SINGLE-ROW RADIAL ENGINES

Static radial engines, those in which the cylinders do not rotate, may be divided into two main classifications: the single-row, and the twin-row. In the single row type, an example of which is shown in Fig. I, the cylinders are spaced evenly, in one plane around the crankshaft. All the connecting rods lead to their respective pistons from one large bearing on a single-throw crankshaft.

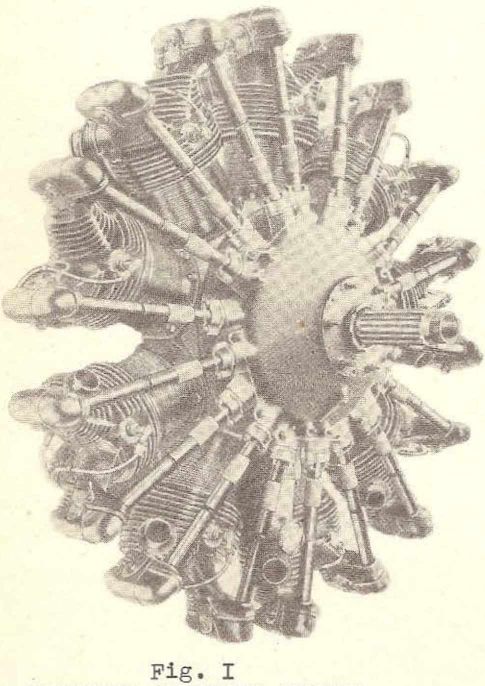


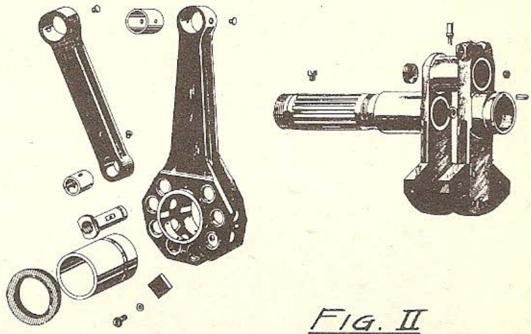
Fig. I
LYCOMING AVIATION ENGINE

Single-row radial engines have an odd number of cylinders usually three, five, seven or nine. They are made in this manner in order to secure a combination of power impulses that will be spaced evenly throughout the entire 720° of the operating cycle. For example, a six-cylinder single-row radial could have a firing order of 1, 2, 3, 4, 5, 6, as each piston comes to top center in rotation. However, in this event, all of the cylinders would fire in one revolution of the crankshaft and the engine would have to "coast" through the next revolution to allow each cylinder to exhaust. Or, it would be mechanically possible to have the explosions spaced 1, 3, 5, 6, 2, 4, but this would mean that two cylinders, 5 and 6, would fire consecutively, and then there would be a large gap between #4 and #1. In either case the engine would be exceedingly rough.

With an odd number of cylinders the power impulses are spaced so that there is a gap of one cylinder between each explosion. Thus on a nine-cylinder engine, the cylinders to fire on the first revolution of the crankshaft are 1, 3, 5, 7 and 9. Meanwhile, the even numbered cylinders are exhausting. On the second crankshaft revolution cylinders 2, 4, 6 and 8 fire and the others exhaust. Thus, it may be said that the firing order of single-row radial engines is every other one, or 1, 3, 5, 2, 4 for a five-cylinder; 1, 3, 5, 7, 2, 4, 6 for a seven, and 1, 3, 5, 7, 9, 2, 4, 6, 8 for a nine. Of course it would be possible to fire the cylinders in rotation but as previously mentioned, this would necessitate the engine coasting for one crankshaft revolution.

The crankshaft, having only one throw, can consequently be made quite strong without being as heavy as those on in-line engines. The crankshaft main bearings are on each side of the throw and are usually of the ball or roller bearing type. The connecting rods are of the articulating type, similar to those used on the W and X engines. The master, or "mother" rod has a large crankshaft bearing and all other rods are pinned to this bearing with knuckle pins. See Fig. II

The overhead valves are opened by a rocker arm and push rod assembly which in turn is actuated by the cam lobes on a cam ring geared to the crankshaft. The cam ring, having four lobes (in most cases) naturally turns only one-eighth of crankshaft speed, since each valve is actuated four times for each cam ring revolution which allows for eight crankshaft revolutions.



Courtesy WRIGHT AERONAUTICAL

FIG. II

Radial engines are usually air cooled, saving considerable weight, due to the elimination of water radiators, tanks, plumbing, etc., as well as avoiding all trouble with liquid cooling systems. These engines present a larger frontal area than in-line and Vee engines of equal horsepower, but this objection is partially offset by their compactness and lower weight.

