinders.

4.1.1 At sea-level the throttle valve in the supercharged engine must be partially closed, so as to restrict manifold pressure and prevent excessive cylinder pressures, but as the aircraft climbs the throttle valve must be progressively opened (either manually or automatically) to maintain this manifold pressure. Eventually a height is reached where the throttle is fully open, and this is known as full-throttle height; above this height power will fall off as with the normally-aspirated engine. Since the effect of the supercharger depends on the speed of rotation of the impeller, each power setting will have a different full-throttle height according to the engine speed and manifold pressure used; the full-throttle height at Rated Power settings is known as Rated Altitude.

4.2 **Supercharger Drives.** A shaft, splined into the rear of the crankshaft, provides the initial drive to the supercharger impeller and often also drives a number of accessories and transmits the drive from the starter motor to the engine. Such a shaft may incorporate a spring-drive unit, which transmits the drive through intermediate gears to the impeller pinion, and the impeller pinion may also include a centrifugal clutch.

4.3 **Supercharger Controls.** Since a supercharger is designed to compress air and provide sea-level pressure, or greater, in the induction manifold when atmospheric pressure is low, excessive manifold pressures could be produced when atmospheric pressure is high. It is necessary, therefore, to restrict throttle opening below full-throttle height, and, to relieve the work load on the pilot, this is often done automatically.

4.3.1 An aneroid capsule, which expands or contracts under varying pressure, is normally used in any system designed to control manifold pressure. The capsule (or in some cases a stack of individual capsules) is enclosed in a chamber connected to supercharger outlet pressure, and is attached to a servo valve to control the flow of pressure oil to a servo piston. The servo piston is connected to the throttle linkage so as to adjust throttle valve opening and thus control and limit manifold pressure.

4.3.2 A fixed-datum control, such as is illustrated in Fig. 3, is designed to prevent manifold pressure exceeding the Rated Power setting. When the engine is started, the throttle valve is only slightly open and manifold pressure is low; the capsule expands, lowering the servo valve and directing pressure oil to the underside of the servo piston, which moves to the top of its cylinder. As the throttle lever is advanced, the manifold pressure rises until the capsule has contracted sufficiently to lift the servo valve and block the flow to the servo piston; this is the neutral position of the valve and coincides with Rated Power. If the throttle lever is advanced further, the manifold pressure will increase and the capsule will contract, lifting the servo valve and directing pressure oil to the top of the servo piston. This action moves the servo piston downwards, closing the throttle valve until manifold pressure has returned to the rated value and the servo valve has returned to its neutral position. When climbing at Rated Power settings, the decreasing atmospheric pressure results in a lower supercharger outlet pressure, and the capsule gradually expands, progressively opening the throttle valve until full-throttle height is reached. In order to enable maximum power to be obtained during take-off, a means of overriding the control unit is required; this is often in the form of a calibrated leakage from the capsule chamber which is activated by linkage to the throttle lever. The main disadvantage of the fixed-datum system is that it has no effect on the throttle valve at power settings below Rated Power, and the throttle lever must be continually adjusted when climbing or descending at a lower power. There is also some "lost motion" of the throttle lever, which is greatest at sea level and decreases with altitude, and this means that the mixture enrichment required at high-power settings must be obtained by pressure-controlled devices rather than by the use of jets which are controlled by throttle movement (see Leaflet **EL/1-2**).

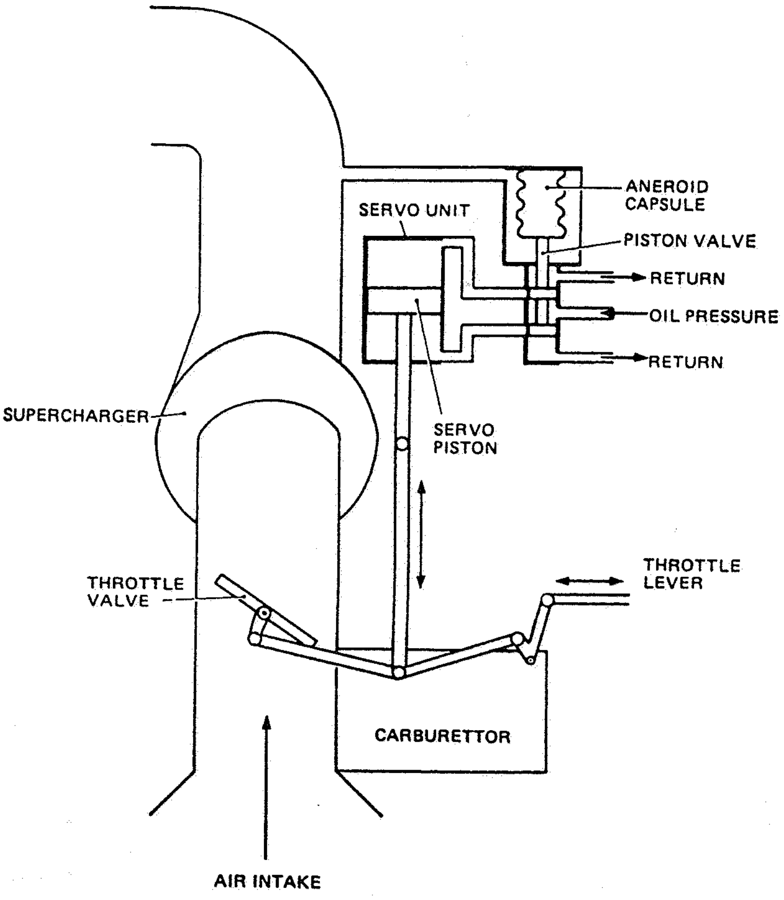


Figure 3 MANIFOLD PRESSURE CONTROL

4.3.3 A method used to overcome the deficiencies of the system described in paragraph 4.3.2, is the variable-datum control which is illustrated in Fig. 4. A cam connected to the throttle lever controls the datum setting of the aneroid capsule; as the throttle lever is closed from the fully-open position, the cam rotates and allows the capsule to rise under spring pressure. Thus the neutral position of the servo valve varies according to throttle lever position, and enables the capsule to exercise control at whatever manifold pressure is selected by the throttle lever. There is no lost motion in the throttle lever, and adjustment of the throttle valve to compensate for changes in atmospheric pressure is carried out automatically at any power selected by the throttle lever.

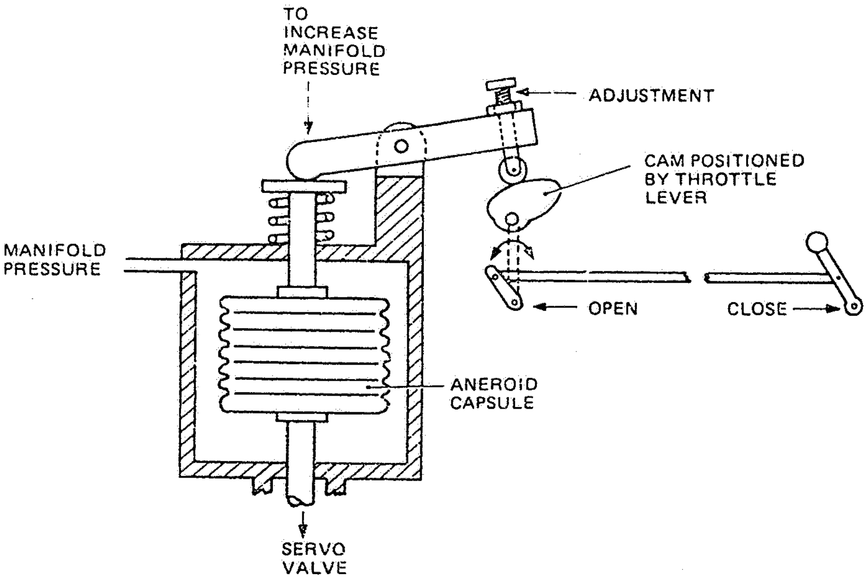


Figure 4 VARIABLE DATUM CONTROL

4.3.4 When an engine is operating in the idling range the induction pressure is very low, and a reversal of flow may occur in which air or exhaust gases are drawn into the induction manifold during the period of valve overlap. This would produce an increase in pressure in the manifold, which would be communicated to the capsule chamber and, on engines fitted with a variable-datum control, would have the effect of closing the throttle valve. This would effectively prevent any acceleration, and with this type of control the cam is so contoured and adjusted that the throttle lever is the sole means of controlling the throttle valve in the idling range.

5 EXTERNALLY-DRIVEN SUPERCHARGERS The main differences between an internally-driven and an externally-driven supercharger are in the method of driving the impeller and in the fact that the latter delivers compressed air to the throttle and carburettor. Externally-driven superchargers are powered by the energy of the engine exhaust gases and do not directly lower the power output of the engine; they are generally known as turbo-superchargers or turbochargers. Some turbochargers are designed to maintain approximately sea-level air pressure in the engine air intake up to a high altitude, and are known as Altitude Turbochargers. Others are designed to provide an intake pressure which is higher than sea-level pressure, and thus produce a higher power output at all altitudes than would be available from an unsupercharged engine, and these are known as Ground Boosted Turbochargers. The former type may be fitted without significant engine design changes to normally-aspirated engines in order to maintain sea-level power up to a high altitude, but the latter may only be fitted to engines which are designed to withstand the higher stresses imposed by the higher combustion pressures.

A few large engines with internally-driven superchargers are also fitted with a turbocharger, which is used to increase the altitude at which a given power can be developed; because of the increased air temperature arising from the two stages of compression, it may be necessary to fit an intercooler between the turbocharger and the carburettor.

5.1 A turbocharger consists of a turbine wheel and an impeller fitted on a common rotor shaft, the bearings for which are contained within a bearing housing and are lubricated by oil from the engine. The turbine and compressor casings are attached to the bearing housing and are connected to the exhaust and intake systems respectively; the compressor is shielded from the heat of the turbine, and intake or external air is ducted between the two casings to remove excess heat. The turbocharger is not necessarily an integral part of the engine, but may be mounted on the engine or on the fireproof bulkhead, and shielded from combustible fluid lines in the engine bay. A typical turbocharger is illustrated in Fig. 5, and a turbocharged engine installation is illustrated in Fig. 6.

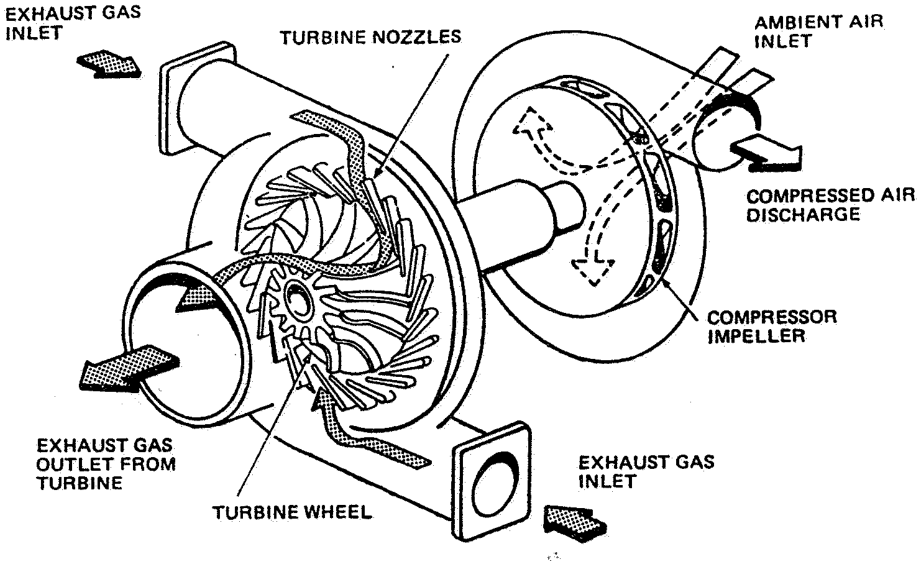


Figure 5 TYPICAL TURBOCHARGER

5.1.1 Exhaust gases are ducted to the turbine casing, where they pass through nozzles and impinge on vanes on the turbine wheel, causing it to rotate; the gases then pass between the vanes and are exhausted overboard. Since the impeller is attached to the same shaft as the turbine wheel it also rotates, drawing in air from the intake duct and throwing it outwards at high velocity through diffuser vanes in the compressor casing; these vanes convert the velocity energy into pressure energy, and the compressed air is delivered to the engine.

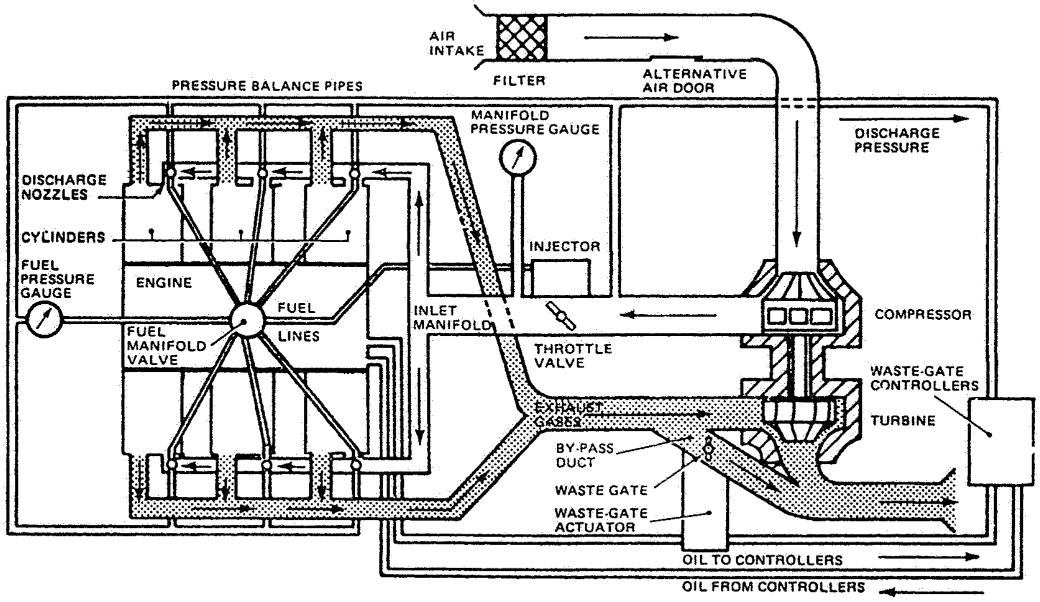


Figure 6 TURBOCHARGER INSTALLATION

5.2 For any particular power output the turbocharger delivers a fixed weight of air to the engine in a given time, and, since the density of air decreases with altitude, a greater volume of air is compressed and the impeller rotates faster at high altitude than it does at low altitude. Therefore, some form of control over compressor output must be provided, and this is done by varying the quantity of exhaust gas passing to the turbine. A turbine by-pass, in the form of an alternative exhaust duct, is fitted with a valve (known as a waste gate) which shuts or regulates the degree of opening of the by-pass. When the waste gate is fully open nearly all the exhaust gases pass directly to atmosphere, but as the waste gate closes gases are directed to the turbine, and the maximum rotor speed is achieved when the waste gate is fully closed. The waste gate may be controlled manually by the pilot, but in most turbocharger systems automatic controls are fitted to prevent over-boosting the engine.

5.3 In an automatic control system, the waste gate is mechanically connected to an actuator (Fig. 7), the position of which depends on the opposing forces of a spring and engine oil pressure. Spring force tends to open the waste gate and oil pressure tends to close it. Engine oil pressure is fed to the actuator through a restrictor, and the waste gate controllers are placed in the return line. When a controller opens the return line, oil flows through the actuator and controller back to the engine sump, and pressure in the actuator falls. The extent to which the oil pressure will fall depends on the size of the restrictor and the size of the bleed through the controllers; the larger the bleed the lower the oil pressure will drop. Thus oil pressure in the actuator is controlled to regulate the position of the waste gate according to engine requirements. Various types of controllers may be used to vary waste-gate actuator oil pressure, and these are discussed in paragraphs 5.3.1 to 5.3.5.

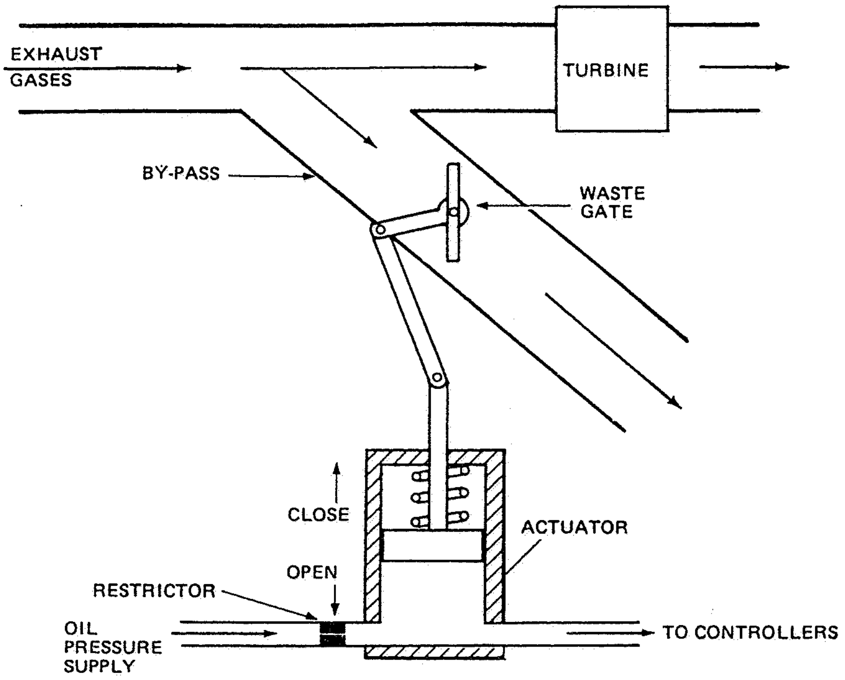


Figure 7 OPERATION OF WASTE GATE

5.3.1 Some simple turbocharger systems use a single controller, called an Absolute Pressure Controller, which is designed to prevent supercharger outlet pressure from exceeding a specified maximum; this type of controller is illustrated in Fig. 8. At low power settings full oil pressure is applied to the waste-gate actuator, which closes the waste gate and diverts all exhaust gases through the turbine. As the throttle is opened, engine speed increases, and more exhaust gas passes through the turbine; this results in an increase in the speed of rotation of the turbine and impeller, and produces a higher supercharger outlet pressure which is communicated to the capsule chamber in the Absolute Pressure Controller. When the controlling supercharger outlet pressure is reached, the capsule is compressed sufficiently to open its bleed valve and thus to bleed off oil pressure from below the waste-gate actuator piston. The piston moves down under spring pressure and starts to open the waste gate, diverting exhaust gas from the turbine and reducing its speed. Thus at high power settings at low altitude the waste gate is almost fully open, but as the aircraft climbs and more air has to be compressed it is gradually closed until, at critical altitude (equivalent to Rated Altitude on an internally-driven supercharger) it is fully closed. Above this height both manifold pressure and power output will decrease, even though the turbocharger is operating at its maximum speed.

NOTE: Since the speed of the impeller increases with altitude, the temperature of the charge will also increase, and this will reduce power output for a given manifold pressure and engine speed. Engine oil and cylinder temperatures will also increase as a result of the higher combustion temperatures.

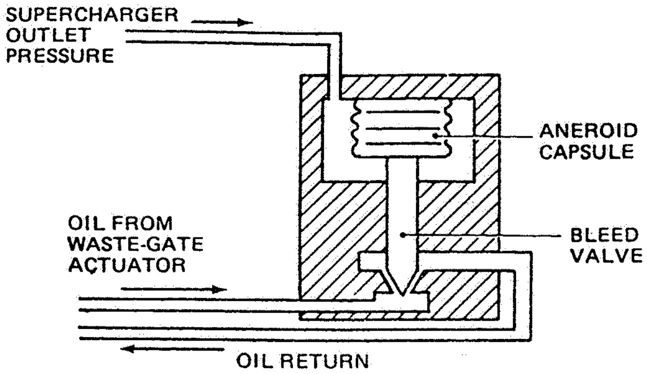


Figure 8 ABSOLUTE PRESSURE CONTROLLER

5.3.2 A variation of the single controller is the Variable Pressure Controller (see Fig. 9), which is similar in operation to the variable datum control described in paragraph 4.3.3 for internally-driven superchargers. A cam, operated by linkage to the throttle control lever, adjusts the datum of the valve in the Variable Pressure Controller, so controlling the degree of opening of the waste gate and producing a manifold pressure which is related to the power selected by the throttle lever. Operation of this system is otherwise similar to the operation of the Absolute Pressure Controller.

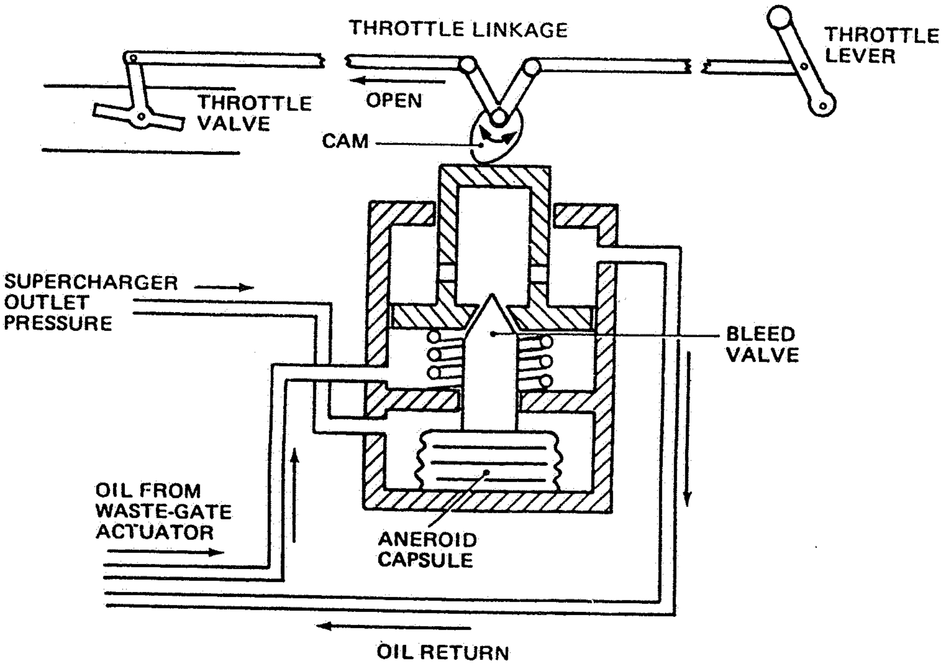


Figure 9 VARIABLE PRESSURE CONTROLLER

5.3.3 On some Ground Boosted Turbochargers a dual-unit control system is used to adjust waste-gate actuator oil pressure; the units are the Density Controller and the Differential Pressure Controller, which are installed as shown in Fig. 10.

(a) The Density Controller is designed to prevent the supercharger output from exceeding the limiting pressure; it regulates oil pressure only at full throttle and up to the turbocharger's critical altitude. The capsule is filled with dry nitrogen and is sensitive to both temperature and pressure changes. Contraction or expansion of the capsule varies the quantity of oil bled from the waste-gate actuator and repositions the waste gate, thus maintaining a constant density at full throttle.

(b) The Differential Pressure Controller controls the waste gate at all positions of the throttle other than fully open. A diaphragm divides a chamber which has supercharger outlet pressure on one side and inlet manifold pressure on the other side, thus responding to the pressure drop across the throttle valve. The bleed valve is fully closed at full throttle, when the pressure drop is least, and gradually opens as the throttle is closed and the pressure drop increases. The controller thus opens the waste gate as the throttle is closed, and reduces supercharger outlet pressure in accordance with the power selected.

(i) Any variation in power caused by slight changes in temperature or engine speed will result in a change in exhaust gas flow which will affect turbine speed. This may produce an unstable condition, known as 'bootstrapping', or hunting, of the manifold pressure as the control system attempts to reach a state of equilibrium. This condition is smoothed out by the Differential Pressure Controller, which reacts quickly to changes in the pressure drop across the throttle valve, and reduces the effects of small power changes.

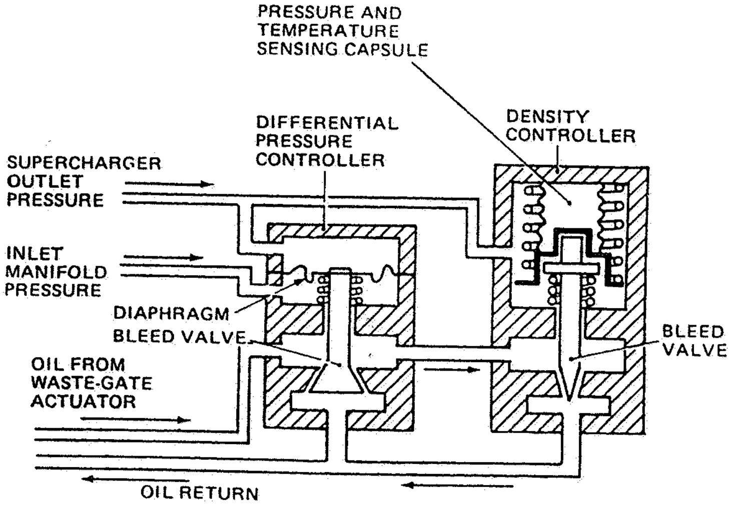


Figure 10 DUAL-UNIT CONTROL SYSTEM

5.3.4 On some Ground Boosted Turbochargers three separate controllers are used; two of these control the waste gate up to the turbocharger's critical altitude and the third controls the waste gate above critical altitude. This system is illustrated in Fig. 11.

(a) An Absolute Pressure Controller is used to control the supercharger outlet pressure below critical altitude. Operation of this unit is as described in paragraph 5.3.1.

(b) A Rate Controller is fitted to control the rate at which supercharger outlet pressure will increase, thus preventing overboosting the engine initially when the throttle is opened. Both sides of a diaphragm in the unit are connected to supercharger outlet pressure, but the opening to the lower chamber is fitted with a restrictor. If supercharger outlet pressure increases at too high a rate, air pressure will increase more quickly above the diaphragm than it does below it, because of the presence of the restrictor. The downward force on the diaphragm opens the bleed valve, bleeding oil pressure from the waste-gate actuator and opening the waste gate. Thus the rate of increase of supercharger outlet pressure is controlled, regardless of the rate of acceleration of the engine.

(c) As altitude is increased, the supercharger has to rotate faster and compress more air to maintain maximum power, and this results in an increase in the temperature of the air delivered to the engine. This rise in temperature could eventually reach a point where detonation would occur, and is controlled by placing limits on the maximum manifold pressure which can be used above a specified altitude (often 16,000 ft). Whilst it is possible to operate within these limitations, by retarding the throttle lever above the specified altitude, a Pressure Ratio Controller can be fitted to limit supercharger outlet pressure automatically. This controller contains a chamber which is open to atmospheric pressure, and at the specified altitude a capsule in the chamber will have expanded sufficiently to contact the stem of a bleed valve. As the aircraft climbs above this altitude the valve is opened by an increasing amount, and gradually increases the bleed from the waste-gate actuator to reduce supercharger outlet pressure at a set ratio to the atmospheric pressure (normally 2·2 : 1).

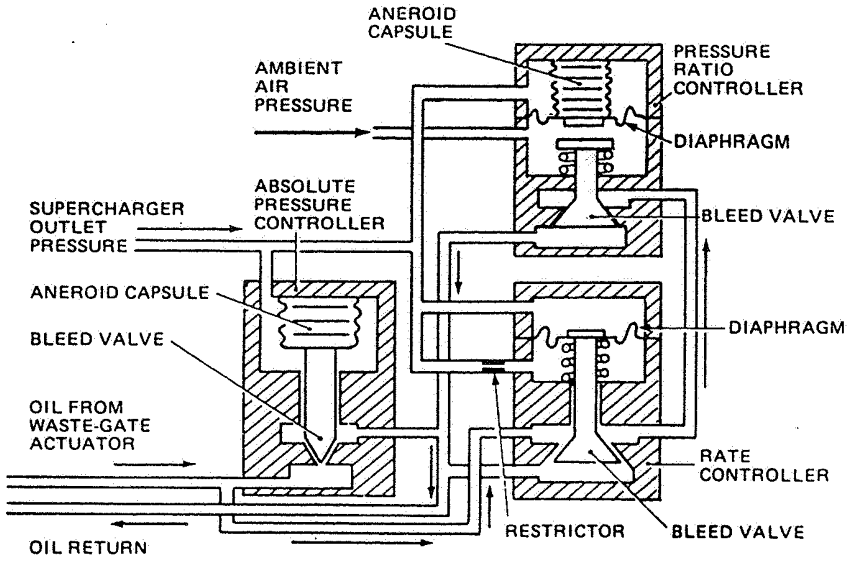


Figure 11 TRIPLE-UNIT CONTROL SYSTEM

5.3.5 On some aircraft a manifold pressure relief valve is fitted in the compressor discharge duct, to prevent overboosting of the engine during rapid acceleration, and in the event of failure of the controllers or sticking of the waste gate. The valve is usually a simple poppet type valve, which is adjusted to relieve the supercharger discharge pressure to atmosphere whenever the controlled maximum pressure is exceeded. A manifold pressure relief valve is usually fitted in conjunction with an Absolute Pressure Controller or a Variable Pressure Controller.

5.4 Turbocharger systems are very sensitive to changes in exhaust gas flow, and automatic controls take time to reach a state of equilibrium. It is important, therefore, that the throttle and propeller controls are operated slowly and that time is allowed for the control system to settle down.

6 INSPECTION AND MAINTENANCE Internally-driven superchargers, being contained within the engine casing and handling only clean air, generally require no attention between engine overhauls; however, the air intake filter must be cleaned at the times specified in the approved Maintenance Schedule, and the control linkage should be checked for security and operation, and lubricated as required. To ensure that only clean oil passes to the clutch units, some engines are also fitted with a device, known as a centrifuge, which is driven from the supercharger gear train and removes sludge from the oil by centrifugal force; this centrifuge should be removed for cleaning at the intervals specified in the approved Maintenance Schedule. If failure of the supercharger or its drive train should occur, the engine must be removed for repair or overhaul, but if system components such as an automatic manifold pressure control unit or an interconnected carburettor are changed, the linkage may have to be adjusted to obtain the required manifold pressure according to throttle position; details concerning the adjustment of particular components should be obtained from the relevant Maintenance Manual. An externally-driven supercharger, however, has a more severe operating environment; the turbine is subjected to the hot and corrosive exhaust gases, and the compressor and lubrication system may be subjected to heat from the turbine. Dirt, dust, carbon deposits, and ineffective lubrication, may all have adverse effects on turbocharger operation, and output may also be affected by incorrect engine oil pressure, or leaks in the intake or exhaust ducting. The inspection and maintenance requirements of a turbocharger are, therefore, more rigorous, and are outlined in paragraphs 6.1 to 6.6; these operations are typical of those required on the turbocharger installations on many light aircraft.

6.1 **Periodic Inspections.** At the periods specified in the approved Maintenance Schedule, the following inspections should be carried out.

(a) Remove and clean the intake air filter (Leaflet **EL/1-2**) and inspect for damage. If the element is damaged is must be renewed.

(b) Inspect the turbocharger mountings and the connections to the intake and exhaust ducting, for security and locking.

(c) Inspect all ducting in the intake and exhaust systems for gas leaks, and all oil and drain connections for oil leaks.

NOTE: Constant leakage from a drain line indicates a leaking seal, and the affected unit should be removed and checked in accordance with the relevant Overhaul Manual.

(d) Check the turbine insulation blanket (shield) for condition and security.

(e) Run the engine and check the turbocharger for vibration and unusual scraping or whining noises. Vibration could result from unbalanced accumulations of dirt or carbon on the rotors, whilst unusual noises could be indicative of bearing failure or incorrect running clearances. Any vibration or unusual noises would necessitate removal and overhaul of the turbocharger.

(f) Disconnect the inlet duct from the compressor and remove the compressor housing. Check the compressor impeller for nicks, cracks, bent or broken vanes, and signs of rubbing. Check for a build-up of dust and dirt and remove any deposits with a lint-free cloth moistened in solvent.

(g) With the compressor housing removed, check the axial play of the impeller shaft by pushing the shaft in both directions and rotating the impeller manually. Physical contact between the turbine wheel or impeller and their housings will require removal of the turbocharger, in order to adjust or replace the bearings.

(h) With the overboard exhaust duct removed, check the turbine wheel for excessive carbon build-up, nicks, cracks, and bent or broken vanes.

(j) Check the waste-gate/actuator linkage for security, free movement and correct operation, and clean as necessary.

(k) Remove the controllers to enable them to be checked for internal leakage in accordance with the appropriate Overhaul Manual.

(l) Remove the oil filter in the supply to the turbocharger and controllers, and clean in solvent.

(m) Check the engine breather pipe for obstruction.

(n) Before returning an aircraft to service after an inspection has been carried out, all items which have been removed must be refitted, all bolts and nuts must be tightened to the appropriate torque values, and locking must be renewed as appropriate. If parts have been disturbed, an engine run should be carried out to check the operation of the system.

6.2 **Bearing Checks.** When called for in the Maintenance Schedule, or when incorrect operating clearances are suspected, the radial and axial play in the rotor bearings should be measured. This may usually be carried out 'in situ', but on some installations, because of insufficient clearance in the engine bay, it may be necessary to remove the turbocharger. The intake and exhaust ducts should be disconnected from the turbocharger, and a dial test indicator (DTI) should be used to measure the bearing clearances; a mounting fixture for the DTI will usually be required.

6.2.1 To measure the radial clearance in the bearings the centre housing drain pipe should be removed and the DTI should be mounted so that its spindle (fitted with an extension rod of suitable length) protrudes through the oil drain hole and rests on the centre of the rotor shaft. By moving the shaft towards and away from the DTI in the direction of its travel, and applying equal pressure at both ends of the shaft, the total radial clearance will be indicated and should be within the limits specified by the manufacturer.

6.2.2 To measure axial clearance in the bearings the DTI should be mounted so that the tip of its spindle rests on the end of the rotor shaft, with its direction of travel along the axis of the rotor shaft. By moving the shaft axially in both directions the total axial clearance will be indicated and should be within the limits specified by the manufacturer.

6.2.3 If bearing clearances are found to be excessive, the turbocharger should be removed for overhaul.

6.3 **Rotor Shaft Binding.** If running clearances appear to be satisfactory, but sluggish or low-powered engine operation is apparent and difficulty is experienced in rotating the turbocharger rotor by hand, the cause may be deposits in the turbine shaft seal ring area. These deposits are caused by water vapour accumulations, and occur during the early life of a turbine, before combustion products have formed a protective coating on seal surfaces. In order to remove these rust deposits, the exhaust outlet duct from the turbine should be removed, and an approved penetrating oil should be sprayed behind the turbine wheel. After leaving this to soak for at least ten minutes it should be possible to turn the rotor by hand, but light taps with a soft mallet on the end of the rotor shaft may be necessary in some cases. After refitting the exhaust duct an engine power check should be carried out to confirm turbocharger output.

6.3.1 A further cause of rotor shaft binding may be the accumulation of carbon deposits on the turbine wheel and in the turbine housing. These deposits build up during the life of a turbocharger and cannot easily be removed; the turbocharger should be removed for cleaning and overhaul.

6.4 **Exhaust Leaks.** Whilst exhaust gas leakage in a normally-aspirated engine may have serious safety aspects, the leakage of exhaust gas from a turbocharged engine is much more serious, because of the pressure differential which exists between the inside and outside of the exhaust pipes, particularly at high altitude. The turbine itself is usually shielded to contain any leaking exhaust gases, but the ducts from the cylinders to the turbine contain a number of separate pipes, gaskets and expansion joints, leakage from which could produce a flame in the engine bay and have serious consequences; in addition, leakage will reduce the gas pressure on the turbine and thus reduce its maximum output. Regular inspections of the exhaust system are, therefore, very important to safety.

6.4.1 Exhaust gas leakage is usually indicated by sooty streaks on the exhaust piping and joints, or by signs of overheating of adjacent parts and shields. Cracks are most often found at welds, changes of section or clamping points, and an inspection should include a check for broken or missing parts such as attachment clips, and the tightness of any clamping bolts. Exhaust pipes should also be checked for evidence of physical damage, since uneven internal surfaces can produce hot spots, and these could lead to scaling and cracks.

6.5 Removal and Replacement of Components

6.5.1 **Turbocharger.** A turbocharger may be mounted on the engine, on the engine bulkhead, or on a component in the exhaust system, and is connected to the intake and exhaust systems and to the engine lubrication system. Removal is usually straightforward and involves removal of the turbine heat shielding, and disconnection of the various ducts, oil pipes, stays and attachment bolts as necessary; however, precautions must be taken to prevent the ingress of debris into the oil system and into the intake and exhaust ducts where it could, if undiscovered, be subsequently drawn into the turbocharger or engine and cause damage. Ducts and pipes should, therefore, be blanked immediately they are disconnected, and the blanks should remain in position until the item is re-connected. A new or replacement unit should be examined to ensure that it is the correct type, that it is undamaged, and that the rotor rotates without binding or scraping. When installing the turbocharger the blanks should be removed and the intake and exhaust ducts should be inspected for debris immediately before re-connection. New washers, O-rings or gaskets should be used where appropriate, and high temperature anti-seize compound should be used on all threads which are heated by the exhaust gases. Proper fit of ducts and pipes should be checked, and any special dimensional requirements stipulated in the approved Maintenance Manual for couplings and expansion joints, should be met. Fasteners should be torque loaded to the required values and properly locked, and when installation is complete the engine should be run to check turbocharger operation. An inspection for gas and oil leaks should be carried out after the engine run.

6.5.2 **Waste gate and Actuator.** The waste gate and actuator are usually adjusted together during assembly, and are considered as a single unit. When either component becomes unserviceable, both should be changed, and adjustment should not be attempted without a suitable test rig. The unit is usually bolted onto an exhaust manifold flange and may usually be removed, complete with exhaust discharge duct, after disconnecting and blanking the oil pipes and drain. A new gasket should be used when refitting the unit, the threads of the attachment bolts should be lubricated with high temperature anti-seize compound, and fasteners should be torque loaded and locked as appropriate. A ground run should be carried out to check waste gate operation.

6.5.3 **Controllers.** Removal and installation of most controllers is straightforward, and usually entails only removal or refitting of the oil and air pressure sensing pipes and the mounting bolts; the precautions outlined in paragraph 6.5.1 regarding the blanking of open pipes and the tightening and locking of fasteners should be taken. The Absolute Pressure Controller and the Variable Pressure Controller, however, may require adjustment after installation. The former may be adjusted to set the limiting manifold pressure, but the latter, being connected to the throttle linkage, must be adjusted to control manifold pressure over its whole range of operation. Two adjustments are provided on the Variable Pressure Controller; one is the initial (low) setting of the valve when it contacts the cam dwell (Fig. 9) and the other is the position of the cam to obtain maximum manifold pressure (high setting). The exact method of adjustment varies between aircraft and the appropriate procedure should be obtained from the relevant Maintenance Manual. Operation of the controllers should be confirmed by engine runs.

6.6 **Testing Turbocharger Operation.** Whenever major components in the turbocharger system are changed or incorrect operation is suspected, the engine should be ground tested, and if necessary air tested, to confirm proper operation and to enable any faults to be correctly diagnosed.

6.6.1 The ground test normally consists of ensuring that take-off rev/min and manifold pressure can be obtained at full throttle, but depending on the types of controller fitted, additional checks may be required. After starting and warming-up the engine to normal operating temperatures and pressures the following checks should be carried out:—

(a) With the propeller in fully-fine pitch, slowly open the throttle control and check that take-off rev/min and manifold pressure are obtained. The manifold pressure should be watched carefully as engine power increases, to ensure that the limiting pressure is not exceeded. Excessive pressure could result from failure of the manifold pressure relief valve to open, or from failure of the rate controller to control acceleration. Failure to obtain maximum power may be caused by induction or exhaust leaks, low oil pressure in the waste-gate actuator, or a sticking waste gate.

(b) If a Variable Pressure Controller is fitted, a gauge which registers supercharger discharge pressure should be connected to the test ports provided on the controller, before starting the engine; this gauge is used to check the low setting of the controller. Two different combinations of rev/min and manifold pressure are prescribed for this check in the approved Maintenance Manual, and these should be set-up during the ground run. The supercharger discharge pressures recorded at these settings should be noted, and should be within the limits prescribed by the manufacturer.

6.6.2 The flight test is designed to check all aspects of turbocharger operation and control. The full test is detailed in the relevant Maintenance Manual, and varies according to installation and types of controllers fitted.

(a) The turbocharger should maintain maximum power from take-off to critical altitude. An early fall-off in power may be caused by induction or exhaust system leaks, 'coking' of the turbine, or incorrect setting of the manifold pressure relief valve. Incorrect manifold pressure, either high or low, may result from incorrect operation of the Density Controller, Absolute Pressure Controller or Variable Pressure Controller.

(b) 'Bootstrapping' is checked by flying at a specified altitude then reducing engine speed until manifold pressure starts to fall, indicating that the waste gate is closed. The manifold pressure, engine rev/min and outside air temperature at this point should be noted, and a slight increase in rev/min should not produce bootstrapping. The power settings and outside air temperatures at which bootstrapping may occur, are stated in the relevant Maintenance Manual.

(c) Operation of the manifold pressure relief valve or the Rate Controller is checked by opening the throttle rapidly during level flight at a specified altitude. The increase in manifold pressure produced by this acceleration should be within the limits specified in the Maintenance Manual.

(d) The Differential Pressure Controller is checked by climbing above the altitude at which maximum manifold pressure is permitted. The fall in manifold pressure with increased altitude should be in accordance with the specified limits.

EL/1-4

Issue 1.

18*th May*, 1977.

AIRCRAFT

ENGINES

PISTON ENGINE INSTALLATIONS

1 INTRODUCTION This Leaflet deals with the systems and components required for the installation of a basic piston engine into an aircraft fuselage or nacelle. It also includes the maintenance aspects not previously covered in Leaflets **EL/1-2** and **EL/1-3.** The topics discussed are as follows:—

Para.	Topic	Para.	Topic
2	Engine Mountings	8	Instrumentation
3	Controls	9	Starters
4	Air Intake System	10	Oil Coolers
5	Exhaust System	11	Removal and Installation
6	Cooling	12	Routine Maintenance
7	Access	13	Non-Routine Inspections

2 ENGINE MOUNTINGS Radial engines, and most horizontally-opposed engines, are generally mounted in a tubular framework such as is illustrated in Figure 1. This welded framework is rigidly attached through the fireproof bulkhead to the fuselage or nacelle structure, and connected through a vertical mounting ring and flexible mountings to the engine. In some cases the fuselage or nacelle monocoque structure is continued forward and connects to the mounting ring to which the engine is attached. In-line engines, and some horizontally-opposed engines, may be mounted in bearers which provide four attachment points in a substantially horizontal plane. The bearers are often welded tubular cantilever structures running down each side of the engine and attached through the bulkhead at the rear, but may also be an extension of the lower fuselage or nacelle structure; the cantilever method facilitates the installation and removal of the engine, particularly if it is fitted with a turbocharger or other large accessories at the rear.

2.1 **Flexible Mountings.** The engine is usually attached to the mounting ring, bearers, or airframe structure, by means of flexible vibration isolators; these are specially designed for each engine and mounting position, and transfer propeller thrust to the airframe but limit the transfer of propeller or engine vibrations. The load is transmitted through rubber in shear or compression, and a typical mounting for a horizontally-opposed engine is illustrated in Figure 2.

3 CONTROLS Linkage between the cabin controls and the engine provides for operation of the throttle, mixture control, propeller governor, and oil or air temperature-control flaps or gills. On light aircraft this linkage is usually mechanical, but in some cases the temperature-control flaps are electrically actuated and may be automatically controlled.

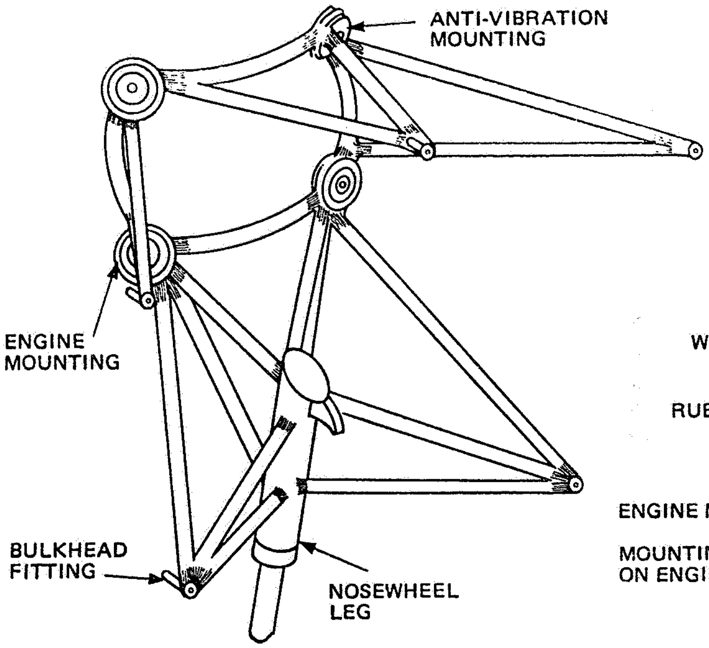


Figure 1 ENGINE MOUNTING FRAME

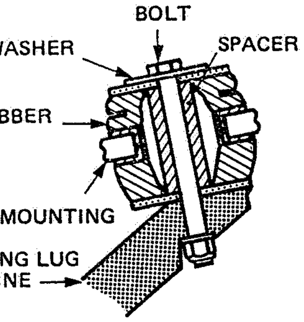


Figure 2 ANTI-VIBRATION MOUNTING

3.1 Mechanical connection between the cabin controls and the engine can be by various methods, such as rods and levers, pulleys and cables, cable contained within rigid or flexible conduit, or, in the case of controls which are only used infrequently (such as a slow-running cut-out), by means of a single-acting cable and return spring.

3.1.1 The rod and cable ends terminate in a fork-end or eye-end fitting, for connection to the associated lever or control, and these afford the means of adjusting the linkage so that movement of the cabin control lever corresponds to engine control movement. When pulleys and cables are used the cable ends are joined by turnbuckles, which are used to adjust cable tension. Initial setting of the linkage is usually by placing the cabin and engine controls in the required positions, then adjusting the length of the connecting linkage to suit these positions; the inspection holes in the end fittings should be used to check that sufficient thread is engaged to provide a safe connection. In some cases rigging pins or graduated quadrants may be used to fix the positions of the levers or pulleys in the system, before connecting the rods and cables. Positive locking such as split pins or locking wire are used on all parts which, if not properly secured, could loosen and lead to disconnection of the linkage.

3.2 Electrically-powered actuators usually take the form of a screw jack, which is driven through a reduction gear by an electric motor. The direction of rotation of the motor depends on the current direction, and this is controlled by a switch. When automatic operation is provided, the manual switch is by-passed and current is directed to a temperature switch, which then controls operation of the actuator.

4 AIR INTAKE SYSTEM The air intake system comprises a smooth-walled duct from the outer surface of the engine cowling to the carburettor or injector, and generally includes an air filter and alternative air door (see Leaflet EL/1-2); the duct may be separate from the cowling or, particularly in the case of radial engines, an integral part of the upper or lower portions of the cowling. The duct entrance is usually located at the front of the engine cowling where the airstream provides some ram effect, and the duct may pass over or under the engine, depending on whether an updraught or downdraught carburettor is fitted. On light aircraft the air filter is usually located at the front of the duct and, in normal circumstances, filters all incoming air; operation of the alternative air door may be either manual or automatic. Joints and mating surfaces in the air intake are sealed to prevent air leakage, and often include a flexible bellows type of joint at the carburettor to accommodate engine flexing and vibration.

5 EXHAUST SYSTEM An exhaust system is designed to carry the exhaust gases from the engine cylinders and discharge them safely outside the fuselage or nacelle skin. In addition, the exhaust pipes may be used as a source of warm air for the carburettor during icing conditions, and to provide cabin heating. A typical exhaust system for a horizontally-opposed engine is illustrated in Figure 3.

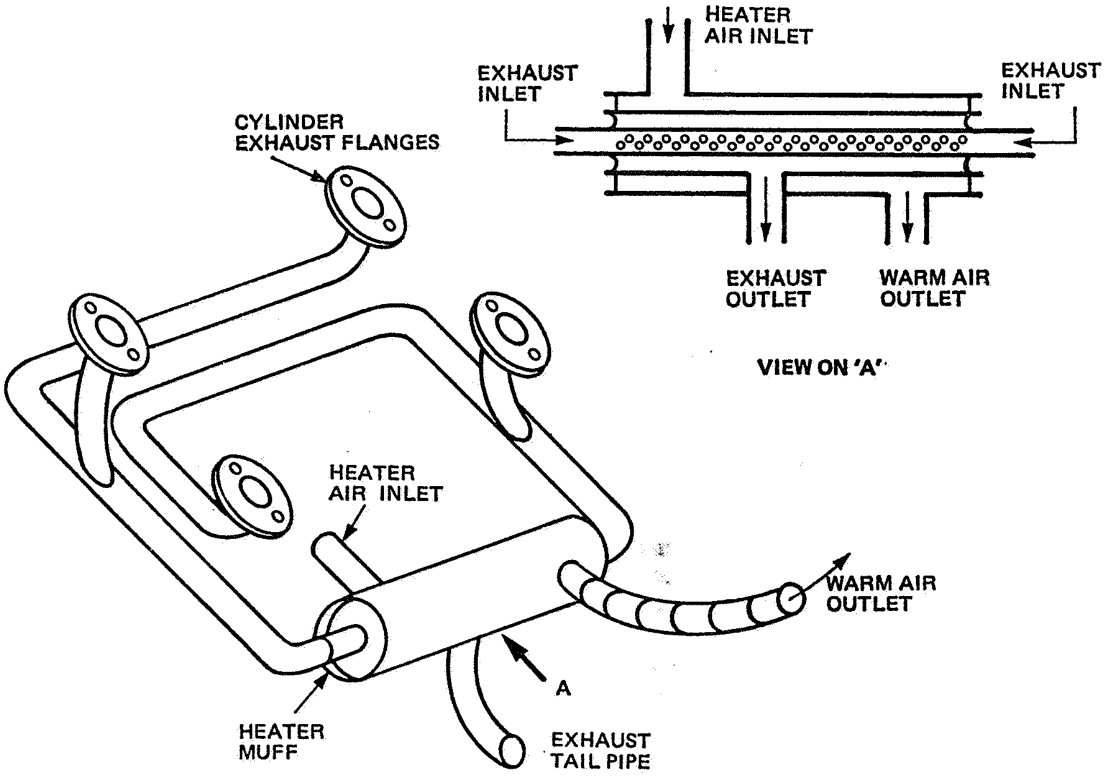


Figure 3 TYPICAL EXHAUST SYSTEM

5.1 On a horizontally-opposed engine, individual pipes from the cylinders (stack pipes) are fed into a muffler (silencer), and a tail pipe leads the exhaust gases to atmosphere. The muffler is generally surrounded by a detachable jacket, which is fed by ram air from an intake at the front of the engine, and exhausts into the cabin heating system. Warm air for the carburettor may be drawn from a scoop adjacent to the muffler.

5.2 On radial engines the individual pipes from each exhaust port are fed into an exhaust collector ring, which is a large diameter pipe surrounding the engine, and usually contained within the engine cowling. One or more tail pipes from the collector ring lead the exhaust gases to atmosphere, and often incorporate a heater muff to supply warm air to the cabin.

5.3 On some installations the exit for cooling air from the engine bay is through a duct known as an augmentor, and by discharging exhaust gases into this duct, a better cooling air flow is induced through the engine compartment.

5.4 An exhaust system consists of a number of components, most of which are made from sheet steel parts welded together, and connected by clamps or slip joints to their adjacent parts. With normally-aspirated or internally-supercharged engines the exhaust system is usually connected rigidly to the engine, but when a separately mounted turbocharger is fitted, flexible couplings are also used in the exhaust ducting. Because of the temperature and corrosive nature of the exhaust gases (maximum temperatures and pressures being experienced on turbocharged engines), many parts of the system have a limited life and require regular inspection for leakage, cracks, and damaged or broken parts, in order to ensure that the exhaust gases are contained within the exhaust system (see also Leaflet **EL/1-3**). Inspection is particularly important on those installations which use a cabin heater muff, since any gas leakage into the heater system could introduce carbon monoxide into the cabin, with fatal effects on passengers and crew; a similar effect could result from poor sealing of the engine bulkhead or the introduction of exhaust gas through unsealed seams or openings in the aircraft skin.

6 COOLING The cowlings on an air-cooled engine are designed to provide a streamlined shape round the engine and so reduce drag, and to provide adequate cooling by forcing air to flow between the cylinder cooling fins.

6.1 On a horizontally-opposed engine, cooling-air is admitted through an aperture on each side of the propeller spinner and passes to the top of the engine and cylinders. The space between the top cowling and the cylinders is sealed at the sides and rear by baffles attached to the engine, and air entering through the front of the cowling is compressed in this space. This increase in pressure forces air past the cylinders, where inter-cylinder baffles direct it between the cylinder cooling fins to remove excess heat, and discharge it into the lower part of the engine bay (Figure 4). Apertures at the rear of the pressurized compartment direct air through the oil cooler, into the alternative hot-air intake, and through blast tubes to cool specific components such as the magnetos, generator and sparking plugs. Cooling air is finally exhausted at the rear of the engine cowling, the size of the exit controlling the flow of air over the cylinders, and thus the engine temperature. On some light aircraft the exit is of fixed size and is designed to provide adequate cooling during all normal flight operations, but many aircraft are fitted with flaps which can control the amount of air released from the engine compartment, thus enabling engine temperatures to be controlled. These cooling flaps may be mechanically operated by linkage to a lever in the cabin, but are often operated by electric actuators (paragraph 3.2).

6.2 A radial engine is usually contained within a cylindrical cowling which directs air into the face of the engine while maintaining a streamlined flow external to the engine. Baffles attached to the cylinders ensure that the air passes between the cylinder cooling fins and the air is finally exhausted through the gap between the cowling and the nacelle structure. The rear edge of the cowling is fitted with movable gills, which open to increase the flow of cooling air and close to reduce it; they are usually electrically operated.

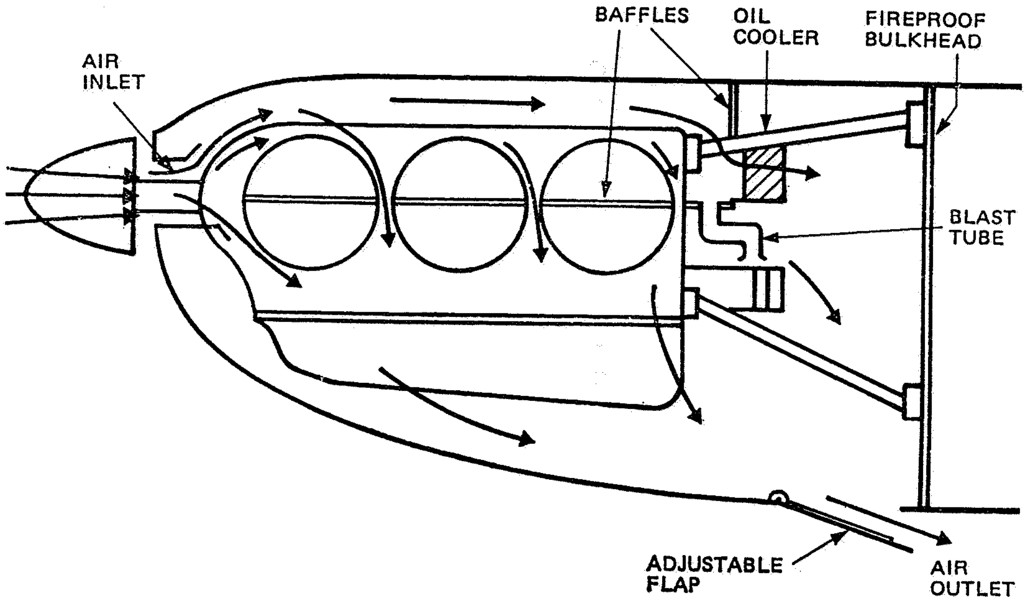


Figure 4 TYPICAL COOLING SYSTEM

6.3 The cooling arrangements for a particular engine are designed to ensure satisfactory cooling during flight, when the forward speed of the aircraft produces an adequate flow of cooling air. When an engine is being run on the ground the only airflow to the engine is produced by the propeller, and in most cases this is not sufficient to provide adequate cooling of all parts of the engine. Unless otherwise stated in the relevant Maintenance Manual, therefore, ground running, particularly at high power, must be kept to a minimum, and careful watch must be kept on both cylinder and oil temperatures.

6.4 Cracked or broken cylinder-cooling fins are generally repaired by cutting away the damage to form a smooth contour, but the size of the fin area which can be removed is limited, since it reduces the cooling area available. Care should be taken not to exceed the limitations imposed by the manufacturer, concerning the number, position and area of any repairs to cylinder cooling fins.

7 **ACCESS** In order to provide a means of carrying out the various servicing tasks required on an engine it is necessary to provide access openings in the cowling, the type of opening usually depending on the frequency at which access is required.

7.1 On a horizontally-opposed engine access to the oil filler cap, which is required daily or before flight, is often obtained by means of a hinged side panel, which is secured by quick-release fasteners, but may be by means of a small similarly-secured panel in the cowling, located immediately adjacent to the oil filler cap. Access to less frequently serviced items is usually obtained by removing large panels, which may be attached by threaded or quick-release fasteners to the cowling structure.

7.2 Radial engines may also have access panels attached by quick-release fasteners or screws at the rear of the engine for access to the ancillaries, but the main cylinder cowlings are generally in two or three parts, which are positioned by cylinder head mountings and secured together by quick-release fasteners. On some large radial engines a 'clam-shell' type of cowling is used which, when opened, provides access to the complete engine.

7.3 The maintenance of a smooth airflow over the engine is most important (see also Leaflet **AL/7-11**), and great care is necessary when removing or refitting access panels. Bent corners or other damage to these panels could cause excessive drag or prevent cooling of the engine. Quick-release fasteners should also be treated with care, particularly on panels which are frequently removed; fasteners which are loose or poorly positioned should be adjusted or renewed as appropriate.

8 INSTRUMENTATION Instruments located on the instrument panel in the cabin provide constant indications of certain parameters of engine operation. Numerical marking on the instruments is often combined with colour to indicate minimum, maximum or normal readings, but on some light aircraft the numerical markings are omitted. The parameters which may be covered are engine speed, oil pressure, oil temperature, cylinder head temperature, manifold pressure, fuel flow, fuel pressure, air intake temperature and exhaust gas temperature. Operation and maintenance of engine instruments are dealt with fully in Leaflet **AL/10-3.**

9 STARTERS The normal method of starting a piston engine is by means of a direct-cranking electric starter motor, which may be engaged with the engine either manually or automatically. The starters on some horizontally-opposed engines turn the crankshaft by engaging the starter pinion gear with a large-diameter starter gear ring attached to the forward end of the crankshaft, whilst others are connected through a clutch arrangement to gearing in the rear cover. On radial engines the starter is usually attached to the rear cover, and engages the crankshaft by means of a starter jaw similar to that described in Leaflet **EL/3-12** for the electric starters used on turbine engines.

9.1 Figure 5 (a) illustrates a typical manually-engaged starter motor. A gear on the end of the armature shaft meshes with a larger gear, which is attached to an overrunning clutch and drive pinion. The drive pinion assembly is free to move axially into engagement with the starter gear ring, and is spring-loaded to the disengaged position. The starter control is attached to the engaging lever, and when it is pulled the engaging lever pushes the drive pinion into engagement with the starter gear ring. At the end of its travel the engaging lever operates the starter switch to supply electrical power to the motor. When the engine starts, the overrunning clutch disengages the drive pinion from the motor, and when the starter control is released the drive pinion assembly is disengaged from the starter gear ring by spring pressure. The starter-switch operating stud on the engaging arm must be adjusted so that the drive pinion is fully engaged before electrical power is supplied to the motor.

9.2 Figure 5 (b) illustrates a method of engagement which is similar to that described in paragraph 9.1, but in this case the engaging arm is operated by a solenoid. The overrunning clutch and drive pinion slide on helical splines on the armature shaft and are moved into engagement when electrical power is supplied to the solenoid. Final movement of the solenoid makes the connection to supply electrical power to the motor, and when the starter switch is released the spring surrounding the solenoid extends to disengage the drive pinion.

