WAR DEPARTMENT TECHNICAL MANUAL

TM 1-405

AIRCRAFT ENGINES

WAR DEPARTMENT • JANUARY 1945

United States Government Printing Office, Washington, 1945

For sale by the Superintendent of Documents, Washington 25, D. C.

WAR DEPARTMENT
Washington 25, D. C., 2 January 1945

TM 1-405, Aircraft Engines, is published for the information and guidance of all concerned.

[AG 300.7 (20 Nov 44)]

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For explanation of symbols, see FM 21-6.

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This manual supersedes TM 1-405, 9 December 1941

SECTION I

INTERNAL-COMBUSTION ENGINE PRINCIPLES

1. GENERAL. a. In order to grasp the fundamentals governing the operation of an aircraft powerplant, it is necessary to understand the operating principle of the internal-combustion engine. The study of the powerplant begins with the definition of the term "internal-combustion engine." Internal

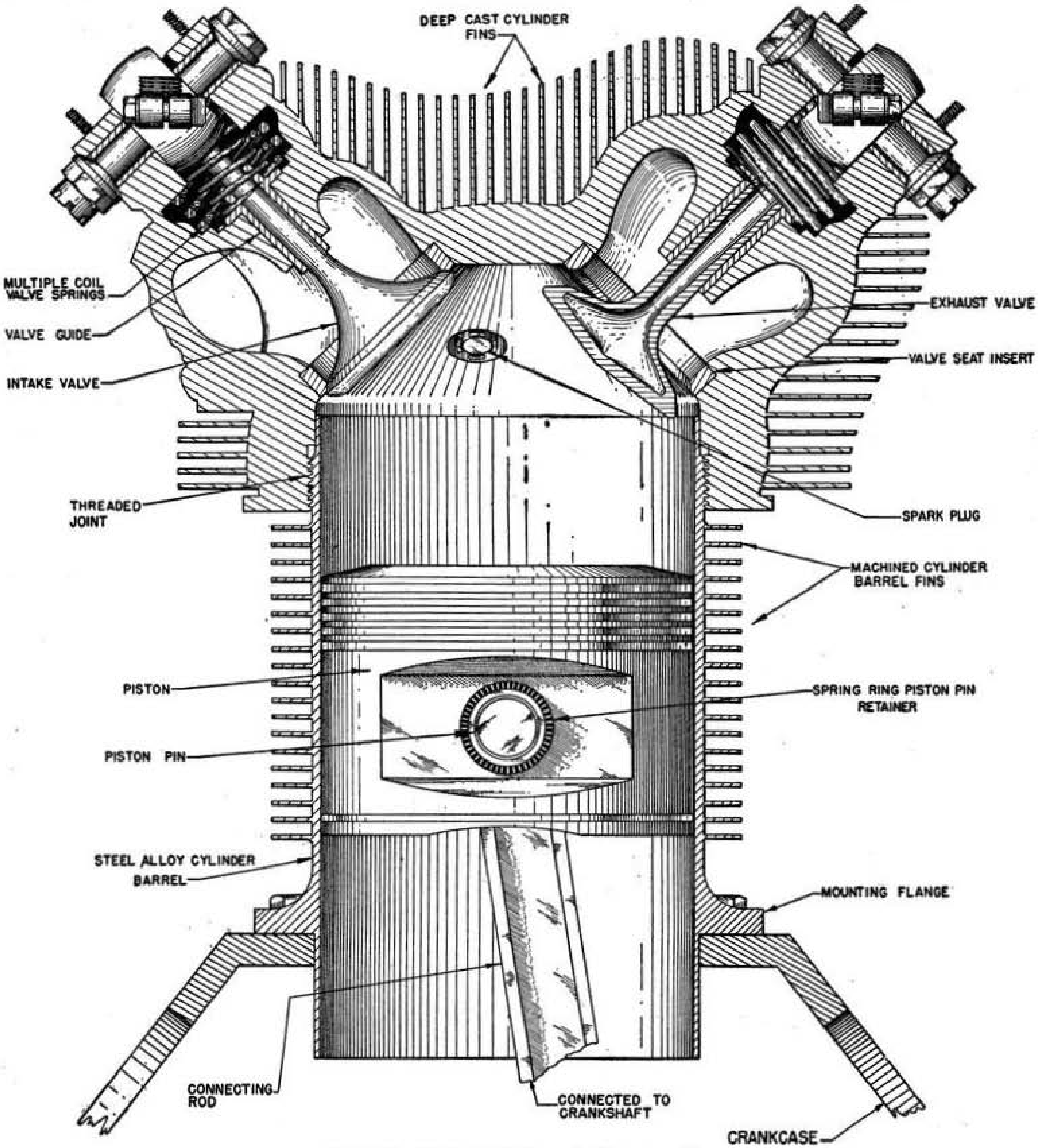


Figure 1. Engine-cylinder and piston assembly.

combustion means the process by which a mixture of fuel and oxygen is burned in a sealed chamber. The word "engine" is interpreted as meaning a machine in which heat energy (released from burning gases) is transformed into mechanical energy (rotation of the crankshaft). Inside the cylinder of a 12-cylinder airplane engine, the crankshaft of which is revolving at 2,000 rpm, a series of events is being repeated very rapidly. In 1 minute, 12 pistons start and stop 4,000 times each; 24,000 electrical sparks jump across the points of 24 spark plugs; and the cylinder inlet and exhaust valves open and close 1,000 times each. The rapidity with which these things take place can only be followed by the imagination. The operation of an engine may therefore seem complicated to the beginner. However, an examination of these happenings will show that there are actually only five different operations (known as "events") taking place. These five events occur over and over, in the same sequence, with great rapidity. Therefore, if the student mechanic understands each of these five events, he will understand the operating principle of an internal-combustion engine. Within each cylinder of an engine the events occur in the same sequence so that the mechanic need understand the operation of only one cylinder in order to understand the operation of all of them.

b. Basic parts. The basic parts of an internal-combustion engine are the crankcase cylinders, pistons, connecting rods, valves and crankshaft. (See fig. 1.) At one end of the cylinder is the cylinder head, in which are located the valves and spark plugs. One of these valves is in a passage leading from the carburetor and is called the inlet (or intake) valve. The other is in a passage leading to the atmosphere and is called the exhaust valve. These valves are operated by a mechanism which is discussed in a later section. The piston is attached to a crankshaft by means of a connecting rod. As the piston moves up and down within the cylinder the crankshaft is rotated.

2. ENGINE CYCLE. a. An engine cycle is a series of operations or events which an internal-combustion engine must perform in order to operate continuously and deliver power. These events are timed (made to occur in a certain sequence). The piston will draw in a mixture of fuel and air, and compress it. The mixture is ignited at the end of the compression stroke by an electrical spark, causing it to burn and expand. The expanding gases force the piston down rotating the crankshaft. The piston then moves upward and forces the burned gases out of the cylinder. This series of five events (composed of four *strokes*) is called a cycle of events and must take place in the aforementioned order if the engine is to operate.

b. Stroke. Stroke, as used in the discussion of internal-combustion engines, is the distance that the piston travels from the top-dead-center to bottom-dead-center, or vice versa. There are, therefore, two strokes of each piston for each revolution of the crankshaft.

(1) *Top-dead-center.* Top-dead-center is the position that a piston assumes when it has reached its maximum distance from the center line of the crankshaft. This may also be termed "the top of the stroke." Top-dead-center is abbreviated T.D.C.

(2) *Bottom-dead-center.* Bottom-dead-center is the position that the piston assumes when it has reached its minimum distance from the center line of the crankshaft. Bottom-dead-center is at the opposite end of the cylinder from top-dead-center. This is also known as "the bottom of the stroke" and is abbreviated as B.D.C.

3. FOUR-STROKE CYCLE PRINCIPLE. Most internal-combustion engines operate on the four-stroke, five-event cycle principle. There are four strokes of the piston, two up and two down, for each operating cycle. (See fig. 2.)

a. Intake Stroke. As the piston moves downward on the intake stroke, the intake valve is open and a charge of fuel and air is admitted into the cylinder. This is the intake stroke (event No. 1). At the completion of this stroke the intake valve closes.

b. Compression stroke. As the crankshaft continues to rotate, the piston is forced upward in the cylinder. This compresses the fuel-air mixture and is called the compression stroke (event No. 2).

c. Power stroke. As the piston nears the top of its stroke within the cylinder, an electrical spark jumps across the points of the spark plugs and ignites the mixture. This is called the *ignition event* (event No. 3). The fuel-air mixture, now ignited, burns. As it burns it expands and drives the piston downward causing the crankshaft to revolve. This is called the power stroke (event No. 4). It is the only stroke and event that delivers power to the crankshaft.

d. Exhaust stroke. The exhaust valve opens as the crankshaft continues to revolve and the piston is again moved upward in the cylinder. This forces the burned gases out of the cylinder, and is called the exhaust stroke (event No. 5). The exhaust valve then closes, the intake valve again opens, and the entire four-stroke, five-event cycle is repeated.

e. Summary. This five-event sequence of intake, compression, ignition, power and exhaust is called a cycle, and is repeated over and over as long as the engine continues to operate. For example, it is only when ignition is added to the other four events and takes place in the proper sequence that the engine will operate. If the ignition switch is turned off, the mixture will not be ignited, there will be no power stroke or event, and the engine will stop. If the gasoline supply is shut off, there is no gasoline in the charge to ignite and therefore no power event occurs and the engine stops. It must be understood that in order to start the engine, the crankshaft must be rotated by an outside source of power such as a crank or starter, until a power event takes place.

4. CONVERSION OF HEAT ENERGY INTO MECHANICAL ENERGY. There may be some question as to why the burning of the fuel-air mixture causes the piston to be forced down in the cylinder on the power stroke. When the mixture is ignited by the spark it burns, and it gives off heat. The heat is absorbed by the carbon dioxide, nitrogen, and other

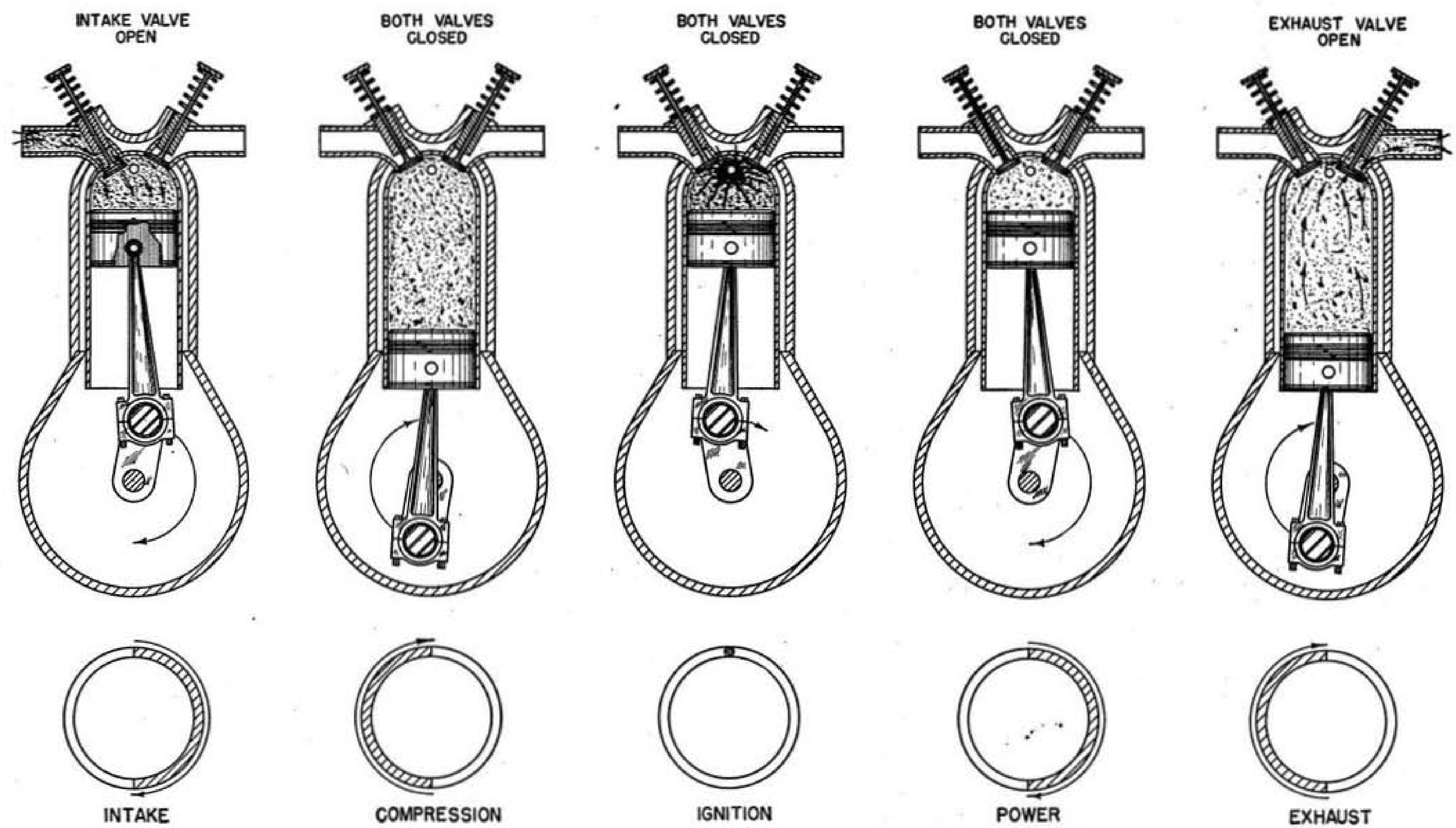


Figure 2. Four-stroke five-event cycle principle.

gases in the cylinder and causes them to expand. The pressure of a confined gas is directly proportional to its temperature. (Charles Law). Therefore, as the temperature of the gas is increased, the pressure of the gas is increased. It is this gas pressure acting evenly over the entire head of the piston that imparts motion to it and produces mechanical power. The straight-line motion of the piston is converted to rotary motion by connecting the piston to the crankshaft with a connecting rod.

5. TWO-STROKE CYCLE PRINCIPLE. a. Principle of operation. The explanation previously given was for a four-stroke cycle engine. While most aircraft engines operate on the four-stroke cycle principle, a few of the small auxiliary engines operate on the two-stroke cycle principle. The principle of operation of the two types is similar. The difference is in the method of inducting the fuel-air mixture into the cylinder, and the number of strokes per operating cycle. As the piston of the two-stroke cycle engine moves up in the cylinder, a partial vacuum (low pressure) is created in the crankcase. This partial vacuum draws the fuel-air mixture from the carburetor, through a check valve, and into the crankcase. As the piston moves downward and nears the lowest point in its stroke, the intake port is opened and the mixture compressed in the crankcase flows into the cylinder. This is the intake event. As the piston moves up in the cylinder, the intake port is closed and the fuel-air mixture in the cylinder is compressed. At the same time, a new charge is drawn into the crankcase. (See fig. 3 ①.) This is the compression event. As the piston nears the top of the stroke, a spark occurs between the points of the spark plug and ignites the fuel-air mixture. This is the ignition event. The burning, expanding gases drive the piston down. (See fig. 3 ②.) This is the power event. As the piston moves down, the charge in the crankcase is compressed. As the piston nears the bottom of the cylinder, the exhaust and intake ports are opened. The exhaust gases escape through the exhaust port and a new charge of fuel-air mixture enters from the crankcase. This is a combination of exhaust and intake events. (See fig. 3 ③.) A baffle is incorporated on the head of the piston to deflect the incoming gases upward and prevent their escape through the exhaust port. The crankcase is part of the intake manifold of this type of engine and must be air tight.

b. Advantages and disadvantages. Mechanical simplicity is the principal advantage of the two-stroke cycle engine. However this type is less efficient than the four-stroke cycle engine and presents problems in cooling and lubrication which limit its use at the present time.

6. DIESEL-ENGINE PRINCIPLE. a. Principle of operation. (1) Another type of internal-combustion engine is the Diesel. The principle of operation of this engine varies from the principle previously explained in that no electrical ignition is necessary. On the intake stroke of a Diesel engine, air only is drawn into the cylinder. On the compression stroke this air is highly compressed; therefore its temperature is greatly increased. For a Diesel engine to operate, the air in the cylinder must be hot enough to ignite the fuel. As the piston reaches the top of its stroke, the fuel is injected into the cylinder under a high pressure in a finely atomized state. (See fig. 4.) The highly-compressed, hot air in the cylinder ignites the fuel.

(2) The compression ratio (par. 7c) of a Diesel engine may be as high as 14:1 as compared to a maximum of 7.25:1 for gasoline internal-combustion engines. The compression ratio of present-day gasoline engines cannot be much over 7.25:1 or the fuel-air mixture will ignite before it should and cause loss of power, rough engine operation, and overheating of the engine. A Diesel engine may be either a two-stroke cycle or four-stroke cycle engine.

b. Advantages and disadvantages. The high operating pressure of a Diesel engine increases its efficiency, but also necessitates that it be made stronger and heavier in order to withstand the high pressure and temperatures. This increased weight has limited the use of Diesel engines in airplanes.

7. HORSEPOWER. a. Definition. A horsepower is a measure of the *rate* at which work is being performed. It equals 33,000 foot-pounds of work *per minute*. A foot-pound is a measure of work. One foot-pound of energy is required to lift a 1-pound weight 1 foot. Ten foot-pounds are necessary to lift a 1-pound weight 10 feet, or a 10-pound weight 1 foot, or a five-pound weight 2 feet, etc. The foot-pound is a measure of the amount of work; it does not take *time* into consideration. If a 1,000-pound weight is lifted 33 feet, 33,000 foot-pounds of energy will be expended. It makes no difference whether the time expended is 1 minute, 1 hour, or 1 day, it still takes 33,000 foot-pounds of energy. Therefore, to measure the *rate* at which work is accomplished, the unit, horsepower, which is 33,000 foot-pounds of energy per minute, will be used. If a 1,000-pound weight is lifted 33 feet in 1 minute, 1 horsepower would be used. If 2 minutes are necessary, $\frac{1}{2}$ horsepower is used. The capacity of an engine to do work is measured in horsepower.

b. Piston displacement. The maximum horsepower an engine is capable of developing is dependent upon several factors. One of these is piston displacement. The displacement of one piston may be found by multiplying the area of a cross section of the cylinder bore by the total distance the piston moves in the cylinder in one stroke. This figure is then multiplied by the number of cylinders in the engine to find the total piston displacement. For example, a piston 5 inches in diameter traveling a stroke distance of 6 inches will have a piston displacement of 117.8 cubic inches. (See fig. 5.) (Area of the cross section of the cylinder bore = $\frac{1}{4}\pi \times D^2 = 0.7854 \times 5 \times 5 = 19.63$ and $19.63 \times 6 = 117.8$.) If an engine has 14 cylinders of this size, it will have a total piston displacement of 1649.2 cubic inches ($117.8 \times 14 = 1649.2$). This would be spoken of as a 1650 engine. A 14-cylinder engine with a $5\frac{1}{2}$-inch bore (diameter of cylinder) and a $5\frac{1}{2}$-inch stroke will be an 1830 engine. ($0.7854 \times 5\frac{1}{2} \times 5\frac{1}{2} \times 5\frac{1}{2} \times 14 = 1830$.) Other factors remaining equal, the greater the piston displacement, the greater the maximum horsepower

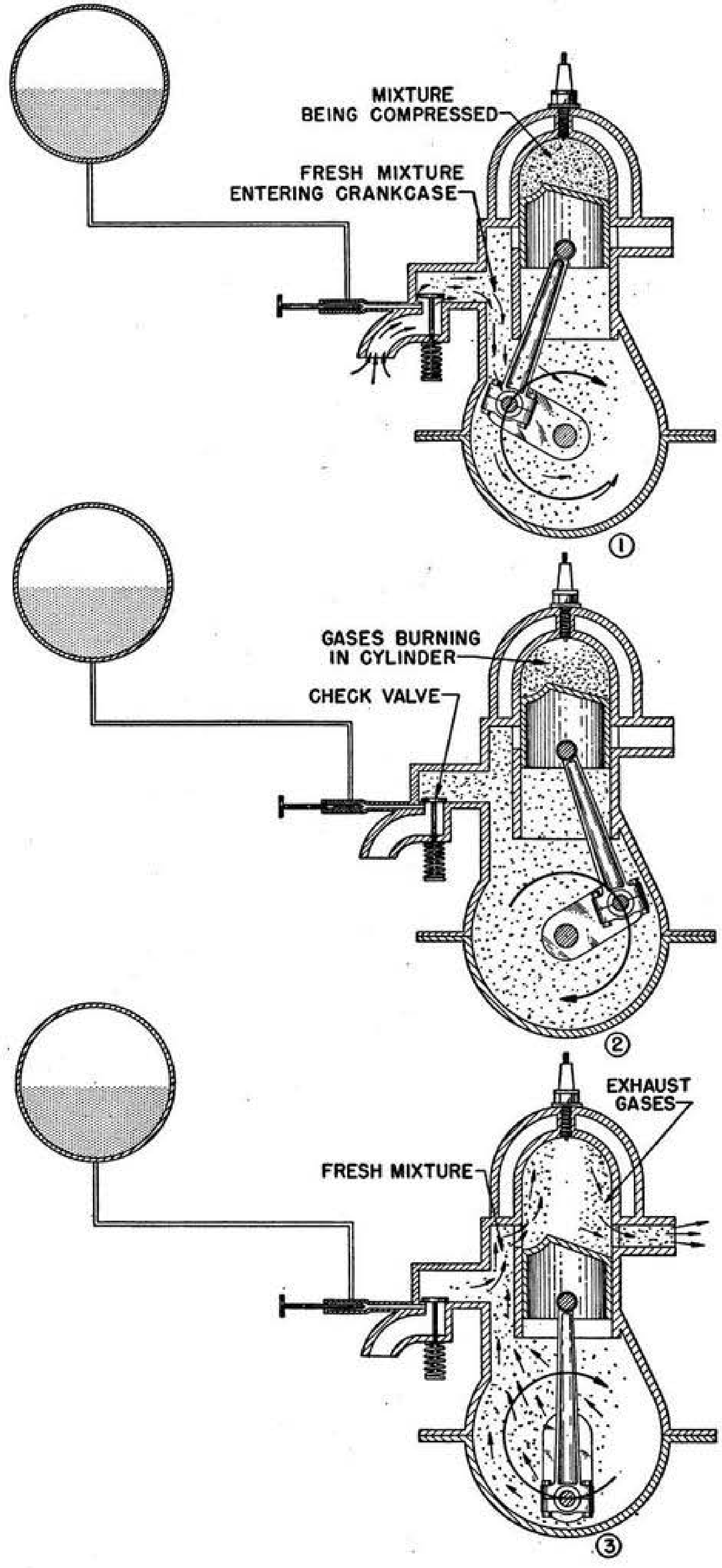


Figure 3. Two-stroke cycle principle of a gasoline engine.

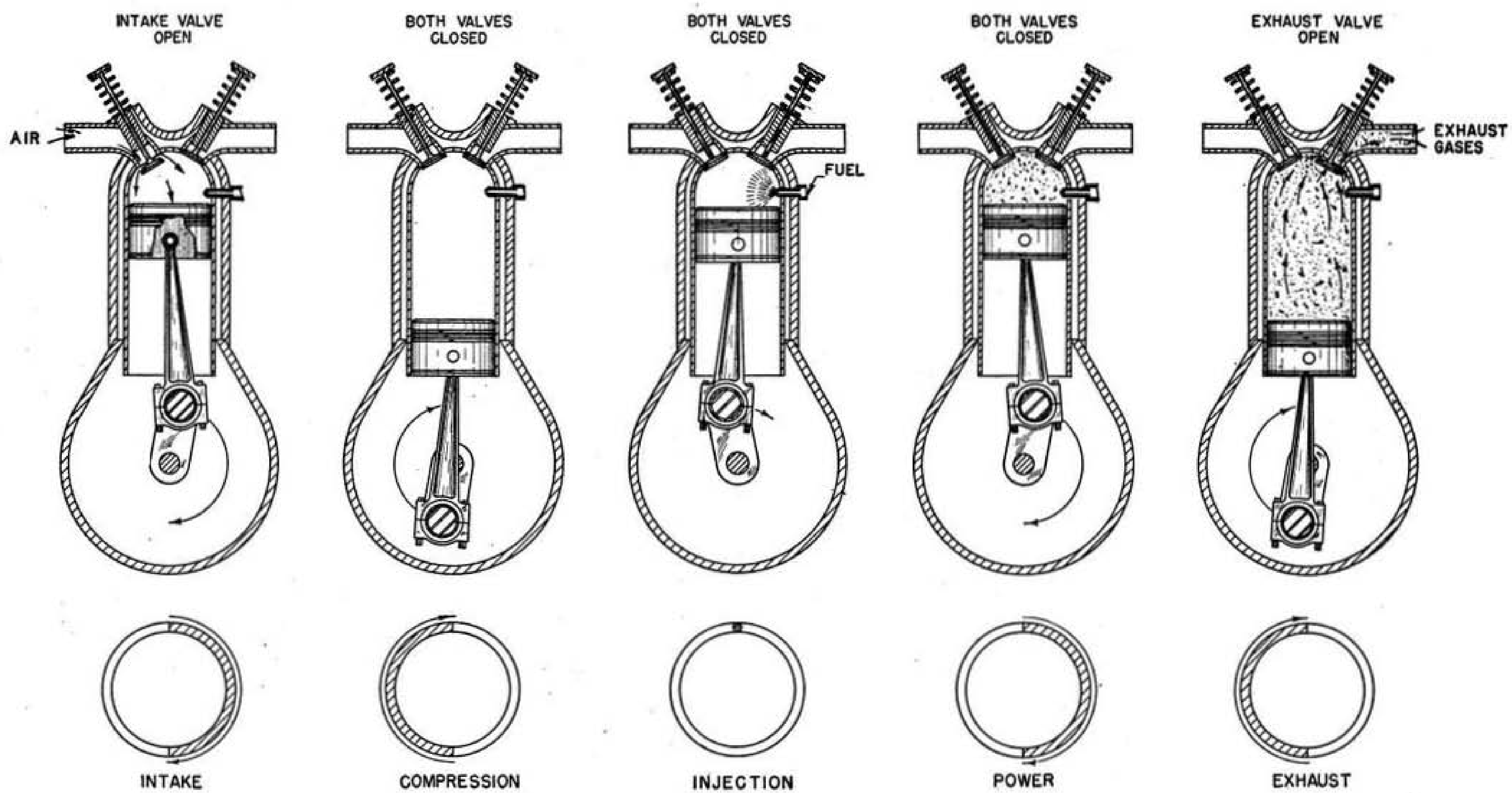


Figure 4. Diesel-engine principle.

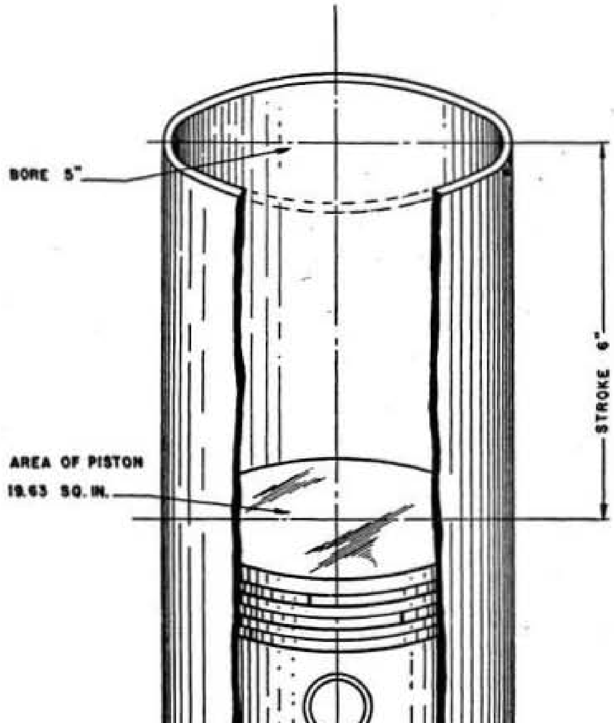


Figure 5. Piston displacement.

an engine will be capable of developing.

c. Compression ratio. The compression ratio of an engine is also a controlling factor of the maximum horsepower developed by the engine. The higher the compression ratio, within limits, the greater the maximum horsepower. The compression ratio is the ratio of the volume of space in a cylinder when the piston is at the bottom of its stroke to the volume when the piston is at the top of its stroke. For example, if there are 120 cubic inches of space when the piston is at the bottom of its stroke and there are 20 cubic inches of space when the piston is at the top of its stroke the compression ratio would be 120 to 20. (See fig. 6.) Both numbers are then divided by the smaller number and the compression ratio in this case is 6 to 1. It is generally written 6:1. As mentioned before, there is a maximum ratio which may be used in an internal-combustion gasoline engine. If too highly compressed, preignition (premature ignition of the fuel) will occur. This will result in overheating and loss of power.

d. Brake horsepower. The horsepower that an engine is capable of transmitting to a propeller or other mechanism is known as the brake horsepower. This is not the total horsepower developed by the engine, but is that part of the total which can be used to do work. It is usually between 85 and 90 percent of the total (indicated) horsepower of the engine.

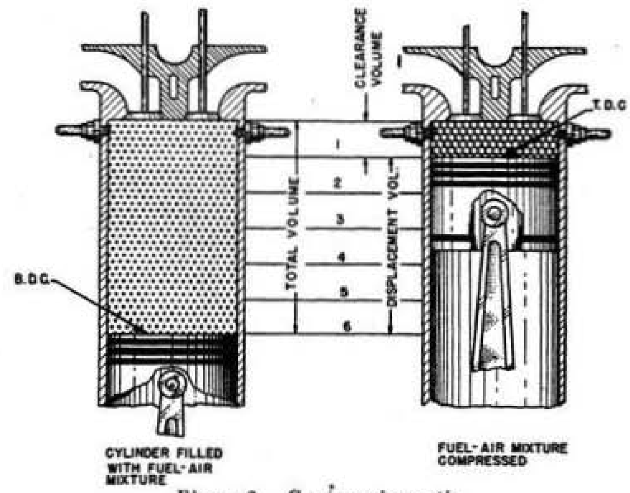


Figure 6. Compression ratio.

e. Friction horsepower. All the horsepower developed by an engine cannot be delivered as brake horsepower. A part of it is necessary to overcome the friction of the moving parts within the engine. This part is known as the friction horsepower. In modern aircraft engines, the friction horsepower is usually between 10 and 15 percent of the total horsepower developed by the engine. The friction horsepower (FHP) is determined by subtracting the brake horsepower (BHP) from the total indicated horsepower (IHP).

$$FHP = IHP - BHP$$

f. Indicated horsepower. The indicated horsepower is the total horsepower converted from heat energy to mechanical energy by the engine. The indicated horsepower is found by using an indicating device which records the combustion pressure within the cylinder. This reading of combustion pressure is then used in a formula to calculate the indicated horsepower. A combustion pressure card is shown in figure 7.

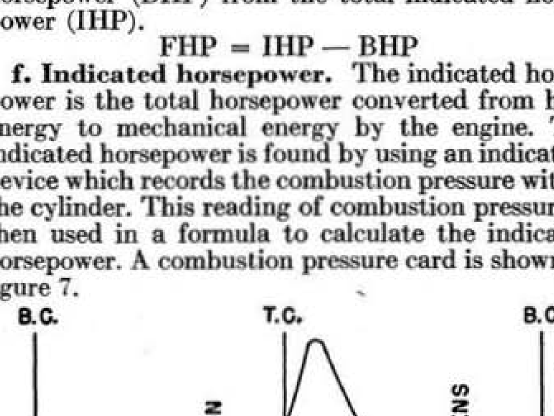


Figure 7. Pressure indicator card.

g. Heat losses and efficiency. Internal-combustion engines are only about 34 percent thermally efficient. That is, they transform only about 34 percent of the total heat produced by the burning fuel into mechanical energy. The remainder of the heat is lost through the cooling of the engine or exhausted through the exhaust manifold. This means that of every 100 gallons of fuel completely burned in an engine, only about 34 gallons are used to do work. It is ,of course, undesirable, but the heat must be removed to prevent damage to the engine.

SECTION II

CLASSIFICATION AND DESCRIPTION OF AIRCRAFT ENGINES

8. GENERAL. Many types of internal-combustion engines have been designed. However, the use and application of the powerplant unit has caused many manufacturers to develop some designs that are used more commonly than others and are recognized as conventional. Internal-combustion engines may be classified according to cylinder arrangement with respect to the crankshaft (in-line, **V**-type, etc. — see fig. 8) or according to the method of cooling (liquid-cooled or air-cooled). Actually, all engines are cooled by transferring excess heat to the surrounding air. In engines classed as air-cooled, this transfer is direct from the cylinders to the air. In liquid-cooled engines, the heat is transferred from the cylinders to the coolant which is then sent through piping and cooled within a radiator placed in the airstream. The radiator must be of sufficient size to cool the liquid efficiently. Heat is transferred to air

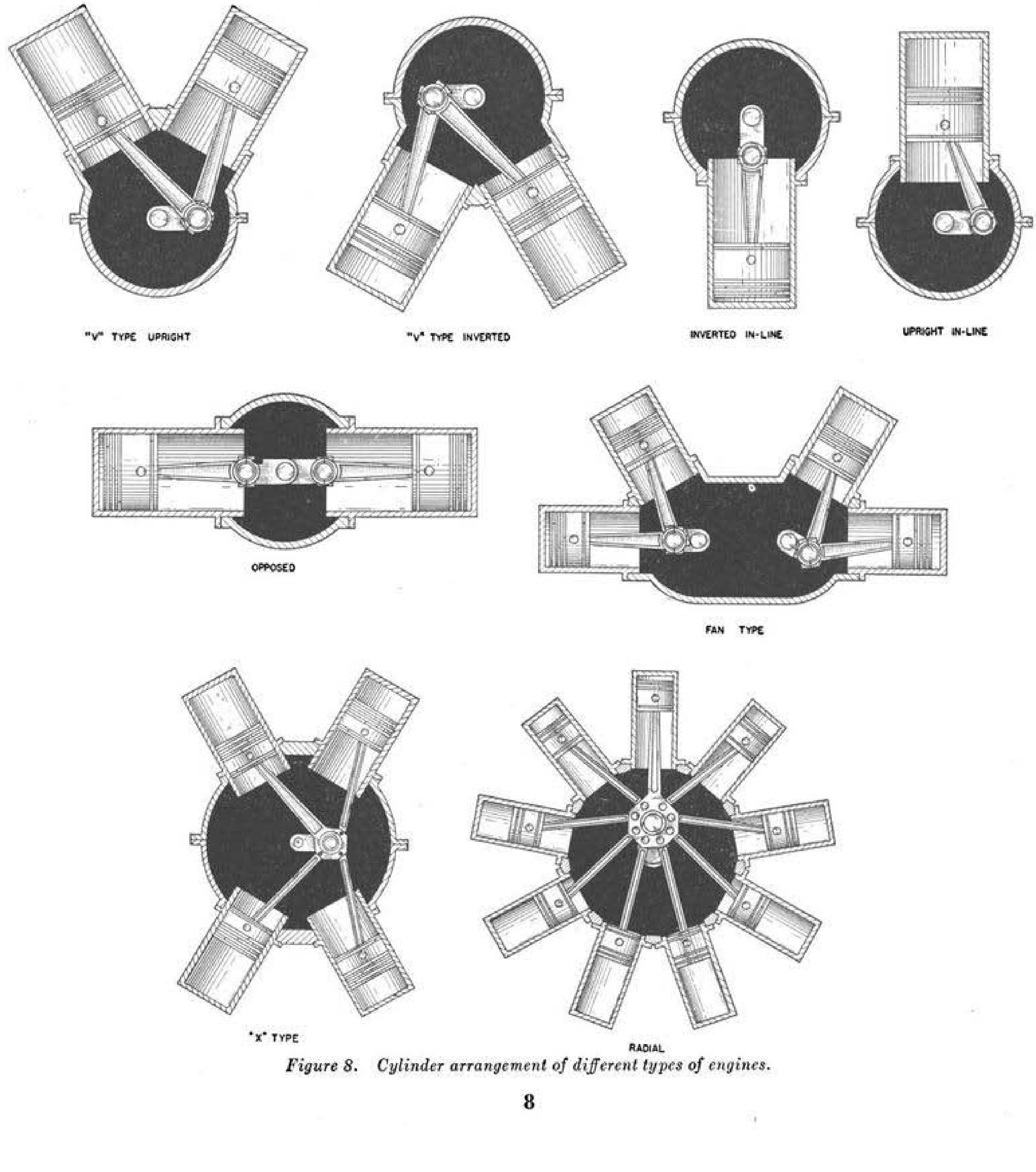


Figure 8. Cylinder arrangement of different types of engines.

more slowly than it is to a liquid. Therefore, it is necessary to provide thin metal fins on the cylinders of an air-cooled engine in order to have increased surface for sufficient heat transfer.

a. Liquid cooling. Liquid-cooled aircraft engines formerly used water as a coolant. Because of its relatively high freezing point (32° F.) and low boiling (212° F.) point, it is not satisfactory for use in present-day aircraft engines. In many places ground temperatures are below 32° F. If water were used as a coolant, some provisions would have to be made to keep it from freezing and damaging the engine. Also, water boils at a much lower temperature at high altitudes. For example, at an altitude of 25,000 feet, water will boil at 60° F. For these reasons, the coolant now used is either ethylene glycol or a mixture of ethylene glycol and water. All types of coolant contain a small amount of corrosion inhibitor. Only the coolant specified in Technical Orders should be used for any particular engine. Glycol sold under the trade name "Prestone" is not suitable for use in aircraft engines.

(1) *Ethylene glycol.* Pure ethylene glycol is a colorless, syrupy liquid with a sharp, sweet taste. It is non-corrosive and has practically no odor. It has a boiling point of approximately 350° F. and a slush-forming freezing point of approximately 0° F. Its high boiling point and low freezing point are advantages which make it a good coolant for aircraft engines. It has a lower rate of heat conductivity than water. It also has a greater tendency to leak out of the system. Ethylene glycol will absorb moisture from the air and is soluble in water in any proportions. Type A coolant (94.5 percent ethylene glycol) is used in unpressurized systems and is inflammable at operating temperature.

(2) *Ethylene glycol and water mixture.* As previously stated, ethylene glycol is soluble in water in any proportion. The types of solutions in general use are listed in Table I. These solutions are used only in pressurized (sealed) systems. To prepare these solutions, measure the correct volumes of water and ethylene glycol into a container and stir them vigorously for 10 minutes. Distilled water or strained rain water is preferred but tap water may be used if it conforms to the specifications listed in Technical Orders. When not known, the specific gravity of the solution may be determined by use of a standard hydrometer or glycol hydrometer. The specific gravity should be checked carefully because a small percentage of water in glycol greatly affects the freezing point and the boiling point.

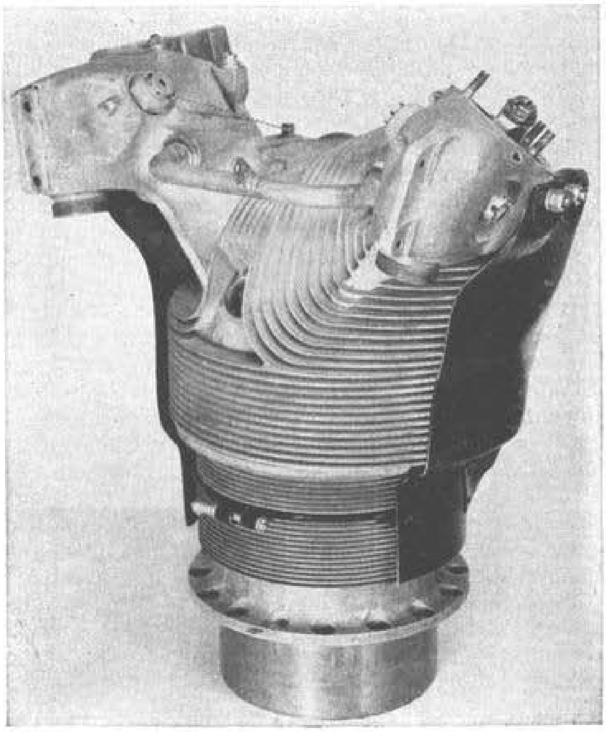
Type of coolant	Composition by volume		Composition by percentage		Boiling point	Freezing point
	Water	Glycol	Water	Glycol		
B	2 parts	8 parts	20%	80%	App. 250° F.	App. 5° F.
C	3 parts	7 parts	30%	70%	App. 230° F.	App. — 65° F.
D	7 parts	3 parts	70%	30%	App. 218° F.	App. — 52° F.

(3) *Coolant systems.* The cooling system of a liquid-cooled engine may be unpressurized (vented to the atmosphere) or pressurized (sealed). A relief valve is incorporated in the pressurized system to prevent the development of excessively high internal pressures. This valve opens when the pressure exceeds the value for which the valve has been adjusted. A check valve (sniffler valve) is also incorporated in this type system. When the pressure inside the system drops, as it does when the engine is stopped and the liquid cools, this valve opens and allows air to enter the system. This equalizes the internal and external pressures and prevents damage to the system. A mixture of ethylene glycol and water is used in a pressurized system.

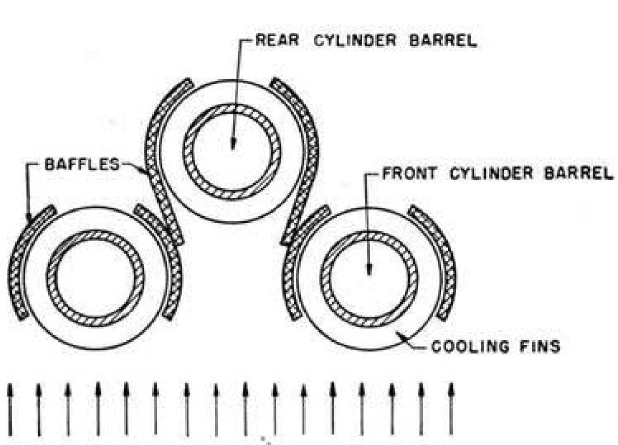
(4) *Precautions.* Ethylene glycol (whether pure or diluted) loosens the rust and scale of metals with which it comes in contact. It should therefore be periodically drained from the system and strained through several layers of cheese cloth. If the glycol has a bluish-green tinge, refill the system with new coolant. It is important that air pockets be eliminated during refilling of the system, as they will cause overheating and other troubles. To eliminate air pockets, fill the system with the cooling system vent plugs (air release plugs) removed. If the required amount of coolant cannot be poured into the tank, install vent plugs and tank cap and operate the engine for 5 minutes, then add the necessary amount of coolant. (See Technical Order applying to the particular engine.) Special mixtures and procedures are specified in Technical Orders for the winterization of liquid-cooled engines.

(5) *Advantages of liquid cooling.* Liquid-cooled installations generally have a smaller frontal area than radial air-cooled engines and therefore are well adapted to streamlining. They also maintain a more constant temperature during operation. When the cooling is more even and excessive temperatures are eliminated, it is possible to obtain a higher compression ratio for a given octane rating of fuel and thus develop a higher power output per cylinder.

b. Air cooling. (1) In an air-cooled engine excess heat is conducted directly from the cylinder walls to the surrounding air. To provide sufficient heat transfer to prevent overheating, the cylinder walls and head have thin metal fins projecting from the outer surface. As the air flows over the fins, it absorbs the excess heat of the cylinder and transfers it to the surrounding air. Deflector baffles are fastened around the cylinders to direct the flow of air, and thus obtain more efficient cooling. (See fig. 9.) Cowl flaps are located on the airplane cowling, usually behind the cylinders, to regulate the amount of air passing over the entire engine and to control the operating temperature of the engine. (See fig. 10.) The operation of these flaps may be controlled either manually or thermostatically.



① *Deflector baffles on cylinder.*
Figure 9.



② *Deflector baffles.*
Figure 9 — Continued.

(2) *Advantages of air cooling.* An air-cooled engine is generally lighter than a liquid-cooled engine of the same horsepower, since it does not have the extra weight of the radiator, connecting lines, hoses, and the coolant liquid. It is also less vulnerable to small-caliber gunfire, which may easily puncture the radiator of a liquid-cooled engine. It is not affected as much by cold-weather operation as a liquid-cooled powerplant.

9. IN-LINE OR L-ENGINE. a. Description. An in-line engine (fig. 11) generally has an even number of cylinders although some three-cylinder engines have been constructed. It may be either liquid-cooled or air-cooled. It has only one crankshaft which may be located above or below the cylinders. If the engine is designed to operate with the cylinders below the crankshaft, it is called an inverted engine.

b. Advantages and disadvantages. The in-line engine has a small frontal area and is better adapted to streamlining. When mounted with the cylinders in an inverted position, it offers the added advantages of a shorter landing gear and greater pilot visibility. The in-line engine has a greater weight-to-horsepower ratio than most other engines. With increase in engine size the air-cooled in-line type offers additional handicaps to proper cooling; therefore, the use of this type of engine is to a large degree confined to low- and medium-horsepower engines for use in light airplanes.

10. VEE- OR V-TYPE ENGINE. a. Description. A **V**-type of engine is shown in figure 12. This type of engine employs an even number of cylinders in each bank (row of cylinders). The two banks are mounted on a common crankcase and form the letter "**V**." The angle between the banks may be 90, 60 or 45 degrees. The **V**-type engine may be either air- or liquid-cooled.

b. Advantages and disadvantages. The **V**-type engine has the same advantages as the in-line engine. These consist of a relatively small frontal area which permits easy streamlining, and, if the cylinders are inverted, a short landing gear and better pilot visibility. It has a smaller weight-to-horsepower ratio than the in-line engine since it has only one crankshaft for two rows of cylinders. It has the same disadvantages as other liquid-cooled engines.