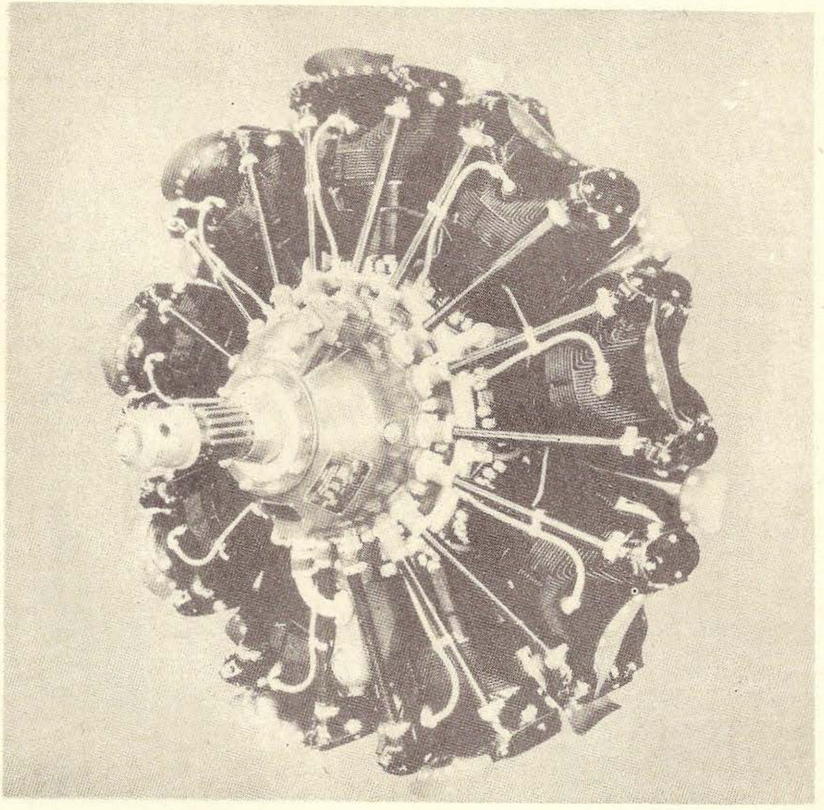
The carburetor delivers the fuel mixture directly into a section of the crankcase, where it is diffused and distributed through individual pipes to each cylinder. There are many types of crankcase diffusers and blowers which will be described later.

Although some radial engine installations still employ short exhaust stacks from each cylinder, in most cases the cylinders exhaust into a common collector ring. From the collector ring, one or two outlets can be led to some suitable place for exhausting the gas. See Exhaust Systems.

RADIAL ENGINES

Radial engines differ from all other types in that their cylinders are arranged in a plane perpendicular to the centerline of the crankshaft. This type of construction is particularly well suited to air cooled engines as each cylinder receives approximately an equal share of cooling air. There are many types of radial engines, ranging from three cylinders to nine or more cylinders; however the most common type for the larger engines has nine cylinders.

Fig. I shows a three-quarters front view of a 1,000 h.p. Wright Cyclone. This illustrates the stamped, sheet metal deflectors between and above each cylinder. These deflectors, or baffles, serve to direct the air around the cylinder, thus assuring pressure air cooling for the rear of the cylinder.



1,000 H.P. Wright Cyclone

Fig. I

Fig. II shows a rear view of the 550 h.p. Pratt & Whitney Wasp. This view further illustrates the construction of baffles.

