CHAPTER 2

PISTON ENGINE CONSTRUCTION

Objectives

1. This chapter has been written with the aim of helping you to satisfy objectives in the relevant Skills and Knowledge Specifications (SAKS) for the trade in this subject area. When you have studied this Chapter, you will be able to:

a. State the important points to be borne in mind when handling and fitting engine components.

b. Discuss the main assemblies of piston engines and their purpose, including the crankcase assembly, piston and cylinder assembly, the rear cover, reduction gear and the exhaust and induction systems.

c. Explain the precautions to be taken when servicing and fitting cylinder heads and explain why a piston must be at TDC on the compression stroke before removing the cylinder.

d. Explain how the performance of an engine can be affected by worn or distorted valves, sticking valves or weak or cracked valve springs.

e. Explain the effects that worn rocker assemblies, camshafts and push rods will have on engine performance.

f. State the importance of valve timing and explain the effects that maladjusted valve timing will have on engine performance.

g. State the safety precautions when working with exhaust and induction manifolds/systems.

Introduction

2. Although the high powered gas turbine engine reigns supreme in the Royal Air Force today, there is still a place for certain types of piston engines fitted in some of our smaller, slow speed aircraft. The greatest problem in research and design of the piston engine has always been to obtain the greatest power for the minimum weight. Remember that the bigger and more powerful we try to make a piston engine the heavier it becomes, and it follows that more horse power is absorbed by the additional weight. Apart from the safety of the aircrew, which is of primary importance, it can be stated that weight and fuel economy are both vital factors in design. To this end we could say that research and development of the piston engine have been second to none over the past 30 to 40 years.

3. Although the basic principles of operation are the same for all piston engines, the construction varies from one engine to another. However, the general layout of the main assemblies, whether the engine is an in-line engine or a radial engine, is the same. The in-line engine is one where the cylinders are disposed one behind the other along the crankcase; they can be in rows of single cylinder construction or can be in blocks of cylinders, and they can be air cooled or liquid cooled. The radial engine is one where the cylinders are disposed radially around the periphery of a circular type of crankcase, and this type of engine is always air cooled. Engines can be normally aspirated or can be supercharged. Piston engines can be metered with fuel through a float type carburettor or an injector type carburettor. However, we will be discussing the fuel system in a later chapter.

General Points

4. Before discussing the main assemblies which go to make up a piston engine, the following important points should always be remembered:

a. The correct location of casings when they are assembled is ensured by spigots, dowels or tight fitting bolts. Each shaft is generally located at one point along its length by a thrust bearing. Adequate allowance is made for the expansion of components that will arise with changes in running temperatures.

b. Most parts carry identification markings to ensure their correct positional assembly and care must be taken to assemble mating parts correctly. Provision is made on the crankcase for mounting the engine in an airframe or engine stand, and points are provided for sling attachments.

c. Never attempt to lift heavy or awkwardly shaped components to engage to the engine when slinging attachments are provided.

d. Only use suitable special tools, extractors and jigs, thereby avoiding damage to components, and never use unnecessary force to separate components. You will find in many cases that the application of hot oil will expand the part and make dismantling much easier.

e. When dismantling units, cultivate the habit of visually examining parts for damage as they are removed. You may require a new part and this will give your Supply Section a better opportunity of supplying the spares you need on time.

f. Place parts on a rack or bench so that they will neither roll off nor get distorted by their own weight, and always use jigs or containers provided.

g. Check the position of assembly marks and numbers, and keep all the parts of one unit together. Discard all locking devices which you know can be used only once.

h. When cleaning components, do not use abrasive or sharp tools on mechanical surfaces. All foreign material, such as parts of jointing or carbon, can be removed with a scraper made of softer material than the actual component. Do not use fluffy cloth or cotton waste to dry washed components.

j. During assembly, lubricate working parts freely with engine oil. Assemble mating parts to the same position they occupied before being dismantled and, when you fit ball or roller races, make sure that the part numbers can be read with the races in position.

k. Do not use excessive force to drive a tight component home—if the type of fit is supposed to be a push fit, then make sure it is not a drive or interference fit. After fitting a component, check that there is freedom of rotation and designed movement. When building up an assembly, this should be done step by step. A good point to remember always is that where drive shafts and gears are involved, there must be end float and backlash.

l. Remember the term 'sequence of operations'—this is vital, particularly when tightening and removing holding down bolts and nuts. If you remove a cylinder, remember that the piston must be at TDC on the compression stroke. You will recall that during this stroke the loading will be off the valve gear, pushrods, rocker arms, *etc.* When tightening down cylinder head bolts, or cylinder blocks (or for that matter any series of highly stressed components), remember that distortion will occur if the proper sequence is not used. This sequence can be found in the Volume 1 or Volume 6 of the engine Air Publication. The same applies when *removing* the holding down bolts or nuts. Full tightening of holding down bolts and nuts on the cylinders or blocks is carried out with a torque loading spanner.

5. We shall now discuss the main assemblies of any piston engine in service today. They are as follows:

a. Crankcase assembly, which houses the crankshaft and connecting rods.

b. Piston assembly.

c. Cylinder assembly and valve gear, mounted on or around the crankcase.

d. Rear cover, which houses the gears and drives for the oil pumps, magnetos, fuel pumps, *etc.* (The carburettor or the fuel injector, whichever is fitted—is also usually at the rear of the engine, but we shall discuss these components in Chapter 3.)

e. Propeller reduction gear assembly.

f. Supercharger assembly.

g. Exhaust systems.

h. Induction systems.

CRANKCASE ASSEMBLY

Crankcase

6. The crankcase forms the backbone of the engine and is made of light alloy for lightness and good heat conductivity. It may be a single casing or built up from two or more sections depending on the type of engine. The crankcase houses the main bearings for supporting the crankshaft and forms the support for the cylinders. It provides mounting faces for the supercharger, front casing, rear casing, sump, reduction gear, *etc* as required. The engine mountings are attached to the crankcase. The main bearings may be plain bearings or roller bearings, depending on the engine type—usually plain with in-line engines and roller bearings with radial engines.

Crankshaft

7. The purpose of the crankshaft is to receive the axial thrust of the pistons, and to convert this thrust to rotary movement through the connecting rod assembly. The crankshaft is normally