11. DOUBLE V- OR FAN-TYPE ENGINE. a. Description. A fan-type engine is shown in figure 13. It has four banks of cylinders and two crankshafts. Each crankshaft is connected to the pistons in two of the cylinder banks. Both crankshafts are geared to the same propeller shaft. In reality the fan-type engine is merely two **V**-type engines joined into a single unit. At present all fan-type engines are liquid-cooled.

b. Advantages and disadvantages. The fan-type engine has a larger frontal area than the **V**-type and so is more difficult to streamline. The principal advantage of this type over the **V**-type is shorter overall length for a given number of cylinders.

12. X-TYPE ENGINE. a. Description. An **X**-type engine is shown in figure 14. This type of engine employs an even number of cylinders mounted on a common crankcase in four banks. The pistons of these cylinders are all connected to a single crankshaft. It may be either liquid- or air-cooled.

b. Advantages and disadvantages. The **X**-type engine has a lower weight-to-horsepower ratio than the fan-type engine since it has only one crankshaft instead of two. Like the fan-type, it is difficult to streamline because of its large frontal area. Its short overall length for a given number of cylinders is its principal advantage.

13. OPPOSED- OR O-TYPE ENGINE. a. Description. An opposed-type engine is shown in

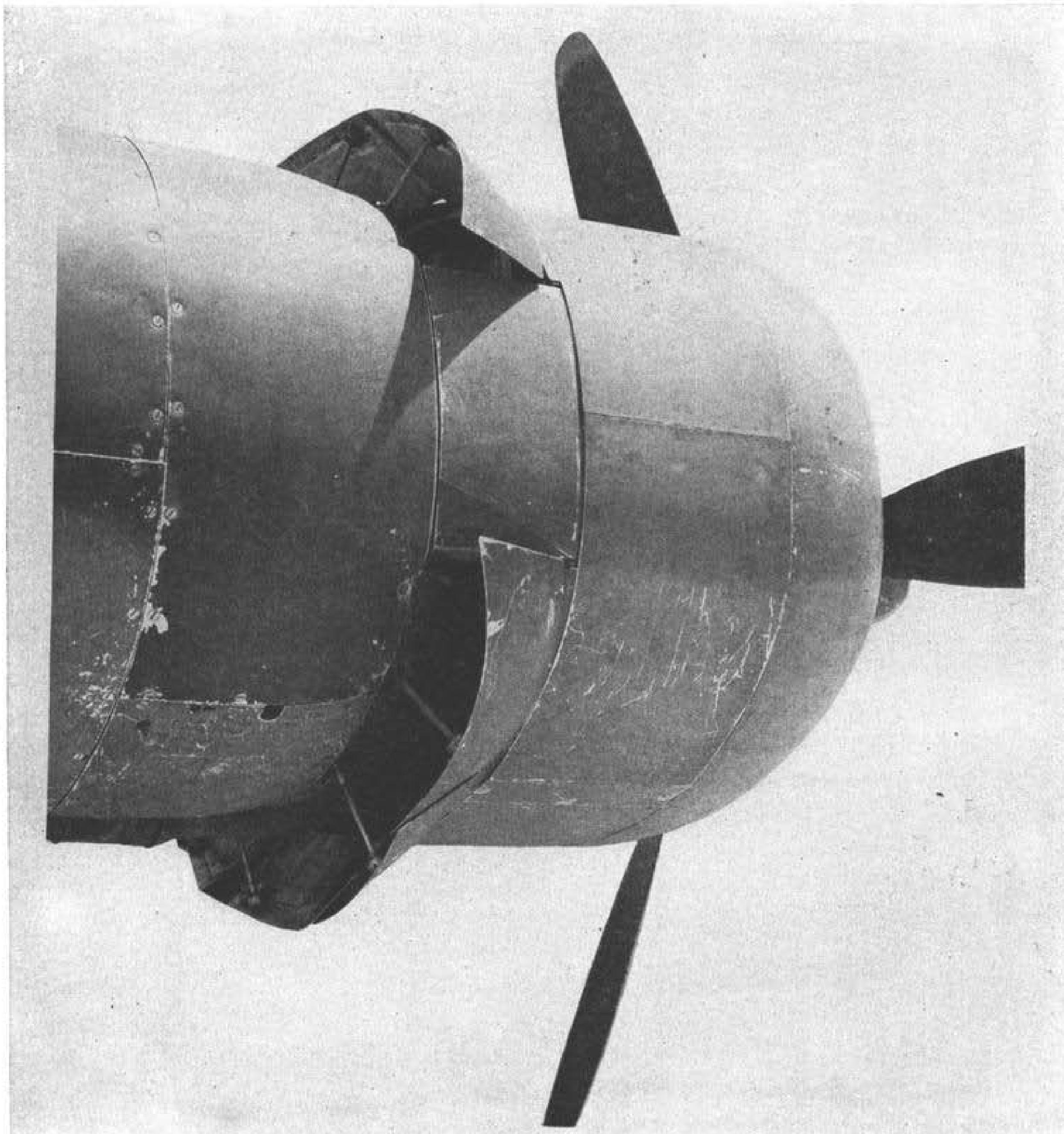


Figure 10. Cowl flaps (open).

figure 15. This type has two banks of cylinders directly opposite each other with a crankshaft in the center. The pistons of both cylinder banks are connected to the single crankshaft. It may be either liquid- or air-cooled. It may be mounted with the cylinders either vertical or horizontal.

b. Advantages and disadvantages. The opposed-type engine has a low weight-to-horsepower ratio, and its narrow silhouette makes it ideal for horizontal installation in the wings of large airplanes. Another advantage is its comparative freedom from vibration.

14. RADIAL-TYPE ENGINE. a. Description. A radial engine is shown in figure 16. The cylinders are arranged radially in one or two rows. Each row has an odd number of cylinders. All of the pistons are connected to a single crankshaft. This type of engine may be either liquid- or air-cooled. Modern radial engines are air-cooled. If there are two rows of cylinders on an air-cooled radial engine, the cylinders of the rear row will be located directly behind the spaces between the cylinders in the front row. This aids in cooling the rear cylinders.

b. Advantages and disadvantages. The radial

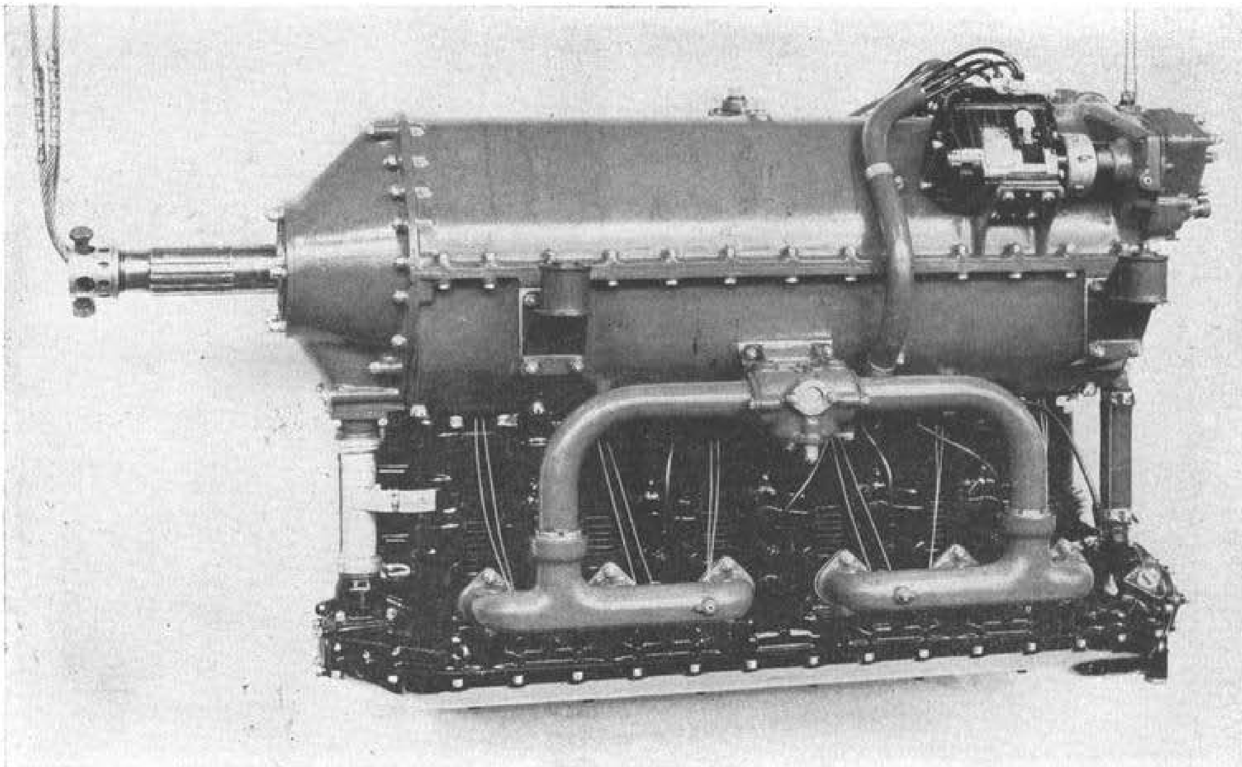


Figure 11. Inverted in-line engine.

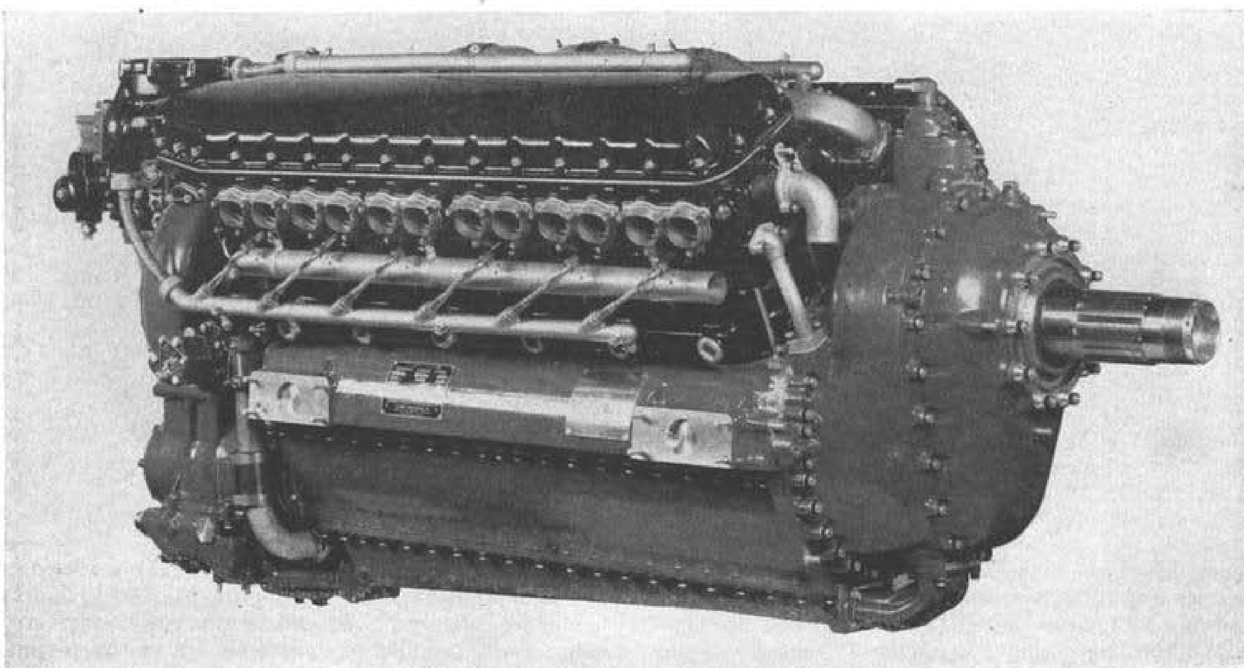


Figure 12. **V**-*type engine.*

engine has the lowest weight-to-horsepower ratio of all the different types of engines. Its principal disadvantage is its large frontal area which makes it difficult to streamline. This problem is being solved, however, and radial engines are used in the majority of present-day American aircraft. Because air is used as a cooling medium, operating temperatures of this type of engine are very high. To some extent this limits the compression ratio for a fuel of a given octane rating.

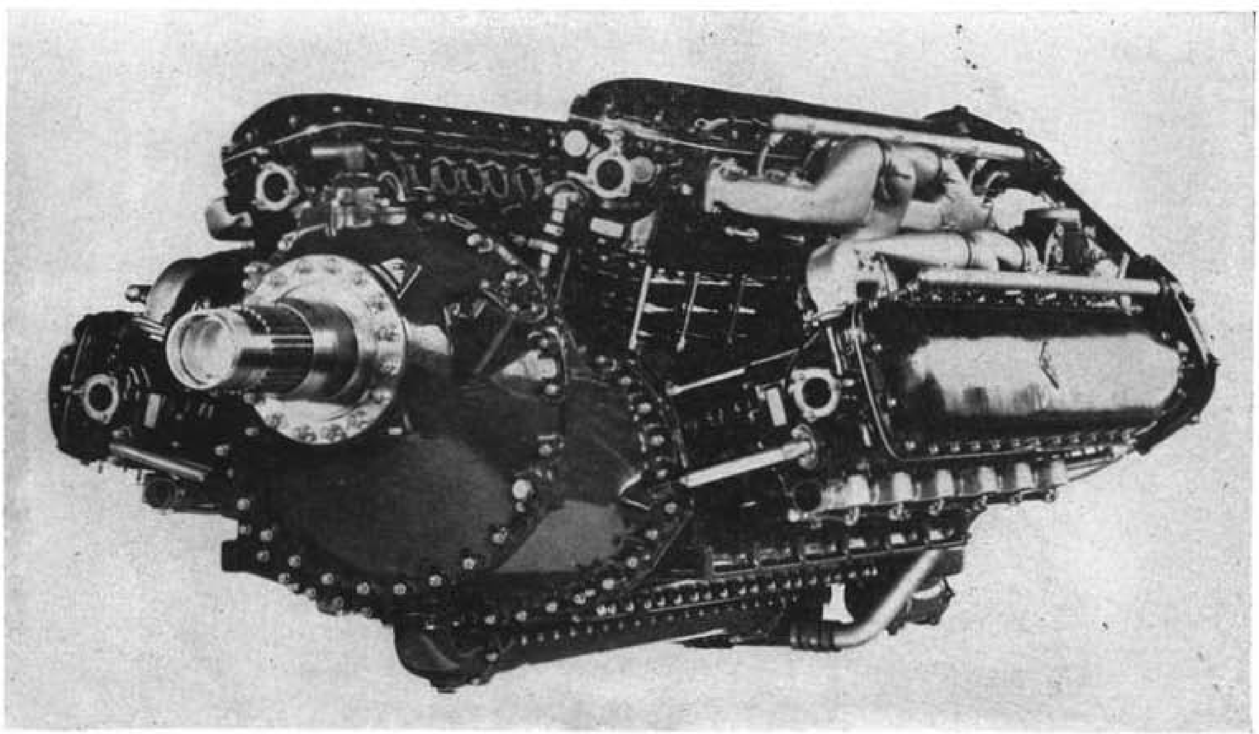


Figure 13. Fan-type engine.

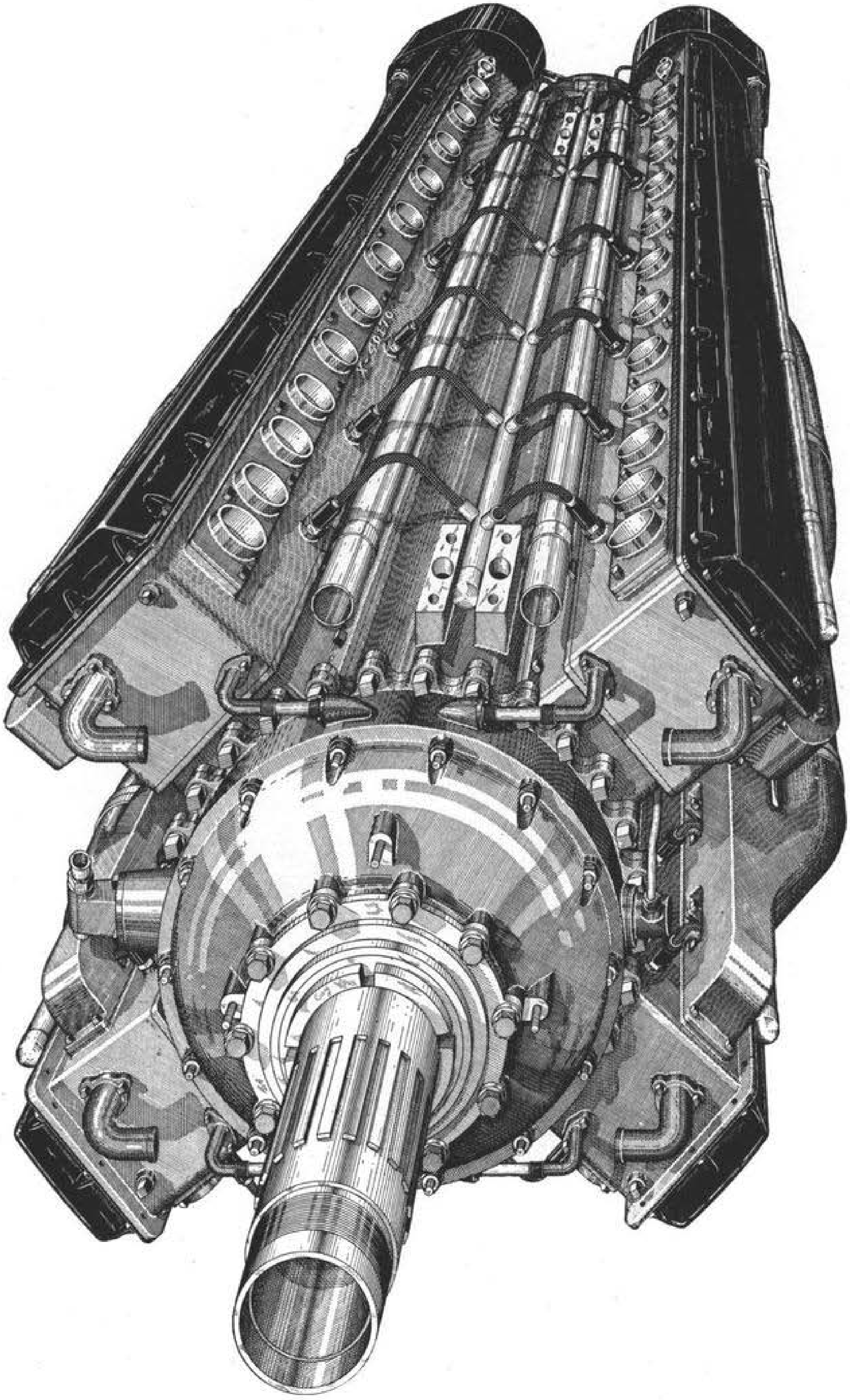


Figure 14. **X-type engine.**

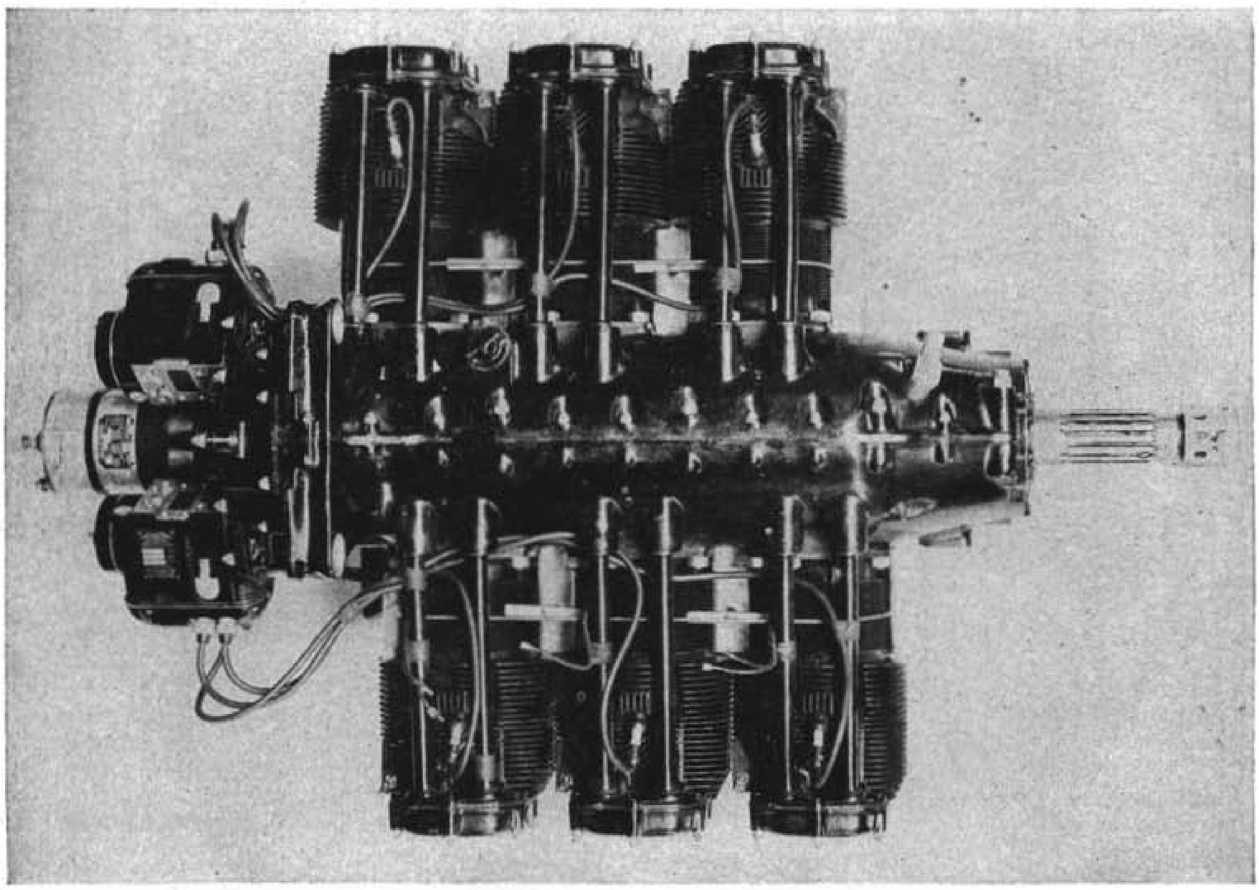


Figure 15. Opposed-type engine.

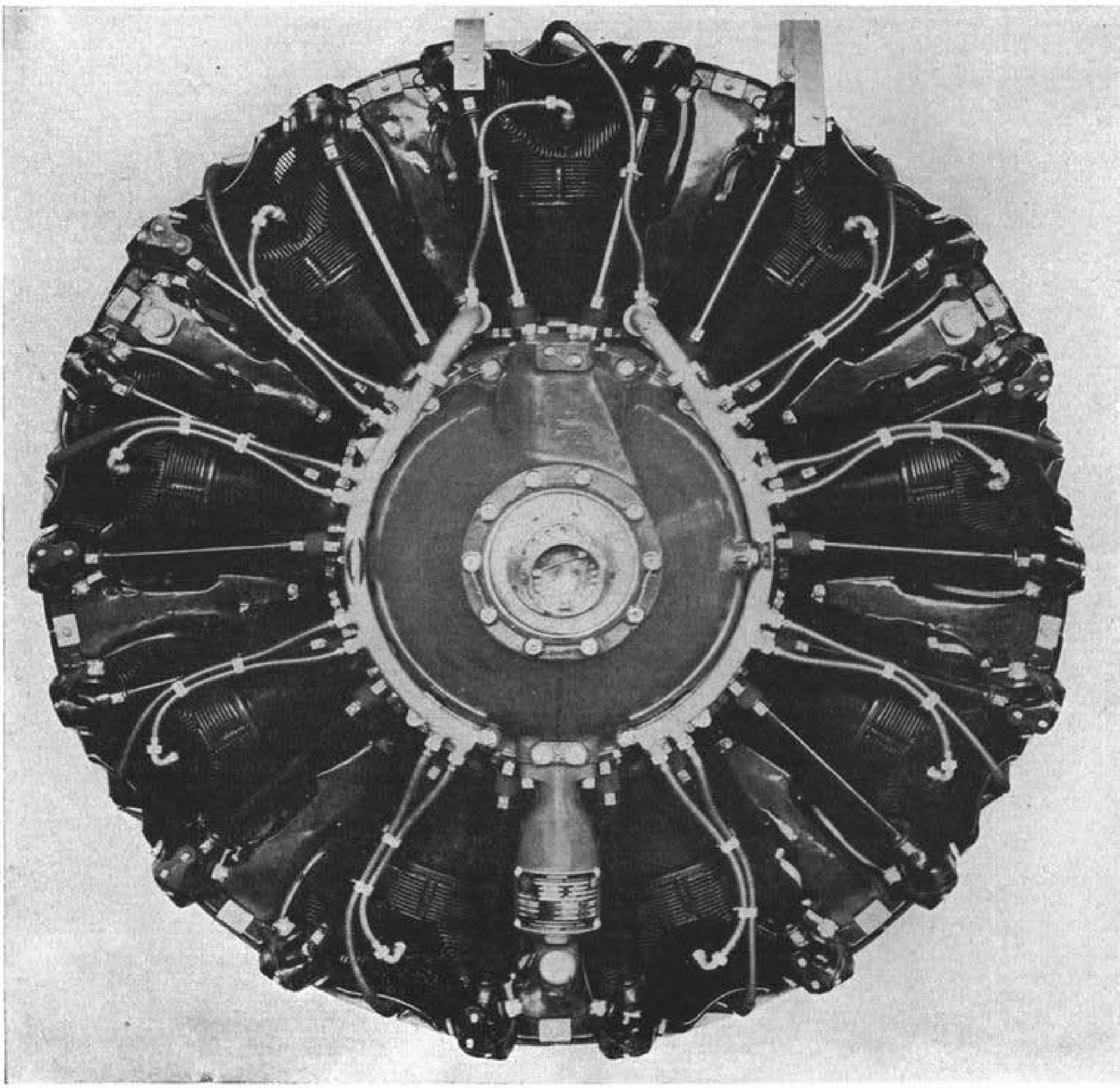


Figure 16. Radial-type engine.

SECTION III

DESCRIPTION AND CONSTRUCTION OF ENGINE UNITS

15. GENERAL. During the designing of an aircraft engine, the engineers attempt to obtain a unit which is efficient, simple, reliable, and comparatively light. Economy of time and expense in its manufacture, line maintenance, and shop repair are also items of major importance. Designing an engine is by no means simple. The designer must constantly make compromises between two or more factors. For instance, present-day airplane engines could be made more efficient, but they would be heavier. They could be made lighter, but they would be less efficient. The final design is always the result of many compromises.

16. CRANKCASE. The foundation of the engine is the crankcase. It contains the bearings in which the crankshaft revolves. Besides supporting itself, the crankcase must provide a tight enclosure for the lubricating oil, support various internal and external mechanisms of the engine, and provide supports for the attachment of the power plant to the airplane and for the attachment of the cylinder assembly. It must be sufficiently rigid and strong to prevent misalignment of the crankshaft and its bearings. Cast or forged aluminum alloy is generally used for crankcase construction because it is light and strong. On some of the higher-power-output engines, forged-steel crankcases are sometimes used. Crankcases often appear in various shapes and forms and may be irregular or symmetrical in shape and may consist of one or many pieces.

a. In-line and V-type engine crankcases. The in-line and **V**-type engine crankcases are generally made in four major parts.

(1) *The front or nose section.* This section of the crankcase is located nearest to the propeller. It may be cast as a part of the power section or it may be of a separate dome-shaped or conical construction for streamline effect. This section houses the propeller shaft, the propeller thrust bearing and the propeller reduction-gear train. It often provides a mounting pad for the propeller governor. In some airplanes, as in one type of fighter, the nose section is located some distance from the engine proper. In this case it is connected to the engine through an extension shaft and the reduction-gear drive incorporates a lubrication system of its own.

(2) *The main or power section.* The main or power section of the crankcase is often made up of two parts, an upper part to which the cylinder assembly is bolted and which supports the upper half of the crankshaft bearings; and the lower part which incloses the crankshaft and supports the lower half of the bearings. (See fig. 17.) The cylinder assembly is mounted on the heavier of the two parts. Reinforcing web partitions support the crankshaft bearings. In many cases this section will provide external mounting lugs and bosses for attaching the engine to the engine mount.

(3) *Fuel induction and distribution section.* This section is usually located next to the power section. It houses the diffuser vanes and supports the internal blower-impeller. The induction manifold is located between the cylinders and this section. The housing provides an opening for the attachment of a manifold pressure line and provides internal passages for the fuel drain valve of the blower-impeller. A crankcase breather opening is sometimes located on the external surface of this housing. This opening is connected through internal passages to the crankcase.

(4) *The accessory section.* The accessory housing may be a part of the induction and distribution section or it may be a separate unit which is mounted directly on the induction and distribution chamber section. It is generally made of an aluminum- or magnesium-alloy casting, contains the accessory drive-gear train, and provides mounting pads for the coolant pump, fuel pump, vacuum pump, lubricating-oil pumps, tachometer generator, and magnetos.

b. Radial-engine crankcase. The radial-engine crankcase has from three to seven principal sections, depending upon the size and type of engine. A larger engine incorporates more sections than a smaller one. For explanatory purposes the conventional radial-engine crankcase assembly can be divided into four major sections. (See fig. 18.)

(1) *Front or nose-section.* The metal used in this section is generally aluminum alloy. The housing is usually somewhat bell shaped and fastened to the power section by studs and nuts or cap screws. It supports a propeller thrust bearing, a propeller-governor drive shaft and the propeller reduction-gear assembly, if used. The nose section of a radial engine may also house a cam plate or cam-ring mechanism and an oil-scavenging pump. A propeller-governor control valve, a crankcase breather, oil sump, magneto, or magneto distributors may also be mounted on the external surface of the nose section.

(2) *Main or power section.* The main section may consist of one, two, or three pieces of high-strength, heat-treated aluminum-alloy or steel forging. If two or three pieces are used, they are bolted together. Crankshaft bearing supports are provided at the center of each main crankcase web section. The main crankcase section usually houses and supports the cam-operating mechanism. Oil seals are provided between the front crankcase section and the main-crankcase and the fuel-distribution section. Cylinder mounting pads are provided radially around the outside circumference of the power section. Studs and nuts or cap screws secure the cylinders to the pads.

(3) *Fuel induction and distribution section.* This section (also called the supercharger or blower section) is located immediately behind the power section. It may consist of one or two pieces. The principal purpose of this section is to house the blower or supercharger impeller and diffuser vanes. Openings are provided on the outside circumference

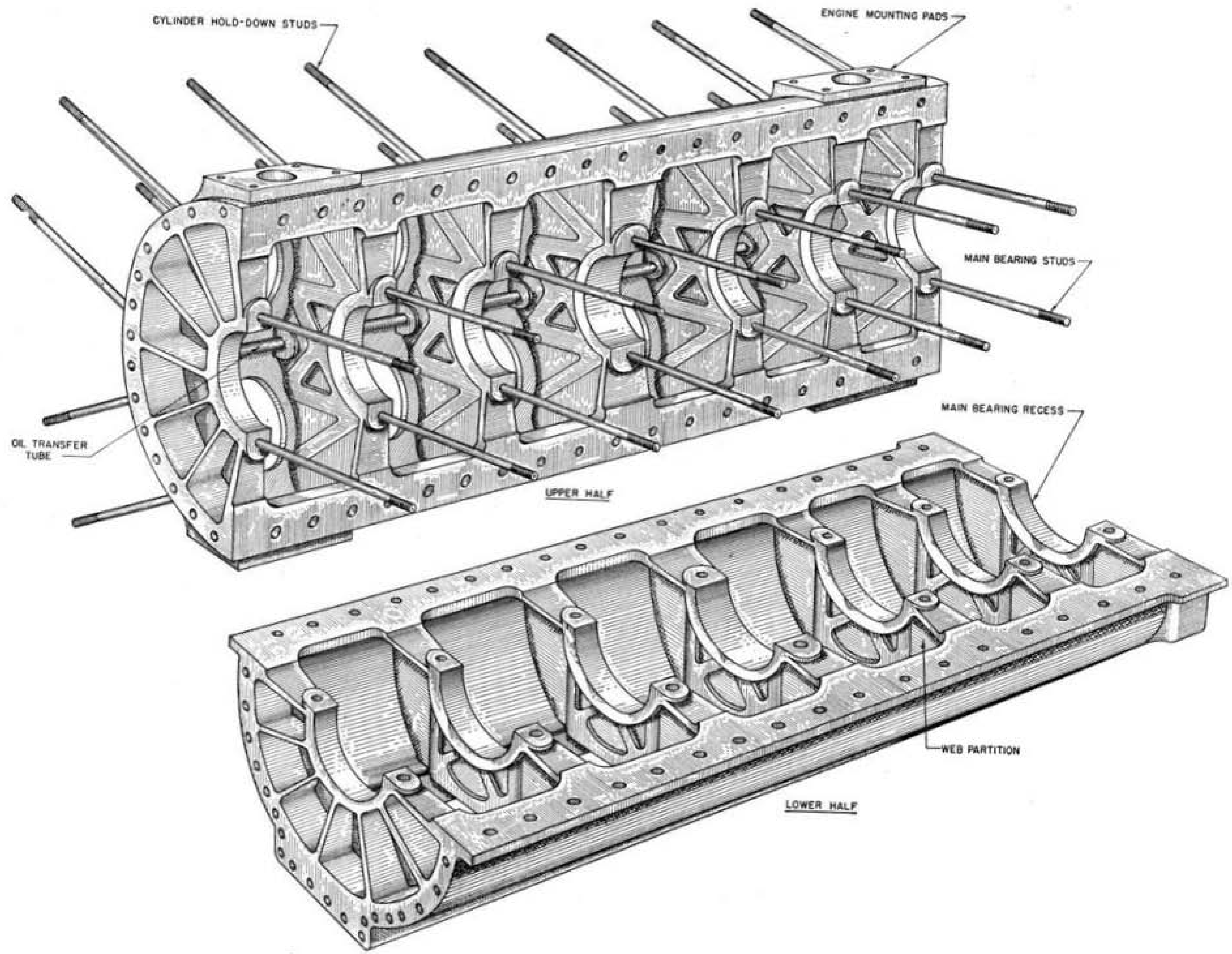


Figure 17. Power section of **V**-*type engine crankcase.*

of the housing to attach the individual induction pipes. A small opening is provided for the attachment of the manifold pressure line. Internal passages are provided for the supercharger drain valve.

(4) *Accessory section.* In some cases, the cover of the supercharger rear housing is constructed of an aluminum- or magnesium-alloy casting in the form of a heavily ribbed plate. It provides mounting pads for the required accessory units. On other engines, the accessory housings may be mounted directly on the rear of the crankcases. In all cases the housings will contain the gears for driving the fuel pumps, vacuum pumps, lubricating-oil pumps, tachometer generators, generators, and magnetos. Mounting pads are provided for starters, two-speed supercharger control valves and oil-filtering screens or Cuno filters.

17. CRANKSHAFTS. The crankshaft is the backbone of an internal-combustion engine. It is subjected to all the forces developed by the engine. Its main purpose is to transform the reciprocating motion of the piston and connecting rod into rotary motion for rotation of the propeller. The crankshaft, as the name implies, is a shaft composed of one or more cranks located at specified spots between the ends. The cranks, or throws, are formed by forging offsets into a shaft before it is machined. As crankshafts must be very strong, they are generally forged from a very strong alloy such as chromium-nickel-molybdenum steel.

a. Parts of the crankshaft. A crankshaft may be of single-piece or multi-piece construction. Corresponding parts of all crankshafts perform essentially the same functions. Each part has a specific name and function.

(1) *Journal.* A main journal (fig. 19) is the part which is supported by, and rotates in, a main bearing. It serves as the center of rotation of the crankshaft and is surface-hardened to prevent wear.

(2) *Crankpin.* This is the section to which the connecting rod is attached. It is off center from the main journals (fig. 19) and is often referred to as a "throw." When a force is applied to the crankpin in any direction other than parallel or perpendicular to and through the centerline of the crankshaft, it will cause the crankshaft to rotate. The outer surface is hardened to increase its resistance to wear. The crankpin is usually hollow. This reduces the total weight of the crankshaft and provides a passage for the transfer of lubricating oil. The hollow crankpin also serves as a chamber for collecting sludge, carbon deposits, and other foreign material. Centrifugal force throws these substances to the outside of the chamber and thus keeps them from reaching the connecting-rod bearing surface. On some engines a drilled passage extends from the chamber to an opening on the outside surface of the connecting rod. This allows clean oil to be sprayed on the cylinder walls.

(3) *Crankcheek.* The crankcheek is the part which connects the crankpin to the journal as shown in figure 19. In some designs, the cheek extends beyond the journal and carries a counterweight to balance the crankshaft. The crankcheek must be of a sturdy construction in order to obtain the required rigidity between the crankpin and the journal.

(4) *Counterweight and dampers.* Every piece of rotating machinery has a certain definite speed at which excessive vibration is set up in the revolving mass. Counterweights and dampers are suspended from specified crankcheeks in order to relieve the whip and vibration caused by the rotation of the crankshaft. Floating damper weights are sometimes incorporated in a counterweight assembly to reduce crankshaft vibrations which are caused by power impulses.

b. Types of crankshafts. In all cases the type of crankshaft and the number of crankpins must correspond with the cylinder arrangement of the engine. The position of the cranks on the crankshaft in relation to the other cranks on the same shaft is expressed in degrees.

(1) *Single throw crankshaft.* The simplest crankshaft is the single-throw or 360° type shown in figure 20 ①. This type is commonly found in a single-row radial engine. It may be constructed in one or two pieces. Two main bearings (one on each end) are provided when this type of crankshaft is used.

(2) *Double-throw crankshaft.* The double-throw or 180° crankshaft is shown in figure 20 ②. This type is usually found on double-row radial engines and on two- and four-cylinder opposed engines. In the radial-type engine, the crankshaft provides one throw for each row of cylinders. It may be constructed in one piece or in three pieces. Three main bearing journals are provided. Plain- or roller- or ball-type bearings or a combination of types may be used.

(3) *Four-throw crankshaft.* Four-cylinder in-line and eight-cylinder **V**-type engines use four-throw crankshafts. (See fig. 20 ③.) Two throws of this crankshaft are placed 180° from the other two. Depending upon the size and power output of the engine, the crankshaft may incorporate three or five crankshaft journals. Any of the aforementioned types of bearings may be used.

(4) *Six-throw crankshaft.* Six-throw crankshafts are used in 6-cylinder in-line, 12-cylinder **V**-type engines and 24-cylinder **X**- and fan-type engines. The crankpins or crank throws are placed 120° apart as shown in figure 20④. When this type of crankshaft is used in a 12-cylinder **V**-type engine or in 24-cylinder **X**- and fan-type engines, two connecting rods are attached to each crankpin. The crankshaft may be constructed with five or seven main journals. The manufacturer may use all plain bearings or a combination of plain bearings and roller or ball bearings.

c. Crankshaft balance. Excessive vibration not only results in fatigue failure of the metal structures but also causes the moving parts to wear rapidly. In some instances, excessive vibration may be caused by a crankshaft which is not balanced. The two kinds of balance are static balance and dynamic balance.

(1) *Static balance.* A crankshaft is statically balanced when the weight of the entire assembly of crankpins, crankcheeks, and counterweights is balanced around the axis of rotation. When testing the crankshaft for static balance, it is placed on two

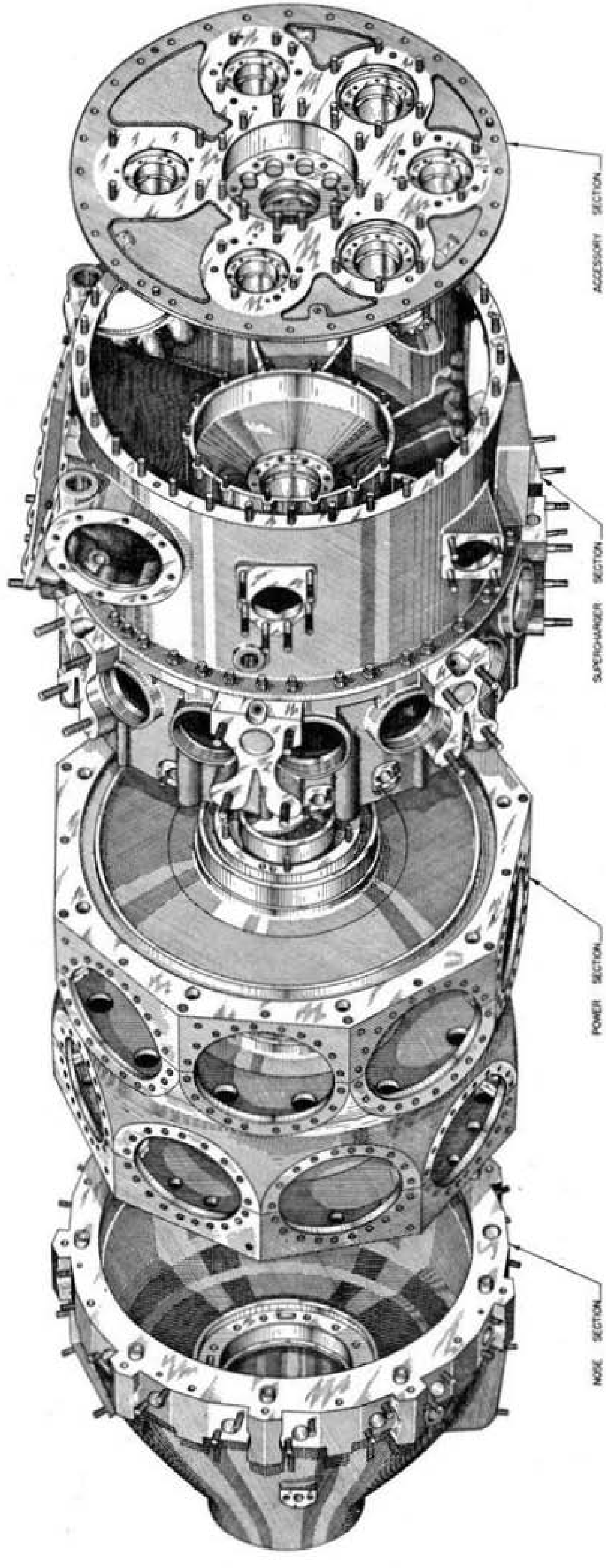


Figure 18. Radial-engine crankcase.

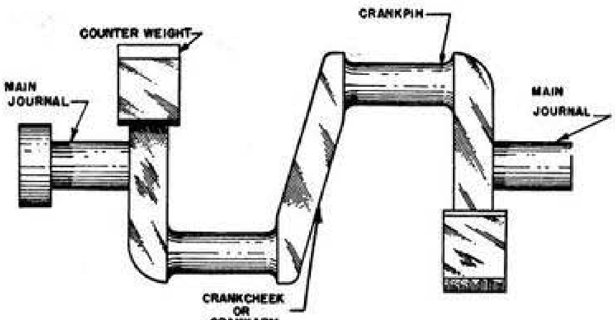


Figure 19. Crankshaft parts.

knife edges. If the shaft tends to turn to one position during the test, it is out of static balance.

(2) *Dynamic balance.* A crankshaft is dynamically balanced when all the forces created by crankshaft rotation and power impulses are balanced within themselves so that little or no vibration is produced when the engine is operating. In order to reduce vibration to a minimum during engine operation, dynamic dampers are incorporated on the crankshaft. A dynamic damper (fig. 21) is merely a pendulum which is so fastened to the crankshaft that it is free to move in a small arc. It is incorporated in the counterweight assembly. Some crankshafts incorporate two or more at these assemblies, each being attached to a different crankcheek. The distance the pendulum moves and its vibrating frequency correspond to the frequency of the power impulses of the engine. When the vibration frequency of the crankshaft occurs the pendulum oscillates out of time with the crankshaft vibration thus reducing vibration to a minimum.

18. BEARINGS. a. A bearing is any surface which supports or is supported by another surface. A good bearing must be composed of material that is strong enough to withstand the pressure imposed on it and should permit the other surface to move with a minimum of friction and wear. The parts must be held in position within very close tolerances to provide efficient and quiet operation and yet allow freedom of motion. To accomplish this and at the same time reduce friction of moving parts so that power loss is not excessive, lubricated bearings of many types are used. Bearings are called on to take radial loads, thrust loads, or a combination of the two.

b. Types of bearings. There are two ways in which bearing surfaces may move in relation to each other. One is by the sliding movement of one metal against the other and the second is for one surface to

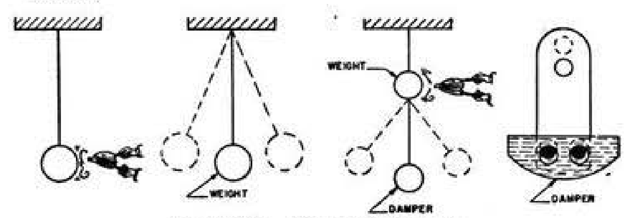


Figure 21. Dynamic damper.