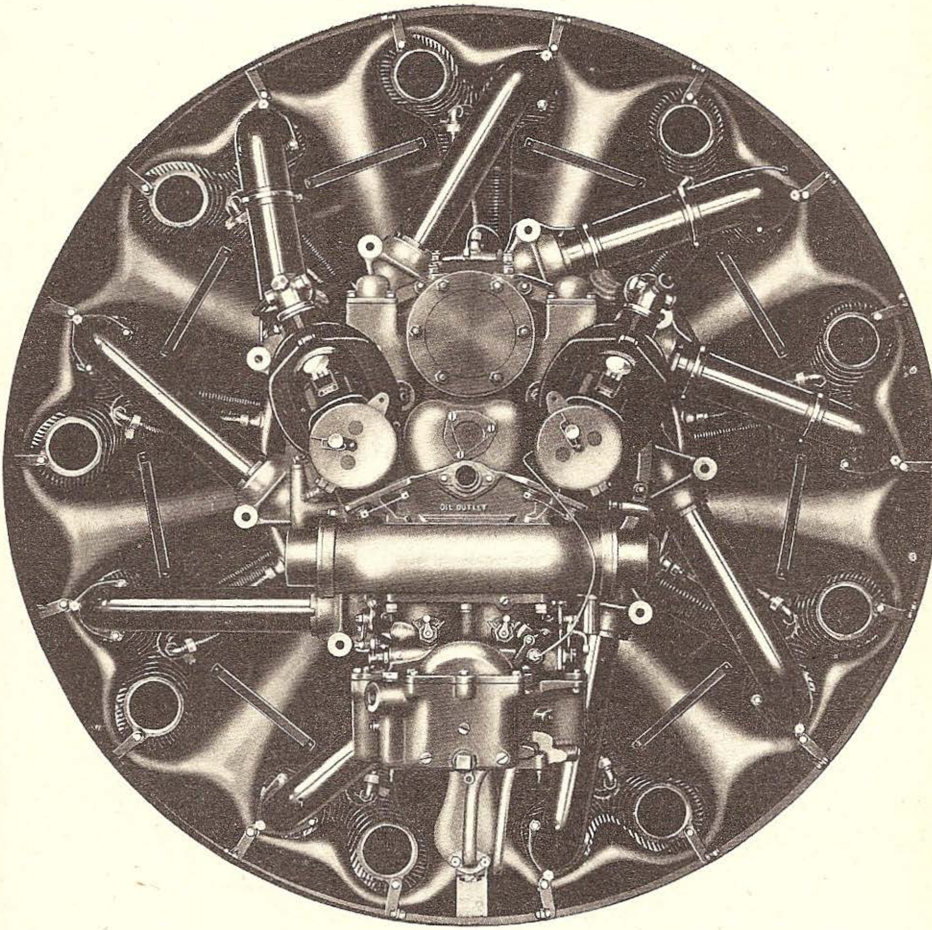


Fig. II

Cylinder Construction - Radial engines use individual cylinders. The cylinder barrels are made of steel and are usually screwed and shrunk into a cast aluminum alloy head. In some of the smaller radial engines, such as the Kinner, the barrels are bolted to the head. The machined steel cylinder barrels are made with a long skirt which extends into the crankcase. As in the inverted engines, this feature prevents the crankcase oil from running down into the lower cylinders. In order to save weight and provide better cooling the cylinder barrels have very thin walls, usually about 1/8" thick, yet these walls must be strong enough to meet the engine requirements.

For this reason the very best grade of steel obtainable is used in their construction. A special type of steel called "nitralloy" is used by the Wright Aeronautical Corp.

The cylinder heads are made of cast aluminum alloy and are finned for better cooling. The head contains the exhaust and intake ports, spark plug ports, and the rocker boxes. Some of the smaller engines have removable rocker boxes. The valve guides are of bronze and are pressed and shrunk into the head. The valve seat inserts are of bronze and are pressed and shrunk into place. Some of the larger engines are using stellite-faced valve inserts. Fig. III shows a typical Pratt & Whitney Wasp cylinder. In this cylinder it will be noticed that the exhaust port has a shrunk-in stainless steel liner which is designed to permit the exhaust stack to be inserted inside the liner and secured by a single stud. Note: The two cables extending from the spark plug base are for a thermo-couple connection.

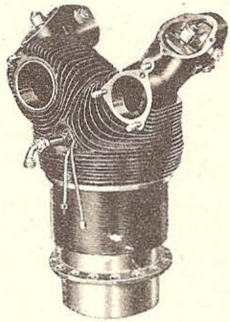


Fig. III

Valve Operating Mechanism - Most radial engines have a cam ring instead of the conventional camshaft. The cam ring in nine-cylinder engines usually has four lobes to operate the intake valves and four lobes to operate the exhaust valves. If provided with four lobes the ring is geared to the crankshaft so that it turns at 1/8 crankshaft speed, or so that the valves open only once for every two revolutions of the crankshaft, as explained in the previous chapter. Fig. IV shows the cam gear arrangement on a Wasp engine. The gear, a, is keyed to the crankshaft and drives gear b. Gear b turns the idler shaft, c, to the rear of which is attached a smaller gear. This small gear meshes with the internal teeth on the cam ring, d. As the cam ring rotates the cam lobes, e, force the cam followers, f, upward. The cam followers transmit this thrust through a push rod to one end of a rocker arm mounted on top of the cylinder. The other end of the rocker arm comes in direct contact with the valve stem, thus forcing the valve open. The valve springs close the valve when the cam follower rolls off the cam lobe. The valve clearance, or the space between the rocker arm roller or tapper and the end of the valve stem, is adjusted by means of an adjusting screw in the rocker arm. The clearance is increased or decreased by loos-

