INTERNAL COMBUSTION ENGINES

SECTION 1

Description and Action of Engine.

1. **External and internal combustion engines.** Both steam and gasoline engines are heat engines, that is machines for converting the heat energy produced by the combustion of the fuel into mechanical work. In the ordinary steam engine the steam is admitted to a cylinder where it exerts a force upon a movable piston but the combustion of the fuel which produces the steam takes place in a boiler *outside* the cylinder. In the gasoline engine, however, the combustion of the fuel takes place *inside* the cylinder and consequently it is called an *internal combustion engine.*

As early as 1680 an attempt was made to construct an internal combustion engine by using gun powder as fuel but nearly two centuries elapsed before the Otto *four-stroke cycle engine* using coal-gas was invented (1876). In 1883 Daimler paved the way for the modern portable engine by using vaporized gasoline and air as fuel. The *two-stroke cycle engine* was invented by Clerk in 1878 and was improved by Day in 1891 while the *Diesel engine* which can utilize heavy oils or even pulverized solid fuels was patented in 1892.

Two-stroke cycle and Diesel engines are used for many purposes but in this book we shall consider only the four-stroke cycle engine which is commonly used in automobiles and in aeroplanes.

2. **The four-stroke cycle.** A cycle is a series of events which keep recurring and an examination of Fig. 1

will show why the Otto engine is designated a four-stroke cycle engine. In the left-hand diagram the piston

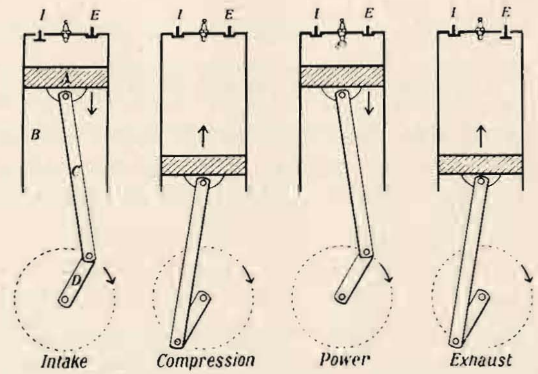


Fig. 1.—The four strokes of the four-stroke cycle.

A is being pulled downwards by the connecting rod C which is attached to the crank D and the explosive mixture is entering the upper part of the cylinder B past the intake valve I which has been opened at the proper time. In the next diagram the crank has revolved far enough to start the piston on its upward journey and since I has closed the mixture is being compressed in the cylinder. In the third diagram the piston is just starting down again and the mixture has been ignited by an electric spark which occurs across the gap in the spark-plug at the proper instant. This is the power stroke. In the last diagram the piston has just started its upward journey again and the exhaust-valve E has opened to permit the products of combustion to escape.

The cycle of strokes, *intake, compression, power* and *exhaust* now repeats.

3. **Function of the fly-wheel.** In the single cylinder four-stroke cycle engine which has just been considered there is only one power stroke in every four single strokes or in every two revolutions of the crank-shaft. In order to carry the piston through the other three strokes a fly-wheel is attached to the crank-shaft and enough energy is stored up in the fly-wheel during the power stroke to cause the engine to keep running through the other three strokes of the cycle.

4. **Further details of the engine.** In Fig. 2 more of the parts of a simple one cylinder engine are shown. A is the piston, hollowed out for lightness and supplied with *piston rings* set in grooves machined in its cylindrical surface, to ensure that no gas leaks past. B is the *wrist-pin* at the upper end of the *connecting-rod* C, the lower end of which is connected to the crank on the *crank-shaft* D.

Fastened to the crank-shaft is a gear wheel E rotating anti-clockwise and meshing with gear-wheels F, fastened to *cam-shafts* carrying the cams G and H which rotate in a clockwise direction. G operates the intake valve L and H the exhaust valve M. The *lifter bolts* I and the *lock nuts* J allow the proper expansion clearance between the *valve stems* and lifters.

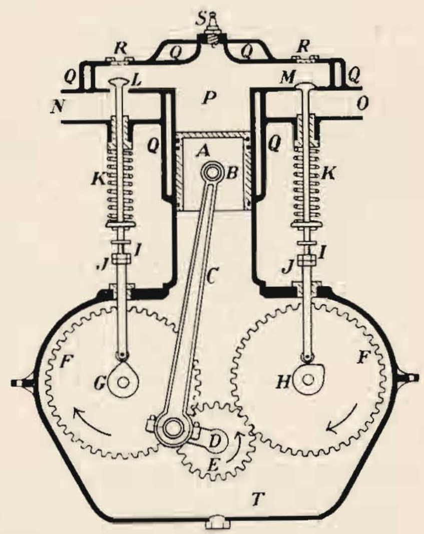


Fig. 2.—Details of a single cylinder four-stroke cycle engine.

Valve springs K are provided to ensure the closing of the valves when the cams are not pushing them open. N is the intake pipe leading from the *carburetor* and O is the exhaust pipe. Cooling of the cylinder is provided by water circulating in the *water jacket* Q. Access to the valves is permitted by *bonnets* R. S is the *spark-plug* and T the *crank-case* or *sump* containing oil for lubrication.