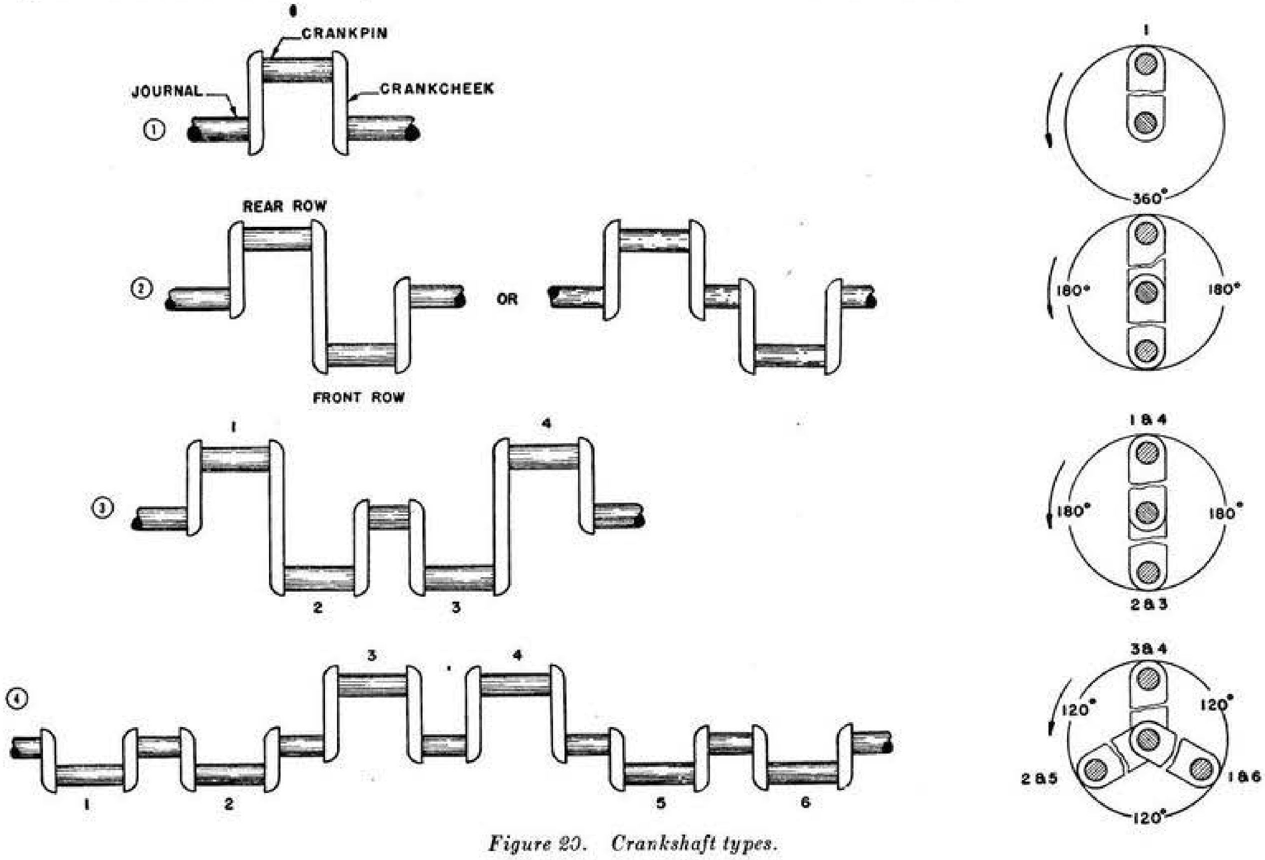
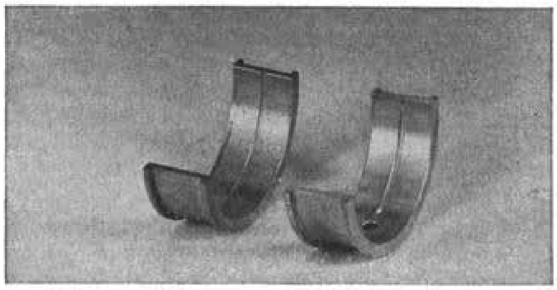


Figure 20. Crankshaft types.

roll over the other. The three different types of bearings in general use are: plain, roller and ball.

(1) *Plain bearings.* Plain bearings (fig. 22) are generally found on the crankshaft, cam shaft, and the connecting rods of an engine. Such bearings are usually subjected to radial loads only, although some have been designed to take thrust loads. The metal used for this type of bearing may be silver, lead, an alloy (such as bronze or babbitt), or a combination



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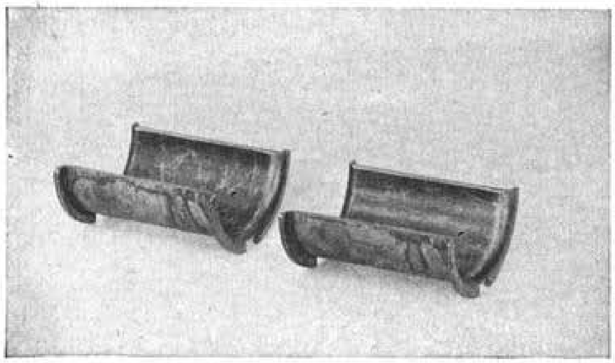
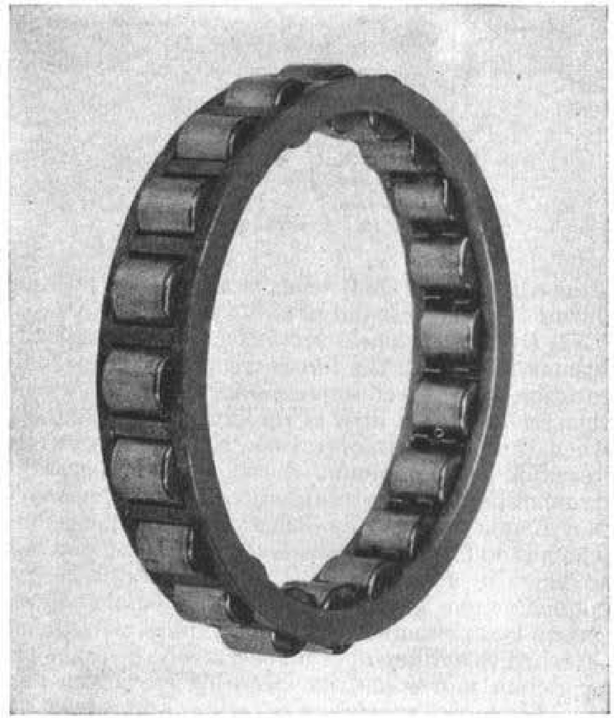


②

Figure 22. Plain bearings.

of two metals. Babbitt offers little friction when used as a bearing but it is unable to withstand high pressures. Bronze on the other hand is able to withstand high compressive pressures but offers much more friction than babbitt. To combine the advantages of these two metals, the bronze-backed babbitt bearing was developed. This type of bearing has a thin layer of babbitt (which serves as a bearing surface) on the inside surface of a bronze body. Other combinations have been developed and are used according to specific requirements of a particular engine. Most modern bearings consist of precision steel shells lined with a suitable bearing lining metal that is able to withstand the high unit loads, high speeds and high temperatures encountered in aircraft engines. This type of bearing is very practical because it can be replaced without scraping or fitting and it will sustain high shock loads.

(2) *Roller bearings.* This type of bearing is made in various types and shapes. Straight roller bearings are used in places where only radial loads are present. Special roller bearings are manufactured to absorb thrust loads. The roller itself rolls between an inner and outer race, both of which are of case-hardened steel (See fig. 23.) When a roller is tapered, it rolls on a cone-shaped race inside an outer race. Such a bearing will take both radial and thrust loads.



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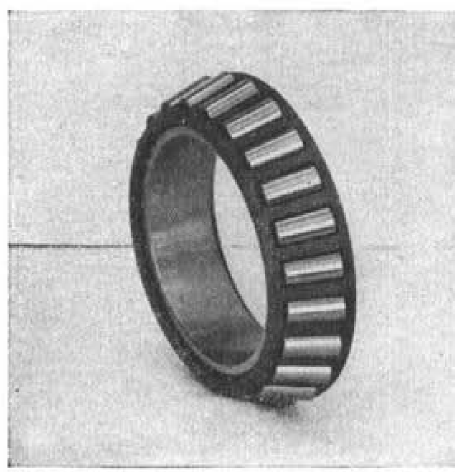

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Figure 23. Roller bearings.

(3) *Ball bearings.* The ball bearing consists of an inner race, one or two sets of steel balls, and an outer race. (See fig. 24.) The balls may be arranged in one or two rows. The inner and in some cases the outer races are designed with grooves to fit the curvature of the balls, thus allowing large contact surface for carrying high radial loads. The bearing may or may not be self-aligning. If the bearing is self-aligning the outer race may not have grooves. The self-aligning

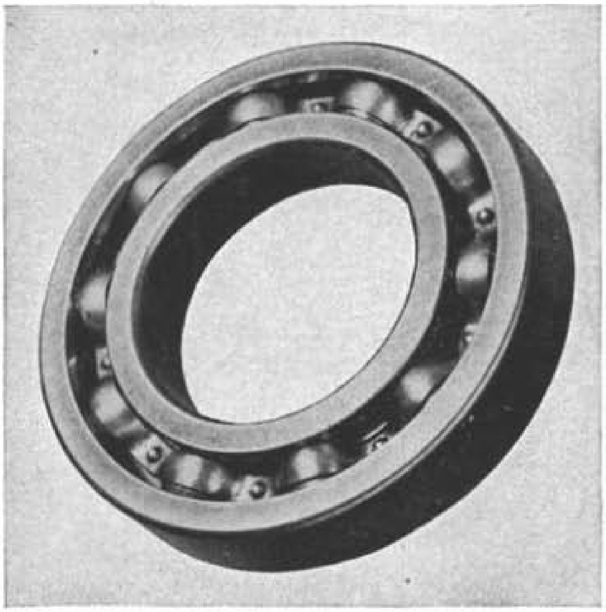


Figure 24. Ball bearing.

feature enables the bearing to provide satisfactorily for unavoidable conditions of slight misalignment caused by frame distortion or shaft deflection.

19. CONNECTING RODS. a. A connecting rod is the link which transmits forces between the piston and the crankshaft. While some connecting rods have been made with tubular cross-sections, most of them are of "H" or "I" cross sections. A tough steel alloy is generally used as the material for a connecting rod, although aluminum alloy is used in some of the smaller engines. The end of the rod which connects to the crankshaft is known as the *big end.* The other end is known as the *piston-pin end.* Connecting rods must be strong enough to remain rigid under load and yet be as light as possible to reduce the inertia forces which are produced when the rods stop, change direction, and start at the end of each stroke.

b. Types of connecting rods. (1) *Plain-type connecting-rod assembly.* A plain-type connecting rod is shown in figure 25. This is used on in-line engines

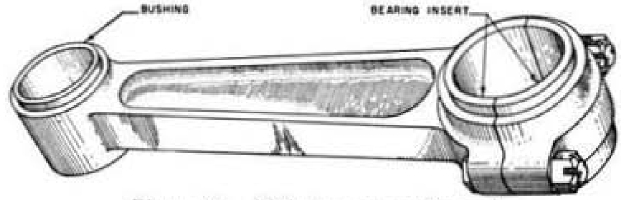


Figure 25. Plain-type connecting rod.

and the smaller opposed engines. It has a bushing in the piston-pin end. This bushing is usually made of bronze, pressed into place, and then reamed to size. On the big end is a cap and a two-piece bearing shell. The bearing shell is usually made of steel and is lined with some nonferrous bearing material such as babbitt, bronze, leadbronze, copper-lead, or lead-silver. The two-piece shell fits snugly in the big end of the connecting rod. Dowel pins or retaining lugs prevent it from turning. The cap is held on the end of the rod by bolts or studs. To maintain proper fit and balance, connecting rods are always replaced in the same cylinder, and in the same relative position.

(2) *Fork-and-blade connecting-rod assembly.* A fork-and-blade connecting-rod assembly is shown in figure 26. The forked part is split on the big end so that space will be provided for the blade rod to fit

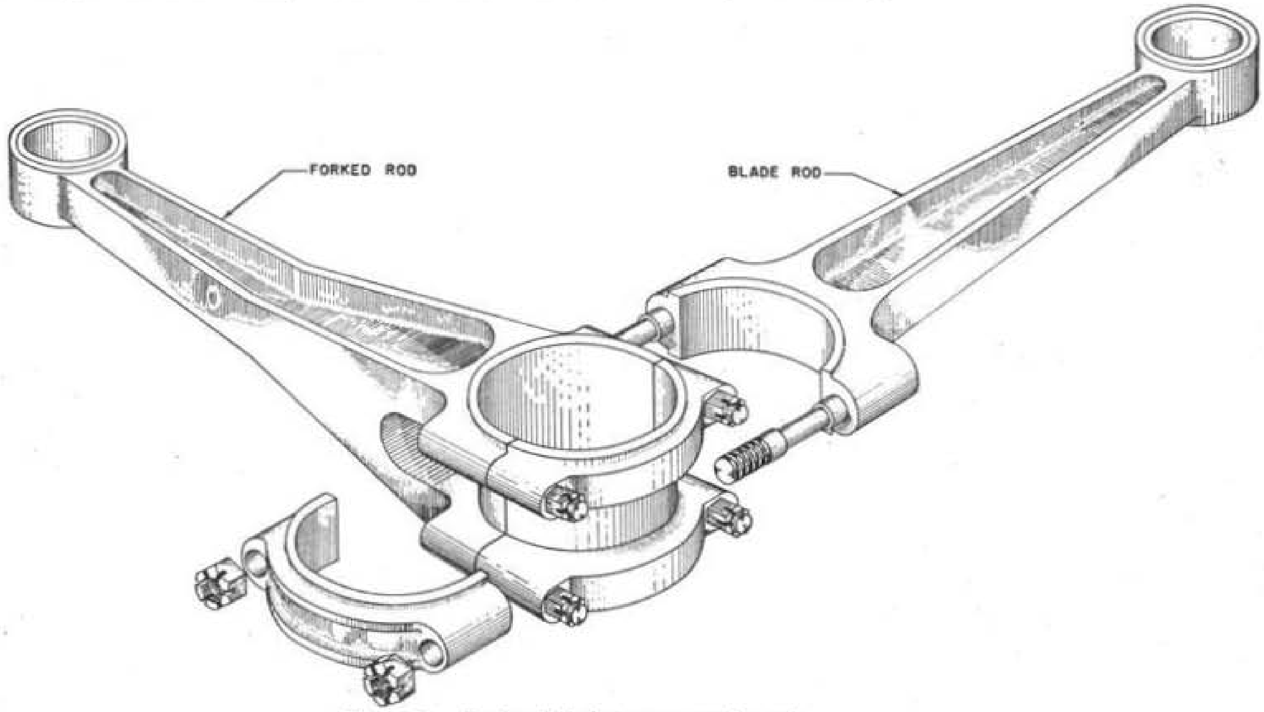


Figure 26. Fork-and-blade-type connecting rod.

between the prongs. One two-piece bearing shell is used. This is fastened by lugs or dowel pins to the forked rod. The center area on the outer surface of the bearing shell between the prongs of the forked rod is coated with a non-ferrous bearing metal to act as a journal for the blade rod and cap. The fork-and-blade connecting rod is used on the **V**-type and on large opposed-type engines. In order to maintain proper fit and engine balance, the fork-and-blade rods are always replaced on the crankshaft in the same relative positions as they were in the original installation.

(3) *Master-and-articulated rod assembly*. A master-and-articulated connecting-rod assembly is shown in figure 27. This type of connecting-rod assembly is used on **X**-type, radial-type, and on some **V**-type engines. The master rod is similar to any other connecting rod except that provision is made for the attachment of the articulated rods on the big end. The articulated rods are fastened by knuckle pins to a flange around the master rod. A bushing of non-ferrous metal, usually bronze, is pressed or shrunk into each articulated connecting rod as a knuckle-pin bearing. The knuckle pins are sometimes full-floating and are sometimes held tightly in the master-rod holes by press-fit and lock plates. When the big end of the master rod is made of two pieces, namely the rod and cap, the crankshaft will be one solid piece. If the rod is made of one piece, the crankshaft will be of two- or three-piece construction. In either case, suitable bearing surfaces will be provided.

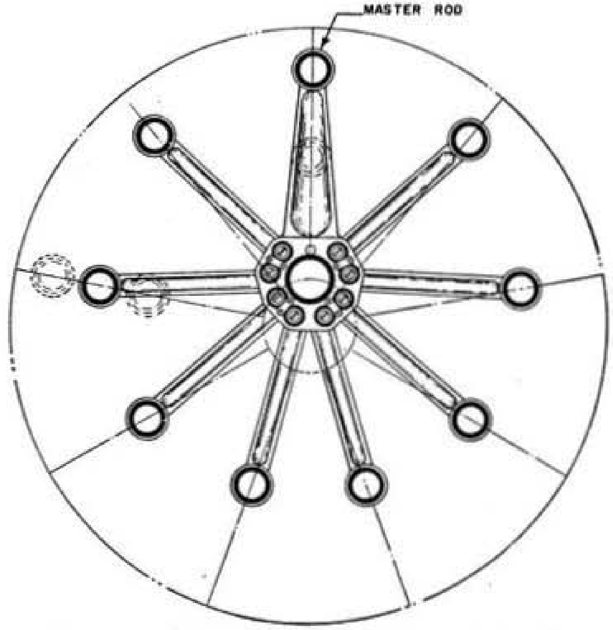


Figure 27. Master-and-articulated connecting rod.

20. PISTONS. The piston of an internal-combustion engine is simply a plunger which moves back and forth within a steel cylinder. As the piston moves down in the cylinder, it draws in the fuel-air mixture. As it moves upward it compresses the charge. Ignition occurs and the expending gases cause the piston to move toward the crankshaft. On the next stroke (toward the head) it forces the burned gases out of the combustion chamber.

a. Description. A typical piston is shown in figure 28. The top of the piston is known as the *head*. The sides are known as the *skirt*. The ring *grooves* are machined around the body of the piston. The metal between two grooves is a *groove land*. In order to obtain maximum engine life the piston must be able to withstand high operating pressures and temperatures. The most common piston material is cast iron or aluminum alloy. Cast iron gives longer life with little wear, it can be fitted to closer clearances and it distorts less than aluminum. The advantages of aluminum are its light weight and its higher

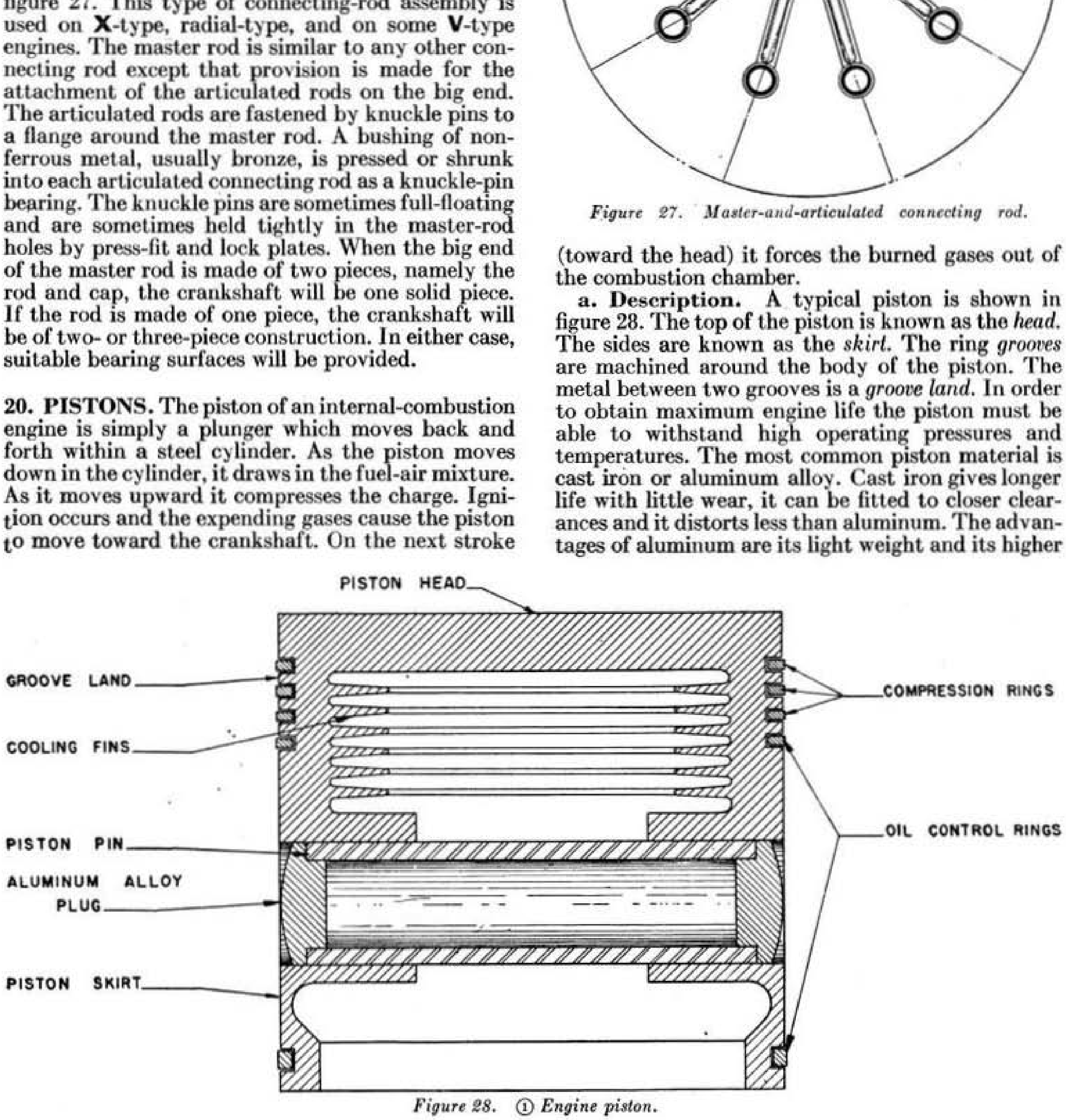


Figure 28. ① Engine piston.

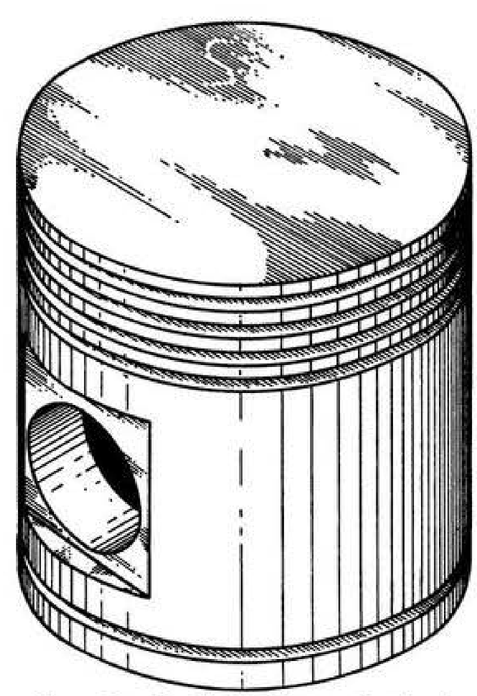


Figure 28. ② *Engine Piston—Continued.*

heat conductivity. The piston and ring assembly must form as nearly a perfect gas-tight seal with the cylinder wall as possible. It must slide along the cylinder wall with very little friction. All of the piston assemblies must weigh within ½ ounce of each other in order to have a smooth-running engine.

(1) *Piston speed.* Some conception of the importance of lightness in a piston may be gained by considering the action of a piston when the engine is in operation. For example, a piston in an engine operating at 2,000 rpm will stop and start 4,000 times in 1 minute. Moreover, if this piston has a 6-inch stroke, it will reach maximum velocity of more than 35 mph after each start. It is obvious that the piston must be as light as possible to keep the inertia forces and vibration to a minimum.

(2) *Piston pressure and temperature.* The pressure against the piston during operation will be as high as 500 pounds per square inch and the temperature inside of the cylinder will reach 4,000° F. Aluminum alloy is usually used for pistons because it is light and strong and because it conducts heat away rapidly. The heat in a piston is transmitted to the cylinder wall through the outside of the piston and to the engine oil in the crankcase through ribs or spikes on the inside of the piston head. Spikes offer more area from which the heat can escape, but fins increase the strength of the piston and are more generally used.

(3) *Piston and cylinder-wall clearance.* Piston rings are used as seals to prevent the loss of gases between the piston and cylinder wall during all strokes. (See fig. 1.) If the piston itself were large enough to form a gas-tight seal with the cylinder wall, the friction between the piston and cylinder wall would be excessive. Therefore, the piston is made several thousandths of an inch smaller than the cylinder and rings are installed in the grooves machined in the piston. These rings act as seals and prevent the gases from escaping.

b. Types. Pistons differ as to the type of head used. The head may be flat, recessed, cup-shaped, dome-shaped, or truncated-cone. (See fig. 29.) Each type is supposed to have some advantages over the others. However, most engine manufacturers are using a plain flat headed piston if its use is at all possible.

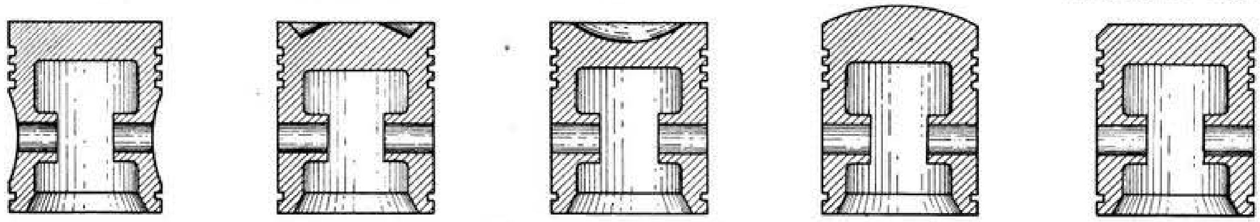


Figure 29. Piston-head types.

21. PISTON RINGS. Piston rings are bands of carefully machined, high-grade cast iron. They are used to seal the opening (clearance) between the piston and the cylinder wall. They are split so that they may be slipped over the outside of the piston and into the ring grooves which are machined on the circumference of the pistons. When they are fitted in the cylinder, they must exert equal pressure at all points on the cylinder wall. They must also fit the cylinder wall perfectly to provide a gas-tight fit. In addition to the foregoing, the rings must also make a gas-tight fit against the sides of the groove. Although many materials have been used in making piston rings, cast iron is most generally used. In some cases chrome-plated cast-iron piston rings are used in the top ring groove *only* because they are better able to withstand high temperatures, form a good wearing surface, and retain a greater amount of the original elasticity after considerable use.

a. Types of piston rings. Piston rings may be of the same thickness all the way around or they may vary in thickness. Those generally used in aircraft engines are of the same thickness. The two types of piston rings used in an internal-combustion engine are compression rings and oil rings.

(1) *Compression rings.* The principal function of the compression ring is to prevent gases from leaking past the piston during engine operation. These rings are placed in the ring grooves just below the piston head. The number of compression rings used on a

piston is specified by the designer, although three are found on most aircraft-engine pistons. These rings may have any of the three cross sections described in paragraph 21b. A compression ring may have a straight bearing edge, or a slightly tapered edge for bearing against the cylinder wall. The tapered edge hastens the seating of new rings against the hardened cylinder-wall surface.

(2) *Oil rings.* The principal purpose of this type of ring is to control the amount of lubricant supplied to the cylinder walls and to keep this oil from passing into the combustion chamber. Two types of oil rings—oil-control rings and oil-wiper rings—are used. Oil-control rings occupy the ring grooves just below the compression rings. The number of oil-control rings varies from one to three for each piston. The thickness of the oil film on the cylinder wall is controlled by these rings. If oil in excessive amounts is allowed to enter the combustion chamber, it will burn and possibly leave a thick coating of carbon over the piston head, combustion-chamber walls, and valve heads. This carbon condition may also result in sticking valves and piston rings if it enters the valve guides and ring grooves. It may also cause preignition, detonation, and increased oil consumption. Holes are usually drilled through the base of the grooves of the oil control rings or in the lands next to these grooves to allow the surplus oil to return easily to the crankcase or sump. To prevent oil from seeping into the cylinders when the engine is not operating, pistons used in inverted cylinders may be manufactured without these holes. On some engines, oil rings, generally called the oil-wiper or oil-scraper rings, are installed on the skirts of the pistons. These rings regulate the amount of oil passing between the piston skirts and the cylinder walls during each piston stroke. They are usually beveled in cross section. The beveled edge may be installed in either of two positions. When installed with the beveled edge nearest the piston head, the ring scrapes oil toward the crankcase. When installed in reverse (beveled edge away from the piston head) the ring acts as a pump to maintain a flow of oil between the piston and cylinder wall.

b. Piston-ring cross sections. The cross section of piston rings used in an aircraft engine will vary with the type of engine and the manufacturer's specifications. Generally a narrow-surfaced ring is preferable to a wide one because of its better seating characteristics. By using several narrow rings in place of fewer wide ones, more contact area is provided between the ring lands and the rings. To function in modern high-performance engines, piston rings, especially the top ones, must be constructed as ruggedly as possible. Some rings are marked to indicate the proper position of installation. Figure 30 ①, ②, and ③ are common types of cross sections found in the manufacture of compression rings; figure 31 ①, ②, and ③ are examples of cross sections found in oil-control rings.

(1) *Rectangular cross section.* The early piston ring was generally rectangular in cross section. (See fig. 30 ①.) The particular advantage of this type lies in the ease of its manufacture.

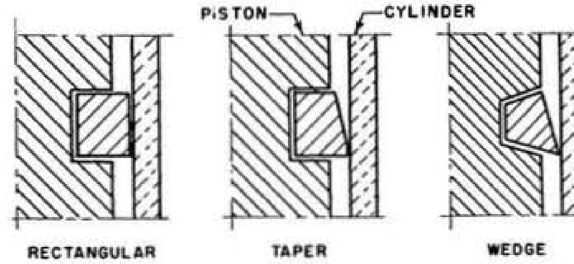


Figure 30. Piston-ring cross sections — compression rings.

(2) *Tapered-edge types.* The tapered- or beveled-edge ring (fig. 30 ②) is the most commonly used type. The tapered-edge bearing against the cylinder wall hastens the seating of new rings against the cylinder's hardened surface.

(3) *Wedge-type cross section.* Wedge-shaped rings (fig. 30 ③) are fitted to beveled-edge grooves so self-cleaning, sliding action will prevent ring-to-groove sticking. These rings are installed as compression rings, since compression rings operate at the highest temperature, get the least lubrication, and therefore have the greatest tendency to stick. The beveled-edge grooves on the piston also leave stronger ring lands.

(4) *Ventilated type.* The oil-control rings may be of the ventilated type. The two-piece ventilated type is probably the form most often used. The ventilated piston ring is designed with a number of equally spaced slots around the entire circumference of the ring. These slots allow the oil to drain through to the holes in the ring groove and into the crankcase. (See fig. 31 ①.)

(5) *Oil wiper.* The oil-wiper type (also called the scraper or bevel ring) is generally used in the bottom grooves of the piston. It is placed so that it wipes the oil toward the crankshaft. (See fig. 31 ②.)

(6) *Uniflow-effect type.* On several radial-type engines the oil-wiper rings on the upper cylinders are faced toward the dome or head of the piston to help carry more oil to the top rings. With this method of assembly the oil rings located above the top ring serve as oil wiper rings. In an installation of this type, the oil-control rings on the lower cylinders are usually faced toward the crankshaft to prevent over-oiling. (See fig. 31 ③.)

c. Types of piston-ring joints. Piston rings are split to permit them to be slipped over the head of the piston. The split is commonly called a piston-ring joint and may be any one of many different

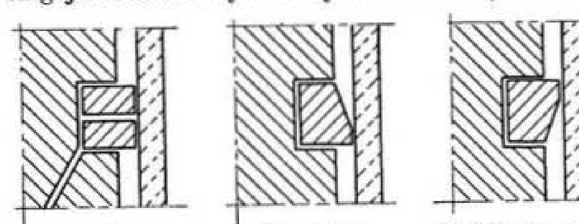


Figure 31. Piston-ring cross sections — oil rings.

shapes. There appears to be no particular advantage of one shape of joint over another. When a ring is installed in a cylinder, there should be a specified gap clearance between the joint ends. This gap allows for expansion during engine operation. When a piston is installed in a cylinder, the joints of the rings must be staggered around the piston to reduce blowby. The three most common types of joints used are: the straight-cut or butt joint, the angle joint, and the step joint. (See fig. 32.)

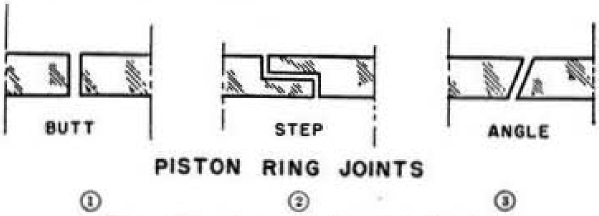


Figure 32. Types of piston-ring joints.

(1) *Straight-cut or butt joint.* In this type of joint, the ends of the ring are cut at right angles to the parallel edges of the piston ring.

(2) *Step joint.* This type is known by this nomenclature because the joint resembles a step. It is used less frequently because it is more difficult and expensive to manufacture.

(3) *Angle joint.* This type is so named because the split occurs at an angle to the edges of the ring.

22. PISTON PINS AND KNUCKLE PINS. The piston is attached to the connecting rod by means of a piston pin, sometimes called a "wrist pin." The knuckle pin is used to attach an articulating rod to a master rod. In construction, these two pins are very much alike.

a. Piston pins. The piston pin is located in the piston bosses as shown in figure 33. The pins are made of steel—hollowed for lightness and surface hardened to resist wear. The piston - pinbosses are of the same metal as the piston. When the piston is made of an aluminum alloy, the bosses may or may not have bushings of some nonferrous metal such as bronze. The piston pin passes through the bosses and the little end of the connecting rod which rides on the central part of the pin. Piston pins are generally classed as stationary, semifloating, or full-floating type. A rigid type is fastened securely in the boss by means of a set screw and is not free to move in any direction. The semifloating piston pin is held securely by means of a clamp screw in the end of the connecting rod and a half slot in the pin. The piston pins used in aircraft engines are of the full-floating type, that is, they are free to turn or slide in both the piston and connecting rod. Contact between the piston pin and the cylinder wall is prevented by circlets (circlips), by spring rings, or by nonferrous metal plugs.

(1) *Circlets.* Circlets or circlips, as shown in figure 34, are almost complete circles of spring steel which fit into grooves at the outside end of each piston boss. They perform the same function as the spring rings.

(2) *Spring rings.* A spring ring, as shown in figure 34, is an endless circular coil of spring steel which fits

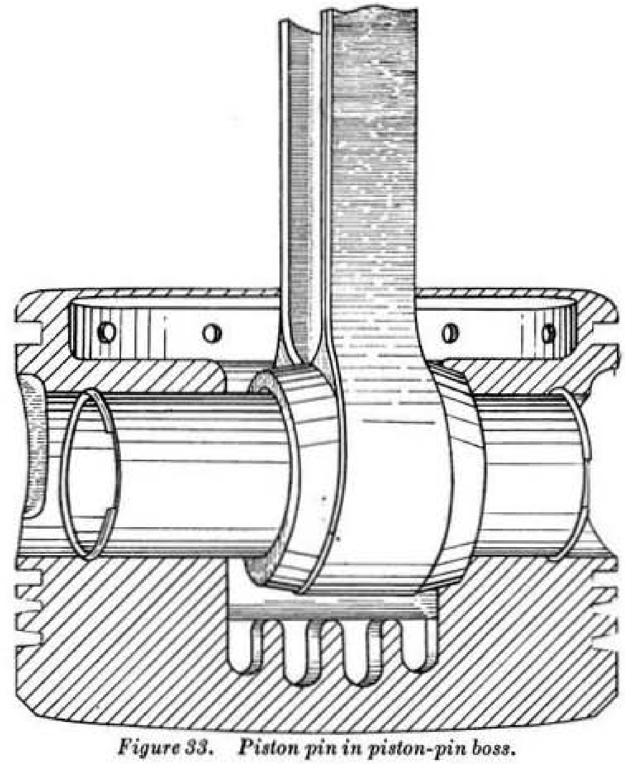


Figure 33. Piston pin in piston-pin boss.

the circular grooves cut into the outside end of each piston boss and prevents the movement of the pin against the cylinder wall. These rings are also known as garter-spring retainers.

(3) *Nonferrous metal plugs.* Nonferrous plugs, usually aluminum alloy (fig. 34), are inserted into the open ends of a hollow piston pin to prevent the steel pin from bearing against the cylinder wall. Piston-pin bosses frequently incorporate drilled holes through them to aid in supplying lubricant to the piston-pin bearing surfaces since these surfaces are not pressure lubricated.

b. Knuckle pins. These are the hinge pins by which the articulated or link rods are fastened to the big end of the master rod. (See fig. 35.) They are surface hardened to reduce wear and are hollow to make them light and to provide a passage for the lubricating oil.

(1) *Knuckle-pin bore.* The knuckle-pin bore of each steel articulated connecting rod incorporates a bushing of nonferrous bearing metal, usually bronze. These bushings are usually shrunk, pressed, pinned, or spun into place.

(2) *Knuckle-pin installation.* Knuckle pins may be retained and prevented from turning in the master rod by a tight press fit or they may be installed with a loose fit. In both cases a lock plate on each side bears against the pin and keeps it from moving laterally. (See fig. 35.) If the pin is installed with a loose fit, it can turn in the master-rod flange holes as well as in the articulated-rod bushings. Knuckle pins installed in this manner are known as the full-floating type.

23. CYLINDERS. The cylinder of an internal-combustion engine is that part in which the power for

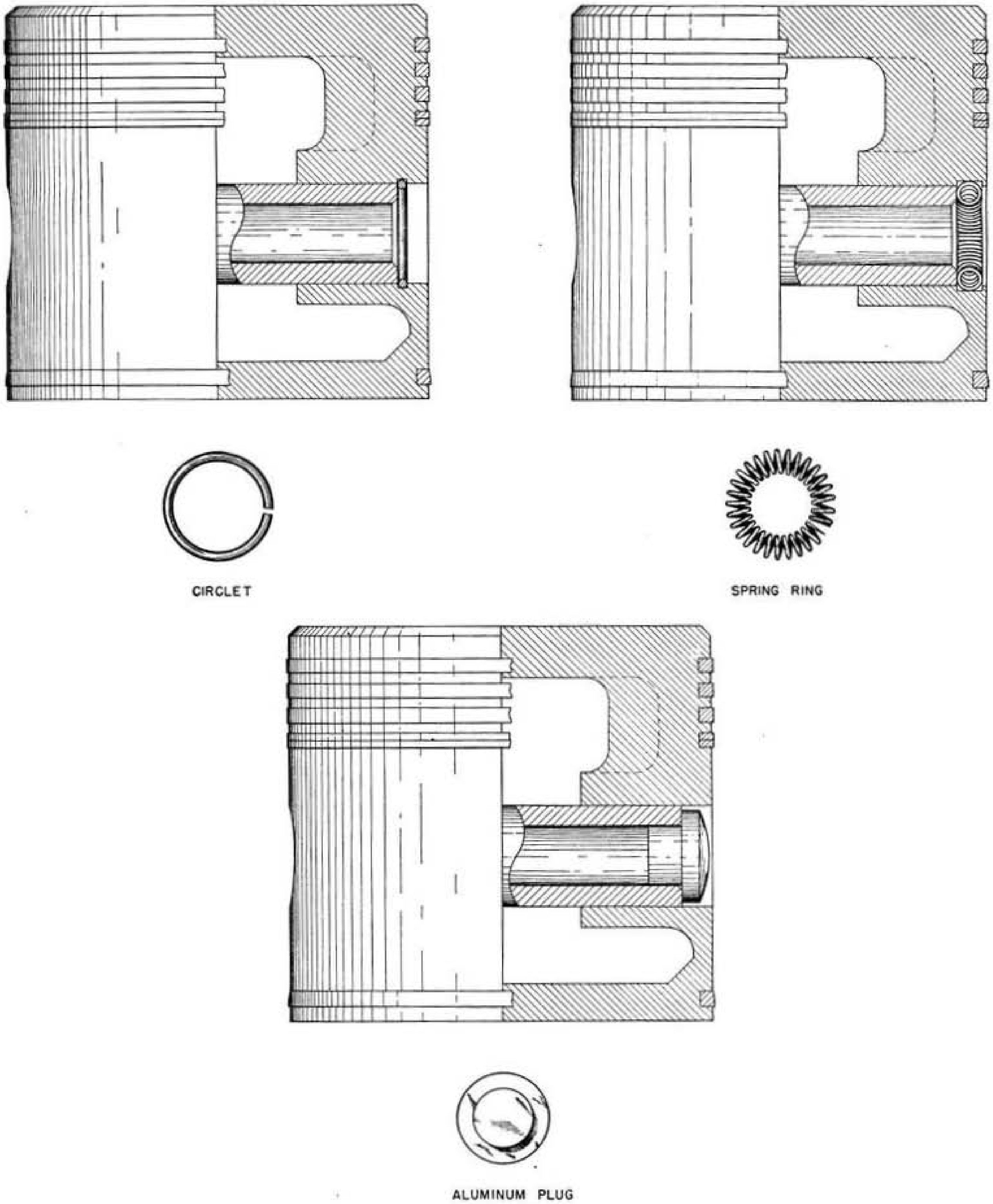


Figure 34. Piston-pin retainers.

rotating the crankshaft is developed. The modern cylinder assembly consists of a cylindrical steel barrel, capped at one end, usually by an aluminum-alloy head. The primary purposes of the cylinder assembly are to provide a combustion chamber (in which the burning and expansion of gases take place) and to house the piston and connecting rod. Together with the crankcase it forms the power or main section of the engine. The two major parts of the cylinder assembly are the head and the barrel. In the design

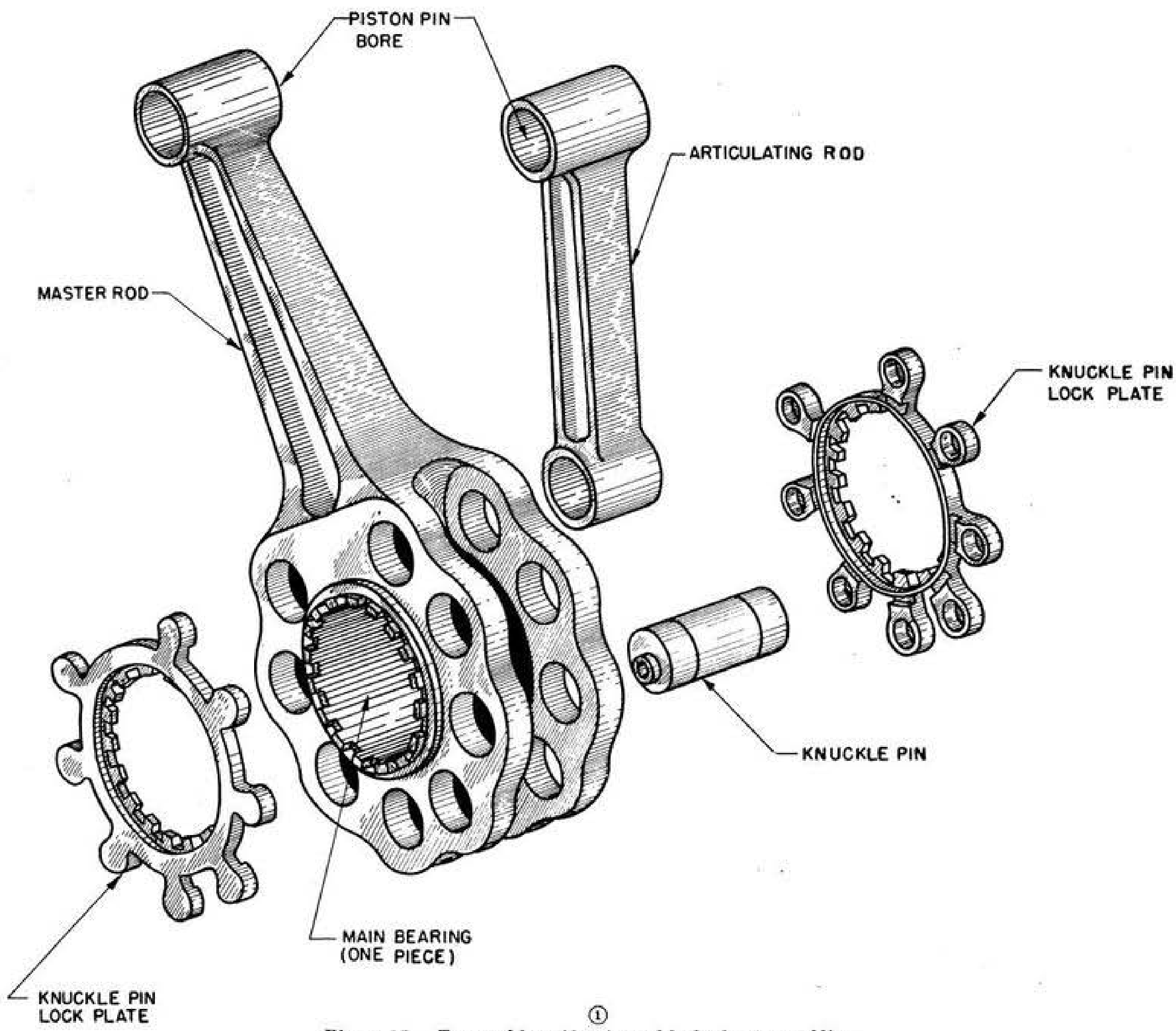
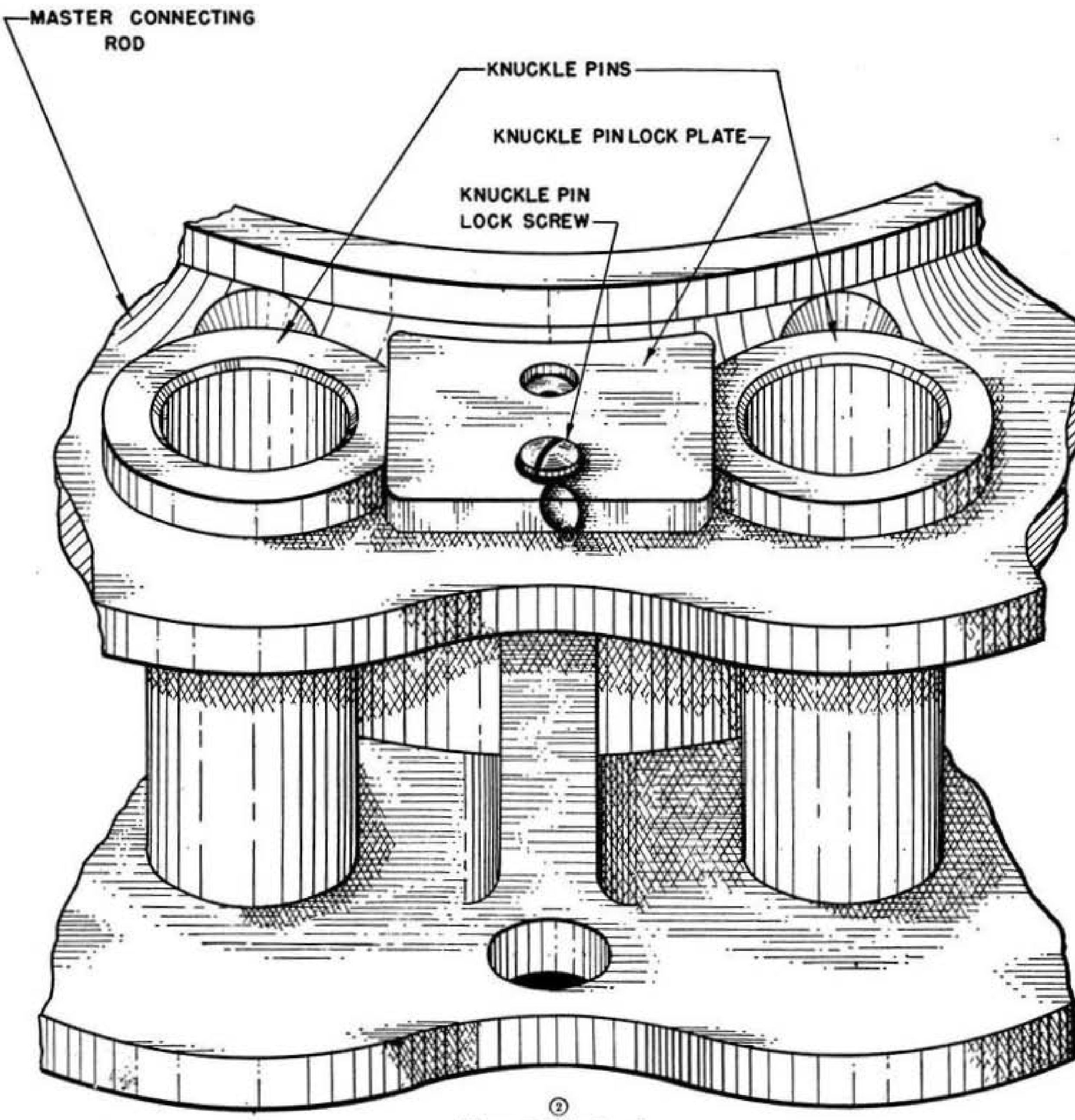


Figure 35. Types of knuckle-pin and lock-plate assemblies.

and construction of the assembly, many factors must be considered. The unit must be strong in order to withstand the internal pressures created during engine operation; it must be constructed of light-weight metal to reduce the total engine weight; it must provide adequate heat-conducting properties for efficient cooling; and it must conform with certain manufacturing requirements.

a. Cylinder head. The head may be produced singly for each cylinder in the air-cooled engine, or cast in-block (all cylinder heads in one block) for an in-line engine. The cylinder head is generally made of aluminum alloy because aluminum alloy is a good conductor of heat and its light weight reduces the over-all engine weight. Cylinder heads are forged or die-cast for greater strength. The inner shape of a cylinder head may be flat, semispherical, or peaked in the form of a house roof. (See fig. 36.) The semispherical shaped type has proved most satisfactory because it aids in a more rapid and thorough scavenging of the exhaust gases. In each cylinder one or two round openings are provided for the installation of one or two spark plugs. Aluminum alloy is not hard enough to serve as a spark-plug opening. Therefore, bronze, brass or steel bushings are shrunk and screwed into the openings. Each bushing is pinned in place by two brass pins to insure further the rigidity of the bushing. Bronze or steel valve bushings are usually shrunk or screwed into drilled openings in the cylinder head to provide guides for the valve stems. These are usually located at angles to the centerline of the cylinder.