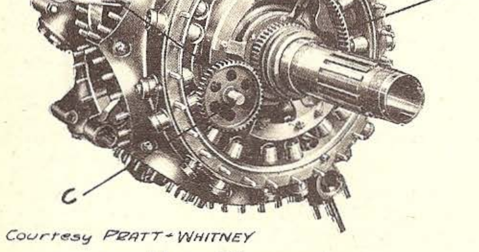
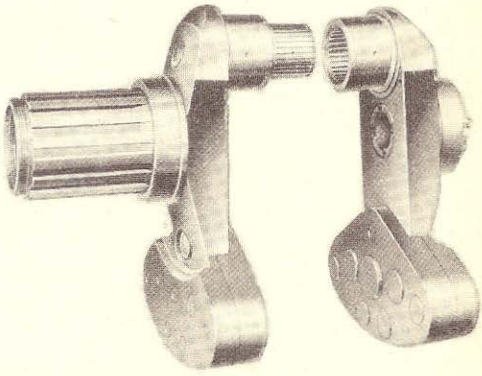


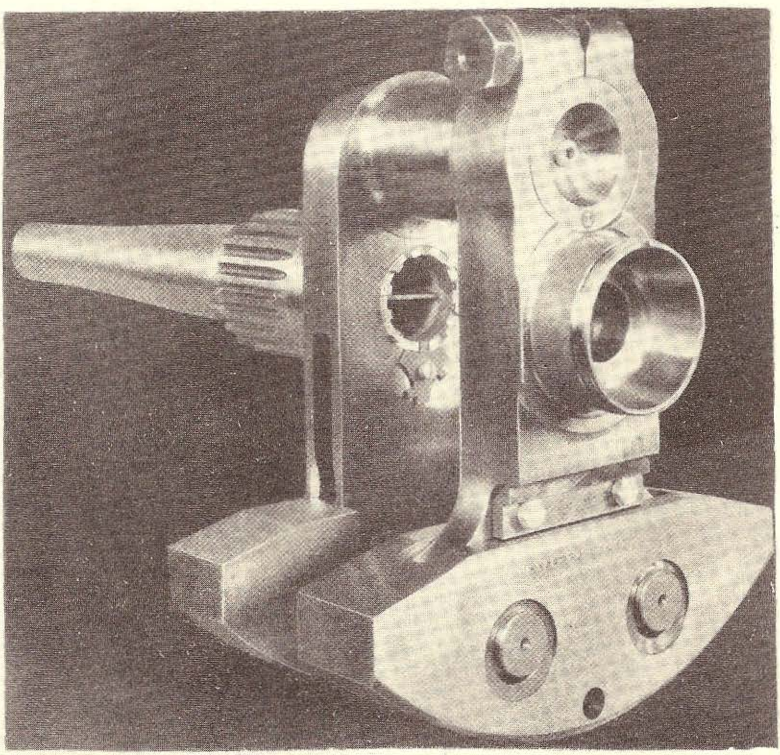
Fig. IV

ening or tightening the adjusting screw. The adjustment is locked either by a lock screw or by a jam nut.

<u>Crankshaft Construction</u> - Most radial engines use a two-piece, single throw, counter-balanced crankshaft made of chrome-nickel steel. Some of the small engines, such as the Warner and Rearwin Le Blonds, use a single-piece drop forged crankshaft. Fig. V shows the two-piece crankshaft used on Pratt & Whitney Wasp engines. The rear section of the shaft telescopes into the front section and is held in angular position by splines. A through bolt holds the sections together. Most engine manufacturers use a rigid type of counter-balance similar to the type



Wasp Crankshaft
Fig. V



Cyclone Crankshaft Fig. VI

shown in Fig. V. However, the Wright Aeronautical Corporation uses a semi-floating counter-weight, illustrated in Fig. VI. This device is called a dynamic dampener and is best explained by the following excerpt from the manufacturer's description.

"The general appearance of the dynamic damper, as may be seen from the illustration (Fig. VI) ,does not differ greatly from the conventional counterweight. It is extremely simple and rugged in construction. It is entirely self-contained and introduces no complications that can in any way adversely affect engine operation. It is, in principle, a pendulum counterweight which is mounted on the crankshaft in place of the conventional rigidly mounted counterweight; the pendulous mass being free to oscillate in a restricted arc and in the plane of rotation of the counterweight. When disturbed, the restoring force and the frequency of a given pendulum so mounted is determined by the acceleration due to the centrifugal force of rotation of the counterweight. The magnitude of the acceleration is in turn determined by the speed of the rotation of the crankshaft. Hence, the frequency of any given pendulous mass so mounted will bear a fixed ratio to the speed of rotation of the crankshaft.

"In the case of the Cyclone engine the mass and dimensions of the pendulous weight are of such values that the natural period of oscillation is four and one-half times crankshaft speed, which equals the frequency of explosion impulses. In operation the pendulous weight is of such dimensions and so mounted that it oscillates at explosion frequency but out of phase with the explosion impulses, and thus applies a counter-torque to the crankshaft which balances out the periodic torque fluctuations arising from the explosion impulses, which explosion impulses cause torsional vibration in any conventional rigid crankshaft system.