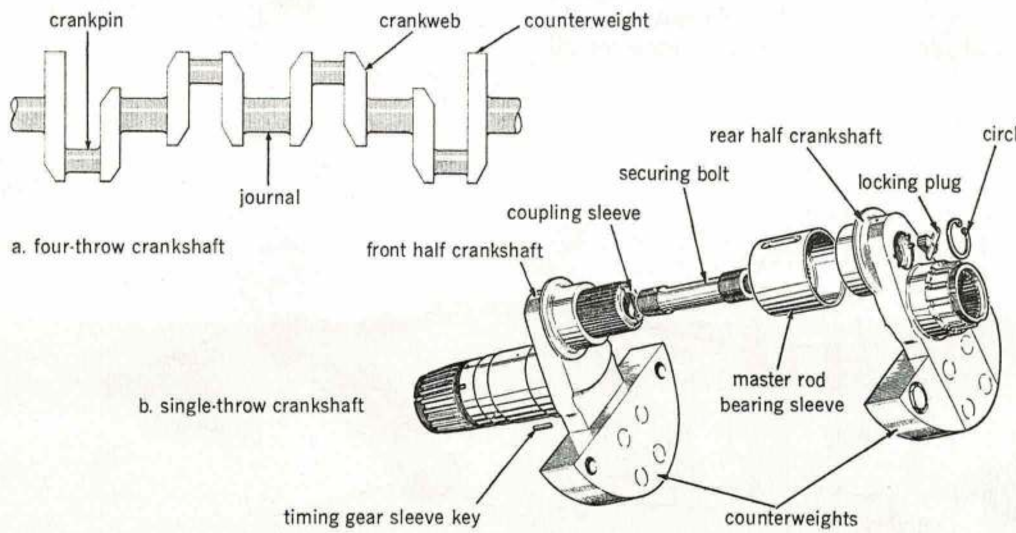
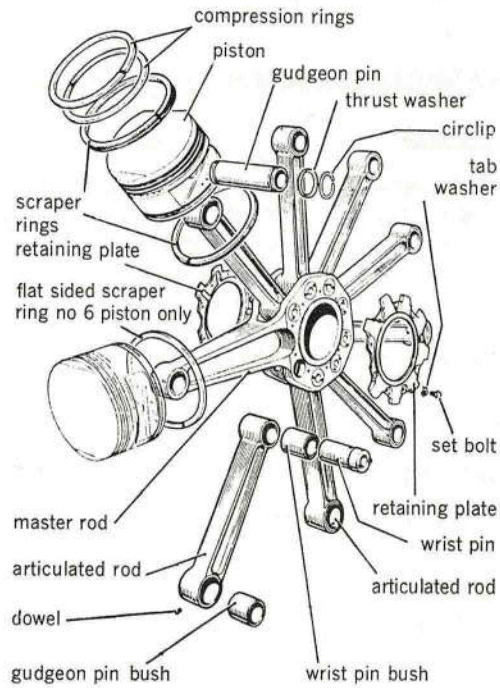


Fig 1.2.1 A single and a four throw crankshaft

machined from a nickel chromium steel forging. Crankshafts are classified according to the number of cranks. A shaft with one crankpin is called a 'single throw' crankshaft, and one with six cranks, a 'six throw' crankshaft. Examples of a single throw crankshaft and a four throw crankshaft are illustrated at Fig 1.2.1. Suitable drives at each end of the shaft transmit the torque to the propeller, sometimes through a reduction gear, and to the accessory drives, *eg* magnetos, oil pumps and fuel pump. To provide oilways, the crankshaft is hollow, which also makes the crankshaft lighter. A crankshaft is balanced by counter-weights fitted to the crank webs.

Connecting Rods

8. Connecting rods link the gudgeon pin to the crankpin and transmit the force on the piston to the crankshaft. They are usually made of H section alloy steel forgings, the girder section increasing their resistance to bending and compression loads. A connecting rod may be made in one piece where a built-up crankshaft is fitted, but it is more usual to have a big-end bearing with the 'cap' secured by bolts. The 'big-end' may be lined with white metal to form the bearing on the crankpin, with the 'small-end' of the rod lined with bronze to form the bearing for the gudgeon pin. Radial engines have one 'master' rod running on each crankpin, with 'articulated' rods attached to this master rod by 'wrist-pins' for the other cylinders in the row. The master rod takes the side thrust of the articulated rods and steadies the whole assembly. (The word 'articulate' means that the assembly is formed with joints—hence the term 'articulated rods'.) Examples of connecting rods for radial and in-line engines are shown at Fig 1.2.2. The big ends or main bearings are lubricated by high pressure oil



a. radial engine

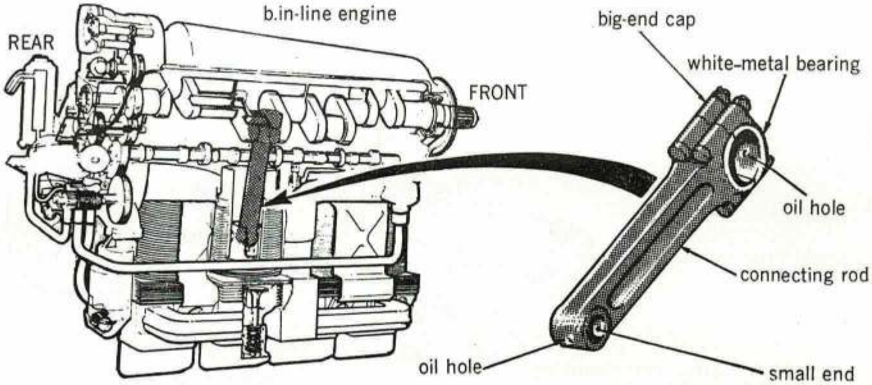


Fig 1.2.2 Connecting rod

through oil holes drilled in the crankshaft (crankpin); the small ends, also drilled, are lubricated by splash oil. Where big end caps are fitted, two oil holes drilled in each cap half-bearing shell and the bearing caps align with a hole in the crankpin. The oil under pressure, separates the bearing faces and escapes through drillings to lubricate the cylinder walls and the gudgeon pin.

Gudgeon Pin

9. This component is used to attach the piston to the connecting rod. It is usually hollow and made of case hardened steel. There are various methods of locating the pins, the most common being 'fully floating'. End movement is limited either by spring circlips in the piston bosses or on the gudgeon pin. Another method is to fit light alloy or bronze plugs in the gudgeon pin to prevent scoring of the cylinder bore.

PISTON ASSEMBLY

Piston

10. This component, when fitted with piston rings, forms a gas-tight plug to keep the charge in the cylinder (Fig 1.2.3). It also transmits the force of the burning charge to the connecting rod. Because it acts as a guide and bearing to the connecting rod small ends, it takes side thrust produced by the angular inclination of the connecting rod. Pistons are forged from light alloy to combine strength with lightness and good heat conductivity. Because light alloy has a high rate of expansion, piston clearances must be large when cold. As the head is hotter than the skirt, the pistons often taper to the crown, producing parallel sides at running temperatures. The piston bosses are bored horizontally to house the gudgeon pin; the exterior of the piston houses the piston rings. Transfer holes are drilled in the piston to allow oil to pass to the inside of the piston. On multi-cylinder engines the pistons are all of similar weight to maintain balance and avoid vibration. The weight of the piston is usually shown on the underside of the gudgeon pin boss. Apart from examining the piston for signs of scuffing, make sure that the oil holes are not blocked. An indication that excessive oil is leaking to the thrust faces of the piston, and wear in the piston generally, will be indicated by burnt carbon on the piston crowns and also by excessive oil consumption. Rough running of the engine is also an indication. A piston is illustrated at Fig 1.2.3.