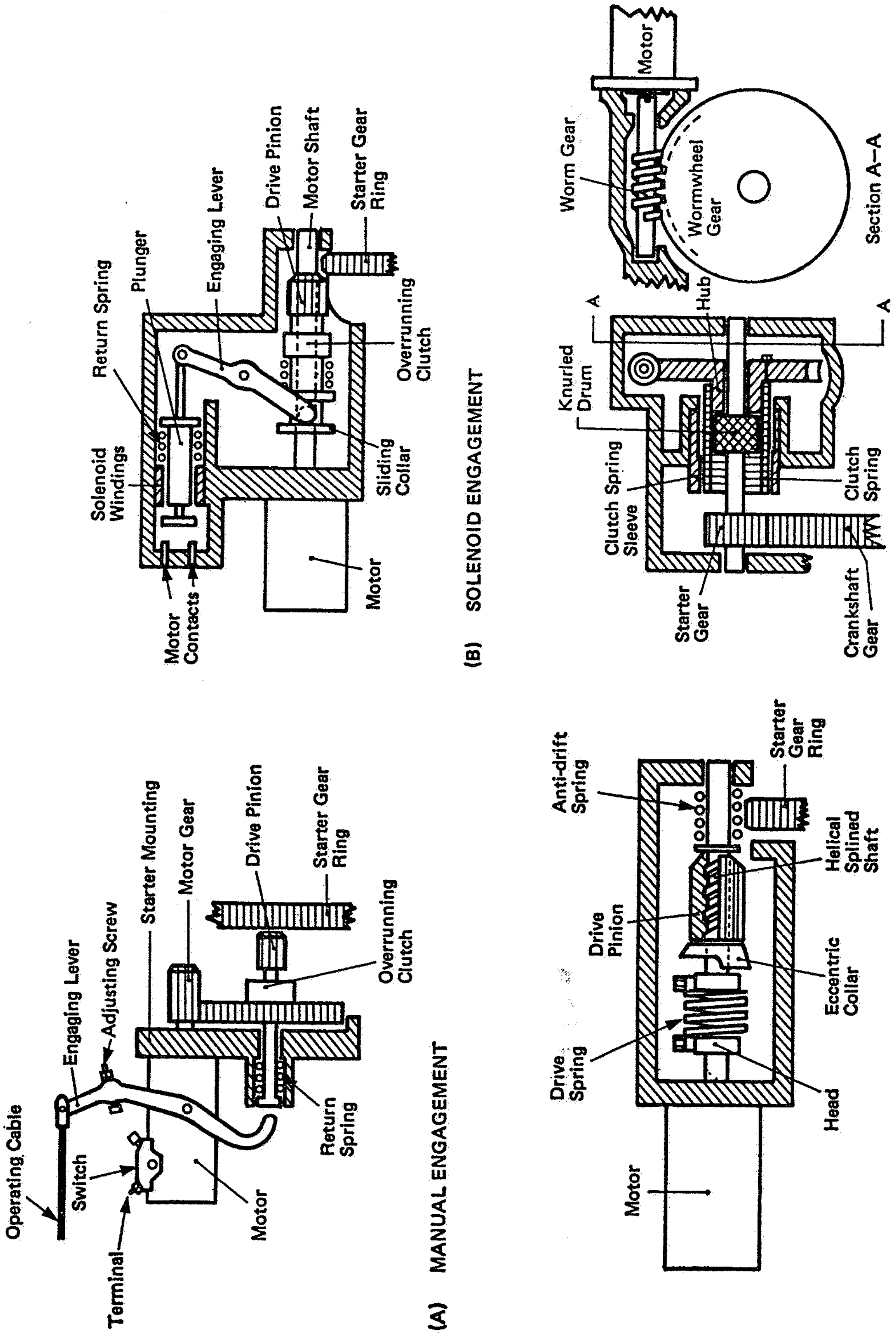


Figure 5 METHODS OF STARTER ENGAGEMENT

9.3 Figure 5 (c) illustrates a method of automatic engagement of the starter known as a Bendix drive. The head is keyed to the armature shaft and the drive spring transmits torque to the drive shaft and pinion assembly. The pinion runs on helical splines on the drive shaft, and is normally held out of engagement with the starter gear ring by an anti-drift spring. When electrical power is applied to the motor the armature turns, and because of its inertia the pinion moves axially along the drive shaft into engagement with the starter gear ring, and turns the engine. When the engine starts, the pinion rotates faster than the starter drive shaft and is forced back along the helical splines out of engagement with the starter gear ring. When electrical power to the motor is cut off, the anti-drift spring holds the pinion in the disengaged position.

9.4 Figure 5 (d) illustrates the use of a worm gear and clutch to transmit starter-motor torque to the crankshaft. A tang on the end of the armature shaft engages a slot in the worm gear shaft, which rotates the wormwheel. As the wormwheel turns, a clutch spring mounted on its hub is tightened to grip a knurled drum on the starter gear shaft and transmits torque to a gear on the end of the crankshaft. When the engine starts and the starter gear shaft rotates faster than the wormwheel drum, the clutch spring returns to its normal position and disengages the knurled drum from the wormwheel.

10 OIL COOLERS Except for some small engines which have wet sump systems and others which have the oil tank located in the slipstream, most engines are fitted with a cooler to remove excess heat from the engine lubricating oil. In an oil cooler the oil is passed through a block of finned tubes, which present a large surface area to the cooling airflow. With horizontally-opposed engines the cooler is usually located at the front or the rear of the engine, and is cooled by the airstream. Front-mounted coolers are cooled directly by air entering the engine cowling, whilst rear-mounted coolers are cooled by air passing through an aperture in the rear cylinder cooling baffle; in some cases the airflow may be reduced by fitting a blanking plate to the cooler, so as to prevent over-cooling during cold weather.

10.1 Most oil coolers are fitted with a thermostatically-controlled by-pass valve, which regulates oil temperature within specified limits. When the oil is cold the valve blocks flow through the oil cooler and all oil flows directly to the engine. When the oil reaches a temperature high enough to require cooling, the valve begins to open the passage through the cooler and close the by-pass, thus reducing the temperature of the oil delivered to the engine.

11 ENGINE REMOVAL AND INSTALLATION There are many reasons why an engine may have to be removed from an aircraft and replaced by a new or overhauled engine. These may include expiry of the prescribed life of the engine, failure of bearings or other internal components, shock loading of the propeller shaft, and excessive vibration not attributable to propeller unbalance. The procedures which should normally be followed when removing and installing an engine are outlined in paragraph 11.1 to 11.5, but particular installations may demand additional operations and reference should always be made to the relevant Maintenance Manual.

11.1 The method adopted when changing an engine depends on the type of engine and the requirements of the particular operator. With most light aircraft the bare engine is changed, transferring accessories from the old engine to the replacement as appropriate, but some commercial operators prefer to hold one or more 'quick engine change assemblies' (QECA) in stock, to minimize the time the aircraft is out of service. A QECA generally consists of an engine complete with accessories, baffles, cowlings and mounting structure, which has the minimum number of attachments to the aircraft and which can be removed and installed in a few hours. The use of a QECA is generally confined to large radial engines, and the aircraft structure must be specially designed to be compatible with them. Paragraphs 11.2 to 11.5 apply mainly to changing a bare engine but the precautions and tests may also be applicable to a QECA.

11.2 **Removal of Engine from Airframe.** Before commencing to remove an engine from an aircraft, all electrical supplies to the engine should be disconnected (preferably by removing the batteries) and the fuel supply to the engine should be turned off. A crane or lifting tackle, and an engine sling of adequate capacity and of the correct design should be available for lifting the engine, and should be inspected for serviceability before use. Drip trays should be placed under the engine, and suitable receptacles made available to catch draining fluids. The main undercarriage wheels should be chocked front and rear to prevent the aircraft from moving, and, on aircraft with a nosewheel landing gear, it may be necessary to support the rear fuselage at the rear jacking or trestling point, to prevent the aircraft from tipping on its tail when the engine is removed. Aircraft with a tailwheel landing gear should be placed in the rigging position. The propeller should then be removed and the propeller shaft fitted with a blanking sleeve; if the propeller is to be fitted on the replacement engine it should be inspected for damage and corrosion, placed in a suitable rack or stand, and protected from dust or other foreign matter, but if it is to be sent for repair or overhaul it should be prepared for storage (Leaflet **PL/1-1**). In order to remove the engine, the operations listed in paragraphs 11.2.1 to 11.2.8 should normally be carried out.

11.2.1 The engine cowlings should be removed to gain access to the engine disconnection points, and should be inspected for cracks, dents and other damage, and the security and operation of the fasteners.

11.2.2 All lubricating oil should be drained from the engine, oil cooler and oil tank, and the drain plugs refitted.

11.2.3 All engine controls should be disconnected at the engine end, the attaching parts refitted to prevent their being lost, and the control runs secured to adjacent structure to prevent damage when the engine is changed.

11.2.4 Disconnection of electrical cables is usually made at the engine components concerned, such as the starter, generator, or magneto, and the end connectors should be covered with moistureproof tape to protect them from dirt and moisture; cable ends should be identified to assist reconnection and loose cables should be temporarily secured to adjacent structure to protect them from damage. On some engines the electrical cables are disconnected at plug and socket assemblies or junction boxes on the fireproof bulkhead, and are removed with the engine; these connections should be protected by blanking until the replacement engine is installed.

NOTE: The magneto lead earths the magneto primary circuit through the associated cabin switch. Without this lead the magneto is live, and as a safety precaution the sparking plug leads should be removed before the earth lead is disconnected.

11.2.5 Various types of pipe connections are used on the system pipes running between the engine and the airframe. Flexible pipes with union nuts are generally used to connect the engine component concerned to a fitting on the fireproof bulkhead, so as to take up engine vibration; in some cases self-sealing bulkhead couplings (Leaflet **BL/6-15**) are used, to prevent the system from losing fluid when the disconnection is made, and to minimize the need for bleeding when the system is reconnected. In other systems hose connections are used to join pipelines which are not subject to high internal pressures. Pipes should be disconnected and, where applicable, drained of fluid, then blanked to prevent the entrance of extraneous matter, and temporarily tied out of the way of the engine.

11.2.6 Other disconnection points will depend on the engine installation, and may include intake ducts and exhaust pipes, heater pipes, priming pipes, drain pipes and tachometer flexible cables. In addition, some engines may be fitted with temperature bulbs and pressure transmitters in the oil system, which are connected by capillary tubing to the associated cabin instruments. When removing these connections from the engine, care should be taken to bend or twist the capillaries as little as possible, and they should only be moved sufficiently to prevent fouling the engine when it is removed. In some cases it may also be necessary to remove the carburettor in order to clear the engine mounting; in these cases the engine intake manifold should be blanked as soon as the carburettor is removed.

11.2.7 When all controls, pipes and cables between the engine and airframe have been disconnected and secured clear of the engine, the engine sling should be attached to the engine lifting points, and the crane should be positioned and attached to the sling. The engine should then be lifted just sufficiently to remove its weight from the bearers, and the bearer bolts should be removed after checking that they are free to rotate and are not taking any strain. Depending on the type of mounting, the engine should be lifted or moved slowly away from the mounting, and guided clear of the airframe structure. Once clear, the engine should be lowered into an engine stand and prepared for storage (Leaflet **EL/3-14**).

11.2.8 If the engine is being changed because of internal failure, the lubricating oil may have become contaminated. Accessories lubricated by engine oil, such as a variable-pitch propeller and propeller governor, and the oil cooler, should also be sent for overhaul. The oil tank and pipelines remaining in the airframe, should be removed and thoroughly flushed before being connected to the replacement engine.

11.2.9 With the engine removed from the engine bay, the mounting frame and other fixed parts are readily accessible for inspection and should be checked for corrosion, scratches, dents and other damage, which should be made good before the replacement engine is installed. Similarly, the opportunity should be taken to visually inspect all pipes, cables, controls, fire detection and extinguishing equipment, and other components in the engine bay, for security, corrosion and damage, and to repair or renew parts as necessary.

NOTE: If one anti-vibration mounting has been found unserviceable, it is advisable to consider changing the whole set, otherwise the effectiveness of vibration damping may be reduced.

11.3 **Preparation of Replacement Engine.** An engine required for installation in an aircraft should be removed from its packing case, mounted in an engine stand, and built up to the standard required for the particular installation.

11.3.1 External corrosion-preventative compound should be washed off as necessary, at the same time ensuring that any breather orifices in such accessories as magnetos and injectors remain unobstructed. The engine should be inspected for signs of corrosion and damage, which may have occurred during storage or transit. The dehydrator plugs should be removed from the cylinders, and a careful inspection for corrosion should be made in any cylinders in which these plugs indicate, by their colour, the presence of moisture. Internal inhibiting oil should be drained out through the sparking plug holes, the crankshaft being turned several revolutions while the oil is draining. Any excess oil in the cylinders (particularly the lower cylinders of a radial engine) should be removed with a syringe. Unless suitable for engine running, the inhibiting oil should be drained from the crankcase and sump by removing the sump drain plug, and the oil filters should be removed and cleaned in solvent. When draining is completed the dehydrator plugs or dummy sparking plugs should be temporarily replaced to prevent the ingress of foreign matter, and the sump drain plug and filters should be refitted and locked as appropriate.

11.3.2 Blanking plates should be removed from the mounting faces provided for any accessories which have to be fitted, and the faces should be inspected for corrosion and damage. In some cases engine accessories (such as the carburettor) may have been removed from the engine and packed separately in the engine packing case; these should be inspected for corrosion and damage, and fitted on the engine, or, if this is not possible, retained in their cartons until the engine has been installed in the airframe. In other cases (except as noted in paragraph 11.2.8 and provided sufficient hours remain), accessories may have to be transferred from the old engine; these should be inspected for damage and excessive wear, and, where appropriate, the operating times should be recorded in the engine log book. When installing accessories, new gaskets or seals should be used where appropriate, and the attaching parts should be tightened and locked as specified in the relevant Maintenance Manual. Care should be taken to remove any silica gel bags which have been used during storage, particularly those which may have been placed in the air intake passage.

11.4 **Installation of Engine.** When the engine bay has been cleaned and inspected, and any necessary repairs or replacements have been carried out, the engine should be attached to the sling and crane, and carefully lifted out of the engine stand and moved into its mounting position in the airframe. The engine must be steadied whilst being moved, and must be guided past any obstructions, to mate with the bearers and other connections such as the exhaust tail pipe. The correct anti-vibration mountings should be assembled at each position on the mounting frame, and the engine should be accurately aligned with the mountings, so that the bearer bolts slide in easily; the bolts should then be tightened in the sequence and to the torque values specified by the manufacturer, and locked in the appropriate manner. The engine sling may then be removed and, where appropriate, bonding strips fitted across the mountings.

11.4.1 The sequence for connecting the pipes, ducts, controls and cables to the engine may not be important, but the quickest and most satisfactory sequence will normally be given in the relevant Maintenance Manual. The general precautions which should be taken when making these connections are outlined in paragraphs 11.4.2 to 11.4.8.

11.4.2 Carburettor controls should be connected and adjusted as outlined in Leaflet **EL/1-2**, and the propeller control should be connected as outlined in Leaflet **PL/1-1**; they should be checked, locked and lubricated as appropriate. Other controls, such as those for the hot-air intake and cabin heater, should be connected so that the flap or valve position corresponds to the position of the operating lever in the cabin, closes and opens fully, and operates smoothly.

11.4.3 Electrical connections should be clean before assembly, and must be effectively locked, and the associated cable or conduit should have sufficient slack to allow for engine vibration. Sparking plugs should be installed, with new washers, and the plug leads connected. The magneto earth leads should be connected after ensuring that the ignition switches are in the off position.

11.4.4 The exhaust system should be connected using the correct type of nuts or clamps, and new gaskets should be fitted to the cylinder exhaust flanges. Where ball or expansion joints are fitted, these should be adjusted to the dimensions specified in the relevant Maintenance Manual, so as to prevent gas leakage or binding when the pipes expand during engine operation; the joints should be lubricated with graphite grease when specified. If the exhaust piping from the old engine is being re-used, it should be inspected for cracks, dents, pinholes and other damage, and attaching parts should be checked for serviceability.

11.4.5 Before connecting flexible pipes with threaded end-fittings to the engine, the blanks should be removed and the threads should be inspected for cleanliness and condition; the routeing of the pipes should be as originally fitted and should enable the pipes to retain their natural shape. System fluid or engine oil, as appropriate, may be used to lubricate the threads of the end fittings prior to assembly. Care must be taken not to twist a flexible pipe, and the hexagon on the fixed end fitting should be used to hold the pipe whilst the nut is tightened. Low-pressure hose should be inspected for damage, particularly at the positions where the hose clips are fitted, and should not be twisted when it is fitted; the hose clips should be checked for smooth operation.

11.4.6 When a hydraulic pump is refitted, it will need to be bled before starting the engine. This is normally carried out by pressurizing the reservoir (Leaflet **AL/3-21**) and opening the pump bleed valves until bubble-free fluid is discharged. The reservoir should then be topped-up and re-pressurized as necessary.

11.4.7 Before connecting the intake duct to the engine, the intake filter should be cleaned (Leaflet **EL/1-2**) and the duct should be inspected for cleanliness and freedom from foreign objects. It is important that there are no leaks in the intake ducting, and the seals fitted at the filter, hot-air flap and carburettor flange should be checked for effectiveness.

11.4.8 The aircraft Maintenance Manual may specify a clearance between the fixed structure in the engine bay and the engine, or parts attached to the engine. This clearance should be checked and any adjustments necessary should be carried out, but the re-routeing of pipes, hoses, controls and cables should be carefully controlled, and must not restrict movement caused by engine vibration, place a strain on connections or supports, or result in further chafing.

11.4.9 When the engine has been completely installed, the oil tank (or sump) should be filled with clean oil, the aircraft batteries should be reconnected, the carburettor or injector should be flushed and bled (Leaflet **EL/1-2**), and the propeller should be refitted (Leaflet **PL/1-1**). The lubricating system should then be primed in preparation for ground running, and the cowlings should be refitted.

NOTE: If a new propeller is being fitted it will be necessary to check that it is the correct type (Airworthiness Notice No. 4) and that, in the case of a variable pitch propeller, the fine and coarse pitch stops are correctly set (see relevant aircraft data sheets).

(a) The method of priming the oil system varies between different engines, but basically the aim is to ensure that all bearing surfaces have a film of oil on them when the engine is started for the first time. A priming rig is connected to the inlet side of the oil system, either by disconnecting a pipeline or by using the oil pressure gauge transmitter union, and oil (preferably hot) is pumped through the engine under pressure, using the pump or pressurized container on the rig. The sump drain plug is usually removed in order to drain off the oil which has passed through the engine, and it is usually recommended that the engine is turned by hand whilst priming is being carried out. The engine should normally be run within four hours after priming the oil system.

11.5 **Engine Testing.** Before starting an engine the cowlings should be fitted, the aircraft should be faced into wind and securely chocked, the brakes should be applied, and suitable fire extinguishers should be made available. When starting a new engine it is advisable to use an external power supply rather than the aircraft batteries, and this should be connected to the aircraft. The method of starting will vary according to the type of carburettor and the engine installation, and the procedure recommended by the aircraft manufacturer should be followed. Engine speed should be kept as low as possible until the oil pressure has built up to a prescribed value in a given time. If the minimum oil pressure is not achieved within the specified time the engine must be stopped and the cause determined. The engine should then be warmed up until the recommended minimum cylinder and oil temperatures are reached. At this power setting the magnetos should be checked for a dead cut (by momentarily switching off both magnetos), then the engine should be stopped and inspected for fuel and oil leaks. The engine cowlings should then be refitted, the engine started, and the following checks carried out as appropriate and in accordance with the manufacturer's instructions.

(a) Exercise the propeller several times by operation of the pitch control lever, to ensure that it is filled with oil and is operating properly.

(b) Check the operation of the magnetos at the recommended power settings.

(c) Carry out an engine power check (Leaflet **EL/3-15**).

(d) Open up to full power and check the maximum engine speed. Correct by means of the constant speed unit adjustment as necessary.

(e) Check the carburation over the full power range (Leaflet **EL/1-2**).

(f) Check operation of the supercharger (Leaflet **EL/1-3**).

(g) Check operation of all engine-operated systems. This may include checking battery-charging rate, hydraulic pressure and system operation, pneumatic pressure and system operation, vacuum pressure, and operation of the instruments and de-icing boots. The maintenance of the correct fuel pressure over the full power range should also be checked, to ensure correct operation of the engine-driven pump.

(h) Close the throttle and check the idling speed and mixture strength (Leaflet **EL/1-2**).

(j) Cool the engine by running it at approximately 1000 rev/min for a short period, or until the cylinder head temperature is within limits, then close it down.

NOTE: Prolonged ground running at high power settings must be avoided, since the cylinders are not adequately cooled when the aircraft is stationary.

11.5.1 After the ground run, the engine should be inspected for gas, fuel or oil leaks, and any adjustments found necessary during the run should be carried out. It will usually also be found necessary to replenish the oil system, since some of the oil from the tank will now occupy the sump and pipelines.

11.5.2 The results of the engine run, including the manifold pressure and engine speed obtained during the power check, and the drop in engine speed obtained during the magneto checks, together with any adjustments carried out, should be recorded in the engine log book.

12 ROUTINE MAINTENANCE In order to guard against malfunction or failure of an engine and its associated equipment, a programme of inspection and maintenance is carried out in accordance with a schedule approved by the CAA. The engine and component manufacturers stipulate the work which should be carried out to maintain their particular products in a satisfactory condition, and the combined inspection and maintenance requirements for the complete engine installation are included in the Maintenance Schedule for the particular aircraft. The bulk of the items will normally be repeated at intervals of 100 flying hours, but some items may be carried out more frequently and some less frequently. The following paragraphs indicate the work required for a typical light-aircraft engine installation.

12.1 **Lifed Items.** The engine itself must be removed for overhaul after a specified number of flying hours (see Airworthiness Notice No. 35), the time depending on its proven reliability; a new type of engine normally has an initial overhaul life which is capable of being extended as experience is gained during its operation. Some components (such as the alternator) may also have to be removed for overhaul after a specified time, but these "lives" are usually arranged to coincide with the engine life. Other components may have to be replaced at more frequent intervals, depending on their condition.

12.2 **General Condition of Engine.** The general condition of an engine should be checked after each routine inspection, by carrying out an engine run as outlined in paragraph 11.5. At less frequent intervals a compression check should be carried out on all cylinders, to determine the condition of the cylinders, pistons and valves. Various methods of carrying out this check are outlined in Leaflet **EL/3-15,** but the particular manufacturer's recommendations should be followed. If any particular cylinder shows excessive loss of compression, that cylinder should be replaced with a serviceable component; it is not normally necessary to change the engine because of cylinder unserviceability.

12.3 **Basic Engine.** The crankcase, sump and reduction gear casing, should be inspected for damage, cracks, corrosion and oil leaks, and the security and locking of attaching parts. The cylinders should be checked for damaged fins, corrosion, cracks, security and locking of attaching parts, oil leaks at the cylinder base, rocker covers, and push-rod covers, and gas leaks at the barrel/head joint and at the inlet and exhaust pipe flanges. Any apparent gas/oil leaks at the barrel/head joints should be checked carefully, to ensure that they result from oil seepage and are not the beginning of barrel/head separation. Any damaged paintwork should be repaired according to the manufacturer's instructions, and oil leaks should be rectified as appropriate.

12.4 **Cowlings and Baffles.** Cowlings should be cleaned and checked for cracks, distortion, condition of any rubbing strips attached to them, and loose or unserviceable fasteners. The interior of the cowlings should be inspected for evidence of chafing against engine structure, accessories or baffles; the cowlings should be repaired as necessary, and adjustments should be made to the chafing parts, to provide clearance. Baffles should be checked for cracks, security, and condition of any sealing strips attached to them. Cracks may normally be repaired by welding or patching, but temporary repairs may be effected by drilling the ends of the cracks. Fasteners which are not fully effective should be renewed. Paintwork should be made good in accordance with the manufacturer's instructions and the particular paint scheme.

12.5 **Engine Mountings.** The engine mounting framework should be carefully inspected for cracks, corrosion, distortion, and security of attachment to the airframe. The flexible mountings should be inspected for condition and security; some sag may occur during service, and if this reduces the clearance between engine parts and the structure below the minimum figure specified, it is usually permitted to add spacers to restore the clearance. Damage to the mounting frame and paintwork must be repaired.

12.6 **Intake Duct.** The ducting to the carburettor or injector air intake should be inspected for cracks, corrosion and security, and the condition of the seals at the air filter, carburettor, and, where fitted, the hot-air flap (see also Leaflet **EL/1-2**). Any controls provided for filtered air or hot air should be checked for correct operation and for full and free movement, and the connections in the control run should be checked for wear and correct locking. Alternative air flaps which are operated by differential air pressure and are held in position by magnetic catches, should be inspected carefully, as they are more prone to wear and failure, particularly when the magnetic catches lose their effectiveness. The air filter should be cleaned regularly (Leaflet **EL/1-2**).

12.7 **Exhaust System.** Because of its operating environment, cracking and wear of parts of the exhaust system are inevitable, and frequent inspections are usually specified in the relevant Maintenance Schedule. All parts of the exhaust system should be inspected for security, warping, cracks, dents, and evidence of gas leakage, particularly at clips, slip joints, V-clamps, bellows and heater muffs. Damage may often be repairable by welding, but when carrying out such repairs, extreme caution is necessary to maintain the original contour, since any disruption to the smooth flow of exhaust gas will result in a hot spot, and lead to early failure at that point. Renewal of damaged parts is preferable to repair, and new gaskets or seals should always be fitted.

12.7.1 Attention is drawn, in Airworthiness Notice No. 40, to the dangers inherent in the use of heating systems which employ an exhaust heat-exchanger to heat the air entering the cabin. A thorough inspection of these systems should be carried out at the specified intervals and whenever carbon monoxide contamination is suspected. In some cases the heating jacket on the muffler is detachable, and can be completely removed to enable a thorough inspection to be made for signs of leakage from the exhaust section of the muffler. In other cases a pressure test may be recommended, and this is carried out by blanking the outlet from the heater jacket and applying air pressure through the inlet; with the air supply shut off, there should be no leakage from the heater jacket.

12.8 **Oil System.** Internal lubrication of the engine is of vital importance, and the oil quantity should be checked daily or prior to each flight. Oil should be changed regularly (usually at 50 or 100 hour intervals) by draining the sump and tank (preferably when the oil is hot) and refilling the system with new oil to the correct specification. Oil screens (wire-mesh filters) should be cleaned and filter elements changed at the specified intervals, but on removal should be inspected for the presence of metal particles, which would indicate internal failure in the engine. The oil-cooler air passages should be checked for blockage and cleaned as necessary, and all parts of the oil system should be checked for cracks, security, chafing, leaks and damage during the routine inspection.

12.9 **Engine Fuel System.** The fuel system in the engine bay, including flexible pipes, injector distribution pipes, carburettor, pump, and filter, should be checked for leakage under pressure, and should be inspected for security, chafing and damage; some engine fuel components also have tell-tale drains from shafts, seals and diaphragms which facilitate checks for internal failure.

12.9.1 The main fuel filter should be drained before flight, daily, or after refuelling, as specified in the relevant Maintenance Schedule, in order to remove sediment and to drain off any water which may have accumulated. A small amount of water will often be removed from the filter or tank drains, but if the amount is excessive the fuel system should be checked as outlined in Leaflet **AL/3-17.**

12.9.2 All filters associated with the fuel system should be removed and cleaned at the specified intervals, and when required by unsatisfactory engine operation. Fuel filters should be cleaned by washing in solvent and blowing dry with compressed air, but the air filters fitted to injector nozzles may not be detachable and are often cleaned with the nozzle, by ultrasonic methods.

12.9.3 Throttle and mixture controls should be checked for full and free movement, for correct locking, and for signs of play or lost motion resulting from excessive wear.

12.9.4 Operation of the engine fuel system should be checked during engine runs. Any adjustments found to be necessary should be carried out (Leaflet **EL/1-2**).

12.10 **Electrical System.** All major components in the electrical system should be checked for condition and security. The generator and starter brushes should be checked for wear, their bearings for play, and their connections for security and locking as appropriate; the alternator drive belt, where fitted, should be checked for condition and tension. The magneto timing and contact breaker gap should be checked and the cam pad should be lubricated (Leaflet **EL/3-9**). Ignition switch leads should be checked for condition and security (Leaflet **EL/5-2**), and the sparking plugs should be removed, cleaned and tested (Leaflet **EL/5-1**). All wiring harnesses and conduits should be checked for security and condition.

12.11 **Pipes.** Rigid pipes should be inspected for security of attachment to the airframe or engine, for cracks, dents, corrosion and chafing, and for signs of leakage. Bonding strips fitted across hose joining rigid pipes should be checked for condition and security. All flexible hoses should be inspected for deterioration, kinks, chafing, security and correct installation, without twists or unnecessary bends. The life of flexible hoses should also be checked, and they must be rejected at the end of this time regardless of their apparent condition. Firesleeves such as are fitted to flexible fuel and oil hoses, should be checked for deterioration, and should be renewed if they are cut, chafed or frayed, or have become impregnated with fuel or oil.

NOTE: Further information on flexible hoses is contained in Leaflet **AL/3-13.**

12.12 **Lubrication.** A diagram is provided in most light-aircraft Maintenance Manuals, indicating the method and frequency of lubrication of various parts of the aircraft, and the types of lubricant to be used. As far as the engine installation is concerned, lubrication is generally confined to the application of oil or grease to the various working parts. These include the lever pivots, rod ends and bearings in the throttle, mixture, air filter, and cabin-heat control linkages, and the links and hinges on filter doors, hot-air intake doors, and cooling-air exit flaps. In addition, the rocker covers of some inverted engines may need filling with engine oil, whilst the rocker bearings of some radial engines may require lubrication by means of a grease gun. Dirt, grit and old lubricant should be wiped off before applying the new oil or grease, and any excess should be removed.

12.13 **Fireproof Bulkhead.** Damage to a fireproof bulkhead, or ineffective sealing of pipes, mounting structure or controls passing through the bulkhead, could result in exhaust fumes passing into the wing or fuselage, and in the case of an engine fire, in the spreading of the fire to the airframe structure, with possible catastrophic results. The fireproof bulkhead should be examined very carefully for cracks and other damage, and for signs of ineffectiveness of the seals or sealing compound used; any faults should be corrected in accordance with the relevant Maintenance Manual.

13 NON-ROUTINE INSPECTIONS Operating limitations on the rotational speed and manifold pressure of an engine are imposed to ensure that the engine is operated within design parameters. There are times, however, when these limitations may be exceeded, through either a mechanical fault or mishandling, and the engine must be inspected to determine whether it is still satisfactory for continued operation. The inspections necessary following overspeeding or overboosting of the engine, and also after a shock-loading of the engine, are included in paragraphs 13.1 to 13.3. The inspections which are required following a lightning strike or static discharge damage are included in Leaflet **AL/7-1.**

13.1 **Overspeeding.** Operation at engine speeds higher than the rated speed (or take-off engine speed when this is specified), can cause rapid wear of highly-stressed parts, and, if the speed is high enough, serious damage or failure can occur. The inspections required by the engine manufacturer are normally contained in the Maintenance Manual or in Service Bulletins, but the inspections outlined in paragraphs 13.1.1 to 13.1.4 are typical of those required on light-aircraft engines.

13.1.1 **Momentary Overspeed up to 2%.** No special inspections are normally required for a momentary overspeed of 2% of the rated engine speed, but the cause should be determined and corrected, and an entry should be made in the engine log book.

13.1.2 **Overspeeding up to 5%.** The following inspections should be carried out following an overspeed of up to 5% of rated speed, and if satisfactory the engine may be returned to service.

(a) Drain all oil from the engine lubrication system, remove all filters and inspect for metal particles.

(b) Carry out a cylinder compression check (Leaflet EL/3-15).

(c) Using a suitable inspection instrument (e.g. a borescope), examine the cylinder walls for scoring, which may have been caused by broken piston rings.

13.1.3 **Overspeeding between 5% and 10%.** Repeated momentary overspeeds or short periods of operation at 5% to 10% higher than rated speed may produce excessive wear in the valve train. A routine 100 hour inspection should be carried out, and the following checks should also be made. Any parts which are found to be unserviceable must be renewed before the engine is returned to service.

(a) Check all filters for metal particles.

(b) Using a suitable inspection instrument, examine the cylinder walls for scoring, and the valves and seats for distortion or damage.

(c) Examine the rockers, valves, valve guides and springs for condition.

(d) Rotate the engine by hand to check the full and free movement of all parts in the valve train.

(e) On a turbocharged engine, inspect the turbine wheel and compressor for damage, and the bearings for excessive wear (Leaflet EL/1-3).

13.1.4 **Overspeed higher than 10%.** Any overspeed in excess of 10% above rated speed will require removal of the engine for overhaul in accordance with the manufacturer's instructions.

13.2 **Overboosting.** On a supercharged engine, overboosting is possible through a mechanical fault (in the control system) or through mishandling, and may result in excessive pressures in the cylinders and overstressing of the working parts of the engine. The inspections which are generally required by engine manufacturers, following overboosting, are outlined in paragraphs 13.2.1 to 13.2.3.

13.2.1 **Overboosting not exceeding 2 inHg (1 lbf/in²).** A momentary overboost which does not exceed 2 inHg does not require any special inspections, but the cause should be determined and corrected, and the relevant details should be entered in the engine log book.

13.2.2 **Overboosting not exceeding 5 inHg (2½ lbf/in²).** An overboost not exceeding 5 inHg which is of short duration (i.e. less than 10 seconds) will require a routine 50 hour inspection to be carried out, and the following checks to be made. Provided that no damage is found, the engine may be returned to service.

(a) Inspect cylinders for cracks around base flange, the sparking plug holes and in the head.

(b) Examine oil filters for metal particles.

(c) Inspect sparking plugs for cracks, and for loose or damaged electrodes.

13.2.3 **Overboosting exceeding 5 inHg (2½ lbf/in²).** If the overboosting exceeds 5 inHg, or is of long duration, the engine must be removed from the aircraft, and overhauled in accordance with the manufacturer's instructions.

13.3 **Shock-loading.** When sudden stoppage of an engine occurs, through, for example, the propeller striking the ground, damage to the engine is likely to occur. The extent of the damage is very difficult to assess, however, and may bear no relationship to engine speed or to the forward speed of the aircraft; damage is most likely to be incurred by the propeller shaft, the engine bearers, the crankshaft counterweights and the crankcase bearing webs. The propeller shaft and engine bearers can be examined for damage, and a limited inspection of the internal parts of an engine can be made by removing one or more cylinders, but satisfactory crack detection is not possible with the engine assembled. Most manufacturers, therefore, recommend that any incident of sudden engine stoppage is sufficient to warrant removal of the engine for complete disassembly and inspection.

EL/3-1

Issue 2.

December, 1978.

AIRCRAFT

ENGINES

PISTON ENGINE OVERHAUL—DISMANTLING, CLEANING AND CRACK DETECTION

1 INTRODUCTION

1.1 This Leaflet is the first of a series on piston engine overhaul; it gives general guidance on the preliminary stages of overhaul and on methods of crack detection suitable for various engine components. It should be read in conjunction with the other Leaflets of the series and the appropriate Overhaul Manuals. Reference should also be made to the manufacturer's technical instructions for details of all modifications and special inspections applicable at overhaul, bearing in mind that the overhaul lives of engines depend to a great extent on the modification standard to which they are rebuilt.

1.2 The series deals mainly with the overhaul of low-power, air-cooled engines but does not aim to provide a complete guide to those engaged on this work. The procedures and practices for the overhaul of such engines are well established, but the purpose of the Leaflets is to draw the attention of individual engineers to a number of important points rather than to restate this practice in full. The series includes those parts of British Civil Airworthiness Requirements which are relevant to the overhaul of piston engines and explains how overhauled engines should be tested to comply with the Requirements.

1.3 The rest of the series consists of Leaflet **EL/3-2**, which covers top overhaul and gives the CAA's recommendations for testing after top overhaul; Leaflet **EL/3-3** dealing with inspection during complete overhaul; Leaflet **EL/3-4** dealing with inspection during engine assembly, and Leaflets **EL/3-5** to **EL/3-8** which cover engine testing after complete overhaul. Ignition equipment is covered in Leaflets **EL/3-9**, **EL/5-1** and **EL/5-3**, and the general principles of operation, construction, and maintenance of typical aircraft piston engines are covered in Leaflets **EL/1-1** to **EL/1-4**.

2 EQUIPMENT Engine overhaul should not be attempted unless the equipment and workshop facilities available are adequate. Special tools, rigs and stands are required for each engine type, and an accurate surface table and a full range of precision measuring instruments are essential. For the non-destructive examination of engine parts, electro-magnetic flaw detection equipment is required in the case of ferrous materials, and provision for making oil and chalk or penetrant dye checks is required in the case of light alloys.

2.1 Precision equipment, such as the surface table, micrometers, vernier calipers and plug gauges, should be treated with care. They should be checked periodically to ensure that their accuracy is within the limits specified in the relevant specifications of the British Standards Institution. Each item should have a history card on which a record of each check is entered.

2.2 When doubt exists regarding the condition of an engine part, it may be desirable to subject it to a more searching examination for concealed flaws than is possible with normal workshop equipment. In this case it should either be referred to an approved test laboratory for examination by X-ray, ultrasonic or surface hardness tests or the part should be renewed.

3 INSPECTION RECORDS During overhaul work a systematic and methodica inspection of all the parts removed should be made and a record of the condition and, where applicable, the dimensions of all parts examined at each stage of the inspection should be entered on an Inspection Report.

3.1 Before dismantling an engine, the log book should be checked so that special attention can be given to items which may have caused defects. The total running times of "lifed" components should also be checked and replacements should be obtained for components which have completed their approved running lives.

3.2 During the inspection, all items should be classified into one of three categories—serviceable, repairable or scrap. Scrap parts should be clearly marked with red paint or should be destroyed to prevent further use. All parts affected by modification action should be clearly labelled and segregated for appropriate attention.

3.3 A record should be kept of all rectifications made during the overhaul. If the nature of the work is such that it affects the fits and clearances of the assembled engine, a special note should be made to recheck the clearances at the final assembly. The renewal of bushes which affect the meshing of gears is a typical case.

3.4 All fits and clearances should be recorded and checked against the schedule given in the manufacturer's manual. The schedule usually gives the data under four headings:

(a) "Dimensions New" are the drawing sizes to which the parts are made.

(b) "Permissible Worn Dimensions" indicate the limits to which parts may be worn and yet be refitted for a further period of service. However, it may be found that some manufacturers use the term in a different sense and advise renewing all parts found to be worn to dimensions described under this heading.

(c) "Clearance New" gives the minimum and maximum working clearance obtainable with new parts when assembled.

(d) "Permissible Worn Clearance" is the limit of working clearance permissible between any two parts assembled together.

NOTE: Parts which are not worn beyond permissible limits may nevertheless cause permissible worn clearances to be exceeded when the parts are assembled.

4 INSPECTION BEFORE DISMANTLING Before the commencement of dismantling and cleaning, engines received for overhaul should be examined externally and a preliminary inspection report should be prepared. Inspection at this stage provides an opportunity of discovering defects that might be obscured by subsequent cleaning.

4.1 The general external examination for condition should be made with the engine secured to the correct type of stand, except where a top overhaul is to be made without removing the engine from the airframe. Evidence of oil leaks should be investigated; any oil seepage should be traced to its source. A visual inspection for cracks should be made; cracks, blown joints at cylinder heads, damaged face joints, etc., are often indicated by dark lines and local seepage. The controls should be checked for incorrect operation and for wear and lost movement.

4.2 If any engine apertures are discovered unblanked it should be remembered that foreign matter may have entered the engine. This may cause damage if the engine is turned during dismantling.

4.3 The engine should be drained of oil and the filters should be examined for metal deposits which could be an indication of possible damage to bearings or pistons. When it is required to identify metal particles found in the scavenge filters, they should be washed in ether and filtered on to a clean sheet of blotting paper. With the aid of a strong lens, they should be separated from any carbon particles by the use of tweezers. For their precise identification the following tests can be applied.

4.3.1 A magnet should be used to separate the ferro-magnetic particles from the other metals. The magnet will pick up cast iron, carbon steels, certain alloy steels and some stainless steels, but not austenitic stainless steels, white metal, copper, magnesium or aluminium alloys.

4.3.2 Magnetic particles can be identified by placing a number in a beaker and pouring a small quantity of nitric acid (sp. gr. 1·20) over them. The acid should then be heated to just below its boiling point and held there until the cessation of chemical action. Stainless steel will not be attacked, but the acid will turn yellow or light brown if the particles are of carbon steel and dark brown if they are of cast iron.

4.3.3 If bronzes cannot be picked out by the colour of the copper in them, they too can be identified by a nitric acid test. In this case the acid should be poured on to the particles but should not be heated until the chemical reaction ceases. The acid should then be boiled for 2 to 3 minutes. If a white precipitate is formed, the metal is a bronze.

4.3.4 Other alloys can be identified by their reactions when attacked by particular chemicals. Thus magnesium alloys are violently attacked by saturated copper sulphate solution, aluminium and its alloys by a 20% caustic soda solution (the solution will become clear if the metal is aluminium but a grey or black precipitate will be evident if it is aluminium alloy), whilst white metal will dissolve slowly in nitric acid leaving black particles in a pale green solution.

5 DISMANTLING

To avoid damage and distortion to the engine components, it is essential that the correct extractors and special tools are used at each stage of dismantling. As items are removed, they should be placed on properly designed stands or in storage bins and should be identified so that they can be reassembled without difficulty.

5.1 The dismantling sequence in the manufacturer's manual should be followed at all times. Pistons, valves, valve springs and collets should be grouped with their associated cylinders so that the effects of any damage can be traced on all related parts.

5.2 Cylinders can generally be pulled off by hand, but, if they are stiff, wedges should not be driven under the flanges to free the crankcase joint. Alternate rocking and pulling will usually free a cylinder, but, for cylinders with integral heads, a last resort is to place the cylinder in question on compression stroke, fill the combustion chamber with oil and fit dummy plugs. A partial turn of the crankshaft will then free the joint.

5.3 Seized gudgeon pins should not be drifted out but should be withdrawn with a special extractor—if one is provided in the tool kit. If no extractor is available the piston should be expanded by the application of heat. This can be done by wrapping the piston in rags soaked in boiling water or by immersing the piston in a can of hot oil.

5.4 When dismantling radial engines, guard plates should always be fitted as each cylinder is removed. The cylinder containing the master connecting-rod should be removed last to avoid collapse of the connecting-rod assembly. This prevents such faults as:

(a) An oil scraper ring springing out of a cylinder and locking the whole assembly.

(b) The crankshaft balance weights fouling the skirts of the pistons.

(c) The articulating rods damaging the crankcase cylinder sockets.

NOTE: If only the master cylinder is being removed, the master rod should be positioned at Top Dead Centre (TDC) before removing the cylinder and the crankshaft and rod should not be moved again until the cylinder has been replaced.

5.5 When unbolting crankshaft and connecting-rod bearing caps, a check should be made to ensure that they are correctly numbered and precautions should be taken to mark the actual positions of bearing shells in case they are to be used again. At this stage the torque loading of the cap nuts should be checked by first slackening them off and then torque-loading them back to positions that give the same split pin hole alignment. Where the torque required to do this is less than that specified by the engine manufacturer, stretch of the bolt or stud is indicated. After this check, dismantling should proceed with every precaution being taken to avoid damaging the shaft, rods or bearing shells.

6 INSPECTION BEFORE CLEANING All components and parts should be inspected before cleaning, otherwise useful evidence of defects and the behaviour of the engine whilst in service may be removed. Defects of an unusual nature should be reported to the manufacturer and to the CAA.

6.1 Brown or black patches on cylinder walls and piston skirts often indicate piston "blow-by." This is caused by combustion gases leaking past worn piston rings, overwide piston ring gaps or gaps which are all in alignment.

6.2 Where valve seat inserts are provided, looseness or displacement of the seats is often more readily detected before the cylinder head is cleaned.

6.3 Scores in cylinder walls, on gudgeon pins, shaft journals, crank pins and valve stems can often be traced to poor oil filtration. Gritty substances in the oil become embedded in the softer metal of the pistons and bearings and score the harder material. Evidence of the presence of harmful solids is often found in the oily deposits found inside the hollow crank pins.

6.4 Many small parts such as piston rings, circlips, locking washers, split pins, gaskets and jointing washers are renewed when an engine is overhauled, but, before they are discarded, they may yield evidence regarding the functioning of the particular assemblies with which they were associated.

7 CLEANING Only cleaning agents suitable to the particular materials of the parts to be cleaned should be used. Care is necessary to ensure that no dimensional changes or deterioration of surface finish is caused by cleaning.

7.1 The most satisfactory method of removing oil and grease from most engine parts is trichloroethylene degreasing (Leaflet BL/6-8). However, the temperature of the degreasing plant may cause disturbance of shrink-fits, so, unless a keeper can be fitted to prevent this, components incorporating shrink-fitted parts should be cleaned by some other method.

7.2 When trichloroethylene plant is not available or is unsuitable for a particular job, soap solutions or proprietary cleaning agents are recommended. For certain steel and aluminium-alloy components a satisfactory cleaning solution which will remove carbon and sludge as well as grease, can be made up in the following proportions:

Cresol	25 litres	(5½ gallons)
Water	423 litres	(93 gallons)
Hard yellow soap	3·6 kg	(8 lb)

The parts should be soaked in this solution for two hours at a temperature of 55°C to 65°C.

NOTES: (1) Paraffin should only be used to clean components containing parts which may be harmed by the above methods, e.g. white metal bearings.

(2) Certain chlorinated proprietary cleaners give off vapours which are slightly toxic. If they are used, the precautions applicable to trichloroethylene should be taken.

7.3 The use of abrasive materials and wire brushes should generally be avoided. Particles of emery or carborundum are easily trapped in inaccessible corners and may later give trouble when the engine is in service. Sand blasting is sometimes recommended for the removal of old paint from the fins of air-cooled cylinders but should only be used if great care has been taken to exclude the sand from valve ports, plug apertures, etc. The use of chemical paint removers is preferred.

7.4 Hard carbon deposits can be removed using special dry blasting techniques. The most suitable types of grit for dry blasting are plastics pellets or processed natural materials such as crushed fruit pips or shells.

8 INSPECTION AFTER CLEANING The following is a summary of essential points which should be included in the inspection procedure.

8.1 The surface finish of all stressed parts should be examined for such defects as tool marks, sharp corners, pitting, etc., which might provide starting points for fatigue cracks.

8.2 An examination should be made for cracks around such points as mounting feet, flanges or bosses, reinforcing webs, stud and bolt holes, bearing housings and in the vicinity of all stud holes and changes of section. Internal threads and holes drilled through castings can be inspected with the aid of a borescope or similar inspection instrument.

8.3 All studs and bolts should be checked for signs of stretching; they should be straight and their threads should be undamaged. All bolt and stud holes should be undamaged and all studs remaining in position should be checked for tightness. The peening of countersunk locking screws, core-plug dowels, balance weight plugs, etc., should also be checked for effectiveness.

9 CRACK DETECTION To avoid unnecessary work, crack detection tests should be made immediately after cleaning. Whilst each engine component should be inspected for cracks by visual examination, it is nearly always necessary to use a non-destructive aid to ensure that small fatigue cracks are not missed. Information on the various non-destructive flaw detection methods is given in Leaflets **BL/8-1** to **BL/8-8.** This paragraph gives general guidance on the application of crack detection and other processes to the inspection of engine parts, but, since these parts are of widely-differing shapes and materials, the selection of the most suitable crack test is not always easy. On occasions it is advisable to apply two or three different methods to prove that an individual part is free from defects.

9.1 **Crankcases and other Castings.** For castings of aluminium alloy the oil and chalk method of testing (Leaflet **BL/8-1**) is recommended, whilst the fluorescent penetrant method (Leaflet **BL/8-7**) is usually more satisfactory for magnesium alloys. The fluorescent penetrant method will generally give better definition of porosity in castings made from either group of alloys and should therefore be used on all items where detection of porosity is important. For certain components, e.g., cylinder heads and induction elbows, a pressure test may also be specified. The test pressure and method of application should be obtained from the appropriate manufacturer's manuals.

9.2 **Pistons.** Both the oil and chalk method and the fluorescent penetrant method of crack detection are suitable for most pistons but some manufacturers recommend an etch inspection for the skirt and reinforcing ribs. Inspection by etching should be made as follows:

9.2.1 The etching solution should be prepared in the following proportions:

Sulphuric acid	200 c.c.
Sodium Fluoride	28·35g (1 oz)
Water	1800 c.c.

A solution of 50% nitric acid in water is also required to remove the black smut deposited by the etching solution.

NOTE: Whenever dilute acid solutions have to be prepared, the acid should always be added to the water and not vice-versa.

9.2.2 The piston to be tested should be free from grease and carbon. To expand any tiny cracks it should first be immersed in hot water, after which it should be placed with crown downwards and the etching solution should be poured into it. The solution should then be swabbed over the whole of the inside surface of the piston and over the lower rim of the skirt. About four minutes should be allowed for the etching to proceed.

9.2.3 After four minutes the piston should be drained and immediately afterwards should be washed thoroughly in clean running water. The nitric acid solution should then be swabbed over the treated area, after which the washing should be repeated. Finally the piston should be immersed in methylated spirit and dried with warm air.

9.2.4 The piston should then be inspected for cracks, pitting and signs of corrosion, using a powerful magnifying lens or a binocular microscope. Particular attention should be paid to the reinforcement ribs, gudgeon pin bores and piston ring grooves.

9.3 **Steel Parts.** Non-magnetic steels can be tested satisfactorily by either fluorescent or non-fluorescent penetrant dyes, but electro-magnetic crack detection is recommended for all ferro-magnetic parts. In many cases the engine manufacturers specify the electro-magnetic technique and test amperage that should be used to suit the shape and nature of each part to be tested. If guidance on these matters is not included in the manufacturer's manual, the following points should be considered.

9.3.1 Amperages to suit particular parts commonly range from 350 to 1000 depending on the size of the part, but higher amperages are sometimes required to show up specific faults such as grinding cracks. It is often necessary to check individual components at several different amperages to ensure that all flaws are detected.

9.3.2 The majority of shafts and gears should be tested by both the current flow and magnetic flow methods, but the geometry of some items makes them suitable for one method only. Tests should be carried out at different current settings, and using portable cracks and flux detectors, to establish a satisfactory technique for each component (Leaflet **BL/8-5**).

9.3.3 To check small parts in situ and to make local checks on awkwardly shaped parts, it is advantageous to use portable detectors of the semi-permanent magnet type. The manufacturers of these detectors generally supply a white spray for application to the area under test before the magnetic ink is brushed on: the white surface gives a better indication than would otherwise be obtained.

9.3.4 During all electro-magnetic crack detection tests, care is necessary to avoid local burning of the part being examined. Burning can be caused by excessively high current or by local concentration of current due to faulty or unsuitable electrodes. Overheating from these causes does not always leave visible evidence on the surface of the metal, even though its mechanical properties may have been impaired; when this trouble is suspected, the part should be submitted to an approved laboratory for hardness tests on the affected area.

9.3.5 It is essential that all parts be demagnetised at the conclusion of the tests. Neglect of this precaution will cause ferrous swarf to cling to the parts and may affect the reading of the aircraft magnetic compass.

EL/3-2

Issue 2.

December, 1978.

AIRCRAFT

ENGINES

PISTON ENGINE OVERHAUL—TOP OVERHAUL

1 INTRODUCTION

1.1 This Leaflet is the second of the series dealing with engine overhaul and gives general guidance on the inspection of cylinders, pistons and valve gear during top overhaul and on the testing of small air-cooled engines after top overhaul.

NOTE: Although the leaflet deals primarily with top overhaul, paragraphs 3 to 7 apply equally to inspection during complete overhaul.

1.2 Although top overhaul is not generally specified as a periodic overhaul in the Engine Maintenance Schedule, it is sometimes necessary to remove one or more cylinders in order to rectify particular defects or to maintain the required performance of the engine: the term "top overhaul" is therefore applied in this Leaflet irrespective of the number of cylinders removed.

2 GENERAL It is often unnecessary to remove an engine from its airframe to carry out a top overhaul, although removal may be advisable if accessibility is limited.

2.1 The oil filters should be checked before removing the cylinders and any metal particles found should be identified by the methods described in Leaflet **EL/3-1.** If the origin of such particles is traced to cylinder defects, it may be possible to restore the serviceability of the engine during top overhaul, but if there is evidence that the engine has been damaged by the circulation of metal, it should be completely dismantled.

2.2 If only a limited top overhaul is to be done, it is important to ensure that an accurate diagnosis has been made and that the defective cyclinders have been correctly identified. To this end a compression check on each cylinder is a useful guide, whilst visual inspection of the combustion space, conducted with the aid of suitable optical equipment, may reveal defects to the experienced eye. Cavity viewing instruments (variously known as endoscopes, borescopes or introscopes) can be inserted through the plug apertures; these devices incorporate their own illumination and project a magnified image of the surfaces within their view to an external eyepiece.

3 CYLINDERS Guidance on the removal and dismantling of cylinder assemblies is given in Leaflet **EL/3-1.** After cleaning, cylinders should be inspected for corrosion, broken fins, internal scoring, "ridging," pitting, cracks, signs of overheating and, in the case of internally-chromed bores, for adhesion of the chromium plating.

3.1 If fins are cracked or broken, the manufacturer's repair scheme should be consulted to determine whether the cylinder should be classified as repairable or scrap. If it is repairable, small cracks at the edges of the fins can be arrested by drilling a 1·5 mm ($\frac{1}{16}$ in) diameter hole at the extremity of the crack. Broken edges of fins should be filed smooth and blended into the general contours of the fins after which the total reduction of fin area should be estimated and compared with the maximum reduction permitted by the manufacturer.

3.2 The valve guides should be checked for freedom from scores, tightness of fit, and, using either a slip gauge or an internal micrometer of the retracting anvil type, for wear and ovality. Unserviceable valve guides should be renewed, the extraction of the old guide being made with the correct extractor. Some manufacturers recommend machining away the external portion of the valve guide with a step drill, after which the guide may be withdrawn into the cylinder; this avoids damage to the cylinder if the guide is distorted or burnt inside the cylinder head. The new guide should be pressed into position, a soft metal plug being interposed between the guide and press to avoid damaging the guide. An alternative way of fitting a guide is to use a draw-bolt rig; it is bad practice to attempt to drift a new guide into a cylinder head. The bore of the guide should then be reamed to the specified diameter, the reaming operation being done by a succession of light cuts. Each stage of reaming should be checked by using a 'GO' and 'NO GO' plug gauge.

NOTE: When inserting a new valve guide it is common practice to heat the cylinder head in an oil bath before inserting the guide.

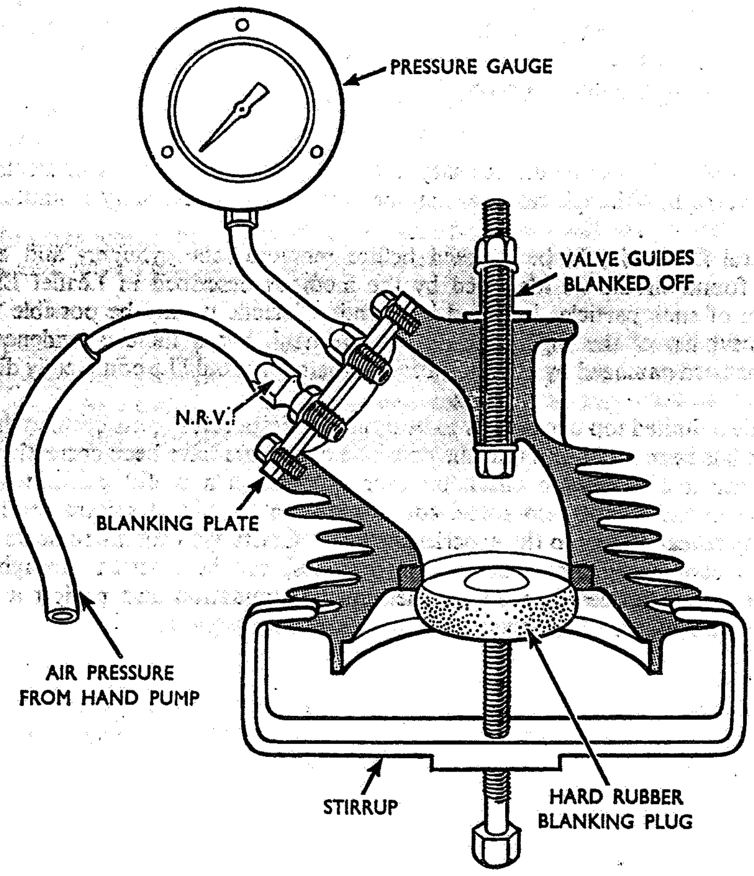


Figure 1 PRESSURE TESTING VALVE SEAT INSERTS

3.3 If a new valve guide has been fitted, the corresponding valve seat should be lightly refaced with a cutter or grinder to true it up to the new guide. Valve seats should also be refaced if they show signs of uneven wear, ridges or pitting, although the extent to which this can be done on stellited exhaust valve seats is very limited. After refacing, the valve seat should be checked with the valve-seat gauge provided in the engine tool kit; this gauge usually resembles a poppet valve with four segments cut from the rim. The valve seat has been cut to its maximum permissible limit when the outside diameter of the gauge coincides with the largest diameter of the seat.

NOTE: The action to be taken in the case of over-cut valve seats depends on the type of seat; cylinder heads with inserted valve seats should be returned to the manufacturer for new seats to be fitted, but those with integral seats should be scrapped.

3.4 A pressure test is often specified as a check on the tightness of inserted valve seats. A method of blanking and pressurising a typical cylinder head is illustrated in Figure 1. The valve guide and seat should be plugged to withstand an applied air pressure of 480 to 550 kN/m^2 (70 to 80 lbf/in^2) and, when this pressure has been reached, the head should be immersed in hot water. Leaks will be indicated by bubbles escaping from the joint between the valve seat insert and its housing.

3.5 The sparking plug inserts should be secure and free from signs of excessive burning, pitting or damaged threads. Plug inserts are usually screwed and shrunk in position and are then locked by a dowel. This makes their removal difficult without special facilities, hence manufacturers often advise that cylinder heads with damaged inserts should be returned to them for renewal of the insert. If this procedure cannot be adopted, the dowel should be drilled out and the cylinder head should then be expanded in a can of hot oil before unscrewing the insert.

3.6 The cylinder bore should be checked with an internal micrometer, comparator or cylinder bore gauge for wear, ovality and lack of parallelism. The greatest diameter should be within the permissible worn dimension. The bore should be checked at the thrust and non-thrust faces at the top, centre and bottom of the piston stroke, bearing in mind that some bores are slightly tapered to allow for differential expansion. Whilst honing of the bore is usually adequate to remove light scores or pitting, bores which have worn oval or out of parallel, or which are more seriously scored or pitted, should be reground. After regrinding it is essential to ensure that the maximum permitted diameter of the bore has not been exceeded. Manufacturers often specify one or two stages of regrinding, which usually necessitates the fitment of oversize pistons.

3.7 Detachable cylinder heads should be checked for distortion by placing them on a surface table and, while pressing them down firmly by hand, attempting to insert feelers between the flat on the underside of the head and the table. The spigot joint between the cylinder head and the cylinder barrel should be checked with engineers' marking. Provided it is not outside the permissible limits, a poorly-fitting spigot joint can be trued up by skimming the cylinder head on a lathe or by lapping the head on to an old cylinder barrel. The maximum amount of material that can be removed by skimming is specified by the manufacturer; the removal of more may reduce the volume of the combustion space by an impermissible amount.

4 VALVES Valves should be checked for wear, ovality and stretch, for profile (using a profile gauge), for loose or cracked end plugs, and for burned, cracked or distorted valve faces.

4.1 Valves that are bowed, stretched, distorted, excessively scored or which show signs of fretting at the collet grooves should be renewed. If the stem is only lightly scored it is permissible to polish it lightly with fine grade emery cloth, after which its diameter should be measured with a micrometer. Bow of the valve stem is checked by mounting the valve between vee-blocks and positioning a dial test indicator (DTI) so that it contacts the centre of the stem. The valve should then be turned through one revolution and the DTI reading noted.

4.2 To remove pitting from valve faces and to ensure that they are concentric about the axes of the valve stems, valves are normally refaced at overhauls on a refacing grinder. Except in the case of valves which have an included angle difference between the valve face and the valve seat, refaced valves should be lapped to their seats with a fine carborundum powder followed by "Crocus" powder and oil. Valves which have a different angle to their seats should be checked with engineers' marking against the valve face gauge provided in the tool kit.

4.3 After grinding and lapping, the thickness of the valve head should be checked. This is measured from the bottom of the valve head to the lower edge of the valve face, and if it has been reduced beyond the limits quoted in the Schedule of Fits and Clearances the valve must be renewed.

4.4 The valve springs should be inspected for pitting, cracks or chafing. A simple rig should be constructed so that the length of the spring can be measured when the spring is compressed by a specified load. After reassembly, tests to determine the load required to open each valve may also be specified.

4.5 On the completion of all overhaul work on the valve assemblies, they should be reassembled, preferably to the cylinders from which they were removed. Finally, the leak-tightness of the valve seatings should be checked by filling either the valve ports or the combustion space with paraffin and noting that there is no leakage past the valve over a reasonable period.

5 PISTONS This paragraph gives guidance on dimensional checks and the assembly and fitting of piston rings. Crack detection tests on pistons are covered in Leaflet EL/3-1.

5.1 Pistons should be carefully inspected for damage to the piston-ring grooves, lands or skirts, and the oil holes should be inspected for cleanliness. The piston skirt should be checked for diameter, ovality and taper, micrometer readings being taken as follows:—

(a) At the top and bottom of the thrust face.
(b) At the top and bottom of the non-thrust face.
(c) At all lands above and between the piston rings.

5.2 The gudgeon-pin diameter should be measured at a number of points along the length of the pin, and the corresponding bores of the pistons should also be measured to determine the clearance of each pin in its bore. The most accurate tool for measuring bore diameters is a pneumatic gauge but if this instrument is not available a slip-gauge is an acceptable alternative. The fit in the small end of the connecting rod should be checked in a similar manner. If the worn dimensions and clearances are within limits, the original pin can be used again but new circlips must be fitted on reassembly. If the wear is beyond the permitted maximum, action should be taken in accordance with the manufacturer's salvage scheme.

5.3 It should be remembered that one or more cylinders may have been ground oversize on previous overhauls, in which case oversize pistons and rings will have been fitted. Since it is customary to renew all rings during overhaul, care must be taken that the correct size rings are fitted to each piston. The ring gaps should be checked by placing the rings in the recommended positions in their respective cylinder bores and squaring them up with their pistons. The gaps can then be checked with feeler gauges or with a 'GO' and 'NO GO' gap gauge. If adjustment is required, the gap can be increased by filing with a smooth file, care being taken to keep the gap square and free from burrs.

5.4 After new piston rings have been correctly gapped to their cylinder bores, they should be fitted to their pistons to check the clearance between the ring and the walls of the ring groove. If this clearance is too small there is danger that expansion of the ring will cause it to break or seize on the cylinder wall. Parallel-sided rings which are over-thick can be reduced by rubbing them on a dead flat surface to which a sheet of fine emery cloth has been fixed, the ring being sprung into a special holding tool with a suitable retaining groove. Tapered piston rings must not be rubbed down in this manner.

5.5 When fitting piston rings it should be ensured that they are all the correct way up (usually with the part number uppermost) and that the gaps are positioned according to the manufacturer's instructions; care should be taken to prevent the corners from scratching the piston. The piston should then be oiled to protect it from corrosion. Although most manufacturers only supply pistons that are within permissible weight tolerances and can therefore be fitted without any special weight precautions, piston weight variations may be critical in the case of a few engine types. When this is the case, the pistons should be weighed carefully and should then be selectively fitted in accordance with the manufacturer's instructions.

6 CONNECTING RODS This paragraph describes the inspection of connecting rods during top overhaul. Tests on connecting rods during complete overhaul are covered in Leaflet EL/3-3.