"Stops are provided to limit the motion of the counterweight during acceleration or deceleration of the engine. These stops are so arranged that they permit a motion considerably in excess of that required to completely damp the torsional vibration at any speed. During normal operation, therefore, the counterweight never strikes the stops.

"The dynamic damper on the other hand is virtually frictionless and dissipates essentially no energy by friction. It acts by introducing a balancing force which is opposite in direction and equal in magnitude to the disturbing force at all speeds. By reason of this action, the dynamic damper has the potential ability to reduce crankshaft torsional vibration to zero.

"Service experience on several of the major airlines has indicated that in addition to accomplishing its primary object of reducing stresses in the crankshaft, the dynamic damper has reduced fatigue effects in propeller blades, and has markedly reduced wear on the components of controllable propellers."

Crankcase Assembly - Fig. VII shows the relative positions of the six section Wright Cyclone crankcase. The first section, or nose section, carries the cam gear mechanism, cam followers, propeller speed reduction gear and crankshaft thrust bearing, and is also designed to provide for the installation of a constant speed propeller control. The main section, or power section, is divided into two parts, divided along the centerline of the cylinders, and forms the angle decks for supporting the cylinders. This section encloses the crankshaft throw, connecting rod assembly, crankshaft main bearings and cam gear drive assembly. The next section, called the mounting section, carries the engine mount lugs and forms the front wall for the supercharger section. The supercharger section, which is also called the impeller section or blower section, contains the supercharger and diffuser vanes. The section also houses the drive gears for the accessories and provides mountings for the carburetor, fuel pump and machine gun synchronizers. The rear section, or accessory section, forms the rear crankcase cover plate and houses the accessory drives.