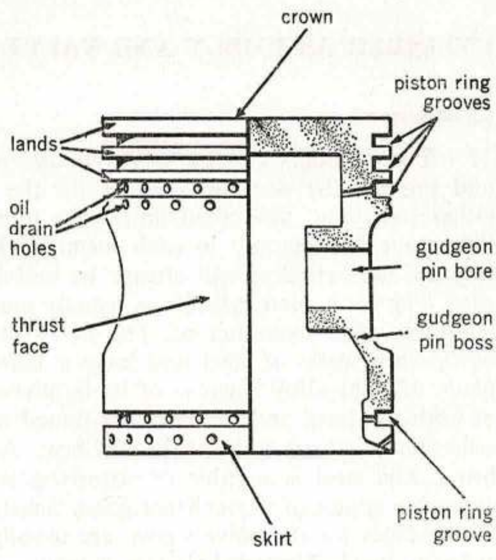


Fig 1.2.3 A piston

Piston Rings

11. Two types of piston ring are fitted to each piston; compression rings to maintain a gas seal between the piston and cylinder, and scraper rings to prevent an excessive amount of oil

from passing from the crankcase to the combustion chamber. The piston rings are made of cast iron; cast iron will retain its springiness at high temperatures and, with its low coefficient of linear expansion, a relatively small 'gap' is required (*see* Fig 1.2.4). The most commonly used gap is the scarf gap; the butt gap is usually used when the ring is 'pegged'—the peg preventing the ring from turning in its groove. The stepped gap is usually associated with oil control rings that assist in reducing oil consumption. It is usual to have a single acting scraper ring on the skirt of the piston to allow some oil to pass to the thrust face of the piston and to have a double acting ring above the gudgeon pin to give a final scraping action.

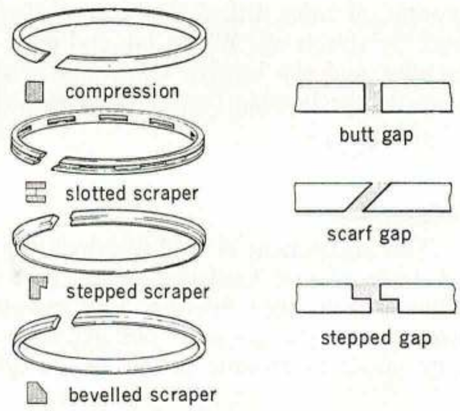


Fig 1.2.4 Piston rings

CYLINDER ASSEMBLY AND VALVE GEAR

Cylinders

12. The cylinders are the 'power house' of the engine. They form the combustion chambers and provide the working surfaces for the pistons. For in-line engines, the cylinders can be either individual air-cooled units or a number of liquid-cooled units positioned inside a block (like your car engine); in each instance they are arranged along the crankcase. For radial engines, the cylinders will always be individual air-cooled units arranged around the crankcase. The air-cooled cylinder is usually made in two sections but is generally considered as one-piece after manufacture. The two sections are known as the 'head' and the 'barrel'. The barrels are made of steel and have a hardened bore to resist wear. The heads are usually made of light alloy because of its lightness and good heat conductivity qualities. The outside of both the head and the barrel is finned to assist in heat dissipation (cooling). The fins are eccentric to ensure uniform loss of heat. As the alloy head is soft, alloy steel valve seats are fitted. The steel is capable of absorbing the hammering action of the valves and resisting the corrosive action of the exhaust gases through the exhaust valve. Valve guides, to form bearing surfaces for the valve stems, are usually made of cast iron or bronze, and are fitted in the cylinder head. Threaded inserts, known as adapters, are fitted to take sparking plugs. The cylinder head supports the valve rocker gear. At the lower end of the barrel a flange is formed to provide a seating on the crankcase (radial engine). A cylinder is illustrated at Fig 1.2.5.

13. When fitting an individual cylinder, remember that the piston must be at TDC. Similarly, when fitting a cylinder block, there will be a laid-down sequence for the best piston position. Make sure that all gaskets and seals are correctly positioned. Cleanliness is absolutely essential. Remember that a great deal of skill is required, particularly in knowing in which order the cylinder or cylinder head block holding-down bolts have to be tightened. There is a strict sequence of operations and these will be found in the appropriate engine Volume 1 or Volume 6 Air Publication. A torque loaded spanner must be used; if the correct sequence and the correct torque loading are not applied, distortion will occur.

14. After fitment of major components and particularly new cylinders, some lengthy periods of ground testing may be necessary, and an examination made for oil leaks.