6.1 The surface condition of connecting rods is of great importance and a careful check should therefore be made for scores, nicks or signs of overheating. On some engines the rods may be checked for bow using a straight-edge and feeler gauges, but in most cases this will not be possible without removing the rods from the engine.

6.2 Using a torch, the external condition of the big ends should be inspected through the crankcase apertures. Top overhaul provides an opportunity for checking the end-float of the big-end bearings, either by inserting feeler gauges or by use of a DTI on the small end; if this is found to be excessive, further investigation is necessary.

7 TAPPETS, PUSH-RODS AND ROCKERS

7.1 Push-rods should be examined for dents, bending or looseness of end fittings, and the ball ends and sockets for wear and fretting. When push-rod springs are fitted, the manufacturers sometimes recommend that checks for spring length and strength be made after reassembly of the valve gear and cylinders. These checks are made with the valves closed but without the push-rod oil tubes fitted. Afterwards the oil tubes, which should be free from dents or cracks, should be assembled with new oil seals fitted at each end.

7.2 Rocker brackets require careful inspection for cracks, the penetrant dye method being recommended. The rocker arms should have been tested for excessive play before they were dismantled, but in any case the bearings and fulcrum pin should be measured to determine the amount of wear. Some manufacturers provide oversize ball bearings which can be fitted if the bore for the rocker bearing is enlarged or, as an alternative means of restoring the fit, allow the bores to be reduced by copper deposition.

7.3 Rocker arms with hardened end pads should be examined for wear of the pads. Light stoning to remove signs of fretting is permissible but badly-worn pads should be renewed. The threads of adjustable ball ends or contact pads should be in good condition. At the final stage of assembly the adjustment should be set to give the specified valve clearances.

8 REASSEMBLY General guidance on the reassembly of piston engines is given in Leaflet EL/3-4 but the following points should be noted before any engines are tested after top overhaul.

8.1 Engines which are not going to be run within seven days after reassembly should be protected against corrosion; guidance on suitable methods of protection is given in Leaflet EL/3-14.

8.2 Before any attempt is made to start and run an engine after reassembly, it is essential that warm oil be circulated round the engine to prime the oil-ways and bearings. A priming rig with a built-in heater is recommended for this operation, although the oil can be warmed before it is poured into the priming rig tank. If the engine is not run within three hours of priming, it should be reprimed.

8.3 To avoid hydraulic locking, the crankshaft should be turned through at least two revolutions by hand immediately before the engine is to be started. If there is any abnormal resistance to turning, rotation should not be continued until the lowest spark plug in each cylinder (or, on radial engines, one plug from each of the lowest two cylinders) has been removed.

9 TESTING AFTER TOP OVERHAUL After top overhaul it is essential that ground running tests be made to establish that the engine is functioning correctly and that the performance is satisfactory. The extent of the ground running necessary depends on whether parts have been renewed; if no parts have been renewed or if "run-in" parts only have been used to replace original parts, the ground run procedure should be that normally followed to re-establish the reference rpm. If new parts which have not previously been run-in have been fitted, they should be run-in according to a recognised procedure and the engine power should be assessed by comparing the rpm obtained before and after the top overhaul under corresponding conditions. Instructions for testing piston engines after top overhaul are sometimes, but not always, included in the Overhaul Manual for the engine concerned. When they are not available, e.g., in the case of foreign-built engines, the procedure outlined in paragraphs 9.1 to 9.7 should be used.

9.1 **Conditions of Test.** Testing after parts have been renewed during top overhaul should be done with the engine installed in the airframe, with the flight propeller and all accessories and cowlings fitted, and with the normal complement of engine instruments. If a cylinder head temperature gauge is not part of the installation, one should be provided for the test, the thermocouple being connected to the appropriate stud on what is normally the hottest-running cylinder. Alternatively, if there is no suitable stud, a ring-type thermocouple can be used at one of the sparking-plug positions.

9.2 To obtain the maximum cooling, the aircraft should be headed into wind. Corrections for wind speed are not practicable and therefore ground testing should be avoided as far as possible in conditions of strong wind.

9.3 **Starting and Warming Up.** After taking the normal precautions in regard to chocks, brakes, etc., the engine should be started and warmed up in the usual way. During the warming-up period, particular note should be taken of the oil pressure, cylinder head temperature and (if an oil temperature gauge is provided) the oil temperature; if the temperatures rise rapidly to above the permitted maximum continuous temperatures, or if the oil pressure is incorrect, the engine should be stopped and the cause should be investigated.

9.4 **Running-in Procedure.** When the oil temperature has reached the minimum opening-up temperature specified for the engine type and the oil pressure has stabilised, the engine speed should be increased by uniform increments of rpm over four or five stages. The engine should be run for 5 minutes at each stage, provided there is no overheating. If overheating occurs, it may be necessary to fit an oversize cooling scoop or to substitute a test fan for the flight propeller.

NOTE: If a test fan is fitted to improve cooling during running-in, it must be replaced by the flight propeller before making the power check detailed in paragraph 9.8.

9.5 The magnetos should be tested at each stage of incremental running by switching OFF each magneto in turn. The maximum rpm drop permitted for the engine type may be exceeded during these tests but, provided the drop is not excessive and it is within limits during the subsequent power check, no action need be taken at this point.

NOTE: For certain engine/propeller combinations, there are restrictions on running at particular rpm because of induced vibration. Vibration periods must be avoided by running the engine only at speeds above or below those at which vibration is known to occur.

9.6 When the final stage of incremental running has been reached, usually at about two-thirds throttle opening, the engine should be run for about 15 minutes, subject of course to the engine temperature limitations not being exceeded. If the engine has a variable-pitch propeller, it should be exercised at this stage. When the propeller control lever is moved to the minimum rpm position, a drop in engine speed should occur. Afterwards the lever should be returned to the maximum rpm position to ensure that the propeller blades are against the fine pitch stop, note being taken that the original rpm are restored.

9.7 **Helicopter Engines.** Although the test procedure for engines installed in helicopters is basically the same, the following special provisions apply:

9.7.1 The helicopter must be firmly anchored to the ground, using the holding-down procedure specified in the Service and Instruction Manual for the helicopter concerned. Before starting an engine in a helicopter, the engine should be turned through four or five revolutions on the hand-turning gear to ensure that the rotor clutch is out of engagement and that there is no hydraulic locking.

9.7.2 When warming up the engine, the rotor should be engaged as soon as the oil reaches the minimum permissible temperature for opening up. In the case of helicopters with automatic clutches, this entails opening up the throttle until the engine is driving the rotor. Helicopter engines should be run for as short a time as possible under "no load" conditions.

9.7.3 Before making the power check (paragraph 9.8), collective pitch has to be selected and this means that the helicopter will endeavour to rise and will strain against its tetherings. The fuselage will also have a tendency to rotate in the opposite direction to the rotor and this should be countered by manipulation of the rudder pedals.

9.8 **Power Check and Reference RPM.** The power check is made by running the engine under conditions which permit the observed rpm to be compared with rpm previously accepted for the same engine when it was run under corresponding conditions. The procedure differs according to whether the engine is normally aspirated or supercharged, since the effects of barometric pressure changes must be taken into account in the latter case (Leaflet EL/3-8).

NOTE: The procedure given in the following paragraphs should also be applied whenever a propeller is changed.

9.8.1 Normally-aspirated engines are tested at full throttle and, where a variable pitch propeller is fitted, with maximum fine pitch selected. The changes in barometric pressure affecting engine power are considered to be balanced by changes in propeller load, so that only a temperature correction is necessary. This correction factor may be obtained from a graph supplied by the engine constructor or, if this is not available, from the graph shown in Figure 1 of Leaflet EL/3-8. The observed full throttle speed multiplied by the correction factor will give the corrected speed.

9.8.2 The magnetos should be checked again at the specified rpm and the oil pressure and engine temperatures should be noted. The engines should not be run at full throttle for periods longer than are necessary to make these observations; thus, when they have been noted, the throttle should be eased back to a low rpm position (usually 1000) to allow the engine to cool off before it is shut down.

9.8.3 **Supercharged Engines.** The standard method of checking the power of a supercharged engine during a ground run is to run the engine at a specified constant manifold pressure with the propeller on its fine pitch stops, and to compare the rpm obtained under these conditions with the reference rpm established previously when the engine was run at the same manifold pressure. However, the comparison has little value unless both the observed rpm and the reference rpm are corrected to common temperature and barometric conditions, normally the conditions at sea-level on a standard day (101·3 kN/m² (29·92 in Hg) and 15°C). A method sometimes used to establish a reference rpm consists of noting the indication of the manifold pressure gauge before the engine is started and then noting the rpm registered when, with the engine running, the same manifold pressure is indicated. On subsequent runs an approximate check on engine power is possible by comparing the rpm obtained at this manifold pressure with the reference rpm. However, the more accurate method given in the following paragraphs is recommended after top overhaul, or after other major adjustments or replacements have been made on the engine.

9.8.4 After top overhaul the reference rpm should be re-established so that there is a rough datum for the detection of any subsequent falling-off in power. Since the disturbance of the engine will invalidate any previously established reference rpm, the results obtained will only give an approximate indication of any power changes caused by the top overhaul.

9.8.5 To establish the reference rpm, the throttle should be opened until the Maximum Take-off manifold pressure is reached and then closed until the manifold pressure stabilises at the pressure used on previous occasions to establish reference rpm for the particular engine. (The engine manufacturers sometimes recommend a specific manifold pressure for the engine type, usually about 36 inHg). The rpm should drop off as the throttle is brought back from the take-off position, thus indicating that the propeller is on its fine pitch stops. When the rpm and manifold pressure have stabilised, the rpm should be carefully recorded. The barometric pressure and local air temperature at the time of test should be recorded at the same time. The engine should then be shut down by the usual procedure.

9.8.6 The rpm observed during the above test must now be corrected to the conditions at sea-level on a standard day. To do this reference should be made to the charts in Figures 2 and 3, which may be used for all types of supercharged piston engines. These charts do not allow for design variations between different engine types but are sufficiently accurate for ground testing. The charts should not be confused with those of Leaflet **EL/3-8.** They should be used as follows:

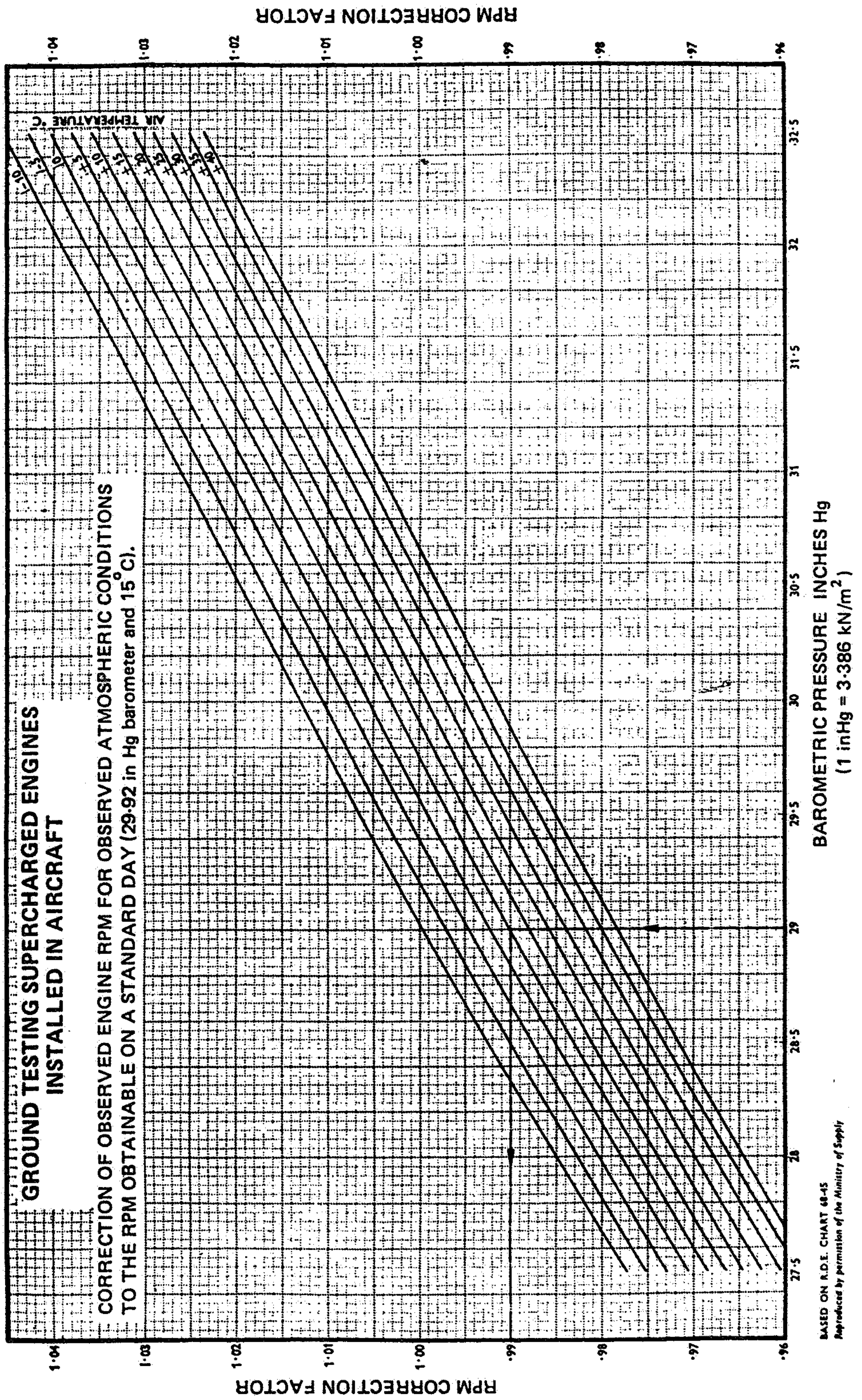
(a) Find the barometric pressure of the day on the horizontal scale of Figure 2 and project a vertical line from this point to intersect the oblique curve corresponding to the observed air temperature. Project a horizontal line from the point of intersection to the vertical scale and read off the rpm correction factor.

(b) The correction can be made by multiplying the observed rpm by this correction factor but, for convenience, the result may be obtained from Figure 3. To use Figure 3, read off the correction factor from the vertical scale and project a horizontal line from it; then read off the observed rpm from the horizontal scale and project a vertical line from it until the two lines intersect. The relationship of the point of intersection to the curves on the chart indicates the amount of rpm which must be added to or subtracted from the observed reading to give the corrected result.

EXAMPLE:—If the observed rpm are 2600 on a day when the barometric pressure is 29 in Hg and the air temperature is +10°C, the correction factor from Figure 2 is ·99. The intersection of the lines corresponding to 2600 rpm and ·99 correction factor on Figure 3 gives a value of approximately 25 rpm to be deducted from the observed results. The corrected rpm is therefore 2575, and this is the reference rpm which should be used as a standard for subsequent power checks made on the same engine.

9.9 **Acceptance Limits.** The rpm observed during the power check on a normally-aspirated engine, or the reference rpm established for a supercharged engine, should be compared with the figures obtained during previous checks made before the top overhaul. When assessing the results allowances have to be made for differences of environment such as wind strength, the proximity of buildings, etc., but in general the rpm values should be an improvement on those previously obtained. In any case the rpm should not be lower by more than about 3%. Differences greater than this may be taken as an indication that the power has fallen by an amount which warrants investigation and rectification. When satisfactory results have been obtained, the reference rpm established during the test should be recorded in the Engine Log Book.

10 AFTER TEST The exact procedure to be adopted after the completion of the test given in paragraph 9 should be determined by the number of items which have been renewed and the results of the power check. The following paragraphs give general guidance covering a number of typical cases.

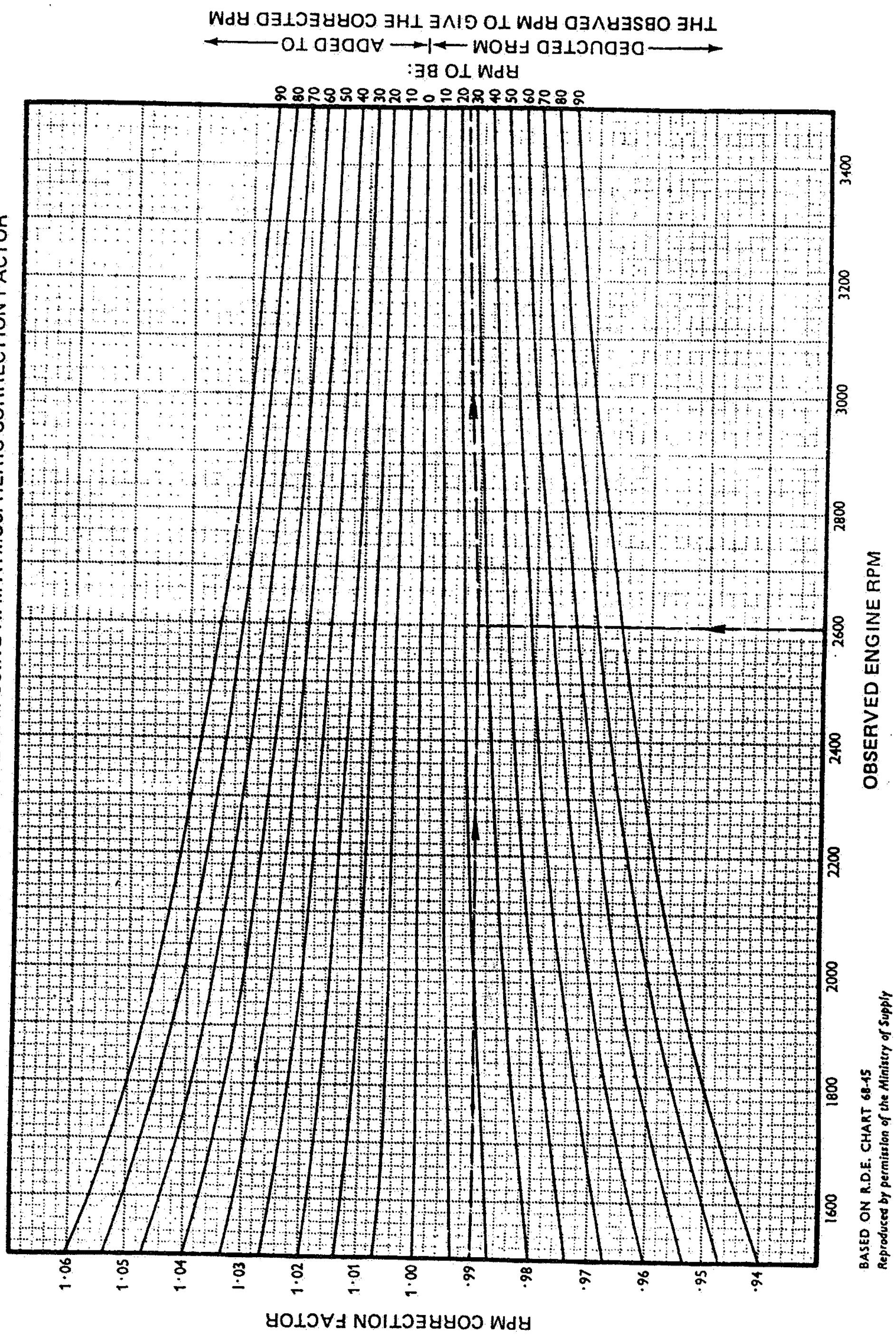


BASED ON R.D.E. CHART 68-45
Reproduced by permission of the Ministry of Supply

Figure 2

GROUND TESTING SUPERCHARGED ENGINES INSTALLED IN AIRCRAFT

CORRECTION OF OBSERVED ENGINE RPM USING RPM ATMOSPHERIC CORRECTION FACTOR



BASED ON R.D.E. CHART 68-45

Reproduced by permission of the Ministry of Supply

Figure 3

10.1 Provided that all aspects of the test run were satisfactory, after-test dismantling should not be necessary unless specified by the engine manufacturer. If the test run was not satisfactory, components which were renewed during the overhaul may require examination.

10.2 If cylinders have been removed a second time for an after-test examination, a final test should be made after reassembly. The final test should be as follows:

10.2.1 The engine should be started and warmed up until a safe oil temperature is reached. It should then be opened up until the throttle is about two-thirds open and a 10-minute proof run should be made. An ignition check should be made by switching OFF each magneto in turn.

10.2.2 A power check should then be made as described in paragraph 9.8. In the case of supercharged engines, the observed results should be corrected by means of the charts in Figures 2 and 3 and the results should be compared with the reference rpm established by the first power check. The new results become the reference rpm for future checks.

10.3 After testing engines which have received a top overhaul, the pressure and scavenge oil filters should be removed and examined for metal deposits. If metal is found it should be identified and, depending on the metal and quantity present, a decision should be made on whether further engine running and filter examination is necessary, or whether the engine should be dismantled for further investigation. If further test running is to be made, the oil tank and cooler should first be drained, flushed and refilled.

10.4 In cases where the results of the power check have not been satisfactory or where valves and valve seats have been changed or rectified, a compression check should be made.

10.5 Finally, the sparking plugs should be retightened, the tappet clearances should be checked and adjusted as necessary, and the tightness of the cylinder holding-down nuts should be checked. The appropriate details of the top overhaul and subsequent tests should then be entered in the Engine Log Book.

EL/3-3

Issue 2.

December, 1978.

AIRCRAFT

ENGINES

PISTON ENGINE OVERHAUL—COMPLETE OVERHAUL

1 INTRODUCTION This Leaflet is the third of the series dealing with engine overhaul and gives general guidance on the inspection of such parts as casings, shafts, bearings, gears and manifolds during complete overhaul. The inspection of cylinders, pistons and valve gear is dealt with in Leaflet EL/3-2.

2 CRANKCASES AND OTHER STRUCTURAL CASTINGS Crankcases, reduction gear cases, top, front and rear covers are subjected to static and dynamic loads which can cause cracks or slight distortion. Small cracks do not always necessitate the scrapping of castings but the manufacturer's guidance should always be sought regarding the amount of cracking which can be considered acceptable. Distortion is usually revealed by making checks on the machined faces of castings. Other points to be examined include all inserts, dowels and studs for condition and tightness, all stud and bolt holes for elongation and burring, and all mating surfaces for signs of fretting.

2.1 Torque reaction from the rotating crankshaft sometimes results in slight distortion of the crankcases of in-line engines. One check which is sometimes of value in showing up distortion is to fit an accurately-ground mandrel in the crankshaft position and, after tightening down the bearing caps, ensure that it can be turned freely. Such mandrels are often used for checking the alignment of the bearing bores after they have been bored, but can be used at this stage before the bearings are overhauled.

2.2 The upper and lower machined faces of an in-line crankcase should be checked for flatness with a straightedge and feeler gauges. The straightedge should first be laid lengthways along the machined flanges of the crankcase joint and then checks should be made with it laid across the crankcase in line with each main bearing station. If distortion is suspected, the studs can be removed and the machined faces can be checked again on a surface table. Another way of testing for distortion is to mount a dial test indicator (DTI) in a scribing block and run it along the machined flanges with the button of the DTI in contact with the bearing alignment mandrel.

2.3 The mating surfaces of castings which bolt on to the crankcase should be checked for flatness, either by using a surface table and engineers' marking or else by mounting them so that they can be measured for flatness with a DTI. The latter method is recommended for faces with protruding studs. Any high spots should be removed with a flat scraper, after which the mating surfaces should be placed together with marking on one surface. Further scraping may be necessary to obtain at least an 80% transfer of marking—which is about the minimum necessary to give a reasonable guarantee that each joint will be leakproof. On no account should machined faces be lapped with grinding paste or abrasives.

2.4 The crankcases of radial engines should be checked at the front and rear machined faces for flatness and parallelism, the bearing housings afterwards being checked for alignment and concentricity. Particular methods of carrying out these inspections will vary from engine to engine according to the design of the crankcase, and in some cases special jigs may be necessary for supporting DTIs and other measuring instruments.

2.5 If the cylinder barrels have caused fretting in the crankcase apertures, the remedial action should be in accordance with the approved salvage scheme. On some engines a repair can be effected by removing the cylinder holding down studs and counter-boring the apertures, after which shims have to be used to restore the original compression ratio.

3 CRANKSHAFTS In addition to a magnetic crack detection test, crankshafts should be carefully examined with a magnifying lens for scores and nicks. Particular attention should be given to splines, from which signs of fretting, corrosion or chipping should be removed by light stoning followed by a polish with fine emery cloth. Dimensional checks should then be made as follows:

3.1 The wear, ovality and taper of the crankpins and journals should be determined before any attempt is made to check for bow, twist or parallelism, otherwise misleading results may be obtained. As shown in Figure 1, readings should be taken with a vernier gauge or micrometer at points 90° to each other around the circumference at two or three stations along the length of each pin and journal; it is not sufficient to measure only at the central points between the crankwebs. If the dimensions are less than the permissible worn dimensions, the crankshaft can probably be trued up by regrinding.

3.2 Twist, bow and parallelism should be checked with the crankshaft supported by vee-blocks on a surface table at the front and rear journals. Twist should be considered over the whole length of the crankshaft: on a four-throw crankshaft with parallel-sided webs it can be detected by first ensuring that the rear crankweb is horizontal and then checking that a zero reading is obtained when a DTI, preset on the rear crankweb, is passed over each web in turn. In the case of a six-throw crankshaft, or any shaft with oval-shaped webs, it is necessary to check for twist and parallelism on the crankpins. Bow should be checked on the central journal, where it will be half the difference between the maximum and minimum dial indicator readings obtained when the crankshaft is turned through one revolution. The reason for this is made clear in Figure 1.

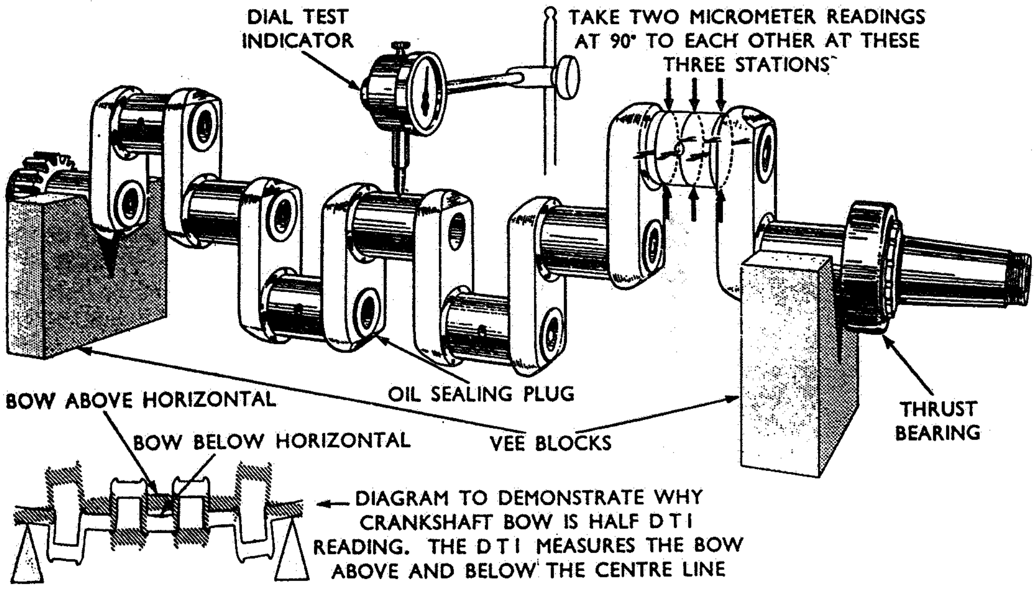


Figure 1 CHECKING A CRANKSHAFT FOR WEAR AND BOW

3.3 If vibration dampers are fitted to the crankshaft, they should be checked for security of attachment but should only be dismantled if defects are apparent or if dismantling is particularly specified. If they are removed for one of these reasons, the hardened steel bush in the crankweb lug should be crack tested. A small portable semi-permanent magnet type detector is suitable for this purpose. On reassembly, the securing screws must be renewed, the ends of the new screws being locked by peening.

3.4 The nose end of the crankshaft should be checked for distortion by turning the shaft through one revolution with a DTI in contact with the small end of the taper. This test is particularly important if the engine has been shock-loaded. A shock-loaded crankshaft may have suffered damage from twisting, bending or cracking. Bending will be indicated by lack of concentricity at the nose end and may be associated with cracking at the junction of the journals and webs.

3.5 After the inspection of the crankshaft is completed, the oil sealing plugs, provided they are in good condition, should be refitted and the crankshaft should be subjected to an oil pressure test to verify that they are oil tight. The oil holes in the journals and crankpins should be blanked off with rubber seals and metal clips, except that one should be fitted with a union for introducing the oil, and a pressure of 550 to 690 kN/m^2 (80 to 100 lbf/in^2) should be applied unless otherwise specified by the engine manufacturer.

4 BEARINGS

4.1 If the manufacturer does not recommend automatic replacement, the main and big-end bearing shells should be examined for condition of the bearing metal; inclusion of grit on the surface of white metal and wear and distortion are reasons for rejection. The adhesion of the bearing metal to its shell should be checked, and the quickest method of doing this is by means of the penetrant dye method described in Leaflet **BL/8-2.** If penetrant dyes are not available, the bearing can be immersed in oil at a temperature of 105°C for 15 minutes. It should then be removed from the oil and thoroughly dried, after which a mixture of French chalk and methylated spirit should be brushed over it. If, after a three-hour cooling period, staining of the chalk is evident, lack of adhesion is indicated and the bearing should be rejected.

4.2 Lead-silver bearings, lead-bronze bearings and thin-walled bearings with silver-lead-indium coatings should be checked for damage to the surface coating, signs of chemical attack, porosity and adhesion. Discoloration can be removed from silver-lead-indium surfaces by burnishing with a hardwood pencil stick.

4.3 The bearing housings and the bearing shells should be examined for signs of fretting. If fretting has occurred, relative movement between the shell and its housing is indicated and may be due to incorrect torque tightening of the bearing attachment nuts. Fretting may also be associated with enlargement of the dowel holes in the bearing shell or oversize bore in the bearing saddle.

4.4 Ball and roller bearings should be examined for signs of corrosion, pitting of the balls or rollers, cracks or scores, and excessive radial or axial movement of the inner race relative to the outer. Fretting marks on the outer race indicate that movement in the bearing housing is taking place: similar marks in the bore of the inner race indicate a loose fit on the shaft. A simple rig for checking the axial movement of ball bearings consists of a clamp made of mild steel with vee-shaped cut-outs arranged so that bearings of various sizes can be accommodated. The DTI is positioned to contact a bolt which is tightened down on to the inner race. The race is checked by moving the bolt up and down and measuring the end float on the DTI. Radial movement may be checked by a rig consisting of a base plate with the threaded end of a bolt protruding from it. The bearing should be placed over the bolt and the inner race clamped to the base plate by a circular plate and wing nut. The radial movement of the outer race relative to the inner can then be measured with a DTI. The outer race should be lightly gripped with one hand and moved only in a plane parallel to the movement of the DTI button.

5 CAMSHAFTS AND CAMRINGS

5.1 Camshafts should be checked for signs of flaking or chipping; minor roughness can be blended out with a stone. Using a profile gauge, the journals can then be checked for wear and ovality and the cams for profile. The shaft should then be checked for bow in the usual way by placing the shaft on vee-blocks on a surface table with a DTI in contact with its centre. The shaft should be turned through one revolution to obtain the maximum and minimum readings and the bow will be half the difference between the two readings.

5.2 The most practical way of testing the camshaft for twist is to reassemble it to the engine and compare the valve opening angles at the front and rear end of the shaft. The lift of the cams should also be checked when the engine is being reassembled.

5.3 Camrings for radial engines should be tested for flatness on a surface table. When checking the cam profiles it should be remembered that the cams may not be symmetrical in shape for design reasons. Minor scores on the profiles may be removed by light stoning but serious chipping necessitates renewal. Timing and lift should be checked after reassembly.

6 CONNECTING RODS

6.1 The bearings and housings at each end of a connecting rod should be checked for wear and ovality before the tests for bow and twist are made. For the latter tests the bearing shells should be removed and closely fitting mandrels should be used to mount the rods as shown in Figure 2. Figure 2 shows the method of setting up a rod to check for twist between the big and small ends; the jack is used to ensure that the centres of the two mandrels are in line when checked with the scribing block. With the connecting rod absolutely horizontal, any difference in DTI readings taken at equal distances each side of the small end will indicate the degree of twist.

6.2 Whilst the connecting rod is mounted as shown in Figure 2, it can also be checked for bending. The distance between the two mandrels should be measured on each side of the rod at points equidistant from the centre line of the rod; the two measurements should be the same.

6.3 Bore alignment should be checked with the bearing shells removed and again, using a different pair of mandrels, with them in position. For these tests the rod, supported by the lower mandrel resting on vee-blocks, should be vertical and the DTI should be passed across the small end mandrel at equal distances from the centre of the small end.

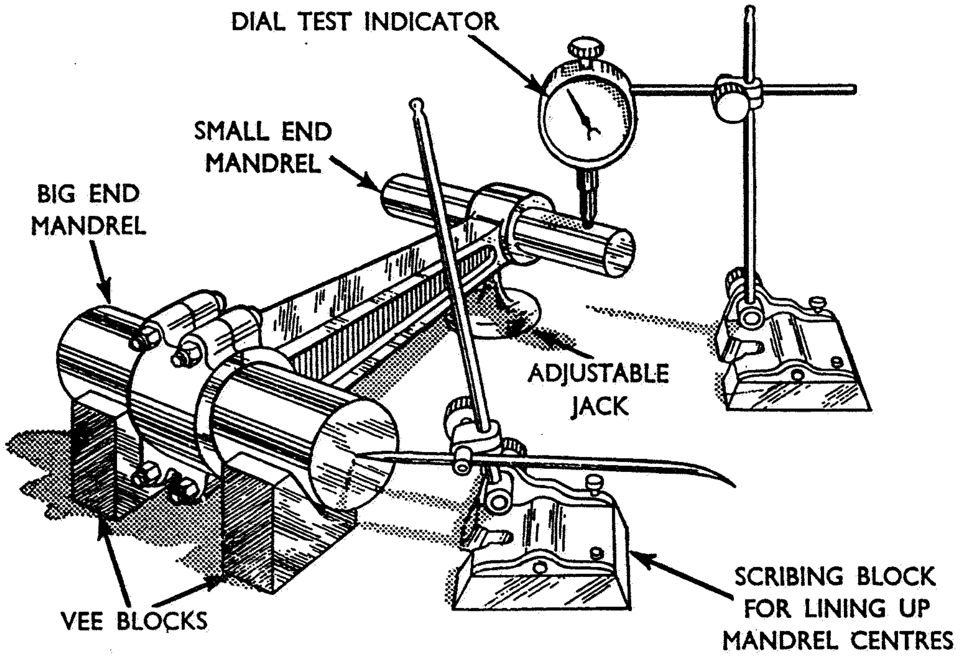


Figure 2 CHECKING A CONNECTING ROD FOR TWIST

6.4 After the rod has been tested for bow and twist with the bearing shells removed and after it has been verified that the big and small bores are in alignment with them removed, it may be found that bore alignment is not obtained when the bearing shells are replaced. This probably indicates that the bore of the big end bearing metal is out of true and may necessitate changing the bearing shells even if they are within the prescribed limits of wear and ovality.

6.5 Before refitting connecting rods they should be cleaned and, if specified for the particular engine type, reprotected as required by the manufacturer. If connecting rods are renewed, it may be necessary to check the weights and balance of the new rods. This should be done in accordance with the manufacturer's instructions. Some manufacturers recommend weighing each rod with its associated piston as a complete assembly.

7 GEARS

7.1 In addition to the magnetic crack detection tests covered in Leaflet **EL/3-1,** gears should receive a careful visual examination with the aid of a magnifying lens. Minor roughness on the teeth may be stoned out, but wear affecting the contact faces cannot be rectified.

7.2 Timing and reduction gears of the spur type should be checked for concentricity with a DTI. The most important check is between the axis of rotation and the pitch circle, since this is where most of the loading, and therefore the maximum wear, occurs.

7.3 Each tooth should be inspected along its full length for parallelism with the axis of the gear, since the bearing of a gear may wear unevenly and, in some cases, the gear itself may tend to slew out of its intended plane of rotation with consequent irregular wear on the teeth.

8 SUPERCHARGERS The impeller, shafts and gears of superchargers are subjected to severe running stresses and require careful examination for cracks during overhaul. Generally, these components should be tested by both the current flow and magnetic flow methods (Leaflet **BL/8-5**).

8.1 Impellers should be examined for nicks and indentations, for erosion of the vanes and cavity floors, and for fretting at the splines in the bore. The backlash between these splines and the matching splines on the impeller shaft should then be measured. With the impeller assembled to its shaft and with the shaft bearings mounted on suitable supports, a test for excessive "wobble" or "swash" should be made. To do this a DTI should be mounted so that its button is in contact with the backplate of the impeller near its periphery and the impeller should then be turned so that any deviation of the DTI reading can be observed and recorded.

8.2 Impeller drive gears are accurately balanced by the manufacturer and this balance may be disturbed when gear teeth are stoned to remove minor defects. A static balance test should therefore be carried out before supercharger drives are reassembled. A simple method of doing this is to mount each gear on a mandrel and place the mandrel across a pair of knife edges. If the gear wheel is in balance, it will not turn of its own accord from any position in which it is set. If it is out of balance, the manufacturer's instructions should be consulted to determine the position from which metal may be removed to restore the balance.

8.3 An important feature of the inspection of any supercharger is the determination of the backlash and end float of the various gear and shaft assemblies. The Schedule of Fits and Clearances will give details of each measurement which has to be determined.

8.4 If the impeller, its shaft or any parts which have been dynamically balanced with the impeller assembly are rejected during the inspection, the complete assembly fitted with the new parts must be rebalanced. This must be done on a dynamic balancing machine and it is customary to return the impeller assembly to the manufacturer for rebalancing.

9 OIL PUMPS

9.1 Increase in the end float of a gear-type oil pump permits the oil to be forced back to the suction side of the pump. To check for end float the pump should be completely assembled, mounted on a jig and positioned on a surface table; with a DTI rigidly bolted to the pump case so that its button contacts the end of the pump spindle, the end float can then be measured by raising and lowering the spindle to the limit of the clearance between the driving gear and its end bushes. The end float of the driven gear should then be checked using an extension rod to contact the DTI button. Excessive float should be corrected by renewing the bushes of both gears, this also being the remedy if the diametral clearance is excessive.

NOTE: Taking up the end float by reducing the length of the pump body should never be attempted since this upsets the pump output and precludes the replacement of parts on future occasions.

9.2 The diametral clearance of the gears should be checked by inserting a pair of feeler gauges between opposing sides of each gear and the pump housing. To check the backlash a pointer should be mounted on the spindle of the driven gear so that it contacts the button of a DTI. It is usual to make the point of contact at a distance along the pointer double the pitch-circle radius of the gear and then to take the backlash as half the DTI reading obtained when the driven gear is rocked against the fixed driving gear.

9.3 The piston and bore of the relief valve, if this is of the plunger type, should be checked for scores and freedom of movement. Relief valve or reducing valve springs should be renewed when necessary; no attempt to pack them up with washers should be made unless this method of adjustment is specifically recommended by the manufacturer.

9.4 All oil pump and oil filter bodies should be pressure tested for leaks at 1½ times their normal working pressure.

10 MANIFOLDS Induction and exhaust manifolds must be free from cracks, porosity and corrosion, particular attention being given to welds at flanges and joints. Flanges should be checked on a surface table with feeler gauges for freedom from distortion; it is important that their condition should be good to ensure leakproof joints when the manifolds are reassembled to the engine.

10.1 Induction manifolds should be pressure tested at the pressure specified in the appropriate Manual; typical pressures are 130 to 170 kN/m^2 (20 to 25 lbf/in^2) for the manifolds of non-supercharged engines and 345 kN/m^2 (50 lbf/in^2) for the manifolds of supercharged engines. All the apertures should be blanked off for the test, one of the blanking plates having a pressure gauge attachment and a Schrader valve connection for introducing compressed air.

10.2 When the manifold is pressurised, a leak test should be made to check for cracks and porosity. A simple test can be made by immersing the manifold in hot water and looking for bubbles. An alternative method is to whiten the exterior of the manifold with a mixture of French chalk and methylated spirit and to insert a small quantity of a 50/50 mixture of engine oil and paraffin in the interior before pressurising. The paraffin mixture will then be forced from any flaws in the manifold walls and will stain the white surface.

10.3 Leaflet **AL/3-8** draws attention to fire risks that can arise from damaged exhaust pipes and manifolds. Fluorescent or penetrant dye tests should be made on these items to find cracks but the high temperatures to which they are subjected may cause intergranular corrosion without any obvious external evidence. To test for this defect each exhaust manifold should be tested over its entire length for increase in magnetic permeability. Whilst the use of a permeability detector is recommended, the tendency of a horseshoe magnet to adhere to any part of the manifold can be taken as sufficient grounds for rejection.

11 REPAIR It is outside the scope of this leaflet to deal in any detail with repairs and rectifications since these vary from engine to engine and are covered in the approved salvage scheme for the engine type. On the completion of approved repairs, the inspector responsible for certifying that they have been carried out correctly should verify the following points:

(a) That the dimensions of all repaired parts correspond to the dimensions specified on the repair drawings.

(b) That all oil-ways and similar passages are free from burrs, swarf and foreign matter. Pressure tests and oil flow tests must be made as specified by the manufacturer and should be witnessed by the responsible inspector.

(c) That any heat treatments or protective processes have been carried out in accordance with approved specifications and that the condition of parts which have received such treatments has been assessed by appropriate inspection and tests.

(d) That all detail assemblies have been correctly put together and that all locking is satisfactory. The fit of split pins is important; they should always be tight in their holes and those fitted to rotating parts should preferably be at right angles to the direction of rotation.

(e) That full particulars of all repair work done are duly recorded as prescribed in Chapter A4—2 of British Civil Airworthiness Requirements.

EL/3-4

Issue 2.

December, 1978.

AIRCRAFT

ENGINES

PISTON ENGINE OVERHAUL—INSPECTION DURING ASSEMBLY

1 INTRODUCTION This Leaflet is the fourth in the series dealing with piston engine overhaul and gives guidance on the reassembly of engines which have been overhauled in accordance with the recommendations of Leaflets **EL/3-1, EL/3-2** and **EL/3-3.**

2 GENERAL Before reassembly commences, it should be verified that details of the dimensions and condition of all components have been recorded as detailed in Leaflet **EL/3-1.**

2.1 All engine parts should receive a final examination for cleanliness before reassembly commences. Scrupulous cleanliness is of course essential at all times during reassembly and care must be taken to ensure that no foreign objects find their way into the engine. All apertures should be blanked off until the appropriate connections are made to them.

2.2 Systematic inspection at each stage of reassembly is necessary to ensure that all mating parts are accurately aligned and fitted, that all locking is in accordance with approved methods, and that the torque-loadings, clearances, etc., are those recommended by the manufacturer. If new parts have been fitted they should receive particular attention, details of their part numbers, fits and clearances, and, if applicable, weights being entered in the Overhaul Records.

3 FITTING BEARINGS The first stages of reassembling an engine involve fitting the main bearings to the crankcase and the big-end bearings to the connecting rods. The majority of the information in the following paragraphs relates to the main and big-end bearings for in-line engines, most of which consist of steel-backed shells lined either with white metal, lead-bronze or some special combination of bearing metals. However, paragraph 3.1 gives some information on ball and roller bearings and is therefore applicable to the main bearings of radial engines, as well as to the thrust bearings of in-line engines.

3.1 With ball and roller bearings two fits are of importance, that of the outer race in the bearing housing and that of the inner race on the shaft. In neither case should the clearance be such that relative movement of the races can occur; if the clearance is excessive it may be permissible to reduce it, either by building up the external diameters of the races by the electro-deposition of chrome or nickel, or by building up the bore of the bearing housing by an approved method. Before attempting such salvage schemes the general condition of the bearing should be re-assessed since it is preferable to renew rather than repair a partially worn bearing. In some cases the engine manufacturers specify that all main ball and roller bearings must be renewed at each complete overhaul of the engine.

3.2 Shell type bearings must be assembled the right way round and in the correct order and must be a good fit in their housings in the crankcase, big ends and bearing caps. To ensure this, a check with engineers' marking should be made. Care should be taken to ensure that the shells are not held proud by poorly fitting dowels or keys, otherwise oil under pressure may force the bearing hard against the shaft. Salvage schemes usually make provision for fitting oversize dowels where the dowel hole has been enlarged.

3.3 On some engines the "nip" of the bearings should be checked by assembling the caps on to the complete bearings and tightening the holding-down bolts to the correct torque value. All the nuts should then be released a little until resistance to rotation ceases, when the nip of the cap on the bearing can be measured by running feelers around each side of the cap. In the case of white-metal or other thick-walled bearings, too large a gap, i.e. excessive nip, can be corrected by rubbing down by an equal amount the edges of each half-shell, using fine emery paper laid on a flat surface such as a piece of plate glass. Thin-walled bearings should be selectively fitted to give the required nip.

NOTE: The bearing housings of horizontally-opposed engines are part of each crankcase half, and provided the crankcase has been checked for distortion on a surface table, bearing shells do not normally need to be checked for "nip" during assembly.

3.4 The diametral clearance of each shell type bearing on its corresponding crankpin or journal should be checked by micrometer measurements. It is essential that the specified minimum clearance all round the shaft is obtained to ensure the maintenance of an oil film when the engine is running. A further check can be made by assembling the shaft and bearing with engineers' marking, tightening down to the specified torque value and rotating the shaft so that the high spots are marked. If the clearance is inadequate or if less than 80% surface bearing contact is obtained, the bearings (provided they are not of the thin-walled type) should be trued up with a bearing boring bar. After boring, the radii at the edges of each bearing must be recut, using the special tools supplied by the engine manufacturer. In some instances, hand scraping may be used to remove high spots from the bearing surface but it is a more tedious method and requires more skill than boring.

NOTE: The practice of measuring the diametral clearance by strips of paper or lead wire is not recommended as it may cause damage to the bearings. However, an exception is made in the case of certain thin-walled bearings which, because of their springiness, are tested with thin strips of oiled paper.

3.5 Some salvage schemes permit the fitting of replacement bearing shells which are oversize on their outside diameters. These are used in instances where the bores of the bearing housings are found to be malaligned or damaged by fretting, corrosion, etc. The bores are first machined out to take the appropriate oversize bearing (there are often three or four stages of oversize allowed), after which the bearings are fitted and the diametral clearance is checked as in paragraph 3.4.

3.6 If the crankshaft has been ground because the journals were oval or worn, the bearing shells should be replaced with shells which are undersized on their internal diameters. The bearings may require boring to ensure that they are correctly aligned and to obtain the correct diametral clearance at each journal. After boring, the bearing radii must be recut and the width of each bearing should be reduced by means of the appropriate cutter so that the side clearances between the bearings and the crankwebs are left slightly smaller than those specified in the Schedule of Fits and Clearances. This means that enough metal is left on the width of each bearing for a final cut to correct these clearances after the crankshaft has been centralised.

3.7 After boring, the bearings should be examined for concentricity, i.e. the bearing metal should be of equal thickness all round the walls of the shells. Lack of concentricity may indicate distortion of the crankcase.

3.8 Thin-walled bearings are a special case and cannot be bored; if they are in any way unsatisfactory in respect of nip, alignment or clearance, they should be renewed.

3.9 When the bearing clearances and alignment have been correctly adjusted, it should be verified that the oil holes are correctly aligned. The journal bearing caps should be fitted to the crankcase with the shells in position and then oil should be pumped through the oil galleries of the crankcase to check that all oilways are clear.

4 FITTING THE CRANKSHAFT The sequence of assembly varies according to the type of engine; the crankshaft of a radial engine is usually mounted on a special stand and the crankcase is assembled around it, whilst it is the crankcase of an in-line engine which is first mounted, the crankshaft and connecting rod assembly being offered to it. With horizontally-opposed engines one half of the crankcase is mounted on its side in a stand, the crankshaft and connecting rod assembly is lowered into position, and the other half of the crankcase is then assembled and secured.

4.1 In the majority of cases the crankshaft should be supported on a stand whilst the connecting rods are fitted, but there are one or two engine types in which the crankshaft is first installed in the crankcase. In either case the big-end cap nuts should be tightened down in the sequence recommended by the manufacturer, each nut being correctly torque loaded but not locked at this stage. Centralisation checks should then be made so that the bearings can, where specified, be machined to give the required side clearance.

4.2 The first check at this stage of reassembly is for crankshaft end float and main bearing side clearance. The crankshaft must be married to the crankcase for these checks, all the main bearing caps being tightened down to the correct torque value. The test for end float is made by tapping the crankshaft fore and aft; generally no end float is allowed and if any is detected it will be necessary to remove the crankshaft and change the front thrust race. The side clearances at the main bearings should now be checked with feeler gauges. If it is found that they are incorrectly distributed fore and aft, it will probably be possible to make a correction by fitting shims between the shoulder at the front of the crankshaft and the inner track of the thrust-race; the shims will not affect the end float but will reposition the crankwebs relative to the bearings.

NOTE: Horizontally-opposed engines often have plain thrust bearings, and crankshaft end-float is usually checked by inserting feelers between the faces of the thrust bearing and the cheeks of the adjacent crankshaft webs.

4.3 When the crankshaft has been centralised, the width of the main bearing shells should be reduced as necessary to give the correct side clearances. These clearances are sufficiently generous to allow for expansion of the crankcase relative to the crankshaft.

4.4 Final adjustment of the width of the big-end bearing shells should be made after the centralisation of the small ends has been checked. In the case of in-line engines, the small end check is made by assembling the crankshaft, complete with connecting rods, to the crankcase and then fitting the pistons and cylinders. The side clearances at the small ends can then be measured by inserting feeler gauges through the top or bottom of the crankcase and into the cylinder bores. If the check has to be made on a radial engine, it is usually necessary to fit the pistons and cylinders one at a time, removing each one as it is checked so that access can be obtained to the next through the adjacent cylinder apertures. Equal clearances should be obtained each side of each small end, and the clearances themselves should be within the limits specified in the Schedule of Fits and Clearances. If the connecting rods are not central between the gudgeon pin bosses, the connecting rods must be taken off again. They should then be mounted in a jig so that the width of the big-end bearing shells can be trimmed with the appropriate cutter. The rods can be centralised by removing metal from the side of the bearing which is on the same side as the smallest clearance found at the small end of each rod.

4.5 When the small-end clearances have been corrected and the widths of the big-end bearing shells have been cut to final dimensions, the connecting rods should be assembled to the crankshaft and all bolts and nuts should be tightened down and split-pinned. The nuts must be torque-loaded to the specified value and thereafter must not be slackened back to align the split pin holes. If the holes do not align, the nuts should be taken off again and reduced on their underfaces by rubbing them on an emery-covered block. After the connecting rods have been finally tightened, a check for freedom from binding should be made by moving each rod to the vertical position and checking that it falls slowly but freely when released.

4.6 The crankshaft complete with connecting rods should next be married to the crankcase again and all the main bearing caps should be tightened down with a torque spanner. The order of tightening is important; for a typical in-line engine it is usually middle, end and intermediate caps in that order.

4.7 An oil pressure test on the crankcase and crankshaft assembly is necessary to detect leaks from the oil seals, to ensure that the oil passages are free and to distribute oil through all the galleries and oilways. With some kinds of in-line engine, this test is carried out by substituting a specially prepared top or bottom cover for the normal crankcase cover. The special cover is cut away to permit observation of the interior of the engine during the test. Double the normal oil pressure is usually specified for this test and the crankshaft should be rotated whilst the pressure is applied.

5 FITTING SHAFTS AND GEARS It is not possible to give detailed guidance on checking shafts and gears because the pattern of these varies so much from engine to engine. For this reason the following paragraphs deal with general principles rather than specific applications.

5.1 The camshafts of small in-line engines are usually housed within the crankcase and are installed before the crankshaft is replaced. The clearances at the camshaft bearings must be within limits; if they are excessive, it may be permissible to correct them by fitting new bearing bushes. New bushes usually require reaming to size and sometimes it is necessary to drill oil holes after the bushes are in position. All swarf must be carefully cleared away and the bushes must be generously smeared with engine oil before the camshaft is fitted. When the shaft is fitted, it must be checked for end float and for freedom of rotation. End float is usually measured with feelers between the shoulder on the shaft and the rear bearing.

5.2 After an internal camshaft has been installed, the tappets and guides should be replaced and correctly aligned with their respective cams. A check for tappet alignment can be made by coating the tappet rollers or shoes with engineers' marking, rotating the camshaft and checking the transfer of marking to the cams. A 90% transfer is desirable and can usually be obtained by slackening off the tappet guide retaining nuts (the studs pass through clearance holes) and re-aligning the tappets.

5.3 All gears and gear trains should be checked for backlash before and during assembly to the engine. Backlash should be checked at more than one position on each gear, the maximum possible number of combinations of gear position being the ideal.

5.4 Checks on end float are usually specified after the installation of cam rings, layshafts, quillshafts, gears, etc. In some cases feeler gauges can be used for these checks, but sometimes it is necessary to mount a DTI in a convenient position for measuring end float. Adjustment of end float is usually obtained by packing with shims or washers, but these must only be used when and where specified by the manufacturer. At all times during the assembly of drives and gears, it is necessary to ensure that each item is inserted in its correct order, is facing the correct way, is free to rotate without binding and is locked with new locking devices of the correct type.

6 ASSEMBLY OF COVERS AND ANCILLARIES

6.1 When assembling sumps, top, front or rear covers or supercharger casings, their location, and the alignment of any bearings integral with them, should be checked before the holding-down nuts are tightened. After a top cover or sump has been placed on a crankcase, a check should be made with feeler gauges for any indications of 'holding-off' at the face joint. When it has been verified that the cover or casing is a good fit at the case, the nuts on the studs and bolts should be tightened in a predetermined order.

6.2 Reduction gears are usually built up as complete sub-assemblies before they are offered to the engine. The separate spindles, gears and washers are normally given group numbers so that all the components of a particular planet-gear group can be reassembled in their original positions. Certain teeth on intermeshing gears will probably be marked to indicate the particular positions in which they have to be meshed together. On completion of the prescribed backlash and end float checks, the reduction gear assembly should be submitted to an oil flow test. Special adapters will have to be fitted to introduce the oil into the rear end of the propeller shaft. It should then be pumped at a pressure one and a half times the normal engine oil pressure, whilst a check is made that it emerges freely from the planet gear spindles and sun gear. If the propeller shaft is of the kind which feeds oil to a variable pitch propeller, the oil flow through the oilways from the constant-speed unit mountings should also be checked and the oil feed sleeves should be examined for leaks. When fitting a reduction gear assembly to an engine, it should be carefully aligned, preferably with the axis of the engine vertical, to ensure that there is no strain on the case when the bolts are tightened.

6.3 Superchargers are also built up in a similar manner to reduction gears as complete sub-assemblies, although the drives and gears will probably have to be mounted on the rear of the engine before the supercharger case is offered up. Great care is necessary to ensure that all bearings, cones, oil seals, washers, etc., are assembled in the correct order and facing the right way, and at all times during the assembly and checking of superchargers it is essential that close attention should be paid to the manufacturer's instructions. Concentricity checks are normally made on the impeller by rotating it with a DTI mounted so that its button is in contact with the tips of the vanes. The clearance between the impeller back plate and the front case of the impeller is usually measured by inserting a depth gauge through a suitably positioned hole in the back plate. Other checks specified will vary according to the particular design of supercharger but in most cases will include an oil flow check.

6.4 When assembling such items as pumps, starters and generators to an engine, only gaskets and washers approved for use on the engine concerned should be used, since any variation of thickness of these items may result in damage to the driven unit or to the driving gear of the engine. Only jointing compounds of the types specified by the manufacturer are to be used, and care must be taken that only sufficient is applied to cover the faces of the joint without any excess to be squeezed out when the joint is tightened. In particular it is necessary to ensure that jointing compound cannot enter fuel pumps or carburettors, where it could cause obstruction, or oilways, where it would restrict the oil flow.

7 FITTING PISTONS AND CYLINDERS

7.1 When refitting piston rings, thin metal strips should be used to enable them to be manoeuvred into their grooves without breaking them. Generally all piston rings are renewed at overhaul but if the original rings are to be refitted, they should be replaced in the grooves from which they were originally removed. Care must be taken that all rings are fitted correctly; this is obviously important with unsymmetrical scraper rings, but some types of compression rings are also marked to indicate that they must be installed with a particular side towards the crown of the piston.

7.2 The procedure for fitting cylinders is much the same for all air-cooled engines. The appropriate connecting rod should first be turned to the top and the piston should then be assembled to it. New gudgeon pin circlips should be fitted, where appropriate, using the circlip fitting tool provided in the tool kit. The piston ring gaps should then be equally spaced on the piston and the ring compressor sleeve should be fitted. The cylinder bore should be well oiled, a new sealing ring should be fitted over the spigot and the cylinder should be slid over the piston until the piston is completely within the bore. After removal of the ring compressor, the cylinder should be pushed right home. If the cylinder barrel is of the type that screws into the crankcase, the threads should be engaged carefully and the cylinder should be screwed right home before the next one is fitted.

7.3 When copper cylinder head washers are to be fitted at cylinder head to barrel joints, it is an advantage to anneal them before fitting. To do this they should be heated for 5 minutes to a red heat by any convenient method that will ensure a uniform temperature of approximately 600°C, and should then be quenched in cold water.

7.4 When the cylinder heads of an in-line engine have been placed in position and secured by finger-tightening the holding-down nuts, an alignment check should be made with a straightedge laid across the machined faces of the valve ports. The nuts should then be tightened down evenly and a final check should be made to confirm that the alignment has not been disturbed.

8 VALVE AND MAGNETO TIMING

Since the procedure to be adopted in timing the valves will depend on the engine type, only a few remarks of a general nature can be made in this leaflet. Magneto timing and synchronisation is covered in Leaflet **EL/3-9.**

8.1 Valve timing should not be commenced until the valve clearances have been set to the timing clearances recommended by the manufacturer. To allow for cylinder expansion when the engine is running, the clearances should be reset to the normal running clearances on completion of the timing operations.

8.2 After the crankshaft has been set to the required position by aligning the appropriate marks on the timing disc with a fixed pointer, the camshaft and valve gear should be set so that the No. 1 exhaust valve is just about to open. Without moving either the crankshaft or camshaft, the two are then linked together by inserting the appropriate shaft or gear. The link is usually designed on a vernier principle so that a fine adjustment may be obtained if the initial timing does not give the exact opening times specified in the Overhaul Manual.

9 OTHER ASSEMBLY WORK The overhaul and fitting of carburettors, fuel pumps, boost control units, etc., is not covered in this series of leaflets but detailed instructions will be found in the appropriate Service and Instruction Manual. Guidance on the testing and inspection of fuel and oil pipes is given in Leaflets **AL/3-13** and **AL/3-14,** and information on various other engine accessories and components is contained in other Civil Aircraft Inspection Procedures Leaflets.

9.1 Sparking plugs are not usually fitted until the engine is prepared for running and thus dummy plugs should be fitted to exclude dirt from the cylinders. Leaflet **EL/5-1** covers the cleaning and overhaul of plugs and gives the precautions to be taken when refitting them.

9.2 When the main assembly work has been completed the engine should be subjected to a systematic inspection to ensure that all nuts have been correctly tightened, that all locking is satisfactory and that the engine controls have been correctly adjusted. When this inspection is completed, the cylinder cooling baffles should be fitted. Care is necessary during the fitting of baffles and airscoops otherwise the cooling of the engine may be adversely affected.

10 AFTER OVERHAUL On completion of the inspection of an overhauled engine, the inspection records should be completed and signed by the responsible inspector or licensed aircraft engineer. The requirements for recording overhaul and repair work are given in Chapter A4—2 of British Civil Airworthiness Requirements and further guidance is given in Leaflet **BL/1-10.** Before being released for installation in an aircraft, the engine must be tested in accordance with the CAA's requirements for testing piston engines after overhaul. These requirements are given in Section C of British Civil Airworthiness Requirements and those parts relevant to the testing of small air-cooled engines are reprinted in the subsequent Leaflets of this series.

EL/3-5

Issue 2.
December, 1978.

AIRCRAFT

ENGINES

PISTON ENGINE OVERHAUL—TEST REQUIREMENTS FOR OVERHAULED ENGINES

1 INTRODUCTION This Leaflet is the fifth in the series dealing with piston engine overhaul. After an engine has received a complete overhaul it must be tested as prescribed in Section C of British Civil Airworthiness Requirements; this Leaflet includes certain parts of the Requirements which are relevant to the testing of the low-power, air-cooled engines covered by the series. There are no requirements in Section C for testing piston engines after top overhaul but the CAA's recommendations are given in Leaflet EL/3-2.

1.1 The test procedure prescribed for piston engines after overhaul includes an Endurance Test followed by a strip examination and a Final Test during which the performance is determined. Engine manufacturers in the United Kingdom prepare Test Schedules and instructions which are approved by the CAA for use when testing particular engine types. These schedules are based on the appropriate schedule from the Requirements (Schedule 1 or Schedule 2 of this Leaflet) and the Engine Technical Certificate. Persons or approved organisations responsible for the overhaul and testing of aero-engines should obtain copies of these schedules from the manufacturers or, in the case of engines for which such schedules are not available, should compile their own and submit them to the CAA for approval.

1.2 Leaflets EL/3-6 and EL/3-7 give guidance on dynamometer testing and fan testing respectively, and, in each case, include the applicable acceptance conditions prescribed in Section C of the Requirements. Leaflet EL/3-8 contains the performance corrections to be applied during dynamometer testing and also explains the correction procedure to be used during the calibration of test fans.

2 APPLICABILITY OF OVERHAULED ENGINE TESTS

2.1 Overhauled engines intended for use in aircraft for which a certificate of airworthiness is sought must be submitted to the tests prescribed in the schedule appropriate to the engine, except that the CAA will consider alternative methods and conditions where it is satisfied that, for technical reasons, those prescribed in the Requirements cannot be complied with.

2.1.1 The schedule appropriate to the engine depends on whether the engine is rated in accordance with the Requirements in force before or after the 18th November, 1946. Schedule 1 prescribes the tests for engines with ICAO ratings, i.e. engines rated after the above date, and Schedule 2 prescribes the tests for engines with pre-ICAO ratings. Any alternative methods and conditions which necessitate departure from the appropriate basic schedule in the Requirements will be incorporated in the manufacturer's schedule and will be individually approved for that engine type only.