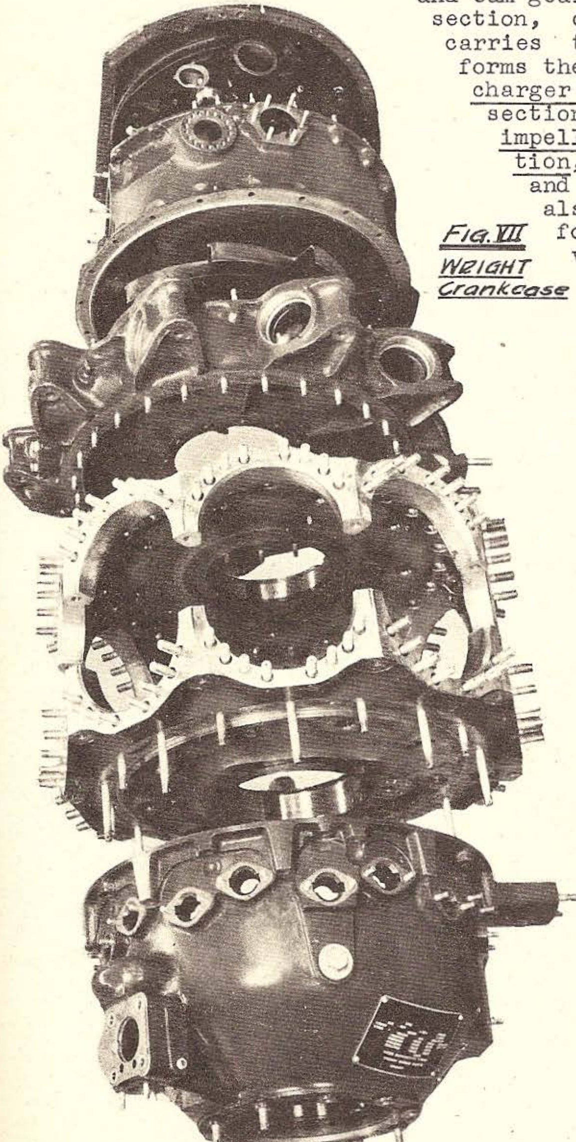


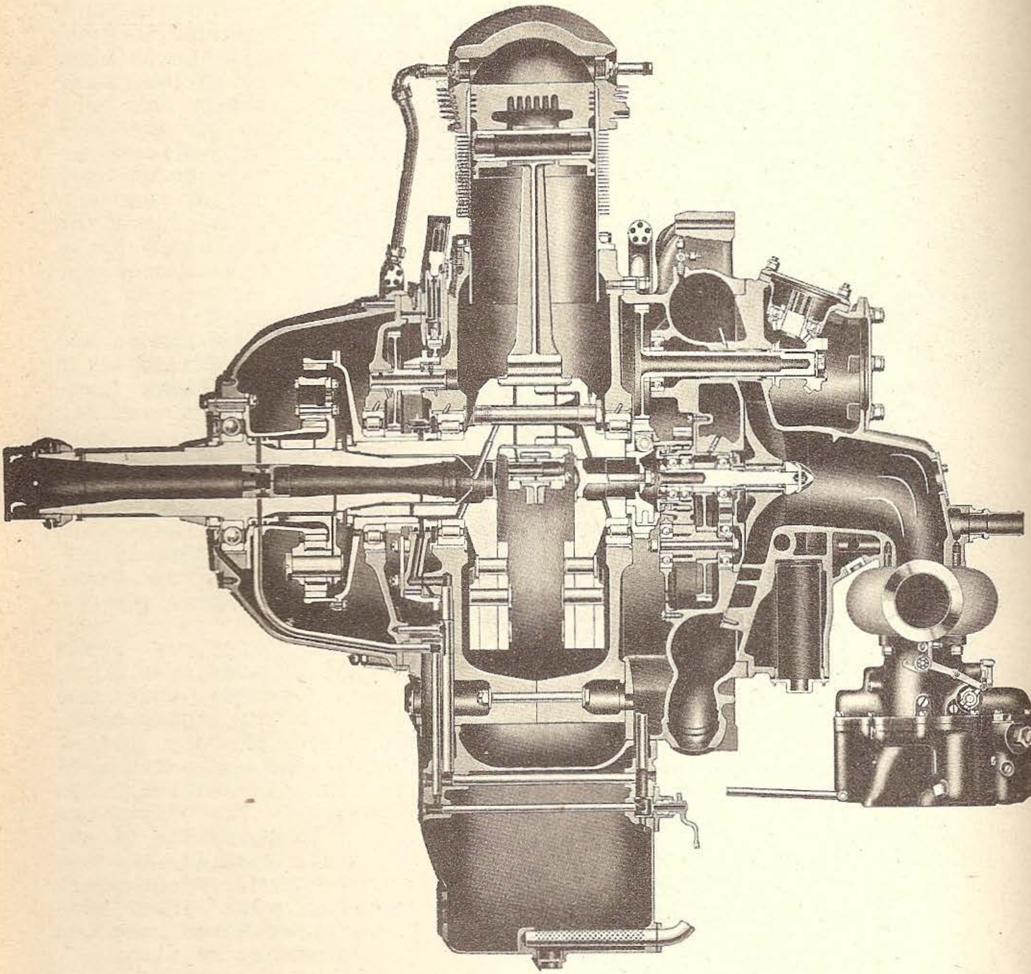
FIG. VII WRIGHT Crankcase

Crankcase sections are often made of forged or cast aluminum alloy. Magnesium alloy is another popular material. Some models of large radial engines use a steel crankcase power section. However, it is unlikely that steel will completely replace aluminum in crankcase construction.

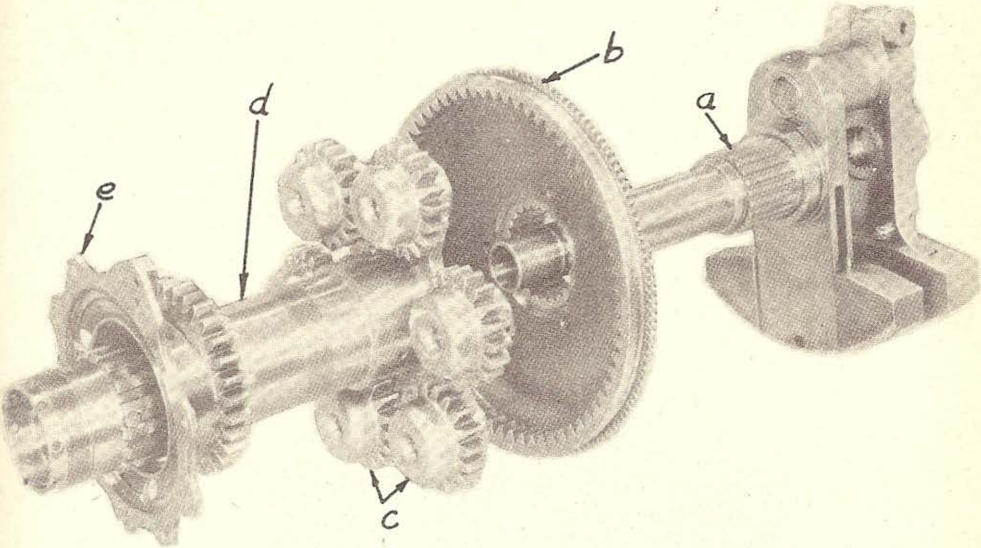
Fig. VIII, a cross section of a Pratt & Whitney Wasp engine, shows not only the crankshaft divisions but plainly illustrates the mechanism carried in each section. In sequence, the divisions are as follows: The first, or nose section, the cam gear section, front power section, rear power section, supercharger section and accessory section.