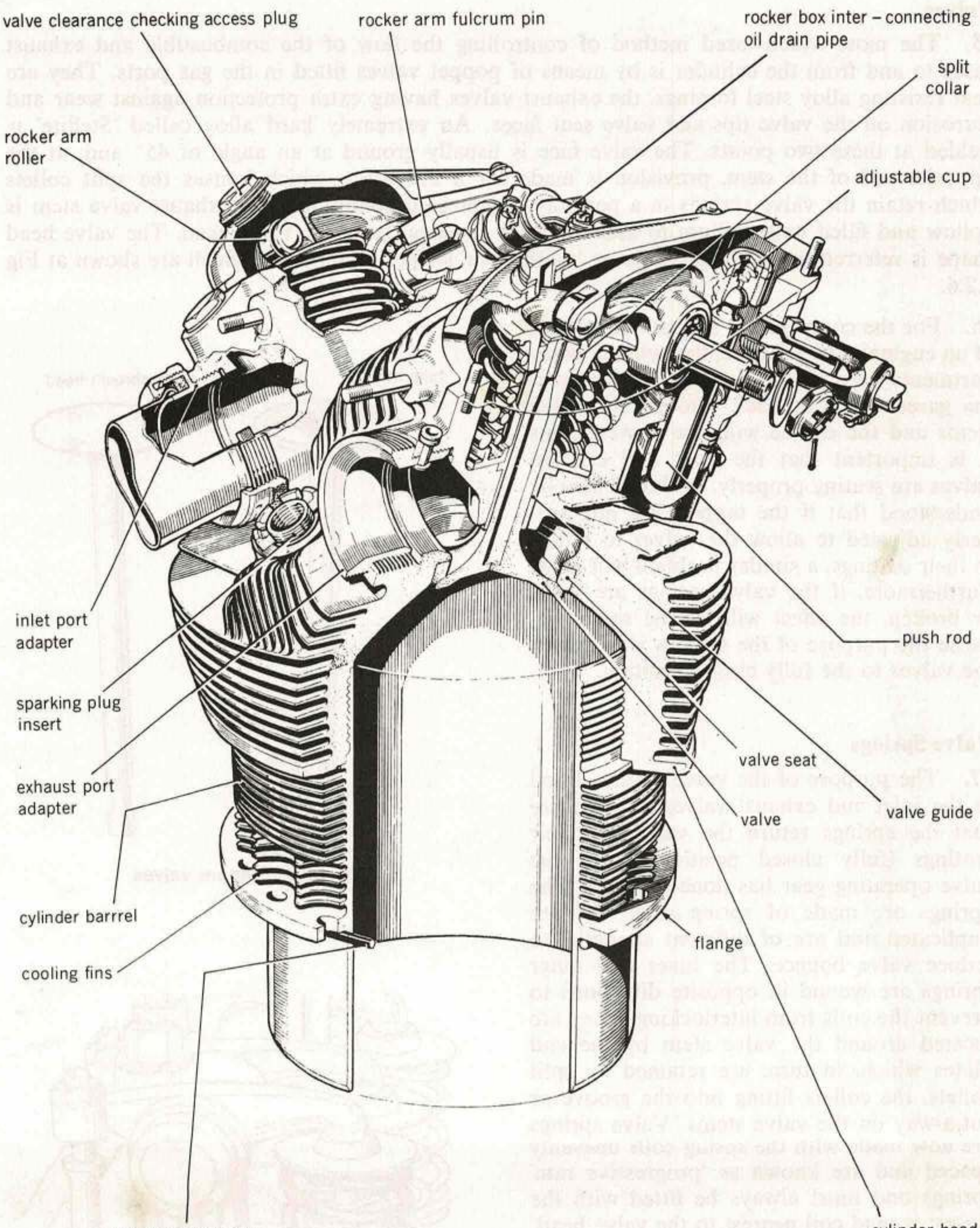


Fig 1.2.5 A cylinder

Valves

15. The most widely used method of controlling the flow of the combustible and exhaust gases to and from the cylinder is by means of poppet valves fitted in the gas ports. They are heat resisting alloy steel forgings, the exhaust valves having extra protection against wear and corrosion on the valve tips and valve seat faces. An extremely hard alloy called 'Stellite' is welded at these two points. The valve face is usually ground at an angle of 45° and, at the opposite end of the stem, provision is made for a cut-a-way which houses the split collets which retain the valve springs in a partially compressed condition. The exhaust valve stem is hollow and filled with sodium to assist in heat dispersal from the valve head. The valve head shape is referred to as 'tulip' shape or 'mushroom' shape, examples of which are shown at Fig 1.2.6.

16. For the compression and power strokes of an engine to be effective, the cylinder compartments must be gas-tight. If they are not, the gases will leak back through the valve stems and the engine will lose power. Thus it is important that the inlet and exhaust valves are seating properly. It should also be understood that if the tappets are not properly adjusted to allow the valves to return to their seatings, a similar problem will arise. Furthermore, if the valve springs are weak or broken, the effect will be the same, because the purpose of the springs is to return the valves to the fully closed position.

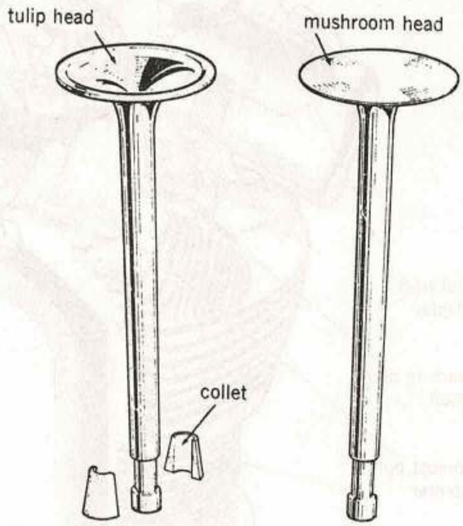


Fig 1.2.6 Poppet valves

Valve Springs

17. The purpose of the valve springs fitted to the inlet and exhaust valves is to ensure that the springs return the valves to their seatings (fully closed position), after the valve operating gear has done its work. The springs are made of spring steel and are duplicated and are of different strengths to reduce valve bounce. The inner and outer springs are wound in opposite directions to prevent the coils from interlocking. They are located around the valve stem by the end plates which, in turn, are retained by split collets, the collets fitting into the groove or cut-a-way on the valve stems. Valve springs are now made with the spring coils unevenly spaced and are known as 'progressive rate' springs and must always be fitted with the closest wound coil nearest to the valve head. An illustration of valve springs is shown at Fig 1.2.7.

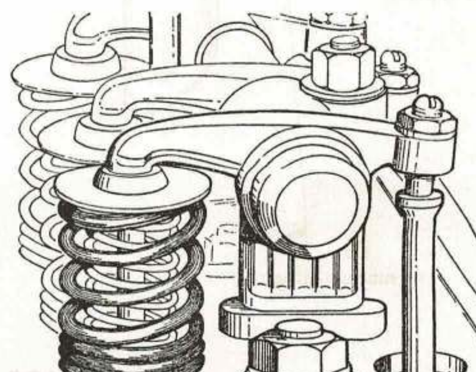


Fig 1.2.7 Valve springs

18. Valve springs should be examined periodically for pitting, cracks and chafing of the coils. The end coils should seat

squarely on the flange of the valve-guide. The spring should be checked for free length and also for length under a specified load. Weak valve springs are a contributory cause of valve bounce and a rough method of detecting a weak spring is to place a new spring and the suspected one together and compress them. If the springs are of equal strength the distance compressed will be the same on both, but a weak spring would compress to a greater extent than the stronger one.

Valve Operating Mechanism

19. As has been described previously, this mechanism is required to open the valves at a position directly related to the angle of the crank on the crankshaft, the valve springs ensuring the closing of the valves. We shall now discuss the operating mechanisms:

a. **Camshaft and cam drum.** In-line engines use a camshaft and radial engines use a cam drum or ring. Fig 1.2.8 illustrates a cam formed on a camshaft; the lobe only is used on a cam drum. The profile of the lobe controls the following: the point of valve opening in terms of crankshaft degrees; the rate of valve opening; the period the valve remains open; the rate of valve closing; and the point at which the valve closes. It can be readily understood what an important part the cam has to play in the sequence of operations with regard to valve timing.

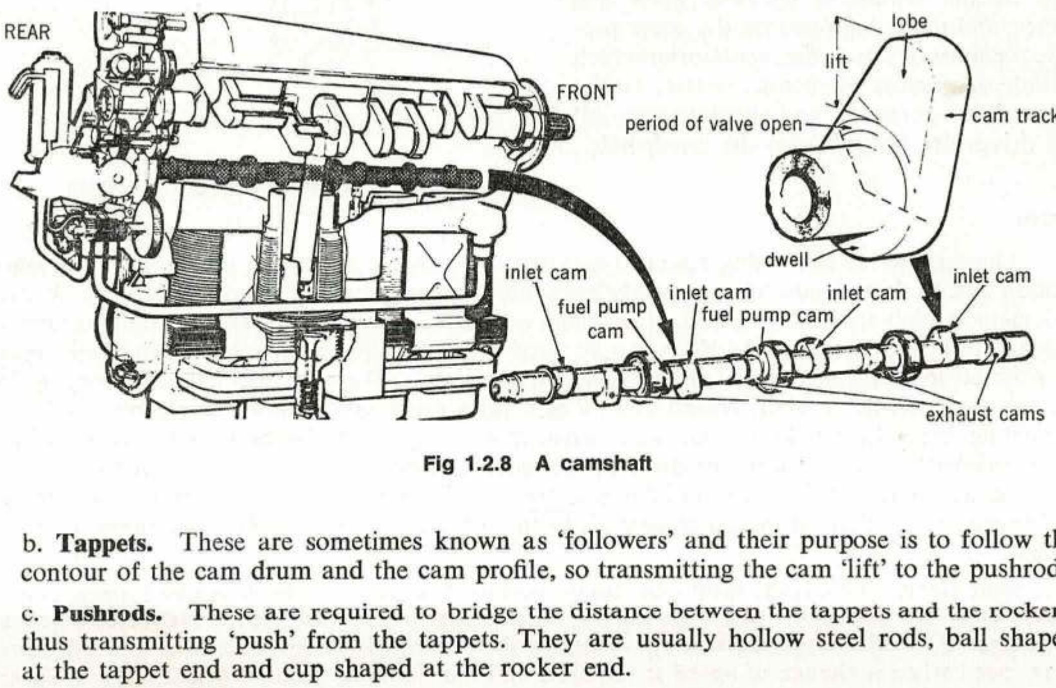


Fig 1.2.8 A camshaft

b. **Tappets.** These are sometimes known as 'followers' and their purpose is to follow the contour of the cam drum and the cam profile, so transmitting the cam 'lift' to the pushrods.