2.1.2 The Requirements for testing overhauled piston engines intended for installation in helicopters are the same as for engines intended for use in fixed-wing aircraft, except that the engines must be tested in the attitude in which they will be installed in the helicopter, and wherever reference is made to Maximum Take-off Power this shall be taken to read Maximum One-hour Power.

2.2 The tests are presented in two groups, the first constituting an Endurance Test intended primarily as a loading check of the engine and an indication of the power performance and fuel and oil consumptions, and the second group a Final Test made, after dismantling, inspection and reassembly, to determine the performance of the engine prior to acceptance.

2.3 All test equipment must be of an approved type and the test bench must be equipped with an approved range of instruments to enable accurate indication of the relevant test data specified in the test schedule appropriate to the engine. The instruments and all measuring equipment must be calibrated periodically and thereafter checked for accuracy at regular intervals, as agreed with the CAA.

3 TEST CONDITIONS The Requirements state that the tests shall be run in the sequence given in the schedule and in accordance with the general requirements prescribed for engine testing and the particular requirements prescribed for testing overhauled engines. Both the general and the particular requirements in which the test conditions applicable to the testing of low-power, air-cooled engines are prescribed, are included in the following paragraphs.

3.1 **Artificial Humidity.** No artificial means of increasing the humidity of the ambient air shall be employed.

3.2 **Fuel and Oil.** Fuel and oil as approved for the prototype engine (unless otherwise agreed by the CAA) shall be used for all tests. The CAA may require a check of the specific gravity of the fuel and oil to be made. The CAA may also require representative samples of the fuel and oil to be taken for analysis.

3.3 **Controls and Adjustments**

3.3.1 Such automatic controls as may be provided shall be in operation.

3.3.2 Adjustments (i.e. variable devices not intended to be varied in flight or ground handling) shall be set prior to each test in accordance with the manufacturer's instructions.

3.3.3 Controls (i.e. variable devices which are intended for use during flight or ground handling) shall be operated in accordance with the manufacturer's instructions.

3.3.4 Adjustments shall be checked and unintended variations from the original settings recorded—

(a) At each strip examination.
(b) When adjustments are reset because the nature of a test clearly demands it.
(c) As required by instructions relating to specific tests.

3.3.5 The manufacturer's instructions referred to in 3.3.2 and 3.3.3 shall be those which are incorporated (with such minor alterations as the CAA may permit) in the Overhaul Manual for the engine type.

3.4 **Engine Parts Replacement during Test.** If, as a result of the tests, replacement of any major component or part is necessary, the test shall be repeated unless otherwise agreed by the CAA.

3.5 **Temperatures.** Cooling conditions shall be controlled so that for each running condition the declared maximum operating temperatures for inlet oil or cylinder head temperatures (measured on the hottest cylinder) are maintained throughout the stage, except that for runs of not more than five minutes duration such temperatures need be maintained for one minute only. A tolerance of ±5°C shall not be exceeded on the cylinder head temperature and of ±3°C on the oil temperature.

3.6 **Engine Accessories.** Engine accessory drives, other than those essential to the satisfactory functioning of the engine, shall be suitably loaded by slave accessories or by a suitable brake, or by rig tests. Accessories not essential to the satisfactory functioning of the engine need not be fitted during the Final Test.

3.7 **Test Fans which may be used.** When an engine is to be tested using a fan, the type of fan to be used shall first have been approved by the CAA as being suitable for the particular type of engine and test cell, and the particular fan to be used shall have been satisfactorily calibrated on an engine of known power in the test cell in which it is to be used in accordance with the instructions issued by the engine manufacturer.

3.8 **Engine Performance Assessment with Test Fans.** When tests are made using fans, the rpm obtained is used as an indication of the power obtained except when approved torquemeters form part of the engine being tested. If there is no torquemeter, no attempts shall be made to quote the output in terms of power and no specific fuel consumption shall be assessed.

3.9 **Limitations not simultaneously attainable when using Test Fans.** If when using a test fan the maximum manifold pressure and crankshaft rotational speed appropriate to the conditions of the tests cannot both be obtained concurrently, the individual periods of the test shall be run at whichever limitation is reached first, except that during the stages to be run at Maximum Cruising or Maximum Continuous Power the observed power of the engine in each supercharger gear shall be not less than 90% of the established Maximum Cruising or Maximum Continuous Power for the Type engine at sea-level respectively.

4 OBSERVATIONS

4.1 Throughout the tests observations shall be made as prescribed in the Observations column associated with the stage or test. The numbers entered in the Observations columns shall be interpreted in accordance with the code given in 4.3.

NOTE: Where the letters N.A. appear in the code it signifies that the observation prescribed in British Civil Airworthiness Requirements against this code number does not apply to the testing of the low-power, air-cooled engines with which this series of Leaflets is concerned.

4.2 Engine operating conditions shall be allowed to stabilise before observations are taken. In particular, during the rating tests observations taken less than 3 minutes after a change in engine operating conditions shall not be included in the performance curves.

4.3 Test Observations Code

Ref. No.	Observation	Standard Units
1	Crankshaft rotational speed	rpm
2	Manifold pressure	kN/m^2 or kPa (inHg)
3	Main oil pressure	kN/m^2 or kPa (lbf/in^2)
4	Auxiliary oil pressure	kN/m^2 or kPa (lbf/in^2)
5	Oil pressure at inlet to pump	kN/m^2 or kPa (lbf/in^2)
6	Fuel pressure at inlet to carburettor or injector	kN/m^2 or kPa (lbf/in^2)
7	N.A.	
8	N.A.	
9	N.A.	
10	N.A.	
11	Oil inlet temperature	°C
12	Oil outlet temperature	°C
13	N.A.	
14	N.A.	
15	Cylinder temperature	°C
16	Cooling air temperature (in front of engine)	°C
17	Cooling air speed (or pressure difference)	m/s or kN/m^2 or kPa (mile/h or inH$_2$O)
18	N.A.	
19	N.A.	
20	Oil circulation rate	litre/h (gal/min)
21	Oil consumption	litre/h (pint/h)
22	Fuel consumption	kg/h or litre/h (lb/h or pints/h)
23	Air intake temperature	°C
24	Power developed	kW (BHP)
25	Exhaust back-pressure	kN/m^2 or kPa (lbf/in^2)
26	Test-house barometer	kN/m^2 or kPa (inHg)
27	Air intake pressure	kN/m^2 or kPa (inHg)
28	Temperature of air passing propeller or test fan	°C

5 GENERAL CONDITIONS

5.1 Each stage of the Tests shall be run non-stop. In the event of a stop occurring during any stage, the stage shall be repeated unless the CAA considers this to be unnecessary. The CAA reserves the right to require the complete test to be repeated if an excessive number of stops occurs.

5.2 Throughout each stage of the Tests, the crankshaft rotational speed and manifold pressure shall be maintained at, or as near as possible to, the declared maximum values appropriate to the engine operating conditions prescribed. The CAA may require a repeat run if, for any reason, the observed crankshaft rotational speed and manifold pressure deviate by more than ±1½% from the declared maximum values.

6 ENDURANCE TEST

6.1 The Endurance Test of the Schedule appropriate to the engine shall be made with the engine either fitted with a propeller or test fan, or coupled to a dynamometer or other approved means of absorbing the power output of the engine. In the event of a propeller or test fan being used, the CAA may be prepared to accept such deviation from the test conditions as may be necessary to enable one propeller or test fan only to be used. The engine manufacturers or overhaulers shall, in agreement with the CAA, establish the equivalent standards of performance (e.g. fuel consumption, oil consumption, etc.) to meet any such deviations.

6.2 Where any of the Engine Rating conditions of Stages 7, 8, 10 and, where applicable, 10a are similar, one run only need be made at the particular conditions, except that the run shall be repeated in each supercharger gear.

7 STRIP EXAMINATION Upon completion of the Endurance Test, the engine shall be dismantled for examination. The extent of any deviation from the complete strip examination which may be permitted will be decided by the CAA after due consideration of the quantities, and functional and inspectional standards of the initial batches of engines. After inspection, the engine shall be rebuilt for submission to the Final Test.

8 FINAL TEST

8.1 The Final Test of the Schedule appropriate to the type of engine shall be made with the engine either fitted with a test fan or mounted on a dynamometer test bench.

8.2 Where, due to the limitations of a test fan, standard test conditions cannot be attained, the engine overhauling agency shall, in agreement with the CAA, establish the equivalent standards of performance (i.e. fuel consumption, oil consumption, etc.).

8.3 Where any of the Engine Rating conditions of Stages 7, 8, 10 and 10a are similar, one run only need be made at the particular conditions, except that the run shall be repeated in each supercharger gear.

9 ACCEPTANCE CONDITIONS Apart from the general running standard of each engine and its ability to satisfactorily complete the tests laid down in the Requirements, the specific standards of performance appropriate to the engines tested shall be attained to the satisfaction of the CAA. These standards are given in Leaflet **EL/3-6** for dynamometer tested engines and in Leaflet **EL/3-7** for fan tested engines.

10 CERTIFICATE OF COMPLIANCE A Certificate of Compliance should be issued for each aircraft engine after the overhaul and testing have been satisfactorily completed.

SCHEDULE 1

OVERHAULED PISTON ENGINES

TESTS FOR ENGINES RATED IN ACCORDANCE WITH THE REQUIREMENTS IN FORCE ON AND AFTER 18th NOVEMBER, 1946 (ICAO RATINGS)

1 GENERAL Detailed requirements associated with the tests of this schedule are given in the text of this Leaflet, acceptance conditions are given in Leaflets EL/3-6 and EL/3-7 and correction formulae in Leaflet EL/3-8.

2 ENDURANCE TEST

Stage	**Duration**	**Operating Conditions**	**Observations** (See paragraph 4 of text)
1	—	Engine run-in light under its own power and then opened up in incremental stages of speed and load until Maximum Continuous Power is attained. Duration and conditions of speed and load for the various stages as agreed by the CAA.	
2	—	Tuning and preliminary tests of the fuel metering and ignition systems, and any other tests considered necessary by the CAA to ensure satisfactory operation of the engine up to, and including, Maximum Continuous Power. The tests shall be repeated in each supercharger gear.	
3	2 Hours	Maximum Continuous Power. Running equally divided between the supercharger gears.	Every 15 mins. 1, 2, 3, 8, 11, 14, 15, 22, 24. Beginning and end 4, 6, 7, 9, 13, 17, 23, 25, 28. At beginning 26. Throughout 21. During this Stage 20*.
4	30 Mins.	Maximum Weak-mixture Power. In the case of a supercharged engine having more than one supercharger gear, the running shall be in the low gear.	Beginning and end 4, 6, 7, 9, 13, 17, 23, 25, 28. At beginning 27. Throughout 21. At end 1, 2, 3, 8, 11, 14, 15, 22, 24.

---

*If acceptable alternative evidence of oil circulation rate is available, the CAA will waive this observation.

Stage	Duration	Operating Conditions	Observations
5	5 Mins.	Minimum rpm for Weak-mixture Cruising and Maximum Weak-mixture manifold pressure, or full throttle. In the case of a supercharged engine having more than one supercharger gear, the running shall be in low gear. NOTE: If the engine is being tested with a propeller or a fan which limits the rpm or manifold pressure of this Stage to unrepresentative values, the Stage shall be run at the same operating conditions as for Stage 4.	Beginning and end 4, 6, 7, 9, 13, 17, 23, 25, 28. At beginning 27. Throughout 21. At end 1, 2, 3, 8, 11, 14, 15, 22, 24.
6	—	Further tuning and checks of the fuel metering and ignition systems, and any other tests considered necessary by the CAA to ensure satisfactory operation of the engine at the high power loading checks. The tests shall be repeated in each supercharger gear.	
7	5 Mins.	Maximum Continuous Power. The test shall be repeated in each supercharger gear.	Once 1, 2, 3, 6, 8, 9, 11, 14, 15, 22, 23, 24, 25, 28.
8	5 Mins.	Maximum Continuous Power conditions and full throttle with reduced air intake pressures (applicable to supercharged engines only—supercharger compression ratio check). The test shall be repeated in each supercharger gear.	,, ,,
9	5 Mins.	Maximum Take-off Power conditions and full throttle with reduced air intake pressures (applicable to supercharged engines only—supercharger compression ratio check). The test shall be repeated in each supercharger gear, if applicable.	,, ,,
10	5 Mins.	Maximum Take-off Power.	,, ,,
11	—	Three supercharger gear change cycles (in the case of supercharged engines having more than one supercharger gear) at Maximum Continuous Power. If automatic gear changing is provided for, the gear changes shall be made under conditions approved by the CAA.	

Stage	Duration	Operating Conditions	Observations
12	—	Three accelerations, from slow running conditions up to the declared Maximum Take-off Power conditions in low supercharger gear. The test shall be repeated up to Maximum Continuous Power conditions in each other supercharger gear.	
13	—	Three hot starts effected by each of the means of starting provided on the engine.	

3 STRIP EXAMINATION As prescribed.

4 FINAL TEST

Stage	Duration	Operating Conditions	Observations
1	—	Three starts, one from cold, effected by each of the means of starting provided on the engine, unless otherwise agreed by the CAA.	
2	—	Engine run-in light under its own power and then opened up in incremental stages of speed and load until Maximum Continuous Power is attained. Duration and conditions of speed and load for the various stages as agreed by the CAA.	
3	—	Tuning and preliminary checks of the fuel metering and ignition systems, and any other tests considered necessary by the CAA to ensure satisfactory operation of the engine up to, and including, Maximum Continuous Power. The test shall be repeated in each supercharger gear.	
4	30 Mins.	Maximum Continuous Power. In the case of a supercharged engine having more than one supercharger gear, the running shall be in the low gear.	Every 10 mins. 1, 2, 3, 8, 11, 14, 15, 22, 24. Beginning and end 5, 6, 7, 9, 13, 17, 23, 24, 28. At beginning 26. Throughout 21. During this Stage 20*.
5	5 Mins.	Maximum Continuous Power in each supercharger gear other than the low gear.	Once 1, 2, 3, 6, 8, 9, 11, 14, 15, 22, 23, 24, 25, 28.

---

*If acceptable alternative evidence of oil circulation rate is available, the CAA will waive this observation.

Stage	Duration	Operating Conditions	Observations
6	—	Further tuning and checks of the fuel metering and ignition systems, and other tests considered necessary by the CAA to ensure satisfactory operation of the engine at the high power performance checks; these shall include slow running, accelerations as in Stage 12 of the Endurance Test, single ignition check at Maximum Take-off Power and at Maximum Continuous Power in each supercharger gear, and one supercharger gear change at Maximum Continuous Power.	
7	5 Mins.	Maximum Continuous Power. The test shall be repeated in each supercharger gear.	Once 1, 2, 3, 6, 8, 9, 11, 14, 15, 22, 23, 24, 25, 28.
8	5 Mins.	Maximum Continuous Power conditions and full throttle, with reduced air intake pressure (applicable to supercharged engines only—supercharger compression ratio check). The test shall be repeated in each supercharger gear.	,, ,,
9	5 Mins.	Maximum Take-off Power conditions and full throttle with reduced air intake pressures (applicable to supercharged engines only—supercharger compression ratio check). The tests shall be repeated in each supercharger gear, if applicable.	,, ,,
10	5 Mins.	Maximum Take-off Power.	
11	—	A selection of at least five rpm settings (as agreed by the CAA) at Maximum Weak-mixture Power manifold pressure, to enable a power/rpm curve to be drawn. The curve shall be obtained in each supercharger gear. NOTE: This Stage may be waived when it is rendered impracticable by the engine being tested with a fan.	At each speed 1, 2, 8, 22, 23, 24, 25. Once during downward portion and once during upward portion of curve 6, 9, 11, 14, 15. Once 17.
12	—	Where the Final Test has been made with fuel containing tetra-ethyl-lead an agreed anti-corrosion treatment of the parts exposed to combustion shall be carried out on completion of the test.	

SCHEDULE 2

OVERHAULED PISTON ENGINES

TESTS FOR ENGINES RATED IN ACCORDANCE WITH THE REQUIREMENTS IN FORCE BEFORE 18th NOVEMBER, 1946 (PRE-ICAO RATINGS)

1 GENERAL Detailed requirements associated with the tests of this schedule are given in the text of this Leaflet, acceptance conditions are given in Leaflets EL/3-6 and EL/3-7 and correction formulae in Leaflet EL/3-8.

2 ENDURANCE TEST

Stage	Duration	Operating Conditions	Observations (See paragraph 4 of text)
1	—	Engine run-in light under its own power and then opened up in incremental stages of speed and load until Maximum Cruising Power is attained. Duration and conditions of speed and load for the various stages as agreed by the CAA.	
2	—	Tuning and preliminary tests of the fuel metering and ignition systems, and any other tests considered necessary by the CAA to ensure satisfactory operation of the engine up to, and including, Maximum Cruising Power. The tests shall be repeated in each supercharger gear.	
3	2 Hours	Maximum Cruising Power. Running equally divided between the supercharger gears.	Every 15 mins. 1, 2, 3, 8, 11, 14, 15, 22, 24. Beginning and end 4, 6, 7, 9, 13, 17, 23, 25, 28. At beginning 26. Throughout 21. During this Stage 20*.
4	30 Mins.	Maximum Weak-mixture Power. In the case of a supercharged engine having more than one supercharger gear, the running shall be in the low gear.	Beginning and end 4, 6, 7, 9, 13, 17, 23, 25, 28. At beginning 27. Throughout 21. At end 1, 2, 3, 8, 11, 14, 15, 22, 24.

---

*If acceptable alternative evidence of oil circulation rate is available, the CAA will waive this observation.

Stage	Duration	Operating Conditions	Observations
5	5 Mins.	Minimum rpm for Weak-mixture Cruising and Maximum Weak-mixture manifold pressure, or full throttle. In the case of a supercharged engine having more than one supercharger gear, the running shall be in the low gear. NOTE: If the engine is being tested with a propeller or a fan which limits the rpm or manifold pressure of this Stage to unrepresentative values, the Stage shall be run at the same operating conditions as for Stage 4.	Beginning and end 4, 6, 7, 9, 13, 17, 23, 25, 28. At beginning 27. Throughout 21. At end 1, 2, 3, 8, 11, 14, 15, 22, 24.
6	—	Further tuning and checks of the fuel metering and ignition systems, and any other tests considered necessary by the CAA to ensure satisfactory operation of the engine at the high power loading checks. The tests shall be repeated in each supercharger gear.	
7	5 Mins.	Maximum Climbing Power. The test shall be repeated in each supercharger gear.	Once 1, 2, 3, 6, 8, 9, 11, 14, 15, 22, 23, 24, 25, 28.
8	5 Mins.	Maximum Climbing Power and full throttle with reduced air intake pressures (applicable to supercharged engines only—supercharger compression ratio check). The test shall be repeated in each supercharger gear.	” ”
9	5 Mins.	Maximum Take-off Power conditions and full throttle with reduced air intake pressures (applicable to supercharged engines only—supercharger compression ratio check). The tests shall be repeated in each supercharger gear, if applicable.	” ”
10	5 Mins.	Maximum Take-off Power.	” ”
10a	5 Mins.	Emergency Cruising Power. The test shall be repeated in each supercharger gear.	” ”
11	—	Three supercharger gear change cycles (in the case of supercharged engines having more than one supercharger gear) at Maximum Climbing Power. If automatic gear changing is provided for, the gear changes shall be made under conditions approved by the CAA.	

Stage	Duration	Operating Conditions	Observations
12	—	Three accelerations, from slow running conditions up to Maximum Take-off Power conditions in low supercharger gear. The test shall be repeated up to Maximum Climbing Power conditions in each other supercharger gear.	
13	—	Three hot starts effected by each of the means of starting provided on the engine.	
3	STRIP EXAMINATION	As prescribed.	
4	FINAL TEST		
1	—	Three starts, one from cold, effected by each of the means of starting provided on the engine, unless otherwise agreed by the CAA.	
2	—	Engine run-in light under its own power and then opened up in incremental stages of speed and load until Maximum Cruising Power is attained. Duration and conditions of speed and load for the various stages as agreed by the CAA.	
3	—	Tuning and preliminary checks of the fuel metering and ignition systems, and any other tests considered necessary by the CAA to ensure satisfactory operation of the engine up to, and including, Maximum Cruising Power. The test shall be repeated in each supercharger gear.	
4	30 Mins.	Maximum Cruising Power. In the case of a supercharged engine having more than one supercharger gear, the running shall be in the low gear.	Every 10 mins. 1, 2, 3, 8, 11, 14, 15, 22, 24. Beginning and end 4, 6, 7, 9, 13, 17, 23, 25, 28. At beginning 26. Throughout 21. During this Stage 20*.
5	5 Mins.	Maximum Cruising Power in each supercharger gear other than the low gear.	Once 1, 2, 3, 6, 8, 9, 11, 14, 15, 22, 23, 24, 25, 28.
6	—	Further tuning and checks of the fuel metering and ignition systems and other tests considered necessary by the CAA to ensure satisfactory operation of the engine at the high power performance checks; these shall include slow	

---

*If acceptable alternative evidence of oil circulation rate is available, the CAA will waive this observation.

Stage	Duration	Operating Conditions	Observations
		running, accelerations as in Stage 12 of the Endurance Test, single ignition check at Maximum Take-off Power and at Maximum Climbing Power in each supercharger gear, and one supercharger gear change at Maximum Climbing Power.	
7	5 Mins.	Maximum Climbing Power. The test shall be repeated in each supercharger gear.	Once 1, 2, 3, 6, 8, 9, 11, 14, 15, 22, 23, 24, 25, 28.
8	5 Mins.	Maximum Climbing Power conditions and full throttle with reduced air intake pressures (applicable to supercharged engines only—supercharger compression ratio check). The test shall be repeated in each supercharger gear.	” ”
9	5 Mins.	Maximum Take-off Power conditions and full throttle with reduced air intake pressure (applicable to supercharged engines only—supercharger compression ratio check). The tests shall be repeated in each supercharger gear, if applicable.	” ”
10	5 Mins.	Maximum Take-off Power.	
10a	5 Mins.	Emergency Cruising Power. The test shall be repeated in each supercharger gear.	” ”
11	—	A selection of at least five rpm settings (as agreed by the CAA) at Maximum Weak-mixture Power manifold pressure, to enable a power/rpm curve to be drawn. The curve shall be obtained in each supercharger gear. NOTE: This Stage may be waived when it is rendered impracticable by the engine being tested with a fan.	At each speed 1, 2, 8, 22, 23, 24, 25. Once during downward portion and once during upward portion of curve 6, 9, 11, 14, 15. Once 17.
12	—	Where the Final Test has been made with fuel containing tetra-ethyl-lead, an agreed anti-corrosion treatment of the parts exposed to combustion shall be carried out on completion of the test.	

EL/3-6

Issue 2.

December, 1978.

AIRCRAFT

ENGINES

PISTON ENGINE OVERHAUL—DYNAMOMETER TESTING OF OVERHAULED ENGINES

1 INTRODUCTION

1.1 After an aero-engine has received a complete overhaul, the tests prescribed in Section C of British Civil Airworthiness Requirements may be made with the engine either fitted with a test fan or mounted on a dynamometer test bench. This Leaflet gives guidance on testing low-power, air-cooled engines when coupled to dynamometers and includes the acceptance conditions required by the CAA when overhauled engines are tested by this method.

1.2 The Leaflet is the sixth of a series dealing with piston engine overhaul and, like the rest of the series, does not aim to provide a complete guide to approved inspection organisations engaged in aero-engine overhaul. The particular purpose of this Leaflet is to give students and individual engineers an outline of engine test procedure and to draw attention to a number of points of special importance. Before actual tests are attempted on engines which are to be released in accordance with CAA Requirements an approved Engine Test Schedule must be available. All overhaul work on such engines must be in accordance with the manufacturer's instructions given in the Overhaul Manual and all tests must be made as prescribed in the Engine Test Schedule for the particular type.

1.3 The Requirements relating to the testing of small air-cooled piston engines after overhaul are reprinted in Leaflet **EL/3-5**, except that the prescribed acceptance conditions are included in this Leaflet **(EL/3-6)** and the prescribed formulae for performance corrections in Leaflet **EL/3-8**. Guidance on the testing of overhauled engines by means of test fans, and the prescribed acceptance conditions when engines are tested by this method, are given in Leaflet **EL/3-7**.

2 GENERAL The tests made after overhaul consist of an Endurance Test followed by a strip examination, and a Final Test during which the performance is determined. The CAA sometimes permits relaxation of the Requirements for complete strip examination, but the extent of any deviation must be approved by the CAA.

2.1 The method of testing an engine on a dynamometer test bench enables the engine output to be determined in terms of brake power, whereas this is not practicable when the engine is tested with a fan or flight propeller unless the engine incorporates a torquemeter of known accuracy or the torque reaction on the engine mounting can be measured with exactitude.

2.2 Since the engines with which this series of Leaflets is concerned are not usually fitted with torquemeters, their performance after overhaul is most often assessed by testing them when fitted with calibrated test fans, in which case, as explained in Leaflet **EL/3-7**, the corrected rpm obtained under specified conditions is taken as a measure of the engine performance. However, before an engine can be so tested, the test fan itself must be calibrated in the test cell to be used, on an engine, the performance of which has been determined on a dynamometer test bench.

3 TEST PLANT A dynamometer is a heavy machine which must be rigidly mounted. This fact and the necessity of making adequate arrangements for water, electricity, fuel and oil supplies, for exhaust gas disposal, for drains, for silencing and for ventilation means that dynamometer testing is usually performed in a permanent test house. It is beyond the scope of this Leaflet to describe such a test house in detail but attention is drawn, in the following paragraphs, to a number of important features:

3.1 A dynamometer test bench consists of a mounting for the engine, a coupling shaft for interconnecting the engine to the dynamometer, a fan and the necessary ducting for cooling the engine, a starting system for the engine, the necessary controls and instruments for operating the engine and measuring its performance, and systems for supplying the engine with fuel and oil and the dynamometer with water. In the case of supercharged engines a depression box should be provided for the air intake so that altitude conditions can be simulated when specified in the Engine Test Schedule.

3.2 When an engine is mounted on the test bench, care should be taken that the engine propeller shaft is in exact alignment with the shaft of the dynamometer, but the coupling should not be completed until the zero setting of the torque measuring equipment has been checked. Guidance on the procedure for this check is given in paragraph 4.

3.3 The coupling shaft between the engine and dynamometer must be specially designed. It must be light in weight, properly supported and in perfect dynamic balance. Cardan shafts incorporating two universal joints are normally used; they should be inspected before the start of the test to ensure that they have not been disturbed in any way that could upset their alignment or dynamic balance.

3.4 All test and measuring equipment must be of an approved type. All instruments should be calibrated periodically and thereafter should be checked for accuracy at regular intervals by an organisation approved for the purpose. Measuring equipment should also be checked at regular intervals, the check periods to be agreed with the CAA. Engine speed indicators should be checked with a stop watch against a revolution counter and, during tests, cross-checks should be made by measurement of the engine speed using a "Hasler" type instrument.

3.5 Before commencing the test, the oil filter elements in the feed lines should be either cleaned or renewed. Oil tanks should be drained and flushed at intervals of approximately 100 hours' running time.

3.6 Before checking oil consumption or oil circulation, the oil temperature must be stabilised at the check temperature specified in the appropriate test schedule. To obtain this condition, the test plant must be provided with suitable means of heating or cooling the oil as required. If the heating is accomplished with an electric immersion heater there is danger of damaging the chemical structure of the oil, since the surface temperature of this type of heater can rise to high values when the flow rate of the oil is low. It is therefore recommended that the oil is heated via a heat exchanger, using steam at a controlled pressure if a source is available but otherwise using a circulating water supply as a means of conveying heat from an immersion heater to the oil.

3.7 Engine oil consumption can be checked by either of the following methods:

(a) Readings of oil volume should be taken from a graduated sight glass fitted externally to the oil tank. The readings should be recorded each 15 minutes during the prescribed stages of the test schedule and the difference between the initial and final readings can be used to calculate oil consumption in litre/h (pint/h).

(b) On an engine which has a "wet sump" lubrication system, the oil should be drained out and weighed at the end of the running-in period, replaced in the engine, then drained out and weighed again after the Endurance Test. The difference between these weights will enable the oil consumption to be calculated.

3.8 The fuel pressure gauge connection should be made at the inlet to the carburettor or fuel injector. A fuel flowmeter calibrated in litre/h or kg/h (pints/h or lb/h) must be tapped into the fuel supply line and readings must be taken as called for in the test schedule appropriate to the engine.

3.9 To avoid unscheduled stoppages during the test, all pipe connections should be properly made and all pipes should be adequately supported. The test bench controls should be checked for alignment and range of movement and the engine baffles and cowlings should be firmly secured.

3.10 Measurements of the exhaust back pressure should be made as close to the engine as possible but, where more than one manifold is provided because of the cylinder configuration, the pressure at each silencer connection should be checked and the mean reading obtained. If it is inconvenient to measure the pressure from each connection throughout the test, the pressure tapping with the value closest to the mean reading may be used.

4 TYPES OF DYNAMOMETER There are three principal types of dynamometer commonly used for the testing of aero-engines, the hydraulic type, the electrical (direct-current) type and the eddy-current type. With all types, the engine under test is directly coupled to the rotor shaft of the dynamometer, which can be loaded to obtain the desired engine speed. The dynamometer absorbs the power output of the engine and, in doing so, experiences a torque reaction on its own casing. It is by measurement of this torque reaction that the brake power of the engine is determined; it can be calculated from a simple formula which takes into account the torque reaction and the rpm of the dynamometer rotor.

$$\text{Brake Power} = \frac{\text{torque (Nm)} \times 2\pi \times \text{rpm}}{60{,}000}\ \text{kW} \quad \text{or} \quad \frac{\text{torque (lb ft)} \times 2\pi \times \text{rpm}}{33{,}000}\ \text{BHP}$$

4.1 **Hydraulic Dynamometers.** A part sectioned view of a typical hydraulic dynamometer is illustrated in Figure 1. The shaft of this machine carries a rotor which has a series of semi-elliptical cups separated by vanes; the rotor runs between two sets of similar cups formed in the casing. Water at constant pressure is fed into the casing. Rotation of the shaft circulates this water by centrifugal force around the orbits formed by the opposing pairs of moving and static cups, the water thus absorbing the power fed into the machine by the engine under test. The shaft is supported in the casing by ball bearings and the casing itself is mounted on trunnion bearings which allow it to rotate in response to torque reaction. The reaction on the casing is balanced, and the rotation of it constrained, by a system of weights and levers and a spring balance which, when correctly preset, indicates the load due to torque. The loading on the engine can be reduced by adjusting a pair of shrouds, known as sluice gates, so that they progressively mask the rotor cups from the cups in the casing, and can be increased by the reverse process. The type illustrated is a non-reversible dynamometer but reversible types are also made. The latter have two rotors and two sets of casing vanes, one to work clockwise and the other anti-clockwise.

NOTE: The following instructions are applicable when the testing is done with a Non-reversible Froude Type D.P.Y. dynamometer. Since this dynamometer is the type most widely used for testing small aero engines, these instructions have been included as an example. Should any other type of hydraulic dynamometer be employed, instructions for its use must be obtained from the manufacturer.

4.1.1 Before coupling an engine to the dynamometer, the static balance of the weighing apparatus should be checked. This is done in the following way:—

(a) Adjust the inlet and outlet water valves so that there is a steady flow of water through the dynamometer.

(b) A dashpot prevents oscillations of the torque lever arm from being transmitted to the spring balance. When the spring balance is being checked the dashpot should be freed by setting its adjusting nut to zero.

(c) Remove all loose balance weights from the end of the lever arm, leaving the fixed static weight in place.

(d) If the lever arm is not in a position slightly above the bottom stop on the bedplate, the adjustment on the interconnection to the spring balance should be reset. The adjustment should be checked by raising the lever arm which should cause the pointer of the spring balance to make one revolution before the lever arm touches the top stop in the spring balance column.

(e) By moving and locking the small sliding weight on the lever arm, the pointer of the spring balance should then be reset to zero. The dynamometer is then ready for the test and the engine should be coupled to it, care being taken to ensure exact alignment of the engine and dynamometer shafts.

(f) A final check should be made by alternately lifting and depressing the lever arm by hand, when the pointer should settle down to zero and it should be possible by depressing the lever arm to move the pointer a few degrees to the minus side of zero, without causing stiffness or binding. The adjusting nut of the dashpot should then be screwed down so that the by-pass will be partially closed, although final adjustments must be made when the engine is running.

NOTE: If the spring balance does not register sufficient load to balance the output of the engine under test, the load may be increased by adding extra balance weights. These are marked with figures representing the correct weight which must be added to the load registered on the spring balance and the sum of weights and registered load will then represent the factor W in the formula given in paragraph 4.1.3 for calculating Brake Power.

4.1.2 Before starting an engine coupled to a non-reversible dynamometer, the water inlet valve should be fully opened but the outlet valve should only be opened slightly. As prescribed in the Requirements, the Engine Test Schedules (Leaflet EL/3-5) specify that engines under test should be run-in under their own power with an initial light load. For starting purposes it is advisable to close the sluice gates to minimise the load on the engine; afterwards, as the engine is opened up in incremental stages, the load should be progressively increased by opening the sluice gates, to maintain the operating conditions to those agreed for each stage by the CAA. As the engine power is increased the water outlet valves should be adjusted so that they pass sufficient water to keep the water temperature at a reasonable level; about 60°C is satisfactory.

4.1.3 It has been stated that the power of the engine can be found if the torque and the rpm of the rotor are known. The torque is calculated by multiplying the length of the lever arm by the effective weight lifted. Since the lever length, the value of π and the power conversion factor are all constant, the simplified formula given below can be used. The formula introduces a constant K known as the dynamometer constant, which has a value determined for each type of dynamometer by its manufacturer. The value of K, which varies with the length of the lever arm, is stamped on the name-plate of each dynamometer. The formula is therefore:

$$\text{Brake Power} = \frac{W \times N}{K}$$

where W = net weight lifted by dynamometer
N = rpm of rotor
K = dynamometer constant

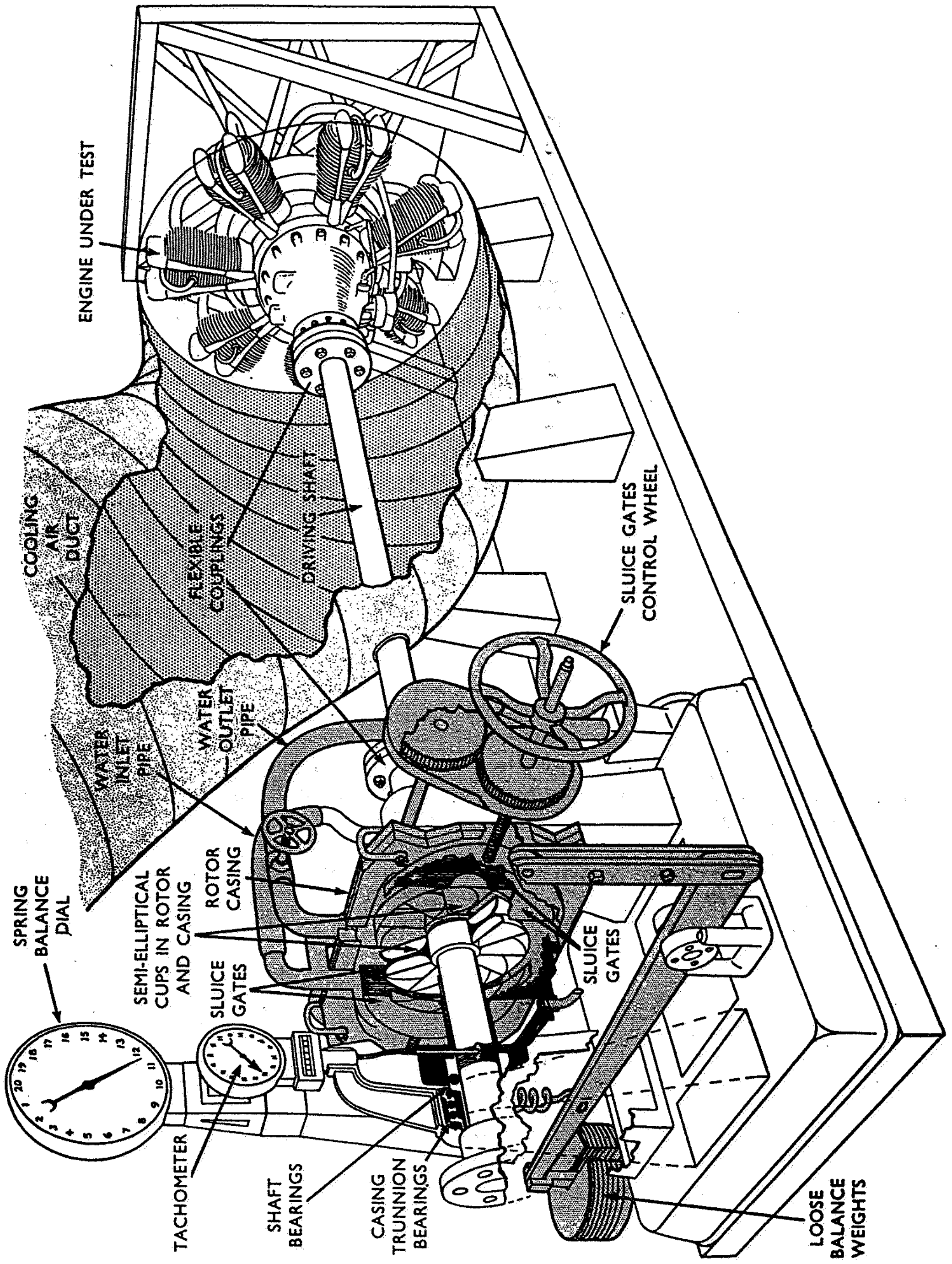


Figure 1 RADIAL ENGINE COUPLED TO FROUDE HYDRAULIC DYNAMOMETER

4.2 **Electrical Dynamometers.** The type of electrical dynamometer usually supplied for the testing of small engines consists of a generator designed so that it will also function as an electric motor. Thus when supplied with electrical power it can be used for running-in a newly-assembled engine or when driven by an engine under test it generates electrical energy. The first of these functions is not normally applicable to overhauled aero-engines, which are run-in under their own power, but it does provide a means of measuring the power required to overcome the internal resistance of an engine when this information is required. The armature shaft of a typical electrical dynamometer is carried by bearings in the casing of the machine and the casing is itself carried in co-axial bearings which allow it to swivel in the same direction of rotation as the shaft. When an engine is driving the armature shaft with the dynamometer connected to an electric circuit, the turning moment is resisted by a combination of bearing friction, electro-magnetic reaction and air resistance. These three loads each tend to rotate the casing, to which is attached a lever arm and weighing apparatus similar to that of a hydraulic dynamometer. The magnitude of the total force acting on the casing is indicated on a spring-balance dial, which enables the engine power to be found by the method given in paragraph 4.1.3.

4.3 **Eddy-current Dynamometers.** The single frame electrical dynamometer described in paragraph 4.2 is not designed to absorb high powers and therefore an eddy-current dynamometer is more often used for testing engines which develop over 150 kW (200 BHP). An eddy-current dynamometer is an electrical machine in which the rotor is constructed with a number of coarse teeth which act as magnetic poles. The rotor turns inside a stator which incorporates one or more field coils excited by a small amount of direct current, so that during rotation concentrations of magnetic flux are produced at each pole of the rotor. The flux concentrations induce eddy-currents in the stator and it is these which resist the rotation of the rotor and therefore load the engine under test. The degree of power absorption is controlled by regulating the amount of excitation of the main field coils. The engine power is converted into heat by the braking effect of the machine and cooling water has therefore to be circulated to conduct the heat away. In this type of dynamometer the water outlet temperature should not exceed 60°C but if possible it should be limited to 50°C as this will help to reduce the possibility of internal scale formation. As with the hydraulic and electric types of dynamometer, the engine power is found by measuring the torque reaction exerted on the stator casing. The casing is mounted on trunnion bearings which allow some freedom of oscillation and attached to the casing is a lever arm which operates weighing gear. The engine power is found by the method given in paragraph 4.1.3.

4.4 **Dynamometer Plant for Helicopter Engines.** British Civil Airworthiness Requirements prescribe that engines intended to be installed in helicopters should be tested in the attitude in which they will be mounted in the airframe (Leaflet **EL/3-5**). Thus when the axis of rotation of the crankshaft is to be vertical in service, one solution is to provide a right-angled gearbox to couple the engine to the dynamometer. The dynamometer itself can be of any type capable of absorbing the power output of the engine, but the brake power readings obtained from it must be corrected for the power absorbed by the gearbox. (This information is usually obtainable from the manufacturer of the gearbox.) Since helicopter engines are not always provided with integral reduction gears, a right-angled gearbox may be designed with a reduction ratio to assist in matching the engine speed to the characteristics of the dynamometer. If required, hydraulic dynamometers can be made to run directly coupled to helicopter engines without the introduction of a gearbox, and in addition special dynamometers can be made to suit vertical or any other shaft inclination desired. In some special cases both dynamometer and engine can be arranged on a swivel to give variable adjustment of shaft inclination. The test bench may also be designed so that the engine is provided with an external source of cooling air since, if it drives its own cooling fan, it may be necessary to make allowance for the power absorbed by the fan.

5 TEST RUNNING AND OBSERVATIONS After the engine has been coupled to the dynamometer and the preparations for starting and running have been completed, the engine should be tested strictly in accordance with the approved Test Schedule appropriate to the type. The observations made during the tests should be recorded on properly prepared test log sheets. During the tests attention should be given to the following points:

5.1 The engine should be tuned according to the instructions in the approved Test Schedule. The observed fuel flowmeter readings must be corrected to standard conditions; formulae and/or charts for this purpose are normally provided with the schedules supplied by engine manufacturers. Likewise, the fuel flow acceptance limits (see paragraph 6.1.2) are normally quoted in the same source.

5.2 At each stage of test running, a careful watch should be kept for signs of defects and such undesirable behaviour as excessive oiling, vibration, breather discharge or detonation.

5.3 Single ignition checks should be made and the power drop measured. As each magneto is switched OFF, the engine load should be reduced, e.g., by opening the sluice gates on a hydraulic dynamometer, so that the rpm is restored to that obtained with both magnetos operating. The differences in power output between operation with single and dual ignition should be recorded on the log sheets.

5.4 Stage 11 of the Final Test calls for a power/rpm curve to be drawn at the Maximum Weak-mixture Power manifold pressure. To obtain this curve the engine should be run over the range of rpm specified in the Test Schedule. The resultant curve should be smooth; if it is not so and any of the points plotted diverge to any appreciable extent, the readings should be rechecked.

5.5 If, after rechecking, it is necessary to adjust or replace any component or part, the test, or portions of it, will have to be repeated, unless otherwise agreed by the CAA.

6 ACCEPTANCE CONDITIONS The acceptance conditions for overhauled engines tested on a dynamometer test bench are prescribed in Section C of British Civil Airworthiness Requirements and are repeated in the following paragraphs. Apart from the general running standard of each engine and its ability to satisfactorily complete the tests detailed in the relevant schedule, the specific standards of performance of 6.1 or 6.2, as appropriate, must be obtained to the satisfaction of the CAA.

6.1 **Engines Rated in accordance with the Requirements in force on and after 18th November, 1946 (ICAO Ratings)**

6.1.1 **Power.** The corrected Maximum Take-off Power shall be not less than 96% of the declared Maximum Take-off Power. Also, in the case of a supercharged engine, the corrected power at the declared full throttle altitude at Maximum Take-off Power and Maximum Continuous Power conditions, as derived from the tests of Stages 7, 8, 9 and 10 of the Final Test, shall be not less than 96% of the declared power. Alternatively, the sum of the ratios of the corrected sea-level power and the corrected supercharger compression ratio (at 15°C) at Maximum Take-off and Maximum Continuous conditions to the established values for the prototype engine shall be not less than 1·96. These conditions shall be met in each supercharger gear.

NOTE: For the assessment of the supercharger performance, it is recommended that a chart should be prepared, for each supercharger gear, showing the absolute pressure which would be required at the air intake of the engine, with a supercharger compression ratio at 15°C equal to that quoted in the Engine Technical Certificate, when running at full throttle at the Take-off and Maximum Continuous manifold pressures (Take-off and Maximum Climbing for engines with pre-ICAO ratings). The chart, a specimen of which is reproduced in Leaflet EL/3-8, should cover a suitable range of rpm and air intake temperatures. The performance of the supercharger under test will be measured by comparing the observed air intake pressure with that determined from the chart.

6.1.2 **Fuel Consumption.** The fuel consumption at all sea-level rating conditions shall be within the limits quoted in the engine specification or technical certificate.

6.1.3 **Oil Consumption.** The mean oil consumption obtained from the tests of Stages 3 and 4 of the Endurance Test and Stage 4 of the Final Test, shall be within the declared limits. In the event of the engine not being able to comply with this requirement during the tests of Stages 3 and 4 of the Endurance Test, it shall be rejected for rectification and re-submission to the Endurance Test. Alternatively, the endurance running of Stages 3 and 4 of the Endurance Test may be extended up to a maximum of an additional 2 hours, until the consumption falls within the required limits over a period of at least 30 minutes duration. The consumption shall be checked in each supercharger gear. As a further alternative, where the applicant is of the opinion that the oil consumption can be improved by adjustment during strip examination, the endurance portion of the Final Test may be extended by the addition of a run limited to a minimum of 1 hour at the declared Maximum Continuous Power conditions. The running shall be equally divided between the supercharger gears. During the period of oil consumption measurement, ignition checks, or operation of any accessory or any other test or adjustment which may affect consumption, shall be avoided. The oil consumption in each supercharger gear shall be reasonably consistent.

6.1.4 **Accelerations.** Accelerations shall be smooth and free from hesitation or other signs of fuel-metering trouble.

6.1.5 **Single Ignition Check.** The power drop when running with single ignition shall not exceed the declared maximum.

6.1.6 **Cleanliness.** The engine shall be free from leaks at all joints and connections, etc.

6.2 **Engines Rated in accordance with the Requirements in force before 18th November, 1946 (pre-ICAO Ratings).** The acceptance conditions for these engines are the same as those in paragraph 6.1 except that Maximum Climbing Power should be substituted wherever reference is made to Maximum Continuous Power.

EL/3-7

Issue 2.

December, 1978.

AIRCRAFT

ENGINES

PISTON ENGINE OVERHAUL—FAN TESTING OF OVERHAULED ENGINES

1 INTRODUCTION

1.1 After an aero-engine has received a complete overhaul, the tests prescribed in Section C of British Civil Airworthiness Requirements may be made with the engine either fitted with a test fan or mounted on a dynamometer test bench. This Leaflet gives guidance on testing low-power, air-cooled piston engines by means of test fans and includes the acceptance conditions required by the CAA when overhauled engines are tested by this method.

1.2 This Leaflet is the seventh of a series dealing with piston engine overhaul. Since the engines with which the series is concerned are more often tested by the fan method than on a dynamometer test bench, this Leaflet gives fairly detailed information on the methods used for choosing test fans to suit particular engines and for calibrating test fans. It also draws attention to a number of other points of special importance. Before tests are attempted on engines which are to be released in accordance with CAA Requirements, an approved Engine Test Schedule (see paragraph 2) must be available. All overhaul work on engines must be in accordance with the manufacturer's instructions given in the Overhaul Manual, and all tests must be made as prescribed in the Engine Test Schedule for the particular type.

1.3 The Requirements relating to the testing of small air-cooled piston engines after overhaul are reprinted in Leaflet **EL/3-5,** except that the prescribed acceptance conditions are included in this Leaflet and the prescribed formulae for performance corrections in Leaflet **EL/3-8.** Leaflet **EL/3-8** also incorporates a set of correction charts for use during test fan calibrations. Guidance on the testing of overhauled engines on dynamometer test benches, and the acceptance conditions prescribed when engines are tested by this method, are given in Leaflet **EL/3-6.**

2 GENERAL The test procedure prescribed for piston engines after overhaul includes an Endurance Test followed by a strip examination, and a Final Test during which the performance is determined. Engine manufacturers in the United Kingdom prepare Test Schedules and instructions which are approved by the CAA for use when testing particular engine types. As explained in Leaflet EL/3-5, these schedules are based on the appropriate basic schedule from Section C of the Requirements and the Engine Technical Certificate.

2.1 Although the Requirements recognise two basic methods of testing piston engines after overhaul, the test fan method, because of its lower cost, is most frequently used for testing the smaller engines. This method entails fitting the engine with an approved type of test fan which is calibrated to absorb the power output of the engine at a specified rpm. Since torquemeters are not usually fitted to the small engines with which this Leaflet is concerned, the rpm obtained when running with a calibrated fan is used to indicate the engine power. However, the results obtained can be grossly inaccurate unless exceptional care is exercised in the application of the method.

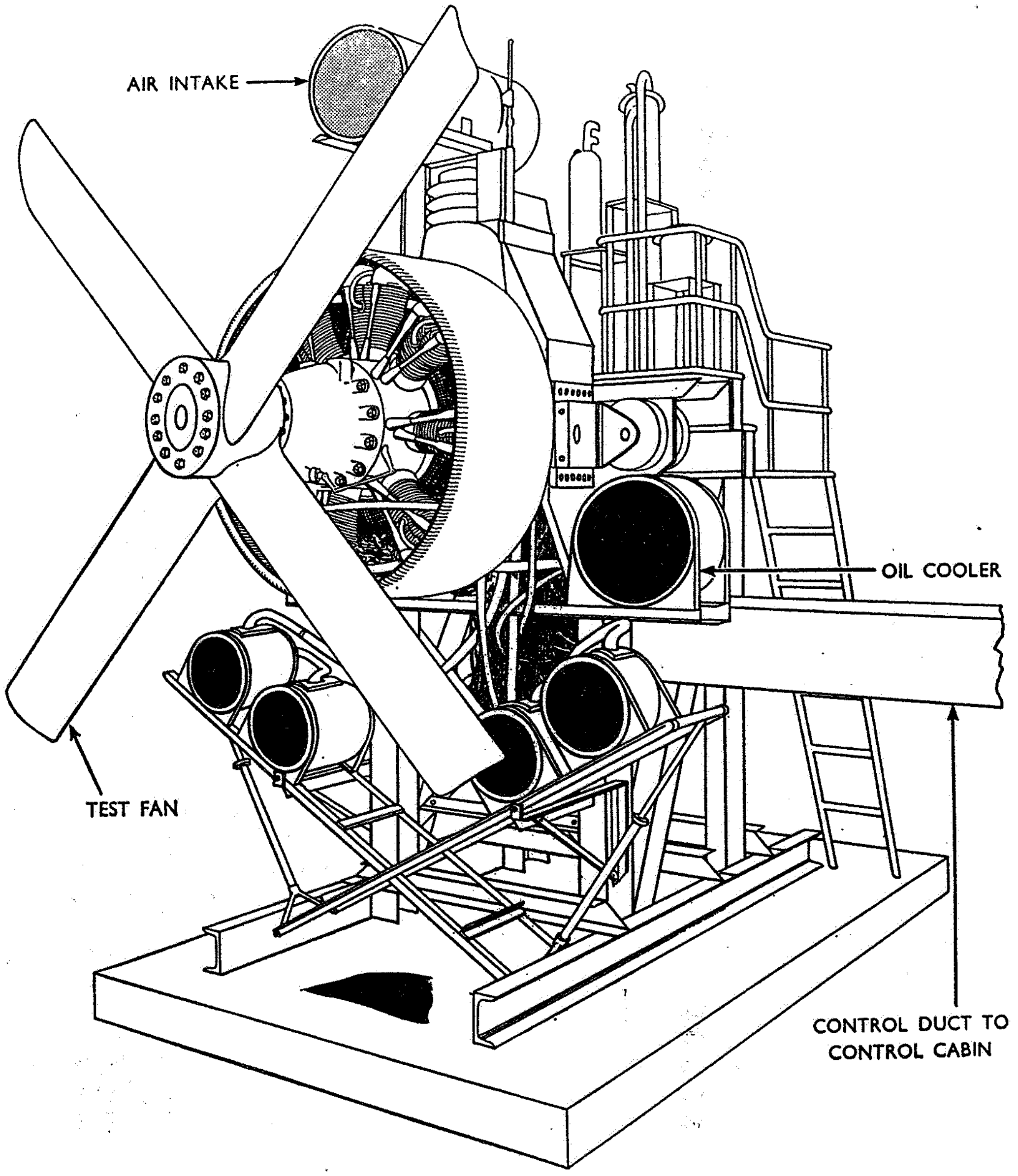


Figure 1 AERO-ENGINE TEST BENCH FOR FAN TESTING

2.2 Since it is a requirement that helicopter engines be tested in the attitude in which they will be installed in the helicopter, engines which are intended to be installed with the axis of rotation either vertical or inclined from the horizontal may be tested on a dynamometer test bench specially designed for the purpose (Leaflet EL/3-6). However, tests on such engines are often run with the engine loaded by a paddle-bladed fan, in which case it is sometimes necessary to change the paddles to suit conditions at the various stages of the test run. Thus paddles of one diameter ('A' plates) may be specified for running at Maximum Continuous Power conditions and paddles of a different diameter ('B' plates) for running at Maximum Take-off Power conditions. Whilst paddle-bladed fans are calibrated in a similar manner to aerofoil-bladed fans, the technique of rendering them 'heavy' or 'light' is of course different.

3 FAN TESTING The fan method of testing an aero-engine consists of running the engine on a test bench with a calibrated test fan fitted instead of a flight propeller, the fan providing the means of loading the engine during the test. To assess the engine power output, the rpm of the overhauled engine when loaded with the test fan must be compared with the rpm which would be developed by the type engine loaded with the same fan and run on the same test bed under the same conditions.

3.1 **Test Plant.** The engine to be tested should be mounted on a test bench which should be provided with the complete oil, fuel and electrical systems required for starting and running the engine, and, in the case of supercharged engines, with equipment for reducing the pressure of the air supplied to the engine intake so that altitude conditions can be simulated when specified in the engine test schedule. A suitable type of test bench for small engines is shown in Figure 1; it can be adapted for either radial or in-line engines. Whichever type of engine is fitted, adequate provision must be made for cooling it. This may necessitate fitting an oversize cooling scoop to in-line engines. Testing should normally be done in a specially designed building, preferably located so that the engines under test inhale air which is free from excess moisture or industrial contaminants. However, some test stands for the testing of small engines are of a mobile type and, in favourable atmospheric conditions, may be used in the open air. In all cases the test bench must be approved by the CAA.

3.2 **Test Instruments.** The test bench should be equipped with an approved range of instruments to enable accurate indication of the relevant test data specified in the test schedule appropriate to the engine. The instruments and all measuring equipment should be calibrated prior to fan calibration and should afterwards be checked for accuracy at regular intervals, as agreed with the CAA. An additional revolution counter which will serve as a master for checking the continuous reading rpm indicator must also be available; an instrument approved for this purpose is the "Hasler", which is a hand-held indicator of great accuracy incorporating its own chronometer. In accordance with the Test Observations Code given in the Requirements (see Leaflet EL/3-5), the following continuous reading instruments are required for the testing of small air-cooled engines:

Instrument	**Calibration**
1. Engine speed indicator	rpm
2. Manifold pressure gauge	kN/m^2 or kPa (inHg)
3. Main oil pressure gauge	kN/m^2 or kPa (lbf/in^2)
4. Auxiliary oil pressure gauge	kN/m^2 or kPa (lbf/in^2)

Instrument	Calibration
5. Pump inlet oil pressure gauge	kN/m² or kPa (lbf/in²)
6. Fuel pressure gauge	kN/m² or kPa (lbf/in²)
7. Oil temperature gauges (inlet and outlet temperatures)	°C
8. Cooling air temperature gauge	°C
9. Cooling air speed indicator (or cooling air differential pressure gauge)	m/s or kN/m² (mile/h or inH_2O)
10. Stop watch for checking oil circulation rate	Seconds
11. Cylinder head temperature gauge	°C
12. Fuel flowmeter	kg/h or litre/h (lb/h or pints/h)
13. Air intake temperature gauge	°C
14. Exhaust back pressure gauge	kN/m² or kPa (lbf/in²)
15. Test house barometer	kN/m² or kPa (inHg)
16. Air intake pressure gauge	kN/m² or kPa (inHg)
17. Fan air temperature gauge	°C

3.3 **Test Plant Oil System.** The instructions given in Leaflet **EL/3-6** for cleaning and heating test bench oil systems and for measuring oil consumption and oil circulation are also applicable when an engine is to be tested with a fan.

3.4 **Instrument and Pipe Connections.** The provisions of paragraphs 3.8, 3.9 and 3.10 of Leaflet **EL/3-6** are also applicable when an engine is to be tested with a fan.

4 CHOICE OF TEST FAN The type of test fan to be used when testing a particular type of engine must have been agreed with the engine manufacturer and approved by the CAA; the criteria determining the choice include the power dispersal characteristics of the fan, the ability to withstand the blade stresses imposed during prolonged bench running, and the cooling requirements of the engine. There are two main groups of fans: fixed-pitch fans, and variable-pitch fans controlled by a constant-speed governor.

4.1 **Fixed-pitch Test Fans.** Fixed-pitch fans may be sub-divided into two types: those which have one pitch that cannot be altered and those which have an adjustable pitch which can be locked at predetermined pitch settings. These two types of fans are usually designed and calibrated to absorb the Maximum Continuous Power of the engine when it is running at Maximum Continuous rpm under standard sea-level conditions and it is also essential that they should not allow the engine to overspeed at the Maximum Take-off manifold pressure.

4.1.1 Fans with unalterable pitch settings are specially made with square-tipped blades of laminated wood construction. The blades are made wide to provide maximum power absorption and maximum engine cooling with minimum blade tip diameter. Because design limitations and variations in test conditions make it impossible to predetermine the exact diameter required to absorb a given power, the blades are supplied oversize and have to be individually calibrated by successively removing material from the blade tips until the required power absorption is obtained. This operation is known as "cropping".

4.1.2 To crop a fan, thin slices are sawn from the tips of each wooden blade, care being taken to ensure that equal amounts are removed from each tip and that all sharp corners are rounded off. After each cropping, the fan must be rebalanced before it is replaced on the engine. On completion of cropping, the cropped blades should be protected against deterioration by applying the approved finish to the bare ends. If the blades are overcropped by a small amount, or are found to be absorbing too little power for any other reason, it may be permissible to make the fan "heavy" by adding spoilers to the blades. The advice of the fan manufacturer should be sought on the method of spoiling appropriate to a particular type of fan.

4.1.3 The power absorption characteristics of a fixed-pitch fan with adjustable-pitch settings are varied by altering the pitch of the blades. The blade pitch is usually altered by resetting stops incorporated in the hub of the fan, and these should be adjusted in accordance with the instructions of the manufacturer of the fan. If the rpm obtained during calibration are too high, the blades should be moved towards coarse pitch; if the rpm are too low, they should be moved towards fine pitch.

4.2 **Variable-pitch Test Fans.** Variable-pitch test fans controlled by a constant-speed governor can be operated at a fixed, predetermined position, e.g. on the fine or coarse pitch stop, and also at variable settings under the control of the governor. Fans of this type are calibrated by adjusting their pitch stops so that the power of the engine at Maximum Take-off manifold pressure is absorbed without over-speeding when the engine is running under standard sea-level conditions. Such fans must also be able to absorb the Maximum Continuous engine power when constant speeding or running against a stop with the engine running under Maximum Continuous conditions.

4.3 **Flight Propellers.** A flight propeller may be approved as a test fan if the engine cooling provided is adequate and the propeller is able to withstand the more severe stresses which occur in the blades when operated under static instead of flight conditions. Once a metal flight propeller has been used as a test fan it must not again be used for flight purposes.

NOTE: Experience has shown that, unless a cable-suspended test rig is used, metal flight propellers are seldom satisfactory for prolonged test bed running.

4.4 **Method of Determining Fan Type Required.** If doubt exists as to whether a fixed-pitch or variable-pitch fan should be used for a particular engine type, the following method of determination may be used.

4.4.1 **Unsupercharged Engines.** The power/rpm curve at full throttle under standard sea-level conditions should be copied from the Engine Technical Certificate and marked at points corresponding to 90% and 97% of the maximum rpm. As shown in Figure 2, the point of Maximum Continuous power and rpm (the calibration point) should also be marked and a fan power absorption curve should be drawn through it to cut the full throttle curve. The fan power absorption curve is drawn on the assumption that the power varies with the cube of the rpm. The rpm indicated at the point of intersection of the two curves should lie between 90% to 97% of the maximum rpm. If it fails to do so, the point of Maximum Continuous power and rpm may be adjusted by ±2% of the rpm value and a cube law curve may be drawn through this adjusted point. If it is possible to bring the absorption curve to intersect the full throttle curve between the 90% to 97% rpm range by the ±2% adjustment, the engine may be tested with a fixed-pitch fan; if not, a variable-pitch fan should be used.