As the engine is shown in the diagram the piston is descending, the intake valve L is being kept open by the cam G and the explosive mixture is entering the cylinder P. Near the end of this intake stroke cam G will have rotated enough to allow L to close, then will follow the compression and power strokes with both valves closed and then, at the beginning of the exhaust stroke, cam H will have rotated far enough to raise the exhaust valve M, thus permitting the products of combustion to escape.

5. **Valve operation and timing.** The method of operating the intake and exhaust valves by cams has been explained in the preceding section. Each valve opens and closes once during each cycle and it is important that the camshaft and crankshaft gears should meet in such a way that the *valve timing* will be correct.

In considering the elementary theory of the four-stroke cycle we usually speak of the intake valve opening at the beginning of the intake stroke and closing towards the end of the stroke and similarly for the exhaust valve. However, in actual practice, greater efficiency is obtained by having the valves open early and close late.

Fig. 3 shows a valve timing diagram for one type of modern engine. In this diagram 180 degrees represent one-half revolution of the crankshaft or a single stroke of the piston. The intake valve opens 5° before the top dead centre position is reached and closes 45° after bottom dead centre. On the other hand the exhaust valve opens 45° early and closes 5° late.

The late closing or *lag* of the intake valve permits a greater charge to enter the cylinder and the early opening or *lead* of the exhaust valve reduces the back pressure on the piston during the exhaust stroke. Both valves are open at the same time or *overlap* for 10°. This results in better scavenging of the products of combustion.

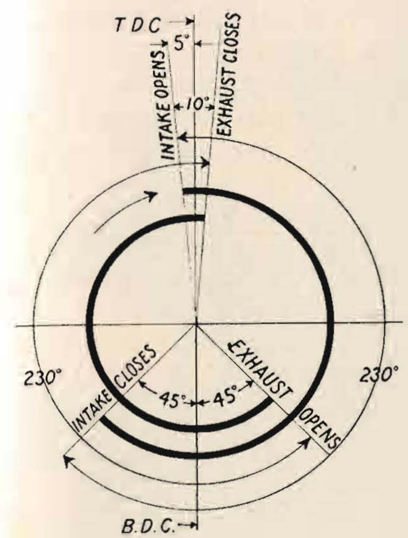


Fig. 3.—A typical valve timing diagram.

Most engines have time marks stamped on the camshaft and crankshaft gears and in assembling the engine proper timing is ensured by setting the gears so that these marks are exactly aligned.

6. **Multi-cylinder Engines.** Single cylinder engines are used for many purposes but automobile and aircraft engines have several cylinders connected to a common crankshaft. Increasing the number of cylinders results in more power and less vibration since with a four-cylinder engine it is possible to have two power strokes for each revolution of the crankshaft and with an eight-cylinder engine four per revolution.

A simplified diagram of a four-cylinder automobile engine is shown in Fig. 4. Here the four cylinders are in *line*. A common intake *manifold* leads from the carburetor to the intake ports and the exhaust ports open into an exhaust manifold. A single camshaft actuates all valves at the proper time.

The four connecting rods are connected to a single crankshaft two *throws* of which are arranged at 180 degrees from the other two. The rear end of the crank-

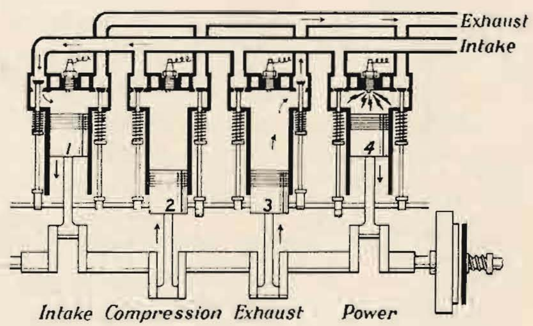
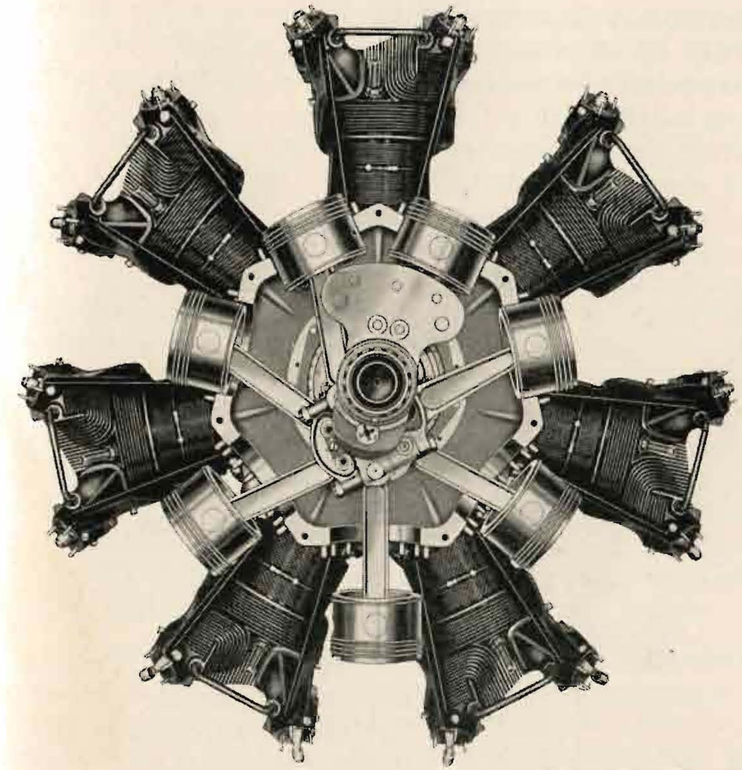