(1) *Air-cooled cylinder heads.* The cylinder heads of modern air-cooled engines are subjected to extreme temperatures and it is therefore necessary to provide adequate fin area and to employ metals which conduct heat rapidly. Cylinder heads of air-cooled engines are usually cast or forged singly. Aluminum alloy is used in the construction for a number of reasons. It is well adapted for casting or machining deep, closely spaced fins and is more resistant than other metals to the corrosive attack of tetraethyl



②
Figure 35—Continued.

contained in gasoline. The greatest improvement in air cooling resulted from reducing the thickness of the fins and increasing their depth. In this way the fin area was increased from approximately 600 square inches to more than 2,500 square inches per cylinder. Cooling fins taper from 9/100 inch at the base to 6/100 inch at the tip end. Because of the difference in temperature in the various sections of the cylinder head it is necessary to provide more cooling-fin area on some sections than on others. The exhaust valve region is the hottest part of the internal surface; therefore, as shown in figure 1, more fin area is provided around the outside of the cylinder in this section.

(2) *In-block cylinder heads.* An in-block cylinder head is cast or forged in one piece to accommodate a bank of cylinders. The metal used is aluminum alloy. Intraconnected passages are provided to permit the flow of coolant liquid. Compactness, a more rigid construction, less cost, and simplicity of assembly at overhaul are advantages of the in-block cylinder head over the individual cylinder head. The in-block cylinder head also simplifies the enclosure of the valve-operating mechanism.

b. Cylinder barrels. The cylinder barrel is generally of a steel-alloy forging. The inner surface is hardened to resist better the wear of the piston and piston rings which bear against it. The steel used must have a high tensile strength and must be able to withstand high operating temperatures. In some instances, the barrel is provided with threads at one end (on the outside diameter) for joining it to the cylinder head.

(1) *Air-cooled cylinder barrels.* Cooling fins are machined on the outside of the steel barrel. These fins serve primarily to conduct the excess heat from the cylinder, but they also serve to strengthen and increase the rigidity of the barrel. Some designs employ plain steel barrels with closely finned aluminum-alloy sleeves or muffs shrunk on the outside of the barrels.

(2) *Liquid-cooled cylinder barrels.* The cylinder barrel of a liquid-cooled engine is sometimes called a liner. This barrel is made of steel which is treated on the inside to give it better wearing qualities. The barrels are shrunk-fit into the cylinder heads and are retained in this position by studs and bolts.

c. Joining the cylinder head and cylinder barrel. Three methods are used in joining cylinder barrels to cylinder heads.

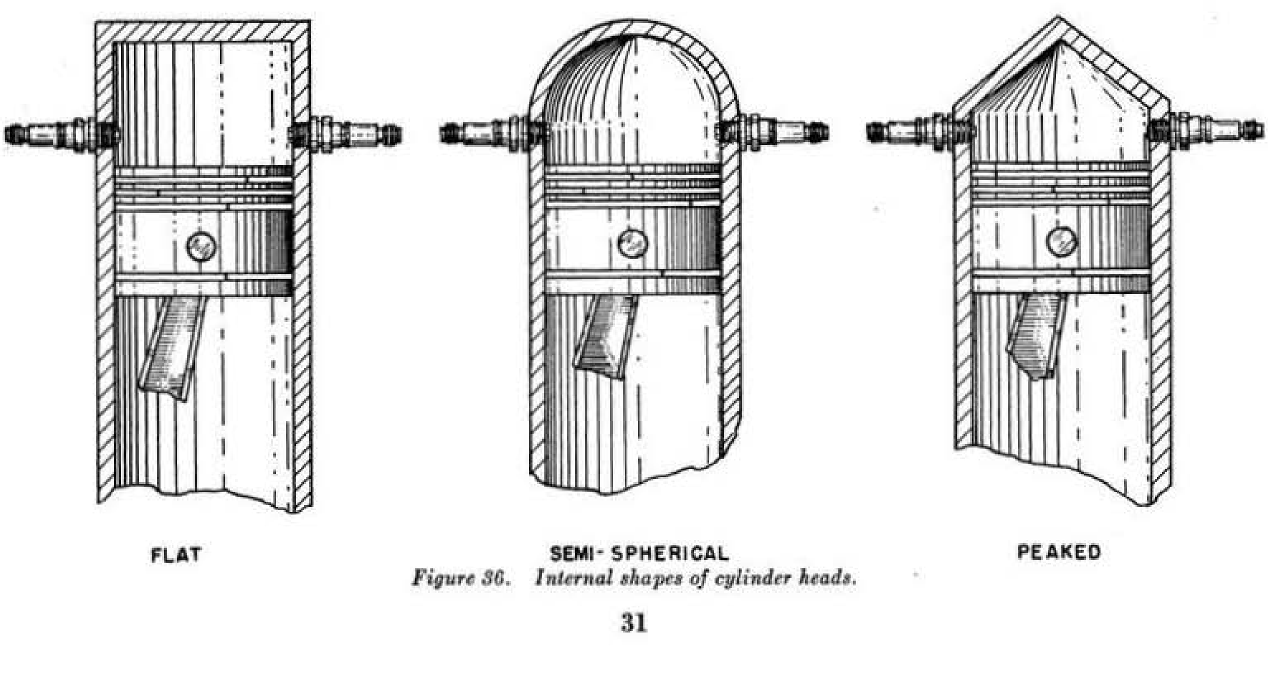
(1) *Threaded joint.* The cylinder head is first heated while the cylinder barrel is retained at room temperature or chilled. The two parts are then joined by screwing the cylinder barrel into the cylinder head (See fig. 1.) A jointing compound is used on the threads to prevent compression leakage.

(2) *Shrink fit.* In this method, the cylinder barrel and the head are joined while the head is hot (expanding the metal) and the barrel is chilled. No threads are used. This provides a pressure-tight joint between the two parts. However, this requires an added means of holding the two parts together and conventionally employs long steel stud bolts set in the crankcase. These studs protrude through holes in the cylinder head and thus provide a means of retaining the whole assembly to the crankcase. Cylinder barrels and head assemblies that are joined by a shrink-fit are not generally separated at engine overhaul since their separation is not necessary unless the barrel of the assembly is badly scored or worn beyond regrinding limits. In this case the whole assembly is usually replaced.

(3) *Stud- and nut-joint.* In this method, the cylinder barrel and the head are joined by a number of short steel studs and nuts. The studs are placed circularly around the cylinder head and protrude through the holes of a heavy steel flange on the head end of the barrel. A metal gasket is placed between the head-and-barrel joint surfaces to provide a pressure-tight joint.

d. Methods of cooling. The intensity of heat produced in engines has increased greatly as a result of the rapid increase in size of cylinders, the volume of charge passing through them at high crankshaft speeds, and the high supercharger pressures. To prevent trouble that would be caused by an excessive rise in cylinder temperature, it is necessary to provide some means of eliminating the unused part of the heat. The combustion-chamber and cylinder-barrel walls are exposed to considerably higher temperatures than that of the outside cooling medium; therefore heat flows from the interior to the exterior surfaces.

(1) *Air cooling.* Heat is transferred from the cylinder to the cooling air by conduction through the metal walls and the fins to the fin surfaces. The fins on the head are of the same metal as the head and are generally die-cast or forged as a part of the unit. Those on the steel barrel are usually of the same metal and machined from the same forging as the barrel. A plain steel cylinder barrel which does not have steel fins may be cooled by a closely finned aluminum-alloy sleeve or muff shrunk on the outside. This increases the transmission of heat to the cooling air. The outside of an air-cooled cylinder assembly is protected against corrosion by a coating of baked, heat-resisting black enamel or a thin coating of aluminum applied by spray in a molten state. The aluminum coating affords greater protection than the enamel against the corrosive action of salt air and salt-water spray and has more resistance to the blasting action of gritty particles in the cooling air flow. In some cases the two methods are combined with the enamel applied last.



FLAT SEMI-SPHERICAL PEAKED

Figure 36. Internal shapes of cylinder heads.

(2) *Liquid-cooling.* The cylinder-head block of a liquid-cooled engine is of cast or forged aluminum alloy with intra-connected passages through which coolant liquid flows. An aluminum-alloy jacket is placed around the steel cylinder barrels in such a manner as to cause the coolant medium to circulate around the cylinder barrels. This coolant absorbs a large percentage of the combustion heat and transmits it to a radiator which in turn is exposed to the airstream.

24. VALVES. a. General. The internal-combustion engine requires passage-ways to and openings into the combustion chamber. These openings are called "ports." The main purpose of the valves is to open and close these ports. One is known as the "intake port." It allows entrance of the fuel-air charge into the cylinder. The other is known as the "exhaust port" and provides an opening through which burned gases are expelled. Each cylinder must have at least one intake and one exhaust valve. On some liquid-cooled engines of high-power output, two intake and two exhaust valves are employed. The shape and form of all valves is determined by the design and specifications of a particular engine.

b. Poppet-type valve. The word "poppet" was derived from the popping action of the valve. This type of valve is called a "mushroom" or "tulip" type because of the general resemblance of the valve heads to these objects. (See fig. 37.) Intake-valve heads are generally tulip-shaped and exhaust-valve heads are usually mushroom-shaped. Valve material must withstand high temperatures without corrosion. For intake valves, which operate at lower temperatures than exhaust valves, chrome-nickel steel is generally used. Exhaust valves are usually made of silchrome, nichrome, or tungsten steel. Poppet valves are forged in one piece from these special steels. The stems are surface-hardened to resist wear better. A hardened-steel tip is welded to the stem end to provide resistance to the wear and pounding to which it is subjected. A machined groove located on the stem below the tip is fitted with a tapered, split (two piece) lock of bronze or steel. After the valve-spring washer is slipped into place, the two-piece split lock

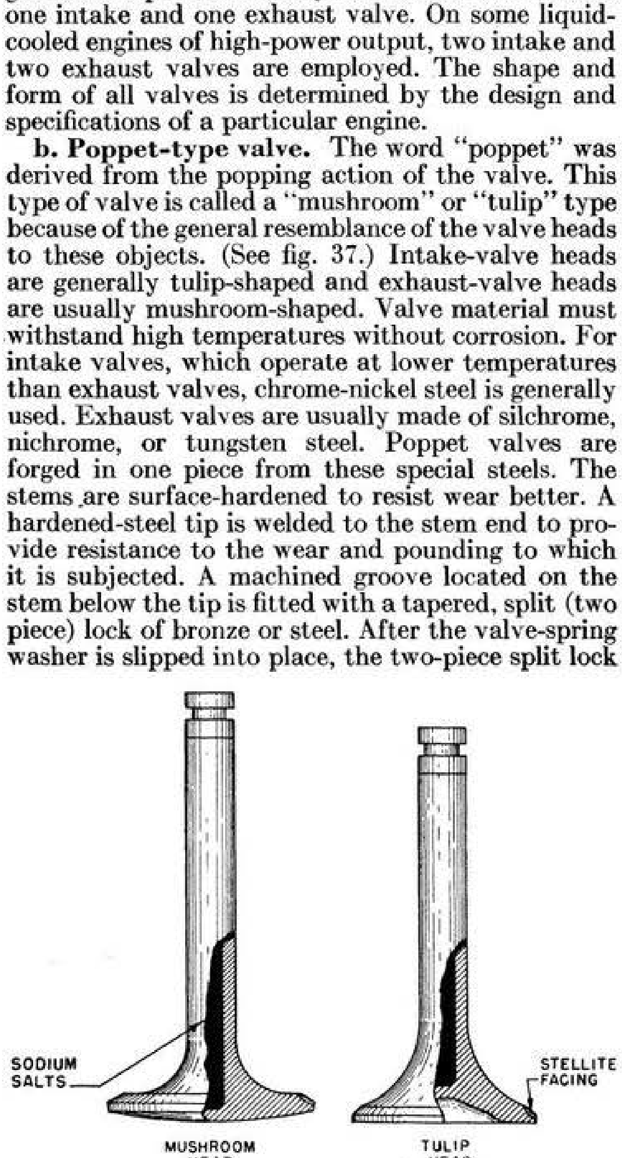


Figure 37. Poppet valves.

ring fits into the groove and the spring tension keeps it in position. On some valve stems (just below the lock grooves) a narrow groove machined for the installation of safety circlets or spring rings for the purpose of preventing the valves from falling into the combustion chambers at valve assembly and disassembly, and during engine operation should the valve springs break. In some engines, two small exhaust and two small intake valves per cylinder are employed. This reduces the over-all size of the valve and the opening and thereby reduces the operating temperature of the valves. The complex mechanism required to operate the valves of radial engines limits the use of valves per cylinder to not more than two.

(1) *Exhaust valves.* An exhaust valve is manufactured with a hollow stem and head. As the valve does not receive the cooling effect of the fuel-air charge, it must be designed to dissipate heat more rapidly. The hollow portion of the valve is partly filled with either metallic sodium, a composition of sodium and mercury, or a chemical salt. During engine operation, this composition carries heat rapidly from the valve head to the valve stem. From here the heat is conducted to the valve guide and thence to the cylinder cooling fins.

(2) *Inlet valves.* The inlet or intake valve is generally of the solid-stem type. With the increase of power output the necessity of cooling the inlet valve has increased. An inlet valve of the hollow type is partially filled with one of the cooling agents mentioned in paragraph 24b(1). The main requirements of the inlet valve are: it must allow unrestricted passage of the maximum possible weight of fuel-air charge into the combustion chamber, its operation must absorb the least possible horsepower, and it must help produce a high port velocity, and a maximum turbulence of the charge within the cylinder to hasten the burning of the mixture.

c. Poppet-valve faces and seats. The valves operate at very high temperatures and the mating surfaces must resist the pounding and burning to insure good contact between the valve and the seat. It is important that a good seal be maintained because pressure leakage or blowing of the valve would later be followed by burning or warping.

(1) *Valve faces.* The angle of the valve face may range between 30° and 45°. An angle nearer 30° gives better fuel-air flow while angles nearer to 45° provide better seating. Because of the high temperature of the gases that pass by the exhaust valve, it is quite important that the valve face be made of the highest quality steel. The valve face is coated (welded) with a hard heat-resistance metal called "Stellite" to prevent corroding, pitting, and excessive wear. Because Stellite is very hard and cannot be cut with cutting tools, it requires grinding for proper fitting. Stellite is almost totally resistant to the effect of hot gases.

(2) *Valve seats.* The metal of the cylinder head is not hard enough to withstand the constant hammering produced by the opening and closing of the valve. Therefore bronze and steel valve seats are shrunk or screwed into the circular edge of the valve openings. The valve seat (fig. 38) is a circular ring of high-temperature-resistant non-corrosive bronze or steel.

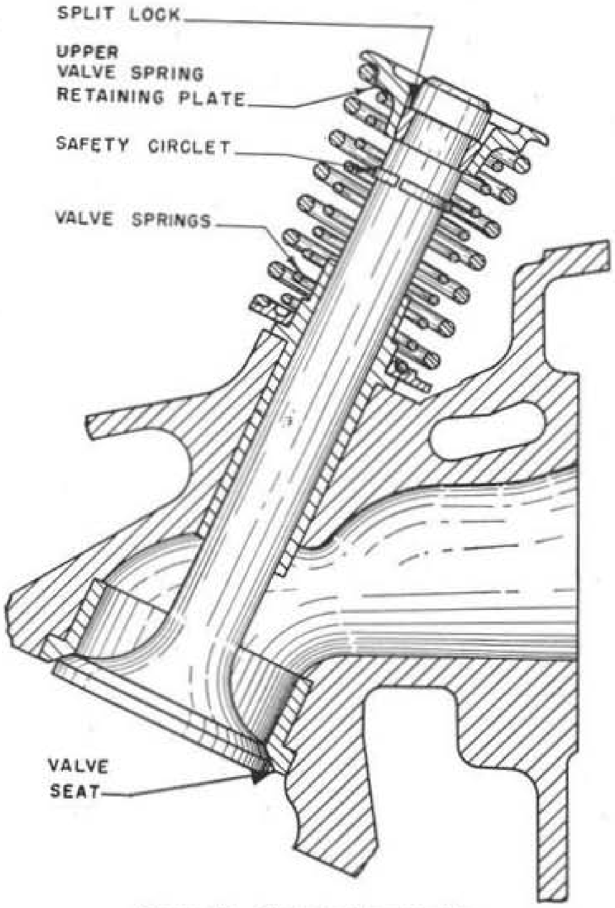


Figure 38. Poppet-valve assembly.

The bronze or steel inserts not only wear longer, but may also be replaced if they become so badly worn that they no longer function satisfactorily. Bronze is generally used for the inlet-valve opening and steel inserts faced with Stellite for the exhaust ports. At the time the cylinder head is heated and fitted on the cylinder barrel, the valve seats are also chilled and slipped into place. The shrink-fit joint provides a more intimate contact for the conduction of heat than is provided by screwing the valve seats in place.

25. VALVE SPRINGS. Valves are closed by helical-coiled springs. If a single spring were used, it would vibrate or surge at certain speeds. To eliminate this difficulty, two or more springs (one inside the other) are installed on each valve. (See fig. 38.) Each spring is made of round wire of a different diameter and the coils differ in pitch. Each spring will therefore vibrate at a different engine speed and rapid damping out of all spring-surge vibrations during engine operation will result. The use of two or more springs also reduces danger of weakness and possible failure by breakage due to heat and metal fatigue.

26. VALVE-OPERATING MECHANISMS. For an internal-combustion engine to operate properly, each valve must be timed to open at the proper time, stay open for the required length of time, and close at the proper time. This timing of the valves is con-

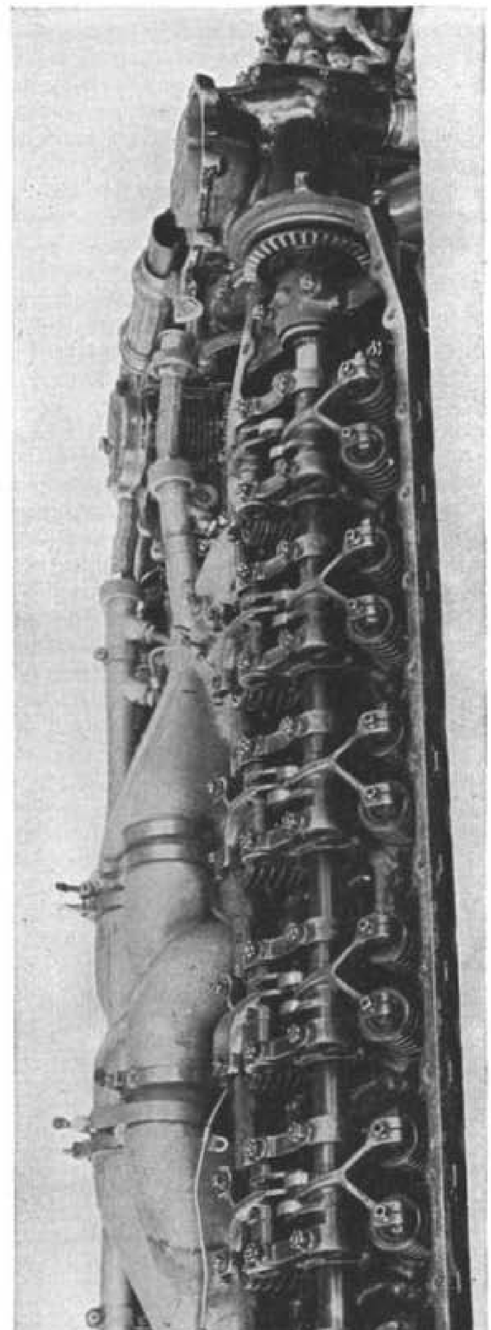


Figure 39. Overhead camshaft.

trolled by the valve-operating mechanism. This mechanism should be simple and rugged in construction and should provide satisfactory service over long periods of time with little care or maintenance. The two types of valve-operating mechanisms in general use are the type used on in-line engines and the type used on radial engines.

a. In-line and V-type engine valve-operating mechanism. The valve mechanism consists of a number of rocker-arm assemblies operated by a camshaft either directly or through push rods. In some engines which have the camshaft on the top of the cylinder block, the shaft is driven from the crankshaft by bevel gears and other necessary shafts. (See fig. 39.) Other engines may incorporate the camshaft in the cylinder block, and use push rods to operate the rocker-arm assemblies. (See fig. 40.)

(1) *Camshaft.* A camshaft is a steel rod with cams or lobes machined at certain specified positions along its length. A cam or lobe is the raised portion on the shaft surface. The shaft extends from one end of a cylinder bank to the other and is parallel to the bank of cylinders. One camshaft is generally used for the operation of all inlet and exhaust valves of each bank. It is so located that, when it turns, the lobes operate the valve mechanism. As the camshaft rotates and a cam lobe moves the valve mechanism, the valve is

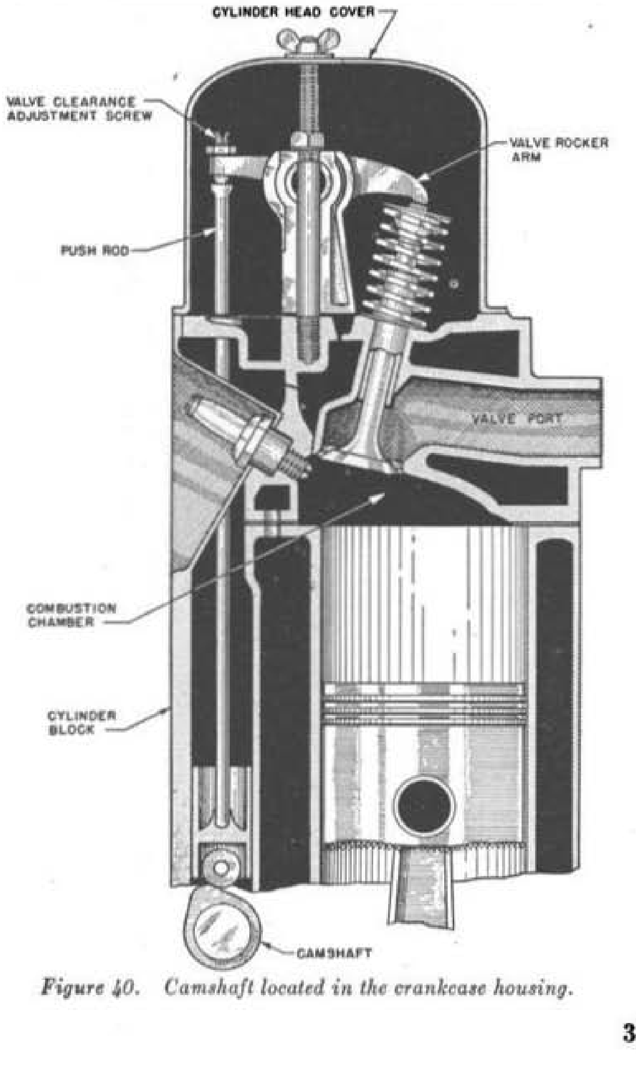


Figure 40. Camshaft located in the crankcase housing.

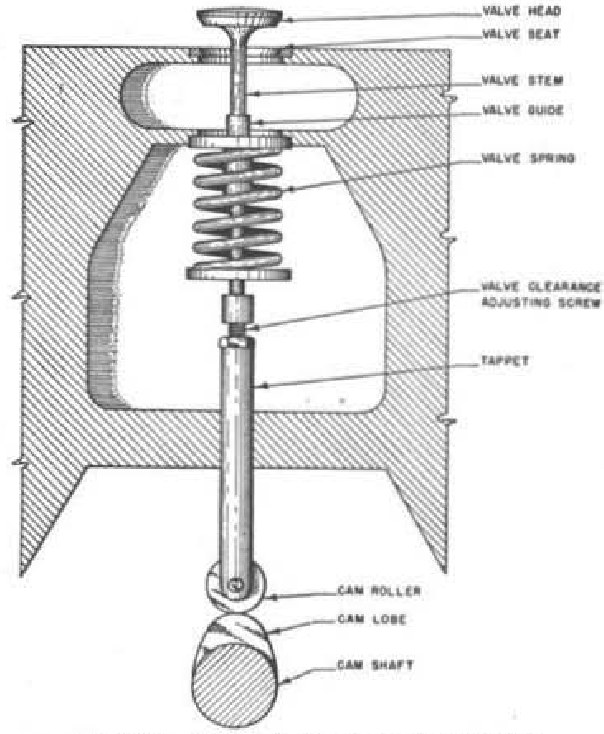


Figure 41. Camshaft valve-operation mechanism.

raised, opening the port in the cylinder, as shown in figure 41. As the camshaft continues its rotation, the cam lobe moves away from the valve mechanism, allowing the valve spring to force the valve closed. This closes the port in the cylinder.

(2) *Push rods.* On some types of engines using overhead valves the camshaft is installed in the crankcase. Push rods are incorporated on these engines to transmit the camshaft action to the rocker assembly. Push rods are usually made of aluminum-alloy tubing, steel rod, or seamless-steel tubing.

(3) *Rocker-arm assemblies.* The valve-actuating rocker used on some in-line and **V**-type engines is constructed with a stationary pivot at one end of the rocker lever. The camshaft bears on the center and the assembly on the other end of the lever bears on the valve stem. A typical arrangement of this kind is shown in figure 42 ①. The pivot end provides an oil passage to the assembly. The valve-stem end of the rocker lever is provided with a screw-type adjusting tappet for the proper adjustment of valve clearance. In some aircraft engines the rocker lever incorporates a plain, roller or ball bearing near the center and pivots from that point. (See fig. 42 ②.) One end of the rocker lever bears on the camshaft and receives the valve-operating force. The other end bears on the valve stem and transmits the camshaft movement to the valve. The camshaft end of the rocker-lever will generally be equipped with a roller. The valve end of the rocker arm incorporates an adjusting screw to permit the setting and adjustment of valve clearances. Many variations as to size and shape of rocker arm levers can be found. In one **V**-type engine a rocker-arm lever is forked to operate two valves per cylinder. (See fig. 39.)

b. Radial-engine valve-operating mechanism. The valve mechanism of a radial engine is operated by one or two cam plates or rings, depending upon the number of rows of cylinders. In a single-row radial engine, one plate or ring with a double cam track is used. One track operates the intake valves and the other the exhaust valves. The mechanism also includes the tappet assemblies, push rods, and rocker-arm assemblies

(1) *Cam ring or cam plate.* A cam ring or cam plate is used in a radial engine for the same purpose as a camshaft is used in a **V**-type or in-line engine. The cam ring is a circular piece of steel with a series of cams or lobes on the outer surface. The surface of these lobes and the spaces between them (on which the cam rollers ride) is known as the cam track. (See fig. 43.) The inner surface of the cam ring rides on a bronze bearing which is securely fastened to the crankcase. A set of gear teeth on one side of the cam ring provides the means for rotating it. As the cam ring revolves, the raised portions or lobes cause the cam roller to raise the tappet in the tappet guide, thereby transmitting the force through the push rod and rocker arm to open the valve. (See fig. 44.)

(2) *Tappet assemblies.* A valve tappet assembly consists of a short steel rod (called a tappet) inclosed in a tube called a tappet guide. (See fig. 44.) At one end of the tappet is mounted a hardened-steel roller which rides on a cam track. This roller is made of steel and is attached to the tappet which slides up and down in the tappet guide. At the other end of the tappet a hardened steel recess is found. This recess accommodates the ball end of a push rod. A hole is drilled through the tappet to allow engine oil to flow to the hollow push rods in order to lubricate the rocker assemblies.

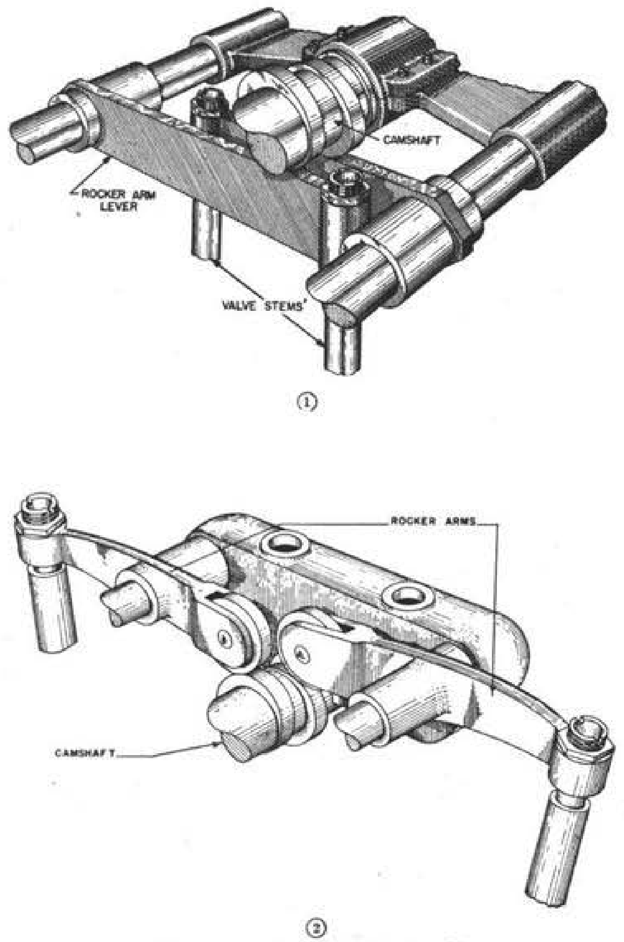
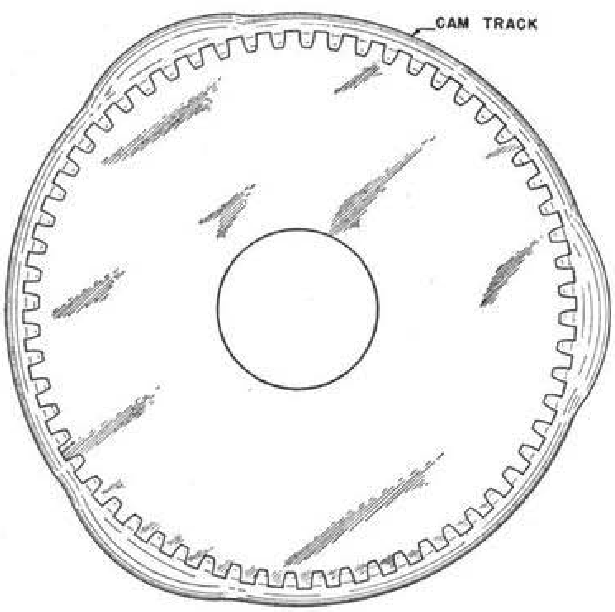
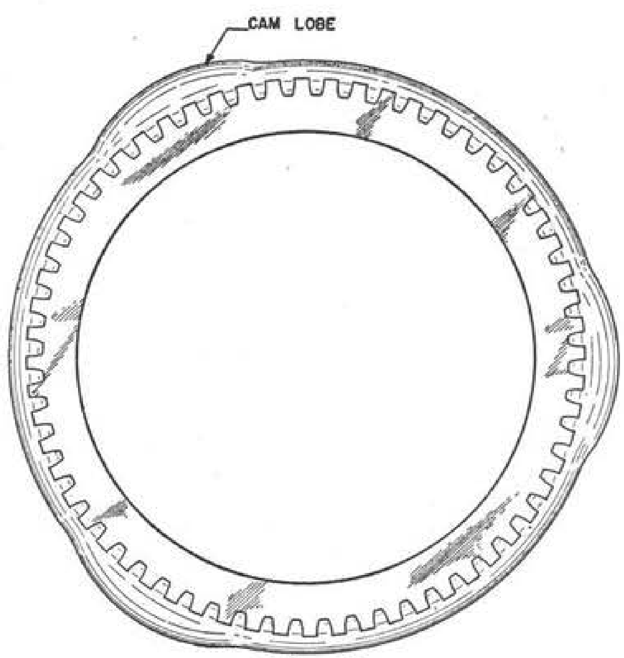


Figure 42. Rocker-arm assembly.



① *Cam plate.*



② *Cam Ring.*

Figure 43. Cam plate and cam ring.

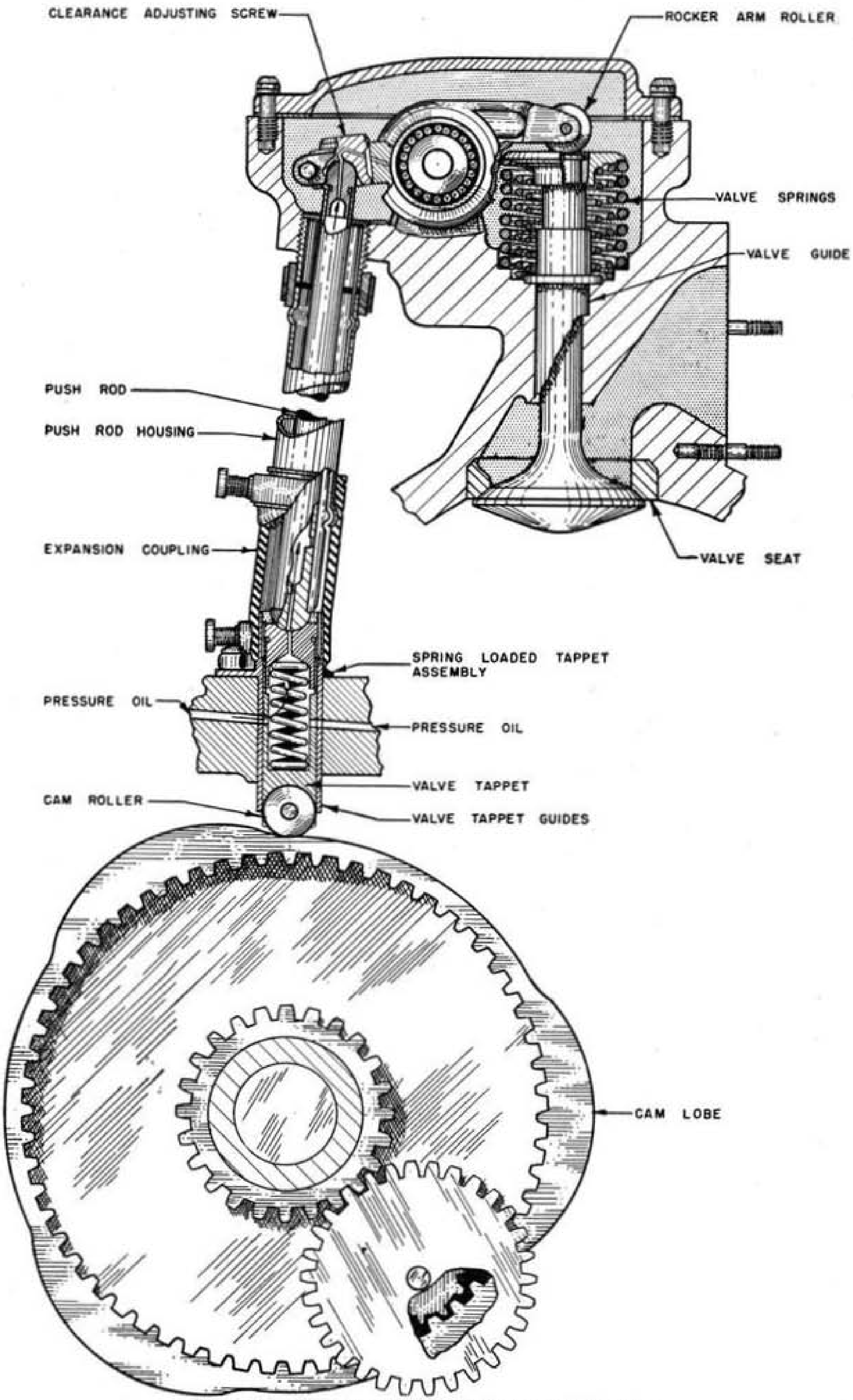


Figure 44. Valve-operating mechanism — radial engine.

(3) *Zero-lash hydraulic-valve lifter.* Another method of transmitting the force to operate the valves employs a column of oil which is confined between the cam follower and a plunger. (See fig. 45.) When the cam follower is pushed upward, the column of con-

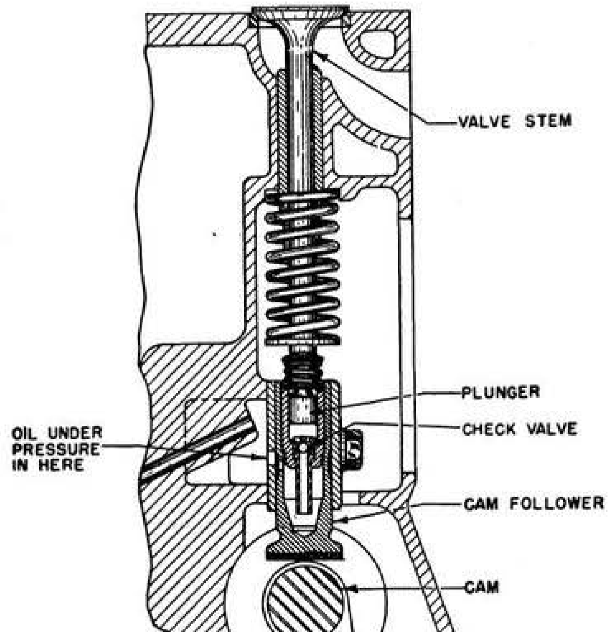


Figure 45. Hydraulic valve-lifting mechanism.

fined oil pushes the plunger upward. As the plunger bears against the valve stem, the valve will be moved upward against the spring. A very small leak is allowed to exist in a system of this type to compensate for temperature expansion. This slight loss is constantly being replaced by the engine-oiling system. No valve-clearance adjustments are necessary on engines using this system except at major overhaul. This device has so far been used only on the low-output engines.

(4) *Push rods.* A push rod is used to transmit the lifting force from the valve tappet to the rocker arm. It is tubular in form and is made of either aluminum alloy or seamless steel. A hardened-steel ball is pressed over or into each end of the tube. One ball end fits into the socket of a tappet and the other into the socket of a rocker arm. In some instances the balls are on the tappet and rocker arm and the sockets are on the push rod. The tubular form is employed because of its lightness and strength. It permits the engine lubricating oil under pressure or gravity feed to pass through the hollow rod and the drilled ball ends to lubricate the ball ends, rocker-arm bearing and valve-stem guide. This circulating oil flow greatly reduces valve-mechanism wear. Frequent checking of the valve clearances has been practically eliminated in engines using automatic valve-gear lubrication. The length of each push rod is determined by the distance between the tappet and the rocker arm sockets. Each push rod is enclosed within an aluminum-alloy tube. The tube or housing provides a passage through which the lubricating oil returns to the crankcase. It also protects the push rod from damage and prevents dirt from coming in contact with the valve-operating mechanism.

(5) *Rocker-arm assemblies.* Rocker arms or levers are mechanical devices for transmitting the lifting force from the cams to the valves. (See fig. 44.) Rocker-arm assemblies are made of steel and are supported by a plain, roller, or ball bearing which serves as a pivot. Generally one end of the arm bears against the push rod and the other bears on the valve stem. One end of the rocker arm is sometimes slotted to accommodate a steel roller. The opposite end may be constructed with either a threaded split clamp and locking bolt (see fig. 46 ①) or a tapped hole (see fig. 46 ②). Adjustments of valve clearances are made at this point. After the clearance has been adjusted, the locking bolt (or the lock nut) locks the adjusting screw so that the proper clearance will be retained. On some engines, the adjusting ball socket is generally drilled to provide a passage for lubricating oil.