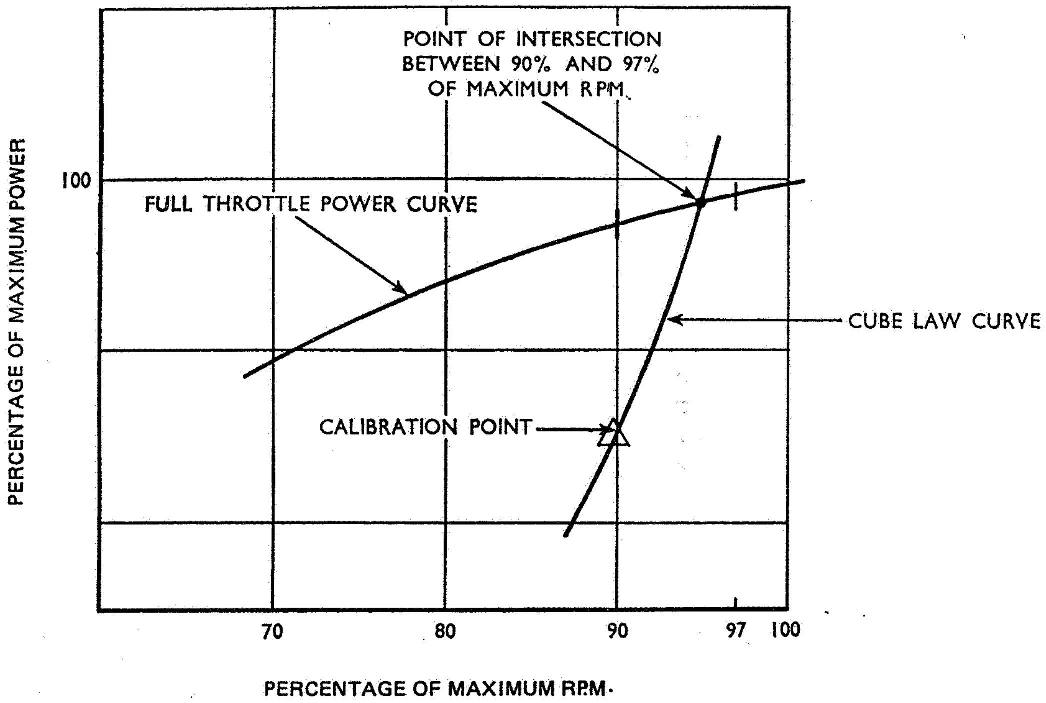


Figure 2 DETERMINATION OF TYPE OF TEST FAN REQUIRED FOR AN UNSUPERCHARGED ENGINE

4.4.2 **Supercharged Engines.** The procedure for supercharged engines with single speed superchargers is similar to that given in paragraph 4.4.1, except that the power/rpm curve at Maximum Take-off manifold pressure should be the curve obtained from the Engine Technical Certificate. Points corresponding to 90% and 97% of the maximum rpm should be marked on the Take-off power curve, and the power absorption curve, originating from the point of Maximum Continuous Power and rpm (the calibration point) should be drawn to intersect this power curve. If, after an adjustment of ±2% of the rpm value, the intersection of the two curves fails to be between 90% and 97% of the maximum rpm, a fixed-pitch fan would be unsuitable for the test.

4.4.3 **Variable-Pitch Fan Settings.** If the procedure given in paragraph 4.4.1 or 4.4.2, as appropriate, indicates that a fixed-pitch fan is unsuitable, a variable-pitch fan should be used. For the power check, one pitch stop of the variable-pitch fan should be set so that 97% of the Maximum Take-off rpm is obtained when running against this stop at Maximum Take-off manifold pressure (see Figure 3). To achieve this, separate engine runs should be made at Maximum Take-off manifold pressure to establish the speeds obtainable with the fan on its fine and coarse pitch stops respectively. The rpm obtained on each run should be marked on the Take-off power curve as an indication as to which stop, after adjustment, will give the fan pitch resulting in a fan power absorption curve passing through the 97% rpm point on the power curve. If the coarse pitch stop is used, the constant-speed unit (CSU) is set to the minimum rpm position and the fan will constant speed for a point below the absorption curve. If the fine pitch stop is used, the CSU control is set to the maximum rpm position and the fan will then constant speed for a point above the curve.

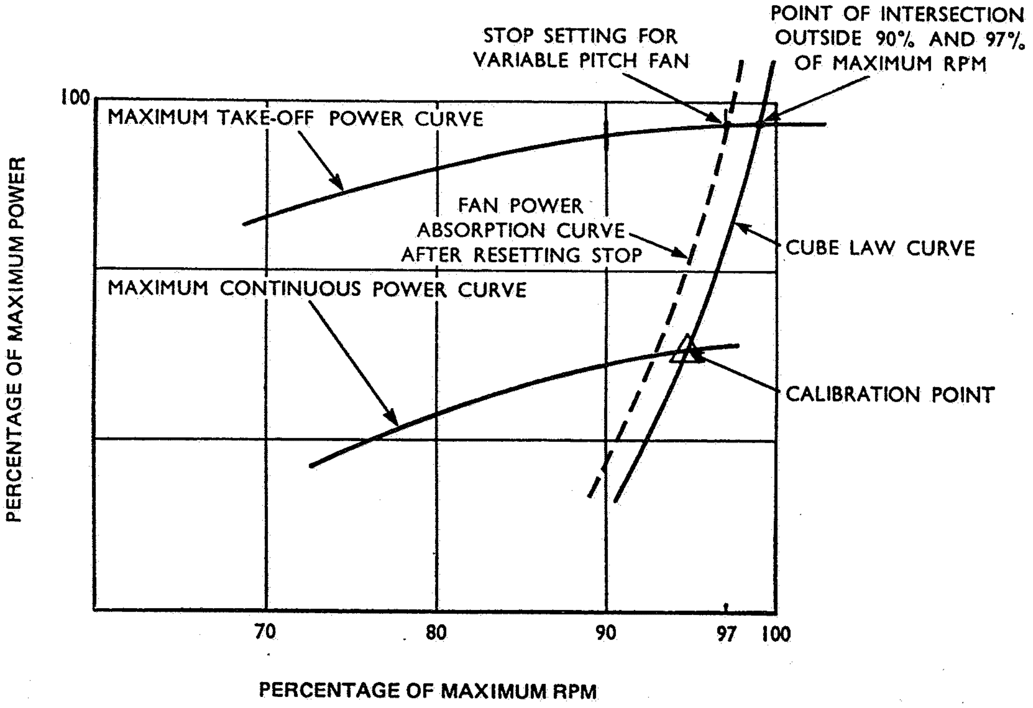


Figure 3 DETERMINATION OF TYPE OF TEST FAN AND PITCH SETTING REQUIRED FOR A SUPERCHARGED ENGINE

5 **FAN CALIBRATION** Before being used for testing overhauled engines, each test fan on each site must be calibrated on a new or recently reconditioned engine (hereinafter referred to as the "calibrated engine") which has not been run to any extent since its power output was last determined, for the purpose of fan calibration, on a dynamometer test bench. The calibration of the fan must be performed in the test cell in which the overhauled engines are to be tested, and unless it can be shown that changing from one test bench to another has no effect on fan performance, a separate calibration should be made each time the fan is used on a different bench. For preference the fan should be calibrated when the wind is unlikely to have any appreciable effect on results, but, if tests must be made when a strong wind is blowing, appropriate corrections may be made. The correction factors applied must be agreed by the CAA.

5.1 For an unsupercharged engine, the Full Throttle power curve of the calibrated engine must be available. In the case of a supercharged engine, the Maximum Take-off and Maximum Continuous constant manifold pressure curves, at standard sea-level atmospheric conditions, are required. An approved Test Fan Calibration Schedule for the engine type (obtainable from the engine manufacturers and normally included in the Engine Test Schedule), the power curves for the engine type (obtainable from the Engine Technical Certificate) and the appropriate correction curves (see Leaflet EL/3-8), must also be available.

5.2 Before commencing fan calibration, it is advisable to use an old engine to enable the test bed to be correctly set up. The calibrated engine should then be mounted on the test bench and primed with warm engine oil (see paragraph 7.1). The manufacturer may specify that a special cooling airscoop should be fitted for test bed running.

5.3 When a test fan is being calibrated, the engine temperatures and pressures should be as near as possible to those recorded when the engine was calibrated on the dynamometer.

5.4 The test fan power absorption characteristics are presented in the form of a cube law curve drawn on the assumption that, under constant atmospheric conditions, the power absorbed varies as the cube of the rpm. Consequently, if the power to be absorbed by the fan at one particular engine speed is known, a cube law curve showing the power/rpm relationship over a range of speeds may be drawn from calculated data. If such a curve is drawn through the power it should absorb at a particular speed so as to intersect the appropriate power curve for the calibrated engine, the value of rpm at the intersection is the rpm to be obtained from the fan after its blades have been cropped or its pitch stop finally adjusted.

5.5 In practice a tolerance of not more than ±20 rpm has to be allowed, which necessitates drawing a cube law curve for the fan, after cropping or pitch adjustment, which is based on rpm values derived from the observed results corrected to standard sea-level conditions. The intersection of the actual fan power absorption curve and the appropriate engine power curve for the type engine then gives the "acceptance rpm" value for the test fan. The corrected values subsequently attained when overhauled engines are tested with the same fan on the same test bed should not be less than 98% of these values.

5.6 The acceptance rpm of the test fan on the particular test bed should be recorded and used as a reference whenever the fan is used for testing. At periods agreed with the CAA, each test fan should be weighed, its static balance should be checked, the blade angles should be measured at specified stations and the general condition of the fan should be assessed. At longer agreed periods, and whenever any change in the environment of the test cell is made or whenever distortion of the fan blades is suspected, the acceptance rpm should be re-checked by a repeat calibration.

6 FAN CALIBRATION PROCEDURE The procedure for calibrating a test fan for use in testing a particular type of engine varies according to whether the engine is supercharged or unsupercharged. In practice a specific method to suit the characteristics of each type of engine is recommended by the engine manufacturer and is included in the approved Engine Test Fan Calibration Schedule. The approved method must be used at all times, but an outline of the general principles of calibration procedure is given in the following paragraphs. Whilst the specimen procedures given are typical, they are not necessarily generally applicable to all engine types.

6.1 **Unsupercharged Engines.** Unsupercharged engines are generally tested with fixed-pitch fans and a typical calibration procedure is as follows:

6.1.1 Draw the power/rpm curves at full throttle for the calibrated engine and for the type engine, as shown in Figure 4.

6.1.2 Plot on the graph the test fan calibration point (obtained from data supplied by the engine manufacturer) and through it draw a cube law curve representing the power absorption characteristics of the fan. Extend this curve as necessary to intersect the full throttle curve for the calibrated engine. The point of intersection gives the corrected rpm to be attained, subject to a tolerance of ±20 rpm, when the test fan has been adjusted and the calibrated engine is running at full throttle.

EXAMPLE: If the calibration point is 142 kW at 2100 rpm, mark this point on the graph and then plot further points obtained by incremental increases of power and rpm. Since the power absorbed by the fan is assumed to increase with the cube of the rpm, the increments of power increase should be cubed thus:

$142 \times 1{\cdot}1^3$ against $2100 \times 1{\cdot}1 = 189$ kW/2310 rpm
and $142 \times 1{\cdot}2^3$ against $2100 \times 1{\cdot}2 = 245{\cdot}4$ kW/2520 rpm

The cube law curve is a line drawn from the calibration point through the points plotted to the full throttle curve of the calibrated engine.

6.1.3 The temperature correction chart (Leaflet **EL/3-8**) should now be used to find the corresponding value of rpm which should be obtained in the actual conditions of fan air temperature prevailing at the site.

6.1.4 With the calibrated engine fitted with the test fan and installed on the test bench in the cell for which the calibration is required, the engine should be run until normal running conditions have stabilised. It should then be opened up to full throttle and careful note taken of the rpm obtained. The rpm observed on the continuous reading rpm indicator should be cross-checked by means of the "Hasler" indicator.

6.1.5 To obtain the value of rpm determined by the method given in paragraph 6.1.3 (within ±20 rpm), the fan should be removed and the blades cropped or the pitch adjusted as necessary. This should be done in successive stages with trial runs and, in the case of cropped propellers, rebalancing between each stage. If a cropped test fan gives a higher speed than that aimed at, it should be made "heavy" in the manner approved by the fan manufacturer.

6.1.6 The fan should then be remounted on the engine and the engine should again be run at full throttle. When the required rpm are obtained, the observed values should be recorded. To obtain reliable results, two or three separate runs should be made and on each occasion the mean of three readings taken in stabilised conditions at 1 minute intervals should be taken as the observed rpm. The mean of the observed rpm readings should then be corrected to standard temperature conditions by means of the appropriate chart and the corrected value should be plotted on the full throttle curve for the calibrated engine. In the example shown in Figure 4, the rpm are higher than the value aimed at but are within the tolerance.

6.1.7 A cube law curve should now be drawn to pass through the point plotted by the method given in paragraph 6.1.6 for the corrected value of rpm. This curve should be extended as necessary to intersect the full throttle curve for the type engine and the point of intersection will give the acceptance rpm of the fan. This value should be recorded together with details of the direction and speed of the wind at the time of calibration. A report on the calibration, including details of the environment in which the fan was tested and the acceptance rpm established for it, should then be submitted to the CAA for approval.

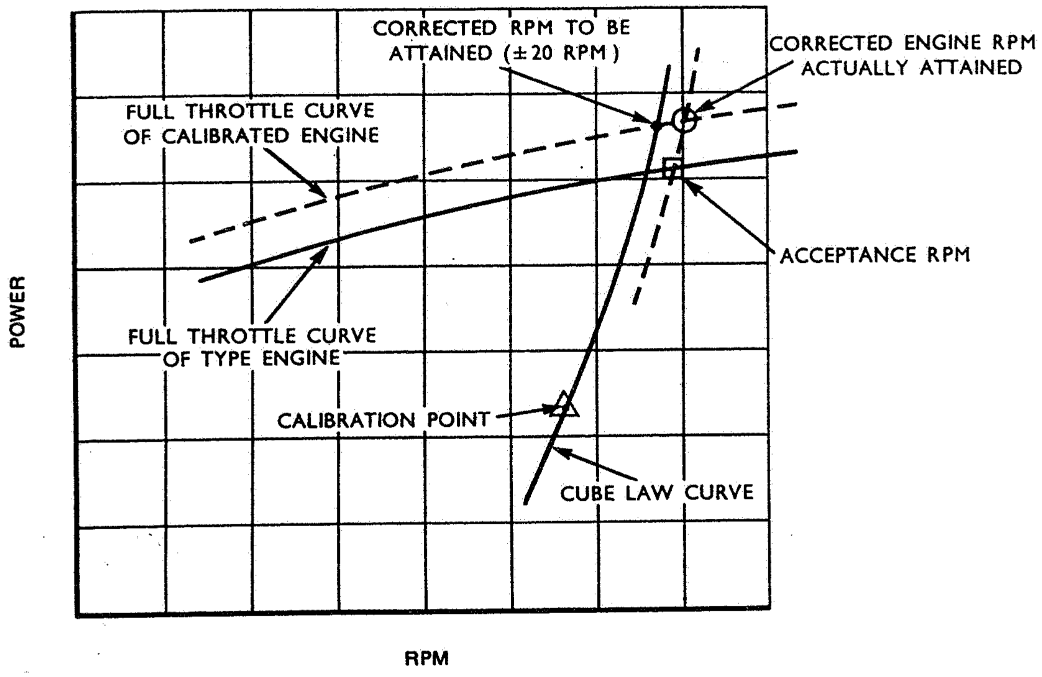


Figure 4 CALIBRATION OF FIXED-PITCH FAN FITTED TO UNSUPERCHARGED ENGINE

6.2 **Supercharged Engines.** Engines with single-speed superchargers are tested either with fixed-pitch fans or with variable-pitch fans, the type of fan required being determined by the method given in paragraph 4.4. Typical calibration procedure is as follows:

6.2.1 Draw the power/rpm curves for constant manifold pressure at Maximum Take-off, Maximum Continuous Power, and, if applicable, Maximum Weak Mixture Power for both the calibrated engine and the type engine, as shown in Figure 5.

6.2.2 For a fixed-pitch fan, plot on the graph the test fan calibration point (normally the point of Maximum Continuous power and rpm) and through it draw a cube law curve representing the power absorption characteristics of the fan. For a variable-pitch fan with governor control, plot the 97% rpm point of the type engine, as determined by paragraph 4.4.3, and draw the cube law curve through it. Extend the cube law curve as necessary to intersect the Maximum Take-off, Maximum Continuous Power and Maximum Weak Mixture constant manifold pressure curves for the calibrated engine. The point of intersection with the Maximum Take-off constant manifold pressure curve gives the corrected rpm to be attained, subject to a tolerance of ±20 rpm, when the test fan has been adjusted and the calibrated engine is running at the Maximum Take-off manifold pressure on a standard day.

6.2.3 The appropriate correction chart (Leaflet EL/3-8) should now be used to find the corresponding values of rpm to be obtained in the actual conditions of fan air temperature and atmospheric pressure prevailing at the site.

6.2.4 With the calibrated engine installed on the test bench and fitted with the test fan in the cell for which the calibration is required, the engine should be run until normal running conditions have stabilised. It should then be opened up to Take-off manifold pressure and careful note taken of the rpm obtained. A cross-check should be made by means of the "Hasler" indicator.

6.2.5 To obtain the value of rpm determined by the method given in paragraph 6.2.3 (within ±20 rpm), the fan should be cropped or the pitch adjusted as necessary. The fan should then be remounted on the engine and the engine should be run at Take-off, Maximum Continuous and Maximum Weak Mixture manifold pressures in turn. Where applicable, the sequence of events for cropping the fan, and then running the engine fitted with the calibrated fan, should be the same as in paragraphs 6.1.5 and 6.1.6.

6.2.6 The rpm observed when the engine is running with the fan finally adjusted should be corrected to conditions at sea-level on a standard day. The corrected rpm at Take-off manifold pressure should be plotted on the Take-off Power curve for the calibrated engine and the corrected rpm for Maximum Continuous and Maximum Weak Mixture on the appropriate power curves. These points should be linked by a test fan power absorption curve of approximately cube law form drawn through them.

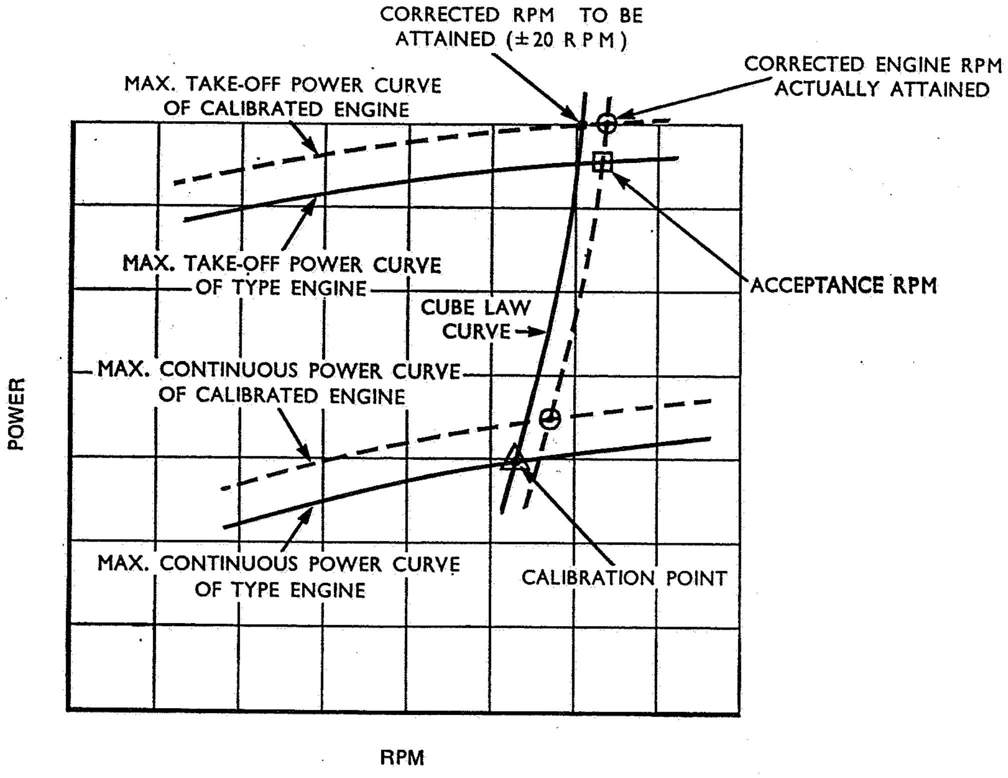


Figure 5 CALIBRATION OF FIXED-PITCH FAN FITTED TO SUPERCHARGED ENGINE

6.2.7 The fan power absorption curve should be extended as necessary to cut the Maximum Take-off Power curve for the type engine. The point of intersection gives the acceptance rpm of the fan. The points where the fan power absorption curve cuts the Maximum Continuous and Maximum Weak Mixture curves give rpm datum points which may be used, as recommended by the engine manufacturer, for engine tuning. These values should be recorded, together with details of the direction and speed of the wind at the time of the calibration. A report on the calibration, including details of the environment in which the fan was tested and the acceptance rpm established for it, should then be submitted to the CAA for approval.

7 USING THE CALIBRATED FAN After calibration, a test fan should only be used to test engines of the type for which it has been calibrated and in the particular cell in which the calibration has been made. If the environmental conditions of the test cell are changed, the fan must be recalibrated. The overhauled engine to be tested should be mounted on the test bench within the cell and the calibrated fan should be assembled to it: the engine should then be run according to the approved Test Schedule appropriate to the type of engine (see Leaflet EL/3-5).

7.1 Before starting the engine, its lubrication system should be primed with warm engine oil. The oil should be fed in under pressure whilst the engine is turned over by hand, care being taken to ensure that the oil is completely distributed through the bearings, gears and accessories drives. Should the engine not be run within three hours of priming it should be reprimed.

7.2 The engine should be correctly adjusted before the commencement of the test and a check should be made that the test plant controls have been correctly assembled. In the case of supercharged engines, the regulating valve of the depression box on the air intake should be fully open; in the case of normally-aspirated engines no depression box should be fitted.

7.3 After starting, the engine should be run-in according to the instructions in the Test Schedule approved for the engine type. Running-in is Stage 1 of the Endurance Test and the other stages should then follow in the sequence prescribed. During the test a suitable position for the thermometer which records the temperature of the air passing through the fan should be determined; a position between 2·5 to 4 metres (8 to 12 feet) forward of the engine and outside the arc of the fan usually proves satisfactory.

8 ACCEPTANCE CONDITIONS The acceptance conditions for overhauled engines when tested with a fan and the performance corrections to be made are prescribed in Chapter C2—5 of British Civil Airworthiness Requirements and repeated in the following paragraphs. Apart from the general running standard of each engine and its ability to satisfactorily complete the prescribed tests, the specific standards of performance of 8.1 or 8.2, as appropriate, must be obtained to the satisfaction of the CAA.

8.1 **Engines Rated in accordance with the Requirements in force on and after 18th November, 1946 (ICAO Ratings)**

8.1.1 The rpm obtained during the power check tests of the Final Test (Stage 10; and Stage 7 in respect of any other supercharger gears), when corrected to standard atmospheric conditions at sea-level, in accordance with paragraph 9, shall not be less than 98% of the acceptance rpm of the fan. Also in the case of a supercharged engine, the corrected supercharger compression ratio (at 15°C) obtained during Stages

8 and 9 of the Final Test and the corrected rpm obtained during the corresponding power check tests of the Final Test shall satisfy the following expression:

$$\frac{r_2}{r_1} + \left(\frac{N_2}{N_1}\right)^2 \text{ shall be not less than } 1{\cdot}96$$

where r_2 = supercharger compression ratio of the engine being tested at the observed rpm of the test.

r_1 = supercharger compression ratio of the standard engine at the observed rpm of the test as derived from the Engine Technical Certificate.

N_2 = corrected rpm obtained from the power check tests for engine being tested.

N_1 = acceptance rpm of the fan.

8.1.2 **Fuel Consumption.** In the case of overhauled engines tested with a fan, the fuel consumption shall be within the limits approved by the CAA.

8.1.3 **Oil Consumption.** The mean oil consumption obtained from the tests of Stages 3 and 4 of the Endurance Tests and Stage 4 of the Final Test, shall be within the declared limits. In the event of the engine not being able to comply with this requirement during the tests of Stages 3 and 4 of the Endurance Test, it shall be rejected for rectification and re-submission to the Endurance Test. Alternatively, subject to the agreement of the CAA, the endurance running of Stages 3 and 4 of the Endurance Test may be extended up to a maximum of an additional 2 hours, until the consumption falls within the required limits over a period of at least 30 minutes' duration. The consumption shall be checked in each supercharger gear. As a further alternative, where the applicant is of the opinion that the oil consumption can be improved by adjustment during strip examination, the endurance portion of the Final Test may, at the discretion of the CAA, be extended by the addition of a run limited to a minimum of 1 hour at the declared Maximum Continuous Power conditions. The running shall be equally divided between the supercharger gears. During the period of oil consumption measurement, ignition checks, or operation of any accessory or any other tests or adjustment which may affect consumption, shall be avoided. The oil consumption in each supercharger gear shall be reasonably consistent.

8.1.4 **Accelerations.** Accelerations shall be smooth and free from hesitation or other signs of fuel-metering trouble.

8.1.5 **Single Ignition Check.** The power drop when running with single ignition shall not exceed the declared maximum.

8.1.6 **Cleanliness.** The engine shall be free from leaks at all joints and connections, etc.

8.2 **Engines Rated in accordance with the Requirements in force before 18th November, 1946 (pre-ICAO Ratings).** The acceptance conditions for engines with pre-ICAO ratings are identical to those in paragraph 8.1, except that Maximum Cruising Power conditions should be substituted for Maximum Continuous Power conditions wherever these conditions are specified.

9 PERFORMANCE CORRECTIONS

9.1 The corrections used in order to convert the observed engine rpm to standard atmospheric conditions at sea-level, and to assess the performance of the supercharger where applicable, shall be approved by the CAA for each type of engine. These corrections shall be prepared in the form of charts (see Leaflet **EL/3-8**).

9.2 For the rpm correction the variation of power with rpm at Maximum Take-off manifold pressure (and at Maximum Climbing or Maximum Continuous manifold pressure in any other supercharger gears) shall be established and a chart giving the correction factor for a suitable range of atmospheric conditions shall be prepared. If variations in wind speed and direction can appreciably affect the power absorption characteristics of a fan in a particular test cell, suitable corrections may be established, but before being used they shall be approved by the CAA.

Issue 3.

December, 1978.

AIRCRAFT

ENGINES

PISTON ENGINE OVERHAUL—CORRECTING ENGINE TEST RESULTS

1 INTRODUCTION

1.1 Section C of British Civil Airworthiness Requirements prescribes that all performance results obtained during the bench testing of aero-engines must be corrected to the conditions of temperature and pressure in the standard atmosphere. Correction formulae from the Requirements which are applicable to the testing of low-power, air-cooled engines are repeated in this Leaflet; other parts of the Requirements relevant to testing piston engines after overhaul are repeated in Leaflets **EL/3-5, EL/3-6** and **EL/3-7.**

1.2 This Leaflet also explains how to make corrections for the effects of prevailing atmospheric conditions during the calibration of test fans, and includes charts which may be used to make such corrections.

1.3 The Leaflet is the last of a series dealing with piston engine overhaul and should be read in conjunction with the other leaflets in the series, i.e. Leaflets **EL/3-1** to **EL/3-7.** In particular it is closely associated with Leaflets **EL/3-6** and **EL/3-7** which deal with the testing of overhauled engines by means of dynamometers and test fans respectively.

2 GENERAL Varying atmospheric conditions affect engine performance by an appreciable amount and corrections must therefore be made for deviations of atmospheric pressure and temperature from standard at the time of test. Humidity changes, whilst not generally as significant as pressure or temperature changes, also have an influence on the results and therefore a method of correcting for humidity is given in paragraph 3.3. If this method is not used, an alternative method approved by the CAA must be used. If the engine power is affected by deviation of cylinder temperature from the values prescribed in the test schedules, appropriate corrections may also be made, but the corrections must be approved by the CAA before use in the calculations.

3 ENGINES TESTED WITH A DYNAMOMETER When an engine is tested on a dynamometer test bench, the brake power is obtained from the products of the net weight lifted by the dynamometer and the rotational speed of the dynamometer rotor, divided by the dynamometer constant (Leaflet **EL/3-6**). This gives the observed brake power for the engine (power_o) and represents the particular power output of the engine under the conditions of air intake temperature, atmospheric pressure, engine manifold pressure and exhaust back pressure at the time of test. To ensure that the power of an engine is within the acceptance limits for the engine type, these results must be corrected to conditions which are standardised for all tested engines, namely to the sea-level conditions of pressure and temperature in the standard atmosphere. These are 101·325 kN/m² (29·92 inHg) and 15°C respectively.

3.1 **Power Correction Formulae.** The corrected brake power, P_c (BHP_c), of normally aspirated engines and supercharged engines in which there is no provision for inter-cooling, after-cooling or heating the charge before it enters the cylinders, is given by the formulae:—

S.I. Units

$$P_c = P_o \frac{(400 + t_o)\left(M_c - \frac{p_c}{R}\right)}{(400 + t_c)\left(M_o - \frac{p_o}{R}\right)}$$

Non-S.I. Units

$$BHP_c = BHP_o \frac{(400 + t_o)\left(M_c - \frac{p_c}{R}\right)}{(400 + t_c)\left(M_o - \frac{p_o}{R}\right)}$$

where P(BHP) = brake power, kW (horse-power)
t = air intake temperature, °C
M = manifold pressure, kN/m² (inHg)
p = exhaust back-pressure, kN/m² (inHg) = atmospheric pressure + any increase in pressure due to the test plant exhaust system. (In the examples given p is assumed to be equal to atmospheric pressure)
R = engine compression ratio

Friction Power (P_f or FHP) is given by the formulae:—

S.I. Units

$$P_f = 27 \times 10^{-16} \times N^2 \times d^2 \times l^2 \times n$$

Non-S.I. Units

$$FHP = 15 \times 10^{-10} \times N^2 \times d^2 \times l^2 \times n$$

where N = crankshaft rotational speed, rpm
d = cylinder bore, mm (in)
l = length of stroke, mm (in)
n = number of cylinders

Suffix "o" denotes an observed condition, corrected for instrument error only.
Suffix "c" denotes the condition in the required (sea-level atmospheric) atmosphere.

NOTES: (1) Standard sea-level atmospheric pressure = $1{\cdot}01325 \times 10^5$ N/m² = 1013·2 mbar = 29·92 inHg = 760 mmHg = 14·7 lbf/in².
(2) 1 kN/m² = 1 kPa = 10 mbar.
(3) 1 lbf/in² = 6·895 kN/m².
(4) 1 inHg = 3·386 kN/m².

3.1.1 **Unsupercharged Engines.** For an unsupercharged engine running at constant rpm at full-throttle, the manifold pressure is normally assumed to be atmospheric, which means that to correct the observed power to sea-level conditions the formulae can be written as follows:—

S.I. Units

$$P_c = P_o \frac{(400 + t_o)\left(101{\cdot}325 - \frac{101{\cdot}325}{R}\right)}{(400 + t_c)\left(p_o - \frac{p_o}{R}\right)}$$

Non-S.I. Units

$$BHP_c = BHP_o \frac{(400 + t_o)\left(29{\cdot}92 - \frac{29{\cdot}92}{R}\right)}{(400 + t_c)\left(p_o - \frac{p_o}{R}\right)}$$

EXAMPLE: If the full-throttle brake power of a particular engine (compression ratio 5·25:1) is observed to be 196 kW on a day when the air temperature is 17°C and barometric pressure is 1000 mbar (100 kN/m²), then corrected to standard sea-level conditions the brake power would be:—

$$P_c = 196\,\frac{(400 + 17)\left(101{\cdot}325 - \frac{101{\cdot}325}{R}\right)}{(400 + 15)\left(100 - \frac{100}{R}\right)}$$

$$= 196 \times 1{\cdot}005 \times 1{\cdot}013$$

$$= \underline{199{\cdot}54\ \text{kW}}$$

NOTE: Assuming the declared Maximum Take-off Power of the engine is 196 to 204 kW at sea-level, the result satisfies the acceptance conditions of BCAR.

3.1.2 **Supercharged Engines.** During the Endurance and Final Tests of a supercharged engine, the power output and the supercharger compression ratio are measured, the former with an unrestricted air intake and the latter with a restricted intake obtained by using a depression box fitted to the intake.

(a) **Power.** When correcting the power observed during a test run with unrestricted air intake to standard sea-level conditions at the same manifold pressure, the correction formula can be written:

S.I. Units

$$P_c = P_o\,\frac{(400 + t_o)\left(M_c - \frac{101{\cdot}325}{R}\right)}{(400 + 15)\left(M_o - \frac{p_o}{R}\right)}$$

Non-S.I. Units

$$BHP_c = BHP_o\,\frac{(400 + t_o)\left(M_o - \frac{29{\cdot}92}{R}\right)}{(400 + 15)\left(M_o - \frac{p_o}{R}\right)}$$

EXAMPLE: If the brake power of a particular engine, having a compression ratio of 6·5:1 and running at a manifold pressure of 41·3 inHg (140 kN/m²) is observed to be 348·5 kW on a day when the air intake temperature is 20°C and the barometric pressure is 1010 mbar (101 kN/m²), the corrected brake power will be:—

$$P_c = 348{\cdot}5\,\frac{(400 + 20)\left(140 - \frac{101{\cdot}325}{6{\cdot}5}\right)}{(400 + 15)\left(140 - \frac{101}{6{\cdot}5}\right)}$$

$$= 348{\cdot}5 \times 1{\cdot}012 \times 0{\cdot}999$$

$$= \underline{352{\cdot}329\ \text{kW}}$$

(b) **Supercharger Compression Ratio.** The variation of supercharger compression ratio with variation of air temperature at constant air intake pressure is given by:

$$r_c = r_o\left(1 + k\,(t_o - t_c)\right) \text{ when correcting to a lower air temperature}$$

$$\text{and } r_c = \frac{r_o}{1 + k\,(t_c - t_o)} \text{ when correcting to a higher air temperature.}$$

In the above formulae the additional notation is used:

r = supercharger compression ratio
k = supercharger temperature constant for particular engine.

The supercharger compression ratio is determined during Stages 8 and 9 of each test by running the engine with the air intake restricted such that the throttle is fully open at Maximum Continuous (or Maximum Climbing) Power and at Take-off Power conditions respectively. With the throttle lever set to obtain the appropriate manifold pressure, the regulating valve on the intake depression box should be closed progressively until the boost control has fully opened the throttle. The corresponding air intake pressure should be found (see paragraph 4.3.1), and the ratio between the two pressures, $\dfrac{\text{Manifold Pressure}}{\text{Intake Pressure}}$ should then be corrected to sea-level temperature conditions in the standard atmosphere by means of the appropriate formula.

EXAMPLE: If when testing the above engine the observed manifold pressure at Maximum Continuous Power conditions is 140 kN/m², and the observed air intake pressure is 101 kN/m², the compression ratio will be:—

$$r_o = \frac{M_o}{P_o} = \frac{140}{101} = 1{\cdot}386$$

Assuming the value of 'k' for this engine is 0·001 under test conditions where the intake temperature is 20°C, the supercharger compression ratio corrected to the sea-level temperature of a standard day will be:—

$$r_c = 1{\cdot}386 \left[1 + 0{\cdot}001\,(20 - 15)\right] = 1{\cdot}386 \times 1{\cdot}005 = \underline{1{\cdot}392}$$

NOTE: Since the sum of the ratios of the corrected sea-level power and the corrected supercharger compression ratio to the values established in the Engine Technical Certificate is greater than 1·96, the results satisfy the acceptance conditions prescribed in BCAR.

$$\text{i.e.}\quad \frac{352{\cdot}329}{351} + \frac{1{\cdot}392}{1{\cdot}4} = 1{\cdot}004 + 0{\cdot}994 = \underline{1{\cdot}998}$$

3.2 Power at Altitude

3.2.1 When drawn on a relative density basis the variation of power with altitude at constant crankshaft rotational speed and manifold pressure may be given by a straight line between the power at sea-level and the power at the full throttle height.

3.2.2 The variation of power with height at constant crankshaft rotational speed and full throttle, when drawn on a relative density basis, may be a curve at high powers but at low powers this curve may be extended as a straight line to the negative friction horsepower at zero density.

3.3 **Humidity Corrections.** In order to determine power ratings in dry air, or conversely to determine the power output in given conditions of atmospheric humidity, the following corrections should be used unless more accurate data are available:

S.I. Units

$$P_c = \frac{P_o + P_f}{1 - xh} - P_f$$

Non-S.I. Units

$$BHP_c = \frac{BHP_o + FHP}{1 - xh} - FHP$$

where x is a factor depending on mixture strength

and h is the humidity, i.e., $\dfrac{\text{water vapour pressure}}{\text{barometric pressure}}$

NOTE: Since the effect of free water on power output is within ±1% over the range of water/air ratios normally encountered in operation, and the amount of free water is exceedingly difficult to measure, no corrections for free water need be made.

3.3.1 For constant fuel flow, the effect of humidity on air/fuel ratio is given by

$$Z_c = \frac{Z_o}{1 - h}$$

where Z = air/fuel ratio.

3.3.2 Table 1 gives values of x over a range of air/fuel ratios corrected to dry air conditions for air-cooled engines with fuel-metering systems which compensate for manifold pressure and charge temperature.

TABLE 1

Air/fuel ratio	9	10	11	12	13	14	15	16
Values of x	2·15	1·80	1·54	1·32	1·18	1·07	1·02	1·00

3.3.3 The following is the temperature correction which should be used in the case of air-cooled engines when the above-mentioned corrections for humidity are utilised:—

S.I. Units

$$P_c = \frac{P_o + P_f}{1 + C(t_c - t_o)} - P_f$$

Non-S.I. Units

$$BHP_c = \frac{BHP_o + FHP}{1 + C(t_c - t_o)} - FHP$$

where C is a constant determined for the appropriate dry air mixture strength.

3.3.4 Table 2 gives values for C over a range of air/fuel ratios corrected to dry air conditions.

TABLE 2

Air/fuel ratios	9	10	11	12	13	14	15	16
Values of C	·00167	·00181	·00195	·00207	·00216	·00224	·00226	·00228

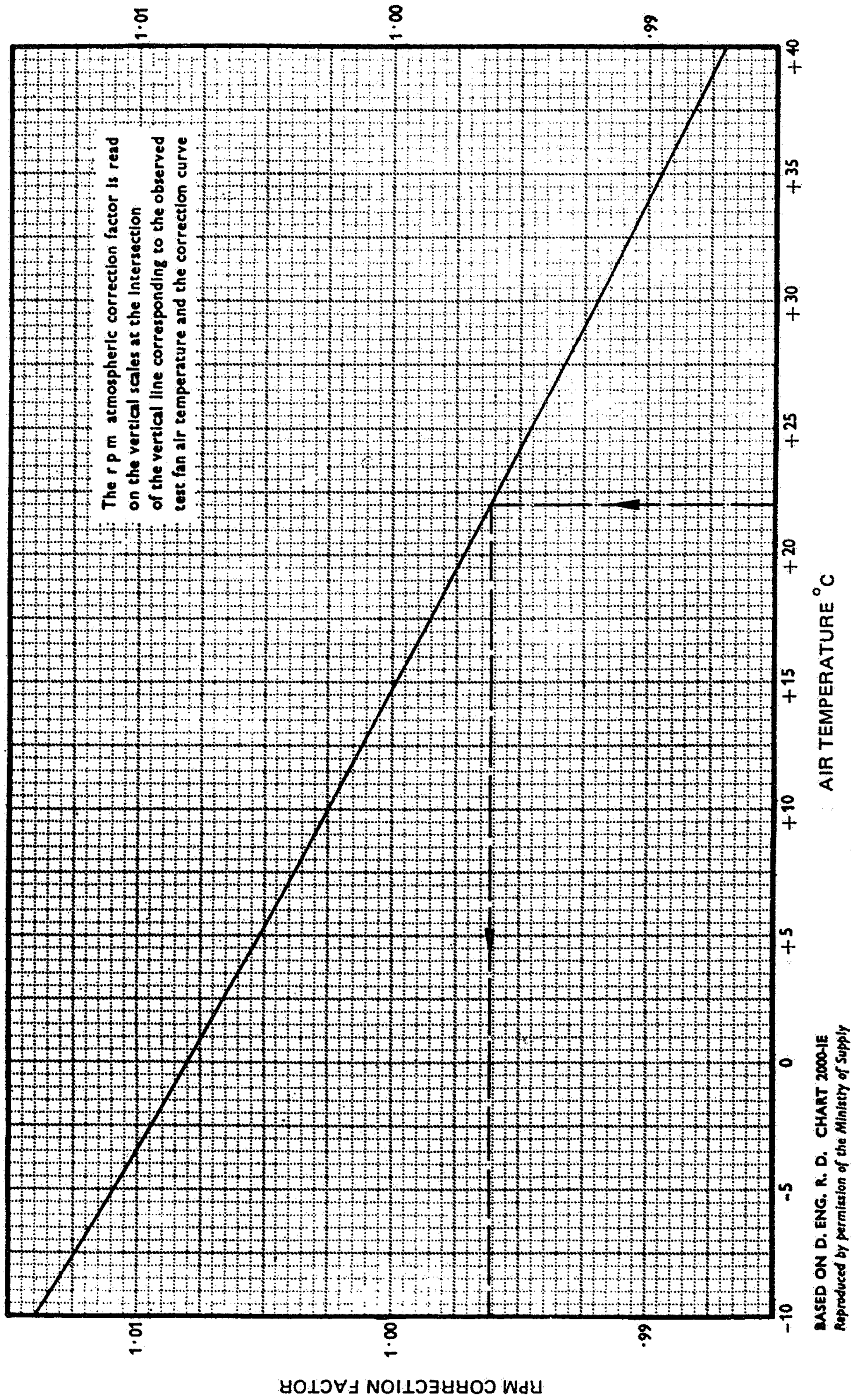
The value of C applicable to take-off conditions when water-methanol injection is used is 0·0022.

4 TEST FAN CALIBRATION CORRECTIONS During the calibration of engine test fans (Leaflet **EL/3-7**), the rpm obtained will be influenced by the conditions of atmospheric temperature and pressure prevailing at the site. Thus cold conditions have two contradictory effects; the engine power tends to increase because of the increased charge density but an increase in rpm is opposed by the increased power absorbed by the fan as a result of the denser air. The net result is that the observed rpm will be lower than under standard sea-level conditions. Corrections of observed rpm to conditions in the standard atmosphere should be made by means of suitable charts; charts suitable for particular engines are normally included by the manufacturer in the approved Test Schedule for the engine concerned. However, two charts, one for normally-aspirated engines and one for supercharged engines, each of which is suitable for a wide range of engines when testing at altitudes between sea-level and 1,000 feet, are included in this Leaflet and the following paragraphs explain their use.

NOTE: If engines are to be tested in cells at altitudes above 1,000 feet, specially prepared charts should be requested from the engine manufacturer.

ENGINE TESTING WITH PROPELLER TEST FANS

CORRECTION OF OBSERVED ENGINE RPM FOR OBSERVED TEMPERATURE CONDITIONS TO THE RPM OBTAINABLE ON A STANDARD DAY



The r p m atmospheric correction factor is read on the vertical scales at the intersection of the vertical line corresponding to the observed test fan air temperature and the correction curve

BASED ON D. ENG. R. D. CHART 2000-IE
Reproduced by permission of the Ministry of Supply

Figure 1

4.1 Unsupercharged Engines

4.1.1 When testing unsupercharged engines at full throttle it can be assumed that barometric changes affecting the engine power, and therefore tending to increase or decrease the engine rpm, are counterbalanced by the variation in fan loading. It is therefore necessary to correct for air temperature only and this can be done with the aid of the chart in Figure 1.

4.1.2 To use the chart, a vertical line should be projected from the observed air temperature point on the horizontal scale to the correction curve, and from the point of intersection a horizontal line should be projected to cut the vertical scale. This gives the rpm correction factor by which the observed rpm should be multiplied.

EXAMPLE: If the observed air temperature is +22°C, the rpm correction factor is 0·9962. If the observed rpm is 2650, the corrected rpm = 2650 × 0·9962 = 2640.

4.2 Supercharged Engines

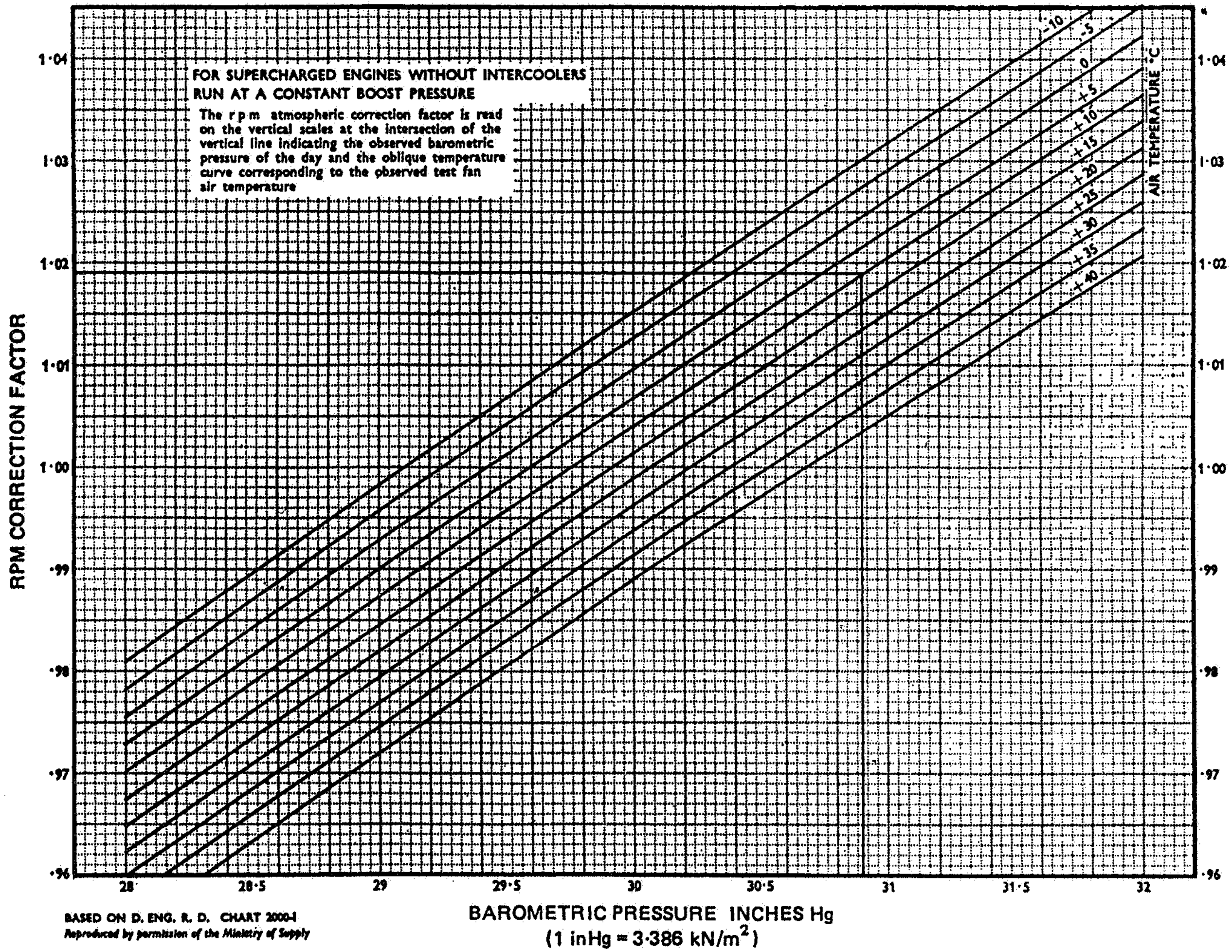
4.2.1 When checking the performance of a supercharged engine with a test fan, the engine is run at the required manifold pressure and the effects of barometric changes on engine adjustment are corrected by throttle adjustment. However, the fan loading will vary with the air density and corrections must therefore be made for barometric pressure as well as for air temperature. The fan air temperature, as recorded by the thermometer in the test cell, is assumed to be the same as the air intake temperature. The chart shown in Figure 2 can be used for correcting the rpm of a wide range of air-cooled supercharged engines.

4.2.2 The method of using the chart is to select the point corresponding to the observed barometric pressure on the barometric pressure scale and project a vertical line from this point until it intersects the curve corresponding to the observed air temperature. A horizontal projection from the point of intersection will give the rpm correction factor by which the observed rpm should be multiplied.

EXAMPLE: Referring to Figure 2, if the observed barometric pressure is 104·6 kN/m² (30·9 inHg) and the observed air temperature is +10°C, the rpm correction factor is 1·019. If the observed rpm is 2640, the corrected rpm = 2640 × 1·019 = 2690.

4.2.3 It sometimes happens that altitude-rated engines reach full throttle before the required manifold pressure can be obtained: either a low full throttle altitude rating, low atmospheric pressure or poor engine performance may be the cause. If, for any reason, a supercharged engine is run at full throttle during the power check (without, of course, exceeding the required manifold pressure), it should be corrected as though it were a normally-aspirated engine by the method given in paragraph 4.1.

4.3 **Supercharger Performance Corrections.** The requirements for testing piston engines after overhaul (Leaflet EL/3-5) prescribe that a supercharger compression ratio check shall be made whilst the engine is run at Maximum Continuous Power (or Maximum Climbing Power for Schedule II engines) and Maximum Take-off Power conditions with reduced air intake pressure. The supercharger performance is checked by running the engine at full throttle at the required rpm and manifold pressure with a restricted air intake and observing the absolute air intake pressure under these conditions. Since


ENGINE TESTING WITH PROPELLER TEST FANS

CORRECTION OF OBSERVED ENGINE RPM FOR OBSERVED ATMOSPHERIC CONDITIONS TO THE RPM OBTAINABLE ON A STANDARD DAY

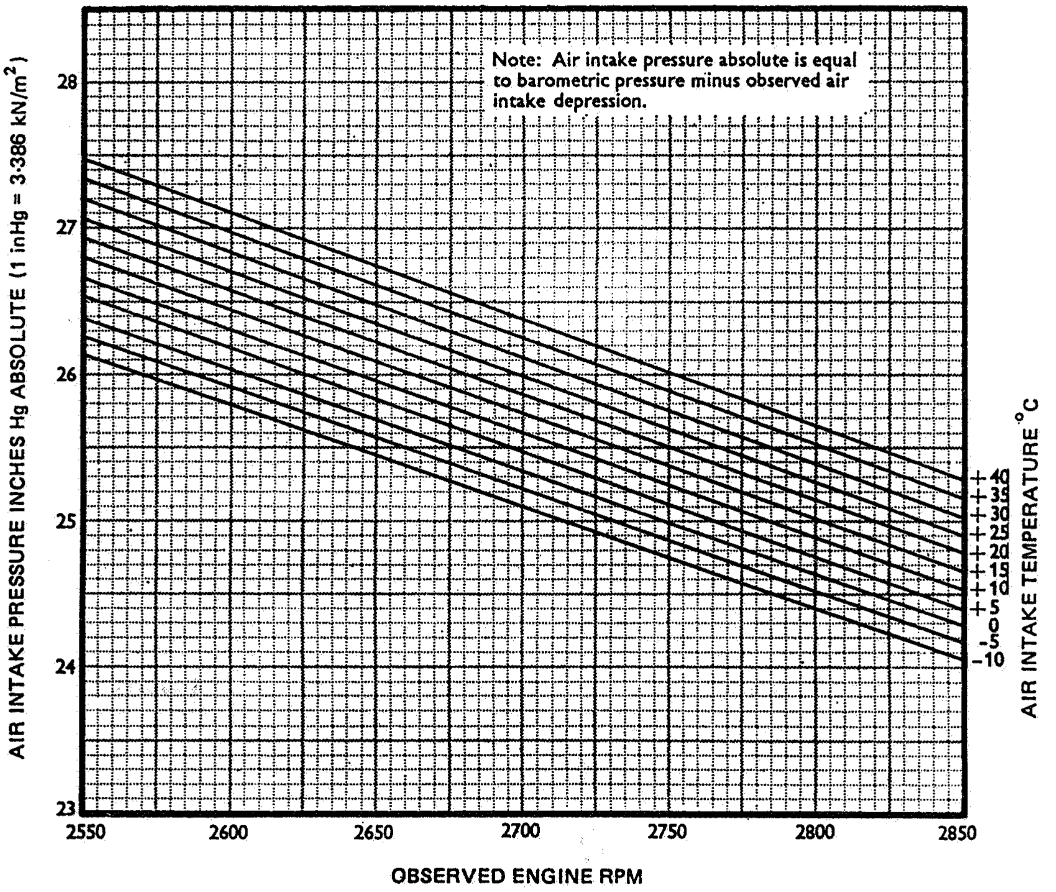
FOR SUPERCHARGED ENGINES WITHOUT INTERCOOLERS RUN AT A CONSTANT BOOST PRESSURE

The r p m atmospheric correction factor is read on the vertical scales at the intersection of the vertical line indicating the observed barometric pressure of the day and the oblique temperature curve corresponding to the observed test fan air temperature

BASED ON D. ENG. R. D. CHART 2000-I
Reproduced by permission of the Ministry of Supply

Figure 2

the absolute air intake pressure is inversely proportional to the compression ratio, any difference in the ratio from standard will be shown by changes in the intake pressure. The compression ratio of a supercharger varies with the air intake temperature and with the tip speed of the impeller.


GIPSY QUEEN 70 Mk. 2
SUPERCHARGER PERFORMANCE CHECK
STANDARD AIR INTAKE PRESSURE FOR 42 inHg MANIFOLD PRESSURE AT FULL THROTTLE

Note: Air intake pressure absolute is equal to barometric pressure minus observed air intake depression.

Reproduced by permission of the De Havilland Engine Co. Ltd.

Figure 3

4.3.1 For each particular supercharged engine, it is usual for the engine manufacturer to prepare a supercharger performance correction chart based on the performance of the type-tested engine and to include this chart in the approved Test Schedule for the engine type. From the chart the absolute air intake pressure which should be obtained at the observed rpm and observed intake temperature can be determined. The performance of the supercharger can then be assessed by comparing this pressure with the absolute pressure actually observed in the intake of the engine under test. The observed air intake pressure is taken as the difference between the barometric pressure in the test cell and the pressure indicated on a depression gauge fitted to the depression box.

4.3.2 A specimen supercharger performance correction chart is shown in Figure 3; the chart illustrated is for the Gipsy Queen 70 Mk. 2 engine. To find the required absolute air intake pressure, the observed rpm should be read off on the horizontal scale and a vertical line should be projected from it to intersect the curve appropriate to the observed air intake temperature. A horizontal line projected from the point of intersection will give the absolute air intake pressure in inches of mercury.

4.3.3 If the observed absolute air intake pressure is greater than the figure obtained from the chart, the supercharger performance is below the performance of the supercharger of the standard engine as derived from the Engine Technical Certificate. The acceptance conditions for the performance of overhauled engines when tested with a fan (Leaflet EL/3-7) state that the corrected supercharger compression ratio (at 15°C) obtained during Stages 8 and 9 of the Final Test and the corrected rpm obtained during the corresponding power check tests shall satisfy the following expression:

$$\frac{r_2}{r_1} + \left(\frac{N_2}{N_1}\right)^2 \text{shall not be less than } 1{\cdot}96$$

where r_1 = supercharger compression ratio of the standard engine at the observed rpm of the test as derived from the Engine Technical Certificate.

r_2 = supercharger compression ratio of the engine being tested, at the observed rpm of the test.

N_1 = acceptance rpm of the fan.

N_2 = corrected rpm obtained from the power check tests for engine being tested.

EXAMPLE: A Gipsy Queen 70 Mk. 2 engine is run at a manifold pressure of 42 inHg and at 2700 rpm with an air intake temperature of +5°C. If the barometer reading is 30 inHg and the depression gauge reading is 5 inHg, the observed air intake pressure is 25 inHg. Reading from the chart in Figure 3, the intersection of the vertical line corresponding to 2700 rpm and the curve for +5°C intake temperature gives an absolute intake pressure of 25·5 inHg

where $$r_1 = \frac{42}{25{\cdot}5} = 1{\cdot}647$$

$$r_2 = \frac{42}{25} = 1{\cdot}68$$

$$N_1 = 2700$$

and assuming $N_2 = 2680$

$$\frac{1{\cdot}68}{1{\cdot}647} + \left(\frac{2680}{2700}\right)^2 = 1{\cdot}02 + 0{\cdot}985 = \underline{2{\cdot}005}$$

Issue 1.

23*rd June*, 1969.

AIRCRAFT

ENGINES

PISTON ENGINES — MAGNETOS

1 INTRODUCTION This Leaflet gives general guidance on the functioning, installation and maintenance of typical magnetos. It should be read in conjunction with the Maintenance Manual for the engine concerned.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet EL/5-3, Issue 1, 1st August, 1950. Information on the installation of sparking plugs is given in Leaflet EL/5-1 and on the installation and maintenance of ignition cables and harnesses in Leaflet EL/5-2.

2 BASIC PRINCIPLES OF A MAGNETO

2.1 A magneto consists basically of two parts, i.e. a generator and a transformer. It is based on the principles of electromagnetic induction summarised below.

2.1.1 When a conductor is moved through a magnetic field in such a way as to cut the lines of magnetic force, an electro-motive force (e.m.f.) is induced in that conductor. If the conductor circuit is closed then an electric current will flow.

2.1.2 Any conductor carrying an electric current generates a magnetic field concentric with the conductor, the strength of the field depending on the strength of the current.

2.1.3 Any change of magnetism, no matter how caused, when acting upon a coil of wire, induces into that wire an electric current. The strength of that current will depend on:—

(i) Strength of the magnet.

(ii) Rate of change of magnetism.

(iii) Number of turns of wire in the coil.

2.2 In a normal magneto two coils of insulated wire are wound round a soft iron core. The first or "primary" coil consists of a small number of turns (approximately 200) of relatively thick wire and the second or "secondary" coil consists of a large number of turns (approximately 10,000) of very fine wire. The soft iron core is subjected to an alternating magnetic flux either by being rotated between the poles of a permanent magnet or by the rotation of a magnet between suitably shaped shoes attached to the core. As the turns are cut by the magnetic flux a low voltage is induced in the primary coil, the current and therefore the magnetic field produced by it, being greatest when the rate of change of magnetic flux is greatest. At this point the primary circuit is broken and the magnetic field collapses round the secondary coil producing a high voltage current which is directed by a suitable conductor to the centre electrode of the sparking plug.

NOTE: Although an e.m.f. is built up in the secondary coil when the magnetic flux is increasing in the core, it is the rapid collapse of the magnetic field which produces the high voltage necessary to produce a spark at the sparking plug points.

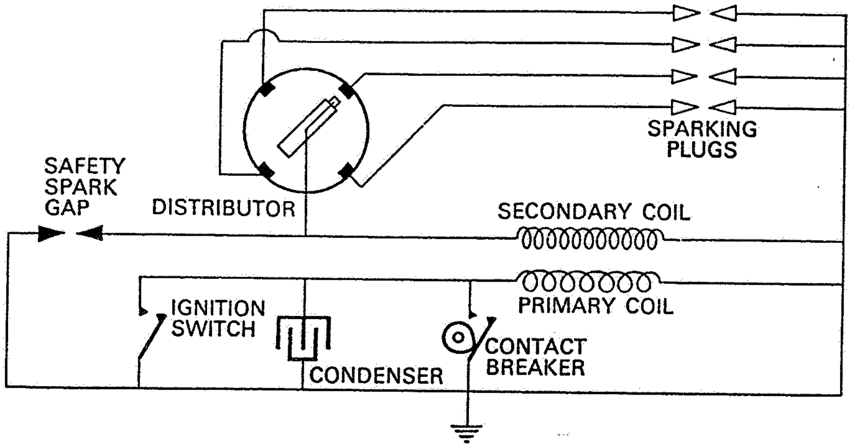


Figure 1 TYPICAL IGNITION CIRCUIT

3 CONSTRUCTION OF A MAGNETO Although the basic principle of operation of all magnetos is similar, the construction may vary considerably. They can, however, be divided basically into two types, i.e. the rotating armature magneto and the rotating magnet magneto.

3.1 **The Rotating Armature Magneto.** The assembly of the primary and secondary coils on a soft iron core discussed in paragraph 2 is known as the "armature". In the rotating armature magneto this is mounted on a shaft driven from the engine and rotated between the poles of a permanent magnet (*Figure* 2). As only two sparks are produced for each revolution of the armature, this type of magneto is normally used only on engines with up to six cylinders.

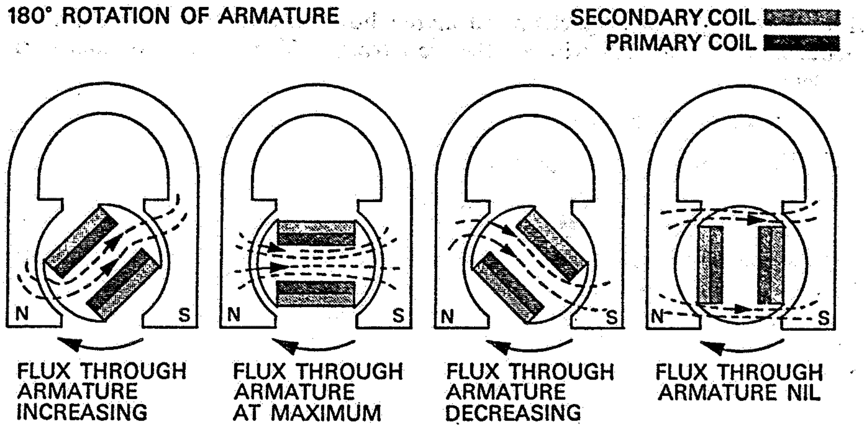


Figure 2 FLUX CHANGE IN ROTATING ARMATURE MAGNETO

3.2 **The Rotating Magnet Magneto.** The most usual type of "rotating magnet magneto" is the "polar inductor magneto" where the permanent magnets are actually stationary and soft iron inductors, mounted on a non-magnetic shaft driven from the engine, are used to guide the magnetic flux through the armature (*Figures* 3 and 4). Four sparks are produced for each revolution of the inductor shaft, making this type of magneto suitable for use on engines with more than six cylinders.