c. **Pushrods.** These are required to bridge the distance between the tappets and the rockers, thus transmitting 'push' from the tappets. They are usually hollow steel rods, ball shaped at the tappet end and cup shaped at the rocker end.

d. **Rocker arms.** These units reverse the direction of movement of the pushrods. It is usual at the pushrod end of the rocker to find a ball-ended adjusting screw. This screw controls the amount of clearance which must always exist when the valve is correctly seated and its tappet is resting on the dwell of the cam. This clearance is provided to ensure that the valve can positively close when the engine running temperatures have been reached. It is known as 'tappet or valve clearance' and is normally measured between the valve tip and the hardened rocker tip. An example of the valve operating mechanism is illustrated at Fig 1.2.9.

20. It will be appropriate at this point to remind you that when timing the valves to operate correctly, the valve clearances are laid down in the Volume 1 of the Engine Publication. *The actual valve timing depends also on the clearance*. If, for example, a very large clearance were left instead of a very small one, when the rocker was operated by the pushrod, it would have to move this large distance before it could open the valve. During this time the engine crankshaft would have moved round a number of degrees; therefore, when the valve did open, it would do so later than the desired operating point.

REAR COVER

21. The rear cover which is bolted to the rear of the crankcase encloses gears and drives, and mounting faces on the cover provide for most of the engine accessories which include magnetos, oil pump, starter, tachometer drive, generator and supercharger. All the drives are geared from the crankshaft.

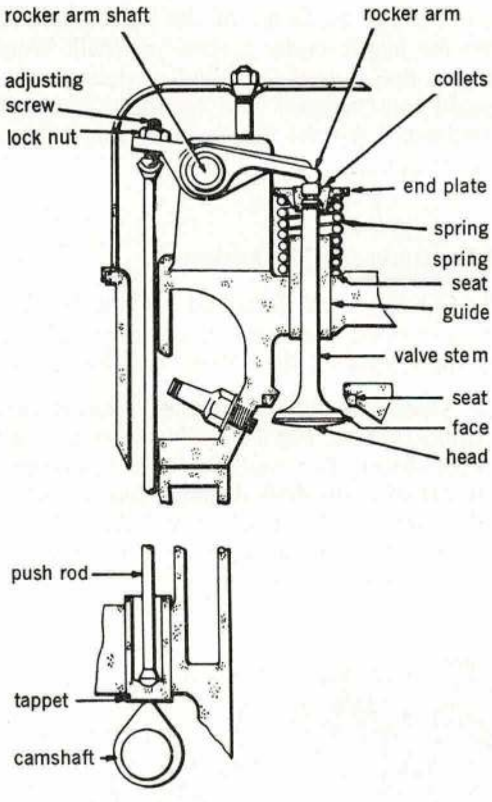


Fig 1.2.9 Valve operating mechanism

Gears

22. The term gears or gearing refers to a system of moving parts that are used to transmit motion and to drive loads. The materials from which gears are made vary considerably. Where quietness at high speed is required, some gears are manufactured from layers of fabric impregnated with synthetic resin, and these can be used in conjunction with steel gears. Gears may be referred to as driving gears, driven gears, or idler gears; they are also named according to the shape of the teeth (spur, helical and so on). Idler gears are mounted freely on a spindle projecting from the crankcase rear wall; when they engage with the gear on the rear end of the crankshaft, they transport the drive to the camshaft and other accessories mounted in and upon the rear cover. It is called an idler gear because it rotates freely or idles on its spindle and transmits the drive from the crankshaft to the other accessories *without alteration of gear ratios*.

a. **Spur Gear.** This is the most commonly used tooth shape. The teeth can be formed either internally or externally (*see* Fig 1.2.10). The internally toothed gears are used when a change of speed is required without changing the axis of the drive. Externally toothed gears are used when a change of speed is required and the shafts lie parallel to each other. These gears are often noisy owing to 'impact engagement' of the teeth.

b. **Helical gears.** Smoother, quieter running is obtained with helical gearing. The teeth are cut in a curve or helix and a sliding engagement is obtained, there being more teeth in mesh at any moment. This tooth shape produces heavy axial loading. Provided the gears always remain in mesh, this drawback can be eliminated by using double helical gears, the teeth being cut with opposite helix.