27. VALVE-TIMING DEVICES. Variations in valve timing will vary the power delivered at a given speed. To obtain the best performance at high speeds means a sacrifice at low speeds and vice versa. A compromise must be made to obtain the desired results. The valve timing on practically all modern engines is arranged in such a manner that it is almost impossible for it to change once the mechanism is properly connected. However, there are some valve mechanisms that are driven by certain types of drives in which the timing may change enough to cause eventual engine failure. In a few instances, the

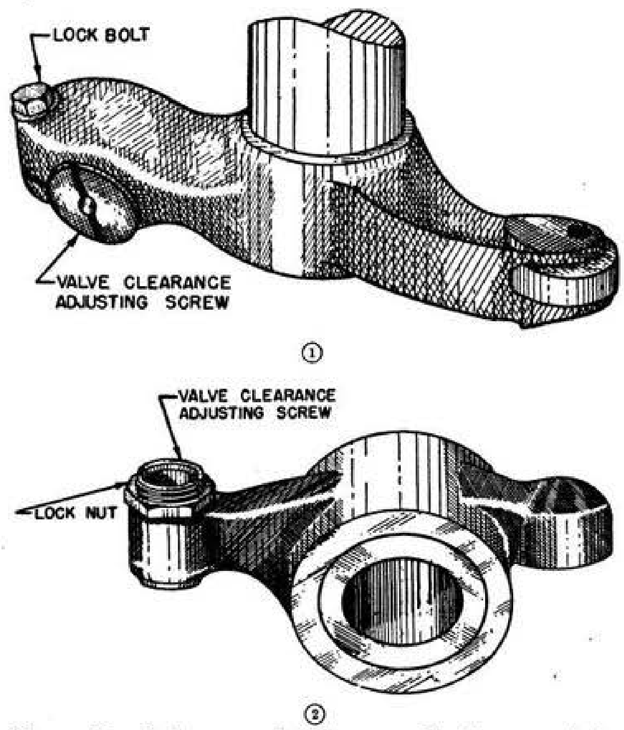


Figure 46. Rocker-arm valve-clearance adjusting-screw locks.

coupling devices have become disconnected and caused malfunction of the valves. In order to provide for ease of valve-timing operation, such special tools as the top-center indicator and the timing disk are used. The top-center indicator is a tool used to determine the top-dead-center position of a piston in a cylinder. The timing disk is a device which measures the crankshaft rotation in degrees and helps to determine when the crankshaft is in the correct position for timing the valves of the engine. These tools are also used in ignition timing. Several methods of adjusting valve timing follow.

a. Vernier coupling. One particular model of **V**-type engine incorporates a gear-coupling vernier. The gear which is bolted to the camshaft by means of 7 bolts, has 36 teeth. (See fig. 47.) Since there are 360° in the circumference of the gear and 36 teeth, adjacent gear teeth are 10° apart and the space be-

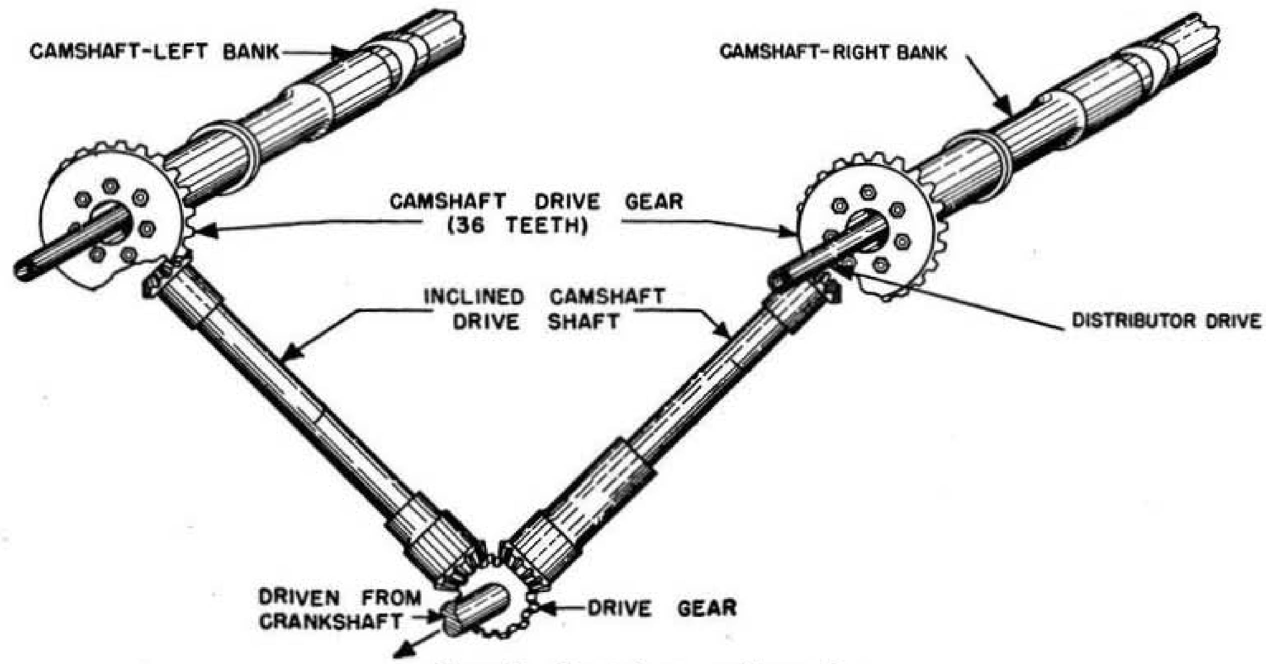


Figure 47. Camshaft gear-coupling vernier.

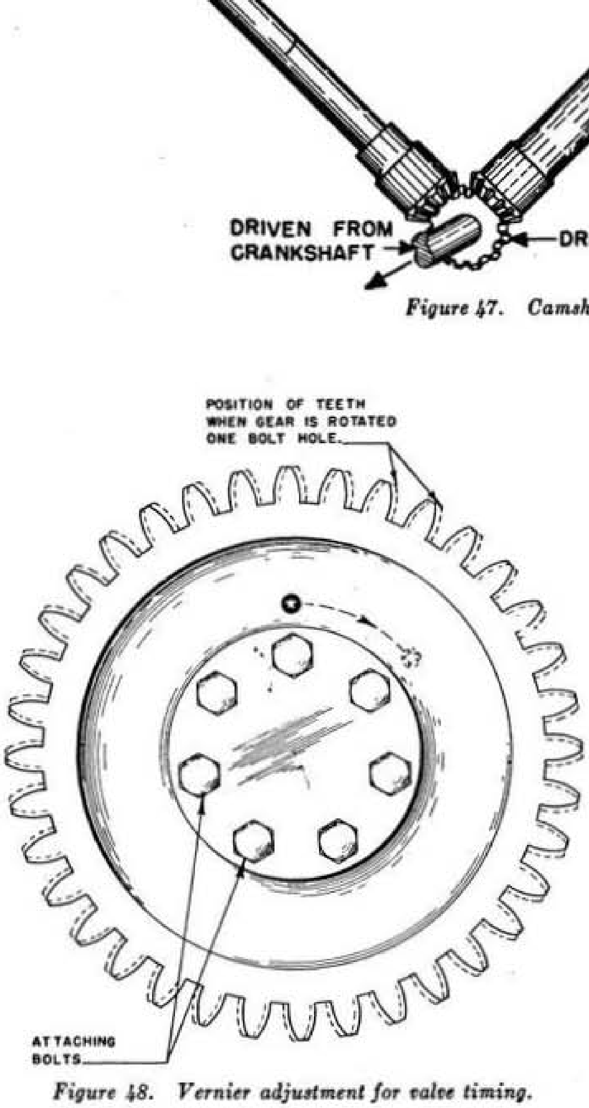


Figure 48. Vernier adjustment for valve timing.

tween the centers of two adjacent bolt holes is 51.4° Therefore, if the gear is removed and turned the distance between two bolt holes and replaced, it will no longer mesh with the driving gear. (See fig. 48.) The camshaft will have to be turned 1.4° to allow the gears to mesh. This arrangement provides an adjustment by means of which the valves can be accurately timed. The number of teeth on the gear and the number of bolt holes could of course be different so long as the number of teeth is not evenly divisible by the number of holes.

b. Splined driveshaft. On some engines the force to drive the camshafts is transmitted from a driveshaft in the accessory section to each of two camshaft bevel gears by an inclined driveshaft. (See fig. 49.) Each of these inclined shafts has 19 external splines on one end and 21 on the other end. The splines at the lower end of the inclined shaft mesh with the internal splines of a bevel gear. The splines at the upper end of the inclined shaft mesh with the internal splines of another bevel gear that drives the camshaft gear. The uneven number of splines permits a vernier adjustment of the valve timing. When the valves are timed, the specified piston must be on its proper stroke (see Technical Orders). In other words, the crankshaft must be in a particular position. This position is usually indicated by markings on the propeller reduction gears. These markings may be

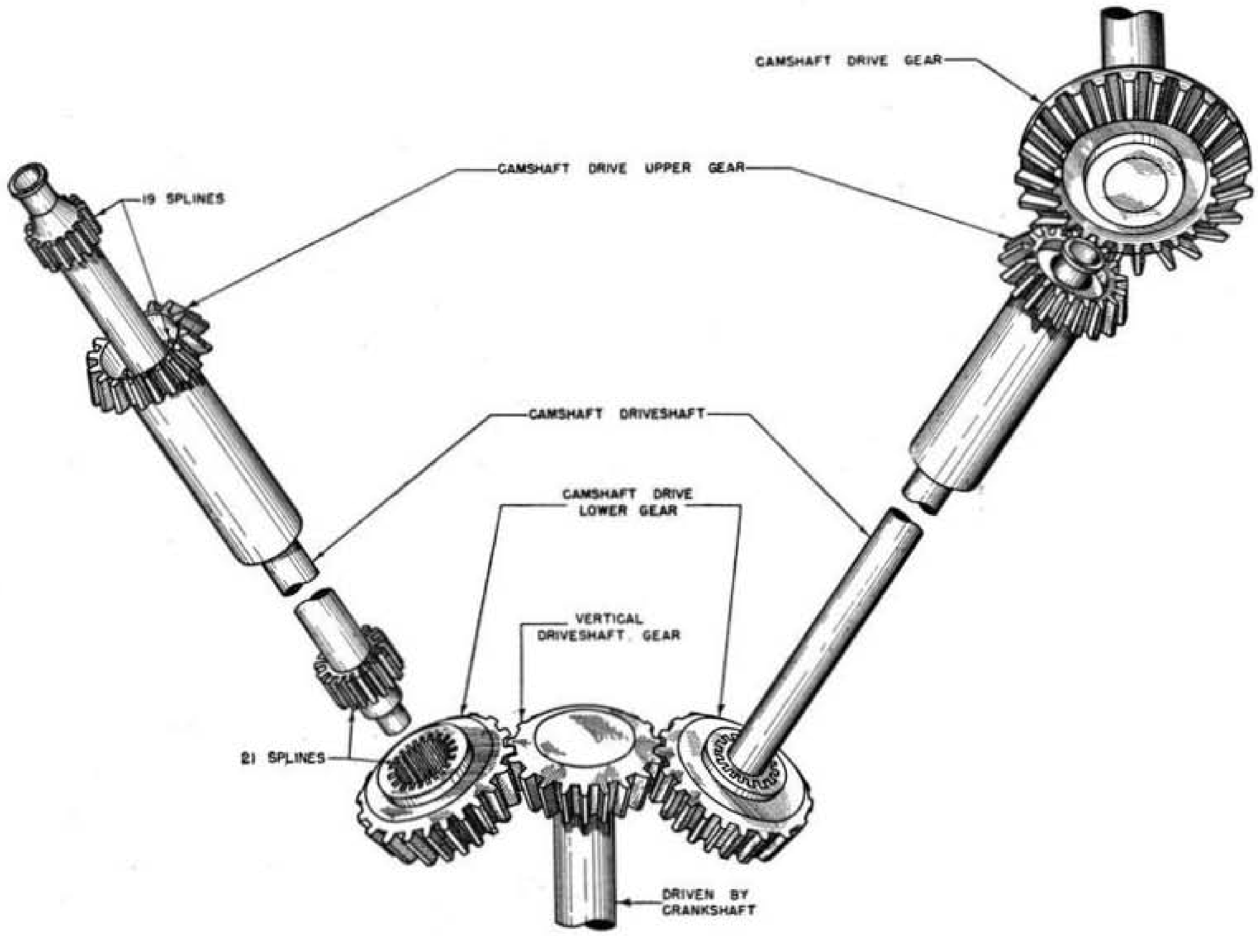


Figure 49. Camshaft splined drive shaft.

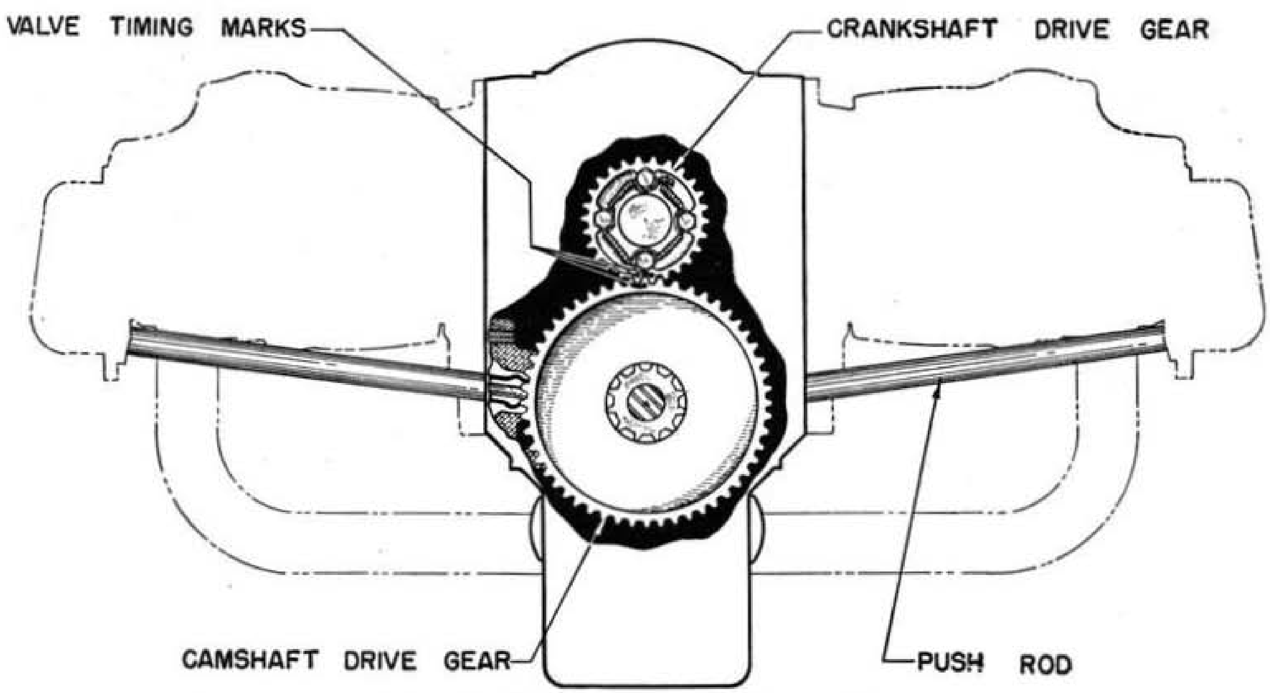


Figure 50. Camshaft drive — opposed-type engine.

seen by looking through the inspection hole located in the front- (nose-) section housing. Before timing the valves, a thrust cap must first be removed from the upper end of the splined drive-shaft bearing retainer. This permits the lifting of the shaft. When the inclined drive shaft is lifted, the upper bevel pinion remains meshed with the gear on the camshaft, but out of mesh with the lower-pinion drive gear. This allows the camshaft to be rotated independently of the crankshaft. The camshaft can then be placed in the proper position. The inclined shaft is then lowered, permitting the splines of the shaft to mesh with the internal splines of the bevel-pinion gear. If the splines do not mesh, the shaft is rotated until the proper mesh is secured. At times, slight movement of the camshaft is permitted, usually within a tolerance of 1°. The same operation is performed in timing the valves of the other bank.

c. Direct gearing. The valve-operating mechanism of some opposed-cylinder engines incorporates a rocker-arm assembly, push rods, and a camshaft driven directly through a set of gears. (See fig. 50.) The camshaft is located within the crankcase housing. This type of camshaft mechanism operates on the same principle as the overhead camshaft previously described. The only difference is that push rods are used to transmit the action of the cam lobe to the rocker-arm assembly. The camshaft is connected to the crankshaft by a gear arrangement that causes the camshaft to rotate one-half as fast as the crankshaft. During engine assembly the cam shaft is installed in its proper location. The crankshaft cam-drive gear is marked with center-punch marks on two adjacent teeth. The camshaft gear is marked with one center-punch mark on one tooth. This tooth is meshed between the two marked teeth on the crankshaft gear. When these gears are meshed according to the marks, the valves are properly timed.

d. Radial-engine valve timing. On most radial-type engines no external adjustments are incorporated to provide for valve timing after the engine has been assembled. During the time of engine assembly, after a major overhaul, the valve-timing operation is performed. The exact meshing of the marked teeth of the cam ring and the marked tooth of the cam-drive gear must be fixed as designated in the Technical Order for the specific engine. The operation of the valve mechanism is accomplished by the cam ring or cam plate. In some engines, the ring or the plate is supported on a journal which is mounted directly on the main crankcase. In other engines, the cam plate rides on a bushing which is mounted directly on the crankshaft. The gear teeth may be on the inside or the outside of the cam ring. These teeth mate with an intermediate cam-drive pinion gear and causes the cam ring (or plate) to rotate at a fraction of the crankshaft speed (depending upon the number of lobes).

28. IGNITION TIMING DEVICES. On nearly all of the present aircraft engines, dual high-tension ignition is supplied. The high voltage necessary for ignition is produced by two separate engine-driven high-tension magnetos. Some engines use two magnetos incorporated in one housing. The magneto is timed to deliver high voltage at certain specified intervals. Since this high voltage must reach each spark plug at the proper time, an arrangement is also provided for timing each magneto to the engine. The magneto has a distributor which directs the electric current to each of the cylinders in the proper sequence (firing order). Therefore, if the magneto is properly timed for one cylinder, it will be properly timed for all cylinders. Two general methods of timing the magneto to the engine are the vernier-coupling and splined-coupling methods.

a. Vernier coupling. Magneto timing may be accomplished by means of a hard synthetic-rubber coupling with gear teeth molded on each side of it. There is one more tooth on one side than on the other; therefore, turning the rubber plate one gear tooth in relation to the two gears that mesh with it will change the magneto timing by the difference in the size of the teeth on each side of the rubber plate. (See fig. 51.)

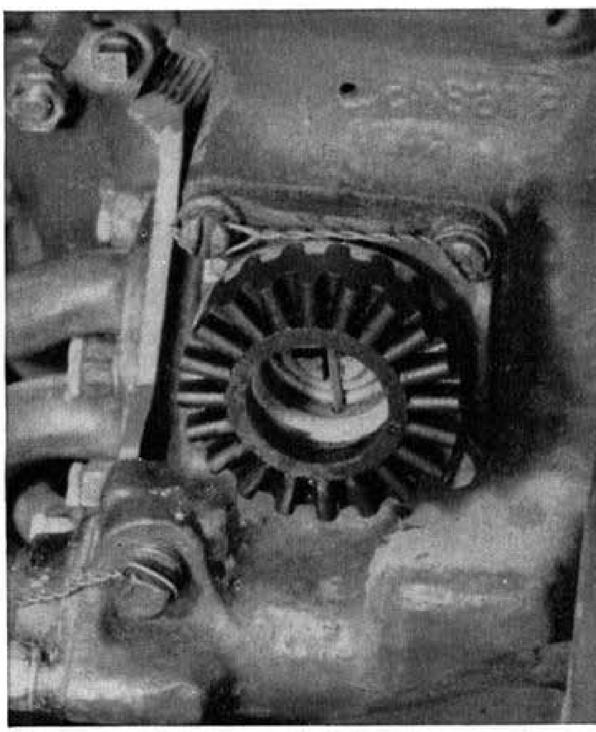


Figure 51. Vernier coupling — ignition timing.

b. Splined coupling. (1) On some types of engines, a splined coupling is used to connect the magneto drive shaft to the splined shaft protruding from the magneto housing. Before installing the magneto, remove the breaker cover and align the step cut with the marks on the edge of the housing with a straight edge. (See fig. 52.) Be certain that the position of the piston is as specified in the Technical Order for the particular engine. Place the splined coupling on the end of the drive shaft and then attempt to mesh the splined end of the magneto shaft with the coupling. If the magneto does not drop into the coupling spline within a specified tolerance, remove the magneto and try another mesh position with the coupling. When the magneto is meshed within the proper tolerance, proceed as explained in c (1) below.

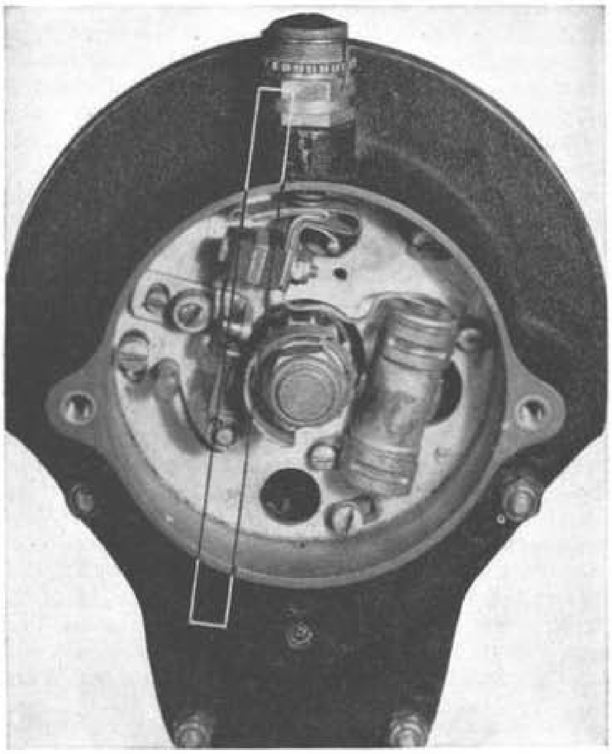


Figure 52. Setting magneto cam prior to installation.

(2) *Slotted magneto flange.* The mounting flanges of magnetos utilizing the splined-coupling method are slotted (See fig. 53.) These slots allow rotation of the magneto housing (within the length of the slots) and permit closer adjustment of engine timing. When the magneto is in the correct position after the splined coupling is correctly meshed, rotate the magneto housing until the magneto is exactly timed to the engine. The mounting bolts are then tightened to hold the magneto securely in place.

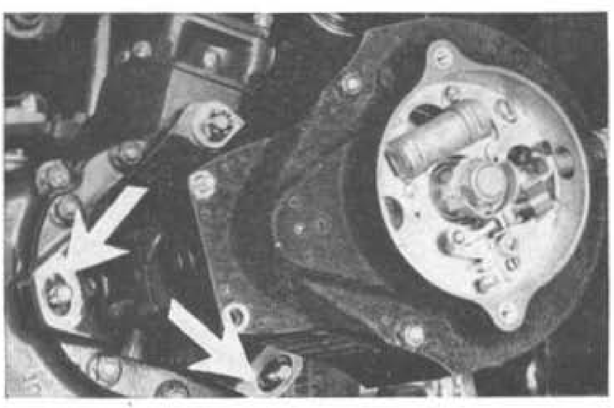


Figure 53. Slotted magneto-housing flange — ignition timing.

29. INTERNAL BLOWERS AND SUPERCHARGERS. The horsepower developed by an engine operating at a given speed depends upon the compression ratio, the piston displacement, and the volumetric efficiency of the engine. The compression ratio and the piston displacement are fixed and cannot be changed on any given engine. The volumetric efficiency however can be changed. The volumetric efficiency is the ratio of the volume (at normal atmospheric pressure and temperature) of the charge drawn into the cylinder to the piston displacement. For example, if the piston displacement in a given cylinder is 100 cubic inches, and 90 cubic inches of fuel-air mixture is drawn into the cylinder the volumetric efficiency would be 90 percent. As an airplane gains altitude, the air becomes thinner and the volumetric efficiency of the engine decreases. In order to increase the volumetric efficiency (and in turn the horsepower of the engine) especially at high altitudes, superchargers are used on most modern airplane powerplants.

a. Internal-blower assembly. The blower is a centrifugal-type air pump. The fuel-air charge is drawn directly into the supercharger, where it is subjected to the action of the rotating impeller. The purpose of the blower assembly is to atomize more thoroughly the fuel-air mixture and assure (as nearly as possible) equal distribution of the mixture to the various cylinders. It also improves the acceleration of an engine during operation.

(1) *Blower impeller.* Aircraft-engine blower impellers are of the centrifugal type and are forged of aluminum alloy. An impeller consists of a circular disk with blades extending radially from its surface. (See fig. 54.) It may be attached directly to the

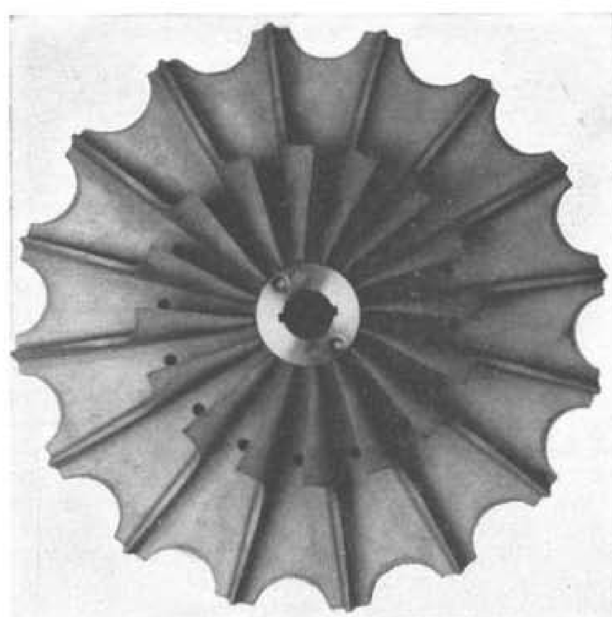


Figure 54. Impeller.

crankshaft or it may be driven through a gear train. If the impeller operates at approximately the same speed as the crankshaft, it does not boost or increase the pressure on the fuel-air charge. The speed is selected by the designer and it is mainly dependent upon the piston displacement of the engine, the octane rating of the fuel used, the diameter of the impeller and the strength of the engine structure. It is also important that the impeller be light, yet perfectly balanced and strong enough to withstand the high centrifugal forces.

(2) *Diffuser section.* The diffuser section is that part of the induction manifold that surrounds the blower impeller. The diffuser plate (fig. 55) is fitted closely around the impeller. The unit consists of a circular plate and curved vanes on one surface. The

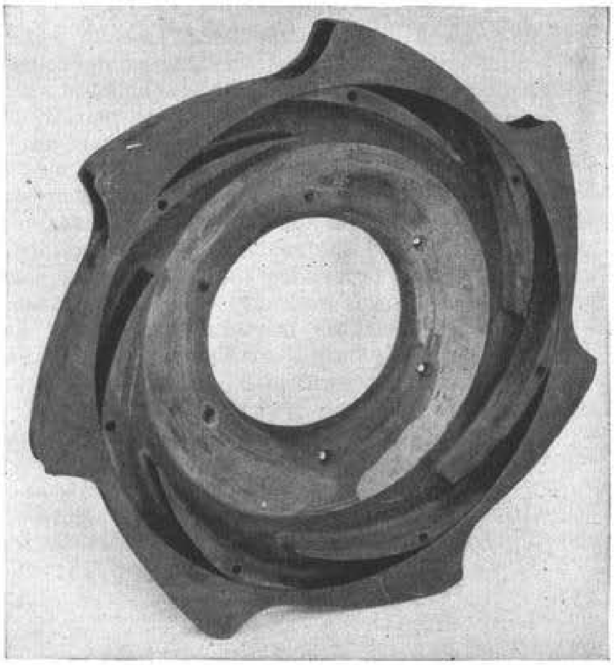


Figure 55. Diffuser plate.

vanes may be plain or shaped as airfoils. The action of the impeller on the fuel-air charge tends to create a swirling of the fuel-air flow. The purpose of the diffuser vanes is to eliminate this swirling of the fuel-air within the diffuser chamber in order to obtain efficient flow into the cylinders.

(3) *Distribution chamber.* This section may be called "the manifold ring," and incloses the entire blower assembly. In a radial-type engine, it forms part of the engine crankcase and is generally made of forged aluminum alloy. Individual intake pipes extend into openings on the ring and provide passageways through which the fuel-air charge reaches the engine cylinders. The pipes are held in the openings by synthetic-rubber packing rings and packing retaining nuts, which form slip joints to allow for cylinder expansion and contraction. In an in-line engine, the fuel-air charge passes from the diffuser vanes into a chamber. From here it is conducted through the main intake manifold to smaller branch manifolds and into the engine cylinders.

(4) An aftercooler unit is incorporated on some engines equipped with a two-stage internal supercharger. The purpose of this unit is to cool the fuel-air charge after it has been compressed by the supercharger. The assembly consists of a housing, a radiator core and the necessary units for a coolant system. It is located between the supercharger outlet and the main induction system. The fuel-air charge circulates around the core tubes in order to dissipate the heat produced during compression. A separate cooling system is maintained for this particular installation. It uses the same type of coolant mixture as used in the engine-cooling system. The liquid is forced through the core tubes by the aftercooler pump. A relief valve is incorporated in the system to prevent the development of excessive pressures.

(5) *Drain valves.* Each time an engine is started or stopped the fuel is not entirely vaporized and taken into the cylinders. This unburned gasoline gathers in the lowest part of the induction system and becomes a serious fire hazard. To remove this unvaporized gasoline from some systems, a drain hole (open to the atmosphere at all times) is provided in the induction system at its lowest point. More frequently, however, an automatically operated drain-valve assembly is incorporated. (See fig. 56.) When the engine is not operating, the weight of the valve causes it to fall away from the seat. This opens a passage to the atmosphere through which unvaporized fuel may drain from the system. When

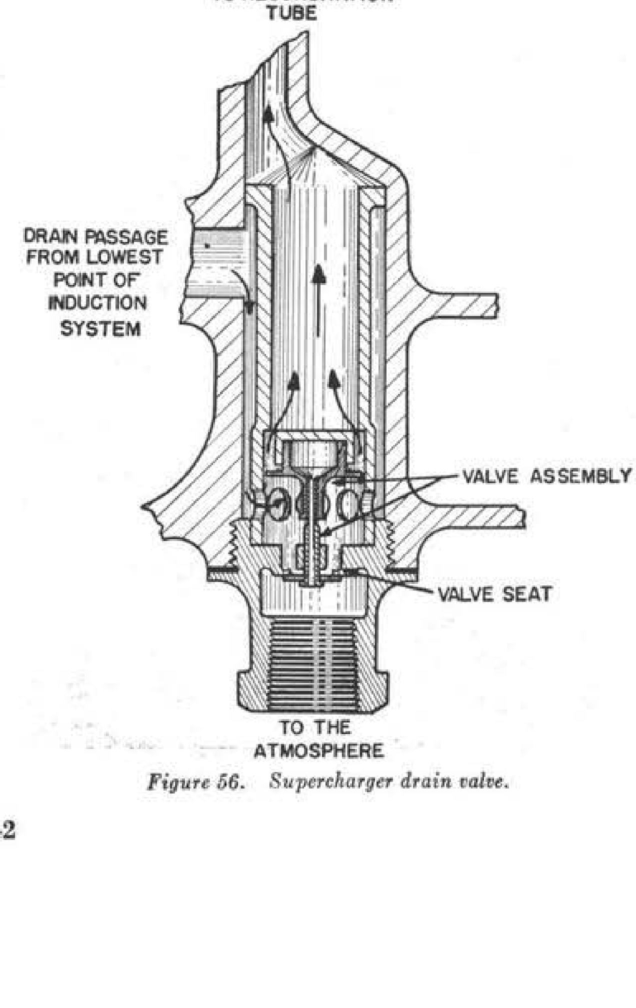


Figure 56. Supercharger drain valve.

the engine is operating, the pressure in the regurgitation or gurgle tube is below atmospheric pressure because the upper end of the tube is open to the inlet side of the impeller. The pressure on the valve will, therefore, be less than that on the bottom and the valve will be held on the seat by the differential pressure. This closes the opening and any gasoline-vapor condensate which forms in the induction system is piped-up to the inlet side of the whirling impeller through the regurgitation tube as shown by the arrows in figure 56. The piped-up action is brought about by the same differential pressure which closes the valve.

b. Superchargers. The supercharger of an internal-combustion engine is a mechanical unit that compresses the fuel-air charge in order to maintain the manifold pressure at or above atmospheric pressure. This unit provides a pressure greater than atmospheric whereas the internal blower does not. Internal superchargers are of several types such as: single-speed, two-speed with a mechanical or hydraulic clutch, and two-stage. External superchargers are of the variable-speed type and are generally turbine driven.

(1) *Internal superchargers.* An internal supercharger (shown in fig. 57) is a unit whose impeller is located in the induction system between the carburetor and the intake ports of the engine cylinders. This unit is designed and assembled as an intergral part of the engine, and is gear- or hydraulic-driven. The speed with which the impeller rotates is limited by the impeller-tip speed and the heating of the charge due to compression. Impeller speeds may be as high as 15 revolutions to one revolution of the crankshaft. The average impeller ratio ranges between ratios of 6:1 and 10:1. The internal supercharger consists of an impeller, a diffuser chamber, a distribution chamber (manifold ring) and an impeller-driving mechanism. It may have a single impeller-speed ratio, a two-speed ratio, or a variable-speed ratio. The *single-speed unit* has a fixed-gear ratio and is similar to the internal blower, although the single-speed unit rotates at a speed sufficient to maintain the manifold pressure at or above standard atmospheric pressure at certain engine speeds. The *two-speed drive mechanism* consists of gears and clutches. When the actuating control valve is moved, oil pressure is applied to one side of a clutch disk. There is no neutral position in which the clutches are disengaged. Selection of the gear ratio

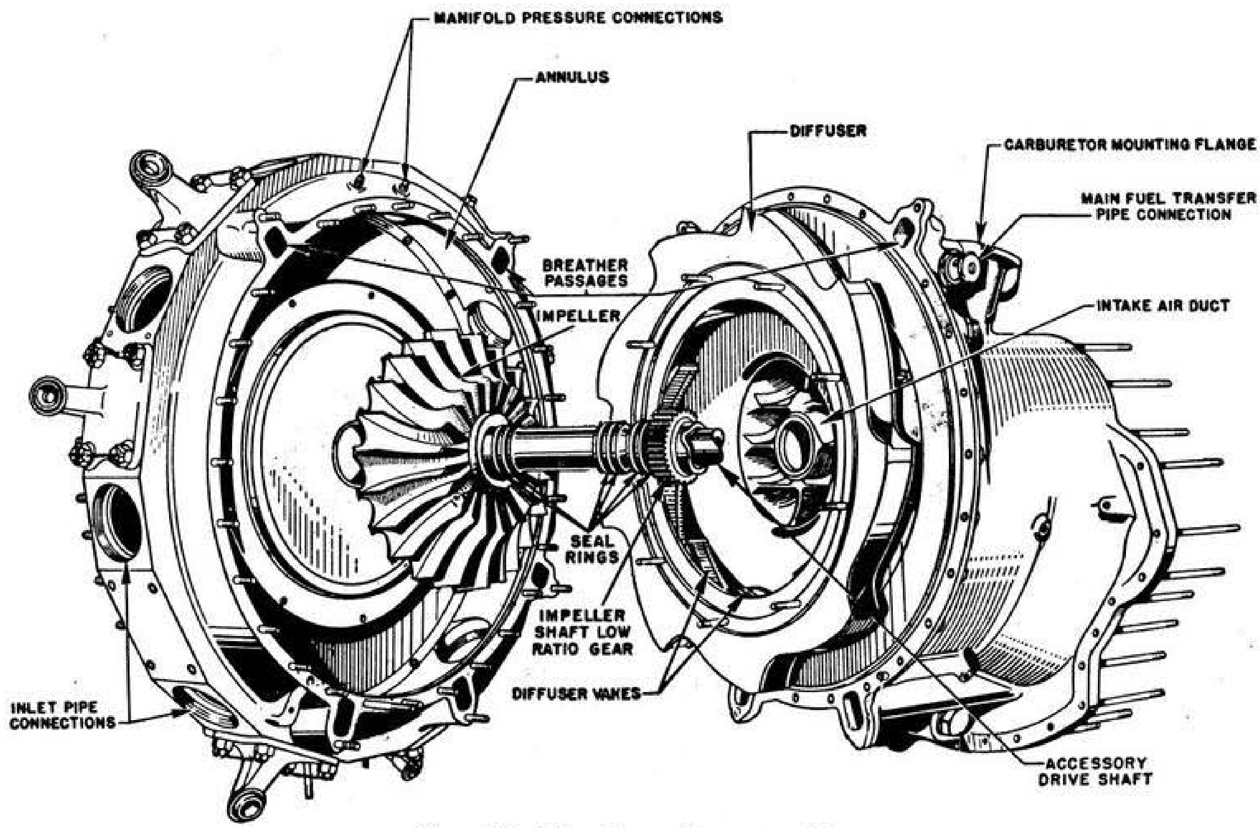


Figure 57. Internal-supercharger assembly.

High supercharger pressure (high manifold pressure) is used to obtain more engine power for take-off, or to maintain or increase engine power at high altitudes. As a plane equipped with an unsupercharged engine rises to a higher altitude, the carburetor-intake pressure will decrease because of the decrease in atmospheric pressure. This will result in a decrease of manifold pressure and power output. To prevent this, aircraft-engine designers have developed internal and external superchargers. Many variations in the methods of supercharging, each with its particular advantages, are used.

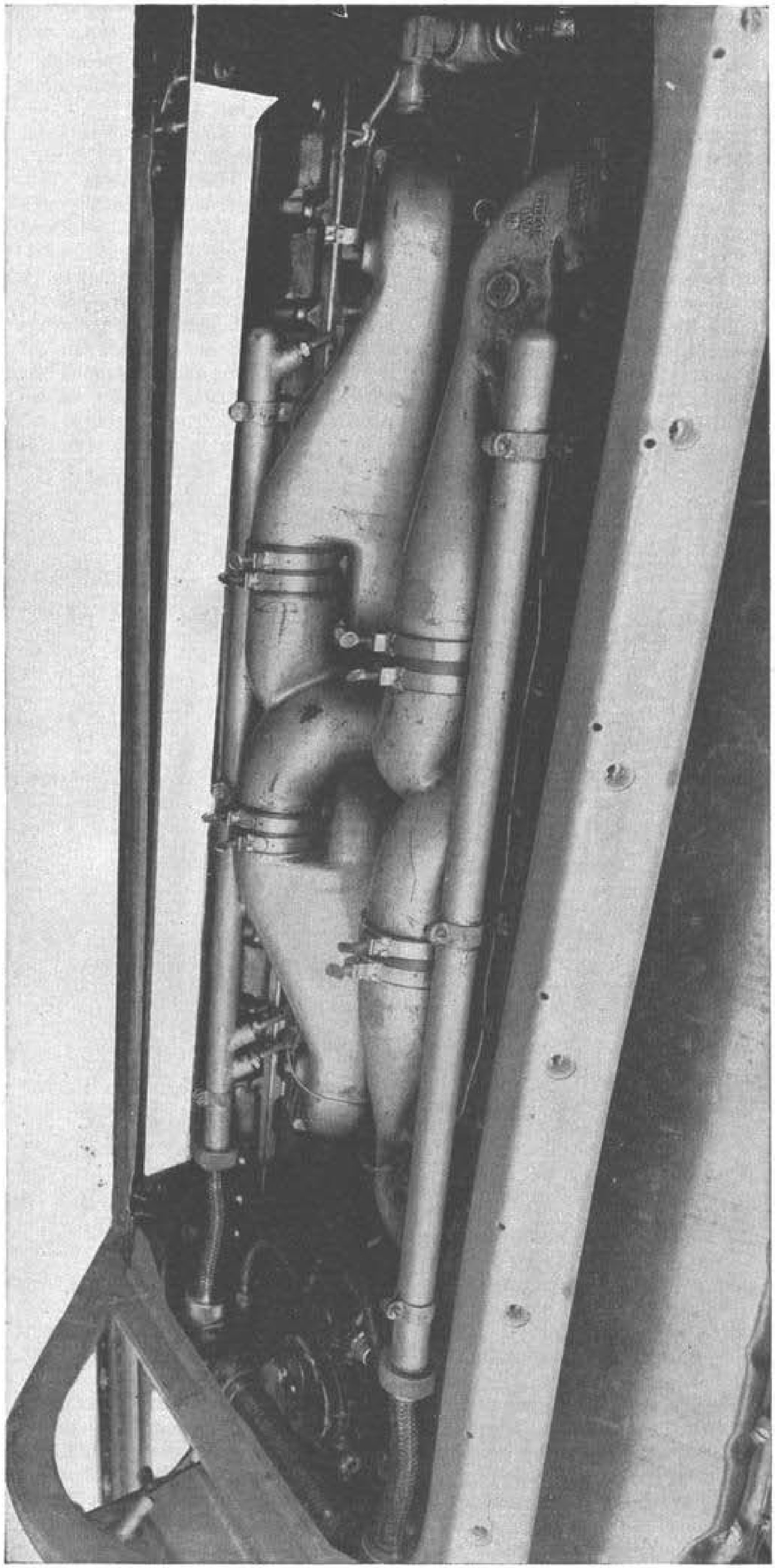


Figure 58. Induction manifold — **V**-type engine.

is performed with a push-pull control. The control unit is a piston-type selector valve located in the supercharger rear cover. The setting for the lower-impeller ratio is called "the low-blower position;" that for the higher-impeller speed is called "the high-blowerposition." Low blower is generally used at take-off and during flight at low altitudes. As the airplane climbs to higher altitudes and engine power begins to decrease, the pilot will shift the control valve to the high-blower position for increased supercharger pressure and engine power.

(2) *External superchargers.* An external supercharger is not a component part of the engine and, therefore, will not be discussed in this manual (reference TM 1–407).

30. INTAKE MANIFOLD AND PIPES. Induction manifolds and pipes are the sealed passageways used to conduct air or fuel-air mixture from the distribution-chamber section to the intake-valve ports of the cylinders. The number and construction of manifolds or pipes depend on the engine type and the total number of cylinders to be supplied. The manifolds and pipes are light in weight and designed to offer the least possible resistance to the flow of the air or mixture.

a. Intake manifolds. An aircraft engine with in-line or multiple banks of cylinders distributes the fuel-air charge through a large main induction manifold into smaller branches attached to the cylinder intake ports. The other end of the main manifold is attached to the distribution chamber. The manifold assembly is generally made of aluminum or magnesium alloy, manufactured in one or two sections per bank. The single-section unit incorporates openings for all cylinders on one bank. The double-section assembly consists of two branches, each supplying the mixture charge to half of the cylinders. Tubular synthetic-rubber couplings are used in connecting the two branches to the main section. (See fig. 58.) This allows for expansion of the cylinder block due to heat of combustion. A gasket is placed between the manifold flange and the cylinder intake ports and the assembly is rigidly secured to the cylinder block by studs or bolts and nuts. Threaded holes are provided for cylinder-primer nozzle connections and for the manifold-pressure-gauge take-off line.

b. Intake pipes. Intake pipes are individual pipe connections between the distribution chamber (manifold ring) and the cylinder intake ports. The pipes are circular in cross section and are generally designed to eliminate sharp bends, thus providing a smooth flow of fuel-air mixture to each cylinder. Most radial-type engines and some in-line engines employ this system of induction instead of the manifold type. (See fig. 59.) In some in-line and double-row radial powerplants, **Y**- or **T**-type intake pipes may be employed. Each of these conducts the charge to two adjacent cylinders. The pipes are generally made of aluminum alloy or steel. Steel intake pipes are stronger and are less subject to dents or warping. A gas-tight connection is provided at the distribution chamber by a synthetic-rubber packing ring and a packing retaining nut. This forms a slip-joint seal allowing the intake pipes to slide in and out of the distribution-chamber opening during the expansion and contraction of the cylinder metal. At the cylinder intake port, a gasket is placed between the pipe flange and the cylinder port, and the flange is rigidly secured by bolts and nuts. Another method provides for attachment of the intake pipe by a packing ring and packing-retaining nut which screws into or over the intake-port opening. On other engines, short stacks protrude from the intake ports and incorporate rubber couplings to attach the pipes to the extensions. The upper intake pipes of some radial engines have threaded holes for the installation of primer nozzles.

31. EXHAUST MANIFOLD AND STACKS. The exhaust manifold is a unit specially designed to provide a passageway for the removal of exhaust gases and flames from the vicinity of the engine. The gases may be conducted directly to the atmosphere, or by-passed through special ducts and used to drive the turbosupercharger or to provide heat for the carburetor intake or the cockpit before being released to the atmosphere. The assembly must conduct the gases away from the engine with a minimum of back pressure. The metal used is generally stainless or inconel steel. Inconel steel is used because it expands very little when heated and is resistant to corrosion. An exhaust assembly may be made in any of the following types: short stacks. exhaust manifold, or a collector-ring assembly.

a. Short exhaust stacks. Short exhaust stacks are short pieces of piping, generally curved toward the rear of the airplane. They are attached to the exhaust-port openings. These stacks may be designed for each individual cylinder or they may combine two adjacent cylinders. (See fig. 60.) They minimize exhaust-gas back pressure and exhaust-valve temperature, and also reduce fire hazard in the event of a crash landing. Short stacks present certain disadvantages because of the possible sudden cooling of the exhaust valves during side-slip maneuvers of the airplane and they are not efficient in conducting the exhaust gases away from the airplane cockpit.

b. Exhaust manifold. On some in-line engines, exhaust manifolds may be attached to the cylinder banks as single units. The unit consists of a manifold housing with one closed end. Protruding from the housing are short stacks which are bolted over the exhaust ports. The manifold housing enlarges progressively toward the outlet. (See fig. 61.)

c. Collector ring. Radial-engine exhaust manifolds are generally known as collector rings. The unit consists of a large ring (usually the approximate diameter of the engine) to which are attached exhaust pipes from the exhaust port of each cylinder. (See fig. 62.) The exhaust-ring assembly is usually constructed in several sections and sliding joints are provided between sections to allow for cylinder and collector-ring expansion. Cases are collected and conducted from all cylinders to the collector ring and thence to the atmosphere through a common outlet.