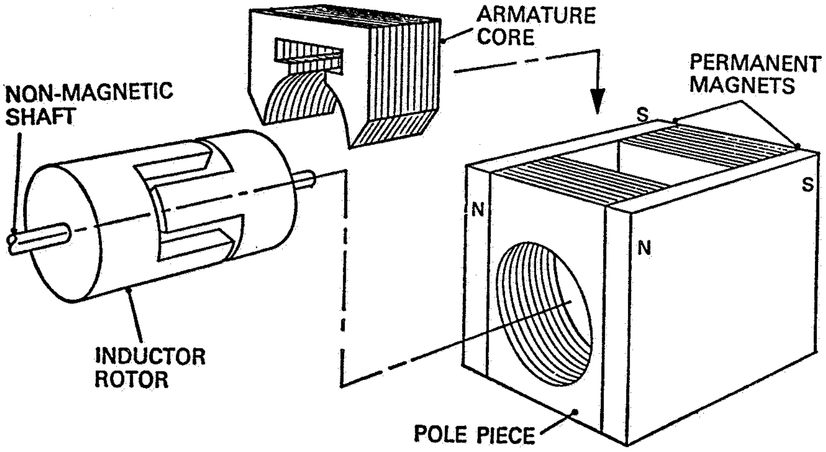


Figure 3 POLAR INDUCTOR MAGNETO

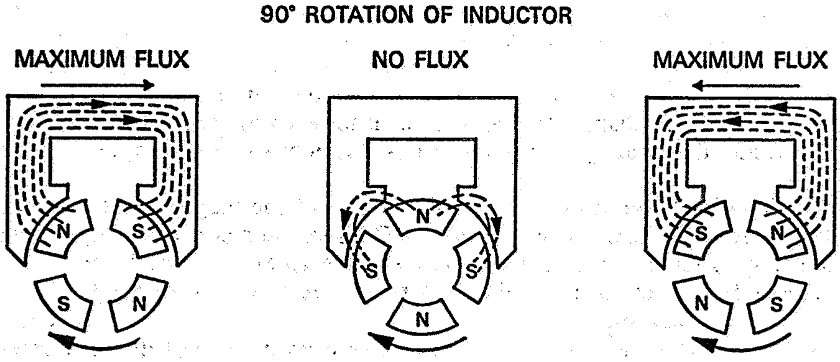


Figure 4 FLUX CHANGE IN A POLAR INDUCTOR MAGNETO

4 MAIN COMPONENTS OF A MAGNETO

4.1 **The Armature.** The armature consists of a soft iron core around which the primary and secondary coils are wound. With a rotating armature a means of transferring the electrical current to the static part of the magneto circuit, such as carbon brushes operating in slip rings, is provided. The armature core is usually laminated to reduce the build up of heat.

4.2 **The Contact-Breaker.** The contact-breaker is a mechanically operated switch which is timed to break the primary circuit when induced current in the primary coil is at a maximum.

4.2.1 On one type of rotating armature magneto, the contact-breaker is usually keyed on to the end of the armature shaft and rotates within a cam ring which is located concentrically round the shaft. As the contact-breaker assembly rotates, the breaker arm strikes each of the two cams in turn and breaks the primary circuit at the required moments.

4.2.2 On the polar inductor magneto, the contact-breaker assembly is normally stationary and the breaker arm is operated by a cam wheel attached directly to the distributor rotor. A separate cam lobe is provided for each of the engine cylinders.

4.3 **The Condenser.** The purpose of the condenser is to absorb the e.m.f. which tends to cause a spark to jump across the contact-breaker points as they begin to open. It ensures that the magnetic field collapses quickly and prevents rapid deterioration of the contact-breaker points due to arcing.

4.4 **The Permanent Magnet.** The magnet provides the necessary magnetic field to induce a current in the primary windings. Modern magnets are extremely powerful and are usually made from an alloy of aluminium, nickel and cobalt.

4.5 **The Distributor.** The purpose of the distributor is to ensure that the high voltage impulses produced in the secondary coil are conducted to the sparking plug in the appropriate engine cylinder in accordance with the firing order of the engine. Ignition of the gases is required in each engine cylinder once in every two revolutions of the crankshaft, thus the distributor has a segment for each cylinder arranged in firing order sequence and the rotating distributor arm is driven at half engine speed.

4.5.1 The distributor is usually an integral part of the magneto, the rotor being gear driven from the main magneto shaft. On some engines, however, the distributor assembly is remote from the magneto and the rotor is driven from an engine gear train or from a camshaft (which also rotates at half engine speed).

4.5.2 As sparking between the rotor and segments in the distributor is essential, the distributor casing is vented to prevent ionisation. The vent is fitted with a flameproof wire mesh screen to prevent combustion of inflammable gases round the engine.

4.6 **Impulse Starters.** During an engine starting sequence the magnetos are rotating only slowly and are not producing a strong enough spark to ensure combustion. Either one or both magnetos may be fitted with an impulse starter to overcome this failing. In one type of magneto fitted with an impulse starter, the drive from the engine to the armature shaft is through a spring loaded clutch device which flicks the armature through the positions at which a spark normally occurs, thus momentarily increasing the rate of rotation and the voltage generated. Once the engine is running, centrifugal weights in the impulse coupling overcome the springs and it operates as a normal "solid" drive shaft.

4.7 **Safety Spark Gap.** On some early magnetos a safety spark gap (see *Figure* 1) provided a means of discharging the secondary impulse to earth. It was provided to prevent damage to the armature in the event of a plug lead becoming detached.

5 ASSOCIATED COMPONENTS

5.1 **Booster Coils.** Where no impulse starter magneto is fitted, the weak spark produced during engine starting is supplemented by means of a booster coil, which takes its power from the aircraft batteries or external power supply, and is connected either to a booster coil switch or the engine starter switch.

5.1.1 High tension booster coils supply a "stream" of high tension impulses to a secondary or "trailing" brush in the distributor rotor arm which, due to its position, automatically retards the ignition timing.

5.1.2 Low tension booster coils supply a stream of low tension impulses to the armature primary windings either to augment or replace the voltage induced in the primary windings by the magnetic flux. On one type of magneto a second contact-breaker, retarded in relation to the main contact-breaker but connected in parallel with it, controls the supply of intermittent current from a low tension booster coil to the armature primary windings. Intermittent high tension current is therefore induced in the secondary coil and a stream of high tension impulses distributed to the sparking plugs.

5.2 **Ignition Switches.** Whenever a magneto is rotated sufficiently to open the contact-breaker points a spark will occur. All magnetos are therefore provided with an earthing wire, which is connected to the contact-breaker end of the primary coil and through a suitable switch to earth. Since this switch is connected in parallel with the contact-breaker, with the switch closed the effect of the opening and closing of the contact-breaker is by-passed and no spark can occur.

5.2.1 Some aircraft are provided with a separate toggle switch to control each magneto, the primary circuit being earthed when the switch is down. Many modern aircraft however are provided with a rotary four-position switch controlling both magnetos. A spring loaded position may also be provided for engine starter operation.

6 LOW TENSION MAGNETOS On some aircraft engines which consistently operate at high altitude, it has been found that the decreased atmospheric pressure leads to the breakdown of insulation within the magneto. The low tension ignition system in which the magneto produces only low voltage was designed to overcome these faults.

6.1 The magneto is similar to the polar inductor magneto described in paragraph 3.2, but does not embody a secondary coil. It is usual for the contact-breaker and condenser to be mounted in the distributor assembly.

6.2 Low voltage impulses from the magneto are distributed to individual secondary coils located near the sparking plugs. The secondary coils transform the current to the high voltage required at the sparking plugs.

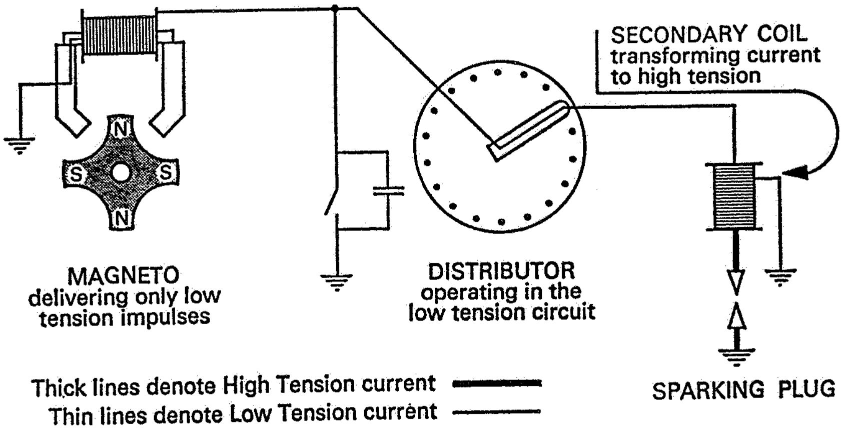


Figure 5 LOW TENSION IGNITION SYSTEM

7 **INSTALLATION** Prior to installation the magneto should be inspected for any defect which might have occurred during transit or storage. The contact-breaker cover, distributor cover and any blanking devices used for transit or storage should be removed and, as far as possible, an examination made for any signs of corrosion or dirt.

7.1 At all times when handling a magneto, such as during pre-installation checks, adequate precautions must be taken to keep all parts of the magneto clean. The working clearances of a magneto are small, and dust, swarf or filings may be drawn into the magneto by magnetic attraction and cause damage to the rotating parts or increase the resistance of contact points. The work-benches, shop equipment, and the vicinity in which magnetos are kept and maintained should therefore be clean. Any work such as filing, grinding, sawing, etc., which produces metallic dust or particles must not be permitted in the area.

7.1.1 It is important to ensure that the storage limiting period has not been exceeded and that the type of magneto is approved for the engine concerned.

7.1.2 On many engines slight variations exist between port and starboard magnetos. It is not unusual for the distributor covers to be handed and the direction of rotation to be different. Some engines may also have special starting devices fitted to one magneto only, such as an impulse starter or booster coil connection.

7.1.3 To prevent the build-up of cumulative errors when a single magneto is changed, it should be synchronised to the engine and not to the already installed magneto.

7.2 **Timing a Magneto.** Various methods are adopted by engine manufacturers for fitting and timing magnetos. The procedure specified in the appropriate engine Maintenance Manual should always be carefully followed. A typical timing procedure is outlined in the following sub-paragraphs.

7.2.1 To take up backlash in the engine drives to the magneto the engine should be turned in its direction of rotation (with some engines this may entail the use of a special friction clutch), until the cylinder on which the magneto is to be timed starts its compression stroke. To facilitate turning, a sparking plug can be removed from each cylinder. The engine should then be turned carefully until the magneto "fully advanced" mark on the moving part of the engine (e.g. on the crankshaft main driving gear), coincides with its related mark on a static part of the engine structure (e.g. on the gear case cover). The engine is then correctly set for the magneto to fire the cylinder concerned.

7.2.2 The spigot and mounting faces should be clean and free from burrs and, if applicable, an engine oil seal should be fitted. The magneto should be checked to ensure that, (a) the contact-breaker gap is correct, (b) it is fully advanced, (c) the distributor arm coincides with the distributor segment for the cylinder concerned, and (d) the contact-breaker points are just opening. The magneto should then be fitted to the engine, taking particular care to ensure that, when coupling-up the drive, the particular type of vernier adjustment is set so as not to disturb the magneto setting. At least two nuts or studs should be used to secure the magneto in position until a timing check is made.

7.2.3 The distributor cover should be removed from the magneto and the primary circuit lead disconnected from the contact-breaker. A lamp and battery should then be connected so that the battery and bulb are in series with the contact-breaker to earth. The timing can now be checked by turning the engine back about 30 deg. (ensuring impulse starter is not armed), then forward until the contact-breaker points open, indicated by the light going out; this should occur at the position shown by the timing mark. Small adjustments are possible by means of the vernier drive coupling. While turning the engine, the distributor rotor arm should be slightly restrained to to take up any backlash.

7.2.4 Where the timing of both magnetos is synchronised, a separate check for synchronisation should be made and the two lights should go out together at the correct timing position. For magnetos that are not synchronised, the timing of each magneto must be checked separately.

7.2.5 On magnetos where it is impracticable to isolate the primary winding from the contact-breaker points, the manufacturer may recommend the use of a proprietary timing indicator and, in some cases, the lamp will light when the points open (this is opposite to the normal lamp-battery timing indicator).

7.2.6 Before connecting the magneto to the ignition (earthing) switch, a check should be made to ensure satisfactory continuity and insulation resistance of the earth circuit. For the continuity test, one lead from a low voltage lamp-and-battery test set should be connected to the switch lead core and the other test lead should be connected to the screen. The lamp should be alight when the ignition switch is OFF and should go out when the switch is ON.

7.2.7 The insulation resistance of the ignition switch (earthing) lead should be checked with the type of insulation tester prescribed by the manufacturer. One lead from the tester should be connected to the magneto end of the ignition switch lead core and the other lead should be connected to the screen. With the ignition switch in the ON position the insulation tester reading should not be less than the minimum figure quoted in the Maintenance Manual.

7.2.8 When a magneto has been satisfactorily fitted and timed and the distributor cover complete with ignition harness has been fitted, it is important that the earthing switch connection is properly made and that the ignition switch is OFF. Unless this precaution is taken any rotation of the engine could cause a spark at the plug lead ends; if not connected to the plugs, this would create a fire hazard and, if connected with the switch at ON, there is a danger of the engine firing.

7.2.9 A check should be made to ensure that all securing devices and interconnecting linkages are secure and suitably locked and that controls operate in the correct sense through the full range of movement. It should also be ensured that the ignition harness connecting nuts are correctly engaged with the magneto adaptors and tightened to the specified torque loading.

8 MAINTENANCE The relevant publications for the engine concerned will specify the periodical inspections and maintenance operations for the magnetos.

8.1 During periodic maintenance, insulated and contact surfaces should not be cleaned until they have first been examined for any indications of high voltage discharge marks, erosion or other defects.

8.2 Only lubricant of the type recommended by the manufacturer should be used and the instructions regarding the periods and amount of lubricant required should be carefully followed.

8.3 Any excess lubricant near the contact-breaker points should be carefully cleaned off otherwise it may get on the points and cause arcing and burning.

8.4 **Contact-Breaker.** It is essential that the points should make good contact so that the primary winding current can build up freely. Special care should be taken to ensure that the points are making full contact and are free from oil, dirt, pitting or burning.

8.4.1 Unless specifically prohibited by the manufacturer, contact-breaker points should be cleaned with an approved solvent and then dried thoroughly with a jet of dry air; care is necessary to keep cleaning fluids away from the felt pads otherwise the lubricant will be dissolved. After cleaning, the contact-breaker gap should be checked.

8.4.2 When checking the contact-breaker gap it is important to ensure that this is accurately measured and adjusted. Any departure from the required gap will affect the internal timing of the magneto as well as the engine ignition timing, thus resulting in a weak spark and a loss of engine performance. The gap will vary with the type of magneto concerned (quite often between 0·009 in and 0·012 in) and this may be ascertained from the appropriate manual.

8.4.3 To check the gap clearance of points, the magneto should be turned in the direction of rotation until the heel of the rocker arm is riding on the top centre of the cam lobe; the points will then be fully open and can be checked with a clean feeler gauge. If excessive force is used when inserting the feeler gauge the contact-breaker spring will deflect and a false reading will be obtained.

NOTE: Before adjusting the gap the heel of the rocker arm should be checked for abnormal wear.

8.4.4 With some magnetos, especially where the contact-breaker points are made of tungsten, the use of a dial test indicator may be recommended. With a dial test indicator secured firmly to the magneto body and in a position that will permit the dial plunger to rest on the rocker-arm end, the magneto should be turned until the points are closed and the dial gauge set to zero. The magneto should then be turned, always in the direction of rotation, until the "points-fully-open" position is reached, the dial gauge indicating the gap clearance.

8.4.5 It is not uncommon for manufacturers to recommend that the contact-breaker gap should be checked on more than one cam lobe. On some magnetos, however, a master cam lobe may be specified for this check. If an excessive gap variation is noted between cam lobes this indicates uneven cam wear.

8.4.6 Adjustment of the gap should be made either by moving the base plate on which the fixed contact point is mounted or, in other cases where the actual contact point is threaded and clamped in its mounting arm, by screwing in or out as required. After any adjustment an engine check run must be carried out, following which it is essential to check carefully for security and locking of the parts disturbed.

NOTE: In some cases the magneto is earthed through the contact-breaker cover and if this is removed for any reason the magneto will be "live". On this type of magneto the plugs or leads should be removed before any servicing is carried out.

8.4.7 Correct spring pressure is essential (a) to prevent bouncing of the contact-breaker points, which could cause a bad electrical contact, or (b) to avoid excessive heel wear. The tension of the contact-breaker spring should be checked by opening the points with an accurate spring balance and noting the reading when the points open. To determine the exact moment when platinum points open, a 0·002 inch feeler gauge should be placed between the points prior to applying tension with the spring balance; when the feeler is released the reading should be noted. For tungsten points a timing indicator or lamp and battery must be used.

8.4.8 The spring balance should have an "L" shaped adaptor fitted so that it can be attached to the contact-breaker arm at the position required; the pull on the balance should be applied in the normal line of operation to ensure accurate results. The load at which the points should open will be specified in the appropriate manual.

8.4.9 The springs should be free from pitting, fretting, corrosion or discolouration; their contour should be smooth and free from kinks. Where auxiliary springs are fitted, they should be in line with the main spring and should lie flush along it, the free ends being slightly curled away from the main spring to prevent chafing.

8.5 **Distributor.** At the periods prescribed in the Maintenance Schedule the distributor should be removed for cleaning and inspection. It is important that all internal cleaning is carried out in accordance with the maker's recommendations. Leaded fuel must not be used for cleaning.

8.5.1 A visual check should be made for cracks or traces of tracking in the vicinity of the segments. If tracking has resulted in a breakdown of insulation, the distributor should be changed. However, if the traces of tracking can easily be removed by the normal cleaning process this should be satisfactory. It is essential that the moulding, especially between the segments, has a clean smooth surface. An insulation test may be specified by the manufacturer.

8.5.2 It is important that any gauze used in vent holes is clean and undamaged.

8.6 **General Maintenance Checks.** The following general points should also be checked during maintenance:—

(i) Carbon brushes or contacts should move freely in their guides and the spring pressures should be adequate to ensure good electrical contact. The contact surfaces should also seat satisfactorily.

(ii) Any other springs, in addition to the contact-breaker springs, should be checked for freedom from corrosion, pitting or fretting, and their strength should be adequate.

(iii) All connections should be tight and correctly made and all internal leads should be adequately supported.

(iv) If any fibre dust is found in the vicinity of the slow speed gear the reason for its presence should be investigated.

(v) Cam rings should be checked for cleanliness, corrosion or excessive wear.

(vi) Where applicable, variable timing devices should be checked for full and free movement and should be lubricated as necessary.

(vii) Impulse starters should be checked for condition and operation, and should be lubricated as necessary. Flexible vernier couplings should have the correct clearance to allow for expansion and should be free from oil soakage.

8.7 **Replacement of Parts.** Some parts may be changed during routine maintenance provided this is specified in the manufacturer's publication. After replacement and adjustment of the new part, a timing check may be necessary and an engine ground run should be made.

NOTE: On some small aircraft engines a sealed type of magneto may be fitted on which very little maintenance is possible. These magnetos are installed by setting the position of the engine crankshaft, fitting a special key to the magneto to lock the main shaft in a predetermined position and assembling the magneto to the engine. Further information may be obtained from the appropriate manufacturer's manual.

EL/3-10

Issue 2

June, 1984

AIRCRAFT

ENGINES

TURBINE ENGINES

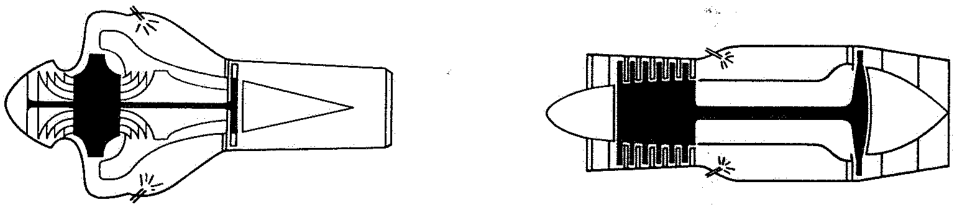
1 INTRODUCTION This Leaflet gives general guidance on the inspection and maintenance of turbine engines in service. A brief description of these engines is also included to stress the reasons for careful inspection. Further information is contained in Leaflet **EL/3-11** Turbine Engine Fuel Systems.

2 GENERAL The gas turbine engine is basically of simple construction although the thermal and aerodynamic problems associated with its design are somewhat complex. There are no reciprocating components in the main assembly and the engine is therefore essentially free from vibration. Power is produced in a continuous cycle by compressing the intake air and passing it to the combustion section where fuel is added and burnt to provide heat. The expansion of the gases rearwards through the turbine produces the power necessary to drive the compressor, the residual energy being used to provide jet thrust or, in the case of turbo-prop engines, to drive a propeller. Propeller efficiency falls off rapidly above approximately 350 knots so that turbo-prop engines are normally used to power comparatively low speed aircraft. Faster aircraft use turbo-jet engines, by-pass or turbo-fan engines being favoured for high subsonic speeds because of their fuel economy and low noise level. After-burning, i.e. the burning of fuel in the jet pipe to provide additional thrust, is normally used only in military aircraft due to the large quantities of fuel consumed, but it may be used on civil supersonic aircraft for take-off and acceleration to supersonic flight.

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

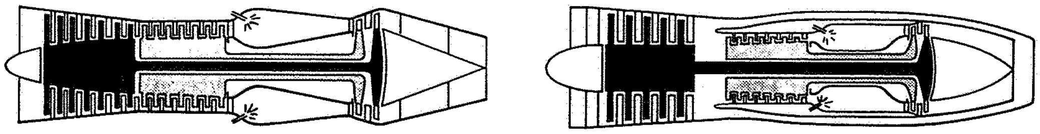
2.2 **Indicators.** Various conditions of the turbine engine must be known to enable satisfactory operation within limitations, and indicators are fitted to the aircraft instrument panel for this purpose. Their functions are explained in the following paragraphs.

2.2.1 **Engine Speed.** The speeds of the rotating assemblies must be known so that the centrifugal forces acting on the compressor and turbine rotors may be kept within safe limits. Propeller speed is also indicated when appropriate. Indicators are usually electrically operated (see Leaflet **AL/10-3**) and are calibrated to show revolutions per minute or a percentage of maximum rotational speed.



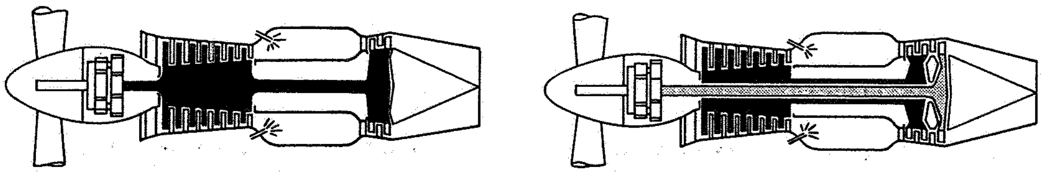
DOUBLE ENTRY CENTRIFUGAL COMPRESSOR TURBO-JET

SINGLE-SPOOL AXIAL FLOW TURBO-JET



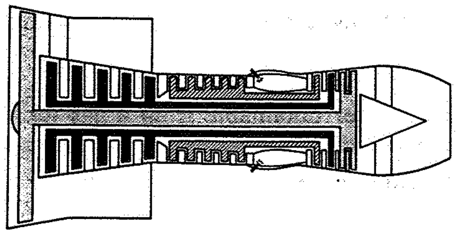
TWIN-SPOOL TURBO-JET

TWIN-SPOOL BY-PASS TURBO-JET



DIRECT DRIVE TURBO-PROP

FREE TURBINE TURBO-PROP



THREE-SPOOL TURBO-FAN

Figure 1 TYPICAL VARIATIONS IN GAS TURBINE DESIGN

2.2.2 **Turbine Gas Temperature.** Turbine gas temperature is a critical variable of engine operation but because of the high temperatures at the combustion chamber exit it is impractical to measure the actual temperature of the gas impinging on the turbine blades. The temperature drop across turbines is a known quantity, however, and temperature probes are often placed either in the stator blades aft of the first or second stage turbine or in the jet pipe. Indicated gas temperature limitations will thus differ considerably between engines and a low gas temperature limitation must not be taken as being less significant than a high one. Normally, a number of thermocouples are arranged radially around the engine with the mean temperature shown on a single indicator. This is known as the Exhaust Gas Temperature (EGT), Turbine Gas Temperature (TGT) or Jet Pipe Temperature (JPT) gauge, depending on the position of the probes.

2.2.3 **Power.** The power or thrust developed by an engine is not always directly proportional to gas temperature and rotational speed. Other factors such as ambient air pressure and temperature and forward speed also affect the power produced. 'Power' is measured in the form of thrust or torque and calibrated on an indicator which also acts as a power deficiency warning.

(a) The thrust of a turbo-jet engine is measured from the jet exhaust pressure. A commonly used indicator is the engine pressure ratio (EPR) gauge which measures the ratio of exhaust pressure to air intake pressure. Alternatively, a simple pressure gauge measuring jet pipe pressure is used. An accurate figure for comparison purposes is obtained by correcting for ambient temperature. In the case of a turbo-fan engine, the fan and exhaust pressures are measured.

(b) On turbo-prop engines the torque produced at the propeller shaft is measured because jet thrust is only a small proportion of the engine power. One particular type of torquemeter measures the oil pressure required to oppose the axial thrust of the helical teeth on the reduction gear, the gauge being calibrated in lbf/in^2.

2.2.4 **Vibration.** A turbine engine has a very low vibration level due to the accurate balancing of the rotating assemblies. Damage to the engine will usually be indicated by out of balance forces which are recorded on a vibration indicator. This instrument continually monitors the vibration level of the engine and takes the form of a milliammeter which receives signals through an amplifier from engine mounted vibration transducers.

2.2.5 **Other Indicators.** Gauges, warning lights or magnetic indicators are fitted to show fuel and oil system functions. Some multi-engine aircraft are fitted with a synchroscope to assist in synchronising engine speeds during flight.

3 MAINTENANCE

3.1 **Maintenance Requirements.** The maintenance required on a turbine engine in service is considerably less than that required on a piston engine and the overhaul life is much longer. This is mainly due to the lack of rubbing surfaces and low vibration. Overhaul lives of up to 15,000 hours are in current use and many engines are now being overhauled 'on condition' only.

3.1.1 An essential part of the maintenance of a turbine engine in service is the in-flight monitoring of indicators provided for certain critical parameters. This monitoring may be carried out by a flight crew member or by electronic recording apparatus and it has been found that a log of such readings provides a good basis for performance comparison and hence for judging engine condition.

3.1.2 Ground maintenance is a process of progressive visual inspection of the engine installation, adjustment to or replacement of components as required by reported defects, lubrication of working parts and replenishment of systems. Regular inspection for damage to compressor and turbine blades is particularly important. Minor repairs may be permitted within specified limits and the engine manufacturer may require periodic removal of certain components in the 'hot' section for detailed examination. Further disassembly is not normally permitted although certain engines are now designed with a view to 'modular' replacement, i.e. replacement of compressors, turbines or combustion chambers without removing the complete engine from the airframe.

4 INSPECTION The following paragraphs describe the inspections which are normally required by the engine manufacturer and specified in the appropriate Maintenance Schedule.

4.1 **General Precautions.** All turbine engines are susceptible to damage through the ingestion of foreign bodies. The axial flow type of compressor is particularly vulnerable to this type of damage and extreme care is necessary when carrying out an inspection of any part of the engine or adjacent structure to ensure that loose articles are not left where they may subsequently be drawn into the compressor. Clothing, buttons, caps, belts, pencils and tools are all items which, if left in intakes or engine cowlings, could cause damage necessitating removal of the engine. Intake and jet pipe covers should always be used when an aircraft is parked for any length of time and the intake area should be inspected for foreign objects or debris immediately prior to starting the engine.

4.2 **Air Intake.** The air intake passage leading to the compressor is designed to permit the required flow of air into the engine under all conditions of flight. Any damage or blockage in the air intake could affect engine performance.

4.2.1 All panels, fairings, fasteners, bolts and locking devices should be inspected for security of attachment, flush fitting or damage. Unserviceable items should be repaired or renewed.

4.2.2 Intake lips should be inspected for dents or other damage which could affect the airflow. Air bleeds or drain holes should be clear.

4.2.3 Pressure sensing probes, where fitted, should be inspected for security, cracks and corrosion.

4.2.4 Electrically heated anti-icing mats located in the air intake should be inspected for adhesion and damage. Controls for these heater mats may be automatic, continuous or cyclic and the manufacturer's manual should be consulted for details of a particular system before carrying out a functional or electrical resistance test.

4.3 **Compressors.** The compressor is an accurately manufactured and balanced component which may become damaged by hail, ice or foreign bodies. Inspection of the guide vanes and as many rows of stator and rotor blades as possible should be carried out with the aid of a mirror and strong spot light. (See also paragraph 4.8.)

4.3.1 **Superficial Damage.** Damage to aluminium, steel or titanium blades in the form of small dents, may be regarded as acceptable provided that it cannot result in the propogation of cracks and is within the limits defined in the manufacturer's manual.

4.3.2 **Impact Damage.** Impact damage caused by the entry of small metal parts can result in rejection of the engine as the damage may extend throughout the compressor. If thread or hexagon impressions are visible on the stator or rotor blades, the engine should normally be removed for strip examination.

4.3.3 **Reparable Damage.** Damage caused to the initial compressor stages by small stones or grit may be blended out within specified limits. A clean cloth should be placed round the blade being repaired to catch any swarf or filings removed during the blending process. File marks on blades should be removed with fine emery cloth and the blades inspected for cracks by a suitable penetrant-dye process (see Leaflet **BL/8-2**) immediately after the work and at regular intervals during the remaining life of the engine. Renewal of the anti-corrosive treatment may also be required.

4.3.4 Diagnosis of damage to later compressor stages may only be possible from the results of engine performance and running checks. Where limited engine stripping to facilitate inspection is permitted, procedures will be detailed in the appropriate Maintenance Manual.

4.3.5 **Compressor Washing.** When compressor blades become contaminated with dust and oil their efficiency is reduced and less power is developed by the engine. Manufacturers often specify compressor washing at regular intervals and when low torque or thrust readings, for which there is no apparent mechanical reason, are encountered. Washing is carried out by spraying kerosene into the air intake during a dry motoring run. This is allowed to soak for about 30 minutes and followed by spraying distilled or demineralised water into the intake during a second dry motoring run. Cabin heating and pressurising systems should be blanked off during these operations and the engine must be left to drain completely before subsequently being started. If a kerosene wash is not effective, certain manufacturers recommend repeating the wash with either kerosene or an approved cleaning solution.

NOTE: Dry cleaning of centrifugal compressor engines using a mild abrasive is sometimes recommended by engine manufacturers.

4.3.6 **Compressor Casing.** The compressor casing should be examined for signs of damage, gas or fluid leaks and the components for security of attachment. Any corrosion should be removed, the affected areas retreated and damaged paint renewed as necessary.

NOTE: Compressor casings are often manufactured from magnesium alloy which requires special anti-corrosive treatment, details of which will be given in the manufacturer's manual.

(a) Certain components attached to the casing may be fitted with 'witness' drains and these should be examined to ensure that the permitted leakage is not exceeded.

4.4 **Combustion Section.** Inspection of the internal features of the combustion chamber is not always possible in service, unless the engine is equipped for this, as described in paragraph 4.8. Where individual flame tubes are fitted the manufacturer may recommend their removal at specified intervals in order to carry out a detailed inspection for cracks or other heat damage. Removal of the flame tubes will permit an inspection of the nozzle guide vanes and high pressure turbine blades similar to that detailed in paragraph 4.5. In other cases the manufacturer often specifies an overhaul of the 'hot' section of the engine which is considered to be equivalent to the top overhaul of a piston engine. These inspections are often possible in situ, but, as radiographic or radio isotope crack detection methods are usually specified, it is often more convenient to remove the engine for inspection at a suitably equipped workshop.

4.4.1 Inspection during service is normally confined to an external examination of the combustion section as follows:

(a) Heat shields and lagging should be inspected for security, signs of burning or gas leakage. Any signs of overheating are an indication that internal damage may have occurred and further examination may be required.

(b) Fuel injectors should be inspected for security, damage or fuel leaks.

(c) The ignition system wiring should be inspected for signs of chafing, security and fluid contamination.

(d) Drain pipes should be inspected for security and must be free from blockage. A blocked combustion chamber drain pipe constitutes a potential fire hazard in certain circumstances. On some aircraft the drains are led to a common collector box which is emptied by suction during flight; these may require manual draining following a failure to start the engine.

4.5 **Turbine and Exhaust Section.** A strong spotlight and appropriate viewing equipment are necessary when inspecting the turbine and exhaust section (see also paragraph 4.8). All components should be carefully checked for damage, cracks or signs of metallic deposits.

4.5.1 Damage to turbine blades, other than slight pitting, is not usually acceptable. Damage to other components, including small cracks in jet pipes, is often permitted. Metallic deposits most likely to be found are aluminium, showing as a dull white or silver splatter, and titanium, which may be in the form of bright blue or golden speckles. Heavy deposits will necessitate removal of the engine for further examination but light deposits should be assessed in relation to engine performance before resorting to engine removal.

4.5.2 The jet pipes of turbo-prop engines are not so highly stressed as those of turbo-jet engines because there is little residual thrust left in the exhaust gases after the turbines have taken the power necessary to drive the propeller. Cracks or holes in these jet pipes may be repaired by patching with a similar material of the same gauge; electric resistance welding is usually specified to limit distortion. The manufacturer's manual should be consulted regarding the extent of repairs permitted and any subsequent limitation on time in service or inspection frequency.

4.5.3 Thrust reversers are often employed in large aircraft and should be subjected to an inspection similar to that carried out on jet pipes. It is particularly important that the doors or buckets used in thrust reversers should be flush with the jet pipe when retracted. Any projection will result in a 'hot spot', which will lead to distortion and cracking. Thrust reverser operating mechanisms should be checked for correct operation in accordance with the appropriate Maintenance Manual.

4.5.4 **Buried Engines.** Additional checks should be carried out on engines buried within the airframe structure as follows:

(a) Long jet pipes are often employed with buried engines and are lagged to prevent the transfer of heat to the surrounding structure. An inspection should be made to ensure that there are no gas leaks at the joint with the engine or cracks in the pipe itself, indicated by burning of the lagging material.

(b) Because of its length the jet pipe is suspended in such a way as to allow for considerable axial expansion. The fixed attachments should be checked for security and the expansion links for freedom of movement.

(c) The surrounding airframe structure should be inspected for signs of excessive heat such as discoloration or blistered paint. There should be adequate clearance from the jet pipe to permit the passage of cooling air.

4.6 **Oil System.** Most turbine engines have a closed cycle oil system similar to that used on piston engines. Rotor main bearings and all accessory drives and gears are pressure lubricated, scavenge oil being either drained in to a wet sump or returned to a tank mounted on the engine casing. The main compressor and turbine bearings on some engines are lubricated by a waste system which employs micro-pumps to provide a metered supply of oil to each bearing. The oil passes through the bearing and exhausts to atmosphere with the burnt gases. In this type of system both maximum and minimum permitted oil consumption figures are quoted.

4.6.1 Routine maintenance of the oil system consists of checking the level of oil in the oil tank and topping up as necessary with the appropriate type and grade of oil. When changing from one type of oil to another it may be necessary for the tank to be drained, partially refilled with the new oil and the engine run for approximately 15 minutes, exercising all oil operated controls as appropriate. The system should then be drained once more and refilled completely.

NOTE: Some synthetic oils used in turbine engines contain tri ortho cresyl phosphate or other additives which are highly toxic and should not be allowed to come into contact with the skin. It is recommended that suitable gloves should be worn by personnel continuously handling these oils.

4.6.2 Filters are provided in the oil system and should be removed for examination at the intervals specified in the Maintenance Schedule. Light metal swarf may be expected in new engines but a heavy deposit indicates a failure in the engine. Metal filters should be washed in kerosene and dried with compressed air before refitting, but 'throw-away' type paper filters should be renewed. It is also essential that the filter casing is flushed out to remove any residual contaminant.

4.6.3 Chip detectors and magnetic plugs are often fitted in the oil system and should be removed for examination at regular intervals. Some chip detectors can be examined in situ by the use of a 250 volt megger, with zero resistance between the centre of the detector and the casing indicating that sufficient metal particles are present to warrant removal and examination of the detector. This principle has been further extended so that detectors can provide an electrical signal for cockpit indication of particle build up, enabling in-flight monitoring and also automatic recording of necessary post-flight maintenance action.

4.7 **Engine Mountings.** Engine mounting structures are designed to allow for engine expansion and usually consist of a main trunnion to transmit engine thrust to the airframe and a secondary support to steady the engine. Turbo-prop engines are normally mounted in a tubular cage similar to that used on radial piston engines.

4.7.1 Turbo-jet engine mountings should be inspected for security, cracks and corrosion. Cracks are not acceptable and any corrosion must be removed and the component re-protected. The mountings are usually subjected to a detailed crack detection test whenever the engine is removed.

4.7.2 Tubular mounting structures should be inspected for dents, bowing, cracks or corrosion and a dimension check carried out whenever the engine is removed. Repairs are usually permitted within specified limits and the procedures in the appropriate Maintenance Manual should be followed.

4.7.3 When engines are subjected to shock loading as a result of a heavy landing or damage to a propeller, the engine mountings should be critically examined for cracks, bending, pulled rivets or other signs of distortion (buckled cowlings are a good indication of damaged mounting structures). The torque loading of bolts held in tension should also be checked; a low value indicates that the bolt has stretched and should be renewed. The mounting should be given a complete dimensional check and tested for cracks by the magnetic-flaw method (see Leaflet **BL/8-5**) following engine removal.

4.8 **Internal Inspection.** In addition to the checks detailed above for specific components some modern engines are provided with access holes at strategic positions through which an endoscope inspection can be carried out. By this means certain internal features such as combustion chambers and compressor or turbine blades can be examined without recourse to engine removal and stripping. (See Leaflet **BL/8-9**.)

5 ENGINE REMOVAL AND INSTALLATION New or reconditioned turbine engines are normally supplied as an Engine Change Unit (ECU), the Unit including the basic engine and the equipment which is common to the engines on the particular aircraft. Items which are 'handed' to suit the different engine positions such as jet pipes or engine mountings, and other items which are not fitted to all engines such as thrust reversers or hydraulic pumps, must be added to the ECU to make it into a complete power plant. The transfer of these components from the old power plant to the new ECU, when approved, must be recorded in the appropriate log books (see Leaflet **BL/1-10**). Similarly when new components are fitted to the ECU the entries must be made in the ECU log book. Engine installation details vary considerably between aircraft and it is not within the scope of this Leaflet to present detailed information on each. The following paragraphs may be taken to be typical of current practices and should be read in conjunction with the appropriate Maintenance Manual. Where the term 'engine' has been used in the text this may equally be taken to imply 'ECU' or 'Power Plant' as appropriate.

5.1 **Engine Removal.** Some aircraft may have to be jacked up and trestled when removing an engine. This is not often practicable with large multi-engine aircraft and other means are sought to ensure that the engine is at the same attitude when suspended from the sling as when installed in the airframe. Manufacturers may specify that the aircraft should be placed in a certain attitude (e.g. 1°30′ nose down) for engine removal and it is also sometimes necessary to add ballast weights to one side of an engine which is not symmetrical. These requirements will be stated in the aircraft Maintenance Manual.

NOTE: If the engine is not being replaced immediately it is sometimes recommended that ballast weights be fitted to the engine mountings to prevent airframe distortion.

5.1.1 **Preparation.** The aircraft should be prepared for engine removal as follows:

(a) Ensure that the landing gear ground lock pins are correctly fitted.

(b) Turn off the fuel supply to the engine being removed.

(c) Disconnect all electrical power to the engine being removed.

(d) Fit blanks to the engine air intakes and jet pipe.

(e) Position lifting gear.

(f) Prepare and position a suitable engine stand ready to receive the engine after removal.

5.1.2 **Safety Precautions.** The maximum safe working load of the lifting gear must exceed the weight to be lifted and the sling must be the correct one for the work being carried out (i.e. a sling designed to lift the bare engine must not be used to lift a complete power plant). The sling should be inspected for frayed wires, bent or worn shackles and any other damage likely to affect its serviceability. An aircraft undergoing engine change will rise or fall as the weight changes. All personnel working near the aircraft should be made aware of this and the proximity of trestles and stands checked to avoid structural damage.

5.1.3 **Removal.** Sufficient cowlings and panels should be removed to gain access to the engine disconnect points, engine slinging points and engine mountings. All system connections should then be broken, the open ends of pipes and electrical connectors being fitted with blanks to prevent the ingress of dust and dirt. Controls and cables should be temporarily secured to prevent damage; slave pulleys are sometimes provided in the nacelle to receive detached control cables. Locking wire, split pins, washers, nuts or bolts which have been removed should be carefully collected and taken away from the engine location. It is good practice to keep an inventory of tools used by the operators to check that none are left where they could cause damage.

NOTE: The electrical charge held by high energy ignition units can be lethal. After removing the LT input lead at least one minute should elapse before touching the HT output lead or igniter plug.

5.1.4 The engine sling should be fitted and the weight of the engine taken on the lifting gear, attaching ballast weights as necessary to level the engine. After a final check to ensure that all the connections are broken, the mountings should be disconnected and the engine lowered into the prepared stand.

5.1.5 Any components required for the replacement engine should be removed, together with the engine sling, and the engine prepared for storage or transit (paragraph 7).

5.2 Engine Installation

5.2.1 **Preparation.** With the engine in its stand an inspection should be made for any damage which could have occurred in transit. Components being installed on the engine should be inspected for serviceability, special note being taken of any lubrication or testing required by the manufacturer. The engine bay area should be thoroughly cleaned and inspected for damage and all engine connections inspected to ensure that no damage was sustained during engine removal. Engine mountings should be lubricated in accordance with the manufacturer's instructions.

5.2.2 The safety precautions appertaining to slings and lifting gear, outlined in paragraph 5.1.2 for removal, apply equally to installation and must be checked before commencing lifting operations.

5.2.3 **Installation.** The engine sling should be fitted and the engine lifted from the stand into the engine bay, connecting the mountings and torque loading the attachment bolts to the values quoted in the Maintenance Manual. When the engine is secured in position the sling should be removed and all systems reconnected, removing the blanks immediately before connecting each item. The high energy ignition units should not be connected until the engine is ready for ground running.

5.2.4 All bolts should be tightened to the recommended torque values and new gaskets, washers and locking devices fitted as necessary. Particular attention must be paid to the setting up of engine controls, the procedure for which will be found in the appropriate Maintenance Manual. A duplicate inspection of these controls is required (see Leaflet **AL/3-7** and BCAR Chapter **A5-3**).

5.2.5 **Priming.** The engine oil tank should be filled with the approved oil, and the oil and fuel systems primed. This is to ensure that all inhibiting oil is removed, that all pipelines are full and that the engine will not rotate in dry bearings when started.

(a) **Oil System.** Using the approved type of oil and a priming rig, the micro-pumps, gearbox and oil filters should be primed with the quantity of oil specified in the Maintenance Manual followed by replacement and locking of all unions, plugs and filler caps.

(b) **Fuel System.** As the aircraft booster pump is used for this operation, electrical power to the engine should be restored and the low pressure fuel cock opened. The booster pump should then be switched on and the appropriate bleed valves opened until clean bubble-free fuel is discharged. The bleed fuel should be collected in a suitable container and the bleed re-locked after use.

NOTE: It is common airline practice to cross-feed the fuel supply when bleeding. This ensures complete purging of the low pressure supply.

5.2.6 **Preparation for Starting.** To prove the engine installation before starting, the following procedure should be carried out:

(a) Check that the engine installation is clean and free from extraneous material, remove the intake and jet pipe covers and place drip trays under the engine.

(b) Open the low pressure fuel cock (LP cock) and the high pressure fuel cock (HP cock) and carry out a motoring run with the ignition system switched off. Check that oil and fuel pressures are indicated and that there are no leaks from the engine or adjacent pipelines.

(c) Allow the engine to drain and carry out a second motoring run with the HP cock closed.

(d) Allow the engine to drain once more then connect the leads to the high energy ignition units and refit all cowlings and panels.

5.2.7 The engine should then be started, all systems tested and adjustments carried out as necessary.

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

(a) After engine installation.

(b) To confirm a reported engine fault.

(c) To check an aircraft system.

(d) To prove an adjustment or component change.

(e) To prove the engine installation after a period of idleness.

6.1 Safety Precautions

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

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

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

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

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

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

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

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

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

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

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

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

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

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

6.4.1 After a new engine has been tested the oil filters should be removed and inspected (see paragraph 4.6.2) and after refitting these items the system should be replenished as necessary.

7 STORAGE AND TRANSIT All turbine engines which are to be either stored or shipped for overhaul should be packed in such a way as to prevent damage from corrosion or rough handling. The procedure to be followed is outlined below and should be observed irrespective of the condition of the engine.

7.1 **Fuel System Inhibiting.** The fuel used in turbine engines usually contains a small quantity of water which, if left in the system, could cause corrosion. All the fuel should therefore be removed and replaced with an approved inhibiting oil by one of the following methods:

7.1.1 **Motoring Method.** This should be used on all installed engines where it is convenient to turn the engine using the normal starting system. A header tank is used to supply inhibiting oil through a suitable pipe to the engine. A filter and an on/off cock are incorporated in the supply pipe, which should be connected to the low pressure inlet to the engine fuel system and the aircraft LP cock closed. After draining the engine fuel filter a motoring run should be carried out bleeding the high pressure pump and fuel control unit, and operating the HP cock several times while the engine is turning. Neat inhibiting oil will eventually be discharged through the fuel system and combustion chamber drains. When the motoring run is complete the bleeds should be locked, the oil supply pipe disconnected and all apertures sealed or blanked off.

7.1.2 **Pressure Rig Method.** This may be used on an engine which is installed either in the aircraft or in an engine stand. A special rig is used which circulates inhibiting oil through the engine fuel system at high pressure. The fuel filter should be drained and, where appropriate, the aircraft LP cock closed. The inlet and outlet pipes from the rig should be connected to the high pressure fuel pump pressure tapping and the system low pressure inlet respectively, and the rig pump turned on. While oil is flowing through the system the components should be bled and the HP cock operated several times. When neat inhibiting oil flows from the combustion chamber drains the rig should be switched off and disconnected, the bleed valves locked and all apertures sealed or blanked off.

7.1.3 **Gravity Method.** This is used when the engine cannot be turned. A header tank similar to the one used in the motoring method is required but in this case the feed pipe is provided with the fittings necessary for connection at several positions in the engine fuel system. The fuel filter should first be drained then the oil supply pipe connected to each of the following positions in turn, inhibiting oil being allowed to flow through the adjacent pipes and components until all fuel is expelled:

(a) High pressure fuel pump pressure tapping.

(b) Fuel control unit pressure tapping.

(c) Burner Manifold.

(d) Low pressure inlet pipe.

7.1.4 Components should be bled at the appropriate time and the HP cock operated several times when inhibiting the fuel control unit. All bleeds and apertures should be secured when the system is full of inhibiting oil.

7.2 **Packing.** The engine should be securely attached to its transportation stand, all blanks fitted and apertures taped over to prevent the ingress of moisture. A compartment is usually provided on the stand for the documents relating to the engine, and any other information considered relevant should also be included. If the engine has been removed because of suspected internal failure, any metal found in the filters, broken blades or other evidence should also be packed for examination during overhaul.

7.2.1 Engines are wrapped in a hermetically sealed moisture-proof bag which should be examined before covering the engine. Any large tears or holes should be repaired using the repair kit contained within the bag but small cuts may be repaired with adhesive PVC tape. Sponginess of the bag material is caused by contamination with oil or fluid and may sometimes be eliminated by washing with water. If the area remains tacky after washing the bag should be rejected.

7.2.2 Bags containing silica gel dessicant should be placed in the air intake and exhaust unit and attached at convenient positions around the engine. Approximately 14 to 18 kg (30 to 40 lb) of dessicant will be required depending on the size of the engine and the manufacturer may specify the use of VPI paper in addition (see Leaflet **BL/1-7**). A humidity indicator should then be placed in the bag where it can be easily seen and the bag sealed up. Where possible the humidity indicator should be inspected at frequent intervals to ensure that the condition of the air inside the bag is still 'safe' (i.e. the colour of the indicator is blue). If an 'unsafe' condition is shown (i.e. the colour of the indicator is lilac or pink) the bag should be inspected and repaired as necessary, and the dessicant renewed.

7.3 **Storage.** Complete engines and individual components should be kept in a clean, well-ventilated store with an even temperature of 10 to 20°C. Components should be stored in open racks in their original packing and rubber items kept away from strong sunlight, oil, grease or heat sources. Any dessicant packs attached to stored components should be checked frequently for moisture contamination.

7.3.1 With certain components (rubber seals, etc) the manufacturer may recommend that the number of components in a stack is limited to a specific number to prevent distortion.

7.3.2 Components which have a shelf life should be used in sequence, any which become time expired being removed for overhaul, test and repacking.

EL/3-11

Issue 1.

10*th December*, 1969.

AIRCRAFT

ENGINES

TURBINE ENGINE FUEL SYSTEMS

1 INTRODUCTION This Leaflet describes the operation of typical turbine engine fuel systems and the maintenance normally carried out in service. Certain aspects of this subject are also dealt with in Leaflet **EL/3-10,** Turbine Engines.

2 GENERAL The fuel supplied to the combustion chambers of a turbine engine must be readily combustible and in a ratio with the mass air flow through the engine which will ensure efficient and economical operation under all conditions of flight.

2.1 **Turbine Fuels.** The fuels used in turbine engines must conform to rigid requirements to give optimum performance and safety. They must also be compatible with materials used in the fuel system components and provide adequate lubrication of working parts. The types most used in civil aircraft are to D. Eng. RD 2494 (AVTUR) or ASTM Spec. D1655 (Jet A or A-1) all of which are kerosene type fuels. A more easily produced fuel is D. Eng. RD 2486 (AVTAG) but as it is a more volatile wide cut gasoline its use is normally restricted to military aircraft.

2.1.1 One problem associated with kerosene fuels is the water taken into solution through the aircraft or storage tank venting system. This water may freeze at high altitude and result in the low pressure fuel filter becoming blocked with ice crystals. Fuel heaters are therefore necessary and are incorporated in most aircraft fuel systems upstream of the low pressure filter.

2.2 **Fuel System Operation.** The required engine speed is set by a throttle valve which passes a fixed amount of fuel to the spray nozzles (burners). Heat produced in the combustion chambers expands the gases rearwards to impinge on the turbine, resulting in rotation of the compressor/turbine assembly with the energy remaining in the gas stream providing engine thrust. An increase in fuel flow results in higher temperatures and increased gas expansion, producing higher engine speed, greater airflow and increased thrust.

2.2.1 The engine speed selected by the initial positioning of the throttle valve will be maintained provided that air intake conditions do not vary. Changes in altitude, air temperature and forward speed will affect mass air flow through the engine and a corresponding change in fuel flow is necessary to maintain the selected speed. In addition, any rapid throttle movements will uspet the air/fuel ratio due to the inertia of the compressor/turbine assembly. Automatic means are therefore necessary to relate fuel flow to mass air flow through the engine and to control maximum speed, idling speed and acceleration rate. A convenient means of achieving these functions is to control output from the fuel pump.

3 FUEL PUMP On some early turbine engines a constant displacement pump was used, the design of which ensured that pump delivery was always in excess of engine requirements. Excess fuel was bled back to the fuel tanks by means of a unit called a Barostat which was sensitive to changes in air intake pressure. Most modern British systems employ a pump of the variable stroke (swash-plate) type, a dual pump often being fitted on large engines to obtain high delivery rates.

3.1 The variable stroke pump is driven directly from the engine and consists of a rotating cylinder block in which a number of cylinders are arranged around the rotational axis. A spring-loaded piston in each cylinder is held against a non-rotating cam plate so that rotation of the cylinder block results in the pistons moving up and down in their respective cylinders. Conveniently placed ports in the pump body allow fuel to be drawn into the cylinders and discharged to the engine. The angle of the cam plate determines the length of stroke of the pistons and, by connecting it to a servo mechanism, delivery may be varied from nil to maximum pump capacity for a given pump speed.

3.2 The servo piston operates in a cylinder and is subjected to pump delivery pressure on one side and the combined forces of reduced delivery (servo) pressure and a spring on the other. A calibrated restrictor supplies pump delivery fuel to the spring side of the piston and this is bled off by the control system to adjust the piston position and hence the angle of the cam plate.

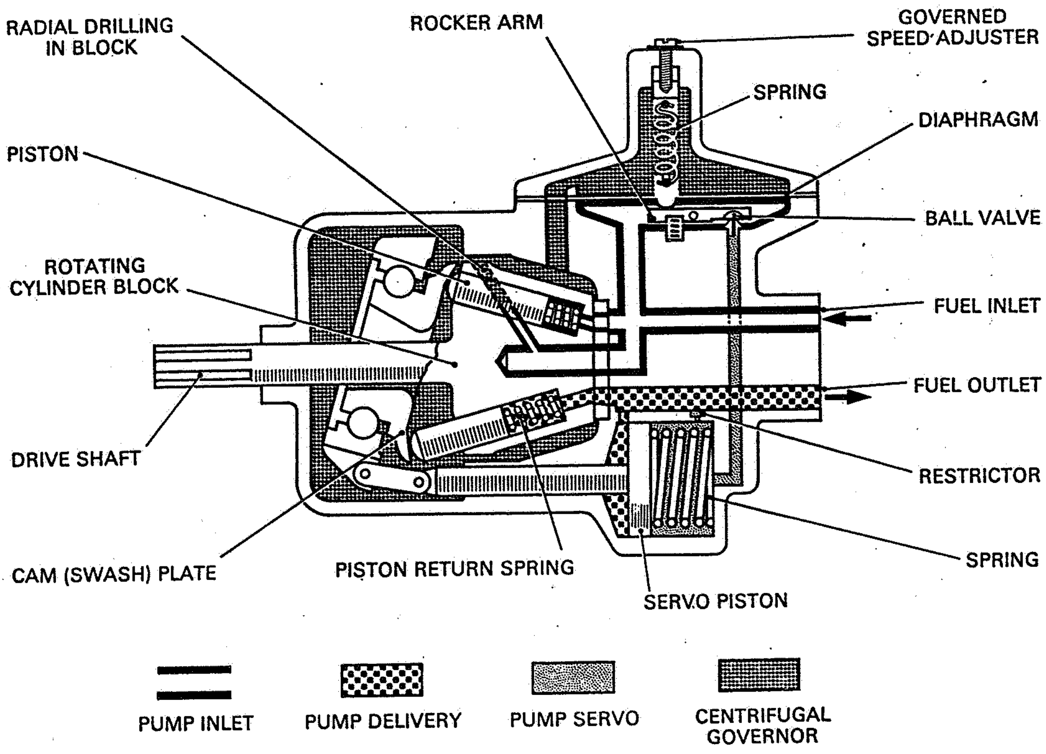


Figure 1. TYPICAL HIGH PRESSURE FUEL PUMP

4 FUEL PUMP CONTROL SYSTEMS Some engines are fitted with a control system which uses electronic circuits to sense changing fuel requirements and adjust pump stroke. Most engines however, use hydro-mechanical systems, with an electro-mechanical element to control maximum gas temperature and these are discussed in the following paragraphs.

4.1 **Pressure Control.** The quantity of fuel passing through a restrictor (the throttle valve) may be varied by increasing or decreasing the fuel pressure. In the pressure control system (Figure 2) fuel pressure is varied in relation to air intake pressure, decreasing with decreased mass air flow through the engine. Spill valves in the Barometric Pressure Control (B.P.C.), Acceleration Control Unit (A.C.U.) and pump governor, bleed off servo pressure to control pump stroke.

4.1.1 Under steady running conditions below maximum governed speed only the B.P.C. spill valve is open. A capsule subject to air intake pressure, contained in the B.P.C., controls the extent to which the spill valve is open. The bleed is arranged to increase as intake pressure decreases thus reducing servo pressure, pump stroke and fuel delivery pressure as altitude increases.

4.1.2 When the throttle is opened slowly, reduced throttle inlet pressure is transmitted to the B.P.C. and the spill valve closes to increase servo pressure and pump stroke. As pressure to the throttle is restored the B.P.C. spill valve again takes up its controlling position, and pump stroke, combined with increased pump speed, stabilises to give the output for the new throttle position. If the aircraft is in level flight the increasing speed will increase intake pressure and act on the B.P.C. capsule to further increase fuel flow to match the increasing mass air flow.

4.1.3 During rapid throttle opening, the action of the B.P.C. is restricted by the A.C.U. to prevent overfuelling. As the B.P.C. spill valve closes, increased fuel flow creates an increased pressure drop across the Metering Valve which is sensed by the A.C.U. fuel diaphragm. Movement of this diaphragm opens the A.C.U. spill valve to reduce servo pressure and limit overfuelling to the maximum amount which can be tolerated by the engine. As the engine accelerates, increasing compressor delivery pressure acting on the A.C.U. air diaphragm gradually closes the spill valve to permit greater acceleration at higher engine speeds.

4.1.4 Radial drillings in the fuel pump rotor direct fuel under centrifugal force to one side of a spring loaded diaphragm in the governor unit (Figure 1). When centrifugal force reaches a pre-determined value the diaphragm flexes sufficiently to open its spill valve and reduce servo pressure, thus limiting the amount of fuel delivered to the engine and so controlling engine speed.

4.2 **Flow Control.** In this system fuel pump delivery is controlled to maintain a constant pressure drop across the throttle valve regardless of engine speed. A common variation of the system is one in which a small controlling flow (proportional flow) is created with the same characteristics as the main flow and is used to adjust the main flow. A different type of spill valve known as a "kinetic" valve is used which consists of opposing jets of fuel at pump delivery pressure and servo pressure; a blade moving between the jets alters the effect of the high pressure on the low pressure. When the blade is clear of the jets, servo pressure is at maximum and moves the fuel pump to maximum stroke but as the blade comes between the jets servo pressure reduces to shorten pump stroke. The control elements which are housed in a single unit called the Fuel Control Unit (F.C.U.) are the Altitude Sensing Unit (A.S.U.), Acceleration Control Unit (A.C.U.), Proportioning Valve Unit (P.V.U.) and throttle, which sometimes also functions as a shut-off (H.P.) cock. The system is illustrated in Figure 3.

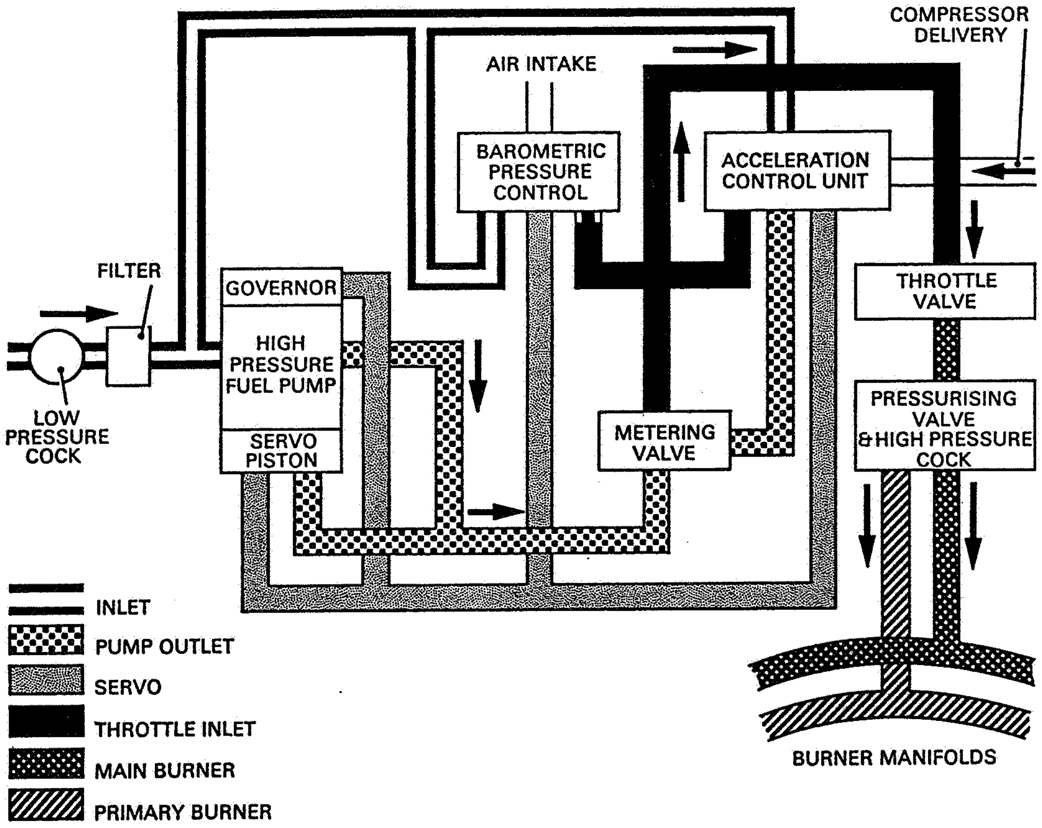


Figure 2. PRESSURE CONTROL SYSTEM

4.2.1 Under steady running conditions below governed speed, flow through two P.V.U. restrictors is proportional to flow through the throttle valve and the P.V.U. diaphragm is held open by spring pressure, allowing fuel to flow through the A.S.U. back to the pump inlet. The A.S.U. adjusts servo pressure in relation to this proportional flow by means of a kinetic spill valve.

4.2.2 When the throttle is opened slowly the pressure drop across the throttle valve and P.V.U. restrictors decreases and the P.V.U. diaphragm adjusts its position to reduce proportional flow through the A.S.U. This results in the A.S.U. spill valve closing slightly to increase servo pressure and therefore pump stroke, thus restoring the pressure difference across the throttle and P.V.U. restrictors.

4.2.3 Variations in air intake pressure are sensed by a capsule in the A.S.U. which adjusts its spill valve to decrease or increase servo pressure as required. The resulting change in proportional flow returns the A.S.U. spill valve to its controlling position.

4.2.4 During rapid throttle opening the sudden decrease in pressure drop across the throttle is sensed by the A.S.U. which closes its spill valve to increase pump stroke. The rapid increase in fuel flow, which would cause overfuelling, is restricted by means of a pressure drop diaphragm and metering plunger. This diaphragm is sensitive to the pressure drop across the metering plunger, the latter being located in the main fuel line to the throttle valve. Rapid throttle opening increases the pressure drop across the plunger and at a fixed rate of overfuelling the pressure drop diaphragm flexes sufficiently to open its spill valve and override the A.S.U., maintaining a fixed pressure drop across the metering plunger. The metering plunger is, in effect, a variable area orifice and by means of a capsule in the A.C.U. sensitive to compressor delivery pressure, its position is controlled to increase the rate of overfuelling as engine speed increases. As the controlled overfuelling and engine speed increase, the pressure drop across the throttle valve is gradually restored until the proportional flow reaches a controlling value once more and the A.S.U. spill valve controls pump stroke.