Fig. 4.—A four-cylinder automobile engine. For simplicity the valves are shown opening outwards.

shaft carries a flywheel beyond which is seen the *clutch* which transmits the power to the transmission gears and drive-shaft.

It will be noted that pistons 1 and 4 are descending while 2 and 3 are rising. From the positions of the valves it is evident that starting from the front of the engine, the cylinders are performing intake, compression, exhaust and power strokes respectively. In any one cylinder, however, the cycle will be intake, compression, power and exhaust as in the single cylinder engine. The *firing order* will be 4, 2, 1, 3 or, as usually written, 1, 3, 4, 2. This order varies in different engines and is arranged to eliminate vibration as much as possible.

7. **Aircraft engines.** Many aircraft use *in-line* engines similar in principle to the automobile engine except for



(*United Aircraft Co.*)

Fig. 5.—Pratt and Whitney Twin-row Radial Engine.

the fact that they are air-cooled instead of water-cooled.

Where many cylinders are needed the *V-type* engine, consisting of the two *banks* or rows of cylinders inclined to one another so that the piston rods can actuate a common crankshaft, is often used. Some of these are liquid-cooled.

Another interesting type is the *radial* engine shown in Fig. 5. Here we have two rows of cylinders arranged like spokes in a wheel with all the pistons connected to a central crankshaft. Fig. 6 shows the arrangement of connecting rods in a nine-cylinder single row radial engine. It will be seen that eight of the rods D are connected to the master rod C which drives the crank G.

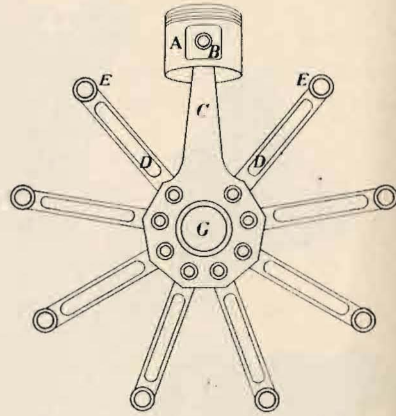


Fig. 6.—Connecting Rod Assembly of Radial Engine. A, piston; B, piston pin; C, master rod; D, link rods; G, crank.

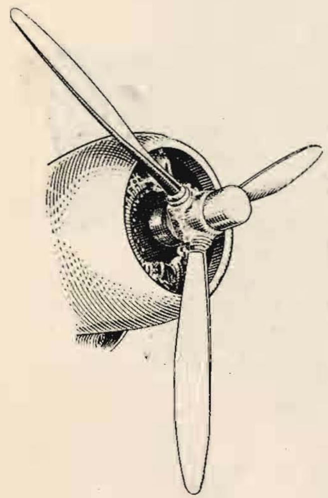


Fig. 7.—A controllable pitch air-screw. The air-screw rotates clockwise as viewed by the pilot.

8. **The airscrew or propeller.** Everyone is familiar with the fact that in an ordinary automobile the engine causes the rear wheels to rotate and that the car is able to travel because of the friction that exists between the tires and the road.

In an aeroplane the airscrew or propeller is made to rotate very rapidly by the engine and the shape of the blades (Fig. 7) is such that the air exerts a thrust on the propeller which gives the aircraft a forward velocity. This action is similar to that of a common screw advancing into a block of wood when rotated by a screw-driver but a more scientific discussion of the forces which act on the airscrew will take place at a later stage.

Section 2

CARBURETION AND IGNITION

9. **Carburetion.** Everyone knows that a supply of gasoline is needed for the operation of an automobile or aircraft engine but comparatively few people realize that approximately 15 pounds of air must be mixed with each pound of gasoline vapour to give the chemically correct mixture for combustion. The *richest* running mixture is about 1 pound of gasoline to 8 pounds of air and the *leanest* about 1 to 20. The gasoline is pumped from the fuel tank to the *carburetor* where it is vaporized and mixed with the proper proportion of air.

10. **Description of Carburetor.** Fig. 8 is a simplified diagram of an *up-draft* carburetor. The *fuel pump* delivers gasoline to *float chamber* G through the opening A, the level of the gasoline being controlled by the float F which operates the *needle-valve* C. Air enters the carburetor through the opening O, the size of which can be controlled by the *choke* N. Opposite the nozzle H the air passes through a constriction J called a *venturi tube* and above this is the *throttle* L, opposite which is another

gasoline opening K. Connection to the intake manifold is made at M.