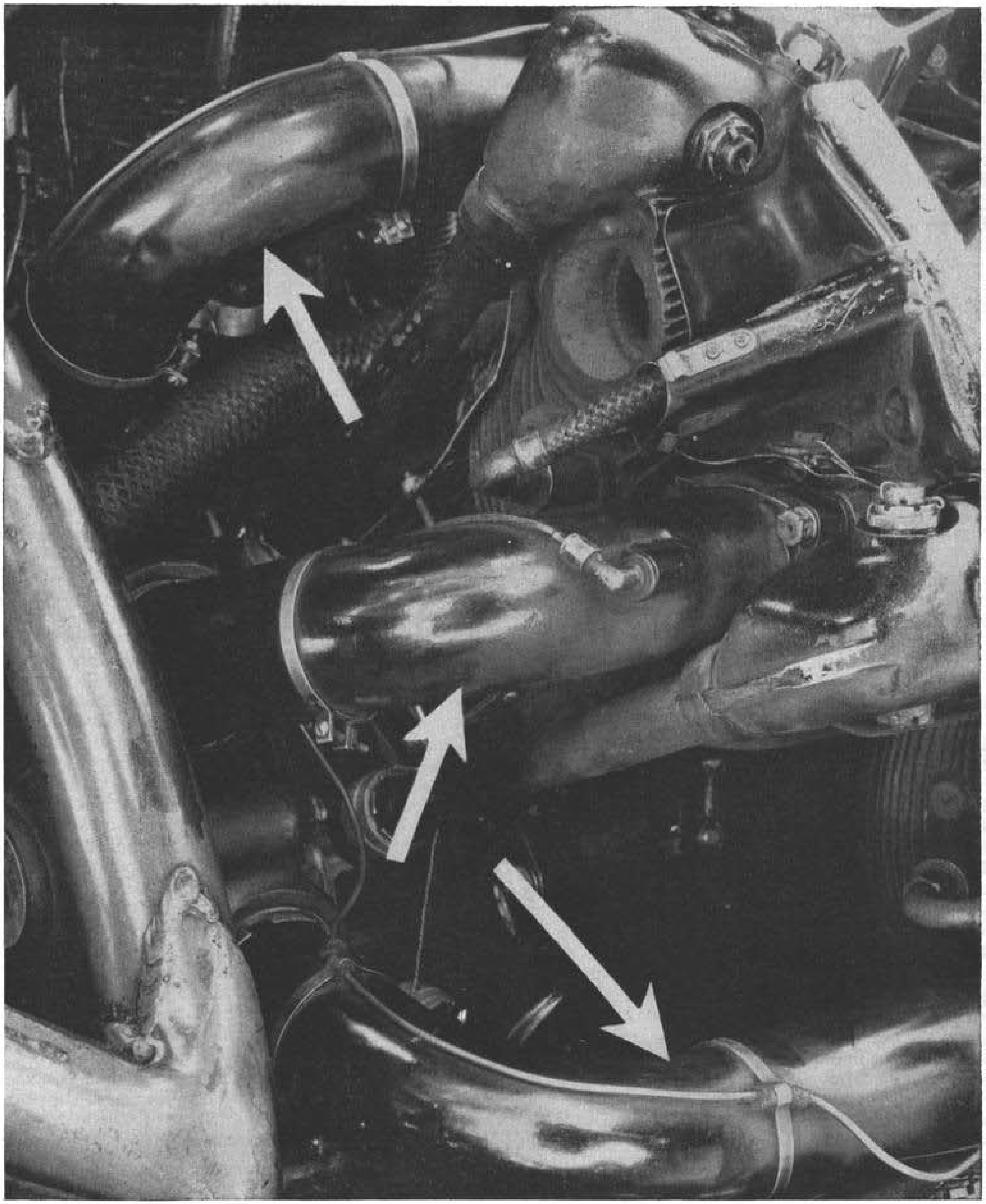


Figure 59. Individual intake pipes — radial engines.

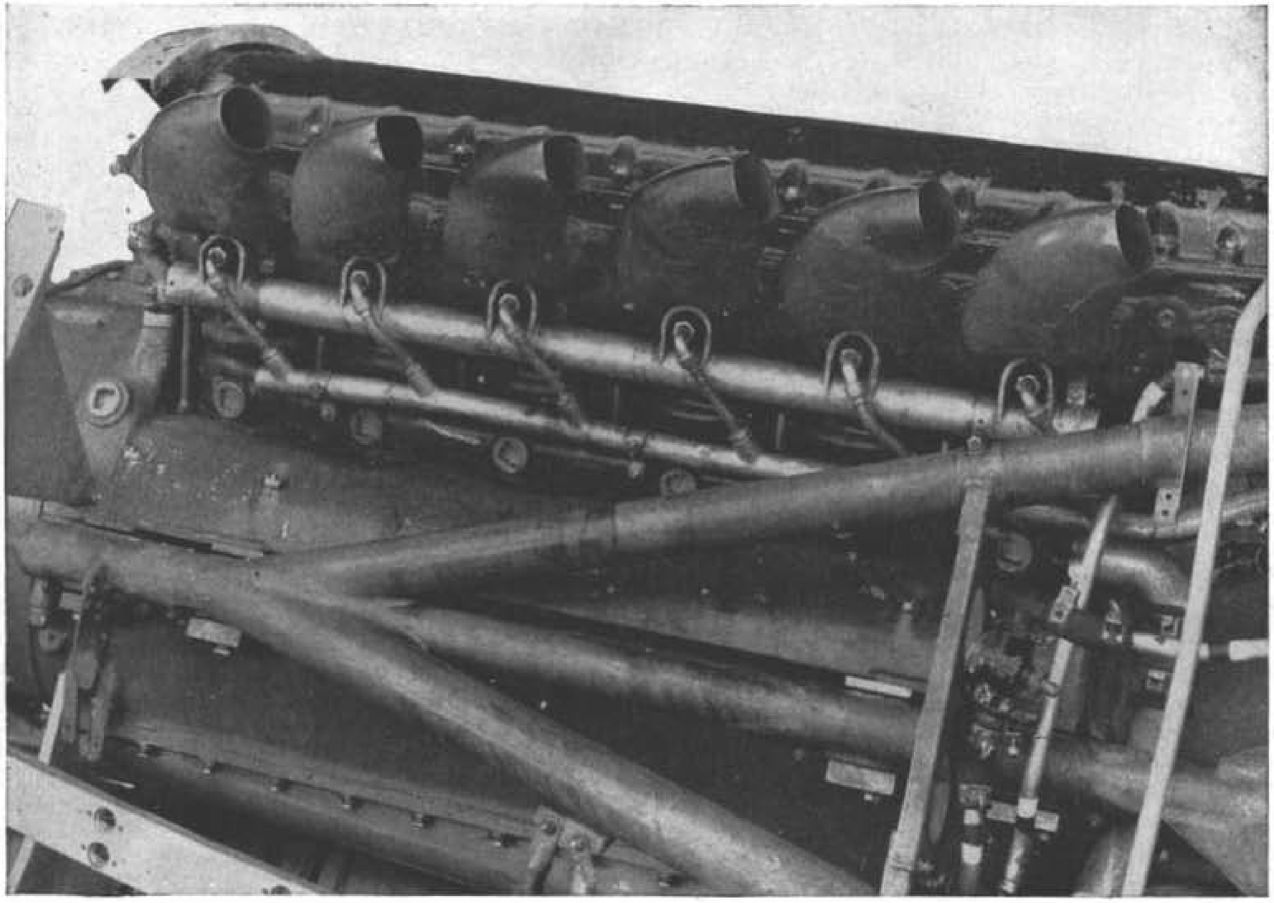


Figure 60. Exhaust manifold — short stacks.

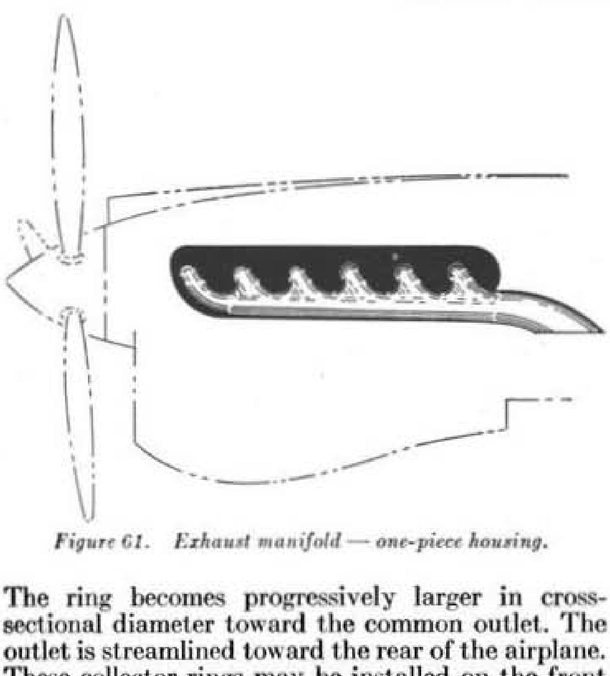


Figure 61. Exhaust manifold — one-piece housing.

The ring becomes progressively larger in cross-sectional diameter toward the common outlet. The outlet is streamlined toward the rear of the airplane. These collector rings may be installed on the front or the rear side of the engine cylinders. The front-type collector ring is not widely used because it tends to cause overheating of the engine.

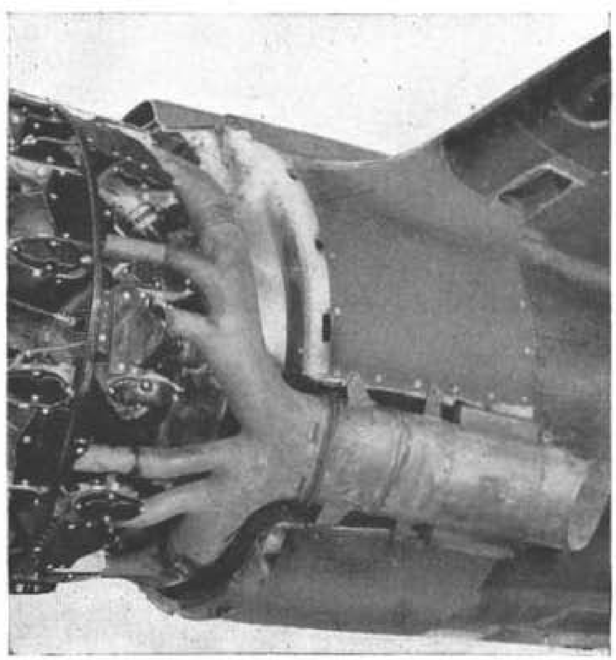


Figure 62. Exhaust collector-ring assembly.

32. PROPELLER REDUCTION GEARING. Propellers used with low-horsepower engines are usually attached directly to the crankshaft. The increased brake horsepower delivered by a high-horsepower engine results partly from increased crankshaft speed. It is therefore necessary to provide reduction gearing to limit the speed of rotation of the propeller to a value at which efficient operation is obtained. The general practice has been to provide reduction gearing for propeller speeds above 2,000 rpm because it has been found that propeller efficiency decreases rapidly above this speed. As the reduction gearing must withstand extremely high stresses, the gears are machined from steel forgings. Many types of reduction gearing systems are in use. Four of these types will be discussed.

a. External spur-and-pinion reduction gearing. This assembly consists of an external spur gear mounted on the propeller shaft and an external pinion (driving) gear located on the crankshaft. (See fig. 63.) In some cases this gear is mounted on an extension shaft which may be attached directly

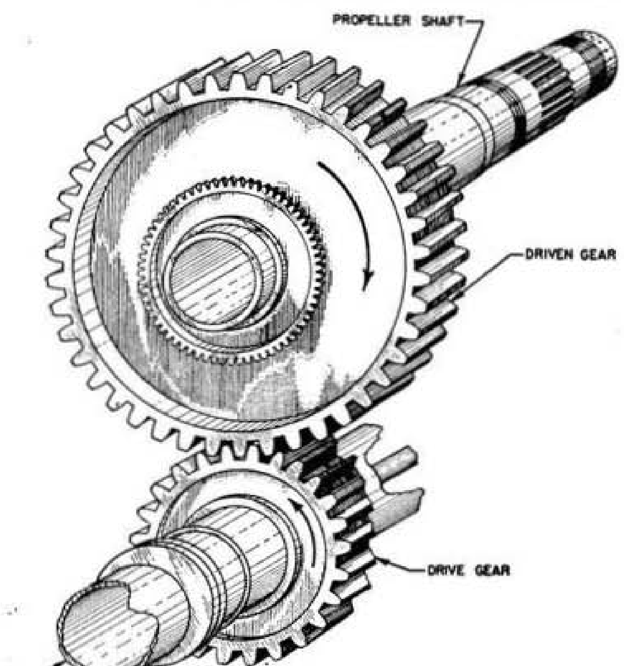


Figure 63. External spur-and-pinion reduction gearing.

to the crankshaft or may be driven through a flexible splined coupling. The propeller shaft is supported in the middle by a thrust bearing and at the rear by a roller bearing or a steel-backed, bronze bearing.

b. Spur planetary-system reduction gearing—rotating bell gear. The spur planetary reduction gearing consists of a large driving or bell gear that is splined (and sometimes shrunk) to the crankshaft, a large stationary gear (called a sun gear), and a set of small spur planetary pinion gears mounted on a carrier ring. (See fig. 64.) The ring is fastened to the propeller shaft and the planetary gears mesh with both the bell gear and the stationary gear. The stationary gear is bolted or splined to the

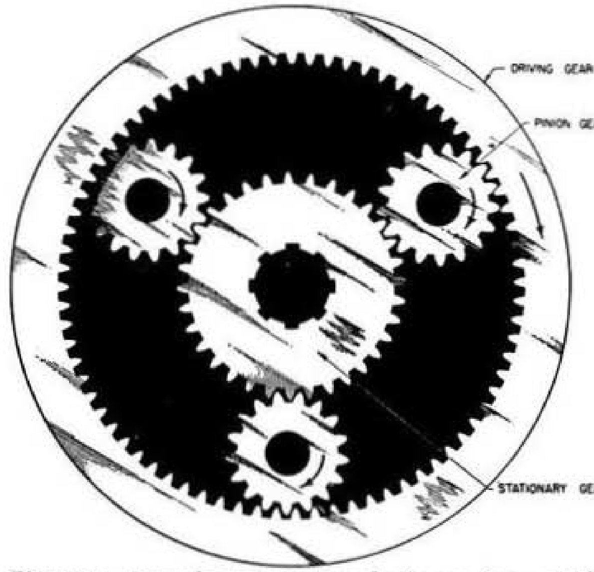


Figure 64. Spur planetary-system reduction gearing — rotating bell gear.

front-section housing. When the engine is operating, the bell gear rotates. As the planetary gears are meshed with this ring, they also must rotate. Since they also mesh with the stationary gear, they will walk or roll around it as they rotate; the ring in which they are mounted will rotate the propeller shaft in the same direction as the crankshaft but at a reduced speed.

c. Spur planetary-system reduction gearing—stationary bell gear. In some engines, the bell gear is mounted as the stationary gear in the front-section housing. The planetary pinion gears walk around inside of it. The sun gear acts as a driving gear because it is splined to the crankshaft.

d. Bevel planetary-system reduction gearing. In this system, the driving gear is machined with beveled external gear teeth and is attached to the crankshaft. A set of mating bevel pinion gears is mounted in a cage which is attached to the end of the propeller shaft. The pinion gears are driven by the driving gear and walk around the stationary gear which is bolted or splined to the front-section housing. (See fig. 65.) The thrust of the bevel pinion gears is absorbed by a thrust ball bearing of special design. The drive and the fixed gears are generally supported by heavy-duty ball bearings.

33. PROPELLER SHAFTS. The types of propeller shafts are the tapered-end and the splined-end. The correct propeller assembly must be used with each type of shaft. Tapered shafts are identified by taper numbers and the splined shafts by SAE number sizes.

a. Tapered ends. In many low-power-output engines, the propeller shaft is forged or cast as a part of the crankshaft. (See fig. 66.) The shaft is tapered and a milled slot is provided so that the propeller hub may be keyed to the shaft. The end of the shaft is threaded to receive the propeller retaining nut.

b. Splined ends. (1) On a high-output engine the propeller shaft is splined. (See fig. 65.) It is

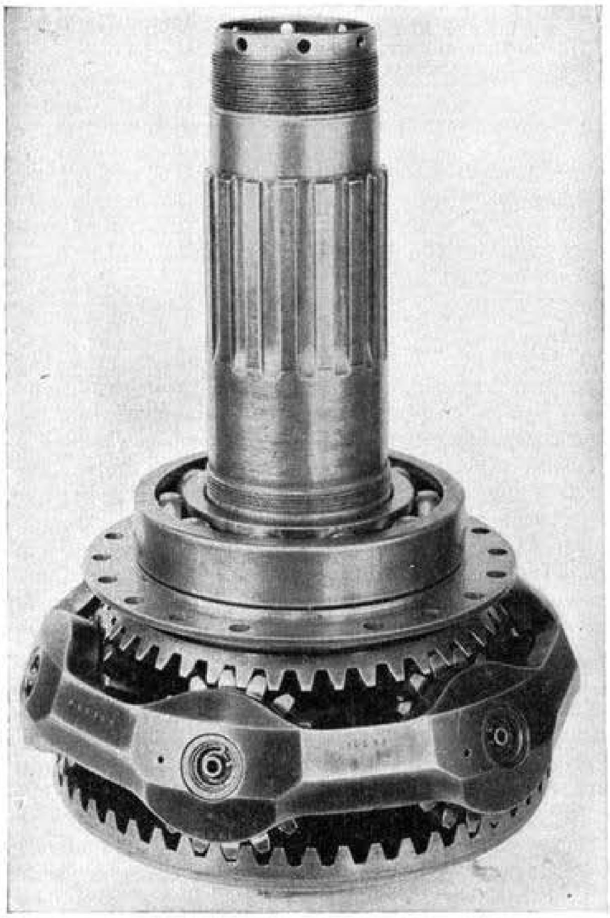


Figure 65. Bevel planetary-system reduction gearing.

threaded on one end for a propeller hub nut. The thrust bearing, which absorbs propeller thrust, is

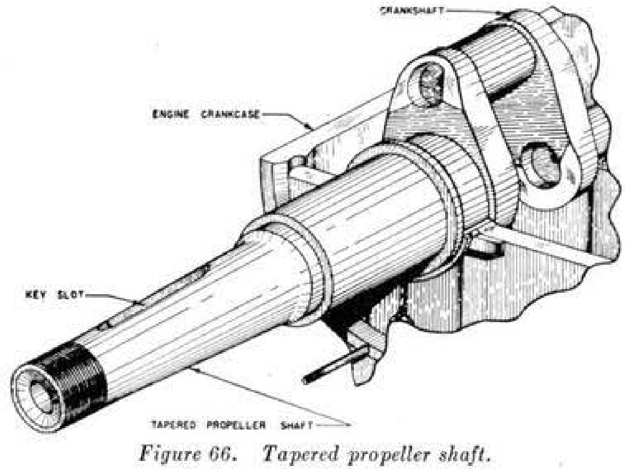


Figure 66. Tapered propeller shaft.

located near the middle of the shaft and transmits the thrust to the front-section housing. The shaft is threaded near the middle to provide a location for the thrust-bearing retaining nut. On the portion protruding from the housing (between the two sets of threads) are located splines to receive the splined propeller hub. The shaft is generally machined from a steel-alloy forging and is hollow throughout its length.

(2) *Propeller shaft-crankcase breathers.* In one type of installation a breather tube is installed inside the hollow propeller shaft and extends into the crankshaft front extension. On an engine equipped with a hydromatic propeller, the tube is so constructed and installed that it also provides a passage for high-pressure oil to operate the propeller unit. These methods eliminate the breather unit generally located in the oil sump or front supercharger housing.

IN-LINE AIRCRAFT ENGINES

34. GENERAL. Engines which have all of their cylinders mounted or assembled in one straight line are known as in-line engines. In the very low-power-output class, this engine may be constructed with one, two or three cylinders. These engines have respectively 360°, 180°, and 120° crankshafts. High-power-output engines of this type are manufactured with an even number of cylinders in one bank. The most common types are the four- and six-cylinder engines which use respectively 180° and 120° crankshafts.

a. Cylinder arrangements. The cylinders of an in-line engine are located in a single row or bank parallel to and mounted above or below the crankshaft. When the cylinders are mounted on the lower side of the crankshaft the engine is called an "inverted type." The in-line engine lends itself to excellent streamlining of the airplane in either the upright or inverted position. The inverted type offers improved pilot visibility and the use of a shorter landing gear. This type of engine may be either liquid- or air-cooled. The problem of cooling the engine by air has been solved by installing baffle plates to direct the air flow around all cylinders, especially the rear ones.

b. Firing order. The firing order of an engine is the sequence in which the power strokes occur in the cylinders. Six-cylinder in-line engines generally have a firing order of 1–5–3–6–2–4. The firing order for a four-cylinder in-line engine may be either 1–3–4–2 or 1–2–4–3.

35. CONSTRUCTION CHARACTERISTICS. **a. General.** Engine parts and engine units vary in shape and size, but each part of any type operates as required to provide satisfactory performance of the entire assembly. It will be well for the student mechanic to familiarize himself with the design of the component parts of each type of engine.

b. Power section. The power section of an in-line engine consists of the main crankcase, the crankshaft, the cylinders, pistons and connecting rods, the valve-operating mechanism and valves, and the necessary bearings.

(1) *Crankcase.* The crankcase is made in two aluminum-alloy halves and is very sturdy. Each half has web partitions which support the main crankshaft bearings. One web is located between each two crankshaft throws. The upper and lower parts of the crankcases are bolted together with long bolts, one of which is located on each side of each main bearing. The outside edges (flanges) of the crankcase are held together by small bolts and nuts. Oil leakage is prevented by a gasket inserted in recesses in the flanges.

(2) *Crankshaft.* The crankshaft of an in-line engine has one throw for each cylinder. It is made of forged steel and is ground not only on the wearing surfaces but also on all other surfaces to remove small scratches which might cause failure of the crankshaft during operation. Passages are drilled through the main journals, the crankpins, and the crankcheeks to provide for the flow of lubricating oil and to make the crankshaft lighter. The crankshaft is statically and dynamically balanced within extremely close limits.

(3) *Cylinder.* The cylinders of an air-cooled in-line engine are made with steel barrels and aluminum-alloy heads. The heads have the valve seats and the spark-plug bushings shrunk into place. Each head is screwed and shrunk on the barrel and both have cooling fins on their surface. The barrel is held to the crankcase by means of studs and nuts.

(4) *Piston assembly.* The pistons are generally of forged aluminum alloy, are heat treated, and are ground to final size. Compression and oil-ring grooves are machined around the piston. The piston may be of the flat-head or dome-shaped type.

(5) *Connecting rod.* The connecting rod is generally forged from a steel beam of **I** or **H** cross section. A bronze or brass bushing is pressed into the small end and reamed to size for the piston pin. The big end has replacable bearing inserts.

(6) *Camshaft.* The camshaft may be located in the crankcase housing (fig. 40), in the cylinder block assembly (fig. 41), or above the cylinder head (fig. 42). If the camshaft is located in the crankcase or the block assembly, it is driven by a set of gears. If located above the cylinder head, it is driven by an extension shaft which is geared to the crankshaft.

(7) *Bearings.* The bearings which support the main crankshaft journals are soft-metal inserts which are backed with bronze or steel. The crankpin bearings are of the same type. The piston-pin bushing is bronze and no special bearing is necessary in the piston since aluminum alloy itself is a good bearing material. The rocker arm is supported in the center usually by a bronze or needle bearing.

c. Front section. The front section is usually made of aluminum alloy. It houses the propeller thrust bearing and the accessory and vertical drive shaft. It is bolted to both halves of the main crankcase section by short bolts and nuts or by cap screws.

(1) *Propeller thrust bearing.* This bearing is a ball bearing. It receives the forward thrust of the propeller and transmits it to the engine crankcase.

(2) *Drive shafts.* An accessory drive shaft is geared to the crankshaft and transmits the power necessary to drive the accessories in the rear section. The vertical drive shaft is driven by the crankshaft and transmits the power to drive the camshaft.

d. Valve mechanism. The valve-operating mechanism used in this type of engine may be any one of several types.

(1) In the type shown in figure 40, the camshaft is located in the crankcase housing. Push rods extend from the cam lobes to the rocker arm. Movement of

the push rod (due to cam action) causes movement of the rocker arm, which in turn opens the valve. The valves are closed by two springs which are held in position by a washer and a split lock.

(2) In the type shown in figure 41, the camshaft is located directly below the valves and cam action is transmitted directly to each valve.

(3) In a third type (fig. 42) the camshaft is located above the cylinder head. The rocker arms bear on the cam lobes and transmit cam action to the valves.

e. Exhaust and induction systems. (1) The exhaust stacks are made of corrosion-resistant steel. These do not muffle engine noise, but merely conduct the engine-exhaust gases to a point where they will neither affect the personnel in the cockpit nor present a fire hazard.

(2) The intake manifold is composed of two aluminum-alloy sections. Each section supplies half of the cylinders. To aid in vaporizing the fuel, a hot spot is sometimes located between the carburetor and induction manifold. This unit warms the fuel-air mixture by heat from the exhaust gases.

f. Cooling. The temperature produced by the burning fuel in an internal-combustion engine often reaches 4,000° F. or more. The hot gases come in contact with the pistons, cylinder walls, valves, and the cylinder head, all of which absorb heat. Two general systems of cooling are used: air-cooling, sometimes referred to as direct cooling; and liquid-cooling, which is accomplished by a circulating liquid.

(1) *Air cooling.* An in-line engine may be cooled by air which is directed around the cylinders by means of baffles. (See fig. 67.) By using cowl flaps to

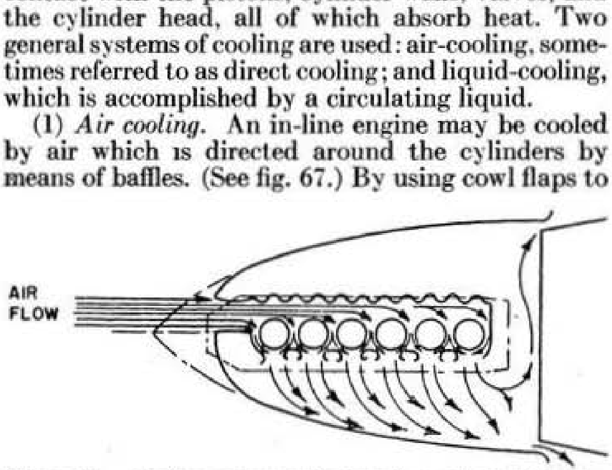


Figure 67. Air flow around cylinders of an air-cooled in-line engine.

control the amount of air that flows around the cylinders, the engine temperature can be kept within the desired range.

(2) *Liquid cooling.* Liquid cooling is accomplished by keeping a coolant medium (ethylene glycol or water) in circulating contact with the metal surfaces to be cooled. The cylinder head and the cylinder block are cast with intraconnected passages (or water jackets) through which the coolant medium circulates. The cold-liquid opening (outlet) is located at the top of the block to prevent the formation of steam pockets. The hot coolant is directed from the top of the engine through pipes to the top of a coolant radiator. As the hot liquid circulates through the radiator, atmospheric air passes around the radiator tubes and removes the heat from the liquid. The cooled liquid then flows from an opening at the bottom of the radiator to a coolant pump and is recirculated through the system. The pipes of the coolant system should have as few bends as possible. To prevent damage from vibration and twisting strains, short lengths of synthetic-rubber hose are used as pipe couplings.

g. Lubrication. A pressure-lubrication system is employed for the main crankshaft bearings, the crankpin journals, and the camshaft bearings. The rocker boxes, valve guides, cylinder walls, piston pins, and gears are splash- or spray-lubricated. Excess oil drains down into the crankshaft housing where it is picked up by the scavenging pump and pumped back to the oil reservoir.

h. Accessories. The accessories of this type of engine are all located in the rear. They are driven by a long accessory drive shaft which is geared to the camshaft at the front of the engine. Because of its length, the accessory drive shaft will twist slightly. This absorbs the vibration (due to power impulses) and prevents overloading of the accessory drive-gear teeth during sudden acceleration and deceleration. The accessories include the generator, magnetos, fuel and vacuum pumps, tachometer, etc.

36. VALVE AND IGNITION TIMING. After a new engine is designed and the first model is made, it is set on test blocks and operated. It is operated at different speeds, various fuels are used, and the valve and ignition timing are changed from one extreme to the other. During these tests under controlled operating conditions, the horsepower developed by the engine is accurately checked. From these data, the design engineers determine the exact timing of the valves and the ignition which will give the best performance. It is important, therefore, that the engine be timed exactly as specified in Technical Orders.

a. Checking valve timing. The valve timing of an in-line engine is checked as follows:

Step 1. Remove the accessory units as directed by Technical Orders.

Step 2. Remove the cylinder-valve covers.

Step 3. Check the clearance of all intake and exhaust valves. If necessary, adjust clearance according to instructions in subsequent paragraph 37b.

Step 4. Install a top-center indicator in a spark-plug hole of No. 1 cylinder and rotate the crankshaft until the piston is at top-dead-center.

Step 5. Set the pointer of the timing indicator at zero and install the indicator on the propeller shaft.

Step 6. Rotate the crankshaft clockwise until No. 1 intake-valve rocker-arm roller cannot be turned with the fingers because of the pressure of the cam. The point of opening of the intake valve will be shown on the timing indicator. This should agree with the value given in the Technical Order for the particular engine.

Step 7. If the valves are not correctly timed, proceed as directed in paragraph 36b.

Step 8. Replace the parts which were removed from the engine.

b. Adjusting-valve timing. To time the valves of an in-line engine, first follow the procedure listed in the first five steps of foregoing paragraph 36a; then proceed as follows:

Step 1. Place the camshaft in its proper position by rotating the crankshaft until the intake valve of No. 1 cylinder is just about to open.

Step 2. Disconnect the vertical drive shaft from the camshaft bevel gear. This will allow the camshaft and crankshaft to be rotated independently.

Step 3. Rotate the crankshaft in the normal direction of engine rotation until the timing indicator shows that No. 1 piston is at the specified number of degrees BTC.

Step 4. Temporarily engage the vertical drive shaft.

Step 5. Rotate the crankshaft backward about 30° and then slowly rotate it forward until the valve rocker-arm roller can no longer be turned with the fingers.

Step 6. Check the valve opening point as shown on the timing indicator. This should agree with the value given in the Technical Order for the particular engine.

Step 7. If the timing is incorrect disengage the vertical drive shaft then disengage the camshaft gear from the camshaft. If the valve opened late, rotate the camshaft gear in a direction opposite to that in which it normally turns, then replace it on the splines. If the valve opened early, rotate the gear in the normal operating direction and replace it on the splines.

Step 8. Repeat foregoing steps 4, 5, and 6.

Step 9. Rotate the crankshaft in the normal direction of rotation and check the closing of the exhaust valve of No. 1 cylinder. This is the point where the pressure of the valve is released and the exhaust-valve roller can be turned with the finger.

Step 10. If necessary, readjust the intake-valve opening to balance the exhaust-valve closing error. In this way, both valves can be timed within the desired tolerance.

Step 11. Replace the parts which were removed from the engine.

c. Ignition timing. To set the ignition timing, the same timing indicator is used. The crankshaft is rotated (on the compression stroke) until the pointer indicates that the No. 1 piston is in the firing position. The magnetos are removed and the drive shaft of each magneto is rotated until the white mark appears in the inspection window of the magneto. This indicates that the magneto is in the proper position to fire the charge in No. 1 cylinder. The magnetos are then placed in position and their drive gears meshed with the gears that are driven by the accessory drive shaft. Adjustment for ignition timing is accomplished by a synthetic-rubber plate which has gear teeth molded on each side. A 0.0015-inch feeler gauge is placed between the breaker points of each magneto. A timing light may be used if available. The crankshaft is then slowly rotated while a light pull is exerted on the feeler gauges. Watch the timing indicator to check the position of the crankshaft just as the breaker points open and release the feeler gauges. If either set of points does not open at the specified position, remove the magneto and rotate the rubber coupling. If the points opened late, turn the rubber coupling in the direction of the magneto drive shaft's rotation. If they opened early, rotate the rubber coupling in the reverse direction. Then install the magneto.

37. VALVE CLEARANCE. All engines must have a slight clearance between the valve stem and the rocker arm. If there were no clearance, the valve might be held slightly off its seat when it should be closed. This would cause erratic operation of the engine and soon cause destruction of the valve itself.

a. Clearance specifications. The specified valve clearance for one type of engine may be 0.015 inch for the intake valve and 0.030 inch for the exhaust valve. These clearances are referred to as the "cold clearances." When the engine warms up during operation, the metal will expand and change these clearances to a certain extent. The exhaust valve will be hotter than the intake valve. Therefore, it expands more and a greater cold clearance may be necessary in order to have the proper clearance during operation.

b. Adjustment procedure. To adjust valve clearance, the lock nut is loosened and the adjusting screw is turned until the proper thickness gauge will enter the space between the valve stem and rocker arm but the next larger thickness gauge will not. The adjusting screw is then held securely and the lock nut is tightened. During the adjustment, the camshaft must be in such a position that the cam lobe does not bear against the rocker-arm roller.

38. INSPECTION AND MAINTENANCE.

a. Inspection procedure. Inspections are performed to prevent trouble on an airplane. By periodically inspecting the airplane and engine parts, minor defects can be found and be corrected before they become serious. The inspection must be performed in a systematic manner and care must be exercised to locate and correct even the smallest defects. To permit the locating of all defects, the parts should be thoroughly cleaned at the time of the inspection.

b. Maintenance and requirements. It is the mechanic's duty to keep the airplane in flying condition as much of the time as possible. To do this, he should be able to recognize probable troubles before they happen and to determine accurately the causes of these troubles. If the mechanic is qualified to perform the proper maintenance, he should do so. If not, he should replace the damaged part and return the unit which contains it to the proper department to be repaired by more highly trained personnel. The airplane mechanic must periodically inspect for and repair any of the following types of minor damage:

(1) Scratches on highly stressed, polished parts are a rather common source of cracks. These scratches may eventually cause a fracture of the part. Inspect thoroughly and remove the scratches at the time of discovery. On some units it is permissible to round or smooth the groove in the early stage of the damage.

(2) Loose connections in the ignition system must be resoldered. Loose spark-plug connections must be tightened. Loose ignition wires will be properly attached. The magneto will be cleaned if necessary. In some cases (designated in Technical Orders) the magneto breaker points will be dressed if found to be burned or pitted.

(3) Loose bonding must be properly secured.

(4) On the fuel and oil systems, loose or leaking connections will be tightened or replaced. Loose lines will be anchored. Screens and strainers will be periodically removed and cleaned. Check all flexible-hose connections and flexible hoses. Replace deteriorated hoses with new hoses.

(5) The control system is more likely to result in malfunctioning than any other part of the engine. The numerous movable parts (consisting of cables, pulleys, bearings, bellcranks, and other units) require constant inspection and in some cases frequent adjustment. On the engine controls, excessive free play must be removed. Binding of the controls must be corrected.

(6) The propeller thrust-bearing nut will be tightened if necessary.

(7) Loose cowling must be tightened and secured in its proper position.

(8) Valve adjustment and valve and ignition timing will be checked and corrected if found wrong.

(9) The crankcase and nose sections should be carefully checked before removing the oil, grease, and dirt. This inspection prior to the cleaning of the engine will, in some cases, reveal an excessive accumulation of oil and dirt which may be an indication of damage. If an excessive amount is found, the engine will be thoroughly cleaned and the section checked for cracks. If any section is found to be cracked, the engine must be replaced.

c. Replacements. Parts that are damaged beyond repair or that require more highly trained personnel for repair must be replaced by the airplane mechanic. Some of the parts that will be replaced, if damaged, are given below:

(1) Spark plugs that are not functioning properly.

(2) Ignition cable that is chafed or abraded.

(3) Shorted or out-of-time magnetos.

(4) Cracked manifolds and leaking gaskets.

(5) Cracked or kinked fuel and oil lines and leaking connections that cannot be sealed by tightening.

(6) Propellers that are out-of-balance or do not track properly. In all cases where the airplane has nosed over or when the propeller has come in contact with some large solid object, the powerplant must be replaced.

(7) Engine cylinders that have excessive damage to the cooling fins.

(8) Any accessory found to be damaged.

V-TYPE AIRCRAFT ENGINES

39. GENERAL. a. Cylinder arrangements. One of the most common types of engines used to power airplanes is the **V**-type engine. The cylinders of this type of engine are arranged in two rows or banks. The centerlines of the banks of cylinders form the letter V. (See fig. 68.) This type of engine may be

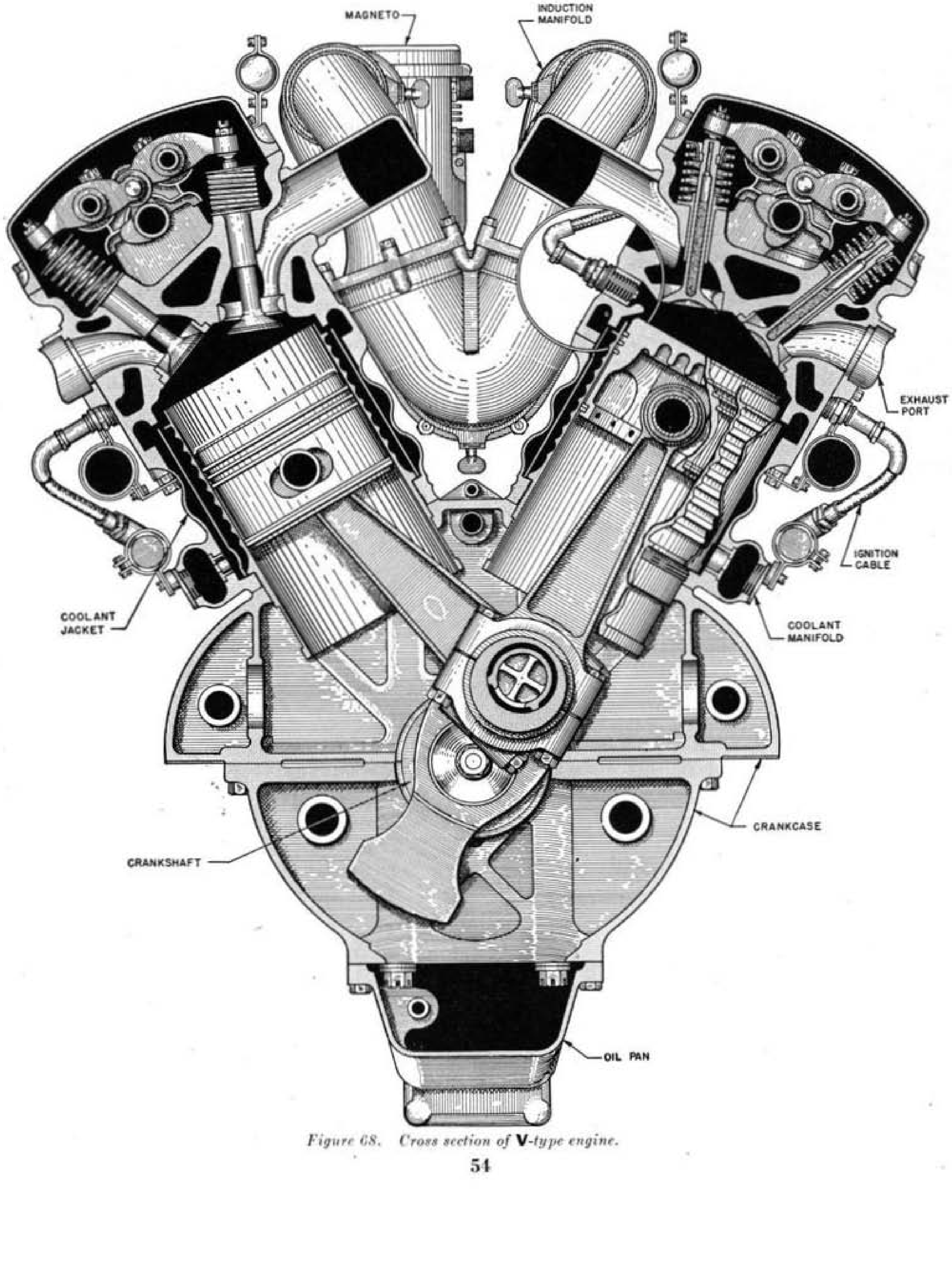


*Figure 68. Cross section of **V**-type engine.*

mounted in the inverted position, but it is generally mounted upright.

b. Firing order. The firing order is the sequence in which the power events occur in the cylinders of the engine. It is determined by the direction of crankshaft rotation. A common firing order of a **V**-12 engine, the crankshaft of which rotates counterclockwise, is 1L–6R–5L–2R–3L–4R–6L–1R–2L–5R–4L–3R. (See fig. 69.) A **V**-12 engine, with a clock-

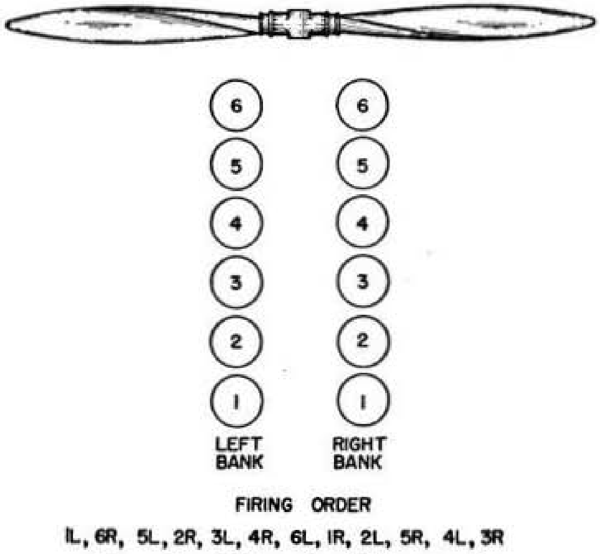


*Figure 69. Firing order of **V**-type engine.*

wise-rotating (right-hand-rotating) crankshaft, may fire 1–L, 2–R, 5–L, 4–R, 3–L, 1–R, 6–L, 5–R, 2–L, 3–R, 4–L and 6–R. An eight-cylinder **V**-type engine with a left-hand-rotating crankshaft will fire 1–L, 4–R, 2–L, 3–R, 4–L, 1–R, 3–L, and 2–R. A **V**-8 type engine with a right-hand-rotating crankshaft will fire 1–R, 4–L, 2–R, 3–L, 4–R, 1–L, 3–R, and 2–L.

40. CONSTRUCTION CHARACTERISTICS.

a. General. The various parts and units of a **V**-type engine accomplish the same purpose as the parts of the other type engines, though they may often differ in shape and size. The mechanic should familiarize himself with these differences.

b. Power section. The power section of a **V**-type engine consists of the upper and lower main section of the crankcase, the crankshaft, the cylinders, the connecting rods and pistons, the valves and valve-operating mechanisms, and the necessary bearings.

(1) *Crankcase.* On some **V**-type engines, the crankcases are divided into two halves at the center of the crankshaft. Each half contains web partitions which support the main bearing inserts. The two halves of some crankcases are held together with long stud bolts, one on each side of each main bearing. Numerous short bolts around the parting flanges hold the two halves rigidly together. The lower half of the crankcase usually has a small oil pan bolted to it. Other **V**-type engines have crankcases which are split well below the centerlines. The upper halves have heavy web partitions. The upper portions of the main bearings are installed in these webs. Individual bearing caps are fastened to the webs by means of studs and nuts. A small dowel prevents the bearing insert from turning. The lower part of the crankcase is held to the upper part by means of closely spaced studs. The engine-mounting pads are located on the upper half of the main crankcase section.

(2) *Crankshaft.* The crankshaft of a **V**-type airplane engine is forged of steel and is machined and polished on all surfaces. A **V**-12 type engine has six crankpins and seven main bearing journals. The **V**-8 type engine has four crankpins and five main bearing journals. The crankshaft must be statically and dynamically balanced. The main and crankpin journals and the crankcheeks are drilled to provide passages for lubricating oil. This also makes the crankshaft lighter in weight.

(3) *Cylinders.* The cylinders are made of steel barrels shrunk into aluminum-alloy heads. The barrels are made as individual units while the six heads of each cylinder bank may be cast or forged in a single unit. The barrels of each bank are inclosed in an aluminum coolant jacket which is secured to the head by studs and nuts. Space through which the cooling liquid flows is provided between the cylinder barrels and the cylinder block. Intraconnected passages for the cooling liquid are provided in the cylinder head. The entire assembly of the cylinder barrels and cylinder block of each bank is held to the crankcase by means of long stud bolts. On some **V**-type engines the cylinder barrels are held to the cylinder block by means of large lock nuts. On other types, the barrels are pressed into the block. In each type a gasket is provided to seal the cooling system from the crankcase. Aluminum gaskets seal the joints between the cylinder blocks and cylinder heads. The bronze spark-plug bushings and steel valve seats are shrunk, or screwed and shrunk, into place.

(4) *Connecting rods.* The connecting rods of this type engine are of I cross section and are forged of steel. They are machined on all surfaces to remove any small scratches which might cause failure during operation. The fork-and-blade type is generally used and each rod is marked by the manufacturer so that it can be replaced in the cylinder from which it was removed. The bearing on the big end of the connecting rod is an insert while the bearing on the piston-pin end is a bronze bushing pressed in place and reamed to size.