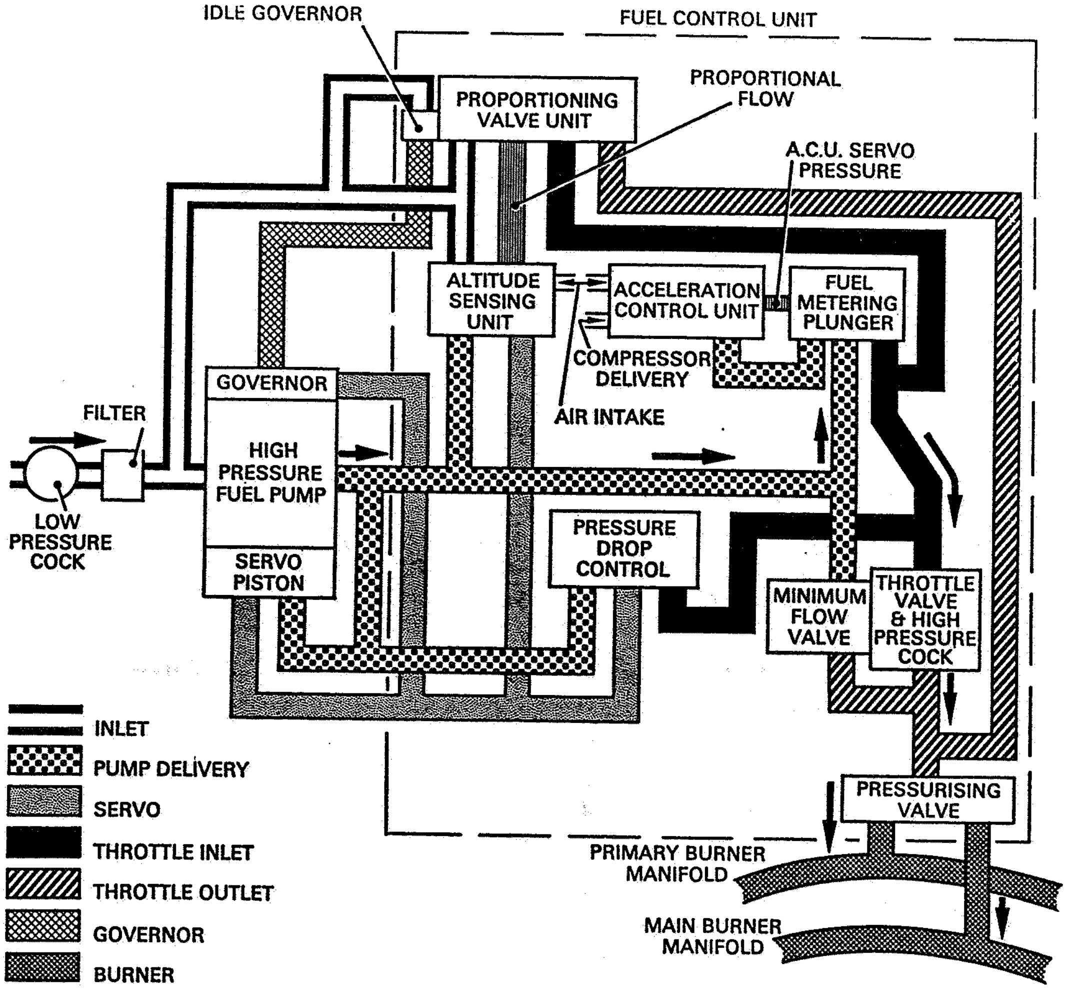


Figure 3. FLOW CONTROL SYSTEM

4.2.5 The maximum speed governor in the fuel pump is similar to that described in paragraph 4.1.4. Fuel under centrifugal force from the fuel pump also acts on a diaphragm in the P.V.U. to adjust the position of one of the restrictors and maintain proportional flow at a value suitable for idling.

4.3 **Combined Acceleration and Speed Control.** This fuel pump control system is contained within a single unit called a Fuel Flow Regulator, the fuel pump servo piston being operated by fuel pump delivery pressure opposed by main burner pressure and a spring. The system is illustrated in Figure 4.

4.3.1 Two rotating assemblies, each with a hollow valve and centrifugal governor, are driven from the engine by a gear train in the regulator and are known as the Speed Control Unit and the Pressure Drop Unit. The speed control valve is given axial movement by a capsule assembly under compressor delivery pressure and has a triangular hole known as the Variable Metering Orifice (V.M.O.). A non-rotating governor sleeve round this valve is given axial movement by the governor unit and restricts fuel flow through the V.M.O. Fuel from the pump outlet flows from the regulator body through the V.M.O. to the inside of the speed control valve and passes through the hollow valve to the pressure drop unit. The pressure drop valve is in the form of a hollow piston, moving axially under the force of fuel from the V.M.O. and governor flyweights, opposed by main fuel pressure. The pressure drop valve has an unrestricted outlet through the regulator body for primary burner fuel and a triangular outlet known as the Pressure Drop Control Orifice (P.D.C.O.) through which fuel flow to the main burners is restricted by the axial movement of the pressure drop valve.

4.3.2 Under steady running conditions the position of the speed control valve is fixed by the capsule assembly and the governor sleeve is held in a fixed axial position by the speed control governor. Pressure drop across the V.M.O. is sensed by the pressure drop valve which adjusts its position and the exposed area of the P.D.C.O. to supply the correct quantity of fuel in relation to engine speed.

4.3.3 When the throttle is opened slowly, spring loading on the speed control governor increases to move the governor sleeve and increase the V.M.O. area. Pressure drop across the V.M.O. decreases and this is sensed by the pressure drop valve which moves to increase the size of the P.D.C.O., the reduced system pressure difference acting on the pump servo piston to increase fuel flow to the engine. As the engine accelerates, the capsule in the speed control unit is compressed by increasing compressor delivery pressure and moves the speed control valve to further increase the size of the V.M.O. Balance is restored when centrifugal force acting on the speed control governor moves the governor sleeve to restore the system pressure difference.

4.3.4 The effect of rapid throttle movements is restricted by mechanical stops acting on the governor sleeve.

4.3.5 Changes in altitude or forward speed affect the capsule in the speed control unit which adjusts the position of the speed control valve to correct fuel flow.

5 BURNERS The purpose of the burners is to provide fuel to the engine in a suitable form for combustion. A burner with a single spray nozzle, although used on some early engines, is not suitable for large modern engines due to the widely varying fuel flow requirements for different flight conditions. If the orifice were of a size suitable for atomising fuel at low rates of flow the pressure required at take-off would be tremendously high, flow through an orifice being proportional to the square of the pressure drop across it.

5.1 One of the methods used to overcome this problem is the provision of a dual spray burner. The central orifice provides the fuel for low flow rates and a second annular orifice is used in addition for high flow rates. Distribution between the primary (low flow) manifold and the main (high flow) manifold is normally controlled by a pressure operated valve. In the case of the Fuel Flow Regulator, fuel flowing through the rectangular outlet from the pressure drop valve is always at a higher pressure than fuel flowing through the outlet from the P.D.C.O. and is used to supply the primary burner manifold.

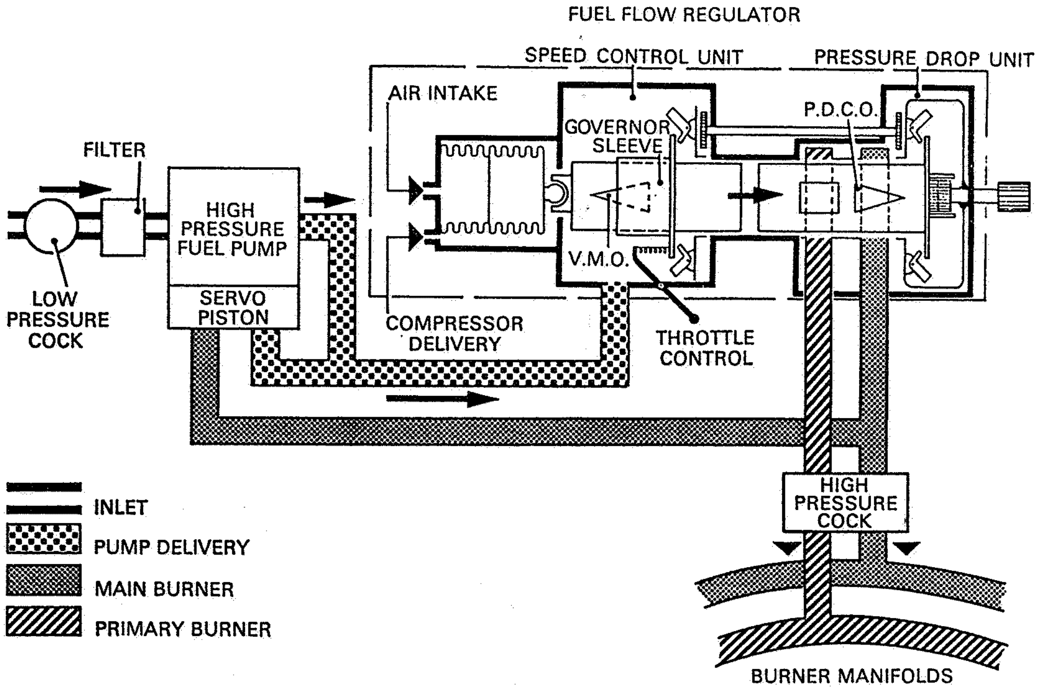


Figure 4. COMBINED ACCELERATION AND SPEED CONTROL SYSTEM

5.2 Another method used on some engines is known as the Vapourising Burner. Fuel is injected at low pressure into one end of a hollow "U" shaped tube located in the combustion chamber. It mixes with the primary air flow, is vapourised by the heat in the chamber and ejected upstream into the combustion zone. In this system a separate burner is necessary for engine starting.

6 ADDITIONAL CONTROLS

In addition to the systems described in paragraph 4, additional controls are usually provided to prevent the engine from exceeding operating limitations.

6.1 **Turbine Gas Temperature Control.** Control of the maximum permitted turbine gas temperature is often exercised electrically. Signals from the T.G.T. thermocouples are amplified to either actuate a solenoid operated valve in the fuel system or reset the throttle linkage to reduce fuel flow to the burners. On engines which have different T.G.T. limitations for climb and take-off, a switch on the flight deck pre-sets the T.G.T. signal reference datum.

6.2 Compressor Control

6.2.1 In certain circumstances such as high forward speed and low ambient temperature it is possible to produce maximum power/thrust at less than maximum engine speed.

Under these conditions the engine could sustain damage due to high compressor delivery pressures and fuel flow is restricted by providing a bleed from the A.C.U. capsule chamber to atmosphere when compressor delivery pressure exceeds a predetermined value.

6.2.2 To prevent the low pressure compressor from exceeding its design speed a centrifugal governor driven from the low pressure shaft is often included in the fuel system. If design speed is exceeded the low pressure governor restricts the fuel flow in the main burner line and reduces both high and low pressure compressor speeds.

7 MAINTENANCE AND INSPECTION

7.1 General

7.1.1 Fuel systems normally operate at very high pressures and a leak from a connection could quickly become a potential fire hazard. Regular inspection of the complete system for security, bonding, freedom from leaks and correct positioning of drains is therefore very important. If a leak does develop the tightness of the connection should be checked but on no account should the recommended torque values be exceeded. If the leak persists the connection should be dismantled, the joint faces inspected for cleanliness, and the connection remade using new gaskets, washers or 'O' rings as appropriate. Pipes which are found to be twisted or damaged, particularly at the connections, must be replaced.

7.1.2 Lubrication of working parts should be carried out in accordance with the approved Maintenance Schedule using the type of lubricant recommended by the manufacturer. All excess oil or grease should be removed. Lubrication of gaskets, washers and 'O' rings is usually required during assembly of components. It is important that only the correct type of lubricant is used, as incorrect lubrication could cause rapid deterioration of the seals, resulting in fuel leakage with the attendant fire risk.

7.1.3 Whenever a component is replaced within the fuel system it is good practice to also clean the main fuel filter, especially where it incorporates a relief valve designed to open in the event of the filter becoming blocked. The surge of fuel on switching on the booster pump with a dry component in the line can open the relief valve and pass dirt into the system.

7.2 **Cleanliness.** Cleanliness of the fuel and fuel components is very necessary because of the small passages, restrictors and valves used in the system. Particular care should be taken to prevent the introduction of extraneous material such as water, dust or grit into the fuel tanks when refuelling an aircraft. Refuelling nozzles should be kept scrupulously clean. Filters which are incorporated in the supply line to the fuel pump and other small filters which may be fitted at the inlet connection of other components should be removed for examination at the intervals prescribed in the approved Maintenance Schedule. Except where renewable elements are used these filters should be thoroughly washed in kerosene and dried with compressed air before refitting. The low pressure fuel filter is normally provided with a drain valve for fuel sampling purposes.

7.2.1 When changing components all pipes and open passages should be blanked off immediately and the blanks removed only when the new component is ready to be fitted. New washers, gaskets or 'O' rings should always be refitted with new components.

7.3 Adjustments

7.3.1 **General.** Adjustments to the fuel system may be necessary when a new engine is installed, when a component is replaced or when incorrect operation of the system in flight is reported. Each component is bench tested before final approval and it is usual for the manufacturer to limit the extent to which adjustments can be made in service. If it becomes apparent that the permitted adjustment would be exceeded in order to achieve correct engine operation then the appropriate air and fuel pipes must be checked for leaks. If the required adjustment is still excessive it must be assumed that the component concerned is unserviceable and it should be replaced. A record of any adjustments made should be entered in the engine log book to provide a history of fuel system operation.

7.3.2 As air temperature, pressure and humidity all affect engine operation, any adjustments to the system must take account of ambient conditions and of the specific gravity of the fuel. Graphs or tables are provided in the appropriate Maintenance Manual showing the correction to be applied to a basic setting under different operating conditions. For example, when setting an idling speed, which may be 40% at standard atmospheric pressure of 1013 millibars, it may be necessary to reset the actual engine speed to 43.5% when the atmospheric pressure is only 950 millibars. On some engine installations it may also be necessary to disconnect or override other controls in order to make an adjustment. For example, when adjusting maximum governed speed it may be necessary to disconnect the Top Temperature Control (T.T.C.) or pressurise the air intake pressure sensing capsule in the B.P.C. to prevent their influence on the system from restricting fuel flow. Under these circumstances visual monitoring of instruments is vital to prevent exceeding J.P.T. limits. The appropriate Maintenance Manual lays down the procedure to be adopted when making an adjustment of this type.

7.3.3 **Mechanical Adjustments.** Adjustments to the idling speed, maximum governed speed and acceleration rate are usually by means of a screw and the effect of a set amount of rotation of the screw is usually quoted in the Maintenance Manual to avoid unnecessary engine running. Before making an adjustment the engine should be run for a sufficient length of time to stabilise engine temperatures and when altering power settings the controls should be operated carefully, and instruments kept under observation, to prevent exceeding operating limitations. This is particularly important after the installation of a new engine or component change. Adjusters must be relocked after use.

7.3.4 **Electronic Adjustments.** Some automatic engine controls are actuated by signals from the jet pipe thermocouples and require special test sets to check or correct their operation. Control is effected by comparing the thermocouple voltage with a datum voltage preset in an amplifier. Excessive temperatures produce an excess voltage and this is amplified to energise a relay in the T.T.C. circuit. This action operates a solenoid located either in the Fuel Bleed Valve or Flow Control Unit and restricts fuel flow to the engine. To adjust a control system of this type it is necessary to attach a special test set to the electrical circuit by means of a conveniently placed multi-pin plug and socket. The test set feeds a voltage to the circuit equivalent to that which would be supplied by the thermocouples at a specified gas temperature and any variations from the datum voltage may be reset by adjustment of resistors in the engine amplifier. Engine installations vary considerably in the layout of the automatic control systems and the appropriate Maintenance Manual should be referred to whenever it becomes necessary to check or adjust a specific system.

7.3.5 **Control Linkage.** The methods used to connect the pilots' controls to the engine throttle valve and the high and low pressure cocks are often very complex. The linkage normally includes cable and chain components in the flight deck and fuselage and a series of push/pull rods and levers leading to the engine bay. There are numerous connections in the installation and this can lead to 'lost motion' at the pilots' controls and irregular engine operation when wear takes place. The procedure for initially setting up the controls is laid down in the appropriate Maintenance Manual and the operation requires the use of rigging pins, datum marks, protractors and pointers. Re-adjustment may be required when wear in the connections causes slackness and insufficient travel of the control. At the periods specified in the Maintenance Schedule the linkage should be lubricated and inspected for security, locking, play and correct adjustment. Excessive wear should be eliminated by replacement of the affected parts.

NOTE: Whenever engine controls are disconnected an inspection in accordance with BCAR Chapter A5-3 is necessary.

7.4 **Pipes.** When changing fuel system components or pipes care is necessary to ensure that the pipes are not strained as this could result in the development of leaks due to the high fuel pressures in the system. Short rigid pipes are often used between components and special fitting instructions may be quoted in the Maintenance Manual. It may, for instance, be necessary to loosen or remove an adjacent component in order to fit a pipe. When installing a flexible pipe care must be taken to prevent the pipe from twisting when the connections are tightened. Before pipes are re-connected they should always be inspected for cleanliness and damage, especially at flared ends and nipples. Seals should be lubricated in accordance with the manufacturers recommendations and union nuts must be correctly locked. Whenever pipes have been disconnected the system should be bled (see paragraph 7.7).

7.5 **Fuel Pump.** It is possible to cause damage to the fuel pump when shutting down an engine in flight. Provided that the H.P. cock is closed first no damage will be caused by a windmilling engine but if the engine is stopped by closing the L.P. cock, or if the pump inlet is blocked in any way, the engine manufacturer usually specifies a time limit on engine windmilling as the pump will be running "dry" and damage may result. If this time limit is exceeded the pump must be changed and an inspection for contamination of the system downstream of the pump carried out. If metal deposits are found all system components must be changed and connecting pipes flushed out.

7.6 **Burners.** Due to their position in the combustion chambers, burners may become contaminated by deposits of carbon which could affect their operation. The deposit should be removed at the intervals laid down in the Maintenance Schedule. by either one of two methods depending on whether or not the burners can be removed from the installed engine. On no account should a wire brush be used to remove carbon, as any scratches will affect the spray pattern and result in hot spots in the combustion chamber.

7.6.1 In-situ cleaning, where approved, is carried out by connecting a pumping rig to the burner manifold feed pipe connection and pumping a set quantity of carbon solvent through the burners. After removing the pumping rig and reconnecting the feed pipe, the engine should be left for approximately two hours to give the solvent time to soften the carbon and then run for a short time to disperse the deposit.

7.6.2 When the burners are easily removed from the engine they should be completely immersed in a carbon solvent for two hours then thoroughly cleaned with an air/water gun, dried and dipped in de-watering oil. They may then be replaced in the engine or, if not required for immediate use, filled with inhibiting oil, blanked off and stored.

NOTE: Burners are often kept in sets and should only be replaced as individual components when permitted by the manufacturer.

7.7 **Bleeding.** Whenever a component is replaced or disconnected and instability in engine speed which could be attributed to air in the system is encountered, the fuel system should be bled. Fuel supply to the affected engine should be selected on and the low pressure cock and fuel pump turned on. Individual components should then be bled in turn commencing at the H.P. fuel pump and working downstream, each bleed valve being opened until bubble-free fuel is discharged, then the valve closed and locked. On some components a special bleed tool is provided and the discharged fuel should be caught in a container to avoid contamination of the engine bay.

8 STORAGE Preparation and storage of the complete engine is dealt with in Leaflet **EL/3-10** Turbine Engines. When it becomes necessary to store or return an individual component a similar procedure should be applied.

8.1 **Inhibiting.** Except for separate electrical parts all components removed from the fuel system should be inhibited as soon as possible to prevent internal corrosion. All fuel should be drained out and inhibiting oil poured in through the inlet connection until full. A blank should then be fitted and the component rotated, topping up through each outlet in turn and fitting blanks until it is completely full of oil and securely sealed. Drive shafts of pumps and fuel flow regulators should be turned while inhibiting and the throttle valve and H.P. cock operated several times to ensure complete distribution of oil. To check that the blanks are not leaking the part should be thoroughly dried and left for thirty minutes. Any leaking blanks should be replaced, the oil level topped up and a further test carried out until satisfactory results are obtained. Drive shafts should then be smeared with the recommended storage oil.

NOTE: The inhibiting oil-can should contain a fine mesh filter to prevent the ingress of foreign material.

8.2 **Packing.** All components, including the electrical ones which are not inhibited, should be wrapped in greaseproof paper, sharp edges being double wrapped, then enclosed in V.P.I. paper (see Leaflet **BL/1-7**) and secured with adhesive tape. The wrapped parts, together with a label giving details of the modification state, reason for return, etc., should be enclosed in a polythene bag, as much air as possible excluded and the bag heat sealed. Transport boxes are normally provided for all components and the wrapped part should be kept in one of these during storage. A label should be affixed to the box giving details of the contents, inhibiting date and storage life.

NOTE: Certain electrical components require the attachment of a "Fragile" label on the transport box in addition to the normal identification label.

8.3 **Storage Conditions.** Components should be stored in conditions that are dry and free from corrosive fumes. Components are best stored in racks but this may not always be possible; a double fuel pump, for example, may weigh up to 75 lb without its transport box and may more conveniently be stored at floor level but raised on blocks to permit the circulation of air.

8.3.1 Every six months the shafts of fuel pumps and fuel flow regulators should be rotated a few turns without removing them from the sealed bag. At the same time the part may be checked to ensure that the modification state is satisfactory and that no leaks have developed.

8.3.2 Some fuel system components may be given a maximum storage life. When this life has expired the components should be removed from storage and subjected to such overhaul and testing as may be specified by the manufacturer.

EL/3-12

Issue 1.

15*th June*, 1970

AIRCRAFT

ENGINES

TURBINE ENGINE STARTER AND IGNITION SYSTEMS

1 INTRODUCTION This Leaflet deals with the starter and ignition systems in use on turbo-prop and turbo-jet aircraft. It is possible that other methods of starting may be used but the general principles outlined in this Leaflet are applicable. Detailed information on specific systems will be found in the appropriate manufacturer's manual. Information on the associated engine fuel systems will be found in Leaflet **EL/3-11** Turbine Engine Fuel Systems.

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

2.1 **Starting Cycle.** The starter motor is capable of cranking the engine to a speed slightly higher than that at which sufficient gas flow is generated to enable the engine to accelerate under its own power. At an early stage in the cranking operation, igniter plugs in the engine combustion chamber are supplied with electrical power, followed by the injection of fuel when fuel pressure has built up sufficiently to produce an atomised spray. Light-up normally occurs at this point and the engine, assisted by the starter motor, accelerates to self-sustaining speed. The starter drive disengages when engine power begins to drive the starter and the engine accelerates to idling speed without further assistance. Power supplies to the starter and igniters are cancelled during this stage.

2.1.2 After selection, operation of the starter cycle is automatic but the engine speed and turbine gas temperature should be monitored to ensure that engine limitations are not exceeded. If necessary the starting operation may be stopped by closing the high pressure (H.P.) fuel cock and switching off the start master switch.

2.2 **Precautions.** If engine acceleration is retarded the possibility of a light-up occurring at a low engine speed would result in overfueling and high turbine gas temperature. Power supplies to the starter should always be checked before starting and must not be less than the minimum figure quoted in the aircraft Maintenance Manual. Facing the aircraft into wind will assist engine acceleration, particularly in the case of turbo-prop aircraft the propellers of which are normally provided with a special fine blade angle for starting and ground running.

2.3 **Cranking.** There are many different methods used to crank the engine to self-sustaining speed, depending on the operational requirements of the particular aircraft.

2.3.1 An air starter is most commonly used on passenger transport aircraft as this is an economical means of starting, causing the minimum disturbance to the passengers.

2.3.2 Electric starters are also commonly used and are fitted mainly to turbo-prop and small jet engines.

2.3.3 Where speed of starting is of the utmost importance, on fighter aircraft for instance, a cartridge or mono-fuel turbine starter is usually fitted. These methods are not used on civil aircraft however due to the high cost and the handling difficulties involved.

2.3.4 Certain operators may need to start the aircraft engines without outside assistance and specify the use of a hydraulic or air starter driven from an auxiliary power unit.

2.4 **Ignition.** On some early engines, a "torch igniter", which combined a sparking plug and fuel spray nozzle was used during starting, fuel being supplied by a priming pump controlled by the timer unit. The resulting flame was used to ignite fuel from the main burners. Although a separate spray nozzle is still used on some engines (i.e. those employing fuel vapourising burners—Leaflet **EL/3-11**), the normal fuel spray nozzles are generally used and ignition is achieved by means of a high energy ignition unit and surface discharge plug.

2.4.1 To provide automatic relighting in the event of flame extinction either a glow plug or continuously operating ignition system are used and manual relighting is accomplished by operating the ignition independently from the complete starter circuit. On some aircraft the ignition circuit is also connected to a stall warning device as a safeguard against flame extinction under stall conditions.

3 ELECTRIC STARTERS (FIGURE 1) The main components of an electric starter are a d.c. motor, a reduction gear, an overload clutch and a ratchet device to provide automatic engagement with and disengagement from the engine. These components may be included in the starter itself, or, except for the motor, form part of the engine gearbox. One particular engine is fitted with a starter/generator unit, the starter mode being engaged by applying an electric current to the field coils. In this case no special reduction gear, clutch or ratchet are required and the unit automatically reverts to the generation mode when generator output reaches a predetermined value.

3.1 **Engagement.** A common method of coupling the starter drive to the engine is by means of a jaw on the starter which moves axially into engagement with a similar jaw on the engine gearbox during initial starter rotation. Axial movement of this jaw is effected either by helical splines on the starter drive shaft or by the pressure of a solenoid operated push rod in the starter motor. Alternative methods of engagement are the ratchet drive and sprag clutch, in which the ratchet pawls or sprags rotate with the engine. Engagement and disengagement are effected centrifugally, engagement by the engine taking place whenever its speed falls below idling.

3.2 **Starting Cycle.** Operation of the starting cycle is normally controlled by either of two methods. On some aircraft the high initial starter current is used to engage an overspeed relay and hold-in solenoid; when the engine begins to accelerate under its own power, starter current decreases and the hold-in solenoid breaks the circuit automatically. On other aircraft a timer unit is employed which, by means of resistances, allows the full voltage to be progressively built up as starter speed increases. This prevents damage to the starter jaws through violent engagement and eliminates excessive loads on the starter motor in overcoming engine inertia. Electrical power is cut off either by an overspeed switch or at the end of the timed cycle.

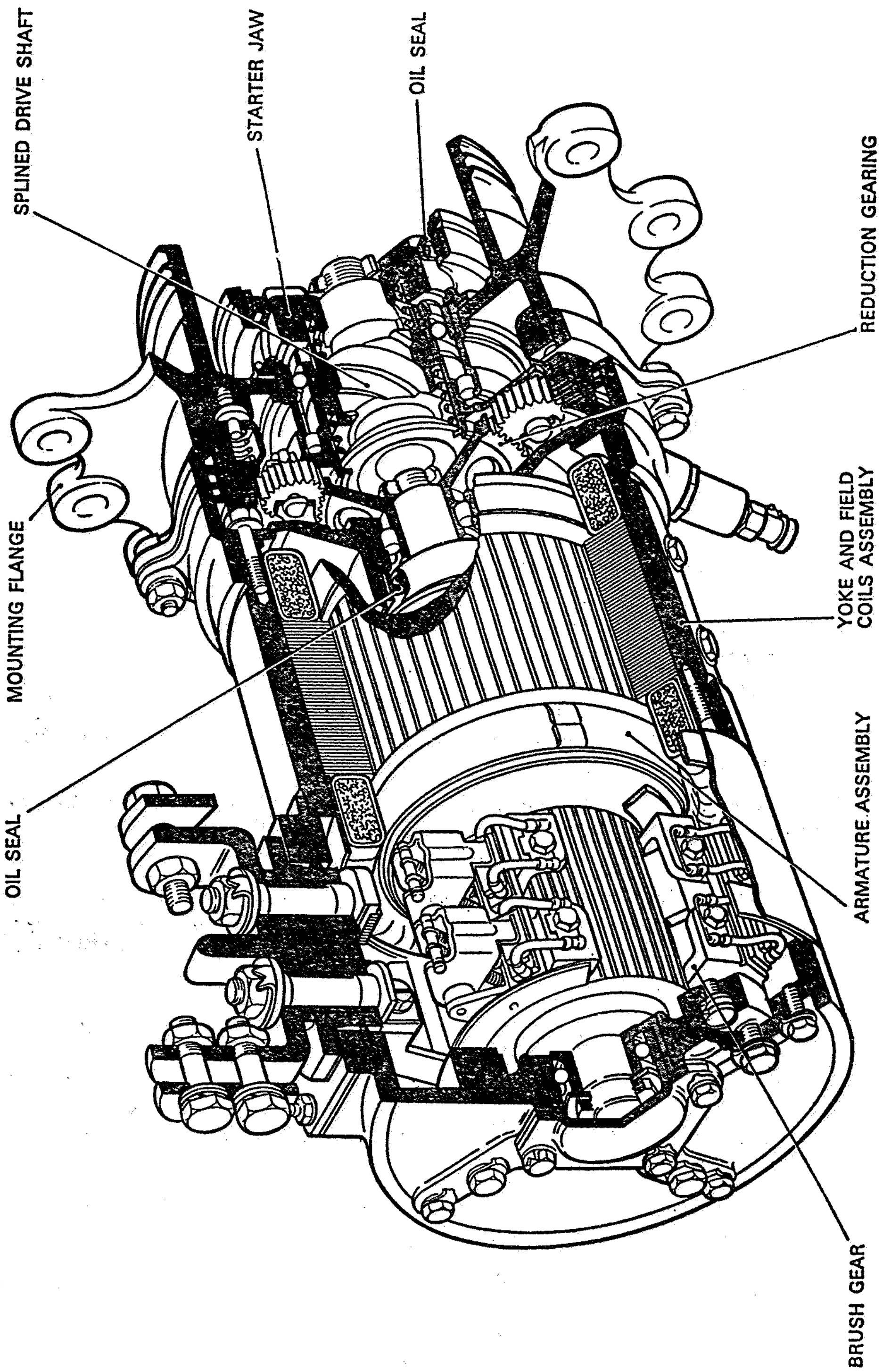


Figure 1 TYPICAL ELECTRIC STARTER

3.3 **Inspection.**

3.3.1 **Routine Inspection.** At the periods specified in the appropriate Maintenance Schedule the starter should be examined for serviceability as follows:—

(i) The starter should be inspected for security, external damage, cracks and oil leaks.

(ii) Brushes should be examined for freedom of movement and wear, and the commutator for scoring or other damage.

(iii) Leads should be secure and rubber grommets or sleeves should not be cracked or perished.

(iv) The gearbox oil level should be checked and topped up as necessary.

3.3.2 **Acceptance Checks on Replacement Starter.** An electric starter normally has an installed life at least equal to that of the engine to which it is fitted, subject to a possible calendar limitation. If replacement of the starter does become necessary the following checks should be carried out before installation:—

(i) The housing should be free from damage, cracks or corrosion.

(ii) Electrical resistance between the insulated terminal and the frame should be tested with a 250 volt insulation resistance tester and a reading of at least 500000 ohms obtained.

(iii) When applicable the axial movement of the starter jaw should be measured in accordance with the manufacturer's manual. The specified new washer or gasket must be fitted to the starter mounting flange to ensure satisfactory jaw engagement.

(iv) The brush inspection window cover should be temporarily removed in order to inspect the brushes for free movement, security and adequate spring pressure. All internal leads should be adequately supported and securely attached to the appropriate fitting.

3.3.3 After installation the starter gearbox should be filled with the recommended oil and a motoring run carried out to check starter operation.

4 AIR STARTERS (FIGURE 2) There are several different turbine engine starting systems which use a compressed air supply as a source of power and most transport aircraft are so designed that the engines may be started by alternative methods as a safeguard against lack of ground facilities.

4.1 Air impingement starting is a very simple method and represents a considerable saving in weight as compared with a normal starting system. An external air supply is connected to the engine and jets of air impinge directly onto the engine turbine to rotate it up to self-sustaining speed. No starter motor is required, the cranking operation being controlled by a simple ON/OFF cock and the ignition system by means of the normal relight circuit.

4.2 Air driven turbo starters are widely used and consist of a turbine wheel, reduction gear, clutch and driving shaft. Low pressure air (approximately 40 lb/in^2) impinging on the turbine produces the power required to turn the engine shaft. The air used for these starters may be obtained from an external supply, an auxiliary power unit in the aircraft or the compressor of a running engine. In addition, one engine of a multi-engined aircraft may be fitted with a "combustor" in which kerosene from the aircraft fuel tanks and air from a high pressure air supply (approximately 3000 lb/in^2) are ignited, the resulting gases impinging on the starter turbine at low pressure and high temperature.

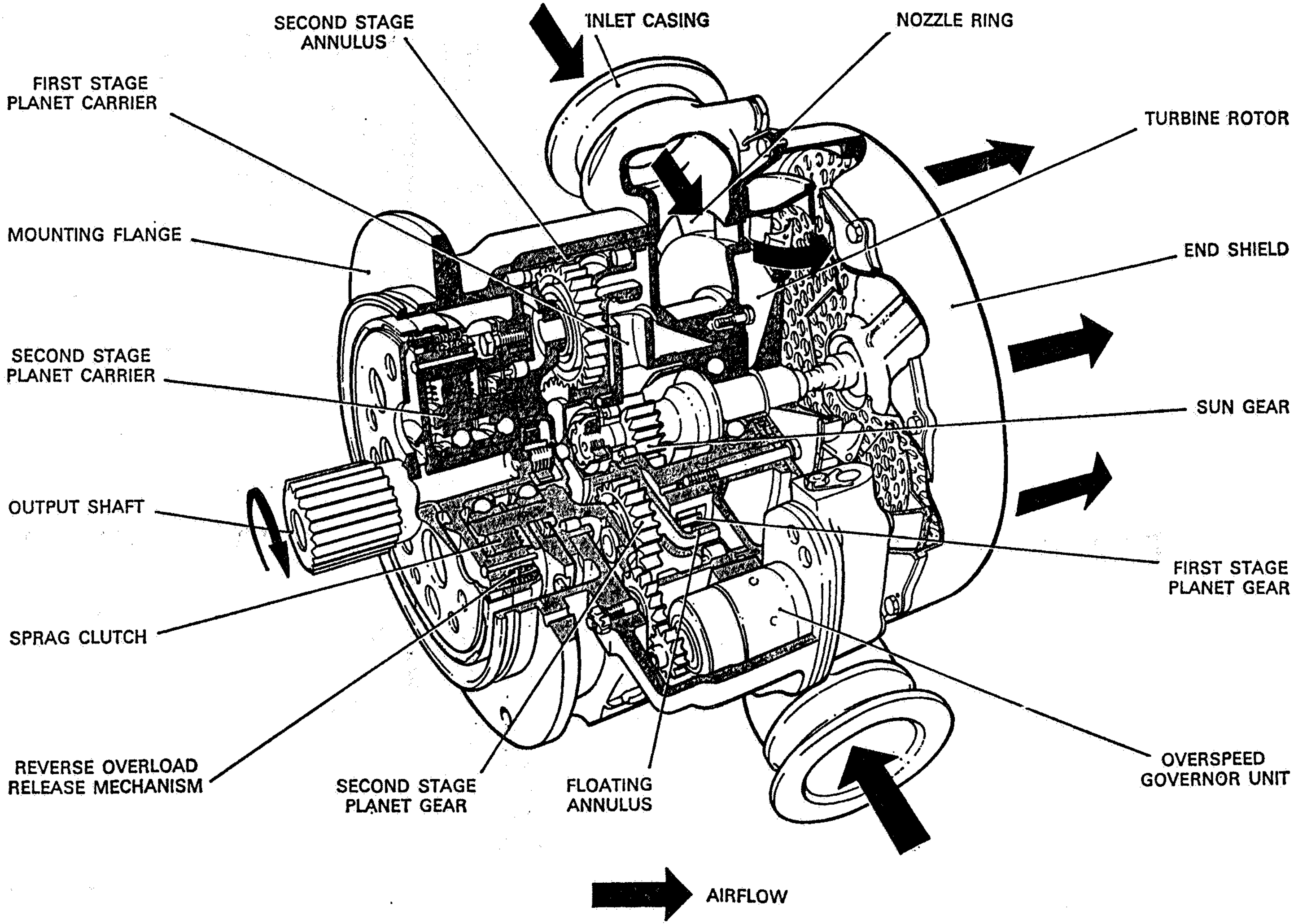


Figure 2 TYPICAL AIR STARTER

4.3 One particular British aircraft has a starter system which employs a Rootes type air motor instead of a turbine. In this case the air motor provides one input to the differential gear of the generator constant speed drive and during starting a sprag clutch engages to drive both engine and generator. When the engine reaches self-sustaining speed, the clutch disengages and air motor speed is controlled by varying the supply of air from the engine compressor. As engine speed increases, air motor speed decreases to maintain a constant speed drive to the generator.

4.4 **Inspection.** The inspections required on the starter motor itself are generally confined to ensuring that it is securely attached, free from damage or corrosion and that the gearbox contains the required quantity of oil. A certain amount of ducting is required with air starting systems however, particularly when air tapped from the engine compressors is also used for aircraft pneumatic purposes, and this, as well as the associated valves, must be regularly inspected. A typical system is shown in Figure 3.

4.4.1 Leaking ducts or incorrectly operating valves could cause malfunction, and in some cases damage to the associated starter or pneumatic system, and lead to loss of engine power. It is important to inspect these components for security, damage, chafing, corrosion or leaks, paying particular attention to sharp bends, connections, attachment points and positions where a duct runs through a panel or bulkhead.

4.4.2 When a leak is known to exist but is difficult to trace, metal pipes and joints should be brushed over with soapy water, and air at operating pressure applied to the inside of the duct; bubbles will indicate the position of a leak. The parts should be subsequently washed and dried to prevent corrosion. This method should not be used on flexible fabric ducts or pipes lagged with absorbent material such as asbestos. Contamination with oil or other fluids should also be avoided and surplus lubricants removed after servicing.

4.4.3 **Component Replacement.** The following inspection requirements should be satisfied whenever it becomes necessary to change an unserviceable item.

(i) The new component should be inspected for damage or corrosion, particularly on mating surfaces, and if possible its operation checked before installation.

(ii) On components with electrical mechanisms the insulation resistance between each pin of the electrical sockets and the case should be tested with a 250 volt insulation resistance tester, the minimum value required being 500000 ohms. The aircraft electrical supply should be disconnected by removing the appropriate fuse before installing a component of this type.

(iii) When the incorrect installation of a valve could cause malfunction or damage to the system, the component is usually designed so that it can only be fitted in one way. When this is not practical an arrow may be embossed on the casing to show the direction of main flow and it is important to take note of any such marking and refer to the Maintenance Manual when the installation procedure is not obvious.

(iv) "V" flange clamps are often used to connect components together and lubrication of the mating faces is sometimes required by the manufacturer. On other types of connection the use of jointing compound may be specified. All bolts should be torque loaded to the value specified in the Maintenance Manual.

(v) New washers, gaskets or seals should always be used when replacing a component in the system.

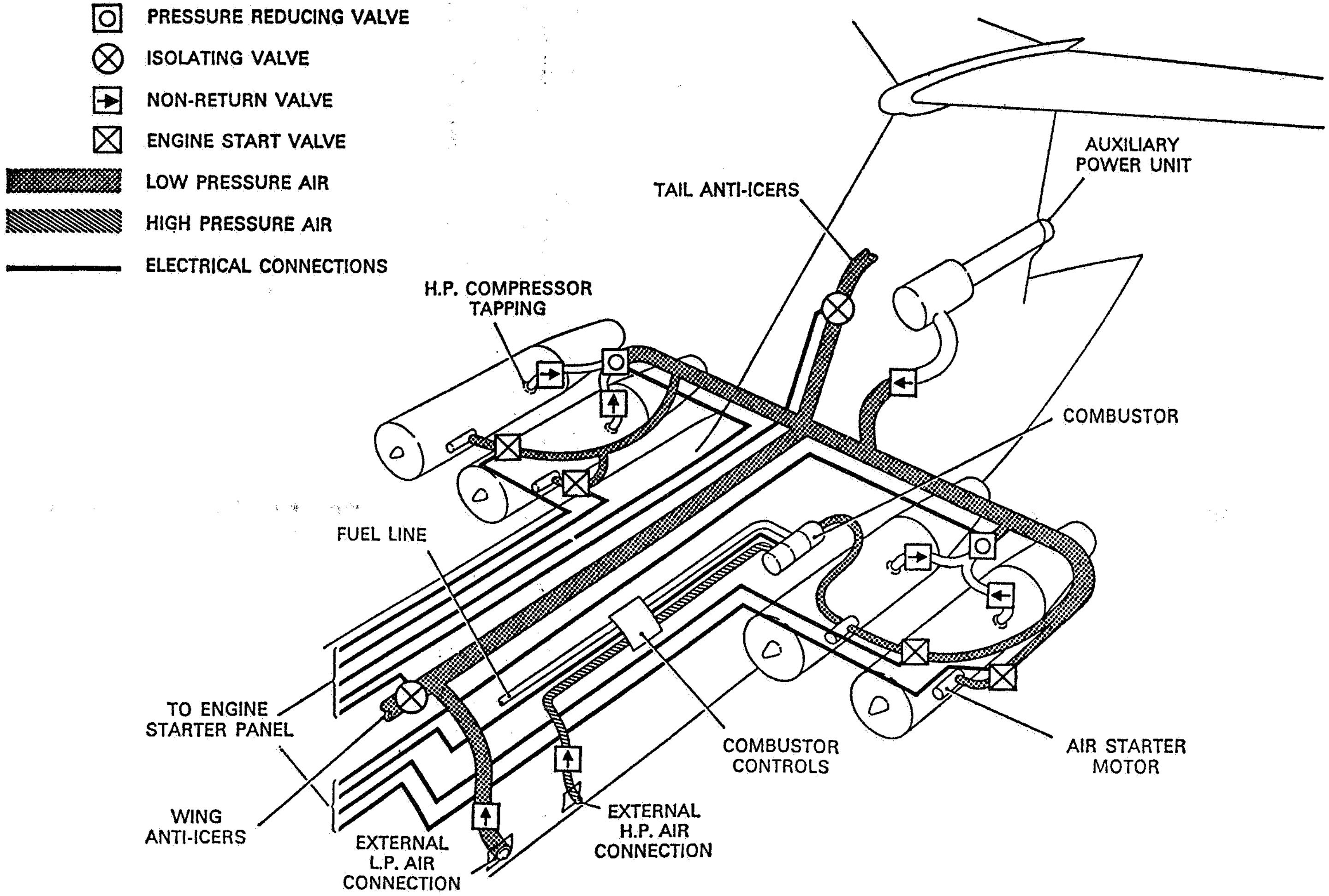


Figure 3 TYPICAL AIR STARTER SUPPLY SYSTEM

4.4.4 **Testing after Component Replacement.** Whenever a new component has been installed a functional check should be carried out to ensure correct operation of the system.

(i) Operation of the starter motor may be checked by carrying out a motoring run. During this test the operation of each valve should be checked against its indicated position and the engine speed obtained should be within the limits quoted in the Maintenance Manual.

(ii) If a valve concerned in the operation of both the starting and pneumatic systems is changed (e.g. an isolation valve), it will be necessary to start the engine and check the operation of both systems. Satisfactory cranking speed and pneumatic duct pressures should be obtained.

5 IGNITION SYSTEMS (FIGURE 4) The ignition system of a turbine engine must provide the electrical discharge necessary to ignite the air/fuel mixture in the combustion chamber during starting and must also be capable of operating independently from the starter system in the event of flame extinction through adverse flight conditions.

5.1 The electrical energy required to ensure ignition of the mixture varies with atmospheric and flight conditions, more power being required as altitude increases. Two independent 12 joule systems are normally fitted to each engine to provide a positive light up during starting but some engines have one 12 joule and one 3 joule system. The 3 joule system is kept in continuous operation to provide automatic relighting.

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

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

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

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

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

5.3.3 At the intervals specified in the appropriate Maintenance Schedule the unit should be inspected for signs of damage, cracks or corrosion. Bonding leads must be secure and the l.t. and h.t. ignition leads securely attached and locked.

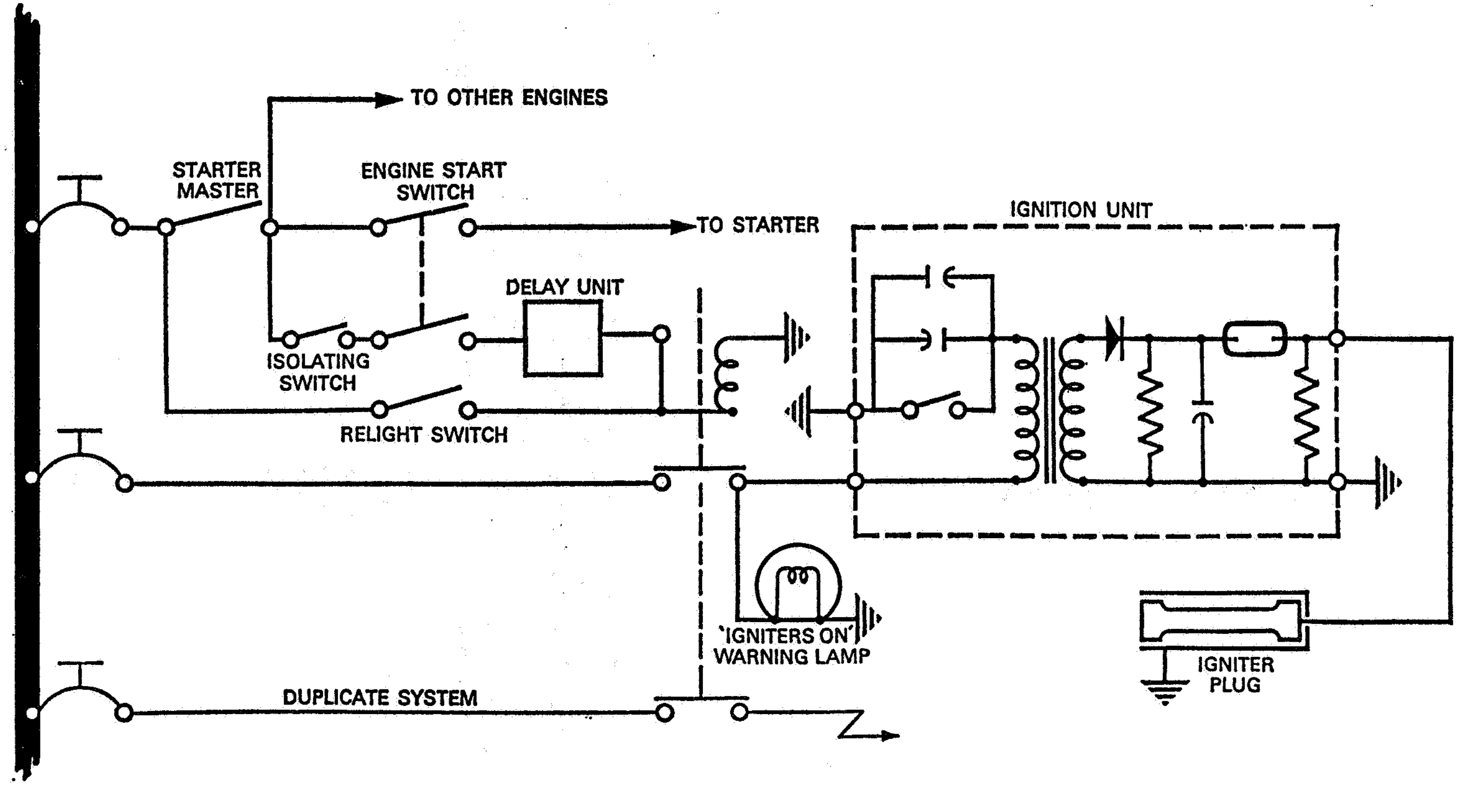


Figure 4 TYPICAL IGNITION SYSTEM

5.4 **Igniter Plug.** The igniter plug consists of a central electrode and outer body, the space between them being filled with an insulating material and terminating at the firing end in a semi-conducting pellet. A spring-loaded contact button is fitted at the outer end of the electrode. During operation a small electrical leakage from the ignition unit is fed through the electrode to the plug body and produces an ionised path across the surface of the pellet. The high intensity discharge takes place across this low-resistance path.

5.4.1 Igniter plugs should be inspected at frequent intervals for security, damage, gas leakage and secure attachment of the h.t. lead. When removed they should be inspected for heat damage, cracks and erosion of the pellet surface. Igniter plugs are not normally cleaned but if carbon deposits make inspection of the pellet impossible the carbon may be removed, care being taken not to damage the surface of the pellet.

5.4.2 When it is necessary to fit a new igniter plug the manufacturer sometimes specifies that the depth of penetration of the plug into the combustion chamber should be checked. This is accomplished by means of a special tool similar to a dummy plug and the adjustment is made by selecting a shim of appropriate thickness to fit under the igniter plug housing. A new sealing washer must be fitted when a plug is replaced.

5.4.3 Lubrication of plug threads is normally specified by the manufacturer and plugs should be torque loaded to the value stated in the appropriate Maintenance Manual.

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

5.5.1 Before installing an ignition lead the spring-loaded contact assemblies should be checked for freedom of movement and, where specified, an insulation resistance check carried out in accordance with the appropriate Maintenance Manual. The sheath should also be checked for fraying and the ceramic insulating sleeves for cracks or other damage. The manufacturer may specify the use of an anti-seize compound on the plug threads during fitting.

5.5.2 During service the leads should be inspected for security and damage. In particular the sheath should be examined in the vicinity of supporting clips for signs of chafing and over its whole length for signs of oil contamination.

5.6 **Testing.** Whenever an ignition component is changed or incorrect operation of the system is suspected a functional check may be made by operating the relight circuit.

5.6.1 The aircraft should be located in the open air and the engine inspected for signs of fuel or fuel vapour which, if present, must be dispersed before operating the ignition units. A suitable CO_2 fire extinguisher should be positioned adjacent to the engine before carrying out the test.

5.6.2 The high pressure fuel cock should be closed and the circuit breaker tripped (or fuse removed if appropriate) from each of the ignition circuits in turn whilst checking operation of the other. When the necessary switches are set for relighting, operation of the ignition system will be heard as regular clicking noises from the igniter plug as the electrical discharges occur and, on some aircraft, shown by illumination of an "igniters on" warning lamp on the flight deck.

5.6.3 If a component common to both the ignition and cranking systems is changed (e.g. a time delay unit), it is advisable to carry out an engine motoring run with the H.P. cock turned off, to check the normal d.c. circuit to the ignition units.

6 STORAGE Starters and ignition components should be stored in conditions that are clean, dry, warm and free from corrosive fumes. A temperature of 16°C (61°F) and humidity of 75% are often quoted by manufacturers as being ideal storage conditions.

6.1 **Starters and Ignition Units.** These components are transported in either a "tropical" or "commercial" pack. "Tropical" packing includes sealing the component with a suitable quantity of dessicant in a polythene bag and placing the bag in a padded wooden or cardboard box. Grease-resistant paper is used instead of a polythene bag for "commercial" packing. Components should be kept in their boxes during storage and when unpacked for use the packaging material should be retained. If the original material is not available a returned component should be packed in accordance with BS 1133 or equivalent specification

6.1.1 Starter gearboxes should be drained before packing and external threads and drive shafts coated with a rust preventative.

6.2 **Igniter Plugs.** Plug threads should be coated with a rust preventative and the plug wrapped in waxed paper or a polythene tube. It may then be placed in a cardboard box, either singly or with other plugs, and the box sealed.

6.3 **Ignition Leads.** These should be wiped with a cloth moistened with white spirit to remove any oil or grease, and the end connections blanked off. The leads should be placed in a natural position (i.e. not coiled or bent) on a flat shelf and covered with a dust cloth.

6.4 **Storage Life.** A specific storage life may be recommended for some components but igniter plugs and leads may normally be kept in storage indefinitely provided that storage conditions are ideal. Any component which has reached the end of its storage life must be subjected to such inspection and testing as may be specified to enable re-certification for a further period of storage.

EL/3-13

Issue 1.

1*st April*, 1973.

AIRCRAFT

ENGINES

TURBINE ENGINES—ANTI-ICING SYSTEMS

INTRODUCTION This Leaflet gives general guidance on the installation and maintenance of the thermal systems employed for the anti-icing of the air intakes of turbine engines. It should be read in conjunction with the installation drawings, Maintenance Manuals and approved Maintenance Schedules for the engine and aircraft concerned.

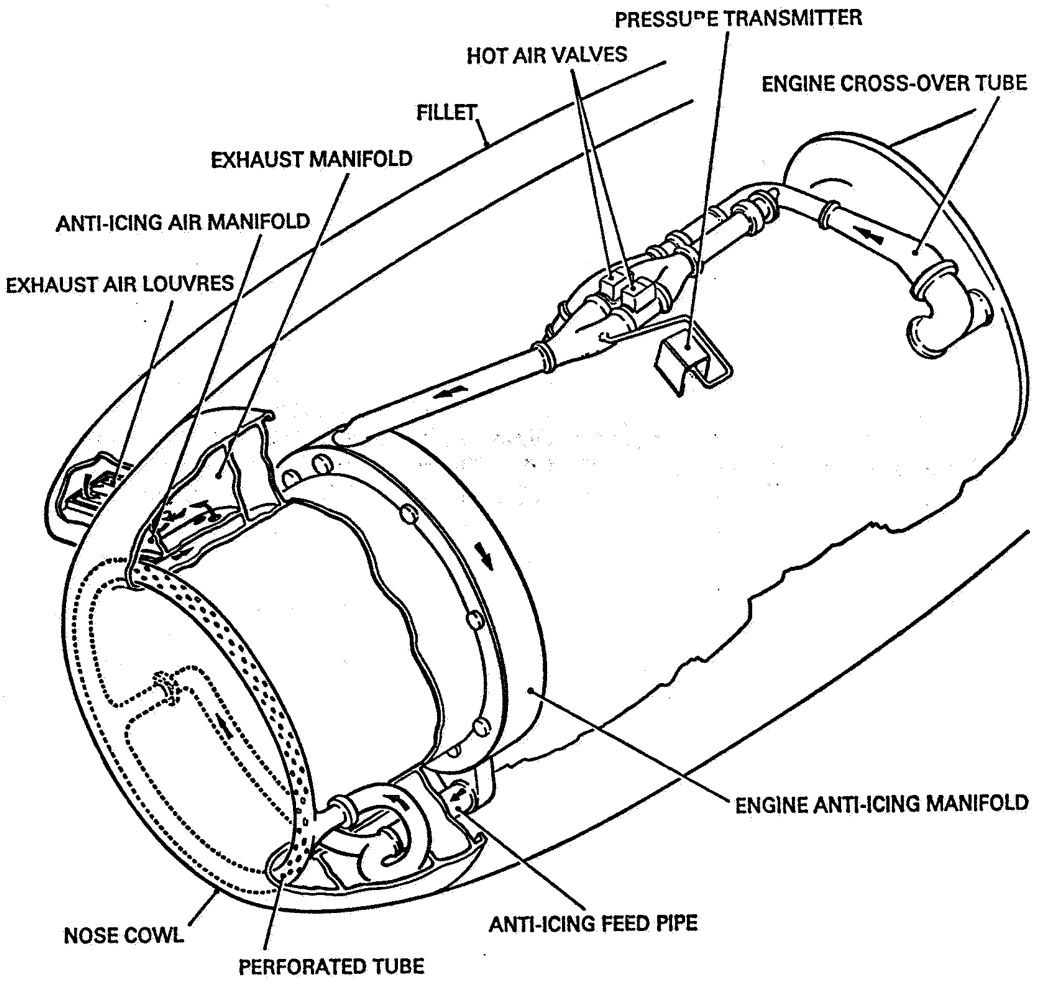


Figure 1 TYPICAL HOT AIR ANTI-ICING SYSTEM

2 GENERAL A gas turbine engine presents a critical icing problem and therefore requires protection against ice formation particularly at the air intake, nose bullet or fairing, and inlet guide vanes. Icing of these regions can considerably restrict the airflow causing a loss in performance and, furthermore, cause damage to the compressor as a result of ice breaking away and being ingested by the compressor. There are two thermal systems in use for air intake anti-icing; a hot air bleed system and an electrical resistance heating system, and although the latter is usually chosen for turbopropeller engines to provide protection for the propeller (see Leaflet **PL/1-4**), there are some examples where both systems are used in combination.

2.1 **Hot Air System.** In a hot air system the air is bled from the compressor and is fed via ducting into the air intake nose cowl, through the inlet guide vanes of the engine and also, in some engines, through the nose bullet. A typical system is illustrated in Figure 1. After circulating the intake cowl and guide vanes, the air is exhausted either to atmosphere or into the engine air intake. The flow of hot air is regulated by electrically operated control valves which are actuated by control switches on a cockpit panel. An air temperature control system is not usually provided in a hot air system.

2.2 **Electrical Heating System.** In an electrical heating system, heating elements either of resistance wire or sprayed metal, are bonded to the air intake structure. The power supply required for heating is normally three-phase alternating current. The arrangement adopted in a widely used turbopropeller engine is illustrated in Figure 2 as an example. The elements are of the resistance wire type and are formed into an overshoe which is bonded around the leading edge of the air intake cowl and also around the oil cooler air intake. Both anti-icing and de-icing techniques are employed by using continuously heated and intermittently heated elements respectively. The elements are sandwiched between layers of glass cloth impregnated with resin. In some systems the elements may be sandwiched between layers of rubber. The outer surfaces are, in all cases, suitably protected against erosion by rain, and the effect of oils, greases, etc. The power supply is fed directly to the continuously heated elements, and via a cyclic time switch unit to the intermittently heated elements and to the propeller blade elements (see also Leaflet **PL/1-4**). The cyclic time switch units control the application of current in selected time sequences compatible with prevailing outside air temperature conditions and severity of icing. The time sequences which may be selected vary between systems. For the system shown in Figure 2 the sequences are 'Fast', giving one complete cycle (heat on/heat off) of 2 minutes at outside air temperatures between —6°C and +10°C, and 'Slow', giving one complete cycle of 6 minutes at outside air temperatures below —6°C. An indicator light and, in some cases, an ammeter, are provided on the appropriate cockpit control panel to indicate correct functioning of the time switch circuit.

3 INSTALLATION AND MAINTENANCE Full details of the methods of installation and checks necessary for the inspection and maintenance of systems and associated components will be found in the relevant aircraft and engine Maintenance Manuals and approved Maintenance Schedules; reference must therefore be made to such documents. Reference should also be made to Leaflets **EEL/3-1** and **EEL/1-6** for guidance on the installation of electric cables and testing of circuits. The information given in the following paragraphs is intended only as a general guide to the installation and maintenance procedures normally required.

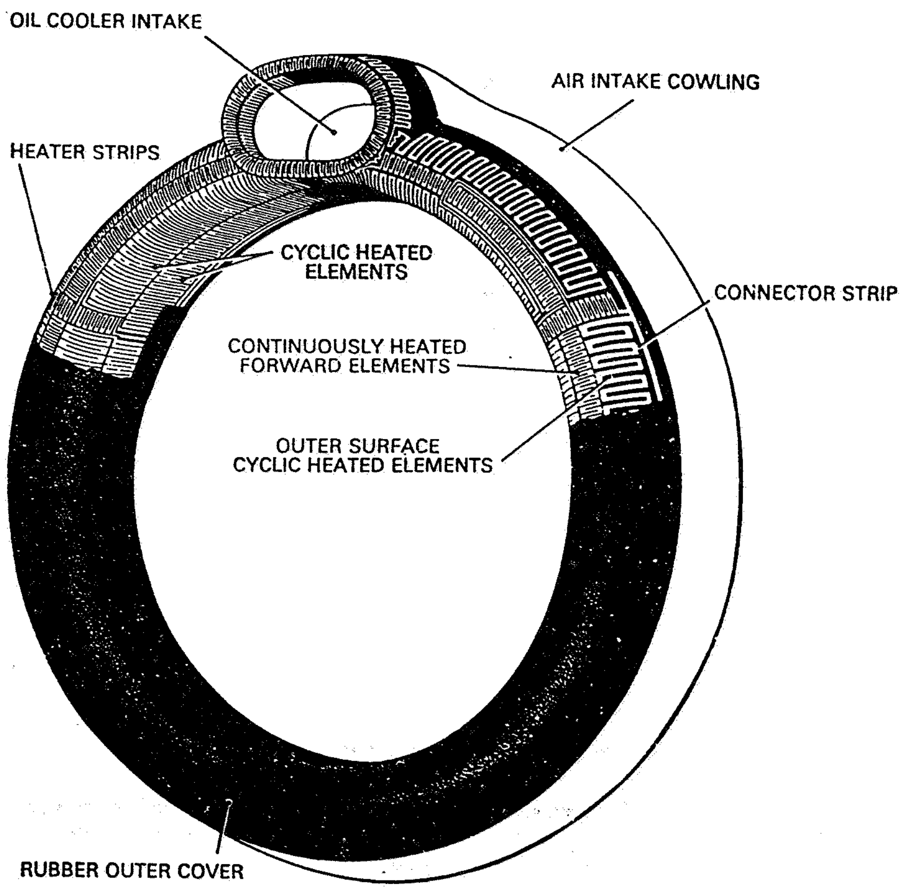


Figure 2 TYPICAL ELECTRICAL ANTI-ICING SYSTEM

3.1 **Hot Air Systems.** The installation and maintenance of components of hot air systems is, in general, a straightforward procedure which only requires checks to ensure security of attachment to appropriate parts of the aircraft structure, security of duct connections and wirelocking, where necessary. After installation of a component and at the periods detailed in the aircraft approved Maintenance Schedule, a system should be tested to ensure proper functioning and checks made for leakage at the areas disturbed. Some important aspects common to installation and maintenance procedures are given in the following paragraphs.

3.1.1 Ducts should be inspected externally and internally for cleanliness, signs of damage and security of end fittings.

3.1.2 During installation, ducts must be adequately supported at all times, and must not be allowed to hang from a joint or other component. There must be adequate clearance between ducts and adjacent structure and components.

3.1.3 In general, new seals should be fitted between jointing faces of end fittings of ducts and components such as control valves. This is also essential whenever a joint is broken down for any reason. The jointing faces should also be checked for excessive ovality or gapping.

3.1.4 Whenever possible ducting should be removed by disconnecting at a point where band-type vee-clamps are used. On some engines bolted spherical connections are employed and, unless it is absolutely necessary, the ducts should not be disconnected at these points since the connections will require special refitting.