Smaller radial engines do not use a supercharger therefore the crankcase is very much simplified, usually consisting of only three or four sections. In such cases, the crankcase is divided into the nose section, one or two power sections and the rear section.

Propeller Speed Reduction Gear - Many of the larger radial engines have a reduction gear in the nose section of the crankcase. The purpose of this reduction gear is to allow the engine to turn faster than the propeller. This permits a greater engine output without exceeding an efficient propeller speed.



Cross Section of Pratt & Whitney Wasp
Fig. VIII



WRIGHT CYCLONE REDUCTION GEAR
Fig. IX

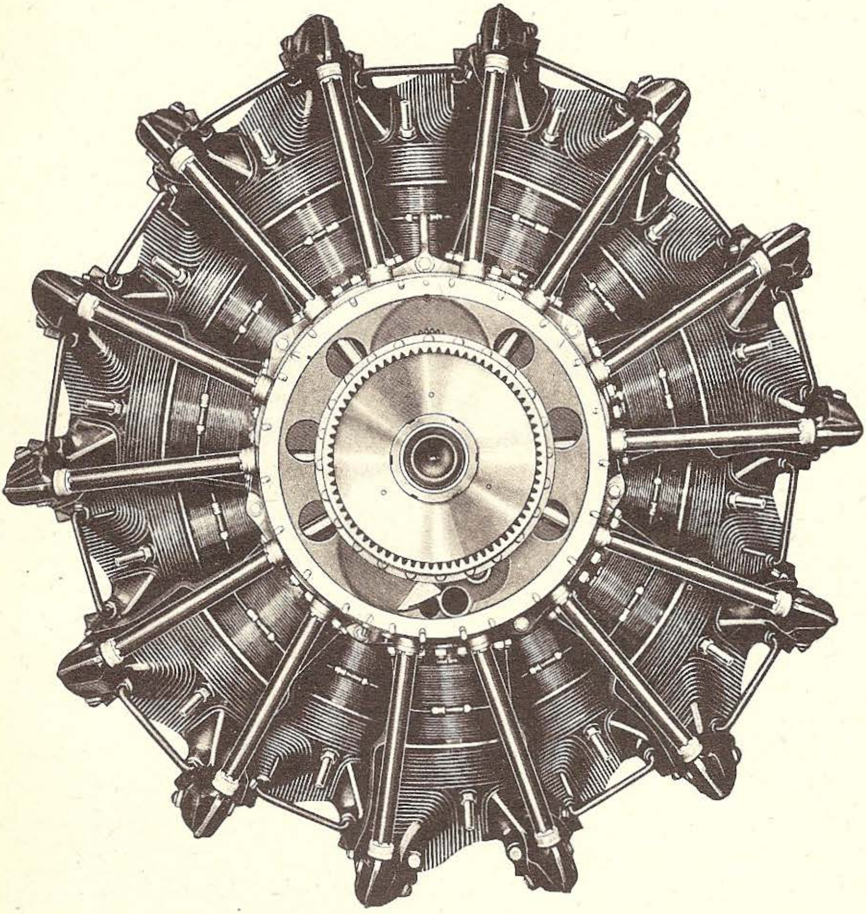
Fig. IX shows the propeller speed reduction gear used on Wright Cyclones. The gear ring, b, telescopes over the crankshaft splines, a, and turns with the crankshaft. The small gears, c, which are free to turn on the propeller shaft, d, mesh with the internal teeth on the gear ring, b, and also with the gear plate, e. The gear plate e, is securely fastened to the crankcase. When the crankshaft revolves, turning the gear ring, the small gears are forced to travel around the stationary gear plate. This causes the propeller shaft to rotate in the same direction as does the crankshaft, but at a slower speed. The ratio between the gears regulates the speed of the propeller shaft. The most common reduction ratio is approximately 3 to 2.

Superchargers - The purpose of a supercharger is to place a positive pressure on the fuel mixture before it enters the cylinder, so that when the intake valve opens a larger quantity of fuel mixture is admitted into the cylinder. This, in effect, increases the compression ratio and results in a more powerful explosion. One of the greatest advantages of a supercharger is that it insures more complete charging of the cylinder when the engine is operating at altitude. Superchargers are discussed more completely in the chapter on Carburetors and Induction Systems.

Piston and Connecting Rod Assembly - The pistons used on radial engines are of conventional type, either of forged or cast aluminum alloy. Some pistons are made with cross ribs, or "waffle plates", on the under side of the head to increase strength and improve cooling.