11. **Action of Carburetor.** When the engine is idling the throttle is practically at right angles to the position shown in the diagram and, because of the partial vacuum created in the cylinders on the intake strokes, air rushes with high velocity through a narrow gap left between I and K. According to a well-known law of physics (Bernoulli's Principle), this high velocity is accompanied by reduced pressure. Consequently the atmospheric pressure on the gasoline in the float chamber pushes gasoline up to the opening K where it is met by the blast of air and vaporized.

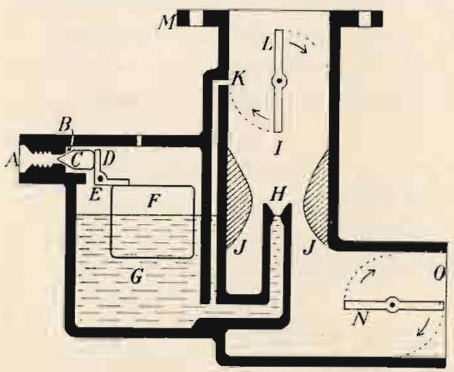


Fig. 8—A simple up-draft carburetor.

When the engine is running more rapidly with the throttle farther open, there will be very little suction at K, but the air passing through the venturi tube J has now sufficient velocity to cause gasoline to feed in through H.

When the choke N is partly closed the mixture is richer. Most engines are now equipped with automatic chokes operated by thermostatic controls, so that a richer mixture is provided for starting when the engine is cold and the gasoline does not vaporize so readily. Many modern automobiles are now supplied with *down-draft* carburetors equipped with air-cleaners.

12. **Effect of Altitude.** As an aeroplane gains altitude the density of the air decreases rapidly and consequently the mixture tends to become too rich causing loss of power and waste of gasoline. To avoid this, aeroplane carburetors are provided with altitude mixture controls some of which operate automatically.

Fans called *super chargers* are also provided on aircraft engines to force the mixture into the cylinders at a greater rate than would take place by suction. These may be used to increase the power at low altitudes as well as to offset the loss of power due to greater height.

13. **Ignition.** After the explosive mixture has been drawn into the cylinder and compressed, it must be ignited at the proper moment to secure the maximum power from the combustion. We have already mentioned that this is effected by an electric spark which occurs at a gap between two *electrodes* in the spark plug. The parts of a well made spark plug are shown in Fig. 9. It must be constructed to withstand great heat and pressure and much of the efficiency of an engine depends on whether it functions properly. Spark plugs should be inspected at regular intervals to ensure that they are not fouled and that the gaps are adjusted correctly.

(Courtesy Champion Spark Plug Co.)

Fig. 9.—Showing the parts of a well made spark plug.

14. **Production of spark.** The distance between the electrodes at the spark gap is about 1 millimetre and an electromotive force of several thousand volts is needed to produce a

spark at this distance. This voltage is produced by *induction*.

In the left-hand diagram of Fig. 10 is shown a coil of

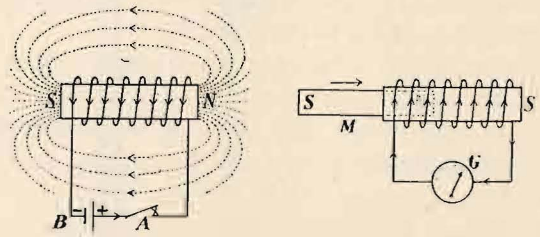


Fig. 10.—Magnetism produced by an electric current and an electric current produced by a moving magnet.

insulated wire wound around a soft-iron core and connected in series with a battery B and a switch A. When the switch is closed a current flows through the coil in the direction of the arrows and the iron core becomes a magnet with North and South poles at the ends marked N and S. The magnetic lines of force reaching out from the magnet are shown by the dotted lines. Here electricity in motion has produced magnetism.

In the right-hand diagram we have the converse operation—magnetism in motion producing an electric current. A coil of insulated wire is connected to a galvanometer which will register when a current is flowing in the circuit. When a bar-magnet M is thrust rapidly into the coil as indicated, the hand of the galvanometer deflects showing that a current is flowing in the coil in the direction of the arrows; and when the magnet is withdrawn quickly the hand deflects in the opposite direction. These *induced* currents last only so long as the magnet is in motion with respect to the coil, and the electromotive force produced depends on the strength of the magnet, on the rapidity of the motion and on the number of turns in the coil. Induced currents may be produced also by moving the coil while the magnet is kept stationary.

15. **Battery ignition circuit.** Most automobiles now use battery ignition which may be studied by referring to Fig. 11. One terminal of the six-volt storage battery B is "grounded" to the frame of the car while the other

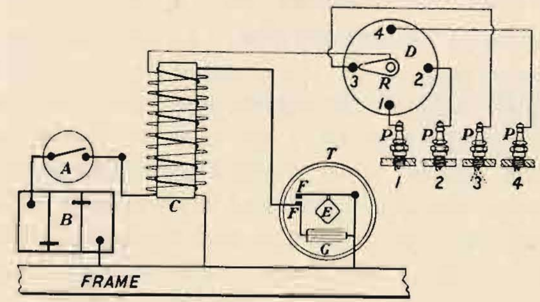


Fig. 11.—Battery ignition circuit diagram.

terminal is connected to the ignition switch A which is in series with the *primary* coil of the induction coil C. The other end of the primary coil is connected to the lower contact point F of the *breaker* T. The upper contact point is carried on a hinged arm which is pressed by a spring against the rotating shaft E which, in the case of the four-cylinder engine shown, has four lobes so that the breaker points open four times per revolution. A condenser G is bridged across the breaker points and the upper point is connected to the frame to complete the circuit to the battery.