3.1.5 Band-type vee-clamps should be lubricated with the dry-film lubricant specified in the Maintenance Manual and torque-tightened to the loads specified. The clearance between the flanges of fittings should be checked in order to ensure that the seal between the jointing faces of duct end fittings has been sufficiently compressed.

3.1.6 Expansion bellows type joints should be checked for full and free movement.

3.1.7 All sections of ducting should be properly aligned with each other and with other associated components. In most cases ducting passes through confined spaces and requires considerable care to ensure stress-free alignment at the joints before finally securing in place. Ducting should not be drawn into alignment by means of flange attachment devices. On some types of engine alignment is facilitated by locating a dowel in a hole. On others alignment is by means of coloured flashes painted on the ducts and components.

3.1.8 If a section of ducting or a component is removed and refitting is not being effected immediately, suitable blanks must be fitted to the open ends of ducts or other connections to prevent the ingress of foreign matter.

3.1.9 Where specified, ducts should be tested for leaks in the manner prescribed in the relevant aircraft and engine Maintenance Manuals. The test pressures and rate of leakage should not exceed the limits quoted.

NOTE: Adequate safety precautions must be taken when inspecting duct sections under pressure.

3.1.10 Control valves should be inspected for cleanliness, signs of damage and their insulation resistance and solenoid resistance values measured to ensure that they are within the limits specified in the Maintenance Manual. When installing valves particular care is necessary to ensure that they are positioned in correct relation to the air flow as indicated by an arrow on the body of the valve.

3.1.11 Cables interconnecting appropriate electrical components must be of the rating specified by the manufacturer. All connections should be checked against the relevant wiring diagrams, and plugs, sockets and terminal screws properly secured.

3.1.12 On completion of the installation of a duct section or component, and at the periods specified in the approved Maintenance Schedule, an in-situ functional test should be carried out. Any limitations as to the duration of the test and other precautions during engine ground running, must be strictly observed. A functional test consists principally of checking the air pressure supplied to the system at a specified engine speed, and checks on the function of associated controlling and indicating devices. Such checks and tests should be performed to a prescribed test schedule.

3.2 **Electrical Heating Systems.** In systems of this type, the overshoes are bonded to the air intake cowls, therefore removal and installation procedure are related to the cowls as combined units. The procedures are straightforward involving only the removal and refitting of setscrews which secure cowls to engine air intake casings, and the making and breaking of the electrical connections. In some cases the procedures also involve the connection and disconnection as appropriate, of fire extinguisher system spray pipes and oil cooler pipes and couplings at the rear face of the air intake cowl. Set-screws pass through steel insert and rubber bush assemblies and care should be taken to avoid losing these during removal. The bushes should be examined for wear and deterioration and renewed as necessary. Where specified, the clearance between the cowl diaphragm and engine air intake casing must be checked before finally securing the cowl, to ensure that it corresponds to the value specified in the engine Maintenance Manual. If the correct clearance cannot be obtained, the complete cowl assembly or diaphragm should be replaced by a serviceable item. Some important aspects common to inspection and maintenance procedures are given in the following paragraphs. These should be read in conjunction with the aircraft and engine Maintenance Manuals and approved Maintenance Schedules.

3.2.1 Cowls and electrical leads should be inspected for security and the overshoes inspected for blisters, gashes, exposure of the heating elements, signs of overheating and general deterioration.

NOTE: Overheating or a complete 'burn-out', can be caused through impact damage to the overshoe, defects in the heating elements or malfunction of the aircraft's electrical power supply to the heating elements.

3.2.2 The lacquer film on rubber covered overshoes should be examined for damage or deterioration and if either is evident the film should be touched-up or completely renewed as necessary, by using the repair kit supplied by the relevant manufacturer.

3.2.3 Checks on the continuity and resistance of the heating elements, and insulation resistance checks of the complete cowl assembly, must be carried out whenever an assembly has been changed or repairs effected and also at the prescribed inspection periods.

NOTE: The metal of air intake cowls is normally anodised and it is necessary to bare a small area to effect the 'earth' connection. On completion of the electrical checks, this area must be re-protected against corrosion.

3.2.4 Functional testing of a complete system must be carried out at the check periods specified in the approved Maintenance Schedule, when a system malfunction occurs, after replacement of an intake cowl or a system component such as a cyclic time switch, and also after any repairs to an overshoe. A functional test consists principally of checking that heating current is applied to the heater elements at the periods governed by the operation of the cyclic time switch and, as indicated by the system indicator light, and ammeter where applicable, to the systems. Tests and checks must be performed to a prescribed test schedule paying particular attention to any limitations on system operation and engine speeds during ground running.

NOTE: The power supply control circuit is usually routed through landing gear shock-strut micro switches so that on the ground the power is automatically reduced to prevent overheating. Therefore, whenever the aircraft is on jacks, or the micro switches are otherwise rendered inoperative, power should not be applied to the heating elements.

3.2.5 If blisters, gashes, exposure of the heating elements, general deterioration and lack of adhesion of either rubber or glass cloth covering is evident, the covering should be carefully cut open to permit examination of the heating elements. If the elements are not fractured or cracked and the rubber or glass cloth below the elements has not deteriorated, the areas affected may be repaired as a minor repair.

3.2.6 The heating element system is made up of a number of sections or pads and if any one of the sections has been fractured due to a localised burn-out or mechanical damage, a repair can be made by welding a portion of element in the appropriate section.

NOTE: The number of repairs in a section or pad is normally limited to one since the weld causes an increase in element resistance.

3.2.7 The repair methods to be adopted, and the nature of the work involved, depends largely on the extent of damage and also on the type of overshoe construction, i.e. glass cloth or rubber laminate. Repair schemes are therefore devised for each type and are usually classified according to the level of the repairs required, i.e. minor repairs which can be carried out in the normal overhaul workshops, or major repairs to be carried out by the manufacturer. Full details of these schemes are given in the Maintenance Manuals and Overhaul Manuals for the relevant type of engine and reference must always be made to these documents.

3.2.8 An air intake cowl assembly which has been damaged or has deteriorated to an extent outside repair standards specified in the Maintenance Manuals and Overhaul Manuals should be removed and replaced by a serviceable assembly.

EL/3-14

Issue 1.

1*st April,* 1973.

AIRCRAFT

ENGINES

STORAGE PROCEDURES

1 INTRODUCTION Under normal operating conditions the interior parts of an engine are protected against corrosion by the continuous application of lubricating oil, and operating temperatures are sufficient to dispel any moisture which may tend to form; after shutdown the residual film of oil gives protection for a short period. When not in regular service, however, parts which have been exposed to the products of combustion, and internal parts in contact with acidic oil, are prone to corrosion. If engines are expected to be out of use for an extended period they should be ground run periodically or some form of anti-corrosive treatment applied internally and externally to prevent deterioration.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet EL/10-1, Issue 1, 1st June 1949, cancelled 1st February 1968.

1.1 The type of protection applied to an engine depends on how long it is expected to be out of service, if it is installed in an aircraft, and if it can be turned.

1.2 This Leaflet gives guidance on the procedures which are generally adopted to prevent corrosion in engines but, if different procedures are specified in the approved Maintenance Manual for the particular engine, the manufacturer's recommendations should be followed.

1.3 The maximum storage times quoted in the Leaflet are generally applicable to storage under cover in temperate climates, and vary considerably for different storage conditions. Times may also vary between different engines, and reference must be made to the appropriate Maintenance Manual for details.

2 INSTALLED PISTON ENGINES If it is possible to run a piston engine which is installed in an aircraft and expected to be out of service for a period of up to one month, sufficient protection will be provided by running the engine every seven days, but if the period of inactivity is subsequently extended, continued periodic ground running would result in excessive wear and the engine should be placed in long term storage. The run should be carried out at low engine speed (1000 to 1200 rev/min), exercising the engine and propeller controls as necessary to ensure complete circulation of oil, until normal working temperatures are obtained. If the engine cannot be run for any reason, the manufacturer may recommend that it should be turned by hand or motored by means of an external power supply, but generally it will be necessary to inhibit the engine as described below.

2.1 **Long Term Storage.** When a piston engine is likely to be out of service for a period in excess of one month it must be treated internally and externally with a corrosion inhibitor. The treatments described below are normally considered satisfactory for six months but this may be extended to twelve months in ideal storage conditions. At the end of this period the engine should be prepared for service, given a thorough ground run and re-protected or, alternatively, removed from the aircraft and stored as described in paragraph 4.

2.1.1 Internal Protection

(i) American Method

(a) Drain the oil sump and tank and refill with storage oil as prescribed by the manufacturer.

(b) Run the engine at low speed (1000 to 1200 rev/min) until normal operating temperatures are obtained.

(c) Spray cylinder protective into the induction system until white smoke issues from the exhaust, then switch off the engine but continue spraying until rotation has ceased.

(d) Drain the oil sump and remove the filters.

(e) Remove the sparking plugs and spray a fixed quantity of cylinder protective into each cylinder while the engine is turned by hand. A further quantity should then be sprayed into the cylinders with the engine stationary.

(f) Fit dehydrator plugs in each cylinder and replace oil filters.

(g) Place a quantity of desiccant in the intake and exhaust and blank off all openings.

(ii) British Method

(a) Drain the oil sump and tank and refill with the storage oil recommended by the manufacturer.

(b) Run the engine at low speed (1000 to 1200 rev/min) until normal operating temperatures are obtained.

(c) Drain all oil from the system and remove filters.

(d) Remove sparking plugs and spray the specified quantity of cylinder protective into each cylinder while the piston is at the bottom of its stroke, at the same time spraying the valve springs and stems with the valves closed, and the valve heads and ports with the valves open. Also spray the valve rocker gear.

(e) Turn the engine at least six revolutions by hand, then spray half the previously used quantity of cylinder protective into each cylinder with the engine stationary.

(f) Replace oil filters and fit dehydrator plugs.

(g) Blank off all openings into the engine (intake, exhaust, breathers, etc.).

(h) Replenish oil tank to normal level with storage oil as specified.

(iii) Special Requirements

(a) Coolant systems should be drained and thoroughly flushed unless an inhibited coolant is used.

(b) Fuel system components such as fuel pumps, injectors, carburettors or boost control units also require inhibiting. This is done by draining all fuel and oil as appropriate, and refilling with storage or mineral oil as recommended by the manufacturer. Blanking caps and plugs should then be fitted to retain the oil.

(c) Auxiliary gearboxes should also be inhibited. The normal lubricating oil should be drained and the gearbox refilled with storage oil.

(d) If the propeller is removed the propeller shaft should be sprayed internally and externally with cylinder protective and correct blanks fitted.

2.1.2 **External Protection.** Exterior surfaces of the engine should be thoroughly cleaned with an approved solvent such as white spirit, by brushing or spraying, and dried with compressed air. Any corrosion should be removed, the area re-treated in accordance with the manufacturer's instructions and chipped or damaged paintwork renewed. The following actions should then be taken:—

(i) All control rods should be liberally coated with a general purpose grease.

(ii) Magneto vents should be covered.

(iii) Sparking plug lead ends should be fitted with approved transport blanks, exposed electrical connections masked and rubber components covered with waxed paper or mouldable wrap.

(iv) Spray holes in fire extinguisher pipes should, if possible, be blanked off, using polythene sleeving or waxed paper suitably secured.

(v) An approved preservative (normally lanolin or external air drying varnish) should be sprayed over the whole engine, in a thin even film.

2.2 **General Precautions.** It is most important that an installed stored engine should not be turned, since this would lead to removal of cylinder protective from the cylinder walls and possibly result in the formation of corrosion at those positions. Physical restraint is seldom practicable, particularly when a propeller is fitted, but warning notices should be fixed on the propeller and in the cockpit to prevent inadvertent rotation of the engine.

3 INSTALLED TURBINE ENGINES Installed turbine engines which are to be out of use for a period of up to seven days require no protection apart from fitting covers or blanks to the intake, exhaust and any other apertures, to prevent the ingress of dust, rain, snow, etc. A turbine engine should not normally be ground run solely for the purpose of preservation, since the number of temperature cycles to which it is subjected is a factor in limiting its life. For storage periods in excess of seven days additional precautions may be necessary to prevent corrosion.

3.1 **Short-term Storage.** The following procedure will normally be satisfactory for a storage period of up to one month.

3.1.1 **Fuel System.** The fuel lines and components mounted on the engine must be protected from the corrosion which may result from water held in suspension in the fuel. The methods used to inhibit the fuel system depend on the condition of the engine and whether it is installed in an aircraft or not, and are fully described in the appropriate Maintenance Manual and in Leaflet **EL/3-10.** On completion of inhibiting, the fuel cocks must be turned off.

3.1.2 **Lubrication Systems.** Some manufacturers recommend that all lubrication systems (engine oil, gearbox oil, starter oil, etc.) of an installed engine should be drained, and any filters removed and cleaned, while others recommend that the systems should be filled to the normal level with clean system oil or storage oil. The method recommended for a particular engine should be ascertained from the appropriate Maintenance Manual.

3.1.3 **External Treatment.** Exterior surfaces should be cleaned as necessary to detect corrosion, then dried with compressed air. Any corrosion should be removed, affected areas re-treated, and any damaged paintwork made good in accordance with the manufacturer's instructions. Desiccant or vapour phase inhibitor should be inserted in the intake and exhaust, and all apertures should be fitted with approved covers or blanks.

3.2 **Long-term Storage.** For the protection of turbine engines which may be in storage for up to six months, the short-term preservation should be applied and, in addition, the following actions taken:—

(i) Grease all control rods and fittings.

(ii) Blank-off all vents and apertures on the engine, wrap greaseproof paper round all rubber parts which may be affected by the preservative and spray a thin coat of external protective over the whole engine forward of the exhaust unit.

3.2.1 At the end of each successive six months storage period an installed engine should be re-preserved for a further period of storage. Alternatively, the engine may be removed from the aircraft and preserved in a moisture vapour proof envelope.

4 UNINSTALLED ENGINES (PISTON AND TURBINE) Engines which have been removed from aircraft for storage, or uninstalled engines which are being returned for repair or overhaul, should be protected internally, and sealed in moisture vapour proof (MVP) envelopes. This is the most satisfactory method of preventing corrosion, and is essential when engines are to be transported overseas.

4.1 A piston engine should be drained of all oil, the cylinders inhibited as described in paragraphs 2.1.1 (ii), (d) to (h), drives and inside of crankcase sprayed with cylinder protective, and all openings sealed.

4.2 A turbine engine should be drained of all oil, fuel system inhibited, oil system treated as recommended by the manufacturer, and blanks fitted to all openings.

4.3 Particular care should be taken to ensure that no fluids are leaking from the engine, and that all sharp projections, such as locking wire ends, are suitably padded to prevent damage to the envelope.

4.4 The MVP envelope should be inspected to ensure that it is undamaged, and placed in position in the engine stand or around the engine, as appropriate. The engine should then be placed in the stand, care being taken not to damage the envelope at the points where the material is trapped between the engine attachment points and the stand bearers.

4.5 Vapour phase inhibitor or desiccant should be installed in the quantities and at the positions specified in the relevant Maintenance Manual, and a humidity indicator should be located in an easily visible position in the envelope. The envelope should then be sealed (usually by adhesive) as soon as possible after exposure of the desiccant or vapour phase inhibitor.

4.6 The humidity indicator should be inspected after 24 hours to ensure that the humidity is within limits (i.e. the indicator has not turned pink). An unsafe reading would necessitate replacement of the desiccant and an examination of the MVP envelope for damage or deterioration.

4.7 After a period of three years storage in an envelope the engine should be inspected for corrosion and re-preserved.

5 INSPECTION Engines in storage should be inspected periodically to ensure that no deterioration has taken place.

5.1 Engines which are not preserved in a sealed envelope should be inspected at approximately two-weekly intervals. Any corrosion patches should be removed and the protective treatment re-applied, but if external corrosion is extensive a thorough inspection may be necessary.

5.2 Envelopes on sealed engines should be inspected at approximately monthly intervals to ensure that humidity within the envelope is satisfactory. If the indicator has turned pink the envelope should be unsealed, the desiccant renewed and the envelope resealed.

6 EQUIPMENT AND MATERIALS

6.1 **Equipment.** The spraying equipment should be of a type approved by the engine manufacturer, and should be operated in accordance with the instructions issued by the manufacturer of the equipment. For inhibiting cylinders a special nozzle is required, and this should be checked immediately before use to ensure that the spray holes are unblocked. Correct operation of the spray gun may be checked by spraying a dummy cylinder and inspecting the resultant distribution of fluid.

6.2 **Materials.** Only the types of storage and inhibiting oil recommended by the manufacturer should be used for preserving an engine. American manufacturers generally recommend oils and compounds to American specifications, and British manufacturers generally recommend storage oil to DEF 2181, wax-thickened cylinder protective to DTD 791, turbine fuel system inhibiting oil to D. Eng. R.D. 2490, and external air drying varnish approved under a DTD 900 specification. Only approved alternatives should be used, and any instructions supplied by the manufacturer in respect of thinning or mixing of oils should be carefully followed.

6.3 **Blanks.** Approved blanks or seals should be used whenever possible. These are normally supplied with a new or reconditioned engine, and should be retained for future use. Pipe connections are usually sealed by means of a screw-type plug or cap such as AGS 3802 to 3807, and plain holes are sealed with plugs such as AGS 2108; these items are usually coloured for visual identification. Large openings such as air intakes are usually fitted with a specially designed blanking plate secured by the normal attachment nuts, and the contact areas should be smeared with grease before fitting, to prevent the entry of moisture. Adhesive tape may be used to secure waxed paper where no other protection is provided, but should never be used as a means of blanking off by itself, since it may promote corrosion and clog small holes or threads.

7 REMOVAL FROM STORAGE For an engine which was not installed in an aircraft during storage the installation procedure described in the appropriate Maintenance Manual should be carried out, followed by a thorough ground run and check of associated systems. For an engine which was installed in an aircraft during storage the following actions should be taken:—

(i) Remove all masking, blanks and desiccant.

(ii) Clean the engine as necessary, e.g. remove excess external protective and surplus grease from controls.

(iii) Ensure fire extinguisher spray pipe holes are clear.

(iv) Replace any components which were removed for individual storage, de-inhibiting as necessary.

(v) Drain out all storage oil, clean oil filters and refill with normal operating oil.

(vi) Piston engines; remove sparking plug blanks and turn engine slowly to drain excess oil from the cylinders, then fit plugs and connect leads. Turbine engines; prime the fuel system in accordance with the manufacturer's requirements (Leaflet **EL/3-10**).

(vii) Prime the engine lubricating oil system.

(viii) Start the engine and carry out a check of the engine and associated systems.

8 RECORDS Appropriate entries must be made in the engine log book giving particulars of inhibiting procedures or periodic ground running. Such entries must be signed and dated by an appropriately licensed engineer or Approved Inspector.

EL/3-15

Issue 2.
January, 1981.

AIRCRAFT

ENGINES

PISTON ENGINES—OPERATION BEYOND RECOMMENDED OVERHAUL PERIODS

1 INTRODUCTION This Leaflet gives guidance on the procedures which are necessary for a small piston engine to be accepted as being in a condition which will allow completion of, or operation beyond, the recommended overhaul period under the terms of Airworthiness Notice No. 35.

2 GENERAL A piston engine which has reached the end of its normal overhaul period may be expected to have suffered some wear to cylinders, pistons, valves, bearings and other moving parts, but an engine which has been carefully operated and maintained may still be in a condition suitable for a further period of service.

2.1 Many factors affect the wear which takes place in an engine, the most important including the efficiency of the air intake filter, the techniques used in engine handling, particularly during starting, the quality of the fuel and oil used in the engine and the conditions under which the aircraft is housed when not in use. Conditions of operation are also relevant; the length of flights, the atmospheric conditions during flight and on the ground, and the type of flying undertaken. Many of these factors are outside the province of the maintenance engineer, but meticulous compliance with the approved Maintenance Schedule, and any instructions provided in the form of service bulletins or constructor's recommendations will undoubtedly help to prolong the life of an engine.

2.2 Airworthiness Notice No. 35 lays down certain conditions which must be fulfilled in order that an engine may be considered for—

(a) operation for the manufacturer's recommended overhaul period,

(b) operation beyond 10 years where the manufacturer's recommended overhaul period is conditional upon a minimum utilisation rate,

(c) operation for up to 120% of the recommended overhaul period, or

(d) in the case of engines installed in aircraft certificated in the Private Category with a Maximum Total Weight Authorised not exceeding 2730 kg, continuation in operation on an 'on-condition' basis.

2.2.1 The inspections and tests which may be necessary to assess the condition of an engine in compliance with Airworthiness Notice No. 35 are detailed in paragraphs 3 to 6.

3 EXAMINATION AND CHECKING OF ENGINE A number of items included in the normal scheduled maintenance of an engine may be repeated to determine the condition of an engine at the end of its normal overhaul period, and additional inspections may also be specified.

3.1 **External Condition.** The engine should be examined externally for obvious faults such as a cracked crankcase, excessive play in the propeller shaft, overheating and corrosion, which would make it unacceptable for further use.

3.2 **Internal Condition.** Significant information concerning the internal condition of an engine may be obtained from an examination of the oil filters and magnetic plugs, for metal particle contamination. These checks may be sufficient to show that serious wear or breakdown has taken place and that the engine is unacceptable for further service.

3.3 **Oil Consumption.** Since the oil consumption of an engine may have increased towards the end of its normal overhaul period, an accurate check of the consumption over the last 10 flying hours would show whether it is likely to exceed the maximum recommended by the constructor, should the overhaul period be extended.

3.4 **Compression Check.** Piston ring and cylinder wear, and poor valve sealing could, in addition to increasing oil consumption, result in a significant loss of power. A cylinder compression check is a method of determining, without major disassembly, the standard of sealing provided by the valves and piston rings.

3.4.1 On engines with a small number of cylinders a simple compression check may be carried out by rotating the engine by hand and noting the resistance to rotation as each cylinder passes through its compression stroke. The check should normally be made shortly after running the engine while a film of oil remains on the rubbing surfaces, to assist sealing and prevent scoring the working parts. If this is not possible, the constructor may recommend that oil is introduced into each cylinder and the engine turned through a number of revolutions before making the test.

(a) This method may be used to determine serious loss of compression on a single cylinder or the difference between the compressions of individual cylinders, but may not accurately show a similar partial loss of compression on all the cylinders of an engine.

(b) An alternative method, which will give a more accurate result, is to fit a pressure gauge (reading up to 1400 kPa (200 lbf/in^2)) in place of one sparking plug in each cylinder in turn and note the reading as the piston passes through top dead centre (TDC) on the compression stroke.

3.4.2 Another method of carrying out a direct compression test is by use of a proprietary type of compression tester equipped with a means of recording cylinder pressures on a graph card. One set of plugs should be removed immediately after an engine run, and the compression tester fitted to each cylinder in turn while rotating the engine by means of the starter motor. The effectiveness of combustion chamber sealing can be judged by assessment of the graph records obtained.

3.4.3 A further method of checking engine compression is the differential pressure test. In this test a regulated air supply (normally 560 kPa (80 lbf/in^2)) is applied to each cylinder in turn and a pressure gauge used to record the actual air pressure in the cylinder. Since some leakage will normally occur, cylinder pressure will usually be less than supply pressure and the difference will be an indication of the condition of the piston rings and valves. By listening for escaping air at the carburettor intake, exhaust and crankcase breather, a defective component may be located. As with the previous tests, it is usually recommended that the differential pressure test is carried out as soon as possible after running the engine.

NOTE: The crankshaft should be restrained during this test as, if the piston is not exactly at the end of its stroke, the test air pressure may be sufficient to cause rotation.

4 POWER OUTPUT OF AEROPLANE ENGINES The power developed by an aeroplane engine after initial installation is established in the form of a reference engine speed, which is recorded in the appropriate log book so that comparisons can be made

during subsequent power checks. The reference engine speed is the observed engine speed obtained using specified power settings and operating conditions, corrected, by means of graphs supplied by the engine constructor (or those contained in Leaflets **EL/3-2** or **EL/3-8** as appropriate), to the figure which would be obtained at standard sea-level atmospheric temperature and pressure; changes in humidity do not produce large changes of power and are ignored for the purpose of establishing a reference engine speed or subsequently checking engine power. Power checks should be carried out using the same power settings and operating conditions as when the reference engine speed was established, and should be corrected in the same way.

4.1 **Power Checks.** The majority of light aeroplane piston engines are air-cooled and rely on an adequate flow of air for proper cooling of the cylinders. This condition can only be obtained during flight, and ground runs should, therefore, be as brief as possible. Cooling can be assisted by facing the aircraft into wind, but high wind conditions must be avoided when making power checks, as they will seriously affect the results obtained. Before running the engine at high power the normal operating temperatures should be obtained (not the minimum temperatures specified for operation) and during the test careful watch should be kept on oil and cylinder temperatures to prevent the appropriate limitations being exceeded.

4.1.1 Normally-aspirated engines are tested at full throttle and, where a controllable-pitch propeller is fitted, with maximum fine pitch selected. The changes in barometric pressure affecting engine power are considered to be balanced by changes in propeller load, so that only a temperature correction is necessary. This correction factor may be obtained from a graph supplied by the engine constructor or, if this is not available, from the graph shown in Figure 1 of Leaflet **EL/3-8**. The observed full throttle speed multiplied by the correction factor will give the corrected speed.

4.1.2 Although normally-aspirated engines are often fitted with variable-pitch propellers, the engine speed obtained at full throttle is usually less than the governed speed and the propeller remains in fully fine pitch. With supercharged engines, however, the propeller is usually constant speeding at high power settings and small changes in power will not affect engine speed. The power of a supercharged engine is, therefore, checked by establishing a reference speed at prescribed power settings.

(a) Since a supercharged engine is run at a specified manifold pressure regardless of the atmospheric pressure, corrections must be made for both temperature and pressure variations from the standard atmosphere.

(b) The procedure is to run the engine until normal operating temperatures are obtained, open up to maximum take-off manifold pressure, decrease power until a fall in engine speed occurs (denoting that the propeller blades are on their fine pitch stops), then throttle back to the manifold pressure prescribed by the constructor and observe the engine speed obtained.

(c) The correction factor to be applied to the observed engine speed of a supercharged engine may be obtained from graphs supplied by the engine constructor or, if these are not available, from the graphs shown in Figures 2 and 3 of Leaflet **EL/3-2**.

4.1.3 Although the engine speed obtained during a check of engine power is corrected as necessary for atmospheric temperature and pressure, no correction is made for humidity, ambient wind conditions or instrument errors and, consequently, the corrected engine speed is seldom exactly equal to the reference speed even if engine condition is unchanged. However, engine power may usually be considered satisfactory if the corrected speed obtained during a power check is within 3% of the reference speed.

4.1.4 If it is not possible to assess power deterioration by means of a power check (e.g. due to fitting a different propeller), a rate-of-climb flight test should be carried out.

5 POWER OUTPUT OF HELICOPTER ENGINES The power developed by the engine of a single-engined helicopter is considered to be adequately checked during normal operations; any loss of power should be readily apparent. It is thus not considered necessary separately to check the power output of a helicopter engine specifically for the purpose of complying with Airworthiness Notice No. 35.

6 POWER LOSS If the power check (paragraph 4) or normal engine operation reveal an unacceptable loss of power or rough running, it may be possible to rectify this by carrying out certain of the normal servicing operations or by replacement of components or equipment. The replacement of sparking plugs, resetting of tappets or magneto contact breaker points, or other adjustments to the ignition or carburation systems, are all operations which may result in smoother running and improve engine power.

7 SERVICING If the engine proves to be suitable for further service, then a number of servicing operations will normally be due, in accordance with the approved Maintenance Schedule. Unless carried out previously (paragraph 6) these operations should be completed before the engine is returned to service.

8 LOG BOOK ENTRIES A record of the checks made, and any rectification or servicing work, must be entered and certified in the engine log book before the engine is cleared to service for its recommended or extended life under the provisions of Airworthiness Notice No. 35.

EL/5-1

Issue 4.

December, 1979.

AIRCRAFT

ENGINES

SPARKING PLUGS

1 INTRODUCTION This Leaflet gives guidance on the installation and maintenance of sparking plugs, and should be read in conjunction with the appropriate manufacturer's manuals.

2 GENERAL Sparking plugs are manufactured in a wide variety of shapes and sizes, each type being designed for use in a particular engine or range of engines, according to the operating conditions likely to be encountered and the design of the cylinder head. A typical modern sparking plug is illustrated in Figure 1.

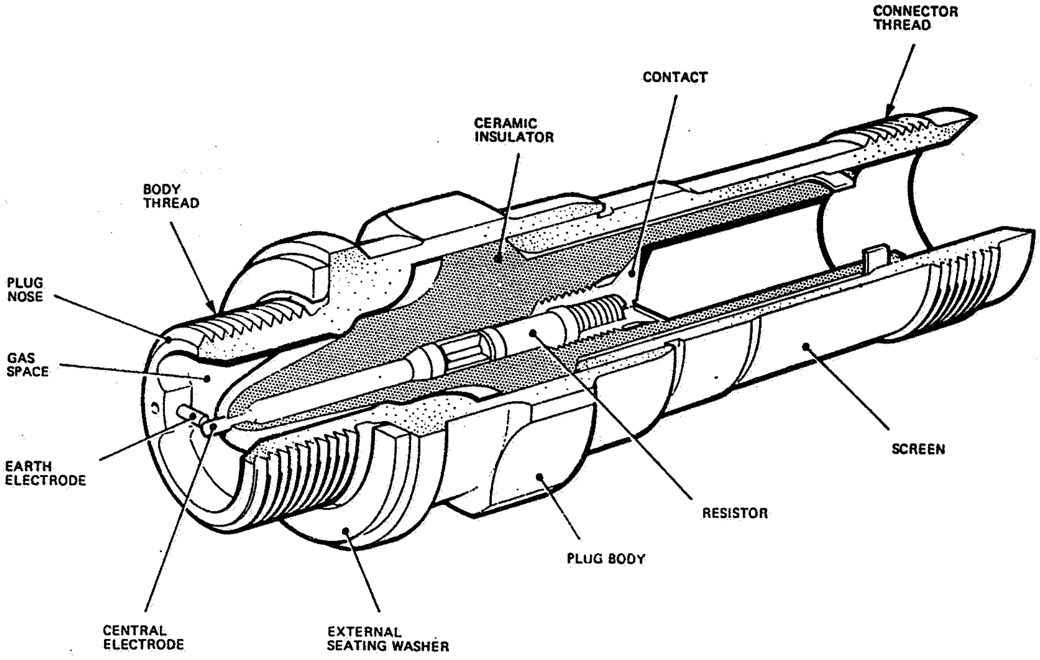


Figure 1 TYPICAL SPARKING PLUG

2.1 A sparking plug consists of a high tensile steel body which screws into the engine cylinder head, and a central electrode which is encased in a ceramic insulating material and secured inside the body. One or more earth electrodes protrude from the nose of the body towards the central electrode to form the spark gap, and the outer end of the central electrode terminates in a contact, which is connected to the magneto distributor via an ignition cable. A resistor interposed between the contact and the central electrode helps to reduce electrode erosion and electrical interference by eliminating current 'spikes' generated by the ignition system.

2.2 The earliest types of sparking plugs were often designed to be dismantled for cleaning and, because no radio equipment was fitted to aircraft, no electrical screening was provided. Later sparking plugs were fitted with suppression screens (as was the complete ignition system) and could still be dismantled for cleaning. The latest types of sparking plugs often have the screen tube brazed to the body and cannot be dismantled.

2.3 The screens on early sparking plugs were insulated with mica, but modern plugs generally incorporate a ceramic sleeve insulator which may be integral with or separate from the electrode insulator.

2.4 The ignition cable is secured to the sparking plug by means of a cable connector, and electrical contact with the central electrode is obtained through a spring attached to the end of the cable core (see Leaflet **EL/5-2**).

2.5 The types of sparking plugs approved for use in a particular engine are specified in the relevant manuals, and no other types should be used; for identification purposes the type number is always marked on a plug body. It is preferable for all plugs in an engine set to be of the same type and make.

3 FITTING SPARKING PLUGS

3.1 **Checks Prior to Fitting Sparking Plugs.** Before fitting new sparking plugs in an engine, all traces of inhibitor should be removed by swilling the nose of the plug in a solvent such as trichloroethane, and wiping the screen insulation with a soft lint-free cloth moistened in solvent. The plugs should then be thoroughly dried and the spark gap should be checked (see paragraph 9).

3.1.1 The correct type of external seating washers should be fitted to the plugs. Some washers are of the disposable type and should not be used more than once, but others, usually made of solid copper, can be re-used provided their condition is satisfactory.

3.1.2 Graphite grease, or the anti-seize compound specified, should be applied to the body threads sparingly, care being taken to ensure that the grease does not come into contact with the electrodes and does not contaminate the surfaces of the seating washers.

3.1.3 Just prior to actually fitting the plugs, a check should be made to ensure that the plug insert thread in the cylinder head is clean.

3.2 **Fitting Sparking Plugs.** It should be possible to screw the plug by hand into the cylinder head until the seating washer contacts the cylinder. If this cannot be done, it will probably be found that the plug insert thread is fouled with carbon or lead deposits, which should be removed by means of a thread cleaning compound of a type recommended by the plug manufacturer.

3.2.1 It is important that plugs should be tightened to the specified torque loading, using the correct spanner and torque wrench. They should not normally be fitted to a hot engine since the torque loading will alter when the engine cools. Over-tightening may tend to loosen or damage the plug inserts in the cylinder head, and under-tightening may result in loose plugs. In exceptional circumstances (e.g. when a plug has to be changed 'in the field' and a torque wrench is not available), a plug may be fitted without the use of a torque wrench provided that a suitable socket or box spanner is used and the length of the lever arm does not exceed the figures shown in Table 1.

TABLE 1

Plug size	Lever arm
12 mm	150 mm (6 in)
14 mm	200 mm (8 in)
18 mm	250 mm (10 in)

NOTE: It is important that side-loads should not be imposed on the outer end of a plug when it is being tightened, since the cable connector threads on a screened plug could be damaged or, in the case of an unscreened plug, the insulator could be damaged and render the plug unserviceable.

3.2.2 The cable connectors should be cleaned with a quick-evaporating cleaner such as white spirit before they are fitted to the plugs, and the threads of the connector nuts should be checked for condition. The presence of oil, dirt or moisture inside the screens could cause a breakdown int he insulation and affect operation of the plugs.

3.2.3 When fitting connector nuts to plug screens, care must be taken to ensure that the screen insulation is not damaged (particularly where mica insulation is used), and that the terminal seats correctly in the plug body. Connector nuts are often easily cross-threaded on plug screens and the connector should be pressed into the plug with one hand while tightening the nut with the other hand; the appropriate spanner should only be used for final tightening. Care should be taken not to overtighten connector nuts, as this may crack the insulation inside the plug screen or create distortion sufficient to affect the performance of the plug.

4 GROUND CHECK ON INSTALLED PLUGS The operation of installed sparking plugs should be checked by running the engine. The engine should be started and warmed up to the minimum operating temperatures before carrying out the check, and all relevant procedures and precautions detailed in the aircraft Maintenance Manual should be observed.

4.1 While warming up the engine each magneto should be switched off in turn to check that a drop in rpm is obtained while running on one magneto, and both magnetos should be momentarily switched off together to check that a dead cut is obtained. This will ensure that both magnetos are operating and can be earthed, and that the switch/switches is/are operating satisfactorily.

4.2 The plugs of inverted cylinders may sometimes cut out when the engine is first started. This may be caused by oil contamination, which will often clear as engine power is increased. However, it is important that the engine power should not be increased beyond that specified for warming-up until minimum operating temperatures are reached.

4.3 When the required temperatures are indicated, the engine should be opened up to the power specified for the magneto check. On normally-aspirated engines this will usually be at full throttle or at a specified rpm (with the propeller in fine pitch if appropriate), but with supercharged engines it will first be necessary to ensure that the propeller is on its fine pitch stops (if a propeller is constant-speeding the drop in power caused by switching one magneto off will be counteracted by the pitch-change mechanism and no rpm drop will be indicated), which is done by opening the throttle to a high power setting, then gradually closing the throttle until a drop in rpm is observed; the power can then be reduced to the setting specified for the magneto check.

4.4 A magneto check is carried out by switching off each magneto in turn and noting the differences between the rpm obtained when operating on both magnetos and those obtained when operating on each magneto separately. The maximum permissible drop in rpm, or the maximum permissible difference between the rpm obtained when operating on each magneto separately, are specified by the manufacturer. If the results of the check are outside these limits it will be necessary to investigate the cause.

4.5 If the magneto drop is excessive and cannot be cleared by further engine running the cause may be a plug which is not firing. If this is the case the magneto drop may also be accompanied by vibration when the 'good' plug is switched off. The faulty set of plugs should be removed and examined for oiling or damage.

4.6 With the majority of engines, rough-running will occur if both plugs in one cylinder are inoperative, although this may not be readily apparent with engines having a large number of cylinders. If rough-running is still apparent after an engine has warmed up, it should be shut down and the plugs removed for inspection; the engine should not be operated at high power.

5 FAULTS WITH AND FAULTS INDICATED BY SPARKING PLUGS A large proportion of engine faults originate in the combustion chambers and careful evaluation of the condition of sparking plugs removed from an engine will often provide an indication of a potentially serious fault. Faults which may be discovered as a result of the examination of sparking plugs are described in paragraphs 5.1 to 5.12.

5.1 **Plug Fouling.** The most common causes of malfunctioning of a plug are the accumulation of electrically conducting matter on the plug electrodes and insulation, and excessive electrode erosion (paragraph 5.12). Although some types of sparking plugs require frequent servicing to prevent these faults, others are so designed that they can be left installed for the overhaul life of the engine, and do not normally suffer from these defects.

5.2 **Loose Plugs.** If a sparking plug which was properly torque-loaded during installation is subsequently found to be loose, this may be an indication that pre-ignition (paragraph 5.3) or detonation (paragraph 5.4) has occurred and has resulted in excessively high pressures and temperatures in the cylinder.

5.2.1 A loose plug will not cool properly during operation and may overheat to such an extent that the ceramic insulation at the nose will become hot enough to ignite the mixture and cause pre-ignition.

5.2.2 When a loose plug is found, an examination should be made for damage to the piston and the exhaust valves. A compression check should be carried out and the cylinder head should be checked for evidence of distortion.

5.2.3 Both plugs in the affected cylinder should be checked for damage and for fusing or melting of the electrodes.

5.3 **Pre-ignition.** Pre-ignition is caused by the cylinder charge being ignited before the spark occurs at the plug points. It is caused by a hot spot in the cylinder, which may or may not be related to the plug (e.g. an abnormal deposit, burned valve, failed piston, or failure of the sparking plug nose ceramic). After pre-ignition has occurred the checks outlined in paragraphs 5.2.2 and 5.2.3 should be carried out.

5.4 **Detonation.** Detonation is caused by the spontaneous ignition of part of the mixture, due to an abnormally high pressure being created ahead of the advancing flame front. In contrast to normal progressive burning, it takes the form of an explosion and may result in excessive loads being applied to components. After detonation has occurred, checks as outlined in paragraphs 5.2.2 and 5.2.3 should be carried out.

5.5 **Mechanical Damage or Peening.** Mechanically damaged or peened electrodes indicate loose particles (e.g. small pieces of metal such as parts of broken piston-rings, etc.) moving around inside the cylinder. Such damage is not always readily apparent and the plugs may only appear to be badly oiled (paragraph 5.6). It is recommended that every badly oiled plug should be inspected carefully for evidence of electrode damage and, where doubt exists, the plugs should be washed and re-inspected.

5.6 **Oil Fouling.** A black oily deposit on the electrodes of a sparking plug may result from several causes. When only one plug in a cylinder is affected, it is usually the result of accumulated matter conducting the electrical impulse to earth and preventing the plug from firing. Oil fouling may also be caused by oil draining into the lower cylinders of an inverted or radial engine (paragraph 4.2), and could affect both plugs in a cylinder. When both plugs are contaminated by oil and this is found not to result from oil drainage, some sort of mechanical failure in the cylinder or a fault in the ignition system should be suspected, and an inspection should be carried out accordingly.

5.7 **Rich Mixture.** A soft furry black deposit on the electrodes often indicates an excessively rich mixture but may also be due to the engine idling for excessively long periods.

5.8 **Lead Deposit.** Lead deposit has the appearance of hard grey or brown globules, or a dark glaze on the insulator, and may build up in the gas space in the body. When the engine is running at high speed under load, with resultant high cylinder temperatures, the deposit tends to form a conductor which cuts out the plug. Plugs which have become severely lead-fouled may be difficult to clean and should be returned to the manufacturer for rectification.

5.9 **Flashover.** Foreign matter or moisture in the plug screen or connector, can reduce the insulation value between the central electrode and earth to such an extent that ignition voltages at high power settings may flash over the plug screen surface to earth and cause the plug to misfire; an excessively large spark gap will increase the possibility of this fault. Flashover is often difficult to detect visually, and the plug may have the appearance of oil fouling.

5.10 **Tracking.** Tracking can be caused by an electrically conducting deposit forming on an insulator, and may result from a hair-line crack. As with flashover, the defect may sometimes be confused with oil fouling.

5.11 **Sprayed Metal Deposits.** Sprayed metal deposits on the nose of a sparking plug can result from a number of causes and a thorough inspection of the combustion chamber should be made to determine the cause. If the deposit is confined to one cylinder it may be caused by a partially seized piston, but if all sparking plugs in an engine are contaminated the cause may be, for example, the supercharger impeller rubbing on its casing. It should be noted that incipient failures often release very small amounts of metal, and the plugs may have the appearance of being badly oil fouled.

5.12 **Weak Mixture or Advanced Ignition.** Premature erosion of electrodes and/or a white appearance of the insulator tips can be caused by either an excessively weak mixture or excessively advanced ignition. The timing and compression should be checked, as should the functioning of the carburettor or fuel injector.

6 REMOVAL OF SPARKING PLUGS Care is necessary when removing sparking plugs from an engine, to prevent damage to the plugs, cables and connectors.

6.1 The connector nut should be removed using the correct spanner and holding the elbow or other type of cable connector to prevent it from twisting. The connector should be withdrawn straight out of the plug screen, care being taken not to damage the screen insulation, particularly when this is made of mica.

6.2 Plugs may often be difficult to remove from the cylinder, and may require a greater torque for removal than for installation. This is usually caused by carbon which has formed on the end of the plug thread where it protrudes slightly into the combustion chamber.

6.2.1 Extreme care must be exercised when removing plugs which require more than the normal torque for their removal. A double-arm sparking plug spanner should be used to permit the use of both hands, thereby providing an even torque during turning; the liberal use of penetrating oil will also assist. Single-arm spanners should not be used, since it is difficult to avoid placing side loads on the plug threads and thus making removal more difficult; in extreme cases the plug threads could fracture, making a cylinder change necessary.

6.3 If new plugs are not to be fitted immediately, dummy plugs should be installed to prevent the ingress of foreign matter, and the ignition cables should be secured to adjacent structure to prevent damage to the connectors.

7 SERVICING OF SPARKING PLUGS Sparking plugs should be serviced strictly in accordance with the manufacturer's instructions, at the intervals specified in the Maintenance Schedule and whenever they are removed because of unsatisfactory operation. Older types of plugs are serviced at frequent intervals (usually every 100 hours of operation) but some modern plugs are designed with servicing periods equal to the engine life and need not be removed between engine overhauls provided their operation is satisfactory. The method of servicing will depend to a certain extent on whether the plug is 'detachable' (i.e. has a separate screen which is screwed into the plug body) or non-detachable (i.e. cannot be dismantled), but it should be noted that some detachable plugs are assembled

in a hot condition during manufacture to ensure a gas-tight seal, and are not considered detachable for servicing purposes.

NOTE: There are still a number of plugs with mica insulating material in service and these may be subject to attack from the lead which is present in aviation fuels. It is recommended that the insulation at the nose of these plugs should be inspected for deterioration at intervals of not more than 50 hours of operation.

7.1 **Inspection Before Servicing.** Before a plug is cleaned and tested, it should be inspected for obvious damage such as distortion, serious corrosion, chipped ceramic, cracks, and loose or fused electrodes. If any of these defects are present the plug should be discarded. Provided a plug has no obvious faults it should be serviced as outlined in paragraphs 7.2 or 7.3 as appropriate.

7.2 Non-detachable Plugs

7.2.1 **Degreasing.** Plugs should be degreased in a solvent such as trichloroethane, by the liquid or vapour methods but should not be completely immersed in the solvent. They should then be dried with a low-pressure dry air jet.

7.2.2 **Cleaning.** The nose of a non-detachable plug may be cleaned by sand blasting, by chemical cleaning or by vibratory cleaning. The method used will generally depend on the plug manufacturer's recommendations and on the equipment available. Cleaning should be carried out strictly in accordance with the relevant Maintenance or Overhaul Manual.

(a) **Sand Blasting.** Carbon and lead deposits can usually be removed by light sand blasting, but extreme care should be exercised to prevent 'scalloping' of the insulator and damaging of the electrodes. It is normally recommended that sand blasting should be limited to periods of not more than 5 seconds and that the plug should be rocked in a circular motion while blasting is in progress.

(b) **Chemical Cleaning.** Specially designed chemical cleaning equipment may be used when recommended, but, because the chemicals are corrosive, care must be taken to ensure that all traces are washed off after cleaning. The cleaning times and temperatures recommended for the process should be strictly adhered to, and only the specified chemicals should be used. Any stubborn deposits which remain after cleaning may be removed by light sand blasting as in (a).

(c) **Vibratory Cleaning.** A vibratory cleaner is illustrated in Figure 2, and employs a vibrating cutter blade which is entered into the nose of the plug to remove deposits. Only light pressure should be applied to the plug and care should be taken to avoid contact with the electrodes. Frequent checks on the condition of the plug should be made during cleaning, and any stubborn deposits should be removed by light sand blasting as in (a).

NOTE: After cleaning, all deposits should be removed with a low-pressure dry air jet, and the gas space should be inspected with the aid of a lens to ensure that no particles of sand, carbon or lead remain.

7.2.3 The outside of the plug body and threads should be cleaned with a fine steel wire hand-brush, care being taken not to brush the electrodes or insulator, and all loose material should be removed with a low-pressure dry air jet.

7.2.4 The inside of the plug screen should be cleaned by wiping with a lint-free cloth moistened in a quick-evaporating solvent such as white spirit. Particular care is necessary with mica insulation, and this should not be submerged in solvent or subjected to an air blast.

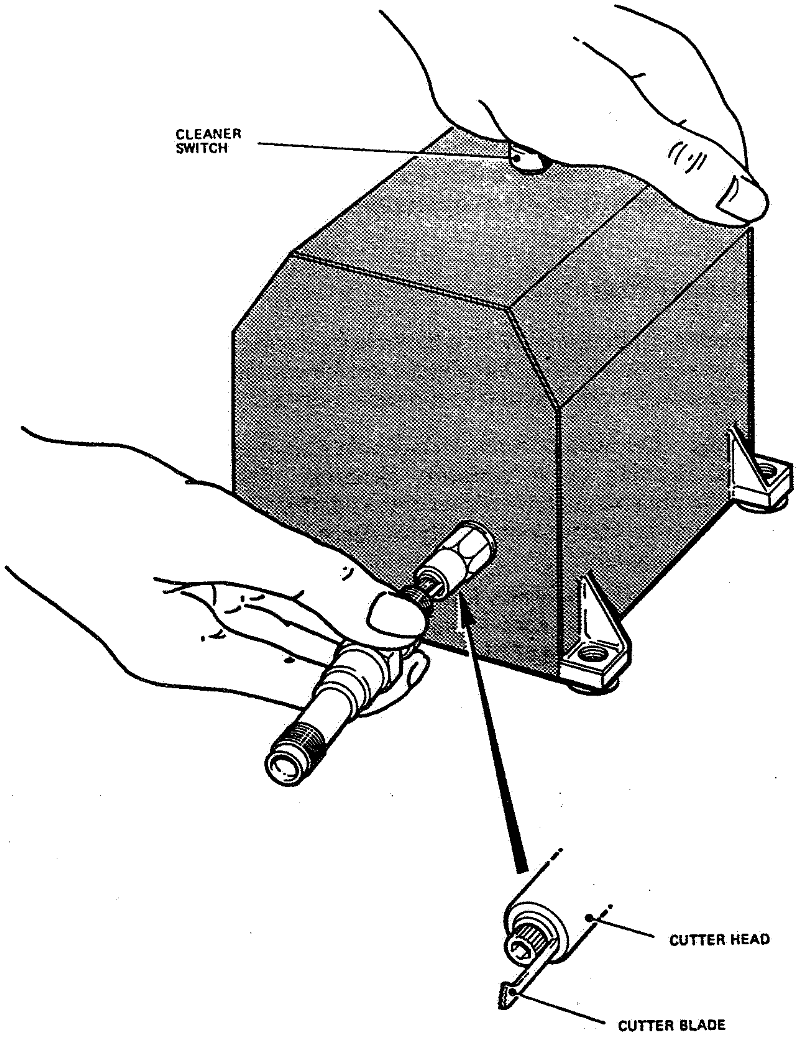


Figure 2 VIBRATORY CLEANER

7.3 Detachable Plugs

7.3.1 **Dismantling.** Detachable plugs should be dismantled using a ring type dismantling block and the appropriate ring spanner; they should not be held in a vice, as this could distort the plug body. If the threads are very tight, a penetrating oil should be applied and left to soak into the threads.

7.3.2 **Degreasing.** The plug body, screen, and centre assembly should be degreased as outlined in paragraph 7.2.1.

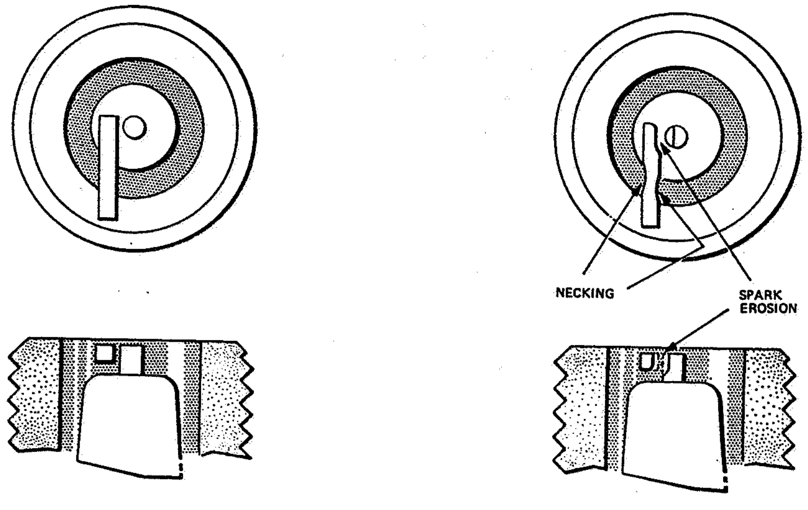
7.3.3 **Cleaning.** The outside of the plug body and screen should be cleaned with a fine steel wire hand-brush, and the plug body should be cleaned internally by light sandblasting. Care must be taken during these operations to avoid damaging the electrodes, joint seating and threads.

7.3.4 The centre assembly and screen ceramic material should be cleaned with a lint-free cloth moistened in trichloroethane or white spirit. Any hard deposits on the nose ceramic may be removed by light sandblasting, but abrasives should not be used on the other ceramic material, as oil or dirt could adhere to the abraided surface and cause tracking (paragraph 5.10).

7.3.5 After cleaning, all parts should again be degreased and, except for mica screen insulation (which should be dried with a soft cloth), dried with a low-pressure dry air jet.

7.3.6 **Inspection.** After drying, the separate parts of the plug should be inspected as outlined in paragraph 8.

7.3.7 **Reassembly.** The seating faces of the plug body and centre assembly should be wiped clean and lightly smeared with oil; new sealing washers should be fitted. When fitting the centre assembly, the screen tube should be tightened lightly by hand and the centre assembly should be centrally located in the plug body. The screen should then be tightened to the specified torque, while holding the body in a dismantling block.



(A) NEW PLUG

(B) ERODED PLUG

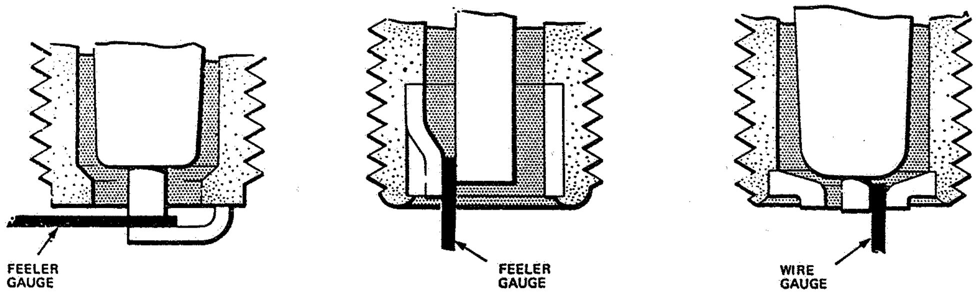
Figure 3 ELECTRODE EROSION

8 INSPECTION After cleaning, all plugs should be inspected as outlined in paragraphs 8.1 and 8.2.

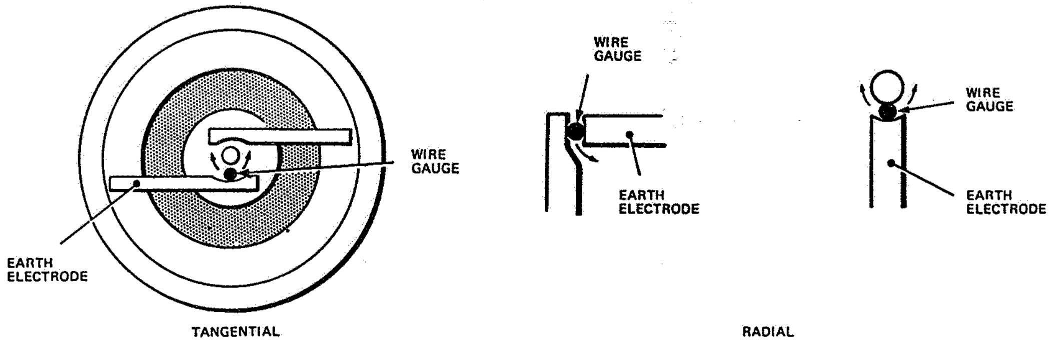
8.1 **General Inspection.** All parts of a plug should be examined visually for cleanliness and for significant distortion, cracks, scores, dents, corrosion, damaged threads and worn or pitted plug washer seatings. Further cleaning may be carried out as necessary, but plugs which are found to have any of the other faults should be discarded.

8.2 **Electrode Inspection.** Electrodes should be examined for security and erosion (see Figure 3). Any plugs with loose electrodes, or with erosion exceeding the limits outlined in 8.2.1 and 8.2.2 should be discarded.

8.2.1 Using a new plug for comparison, the extent of erosion of the electrodes should be estimated. Unless otherwise specified in the relevant Manual, erosion at the sparking point which reduces the cross-sectional area of the electrodes by less than 50%, or which reduces the cross-sectional area of the earth electrode by 'necking' by less than 33%, is acceptable.



(A) NEW PLUGS



(B) ERODED PLUGS

Figure 4 CHECKING THE SPARK GAP

8.2.2 On plugs which have a radial earth electrode, erosion will have the effect of increasing the spark gap. If the spark gap is found to exceed the maximum permitted setting, the plug should be discarded.

9 SPARK GAP SETTING Before testing plugs after servicing, and before fitting new plugs to an engine, the spark gaps should be checked and, except for plugs having radial electrodes (see paragraph 9.3), should be adjusted to the gap specified in the appropriate engine Maintenance Manual.

9.1 A standard feeler gauge may sometimes be used for checking new plugs (see Figure 4), but a wire-type gap gauge should always be used on plugs which have been serviced and new plugs on which the earth electrode has a concave surface.

9.2 Adjustment of the spark gap is achieved by bending the earth electrode (never the central electrode), and extreme care is necessary to prevent overstressing. Bending should be carried out in very small increments, using a suitable blunt tool and applying force only between the plug body and the earth electrode; no force should be applied to the central electrode. The gap should be checked after each bending operation to avoid the necessity for reverse bending; this is particularly important with iridium electrodes, which are comparatively brittle.

9.3 No adjustment is possible with plugs having a single radial earth electrode, and if the spark gap exceeds the maximum permitted value the plug must be discarded.

10 TESTING After a plug has been serviced, it should be tested in accordance with the manufacturer's insructions. A bench test cannot exactly reproduce conditions in the combustion chamber of an engine, and because of the many variables affecting the voltage/spark gap/air pressure relationship, the results of a test using a specified voltage and air pressure may bear little relationship to the performance of a plug installed in an engine. A bench test can, however, establish that the plug insulation is satisfactory and that all electrically conductive deposits have been removed during servicing. The spark test described in paragraph 10.1 is recommended by most manufacturers and the additional test as described in paragraph 10.2 may also be required.

10.1 **Spark Test.** This test should be carried out using ignition equipment specially designed for the purpose. Two main types of equipment are available, one providing a fixed voltage which is somewhat higher than the maximum voltage obtainable from an engine magneto, and the other fitted with a standard spark gap in parallel with the plug under test, which can be used to vary the voltage applied across the plug electrodes. A typical sparking plug tester of the former type is shown in Figure 5.

10.1.1 A test using the tester illustrated in Figure 5 should be carried out as follows:—

(a) Connect the tester to an electrical supply of the required voltage, and connect the bench air supply to the tester.

(b) Screw the sparking plug into the tester to finger tightness.

NOTE: Some air leakage is desirable as it allows ionised air to exhaust from the chamber and also helps to stabilise the air pressure.

(c) Connect the high voltage lead to the sparking plug.

(d) Press the test button for a few seconds and check that regular sparking occurs at the plug electrodes. If not, discard the plug.

(e) Open the air valve until the required test pressure is indicated on the tester pressure gauge.

NOTE: Although an air pressure of 550 kN/m² (80 lbf/in²) is generally considered to be satisfactory for most plugs, some manufacturers may stipulate a test air pressure which is related to the spark gap setting of the plug.

(f) Press the test button for a few seconds and check that regular sparking occurs at the plug electrodes. If not, discard the plug.

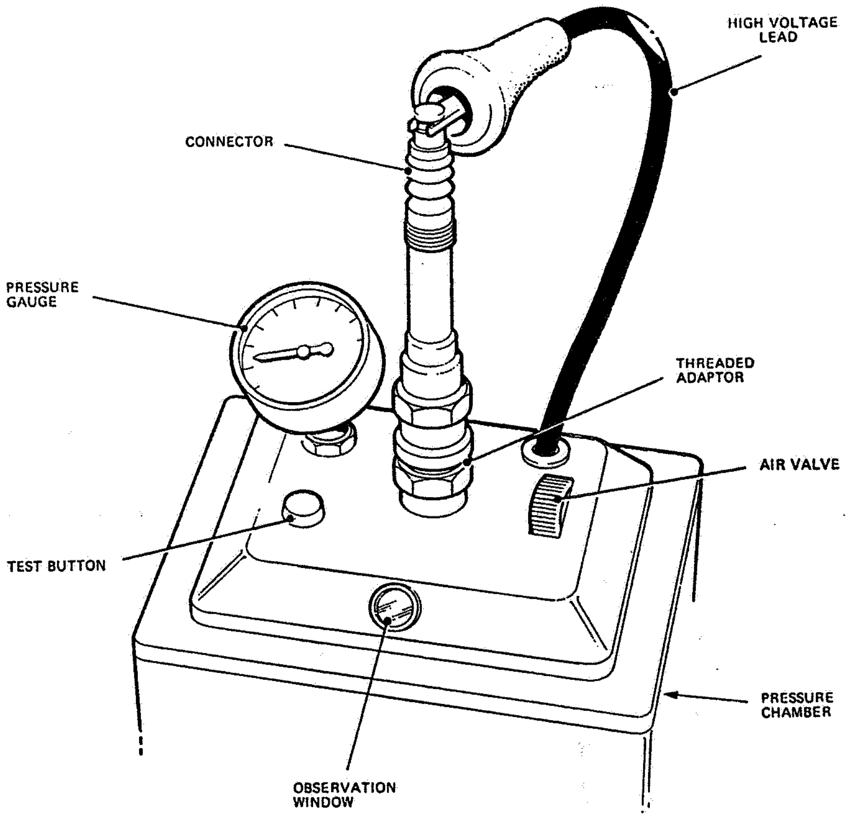


Figure 5 SPARKING PLUG TESTER

10.1.2 If a tester which is fitted with a standard spark gap is used, the gap should be set in accordance with the manufacturer's instructions before a test is carried out. During the test, sparking should occur only at the electrodes of the plug under test; if sparking at the standard spark gap occurs, an open circuit in the plug is indicated; if no sparking is evident a breakdown in plug insulation or a short circuit is indicated.

10.1.3 To check for cracked plug insulation some manufacturers recommend that the plug should be tested in the inverted position and a little water (with a wetting agent added) should be injected into the plug nose. When air pressure is applied during test the water will be forced into any cracks present and the plug will be short-circuited.

10.2 **Leakage Test.** A test for gas leakage may sometimes be specified, to ensure that the seal of a detachable plug or the joint in a non-detachable plug is satisfactory. The plug under test should be screwed into a pressure chamber, and immersed in a container of white spirit so that the liquid covers the joint. Air pressure in the chamber should then be raised to approximately 700 kN/m^2 (100 lbf/in^2) and any leakage will be indicated by bubbles in the white spirit.

11 STORAGE Sparking plugs which have been cleaned and tested should be inhibited against corrosion by coating the nose with a suitable storage oil and fitting thread protectors to the plug body and screen.

11.1 If the plugs are not intended for long term storage, they should be placed in racks and kept in a warm, dry place, preferably a heated cupboard, as a precaution against condensation.

11.2 Plugs which are required for long term storage or transit, should be packaged as follows:—

(a) Select a polythene tube of sufficient size, and cut off lengths suitable for containing one plug. Heat seal one end.

(b) Place a plug in each tube, and also insert an identification label in such a way that the details are visible.

(c) Extract excess air from the tube and heat seal the open end.

(d) Pack the plugs in layers in a strong cardboard box, with corrugated board between each layer.

(e) Close the box and seal with adhesive tape.

(f) Affix an identification and a certified serviceable label to the box.

11.3 Plugs should be stored in conditions which are clean, dry, of even temperature, well ventilated, and free from corrosive fumes.