The connecting rods are of the master and articulated rod type. The master rod has a large crank pin bearing to which all of the other rods are attached with knuckle pins. The master bearing is made in one piece except on some smaller engines which use a one-piece crankshaft, in which case the master bearing is in two pieces and is clamped together by four stud bolts.

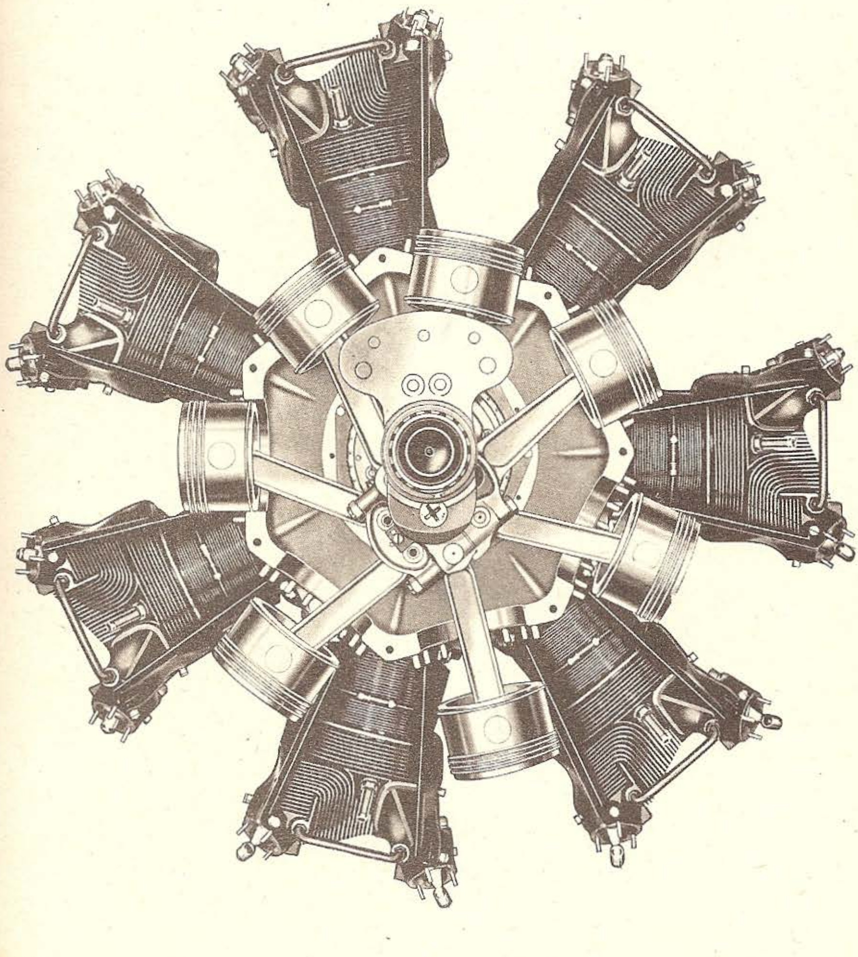
Lubrication - Radial engines are lubricated by a pressure-scavenger system. One or two pressure pumps take the oil from an external tank and force it into the hollow crankshaft. From here the oil is sent to the main bearings, wrist pins, gear drives and also through the pushrods or the pushrod housings to lubricate the rocker arms. Smaller engines do not have pressure lubrication to the rocker arms, in which case the rocker arms are lubricated manually. This is explained in the section "Periodic Check."



Twin Row Pratt & Whitney Wasp
Fig. X

The return oil is not allowed to accumulate in the crankcase but is drained to an oil sump which is lower than the case. From here the oil is returned to an external tank by the return, or scavenger. pump. Oil pumps are explained later.

Twin-Row Radial Engines - These do not differ greatly in general construction from the single-row radial. An external inspection of the engine will show many points of similarity. In fact, many of the parts on the two engines are interchangeable.



Pratt & Whitney Twin-Row Wasp with Front Row of Cylinders Removed
Fig. XI

Fig. X shows a Pratt & Whitney twin-row Wasp with the nose section removed. This view clearly shows the forward cam ring which actuates the valves in the front row of cylinders. There is a second cam ring installed aft of the power section, which operates the valves on the rear row. This means, of course, that each row of cylinders must be timed individually.

Fig. XI shows a front view of a twin-row Wasp in which the front cylinders and the front half of the power section have been removed. It will be seen that only the connecting rods from the front row of cylinders are attached to the throw shown. The rear row connecting rods are attached to the second crankshaft throw, which is diametrically opposite to the first throw.

The crankcase is of the same general construction, with the exception of an additional two sections to accommodate a second row of cylinders. The lubrication system, the exhaust system, the ignition system and the induction system are all similar to those used in the single-row radial, being increased in size to provide for the increased number of cylinders.