The primary coil is made of fairly heavy insulated wire so that it can carry a strong current and is wound around a soft-iron core. About this primary coil is wrapped a secondary coil consisting of a great number of turns of much finer wire. One end of this coil is grounded while the other end is connected to the *rotor* R of the *distributor* D. This rotor is mounted on a continuation of the shaft E and as it rotates the outer end comes in turn very close to the metal studs 1, 3, 4, 2 which are connected to the central electrodes of the spark plugs P. The outer electrodes are in metallic contact with the engine and this completes the secondary circuit.

16. **Action in battery ignition.** As the primary circuit is *made* and *broken* by the breaker the core of the induction coil alternately magnetizes and demagnetizes. The effect on the secondary coil is therefore the same as if a strong magnet were plunged into it and then withdrawn very rapidly. Hence a high-voltage current is induced in the secondary coil and the rotor of the distributor applies this current to the spark plugs in the proper order. For certain reasons fully explained in Physics texts, the induced voltage is highest on the break. The condenser G assists in producing this effect and also prevents bad sparking at the breaker points when they open.

17. **Magneto ignition.** Some automobiles and most air craft use magnetos for ignition. Here again induced currents are set up by altering very rapidly the number of magnetic lines of force passing through a coil. One type of magneto is shown in Fig. 12. A primary coil A and a secondary B are wound on a soft-iron core which is made to rotate rapidly between the poles N and S of a permanent magnet. This rotating assembly is the *armature*. Connections are made to the rotating coils through sliding contacts called brushes but for simplicity these are not shown in the diagram. One end of the primary

coil is grounded while the other end is joined at C to one end of the secondary coil. The other end of the secondary connects to the rotor R which supplies the high-tension current to the spark plugs at the proper time. C is connected to the inner breaker point H, and the breaker lever E which carries the other point is grounded. The points are made to open by the shoes G which rotate in the direction of the arrow. A condenser F is bridged across the breaker points.

As the armature rotates a current is induced in the primary coil and when this is broken suddenly at H a very high voltage current is induced in the secondary. This current is then distributed to the spark plugs.

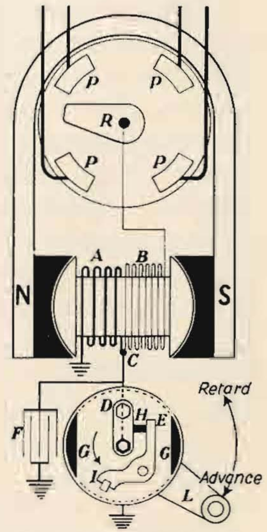


Fig. 12.—A magneto for a four cylinder engine.

Many magnetos are now constructed with rotating permanent magnets and fixed coils but the general principle of operation is the same.

18. **Ignition timing.** A short interval of time occurs between the occurrence of the spark and the combustion of the mixture. Hence the spark must be timed to occur before the piston reaches the end of the compression stroke. This is called *advancing* the spark and the magneto in Fig. 12 is equipped with a lever for advancing the spark to the proper position to secure the maximum power from the engine.

When the engine is running rapidly the spark should be advanced more than when it is running slowly. In most modern engines this change is effected automatically.

19. **Ignition switch.** In battery ignition (Fig 11) opening the switch A stops the engine by cutting off the primary current which magnetizes the core. In magneto ignition, however, permanent magnets are used and the engine is stopped by short-circuiting the primary coil by a switch which could be inserted in Fig. 12 between D and "ground". When this switch is *closed* the opening of the breaker points produces no change in the magnetic flux through the secondary coil and consequently the voltage in the secondary does not rise high enough to produce a spark. This is the "off" position of an aeroplane magneto ignition switch.

SECTION III

LUBRICATION AND COOLING

20. **Importance of Lubrication.** Where one part of a machine slides over another there is friction, which results in loss of mechanical energy and wear of the moving parts. It is essential, therefore, that friction should be reduced to a minimum by proper lubrication. Good lubrication is effected by using the correct quantity and grade of oil and by distributing it to all the sliding surfaces. The use of inferior oil is poor economy and even the best oil must be changed when it becomes dirty or diluted with gasoline.

21. **Oiling System.** Fig. 13 shows some of the details of the oiling system of an automobile engine. A is the crank-case or sump which should be filled with oil to the level specified by the manufacturer. B is a screen to pre-

vent dirt which has settled in the sump from being circulated through the system. The gear-pump C draws oil from A and forces it through the pipes D and E at a pressure indicated by the gauge shown at the right of the diagram. The oil which travels through D lubricates the crankshaft bearings H and then some of it passes through holes drilled in the connecting rods I to lubricate the wrist-pins J. Oil which escapes from these bearings is thrown onto the cylinder walls, pistons, cams and other moving parts after which it drains back into the sump. Another oil line lubricates the camshaft bearings.