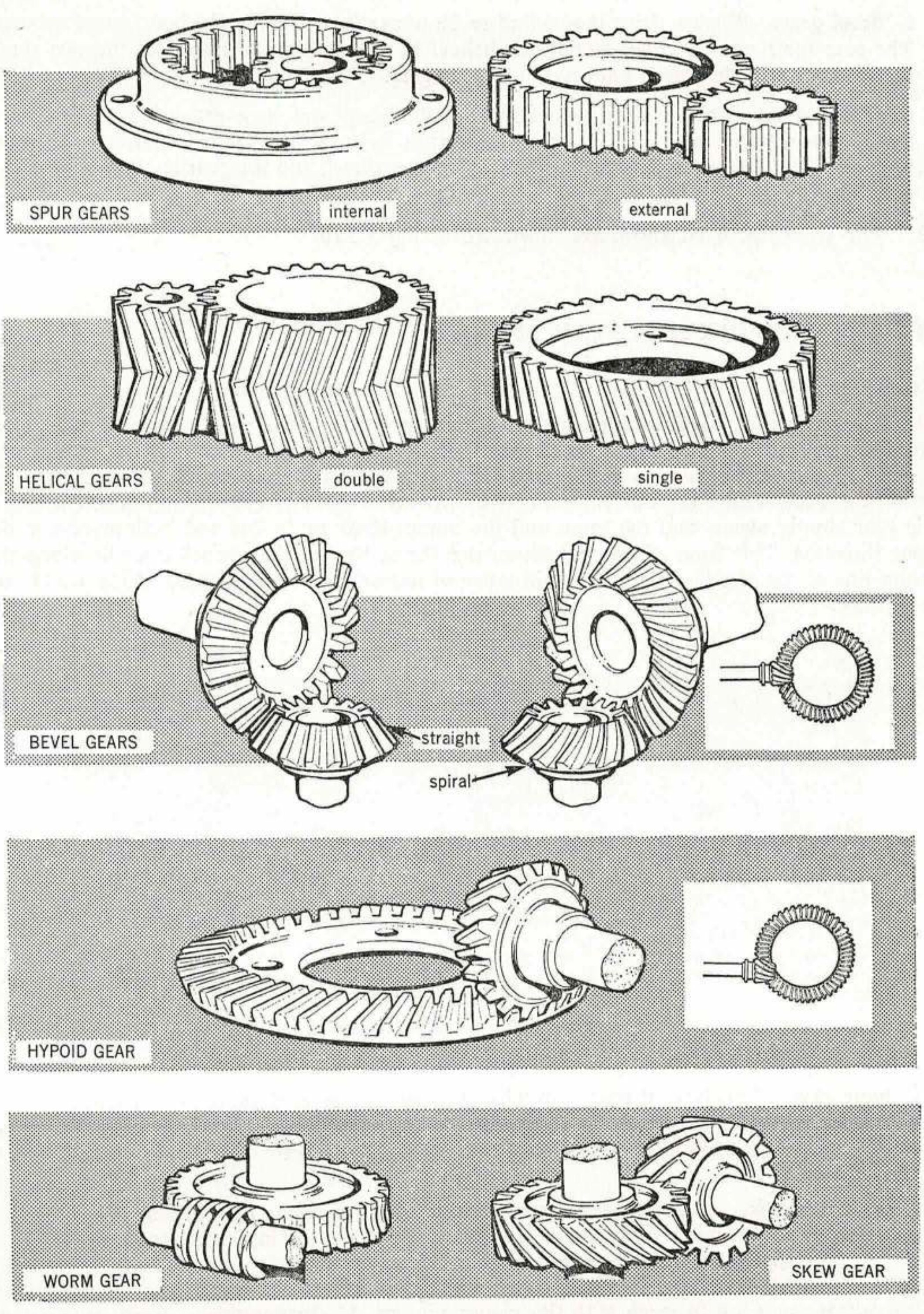


Fig 1.2.10 Types of gears

c. **Bevel gear.** When a drive is required to be transmitted at an angle, bevel gears are used. The gear tooth can be either straight or helical in shape. When the axes of the two shafts do not intersect, the gear is known as a hypoid gear.

d. **Worm gear.** When a large reduction in shaft speed and high resistance to turning is met, a worm wheel gear is often used. The worm teeth are similar to a multi-start thread; the worm wheel teeth are cut at an angle or on the 'skew', and the gear is often known as a skew gear.

23. The gears discussed above are illustrated at Fig 1.2.10.

PROPELLER REDUCTION GEAR ASSEMBLY

Reduction Gears

24. The purpose of a reduction gear is to keep the propeller speed within its range of efficient operation without reducing the peak performance of the engine. To avoid interrupting the cooling air flow, the reduction gear must be compact and smaller in overall diameter than the crankcase. Most radial engines use what is known as a bevel epicyclic gear train. An epicyclic gear simply means that the input and the output shaft are in line and both revolve in the same direction. This form of gearing allows the thrust line of the propeller to lie along the centre line of the engine. The three main types of reduction gear, illustrated at Fig 1.2.11, are as follows:

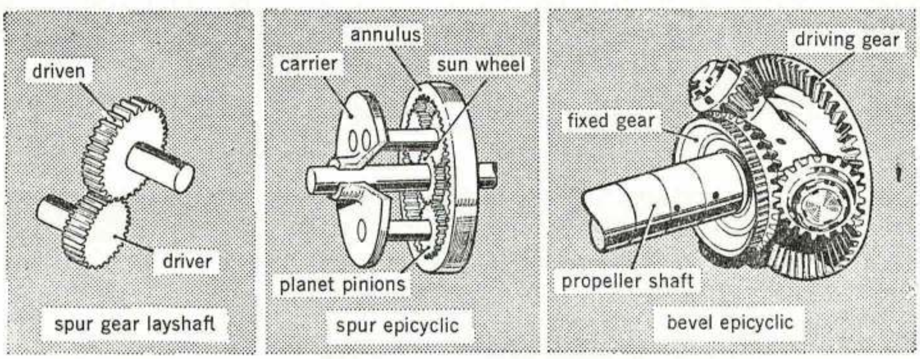


Fig 1.2.11 Reduction gears

a. **Spur gear.** This type of gear is usually used on 'in-line' engines, the small gear receiving the drive from the crankshaft via a coupling shaft having the same axis line as the crankshaft. The drive is then transmitted to the large gear whose axis is usually above the crankshaft.

b. **Spur epicyclic.** A simple gear train consists of a spur gear (sun wheel) driven by the crankshaft, or a similar main drive, meshing with, and driving three equi-spaced gears known as planet pinions. These pinions are mounted on a carrier and rotate independently on their axis. Surrounding this gear train is an internally toothed wheel, known as an annulus, whose teeth are in mesh with the planet pinions. If the annulus is fixed, rotation of the sun wheel will cause the planet pinions to rotate about their axes and at the same time to move around the annulus. This causes the planet pinion carrier to rotate at a lower speed than the sun wheel. With the carrier secured to the propeller shaft, a speed reduction has been obtained, with the crankshaft and the propeller shaft in the same axis. Where high torque is to be transmitted the gear tooth used is the double helical or skew (Fig 1.2.10).

c. **Bevel epicyclic gear.** This train of gears consists of two opposed bevel gears of different diameters. The larger gear is driven by the crankshaft and the smaller gear is held stationary in its casing. Three satellite or planet pinions, free to rotate, are mounted on equally spaced arms radiating from a propeller shaft. They are situated between, and in engagement with, the two bevel gears. The front bevel is stationary and the rear is the driving bevel that is driven by the crankshaft. Rotation of the driving bevel gear causes the satellite bevel gears, their mounting arms, and the propeller shaft, to rotate at a reduced speed.

25. The term 'backlash' associated with the word gearing, is the term used to describe the clearance which must exist between gear teeth at the point of tooth mesh. This clearance is essential with all forms of gearing to allow for expansion and lubrication.

SUPERCHARGER ASSEMBLY

Superchargers

26. One of the main factors governing the maximum output of a piston engine is the weight of fuel that can be burnt during each cycle of operations. The more fuel that can be burned, then the greater will be the power output. To burn the fuel efficiently, the air/fuel mixture ratio must be kept within a comparatively narrow range. The quantity of air that can be induced by a normally aspirated engine depends upon *the difference in pressure* between the depression created in the cylinder by the descending piston and the prevailing pressure at the air intake. It follows that the pressure in the induction system of a normally aspirated engine is always les than the prevailing atmospheric pressure.

27. With such engines, the horse power falls off at a fairly uniform rate with an increase of altitude, owing to the decreasing air density. For example, at 18 000 feet, the horse power available will be approximately half that available at sea level (the atmospheric pressure at that altitude is approximately half the pressure at sea level). To counteract this reduction of atmospheric pressure, and to maintain full power up to a given altitude, *a supercharger* is fitted to the engine to deliver the mixture under pressure. A further advantage of this arrangement is that, within limits, a heavier than normal charge can be supplied to the engine at sea level without increasing the overall weight of the engine. The engine must, of course, be designed to absorb the increased pressure and bearing loads, and must have an adequate cooling system to prevent overheating.