(5) *Piston assembly.* The connecting rod is attached to the piston by means of a hardened-steel, full-floating piston pin. The pin is retained in the piston by two circlets which are fitted in the piston at each end of the pin. The piston is made of forged aluminum alloy and is machined on all external surfaces. Three grooves are provided above the piston pin for the three compression rings. On some types of piston, a groove is provided for one oil ring above the pin and another below the pin. Other models have both oil rings in a single groove located below the piston pin.

c. Nose section. (1) The nose section of the crankcase of a **V**-type engine houses the propeller thrust bearing and the propeller reduction gears. On some models it also contains an oil pump which scavenges the oil used to lubricate the nose-section gears and bearings.

(2) The nose-section crankcase is usually forged of aluminum alloy and is bolted to the main crankcase section by means of studs and nuts. The propeller thrust bearing, located in the forward end of the nose section, receives the forward thrust of the propeller and transmits it to the nose section and to the main crankcase section.

d. Valve mechanism. The valves of **V**-type engines are operated by two camshafts—one on each bank of cylinders. Rocker arms are also located above each cylinder to transmit the lifting motion from the cam to the valve stems.

(1) *Camshaft.* One camshaft is located on top of each cylinder bank and extends from one end of the bank to the other. The camshaft is mounted in plain bearings which are located between each two cylinders. Some models have flanged plain bearings near the drive gear to take care of thrust loads while other models have ball bearings for this purpose. A separate cam is provided for each rocker arm.

(2) *Rocker arm.* The rocker arms used on this type engine may be pivoted on the end or in the middle. They bear directly on the camshaft. (See par. 26b (3).)

(3) *Valve springs.* Each valve is held on its seat by means of multiple compression springs, one inside of the other. The springs are held in place by means of a cone plate and split locks. Some **V**-type engines have one intake and one exhaust valve for each cylinder. Other models have two valves of each kind for each cylinder. This facilitates cool operation of the valves.

(4) *Valves.* The valves are of the poppet type, made of steel, and faced with Stellite or bright-ray. The end of the valve stems are hardened to minimize wear. The stems of the exhaust valves of all models and of the intake valves of some models are partly filled with sodium to aid in dissipating heat from the valve head. The valve guides are made of cast iron or phosphor-bronze and pressed into place in the head.

e. Intake systems. The induction system of a modern **V**-type engine consists of a carburetor, an internal blower or supercharger, and the necessary manifold to conduct the fuel-air mixture to the cylinders. On some models, the internal blowers are of the single-speed centrifugal type. On other models, internal superchargers of the two-speed contrifugal type are used. In either case, the impeller is driven by a gear train from the engine crankshaft. An engine that has a single-speed internal blower is sometimes equipped with an exhaust-driven turbosupercharger. Whether or not a turbosupercharger is incorporated depends upon the type and use of the airplane on which the engine is installed. The intake manifold is made of cast aluminum or magnesium alloy. It is designed to conduct the fuel-air mixture to the cylinders with a minimum of turbulence.

f. Exhaust systems. The type of exhaust manifold used depends on the type of the airplane rather than the type of engine. If a turbosupercharger is used, the exhaust manifold will collect the exhaust gases from all cylinders and direct them to the supercharger turbine. If the turbosupercharger is not employed, the exhaust system will be merely short stacks leading from each cylinder to the atmosphere or to a common exhaust outlet for each bank. In either case corrosion-resistant steel is used for all parts of the exhaust system.

g. Cooling. (1) *Air cooling.* Pressure-type cylinder baffles are standard equipment on an air-cooled engine. Pressure baffling forces the cooling air at high velocity around the finned surfaces of the cylinder. This type of engine does not differ greatly in construction from the liquid-cooled powerplant. The cylinder assemblies of this type of engine are usually cast or forged individually.

(2) *Liquid cooling.* On some models, the liquid used is a mixture of ethylene glycol and water. Systems of this type are sealed to prevent the water from boiling away at high altitudes. Other models use ethylene glycol as the cooling liquid and do not need to be sealed since ethylene glycol has a higher boiling point than the mixture of ethylene glycol and water previously mentioned. The pressure system is a closed system which has a relief valve to prevent excessive pressures. The system using pure ethylene glycol is an open system which is vented to the atmosphere. A centrifugal coolant pump supplies coolant to each cylinder block at two inlets, one located at the coolant jacket and the other at the rear of the cylinder head. An integrally cast, inlet manifold extends the full length of each jacket and distributes the coolant to each cylinder through metering holes. The inlet at the rear of the cylinder head provides an opening through which the coolant flows to the passages surrounding the combustion chambers.

h. Lubrication. Oil is circulated to the moving parts of the engine through a pressure system. Circulation is maintained by a pressure pump and one or two scavenger pumps. A constant desired pressure is maintained by use of the pump and an oil-pressure relief valve. The oil is supplied to the pump from an external supply tank. An oil-inlet check valve (which prevents the flow of oil from the tank into the engine when the engine is stopped) is installed in the main oil-pressure line from the pump. A pressure of approximately 1 to 3 pounds per square inch is sufficient to open the valve. The relief valve may be located in the oil-pressure line from the Cuno or screen filter or it may be incorporated at the discharge side of the pump. The oil is delivered to the Cuno filter where all foreign matter is removed. Oil from the filter outlet is then distributed to the moving parts of the engine.

(1) *Engine oil-pressure control.* Oil pressures must be sufficiently high to provide adequate lubrication of the engine and its accessories during maximum output. They must not be too high or leakage and damage to the oil system may result. To regulate the oil pressure in a **V**-type engine, one of the following types of oil-pressure relief valves is used.

(*a*) *Dual pressure type.* In this type valve, two pressure-regulating valves are built into the same housing. (See fig. 70.) Oil from the pump enters the

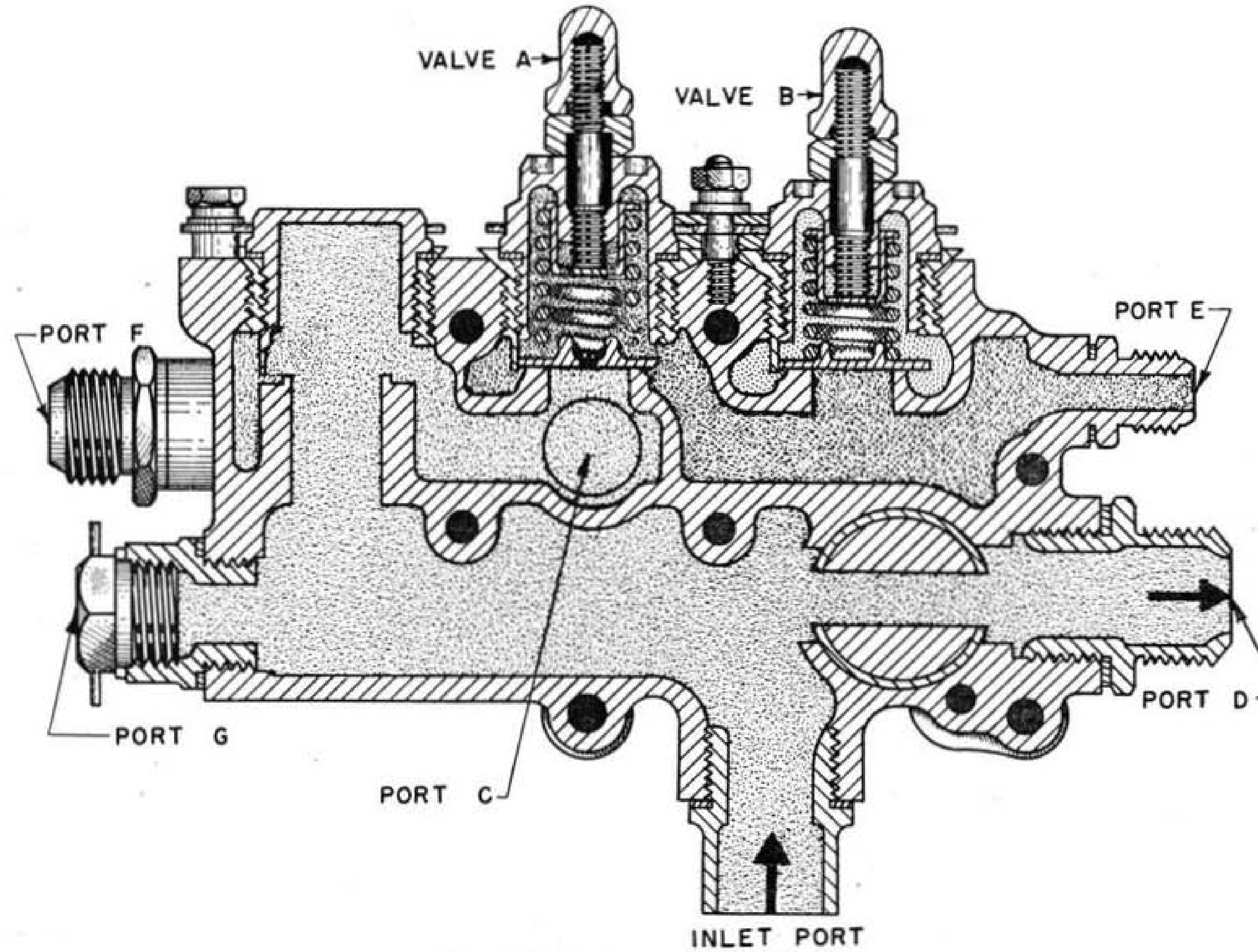


Figure 70. Dual pressure-type relief valve.

high-pressure chamber of the relief valve through the inlet port. Valve *A* limits the pressure of the oil delivered by the pump. If the pressure exceeds the value for which this valve is set (usually 60 to 90 pounds per square inch) the valve unseats and surplus oil is bypassed to the inlet side of valve *B*. This valve is set to open at 4 to 8 pounds per square inch. If pressure in the low-pressure chamber exceeds the value for which valve *B* is set, the valve opens and by-passes oil to the crankcase. A small bleed hole in valve *A* assures flow of oil into the low-pressure chamber at any pump pressure. High-pressure oil is supplied to the crankshaft and bearings through port *C* (located on the back face of the unit). High-pressure oil is also conducted from port *D* to the propeller governor. Low-pressure oil for lubrication of the reduction gearing is supplied through port *E*. Port *F*, which is also connected to the low-pressure chamber, supplies oil to the camshaft and the accessories. Port *G* is an oil-thermometer connection. A pressure-gauge connection (not shown in the figure) is provided on the front of the unit.

(*b*) *Spring-opposed balanced relief valve*. An installation incorporating this type of relief valve is shown in figure 71. The valve consists of a three-port housing which contains a spring-loaded piston. Port *A* is connected (through the check valve) to the discharge side of the pump. Engine-oil pressure is applied to the end of the piston through port *B*. This

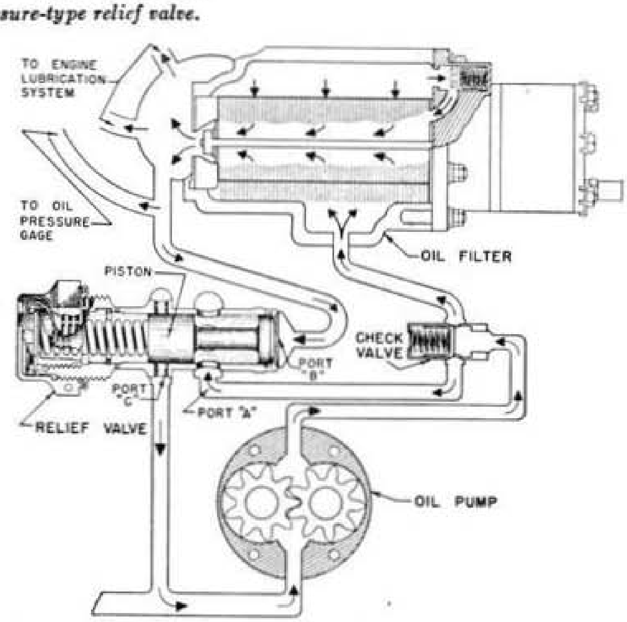


Figure 71. Installation incorporating a spring-loaded balanced relief valve.

tends to move the piston to the left. The spring located on the opposite end of the piston opposes this movement. If engine-oil pressure exceeds the value for which the valve is set, the piston will be moved to the left. Port *A* will then be connected to port *C* by the cut-away part of the piston, and the output of the pump will be bypassed to the inlet port of the pump. When the pressure drops below the value for which the valve is set, the spring will move the piston to the right and the output of the pump will again be directed through the oil filter to the engine lubrication system.

(2) *Oil sumps.* Oil sumps are located in the lowest part of the engine. There are usually two sumps in each engine. The housing of the sump may be cast as part of the main crankcase or it may be a separate unit. The primary purpose of the sump is to provide a well for collecting the engine oil so that the scavenger pump (located in the sump) may return the oil to the supply tank.

(3) *Scavenger pumps.* The number of scavenger pumps in an engine may vary from one to three, depending on the size and type of the engine. The usual practice has been to locate one scavenger pump at the rear of the engine and one at the forward end of the crankcase or in the nose-section housing. The pumps are located in such a way as to permit positive scavenging of the oil at all times during normal flight maneuvers.

(4) *Main-bearing lubrication.* A large tube in the crankcase delivers oil to a drilled passage in each web partition support and lubricates the main bearings.

(5) *Connecting-rod lubrication.* Connecting passages are drilled in the crankshaft to allow oil to flow to each connecting-rod bearing. Oil spray, thrown from the connecting-rod bearings, lubricates the cylinder walls and piston pins.

(6) *Sludge sumps.* In some engines the main bearings and the crankpin journals are hollow and fitted with special aluminum-alloy plugs. (See fig. 72.) These provide passages for the lubricating oil yet permit the collection of foreign matter and oil sludge.

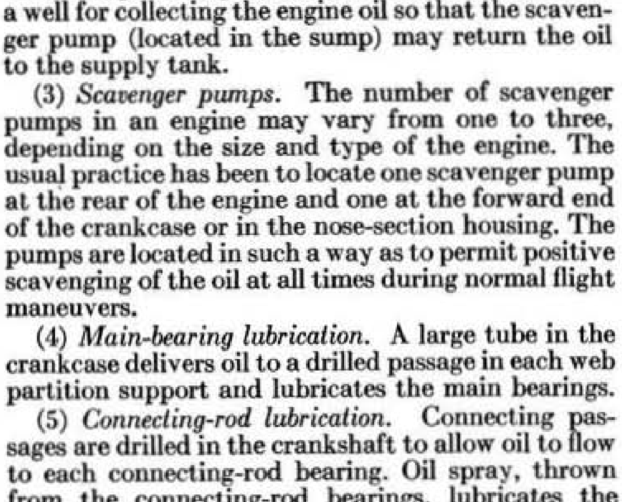


Figure 72. Crankpin oil plugs (sludge sumps).

(7) *Reduction-gearing lubrication.* Oil to lubricate the reduction-gear bushings and bearings flows through passages and hollow shafts to the nose section. The reduction gears are lubricated by spray from these units.

(8) *Propeller operation.* Oil under pressure is directed to the propeller-governor pad and carried through the propeller shaft to provide the operating pressure for hydraulically operated propellers.

(9) *Camshaft lubrication.* A branch lead from the crankcase tube carries the oil to the inclined hollow shafts of the camshaft drive. From there, it passes into the hollow camshaft. At the heel of each cam lobe, a hole is located to lubricate the lobe and rocker-arm mechanism.

(10) *Blower-impeller lubrication.* Drilled passages are usually provided from the Cuno or screen-filter outlet to the supercharger bearings.

(11) *Accessory lubrication.* Other drilled passages are incorporated to provide lubrication from the filter outlet to each accessory-unit bearing.

(12) *Internal oil drains.* Oil drains are provided at every lubricated part of the engine. Oil passages at both ends of the camshaft housing allow the oil to drain to the crankcase sumps. The pumps draw the oil from the sumps and return it through passages and lines to the oil-supply tank.

i. Accessories. Most accessories are located at the rear of **V**-type engines. They are gear-driven by power from the crankshaft. A spring or fluid coupling located between the crankshaft and the accessories absorbs crankshaft vibration and prevents accelerating shock from shearing the gear teeth. The accessories include the generator; magnetos; fuel-oil, coolant and vacuum pumps; tachometer generator; etc.

41. VALVE CLEARANCE. Clearance between the valve stem end and the valve-actuating mechanism is necessary to permit positive valve seating. If cold clearance is inadequate, the intake valve will be held off its seat, causing a loss in compression and power output. This condition also causes backfiring in the induction system. If the exhaust valve is held off of its seat it also causes a loss in compression and power, and "after-firing" will occur in the exhaust manifold. Burning and warping of the valve head and stem results from the escape of the hot flames through the small opening between the valve face and valve seat.

a. Checking valve clearance.

(1) Remove cylinder valve cover.

(2) Rotate the propeller shaft until the cam roller is on the heel (low point) of the cam lobe for the valve being checked.

(3) Insert the correct feeler gauge between the end of the valve stem and the adjusting screw. (The correct clearance may be found in Technical Orders.) The gauge should just slip into the opening and the next larger gauge should not.

(4) If the valve clearance is not correct, adjust according to the procedure given below.

b. Adjusting valve clearance. This adjustment must be made when the engine is cold. It is neither safe nor practical to adjust valve clearances when the engine is operating. Valves should be adjusted at temperatures between 10° C. and 50° C. (50° F. and 122° F.).

(1) Loosen the lock nut on the valve-clearance adjusting screw.

(2) If the clearance is too small, back out on the adjusting screw until the specified feeler gauge can be inserted between the end of the valve stem and the adjusting screw. (See fig. 73.) Tighten adjusting screw until it bears lightly on the feeler gauge. Remove the gauge, hold the adjusting screw and tighten the lock nut. The clearance should be rechecked after the lock nut is tightened.

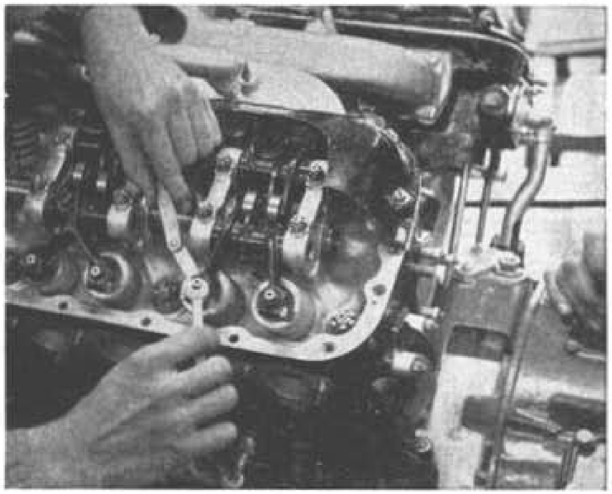


Figure 73. Adjusting valve clearance.

(3) If the clearance is too large, loosen the adjusting screw and proceed as in (2) above.

(4) Care should be exercised to keep the adjusting screw from turning when the lock nut is being tightened.

42. VALVE AND IGNITION TIMING. After a new engine is designed, and the first model produced, it is installed on a test stand and operated. During operation it is operated at different speeds, on different grades of fuels, and the valve and ignition timing are varied. During these tests an accurate record is kept of the brake horsepower developed by the engine. From these data, the design engineers select the best timing for the valves and ignition. It is important, therefore, that the mechanic time the engine exactly as specified in Technical Orders. For timing the valves and ignition of a **V**-type engine, a top-center indicator and a timing disk are used. The top-center indicator is used to locate the top-dead-center (TDC) position of the piston. The pointer and the timing disk are used to indicate the amount of rotation of the crankshaft. The method of using these devices is described in the timing procedures which follow.

a. Checking valve timing. Valves are opened by movement of a cam and closed by spring tension. The shape of the cam lobe determines the opening and closing speed of the valve and the length of time it stays open (in degrees of crankshaft rotation). The crankshaft is always turned in the direction of rotation during timing operations to eliminate errors that might be caused by gear lash (clearance between gear teeth). One purpose in checking valve-opening and valve-closing positions (in relation to piston position) is to determine the amount of wear that exists in the valve-operating mechanism. A few degrees of tolerance are generally permitted for continued operation. Any tolerance greater than that specified in Technical Orders requires that the valves be retimed. If this does not correct the condition the engine must be overhauled.

(1) *Checking valve timing of an engine with right-hand propeller rotation.*

Step 1. Remove the cylinder valve covers and check the valve clearances. If necessary, adjust to that specified by Technical Orders. (See par. 41.)

Step 2. Install the top-center indicator in the No. 6L intake spark-plug opening.

Step 3. Remove the magneto cover and cam screw. Install the timing disk and the pointer on the magneto housing. Be sure that the step of the pointer is properly placed with the step on the magneto cam and secured with the special screw.

Step 4. Rotate the propeller shaft until the top-center indicator shows that No. 6L piston is at TDC. The relative position of No. 1L piston is the same as the position of No. 6L piston because both pistons are connected to crankpins which are of the same angle on the crankshaft.

Step 5. *Checking valves of the left bank.* Rotate the propeller in the normal direction of rotation until the exhaust valves of *No. 6L* cylinder are closed. The pressure must be removed from the rocker-arm rollers. Check the reading on the inner scale of the timing disk. This reading should be that specified in the Technical Order of that engine (for example, $26° \pm 2°$ ATC).

Step 6. *Checking the valves of the right bank.* The next valve to operate is No. 5R (right bank). Rotate the propeller in the normal direction of rotation until the exhaust valves of No. 5R are closed (pressure is off the rocker-arm roller). Check the reading on the *outer scale* of the timing disk. The reading should be that specified in Technical Orders (for example, $26° \pm 2°$ ATC).

(2) *Checking valve timing of an engine with left-hand propeller rotation.*

Step 1. The first six steps of this procedure are the same as Steps 1 through 6, (1) above.

Step 2. *Checking valves of the right bank.* Rotate the propeller in the normal direction of rotation until the exhaust valves of No. 1R are closed (pressure off the rocker-arm roller). The reading on the outer scale of the timing disk should be that specified in Technical Orders (for example, 26° ± 2° ATC).

(3) *Checking the valve timing of a* **V**-*type engine incorporating a timing-inspection opening.*

Step 1. Remove the cylinder valve covers.

Step 2. Remove the timing-inspection plug which is located in the crankcase.

Step 3. *Checking the valves of the right bank.* Adjust the tapper clearance of one of the intake valves of the A-6 cylinders (or No. 6 cylinder in the right bank) to that specified in Technical Orders. Be sure that the rocker is on the base of the cam lobe pointing away from the rocker arm when this clearance is set.

Step 4. Rotate the crankshaft counterclockwise (looking from the rear of the engine). Observe the movement of the crankshaft coupling flange and when the mark "A-6 I-0" (A-6 intake opening) approaches the pointer, stop the rotation.

Step 5. Insert a 0.005-inch feeler between the previously adjusted A-6 cylinder-intake valve and tappet, then continue rotating the crankshaft slowly counterclockwise until the feeler is just pinched.

Step 6. Check the position of the crankshaft by observing the position of the timing marks. If the mark "A-6 I-0" is aligned with the pointer or within ¼ inch past, the valve timing is correct. If the pointer does not register within these limits, retime the valves.

Step 7. Readjust the intake tappet to that clearance specified in Technical Orders (example, 0.010 inch) and reinstall the cylinder-head cover, using a new gasket.

Step 8. *Checking the valves of the left bank.* The valves in this bank are checked in the same manner as the valves in the right bank, except that the *B-1 cylinder* and the B-1 I-0 mark are used.

b. Adjusting valve timing.

(1) *Valve-timing procedure for a* **V**-*type engine with right-hand propeller rotation.*

Step 1. Check valve clearances. (See par. 41.)

Step 2. Install the propeller-shaft wrench. When timing the engine the mechanic must bear in mind that these engines operate with left-hand crankshaft rotation. This rotation is determined when viewing the engine from the rear or starter-shaft end. Also bear in mind that the starter shaft, on which the timing disk is mounted, will rotate in the opposite direction from the crankshaft, that is, right hand.

Step 3. Install the timing disk on the magneto housing.

Step 4. Install the top-center indicator in the intake spark-plug opening of No. 6L cylinder and locate the TDC position of the piston.

Step 5. Set the pointer of the timing disk at 0° when the TDC position of No. 6L piston is located.

Step 6. From TDC position rotate the propeller shaft counterclockwise until the pointer registers about 60° BTC.

Step 7. It must be borne in mind that the propeller shaft must always be rotated in its normal direction of rotation when making a reading on the timing disk. Rotate the propeller shaft in a clockwise direction until pointer indicates the correct number of degrees BTC. This may be found in Technical Orders.

Step 8. Rotate the left-bank camshaft (with the special camshaft wrench) until the intake-tappet clearance of No. 6L cylinder is just taken up and the valves are beginning to open.

Step 9. Remove the camshaft wrench and install the beveled camshaft gear so that the seven bolt holes line up with the flange on the camshaft. Install nuts on two of the bolts to hold the gear while completing the check.

Step 10. Rotate the propeller shaft clockwise until the exhaust valves of No. 6L close. The exhaust-valve closing position is noted (for example, 26° ATC) on the timing disk. If the position does not check with that given in Technical Orders the camshaft should be readjusted so that the differences of the intake-valve opening and the exhaust-valve closing position from the specified values are equal. The intake-valve opening time and the exhaust closing time should be within ±2° of tolerance of their specified positions.

Step 11. If timing is correct, install the remaining five nuts, tighten and safety with cotter keys.

Step 12. The valves of the right bank are next timed. Rotate the propeller shaft clockwise until the timing disk reads 60° ATC which is the top-dead-center position of the No. 5R piston. Since the intake valve of No. 5R should open 48° before TDC, the propeller shaft is rotated in counterclockwise direction 48° which will read 12° ATC on the timing disk.

Step 13. Take up the backlash for this 12° reading.

Step 14. Rotate the camshaft of the right bank so that the intake valves of No. 5R cylinder are just beginning to open.

Step 15. Install the camshaft gear as mentioned in step 7.

Step 16. Rotate the propeller shaft clockwise to the exhaust-valve opening position and check the reading on the timing disk.

Step 17. This reading is specified in Technical Orders (for example, 86° ATC). This is also the top-dead-center position of No. 5R (26° ATC) piston.

Step 18. Divide the difference between the intake-valve opening and the exhaust-valve opening position as it was performed in step 11.

(2) *Valve-timing procedure for a* **V**-*type engine with left-hand propeller rotation.* The procedure for timing the valves of an engine of this type is the same as the procedure described in a(1) above, except that the propeller shaft will be rotated in the opposite direction.

(3) *Valve-timing procedure for a* **V**-*type engine incorporating a timing inspection opening.* (*a*) *Timing the right bank first.*

Step 1. Remove the cylinder head cover.

Step 2. Remove the thrust cap from the upper end of the vertical splined camshaft drive shaft.

Step 3. Remove the timing-inspection plug located in the crankcase.

Step 4. Lift the splined camshaft drive out of mesh with the bevel pinion gear (fig. 51) and tie it with a cord or rubber band in the out of mesh position. This permits the camshaft to be disengaged from the crankshaft. The camshaft then may be turned independently of the crankshaft.

Step 5. Check the taper pin which holds the thrust plug in the upper end of the drive shaft to make certain that it is securely in position.

Step 6. Rotate the camshaft and set one of the intake valves of the A–6 cylinder to the specified clearance. The rocker must be on the base of the cam and the point of the cam lobe must be pointed upward.

Step 7. Rotate the crankshaft counterclockwise (looking from the rear of the engine) until the timing marks "A–6 I–0" on the crankshaft coupling flange aligns with the pointer.

Step 8. Insert a 0.005-inch feeler between the previously adjusted cylinder-intake valve and tappet. Rotate the camshaft until the feeler is just pinched.

Step 9. Remove the cord or rubber band that is holding the camshaft drive and carefully lower it to engage both the upper and lower camshaft drive gears. Only the weight of the shaft is to determine the engagement. It may be necessary to try several different positions.

Step 10. With a 0.005-inch feeler between the A–6 cylinder-intake tappet, check the timing as follows:

Step 11. Rotate the crankshaft backward (propeller is rotated clockwise) about one-eighth of a revolution, then rotate it slowly in normal direction of rotation. Stop rotation when the feeler is just pinched between the valve stem and tappet. (When it is not practicable to rotate the crankshaft backward, rotate it two complete revolutions in the normal direction and stop when the 0.005-inch feeler gauge is just pinched between the valve stem and the tappet).

Step 12. Check the position of the crankshaft by the timing marks. The timing marks "A–6 I–0" should be aligned with the pointer or within ¼ inch past. If the pointer does not register within these limits repeat the operations listed.

Step 13. Reinstall the camshaft drive-shaft thrust cap, tab washers, and nuts. Tighten the nuts securely and bend the tabs.

Step 14. Adjust all exhaust and intake tappets to the proper clearance.

Step 15. Reinstall the timing plug and cylinder-head cover, using a new cover gasket.

(*b*) *Timing the left bank first.* This procedure is the same as that given in (3)(*a*) above, except that the *B–1 cylinder* and B–1 1–0 are used.

c. Ignition timing. To time the ignition, the magneto drive shaft is turned until the breaker points are just ready to open and the distributor rotor is set to direct the current to fire the charge in the proper cylinder. The magneto is then placed on the engine and the magneto drive shaft is engaged with a vernier-coupling shaft. The other end of this coupling is engaged with a shaft which is driven indirectly by the crankshaft. The coupling used in one **V**-type engine has 12 internal splines on 1 and 11 external splines on the other end. The internal splines engage the magneto coupling and the external splines engage the magneto drive shaft. The difference in the number of splines makes it possible to select an engagement which will give very accurate timing.

d. Timing specifications. While all models of a similar type have similar timing specifications, they are not exactly the same. Exact specifications should be checked in the Technical Orders. For example, on one **V**-12 engine model, the intake valve opens 31° before top-center, the exhaust valve opens 72° before bottom-center, the spark occurs in the exhaust spark plug 50° before top-center and in the intake spark plug 45° before top-center. On another model, the intake valve opens 48° before top-center, the exhaust valve opens 76° before bottom-center, the spark occurs in the exhaust spark plug 34° before top-center, and in the intake spark plug 28° before top-center.

43. INSPECTION AND MAINTENANCE. a. Inspection procedure. Inspections are performed on an airplane to locate and correct minor troubles before they become serious. They should be performed in a systematic manner and the parts to be inspected should be thoroughly cleaned to enable the mechanic to locate small defects.

b. Maintenance requirements. It is the mechanic's duty to keep the airplane in flying condition as much of the time as possible. To do this, he should be able to recognize troubles as soon as they appear and to determine accurately the causes of these troubles. A member of an airplane ground crew must be familiar with many types and models of the units that compose a powerplant. The individual must be able to handle maintenance and repair without adding to the damage or malfunction already present. Whether the airplane has crashed or malfunction is due to normal wear, the mechanic must know definitely what action to take. If the maintenance required is not of a nature that can be performed on the site or if it requires the work of a specialist, the part or unit is removed and one known to function properly is installed.

c. Minor repair of subassemblies. Some of the repair work that is done by the airplane mechanic is listed below.

(1) The Cuno strainer or screen filter is removed, cleaned with kerosene or gasoline, coated with engine oil, and replaced whenever necessary.

(2) Loose connection of the ignition system and shielding are tightened or resoldered.

(3) Loose or leaking connections on fuel and oil lines are tightened. If tightening does not correct the difficulty, the line is replaced.

(4) Faulty coolant-hose connections are corrected.

(5) The coolant-pump packing nut is tightened and new packing is installed whenever necessary.

(6) Valve and ignition timing is adjusted when required.

(7) Valve clearance is adjusted as needed.

(8) Cylinder hold-down nuts are tightened periodically after overhaul.

(9) The oil-pressure relief valve is adjusted whenever necessary.

(10) Magneto points are honed if slightly pitted.

d. Replacements. Parts that are damaged beyond repair or that require the service of more highly trained personnel are replaced by the airplane mechanic. Some examples are listed below.

(1) Leaking manifold gaskets.

(2) Broken valve springs.

(3) Defective valve tappets.

(4) Defective ignition wiring.

(5) Defective distributor heads.

(6) Defective engine accessories.

SECTION VI

OPPOSED- OR FLAT-TYPE AIRCRAFT ENGINES

44. GENERAL. The opposed- or flat-type aircraft engine is sometimes referred to as the "pancake" type. The term "pancake" is generally used to refer to an opposed engine with a greater number of cylinders than those used in the Army Air Forces at the present time. Opposed engines of low horsepower have been used for some time, but high-horsepower engines of this type are being developed for horizontal mounting in the wings of large airplanes.

a. Cylinder arrangements. The cylinders of an opposed-type engine are arranged in two banks. The banks are 180° apart with the crankshaft between them. On low-power engines, the cylinders in each bank are not directly opposite each other. Instead, the cylinders of one bank are slightly in front of the cylinders of the other bank. Cylinders arranged in this order are said to be *staggered* as shown in figure 74. The cylinders of an opposed engine are usually numbered with the odd numbers on the left side of the powerplant when observed from the rear of the engine. The cylinder on the left side nearest the rear of the engine is usually designated as No. 1.

b. Firing order. The firing order is the sequence in which the power events occur in the cylinders of an engine. On six-cylinder opposed engines, the firing order is 1–4–5–2–3–6. The firing order of one model four-cylinder opposed engine is 1–4–2–3, while on another it is 1–3–2–4.

45. CONSTRUCTION CHARACTERISTICS. a. General. While all aircraft engines are made up of parts that serve similar purposes, these parts may differ in shape on the different types of engines. The mechanic should be familiar with these differences.

b. Power section. The power section on an opposed engine is made up of the main crankcase, the crankshaft, the connecting rods and pistons, the cylinders, the camshaft and other valve operating mechanisms, and the necessary bearings.

(1) *Crankcase.* The crankcase is made of two halves of cast aluminum alloy which are bolted together with long bolts. These two halves have ribs in them which hold the main crankshaft bearing inserts. The camshaft bearings are also in the main crankcase. In some engines, babbitt lined inserts are used for the camshaft, while in others the aluminum alloy itself is the bearing material. The oil sump is located in the lower part of the main crankcase section.

(2) *Crankshaft.* The crankshaft is made of forged steel and the main and crankpin journals have a ground finish. It has passages drilled through it to decrease weight and to provide for transmitting the lubricating oil. The crankshaft of a four-cylinder opposed engine has three main bearings while that of the six-cylinder engine has four. In each model there are two crankshaft throws between each two main bearings. The front main bearing may be a plain bearing with a flange to take the thrust of the propeller. In some cases, the front main bearing is a thrust-type ball bearing.

(3) *Connecting rods.* The connecting rods are forged of steel and are generally of an **H** cross-section. The big-end bearing is an insert-type bearing. The piston-pin bearing is a bronze bushing which is pressed in and then reamed to size.

(4) *Pistons.* The pistons are made of aluminum alloy and are provided with three piston rings on some models and four on others. The piston pins are made of hardened steel and are of the full-floating type. They are prevented from rubbing against the cylinder wall by aluminum-alloy plugs fitted into each end of the piston pin.

(5) *Cylinders.* The cylinder assembly of an opposed engine is composed of a steel barrel and an aluminum-alloy head. The head is screwed and shrunk onto the barrel. In air-cooled opposed engines, the outside surfaces of the cylinder head and barrel are provided with the cooling fins. The valve seats and valve guides are made of bonze or steel and are shrunk (or shrunk and rolled) into place. The spark-plug holes are also lined with bronze bushings. The liquid-cooled type of opposed engine has a cooling system similar to that used in other liquid-cooled engines.

(6) *Valves.* The valves are of the conventional poppet type and are made of steel. They are closed by coil springs which are held in place by cone washers and split locks.

c. Nose section. The nose or front section of this type of engine is generally cast or forged as a part of the power section. It incloses the propeller shaft and a thrust bearing.

d. Valve mechanism. The valves are operated by a camshaft and a hydraulic valve-lifting mechanism. The hydraulic valve-lifting mechanism automatically compensates for any changes in the length of the cylinders due to combustion heat, so that valve-clearance adjustment is not necessary. The valve-lifting force originates at the camshaft which is driven at one-half crankshaft speed.

e. Induction and exhaust systems. (1) The induction system has an individual pipe leading to each cylinder. On some models these pipes are connected to the manifold by short sections of rubber hose held by clamps. On other models, one end of each pipe is bolted to the cylinder by means of a flange and the other fits into a slip joint in the manifold. On another type, the carburetor is mounted on the oil sump. In this type, the fuel-air mixture flows from the carburetor through passages in the oil sump and out through individual pipes to the cylinders. (See fig. 75.) As the mixture travels

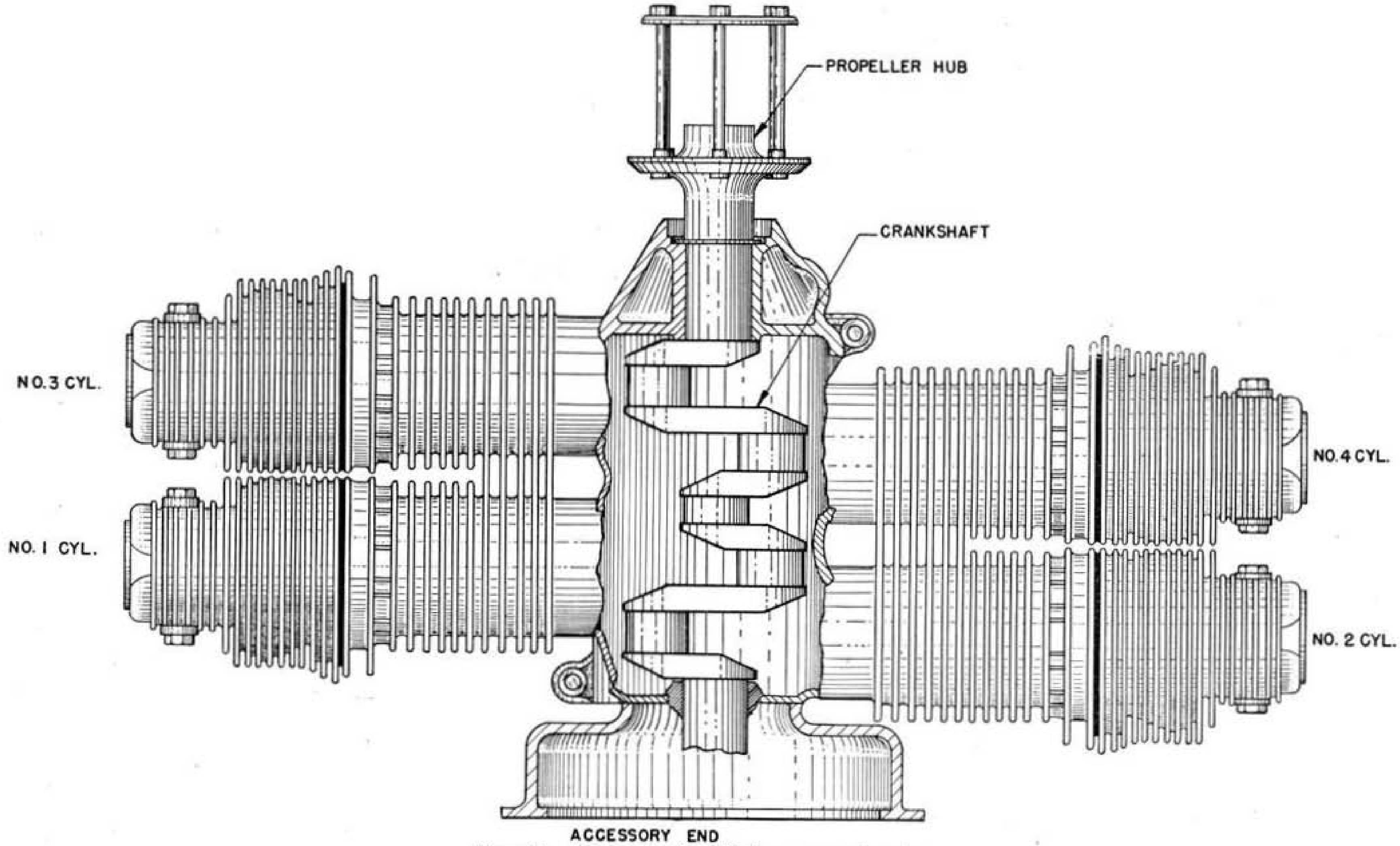


Figure 74. Staggered engine cylinders — opposed engine.

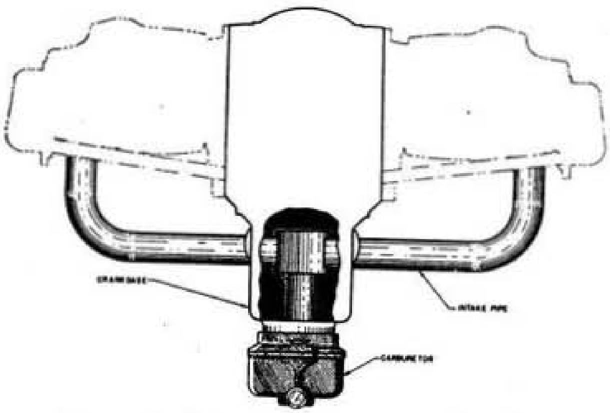


Figure 75. Induction system — opposed engine.

through the passages, heat is transferred from the oil to the fuel-air mixture. This cools the oil to some extent and provides some heat for better vaporization of the fuel.

(2) Exhaust gases are conducted through pipes to a noise-damping unit (muffler) and then to the side of the airplane where they are released. The exhaust-system pipes are made of welded, corrosion-resistant steel.

f. Cooling. On present-day air-cooled opposed engines, a baffle located above each bank of cylinders directs the air between and around the cylinder cooling fins.

g. Lubrication. The oil reservoir is in the lower part of the crankcase. This arrangement is called a wet-sump-type oil system. The oil pump draws oil from this reservoir and forces it through a screen and out through the lubricating system. The crankshaft main and crankpin journals, the camshaft bearings and the valve push rods are lubricated by oil under pressure. The piston pins, pistons, cylinder walls, valve guides, valve tappets, and gears are splash- or spray-lubricated. The oil then drains back to the reservoir in the bottom of the crankcase to be recirculated by the pump.

h. Accessories. The accessory housing is made of aluminum alloy and is bolted on the rear of the main crankcase section. The accessories, such as the generator, magnetos, and tachometer drive, are bolted to the accessory section and driven by the crankshaft through a gear train.

46. VALVE AND IGNITION TIMING. a. Importance of proper timing. After a new engine is designed and the first model is completed, it is installed on a test stand and operated. During operation, various grades of fuels are used, the engine is operated at various speeds, and the valve and ignition timing is varied to achieve the best performance. An accurate record is kept of the brake horsepower developed throughout these tests. The design engineers, with these records at hand, decide on the best timing for the valves and ignition. It is important, therefore, that the mechanic time an engine exactly as specified in Technical Orders.

b. Timing methods. The opening and closing of the intake and exhaust valves at the proper time, and the proper timing of ignition are essential to the efficient performance of the four-stroke-cycle engine.

(1) *Valve timing.* The valves of an opposed engine are timed by meshing the marked tooth of the crankshaft gear between the two marked teeth on the camshaft gear. This can be performed only when the nose section has been removed.

(2) *Ignition timing.* To time the ignition, a timing disk is placed on the crankshaft so that the marks on the disk and on the crankshaft are in line. The timing disk is then fastened securely to the crankshaft—usually by means of a clamp nut. The crankshaft is rotated until the No. 1 piston is at the top-center of the compression stroke. The compression stroke may be identified by placing a thumb over the spark-plug hole while the crankshaft is rotated. The No. 1 piston will be at top center when the mark on the timing pointer is in line with the upper joint of the main crankcase section. The crankshaft is then turned backward 15° to 30° depending on the model which is being timed. The engine is now in firing position and ready for the installation of the magnetos. Rotate the magneto drive shaft until the marks on the gears which show through the inspection window are in line. Place the magneto on its mounting pad so that its drive gear meshes with the drive gear from the engine and tighten the mounting bolts finger tight. Place a 0.0015-inch thickness gauge between the breaker points and rotate the magneto back and forth until the point at which the breaker contacts are just separating is found. This point will be indicated by the release of the thickness gauge. Tighten the bolts to hold the magneto securely in place.

c. Timing specifications. The intake valve of one model of an opposed engine is timed to open at 10° before top-center, the exhaust valve opens at 50° before bottom-center, and the ignition spark occurs at 30° before top-center. On another model, the intake valve opens at 20° before top-center, the exhaust valve opens at 65° before bottom-center, and the ignition spark occurs at 15° before top-center. On another model, the intake valve opens at 20° before top-center, the exhaust valve opens at 65° before bottom-center, and the ignition spark occurs, at 15° before top-center.

47. VALVE-CLEARANCE ADJUSTMENT. On engines using hydraulic valve lifters, no valve-clearance adjustments are necessary between engine overhauls.

48. INSPECTION AND MAINTENANCE. Inspections are performed on an airplane to find and correct minor troubles before they become serious. The inspection should be performed in a systematic manner and the parts being inspected should be thoroughly cleaned. Careful inspection will prevent accidents.

a. Maintenance requirements. It is the duty of an airplane mechanic to keep the airplane in flying condition as much of the time as possible.

His job is to repair and maintain. By periodic inspection he can locate and correct minor failures. If some part cannot be repaired, or if more highly trained personnel is required to repair it, he should replace the unit.

b. Minor repair of subassemblies. Some of the repair work that an airplane mechanic must perform on opposed-type engines is listed below.