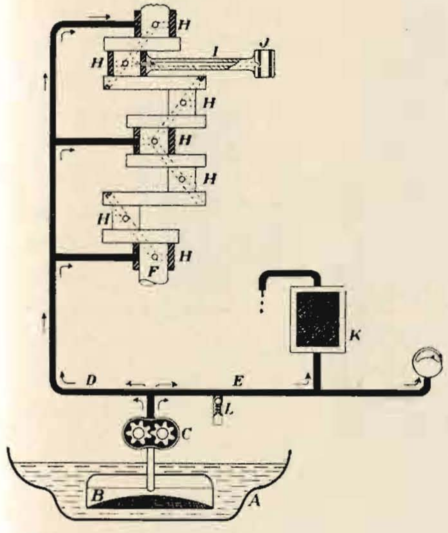
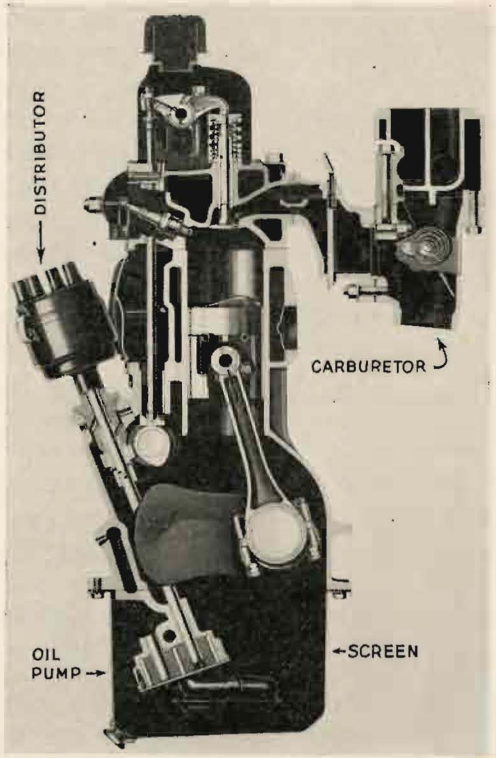


Fig. 13.—Engine lubrication system.

Some oil also passes through the pipe E into the filter K and then returns to the sump. A relief valve L opens to prevent the pressure exceeding the proper amount, which in many automobile engines is about 30 pounds per square inch.

In addition to this *force feed* method of lubrication a *splash* system is sometimes used, the oil being splashed by the revolving crankshaft onto the other moving parts. Also certain external bearings must be oiled or greased by hand.

Fig. 14 shows the position of the screen and oil-pump in a modern engine. The distributor and pump are mounted on the same shaft which is driven by a gear



(*Courtesy of General Motors*)

Fig. 14.—Showing the oil-pump, screen and many other details of a modern engine.

meshing with one on the camshaft. Other details of the engine are clearly seen.

22. **Oiling of aero engines.** Since an aircraft engine must function in any position it is not usually feasible to

have much oil in the sump and consequently *dry sump* lubrication is used. The oil which drains into the sump is removed by a *scavenging* pump and delivered to an oil tank from which it is drawn by a *pressure* pump and forced to the bearings as described in Sec. 21.

23. **Cooling the engine.** A great deal of heat is produced in the engine by the combustion of the fuel and only a small fraction of this is converted to mechanical energy. It is therefore necessary to provide some cooling device to carry the heat away from the metal, as otherwise the temperature would rise so high that the engine would be damaged.

The cooling system must be so designed that the temperature neither rises too high nor falls too low, since a cold engine does not operate efficiently because of incomplete vaporization of the fuel.

Many aeroplane engines and motorcycle engines are *air-cooled.* Some aero engines and almost all automobile engines are *liquid-cooled.*

24. **Liquid cooling.** Some of the details of an automobile liquid cooling system are shown in Fig. 15. The coolant is usually water in summer, while in winter an *anti-freeze* solution is used. The cylinder is surrounded

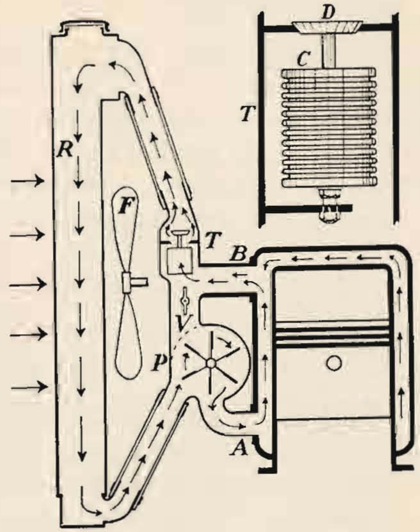


Fig. 15.—Details of automobile cooling system.

by a water jacket with an inlet at A and an outlet at B connected by hose to the radiator R. In normal running conditions the liquid which has been heated in the jacket is made to circulate through the radiator in the direction of the arrows, partly by convection and partly by the action of the pump P. As the liquid descends it is cooled by air drawn through the radiator by the fan F. However, when the engine is cold, a thermostatic valve T keeps the liquid from circulating through the radiator and it is by-passed through the valve V back to the jacket. When the proper temperature for efficient operation is reached T opens and V closes and the water circulates through the radiator. More of the details of the thermostatic valve are shown in the enlarged diagram above the cylinder. D is the valve proper and C a bellows-shaped capsule containing a volatile liquid which vaporizes and causes D to rise from its seat at the required temperature.