28. Superchargers will be considered in more detail in Chapter 3. However, a supercharger is basically an engine-driven centrifugal type of compressor, usually situated between the carburettor and the induction manifold. The power to drive the supercharger is transmitted through a suitable gear train in the rear casing from the crankshaft. The impeller drive absorbs an appreciable quantity of horse power. To reduce the impeller bearing load, it is customary to transmit the drive through a triple gear train. Each driving gear has a friction clutch incorporated to relieve shock loads during sudden changes of engine speed. A spring drive is fitted between the gear train and the crankshaft to further smooth out the drive and reduce impeller vibration.

Types of Supercharger

29. The design of a supercharger for a specific engine is such that the engine develops its full power at the normal operating height of the aircraft to which the engine is fitted. To keep the amount of power absorbed by the supercharger to a minimum, various types of superchargers are used, as follows:

a. **Simple type.** This type consists of a simple gear train and a single impeller driven at a constant gear ratio. It may be designed for a moderately supercharged or fully supercharged engine. If it is for a moderately supercharged engine, the full power will be developed at around 5000 feet. A fully supercharged engine develops its full power at around 10 000 feet to 12 000 feet.

b. **Two-speed supercharger.** This type of supercharger has a single impeller, but the drive consists of two separate trains of gears, either of which can be selected as required. The high speed gear train is selected at high altitude to increase the supercharger pressure ratio and help to counteract the effect of the lower atmospheric pressure at the air intake. The low speed gear train is used at lower altitudes, where the inlet pressure is higher, and the required delivery pressure can be obtained with a lower supercharger impeller speed.

c. **Two-stage supercharger.** This type of supercharger was developed to give the high pressure ratio necessary for high altitude flight. It has two impellers and the mixture is compressed in two stages. The highly compressed mixture is delivered at a high temperature and, if induced into the cylinders in this state, would detonate easily; there would also be a reduced weight of charge. To overcome these problems, a 'matrix' or heat exchanger is fitted between the compressor delivery and the induction manifold. It is called an intercooler and is part of a separate cooling system having its own coolant pump and radiator.

EXHAUST SYSTEMS

General Points

30. An exhaust system is briefly a means of leading the engine exhaust gases safely away from the aircraft; but it can also be a means of obtaining a slight gain in propulsion from the 40% of fuel energy normally lost to exhaust. An exhaust system designed to provide this gain is called an 'ejector-type exhaust system', *ie* the mass of exhaust gases is ejected rearwards at a high velocity thus giving a resultant push reaction forward on the aircraft.

31. The main difficulty in the design of exhaust systems is to make them withstand the great heat of the exhaust gases and the expansion and the contraction of the material of which they are constructed. The factors influencing the design of an exhaust system are as follows:

a. The metal or material in contact with the hot exhaust gases must be capable of withstanding temperatures up to 800°C without losing its strength. In addition, it should be non-corrodible. Means must also be provided for cooling the system by allowing air to blow over it.

b. The system must be designed with expansion joints so as to counteract expansion and contraction, thereby alleviating stresses in the metal.

c. The shape and size of an exhaust system must be arranged so that the gas can get away easily, thus avoiding undue back pressure. Sharp bends and rapid changes in pipe section must be avoided. Those parts of the exhaust system projecting through the engine cowling must be shaped to offer a minimum of air resistance (drag).

Radial Engines

32. This engine usually requires a main collector pipe of ring formation into which branches deliver the exhaust gases from the cylinders. The collector has one or two main outlets which carry the gases back clear of the aircraft structure. The main collector ring and branches are housed inside the cooling lines so as not to present any external projections which would upset the smooth air flow. A well known example of this is the Bristol exhaust system which was designed to form the nose portion of the main engine cowling. This is illustrated at Fig 1.2.12.

33. Other radial engines have their exhaust system behind the engine (also illustrated at Fig 1.2.12) and for cooling purposes it is enclosed in a muff or isolated from the rear of the engine by a trough into which air is fed from the front of the engine.

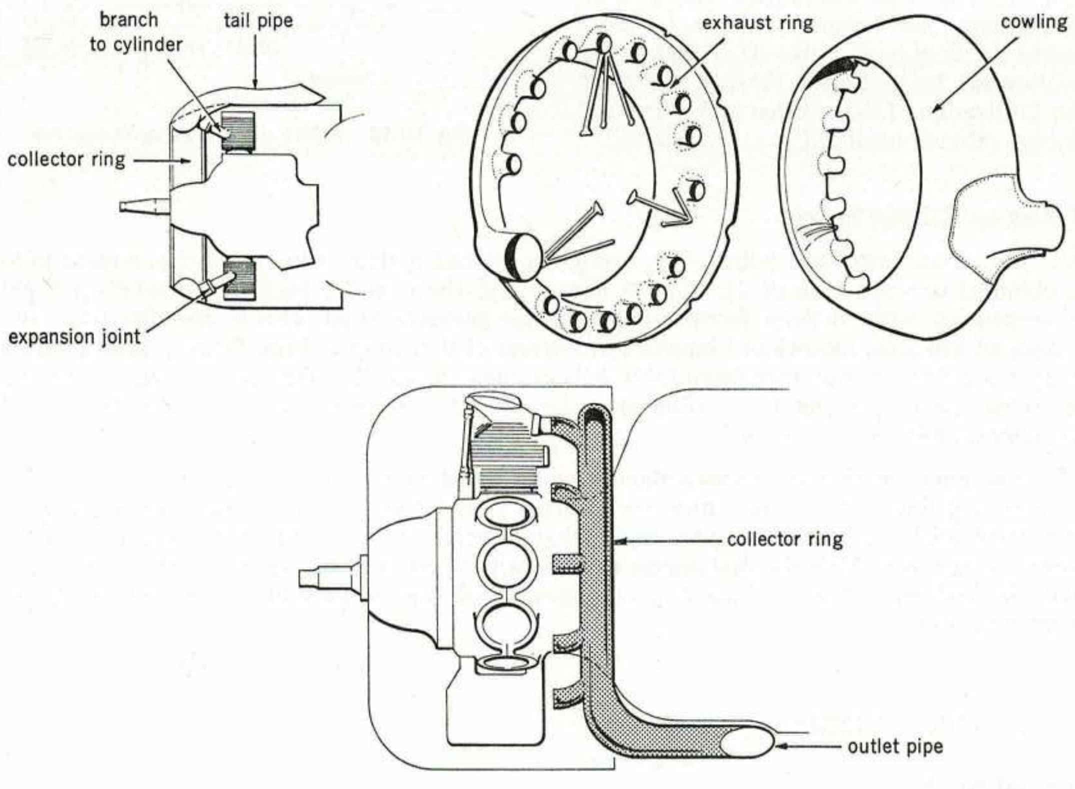


Fig 1.2.12 Radial engine exhaust system

34. Each of these two systems has advantages over the other: one provides a saving in complication and space and helps to keep the accessories cool, whilst the other assists cylinder cooling since the air passing to the cylinders is not preheated by passing in the vicinity of the exhaust pipe.