25. **Air cooling.** The radial engine in Fig. 5, Sec. 7, is air-cooled. It will be noted that the outside of each cylinder is provided with fins which present a great area of metal to the cooling action of the air blast which comes from the propeller. Air-cooled engines are easily recognized by this typical appearance.

SECTION IV

ENGINE CONTROLS AND INSTRUMENTS; AIRSCREWS

26. **Engine controls.** The functions of the throttle, ignition switch, choke and mixture controls have been discussed briefly in preceding sections. Other controls encountered in aero engines are the fuel supply cock, propeller pitch control, carburetor air heater, manifold

pressure regulator, oil cooler shutter and exhaust gas analyzer. Some of these will be dealt with later.

27. **Instruments.** Everyone is more or less familiar with the instruments found on the panel of an automobile although many drivers pay very little attention to them. These are the oil pressure gauge, the thermometer to indicate the temperature of the coolant, the gasoline gauge, the ammeter which indicates the rate at which the battery is being charged or discharged and the speedometer.

In an aeroplane the revolution per minute indicator and the oil temperature and oil pressure gauges are very important instruments and the principles on which they operate should be understood.

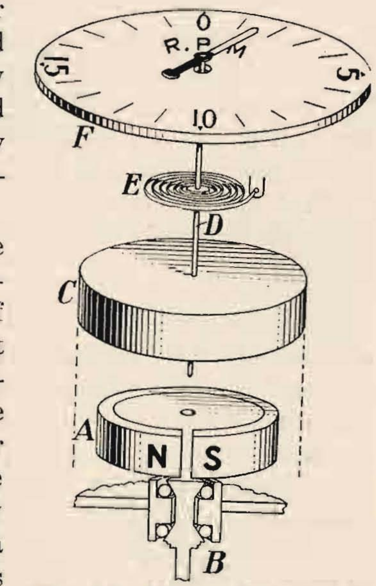


Fig. 16.—The working parts of an r.p.m. indicator.

28. **R.P.M. indicator.** The revolution per minute indicator measures the speed of rotation of the crankshaft and may be of the centrifugal or magnetic type. One form of a magnetic indicator is shown in Fig. 16. The shaft B which is driven by the crankshaft carries a circular magnet A with poles at N and S. Over this fits closely a light aluminium cup C supported on a pivot so that it can rotate independently of the magnet. This cup has been raised in the diagram to show the magnet. Fastened to the spindle D above the

cup is a coiled hair spring E, the outer end of which is fastened to a part of the case of the instrument. The upper end of the spindle carries a hand which moves over a dial graduated in revolutions per minute. (Each division on the dial shown indicates 100 r.p.m.) Around the cup C is fitted a fixed field cup of iron to lead the magnetic lines of force through the aluminium cup. When the magnet is made to rotate rapidly by the shaft, induced currents are set up in the aluminium cup and these currents flow in such a direction as to oppose the motion which produces them (Lenz's Law). Consequently the cup tries to follow the magnet as it rotates and the more rapid the rotation the greater is the deflection of the cup, spindle and pointer against the opposing torsion of the spring. If the spring is constructed properly revolutions per minute may be indicated.

Most speedometers on cars are constructed on this principle but many of them use a bar magnet instead of a circular one.

29. **Pressure gauge.** Fig. 17 shows the details of the Bourdon type of pressure gauge, which may be used to measure the pressure exerted by either a liquid or a gas. The fluid enters at A and passes into a curved tube B made of brass and having an ellptical cross section. The upper end of the tube is closed at C and is connected by the link D to the outer end E of a lever pivoted at F. The inner end of the lever carries a set of teeth and these mesh with a pinion G, to the spindle of which is fastened the indicating hand.

The pressure of the gas or liquid in the brass tube causes it to try to straighten out and as the end C rises the pointer is made to rotate in a clockwise direction. Most gauges read pressure in pounds per square inch.

30. **Importance of oil pressure gauge.** A failure of the oil pressure gauge (Fig. 13) to register means, in all probability, that oil is not being supplied to the moving parts of the engine and consequently the engine should be stopped until the fault is located and corrected.

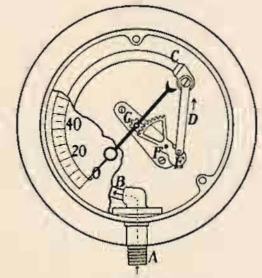


Fig. 17.—A Bourdon pressure gauge.

31. **Oil temperature gauge.** Proper lubrication of an engine depends on the oil having the correct viscosity and this depends on the temperature. It is important therefore to keep the oil temperature between certain limits. Cold oil becomes viscous or "thick" and doesn't flow properly through the small openings to lubricate the bearings while very hot oil is too "thin" to keep the sliding metal surfaces separated. The oil temperature gauge enables the pilot to see whether the temperature is right. Correction of this temperature may be made by adjusting the oil cooler shutter to vary the flow of air past the cooler which is a sort of radiator set in the line between the scavenging pump and the oil tank.