In-line Engines

35. Engines with in-line cylinders of one or more banks usually enable a more simple design of exhaust system to be incorporated. The most simple method is to have short stub-pipes from

each cylinder, but this can be extremely noisy. A more usual design is one in which short pipes from each cylinder are fed into a common pipe or manifold with a single outlet (Fig 1.2.13). The manifold and branch pipes are enclosed in a duct inside the engine nacelle. For cooling purposes, air is forced through the duct from a scoop in the front and is evacuated in a backwards direction at the rear. A small amount of propulsive energy is obtained in this easy way owing to the heat energy absorbed by the air, causing it to work as a jet backwards. This propulsive energy may counter-balance to some extent the drag on the aircraft caused by the cooling air being forced through the duct. An illustration of the exhaust stub pipes and ducted exhaust manifold is at Fig 1.2.13.

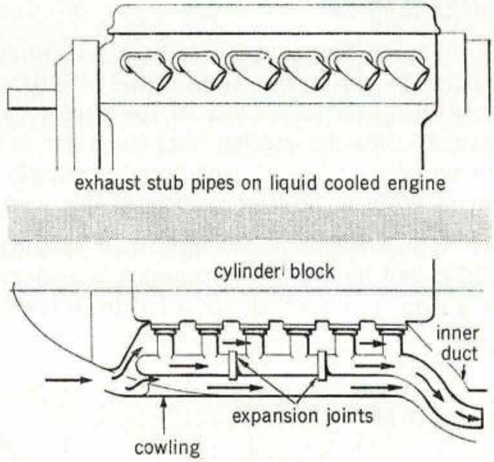


Fig 1.2.13 In-line engine exhaust system

Fitting an Exhaust System

36. The most important point when fitting an exhaust system is to ensure that a good joint is obtained between each of the exhaust flanges and the cylinder facings. To take up slight discrepancies between these faces, a heat-resisting gasket is fitted. This is manufactured from a layer of asbestos, sandwiched between two layers of thin copper sheet. When several exhaust flanges are fitted to one pipe (manifold), it is essential to see that the mating flange-faces line up, otherwise it may not be possible to make a good joint between all faces, as the gasket has only a limited compression.

37. The nuts securing the flanges should be tightened evenly. To prevent the nut and stud from seizing due to heat, brass nuts are invariably used. Care should be taken when attaching expansion joints of the bolted type, to see that overtightening has not prevented free movement taking place. After the first engine run, a newly fitted exhaust system should have all the nuts checked for tightness, since they may slacken off due to the settling down of the flange faces with heat.

INDUCTION SYSTEMS

General Points

38. The purpose of an induction system is to direct the correct air/fuel mixture into the cylinders, via the atmosphere and carburettor, either by positive pressure from the engine driven supercharger, or by the depression caused by the descending piston during the induction stroke. The induction system generally is similar in both types except for the introduction of the actual supercharger.

39. The main problem on unsupercharged engines is to obtain an equal charge in each cylinder, so that the design of the manifold becomes very important; so too does the design of the inlet valves. The relative cross-sectional area of the inlet valves and the manifold passages affect the mixture flow and so the whole efficiency of the engine depends on them, as all the cylinders are the same swept volume and requires the same charge. Another problem is the efficiency of the gasoline globules in suspension in the mixture stream; these tend to stick to

the walls of the passages. This problem is reduced by imparting swirl or turbulence to the mixture, or by heating the passages.

40. The reverse of these conditions apply with supercharged engines since a positive pressure exists at all times in the induction manifold and the increased pressure of air imparts sufficient heat to vaporize the mixture. In many instances, the compressed mixture may require cooling and this is done by an intercooler.

41. **Intercooler.** The intercooler may be part of the engine cooling system or may be independent of it, with an engine-driven circulating pump, a header tank and a coolant radiator of its own.

Air Intake Assembly

42. Having briefly described the problems of design encountered in normally aspirated and supercharged engines, the start point of any induction system is the air intake assembly. Atmospheric conditions at altitude give lower air temperatures than at ground level, and the effects of ice on the air intake and carburettor are serious, both as regards restriction of the air intake (thus affecting the whole induction system) and the mechanical jamming of the throttle valves. To prevent this, ice guards, and provision for drawing pre-heated air from the engine nacelle, are used in the air intake. The pilot can control the alternative hot or cold conditions at the intake by means of shutters, either manually or by electro/pneumatic rams, some of which are operated automatically. Also fitted in the air intake is an air filter. The function of the air filter is to remove all dust and grit from the air before passing through the induction system.

43. Other important characteristics of piston engine construction regarding the induction system are described below.

Flame Traps

44. You will now be aware of the sensitivity of the fuel and air mixture proportions which go to make up the charge before it enters the combustion chamber (cylinders). Over-rich mixture causes rough running, oil dilution (too much fuel on the cylinder walls), cylinder wear and excessive deposits of carbon on the piston; weak mixture causes overheating and consequent burning of the valves, and 'popping back' in the induction system. This 'popping back' may cause a fire in the carburettor or damage to the supercharger.

45. One method of preventing the fire risk is to fit a metallic gauze screen in the induction manifold; this will admit the mixture, whilst preventing the passage of flames. A simpler method on normally aspirated engines is the incorporation of flame traps on the carburettor air intakes. These are merely air intakes of greatly increased diameter, the space being filled with closely formed metal strips with fine corrugations which admit the mixture but will prevent the passage of flames. These external flame traps also act as air filters and can be removed for cleaning.

Induction Manifold Drains

46. When starting a cold engine or when idling under low temperature conditions, part of the fuel may fail to combine with the air in the manifold. Fuel drawn into the cylinders will dissolve the oil film between the piston and the cylinder wall causing wear. To prevent this, drain holes are drilled in the induction pipes and piped away from the cowlings. Air is prevented from entering in unsupercharged engines by interposing a non-return valve in the pipe or, in some cases, by making the drain passages as small as possible so that only the smallest quantity of air can enter.

47. With supercharged engines, where a positive pressure exists under all running conditions in the manifold, the question of leakage is unimportant, the pressure ensuring adequate operation of the manifold drains under all conditions. In some installations, the drains are led to a collector box inside the cowlings and in others, the pipe or pipes lead to atmopshere, clear of the aircraft structure.

Induction Priming Systems

48. To reduce the time for initial engine starting, a fuel priming system is introduced directly into the induction manifold. This obviates the need to vaporize the charge through the carburettor. As a sufficient quantity of air is always contained in the induction system for the initial cylinder charge, a spray of fuel from an external source is mixed with this air; a magneto or booster coil is then operated and the engine is rotated sufficiently by the starter motor to compress a charge in whichever cylinder or cylinders are on the compression stroke. The high tension current is fed through the normal magneto distributor to the correct cylinder and the engine starts. Priming is continued until the carburettor is able to supply the correct mixture. The amount of priming required under varying temperature conditions is given in the appropriate engine Air Publication Volume 1.

Servicing of Induction System Components

49. Although routine servicing is laid down in the Servicing Schedule, you are reminded to watch out for the following points:

a. Make sure that all wire meshing on intakes is free from corrosion, is undamaged and free from obstruction. Such things as leaves, grass or other foreign matter will obstruct the air flow.

b. Make sure that all sealing joints are leak-proof and serviceable.

c. Make sure that the induction manifold or induction pipes are secure.

d. Be careful when handling filter elements. Particular care should be exercised when fitting them; make sure that the direction of air flow is correct.