One type of temperature gauge consists of a Bourdon pressure gauge similar to that in Fig. 17 connected by a fine bore tube to a bulb which is immersed in the oil. The bulb, connecting tube and Bourdon tube are made of steel and are filled with mercury. When the temperature rises the mercury expands and moves the indicator. The dial in this case is, of course, graduated in degrees.

32. **Action of airscrew.** The propeller or airscrew has already been described briefly in Sec. 8. We shall now consider some of the forces acting on it as it rotates. Fig. 18 shows a transverse section through one of the blades of the propeller. The blade is rotating in the direction AB and at the same time the aircraft is moving in the direction BC. The lines AB and BC are proportional to the velocities in these directions. As a result of these two velocities the effect on the blade is the same as if a blast of air were directed against it from the direction CA. This relative air velocity in the direction CA is equivalent to a velocity along the blade in the direction DA and a velocity at right angles to the blade in the direction DE. This latter component produces a force in the direction DE which may be resolved into two forces represented in direction and magnitude by DF and DG. The *thrust* DF is the force which drives the aeroplane

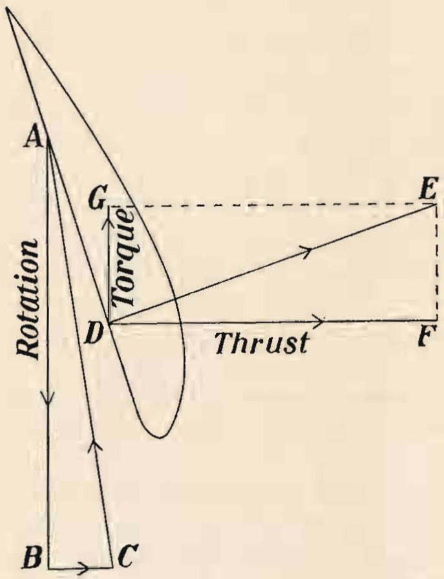


Fig. 18.—Forces acting on a propeller blade.

forward while the *torque* DG is a force tending to oppose the rotation of the propeller. The ratio of these two forces depends on the *pitch* of the airscrew.

33. **Pitch.** The pitch is the distance in feet which the propeller travels forward during one revolution. This depends on the angle at which the blade is set with reference to the plane of rotation and on the diameter of the airscrew.

A "high" pitch airscrew is one where the angle is large and where each revolution would make the aeroplane advance a larger distance than it would if the pitch were "low". With the low pitch airscrew, however, the torque will be less and the engine will be able to make more revolutions per minute and consequently develop greater power.

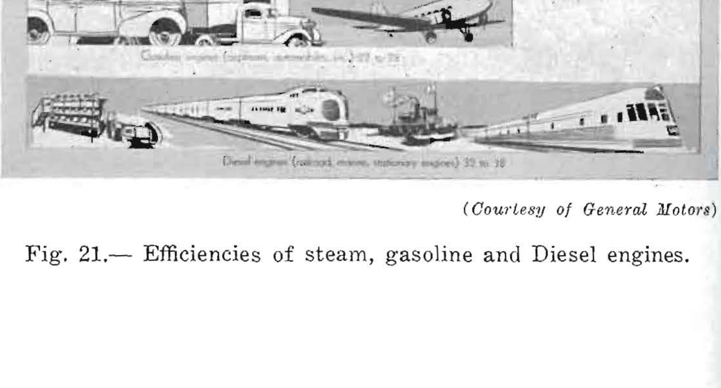
34. **Variable pitch propellers.** Some aeroplanes still have *fixed pitch* propellers but no fixed pitch can be suitable for all conditions.

A low pitch will give good take-off, the plane will climb well and will have a high top speed, but the engine is running so rapidly that it is inefficient in the matter of fuel consumption when cruising. A high pitch will produce good cruising speed at a much lower speed of rotation but it is inefficient in take-off and climb and doesn't develop a high top-speed.

It will be seen, therefore, that it is advantageous to have propellers whose blades may be varied to meet different conditions of flight. The term *adjustable pitch airscrew* is usually applied only to a propeller whose blades may be altered on the ground while a *controllable pitch airscrew* may be changed by the pilot while in flight. A *constant speed airscrew* is one in which the blades automatically adjust themselves so that the revolutions per minute of the engine remain constant.

35. **Engine Efficiency**. By the efficiency of an engine we mean its ability to turn the heat energy of the fuel into mechanical work. This is expressed as a percentage. An engine having a thermal efficiency of 25% converts one-quarter of the heat energy into useful work; the remainder is lost through radiation, friction and in other ways.

Fig. 21 shows graphically the efficiencies of some common engines. It will be seen that on the average gasoline engines are more efficient than steam engines and that Diesel engines have the highest efficiency.



(Courtesy of General Motors)

Fig. 21.— Efficiencies of steam, gasoline and Diesel engines.