(1) Fouled spark plugs must be cleaned. When a spark-plug cleaning machine is available the spark plugs will be cleaned and re-gapped according to the directions specified in Technical Orders. If this unit is not available, replace the spark plugs. In many cases, if only oil fouling is present, clean the electrodes by dipping the lower part into gasoline and blowing it out with compressed air.

(2) Dirty magneto points must be cleaned as specified in the particular Technical Order of the engine.

(3) Faulty ignition connections must be repaired. Cleaning and resoldering of the brass clips is generally necessary.

(4) The fuel system must be cleaned of any accumulated water and foreign matter. Examine the screens, clean them with gasoline and blow them out with compressed air. Be careful not to damage the screen with the compressed air.

(5) The hydraulic valve-operating mechanism must be cleaned only after consulting the specific Technical Order for directions. After the cleaning operation is performed check the valve-tappet clearance.

(6) The oil-relief valve will be cleaned and adjusted when necessary.

(7) All backlash and free play must be removed from the engine controls.

(8) Broken air-cooled engine-cylinder head fins can be repaired if the damage is not excessive. Sharp edges will be removed by filing. In cases where excessive overheating is encountered, the cylinder may be replaced.

(9) Adjust the engine idling speed by adjusting the set screw in the throttle-operating control. Set the screw in order to obtain an engine speed as specified by the particular Technical Order.

(10) Generally, when a leak is present, it is permissible to replace the faulty gasket or seal without replacing the complete unit.

c. Replacements. Some of the replacements that may be made by an airplane mechanic follow:

(1) Faulty spark plugs that cannot be reconditioned by cleaning.

(2) Ignition wiring that has had the insulation burned or worn off.

(3) Cracked, kinked, or broken oil or fuel lines.

(4) Leaking manifold gaskets.

(5) Faulty accessories.

SECTION VII

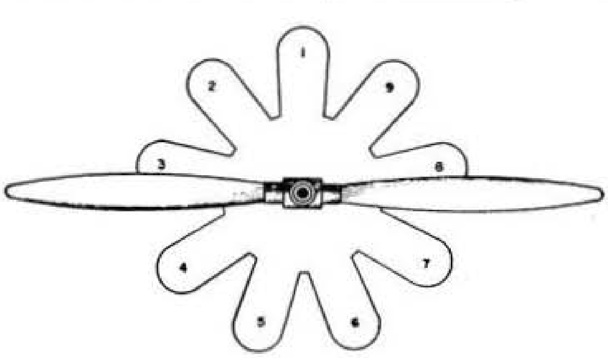
RADIAL AIRCRAFT ENGINES

49. GENERAL. The radial engine supplies power to a wide variety of airplanes, from light trainers to the heaviest bombers. This type of engine has passed rapidly through many stages of development to its present high-power output and low weight per horsepower. The unit is a precision product and will give excellent performance and continued high-power output during operation only when it is treated with the care it deserves. Special tools and fixtures are provided for use in maintenance, and maximum engine life will be secured only by following the procedures recommended in the Technical Order for the particular engine.

a. Cylinder arrangements. The cylinders on an engine of this type are arranged radially in one or more rows around the crankshaft. Engines with all the cylinders in one row are called single-row radial engines while those which have the cylinders arranged in two rows are known as twin-row or double-row radial engines. There is always an odd number of cylinders in each row of a radial engine, because it is impossible to secure even distribution of firing impulses when using an even number of cylinders in one row.

b. Firing order. The firing order of an engine is the sequence in which the power event occurs in the different cylinders.

(1) *Single-row radial engines.* On a single-row radial engine, all the odd-numbered cylinders fire in numerical succession while the even-numbered cylinders fire in numerical succession. For example, on a five-cylinder radial engine the firing order is 1–3–5–2–4, and on a seven-cylinder radial it is 1–3–5–7–2–4–6. The firing order of a nine-cylinder radial is 1–3–5–7–9–2–4–6–8, as shown in figure 76.

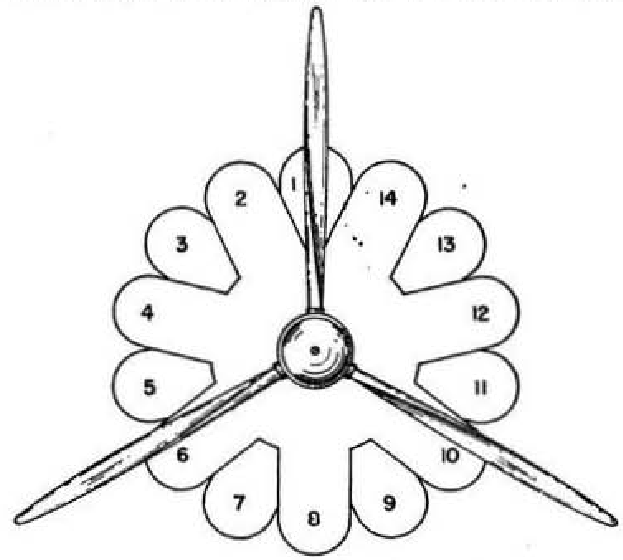


FIRING ORDER

1-3-5-7-9-2-4-6-8

Figure 76. Firing order — nine-cylinder radial engine.

(2) *Twin-row radial engine.* On a twin-row radial engine the firing order is more complicated. The firing order is arranged with the firing impulse occuring in a cylinder in one row and then in a cylinder in the other row; therefore, two cylinders in the same row never fire in succession. The cylinders in a twin-row radial engine are numbered consecutively so that all the cylinders in the rear row will have odd numbers and those in the front row will have even numbers. On a 14-cylinder radial engine the cylinders in the rear row are

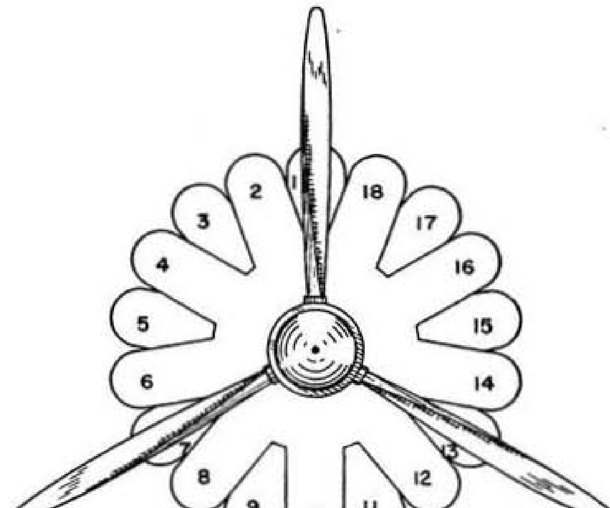


FIRING ORDER

1-10-5-14-9-4-13-8-3-12-7-2-11-6

①

Figure 77. Firing order of 14- and 18-cylinder radial engines.



FIRING ORDER

1 12 5 16 9 2 13 6 17 10 3 14 7 18 11 4 15 8

②

Figure 77.

numbered 1, 3, 5, 7, 9, 11 and 13 and the cylinders in the front row are 2, 4, 6, 8, 10, 12, and 14. The correct firing order for the rear row of cylinders, neglecting the front row, is 1–5–9–13–3–7–11. On the front row it is 10–14–4–8–12–2 and 6 because the two crankpins are 180° apart. Put them together and begin with 1 on the rear row. The firing order is found to be 1–10–5–14–9–4–13–8–3–12–7–2–11–6. (See fig. 77.) An easy method for figuring the firing order of a 14-cylinder radial engine is to start with any number from 1 to 14, and add 9 or subtract 5, whichever will give an answer between 1 and 14, inclusive. For example, starting with 8, 9 cannot be added since the answer would be more than 14; so subtract 5 from 8 to get 3, add 9 to 3 to get 12, subtract 5 from 12 to get 7, subtract 5 from 7 to get 2, and so on. The firing order of an 18-cylinder radial engine is 1, 12, 5, 16, 9, 2, 13, 6, 17, 10, 3, 14, 7, 18, 11, 4, 15, 8. (See fig. 77.) The two numbers used to compute the firing order of an 18-cylinder radial engine are 11 and 7. Begin with any number from 1 to 18 and add 11 or subtract 7. For example, beginning with 1, add 11 to get 12; 11 cannot be added because the total would be more than 18 so subtract 7 to get 5, add 11 to 5 to get 16, subtract 7 from 16 to get 9, subtract 7 from 9 to get 2, add 11 to 2 to get 13, and continue this process for 18 cylinders.

50. CONSTRUCTION CHARACTERISTICS. a. General. An aircraft engine may be composed of as many as 8,000 parts, but in the construction and designing of the powerplant some parts differ externally although they serve similar purposes. It will be well for the mechanic to familiarize himself with these differences.

b. Power section. The power section of a radial engine consists of the main crankcase section, the crankshaft, the master and articulated rods, the pistons and cylinders, the valves and valve-operating mechanisms, and the necessary bearings.

(1) *Crankcase.* The main crankcase section is made of aluminum- or magnesium-alloy or steel. On some models it is split along the center line to facilitate the removal of the master and articulated rods. The two halves will be held together by bolts between the cylinders. The cylinder-mounting pads are located on the outside surface of the main crankcase section and are provided with studs and nuts or cap screws to hold the cylinders. The engine-mounting lugs are usually located near the rear of the main crankcase section.

(2) *Cylinder assembly.* A cylinder assembly is composed of a steel barrel and an aluminum-alloy head. On some models the heads are screwed and shrunk on the barrels and on others the two parts are bolted together. All radial engines are air-cooled; therefore the cylinder heads and barrels have cooling fins on their outer surfaces. Since the aluminum alloy is soft and wears rapidly, the valve guides, valve seats, and spark-plug bushings are made of a more durable metal and are shrunk or screwed and shrunk into place. After installation, the valve guides are reamed to size and the valve seats are faced.

(3) *Crankshaft.* The crankshaft of a radial engine is made of forged-steel alloy and is ground and polished on all surfaces. Holes are drilled through the inside of the crankshaft to make it lighter and to provide passages for the lubricating oil. The crankshaft may be of one-, two-, or three-piece construction. One-piece crankshaft fit master-rod bearings that are of two-piece construction. Two-piece crankshafts fit master-rod bearings that are of one-piece construction. One or the other must be made in two pieces in order to fit them together. Crankshafts of single-row radial engines have one throw and those of twin-row types have two throws. The crankshafts of all engines are statically and dynamically balanced. On some engines the main bearings are inserts while on others ball or roller bearings are used. Two main bearings are used on single-row radial engines and three on the twin-row models.

(4) *Connecting rods.* Master and articulated connecting rods (fig. 27) are used in radial engines. The master rod is generally of the banjo-shaped type When a split-type crankshaft is used, a one-piece master rod is slipped into position and the crankshaft is bolted securely. On solid crankshafts, a two-piece master rod is used. The main section of the connecting rod is slipped into place and a bearing cap is bolted snugly in position. The articulated rods are fastened to the master rod by small, hard-steel pins called knuckle pins. They are similar in shape to piston pins and are usually held in place in the master rod by small plates which are fastened to the side of the master rod by screws. The knuckle- and piston-pin bearing surfaces in the rods are bronze bushings pressed in place and reamed to size.

(5) *Master rod bearing seal.* A bearing-end seal assembly is used to improve the crankpin-bearing lubrication by preventing excessive oil leakage from the end of the master rod. The assembly consists of a steel backed bearing which is shrunk into the bore of the master rod and secured by a dowel bolt. The end seal consists of a disklike, steel knuckle-pin lock plate and phosphor-bronze spacer. The tabs on the knuckle-pin lock plate are drilled to accommodate oil passages and the knuckle-pin lock-plate bolts. The phosphor-bronze spacer is shrunk on the opposite face of the master rod.

(6) *Piston assembly.* The pistons of a radial engine are made of forged aluminum alloy and are of conventional design. They have four to six rings, depending on the size and the compression ratio of the engine. The piston pins are of the full-floating type and are retained in the piston by circlets, cold springs, or aluminum plugs.

(7) *Valves.* Conventional poppet-type valves are used. On some models the valves have mushroom heads while tulip-head valves are used on others. On the high-power-output engines the exhaust-valve stems and heads are sodium-filled to aid in conducting heat from the valve head.

c. Nose section. The nose or front section of the crankcase is also made of aluminum or magnesium alloy. It houses the thrust bearing and the reduction gears, when used.

(1) *Reduction gears*. Planetary-type gear systems are used to reduce the propeller speed on radial engines. (See figs. 64 and 65.) The reduction in speed caused by planetary gears may be determined by finding the ratio between the combined number of teeth on the drive gear and the stationary gear, and the number of teeth on the drive gear. For example, on one model radial engine there are 90 teeth on the drive gear and 30 teeth on the stationary gear. 90 + 30 — 120. Therefore, the ratio of engine speed to propeller speed is 120 to 90. This can be reduced to 4 to 3. It is usually written 4:3. Other models of radial engines have speed ratios of 3:2 and still others 16:9. The two last-mentioned ratios are the most common.

(2) *Thrust bearings*. Ball-type thrust bearings are used in radial engines. The thrust bearing is located in the forward end of the nose section. It receives the forward thrust of the propeller and transmits it to the nose section of the crankcase.

d. Valve mechanism. (1) The valves of the smaller radial engines are operated by camshafts. One camshaft with two cams is used for the valves of each cylinder. These camshafts are driven at half crankshaft speed and are geared directly to the crankshaft.

(2) Larger engines use a cam plate or a cam ring (sometimes called a "cam drum") to operate the valves. The cam ring is the more common at the present time. However, the only difference between the two is the relative size of the hole in the center of the unit. (See fig. 45.) A cam ring has, as nearly as possible, one cam for each two cylinders. On a seven-cylinder radial engine the cam ring will have three or four cams, four if it rotates in the same direction as the crankshaft and three if it rotates in the opposite direction. On a nine-cylinder radial engine the cam ring will have four or five cams. The speed at which a cam ring rotates in relation to crankshaft speed is found by applying the formula: $\frac{1}{\text{number of cams x 2}}$. A cam ring with three cams rotates at $^1/_6$ crankshaft speed. One with four cams rotates at $\frac{1}{8}$ crankshaft speed and one with five cams rotates at $^1/_{10}$ crankshaft speed.

(3) Whether the valve-lifting force on a radial engine originates at a camshaft or a cam ring, it is transmitted to the valve stem through a cam tappet, pushrod and rocker arm.

e. Induction systems. The type of induction system used on a radial engine depends largely on the desired horsepower output of the engine.

(1) *Low-output engines*. On a small radial engine, air is drawn through the carburetor (where it is mixed with fuel) and then conducted to the cylinders through individual intake pipes. In some instances, a part of each of these pipes is cast as part of the rear crankcase. Individual pipes conduct the fuel-air from the outer edge of the rear crankcase to the individual cylinders. These pipes are connected to the crankcase by means of a slip joint to prevent damage from expansion and contraction caused by temperature changes.

(2) *High-output engines*. On a large radial engine, an internal blower or supercharger is built in the rear crankcase housing. On these models the fuel-air mixture passes from the carburetor through the blower or supercharger and then out individual intake pipes to the cylinders. (See par. 29.)

f. Exhaust system. Exhaust gases pass from the cylinders of a radial engine through short, individual pipes from each cylinder and into the collector ring. From there they pass through a large pipe and are discharged into the atmosphere. Some airplanes have turbosuperchargers installed on them. When it is desired to use the turbosupercharger on such an airplane, the exhaust gases are conducted from the collector ring through the supercharger turbine instead of directly to the atmosphere.

g. Cooling. All currently used radial engines are air-cooled. Therefore, the cylinders have fins on the outside to increase the surface from which heat can be dissipated. Baffles are installed to deflect the air through and around the fins to increase the rate of heat dissipation. Cowl flaps are located on the cowling behind the cylinders to control the amount of air flowing around the cylinders. By adjusting the position of the cowl flaps the operator controls the operating temperature of the engine.

h. Lubrication. In most high-power-output radial engines, the lubrication system is of the full-pressure, dry-sump type in which most moving parts are lubricated by oil under pressure. The cylinder walls, piston pins and, in some cases, the lower valve-operating mechanism are lubricated by oil spray. The oil for pressure lubrication is drawn from an external tank by an oil pump. The pump is of a conventional spur-gear type, driven (through a gear train) by the crankshaft. When the oil is drawn into the pump, it is carried around the spaces between the gear teeth and pump housing and is forced into a pressure chamber on the opposite side of the gears. The oil under pressure passes through an oil-inlet check valve, then through a filtering unit which may be a screen or Cuno. The check valve keeps the oil in the tank from seeping through the pump and into the engine while the pump is not operating. When the engine and pump are operating, the valve offers little resistance to the flow of oil.

(1) *Oil-pressure control*. All engines incorporate an oil-pressure relief valve which limits the pressure of the lubricating oil to a desired maximum. The two most commonly used types of oil-pressure relief valves are described in the following sub-paragraphs.

(*a*) *Single-pressure relief valve*. This type consists of a body containing a spring-loaded plunger which has a tapered valve on one end. (See fig. 78.) When the pressure becomes great enough to overcome the spring tension, the valve is pushed off its seat and the oil is by-passed into the oil-inlet passage of the oil-pressure pump. The spring tension may be varied by turning the adjusting screw. Turning this screw in a *clockwise* direction *increases* the spring tention. The locknut keeps the adjusting screw from loosening.

(*b*) *Compensating oil-pressure relief valve*. This

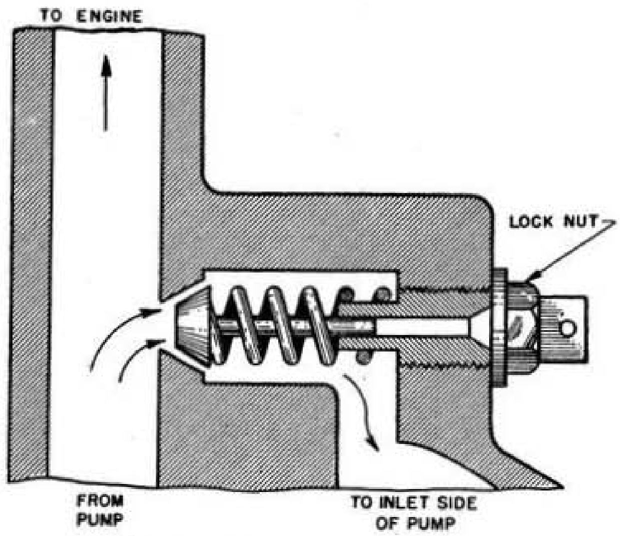


Figure 78. Single-pressure relief valve.

valve is used in conjunction with a thermostatic-control valve. (See fig. 79.) These units automatically regulate the pressure in the lubrication system. High-pressure oil from the strainer enters passage *A*. Most of this oil goes through passage *B* to the engine units. Some of the oil passes through a restriction (which reduces the pressure) and circulates over the thermostatic-control valve. From this unit, the low-pressure oil flows through a hollow shaft and lubricates other units. When the temperature of the oil is below 40° C., the thermostatic -control valve is closed and the oil in passage *C* is not under pressure. The pressure in passage *A* must therefore overcome the spring tension of *both* springs before the main relief valve can be moved off its seat to allow excess oil to return to the inlet side of the pump. The oil in passages *A* and *B* will therefore be under very high pressure. When the temperature of the oil reaches 40° C., the thermostatic-relief valve will open. Low-pressure oil will then pass through passage *C*, act on the compensating piston, and overcome the force of the outer spring. The pressure in passage *A* will then have to overcome the spring tension of only *one* spring; therefore the pressure will drop to its normal value.

1 The setting of the relief valve may be adjusted by removing the cap, loosening the locknut, and turning the adjusting screw. Turning the screw in a clockwise direction increases the kick-out pressure.

2 *Oil sumps.* In most models of radial engines, two sumps are incorporated. These are located in the lowest sections of the engine assembly and permit a thorough drainage of the oil. The usual design incorporates a small sump for the drainage of the rocker boxes. The larger sump is generally installed between the two lowest cylinders.

3 *Scavenger pumps.* Spur-gear scavenger pumps draw the drained oil from the sumps and force it through the oil-temperature regulator and thence to the top of the oil-supply tank from which it is recirculated in the system. In some cases, the scavenging pump and the oil-pressure pump are built into the same housing.

4 *Bearing lubrication.* The oil is delivered under the desired pressure from the pump into a series of drilled passages of the crankshaft to lubricate the main bearings, crankpin and the master-rod bearings.

5 *Knuckle-pin lubrication.* Each master-rod bearing is generally provided with other passages carrying oil into a distributing groove to lubricate the knuckle pins.

6 *Cylinder-wall and piston-pin lubrication.* As the crankshaft rotates, oil is thrown around in a fine spray which lubricates the cylinder walls. Additional oil spray is provided by a discharge from jets drilled in the crankshaft.

7 *Reduction-gear lubrication.* Oil is supplied to the hollow propeller shaft. Some of the oil flows to the reduction-gearing shafts and bearings. The teeth of the reduction gears are splash lubricated by the oil which seeps through bushings and bearings. Some engines provide jets to supply additional reduction-gear lubrication.

8 *Internal-supercharger lubrication.* Oil under pressure to operate the gear ratio selector unit and to lubricate the bearings and bushings of the supercharger generally flows through a direct passage from the oil-filter unit.

9 *Accessory-unit lubrication.* Oil is conducted to the accessory housing through a large internal passage. It is then supplied to each unit through smaller drilled passages.

10 *Valve-mechanism lubrication.* Transfer pipes attached at the blower section carry oil under pressure to a series of internal passages. Oil flowing through these passages lubricates the tappet guide and the valve-operating mechanism. Some of this oil flows through hollow tappets, into the tubular push rods and then to the valve rocker arms. In some radial-type engines, this system is provided only for the valve mechanisms above the horizontal centerline. The valve mechanisms of the lower half are lubricated by gravity feed only.

11 *Internal oil drains.* After performing the necessary lubrication, the oil follows a series of drilled passages and grooves to the oil sump.

i. Accessories. The accessories of a radial engine are usually located in the rear. They are operated through a gear train driven by the crank-

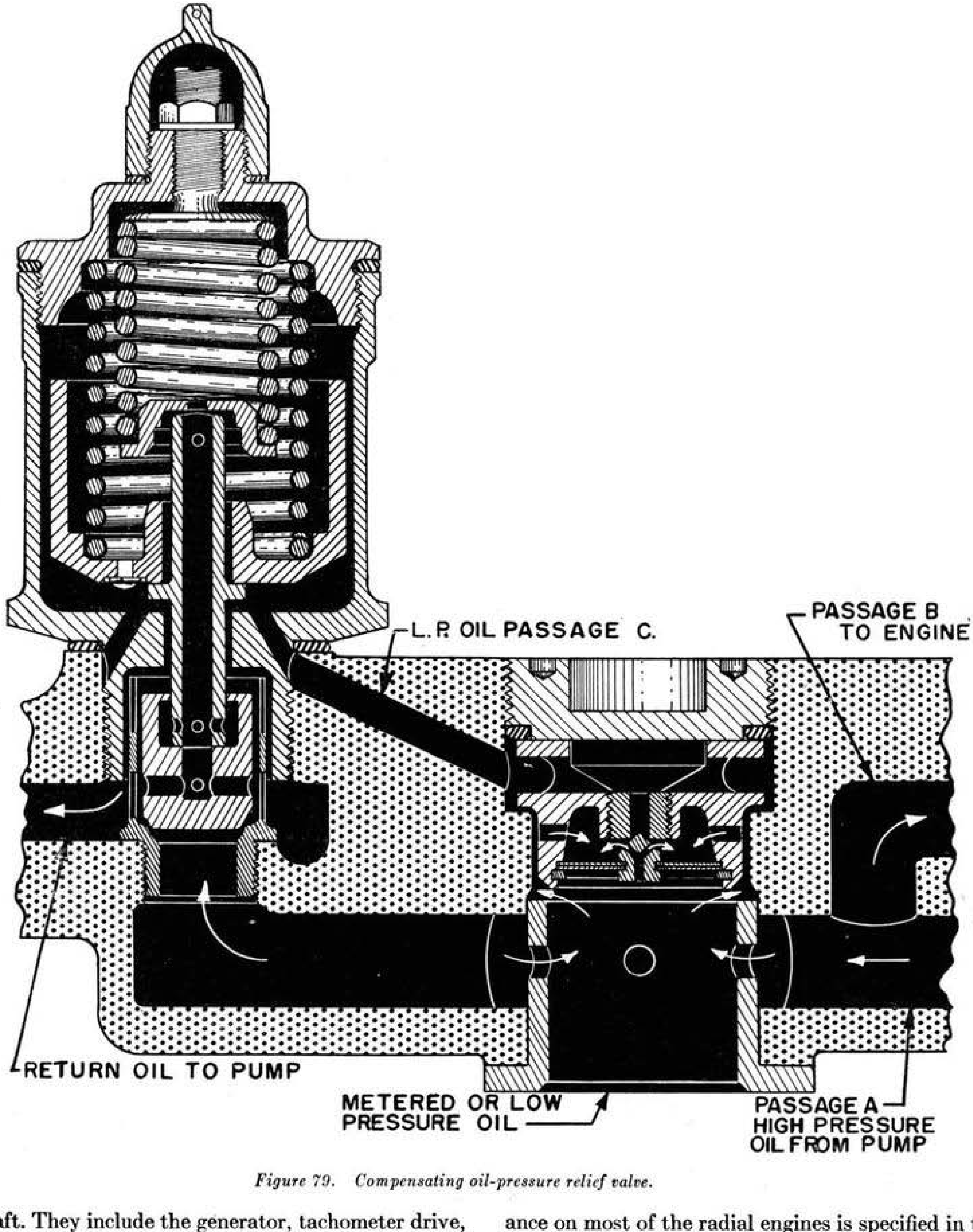


Figure 79. Compensating oil-pressure relief valve.

shaft. They include the generator, tachometer drive, and the fuel, vacuum and pressure pumps.

51. VALVE CLEARANCE. Every engine must have some clearance in the valve-operating mechanism. If there were no clearance, a valve might be held off its seat when it was supposed to be closed. This would result in erratic operation of the engine and eventual destruction of the valve. The valve clearance on most of the radial engines is specified in the Technical Order pertaining to the particular engine model. These clearances are the cold clearances and are adjusted while the engine is at atmospheric temperature.

a. Checking valve clearance. The procedure for checking the clearance of the valves of a radial engine is as follows:

Step 1. Remove the rocker-box covers.

Step 2. Rotate the propeller until the piston of the selected cylinder is approximately at TDC on the compression stroke.

Step 3. Insert the correct thickness gauge in the opening between the valve stem and the end of the adjusting screw. The gauge should just slip into the opening and the next larger gauge should not.

Step 4. Repeat steps 2 and 3 for the other cylinders.

Step 5. Replace rocker-box covers.

b. Adjusting valve clearance. If the valve clearance is checked and found to be incorrect, proceed as follows:

Step 1. Loosen the lock-nut on the adjusting screw.

Step 2. Turn the adjusting screw until the correct clearance gauge will just enter the opening between the valve stem and the end of the adjusting screw. (See fig. 80.) Turning the screw clockwise decreases the clearance.

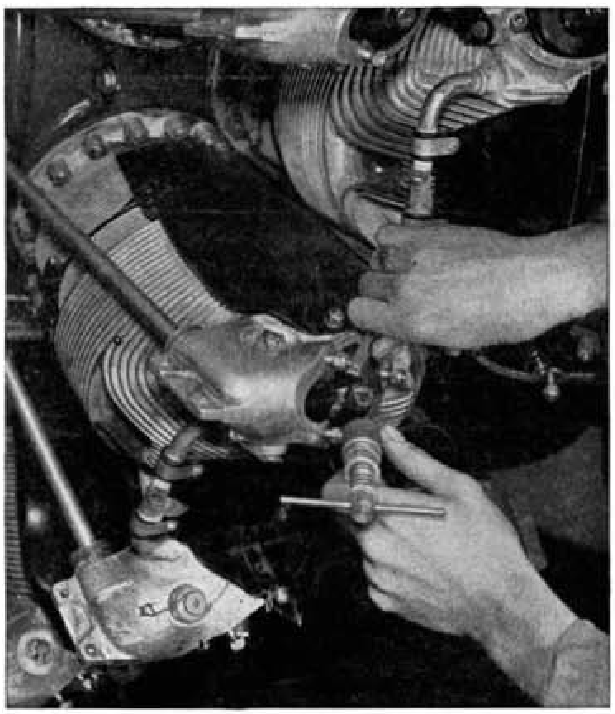


Figure 80. Adjusting valve clearance.

Step 3. Hold the adjusting screw to keep it from turning and tighten the lock-nut.

Step 4. Recheck the clearance.

52. VALVE AND IGNITION TIMING. After a new engine is designed and the first model is produced, it is installed on a test stand and operated. Various grades of fuels are used, the engine is operated at different speeds, and the valve and ignition timing are varied to obtain the best results. An accurate record of the horsepower developed by the engine during this test operation is kept. After the test is completed, the design engineers decide on the exact timing to be used on the engine. It is important, therefore, that the engine be timed exactly as specified in Technical Orders.

a. Checking valve timing. Place the piston of No. 1 cylinder at top-dead-center position of the compression stroke. The valve clearance is then checked and, if necessary, adjusted. (See par. 51.) Install the timing disk and pointer on the engine. Remove the inspection plug in the nose-section housing. To check the opening of the inlet valve, rotate the propeller until the correct mark on the intake-valve-opening (IO) scale on the reduction gear is in line with the two index marks on the sides of the inspection hole. (See fig. 81.) In this example, the intake valve of the No. 1 cylinder should open 27° before

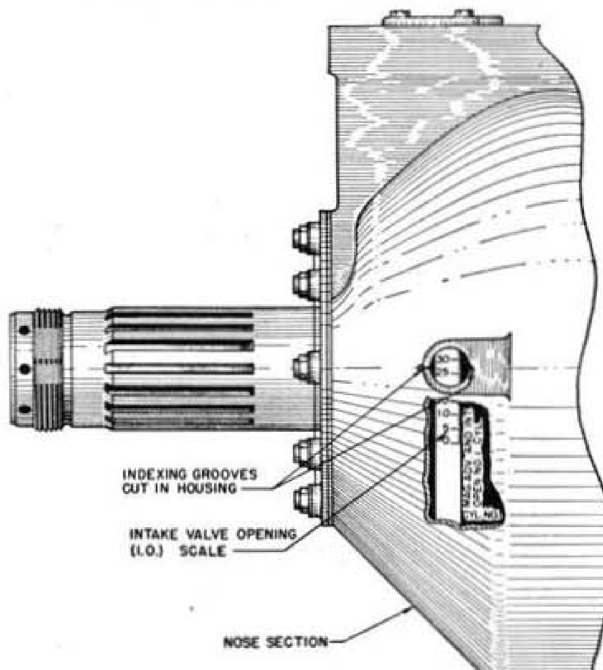


Figure 81. Inspection hole — located in the nose section.

top-dead-center. Check the reading on the timing disk. If the pointer indicates 27° BTC, the valves are correctly timed. At this point the inlet valve should begin to open. As a further check, the crankshaft is turned in the opposite direction until the correct mark of the exhaust-valve closing (EC) scale on the reduction gear is aligned with the marks on the sides of the inspection hole. The timing pointer should indicate the correct number of degrees and the exhaust valve should be closed.

b. Ignition timing. To time the magneto on a radial engine, a pointer is installed on the propeller shaft and a timing segment is fastened to the crankcase. The crankshaft is then rotated until the No. 1 piston is at the top-center of the compression stroke, the pointer is set at zero and fastened so that it will turn with the propeller shaft. The propeller shaft is then rotated in the direction of normal rotation until the pointer indicates the proper number of degrees before TDC. The magneto drive is aligned as described in paragraph 29b. The magneto may now be attached to the mounting pad on the engine.

(1) It is highly improbable that the magneto could be accurately timed within the required limits when placed on the engine if no adjustment were provided. Either of two methods may be provided so the magneto can be adjusted without altering the position of either the magneto drive or the engine crankshaft. One method is to cut slots in the magneto mounting flange, thus permitting some rotation of the magneto housing. With the magneto in the proper position, the mounting nuts are tightened to secure the magneto. The other method is to use a hard-rubber plate which has gear-shaped teeth molded on each side. The teeth of one side fit the magneto drive and the teeth on the other side fit the gear driven by the shaft from the engine. Since there is one more tooth on one side of this coupling than on the other, vernier adjustments can be made which permit accurate timing.

(2) *Checking ignition timing.* To check the ingition timing after the magneto has been secured to the mounting pad, insert a 0.0015-inch thickness gauge between the breaker points and rotate the crankshaft slowly in the operating direction of rotation while maintaining a slight pull on the thickness gauge. When the thickness gauge slips out, the breaker points have just opened and, if the magnetos are correctly timed, the pointer should be in line with the proper mark on the timing segment.

c. Timing specifications. Since there are many different models of radial engines in use at the present time, the timing specifications will vary, but will be approximately as follows. The intake valve opens about 20° before top center, the exhaust valve opens about 75° before bottom-center, and the spark occurs about 25° before top-center.

53. INSPECTION AND MAINTENANCE. a. Inspection procedure. Inspections are performed on an airplane to find and correct minor defects before they become serious. The inspection must be performed in a systematic manner and the parts being inspected should be thoroughly cleaned to enable the mechanic to find small defects.

b. Maintenance requirements. It is the mechanic's duty to keep the airplane in flying condition. In order to do this he must be able to recognize troubles, determine their cause, and remedy them. If a defective part can be repaired and the mechanic is qualified, he should repair it. If he cannot repair the unit, he should replace it and turn in the defective unit to be repaired by more highly trained personnel.

c. Minor repair. An airplane mechanic will repair any defective part that he can if he is qualified and has the necessary tools. Some examples of repair work that may be done by an airplane mechanic on a radial engine follow.

(1) Remove dirty oil screens and filters and clean them by washing in kerosene. After cleaning carefully direct compressed air through the units. Apply a film of oil over the filter element and reinstall it in the engine.

(2) Check and adjust the valve clearance. (See par. 51.)

(3) Check and adjust the ignition timing. (See par. 52.) Always make certain that the clearances, tolerances, and directions listed in the Technical Orders for the particular engine are observed.

(4) Anchor loose tubing properly. Inspect all lines for leaks and repair or replace the line or fitting when necessary. In cases where the lines have vibrated loose inspect them for wear, dents, and cracks. Replace the lines if their condition may cause future trouble.

(5) Repair faulty ignition cable. Check the condition of the spark-plug cable ferrules. When a replacement is necessary, remove about a half inch of insulation from the end of the cable. There are two methods of attaching the ferrule to the wire. One is to separate the strands evenly, bend them back over the insulation so that a copper ferrule can be forced over the end of the cable, and then swage the ferrule in place. The second method is to place the strands of bare wire through a hole in the ferrule, bend them evenly over the ferrule and then solder them in place.

(6) Remove excessive back lash and play from the engine controls.

(7) Round off the sharp edges of slightly chipped cylinder-cooling fins with a fine file.

(8) Remove and replace the spark plugs when necessary. In emergencies, when complete spark-plug servicing equipment is not available, regapping of ceramic-type spark plugs will be sufficient. Regapping more often than the regular specified period may be necessary under conditions of prolonged high-altitude flying.

(9) Check the induction system for fuel leaks, air leaks, and blown gaskets. Either of these conditions may be indicated by slight discoloration (due to the dye in the fuel) on the adjacent parts.

d. Replacements. Defective and damaged parts that cannot be repaired by the airplane mechanic must be replaced. Some of the replacements that are made by an airplane mechanic follow.

(1) Replace faulty spark plugs with new or reconditioned spark plugs of approved types.

(2) *Leaking gaskets.* Be sure that all surfaces with which the gasket comes in contact are clean.

(3) *Damaged pushrods and control-system units.* After the work has been performed, check and make sure that all controls have full and easy action.

(4) *Damaged cylinders and pistons.* In cases of emergency this work is done. During general line service the engine would be replaced.

(5) *Broken valve springs.* After replacement of the springs, be certain that the retaining washers are in place.

(6) *Broken or damaged studs.* Be certain that the stud is exactly as specified in the Technical Order.

(7) If engine trouble is definitely located in the

magneto, remove and replace the unit with one known to operate satisfactorily.

(8) Remove and replace damaged intake pipes. Install a new synthetic-rubber packing ring with every replacement.

(9) When the trouble is traced to the carburetor, remove and replace the complete assembly. A new gasket must be used on the carburetor-mounting flange when the new or reconditioned unit is installed.

(10) Remove and replace damaged priming lines.

(11) Replace the thermocouple if found damaged or defective. The unit is generally installed on the hottest-running cylinder, usually in the cylinder assembly containing the master connecting rod.

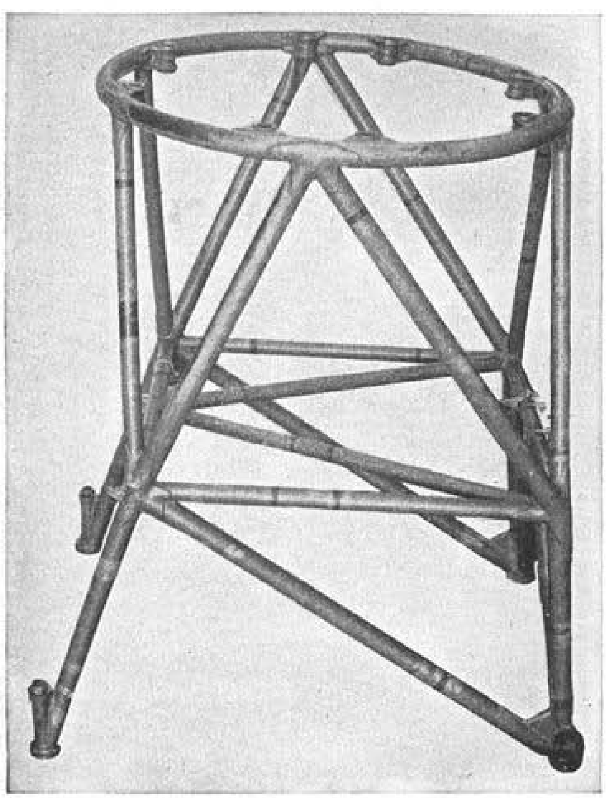
SECTION VIII

ENGINE MOUNTS

54. GENERAL. Modern airplanes require high-power-output engines and are commonly used with large-diameter propellers and low reduction gear ratios. The high-power output of these engines causes very high twisting (torque) loads on the mounting. These are often greater than those produced by other causes. Torque loads must be distributed properly because they have an important effect on the performance of the powerplant.

a. Purpose. An engine mount is used for two purposes. It supports the engine on the airplane and absorbs much of the engine vibration to prevent it from being transmitted to the airplane. The method of mounting the powerplant is governed by the type and size of the engine.

b. Design. Practically all engine mounts are constructed of welded tubular steel. After fabrication, the mount is normalized to remove strains by heating it to the proper temperature and allowing it to cool slowly. The mount is designed so that all working stresses will be direct linear push or pull on the structural members. The actual design depends upon the type of engine. Typical mounts for radial- and **V**-type engines are shown in figure 82.



① *Radial-engine mount.*

Figure 82.

55. ENGINE-MOUNT BUSHINGS. Until a few years ago engines were bolted directly to the engine mount with little or no cushioning material between the engine and the mount. Therefore, engine vibration was transmitted to the airplane. This resulted in structural failure of airplane parts and in the physical fatigue of the flying personnel. The powerful engines now used require some device to absorb engine vibrations and prevent their transmission to the structure of the airplane.

a. Vibration-absorbing type. This type mounting has rubber bushings or pads between the engine-mounting pad and the engine mount. Figure 83 shows a cross section of a mount bushing of this type. It is effective in absorbing much of the engine vibration and preventing it from being transmitted to the airplane. However, it is not completely satisfactory for radial engines since it does not absorb the yaw and pitch vibrations of the engine during operation and it does not eliminate engine droop when the engine is stopped.

b. Dynamic-suspension type. In order to absorb engine torsional vibration and to permit limited yaw and pitch vibrations of radial engines, the dynamic-suspension mount bushing has been devised. A bushing of this type installed on an engine mount is shown in figure 84. There are several different types of these bushings but all of them perform the same service. They effectively absorb engine torsional vibration caused by the rotating propeller, hold engine yaw and pitch to a desired minimum, and, at the same time, prevent droop.

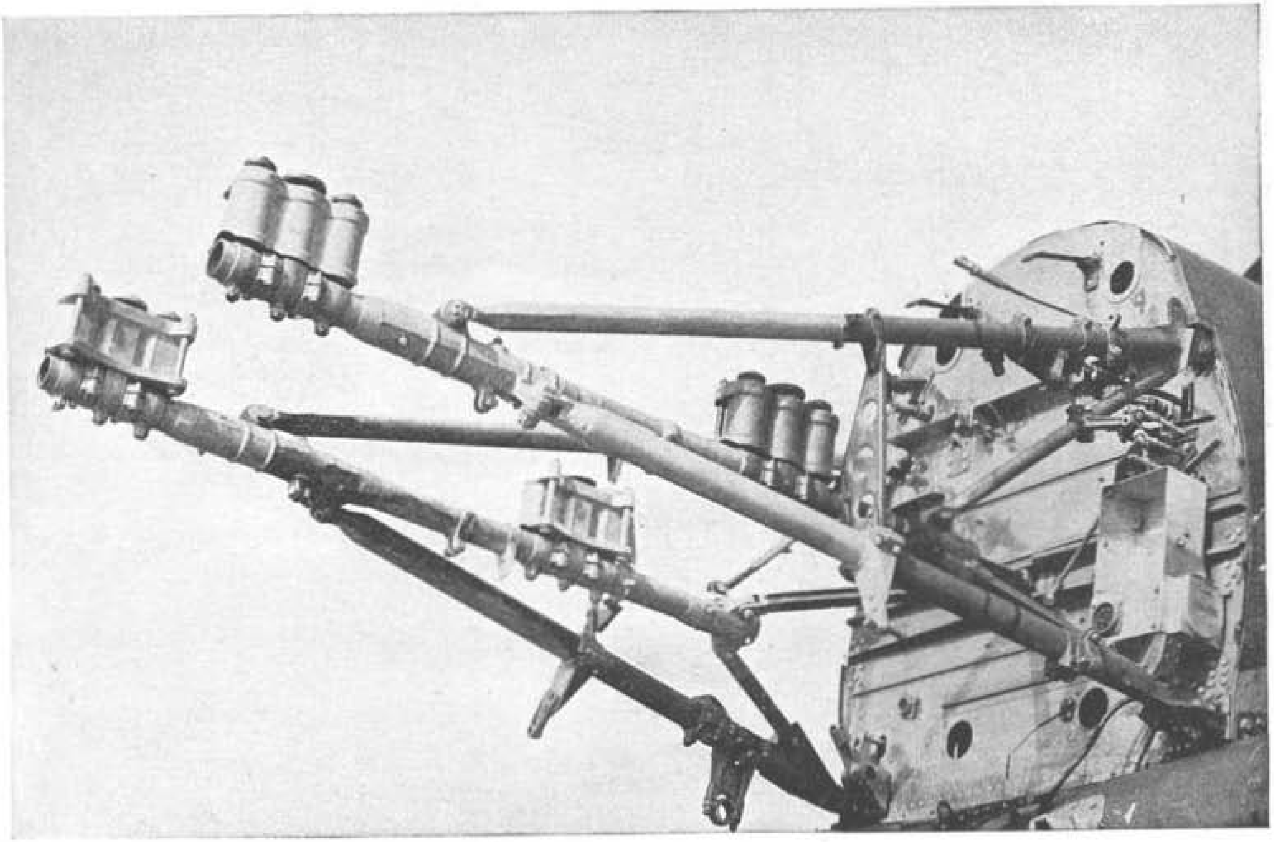
56. INSPECTION AND MAINTENANCE. a. Inspection. Engine mounts are inspected periodically for cracks, distortions, misalignment and condition of the protective coating. The condition of the engine-mount bushings is checked at specified time intervals. The mount should be thoroughly cleaned during inspection to enable the mechanic to find small cracks that may be present in the welded joints.

b. Maintenance. (1) When cracks are discovered the airplane must not be flown until replacement or repair is made. The smallest crack will form a focal point for vibration and rapidly increase in size. At repair stations, the mount is normalized to remove strains developed during welding.

(2) A bent truss member generally requires a replacement of the whole engine mount. The mechanic should never use a part of the engine mount for a support since there is danger of bending the truss members. The mount is designed to support the engine in the proper position but relatively light loads in the wrong position will bend parts of it.

(3) If chipped or deteriorated, the protective coating of the engine mount must be renewed to prevent further corrosion and weakening of the mount.

(4) Engine-mount bushings that show signs of deterioration must be replaced.



② V-type engine mount.
Figure 82.—Continued.

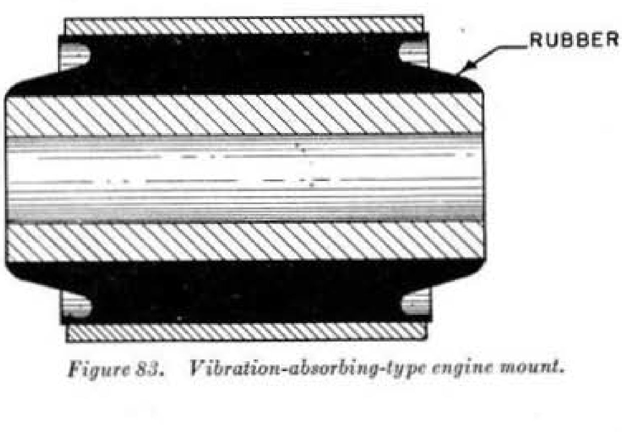


Figure 83. Vibration-absorbing-type engine mount.

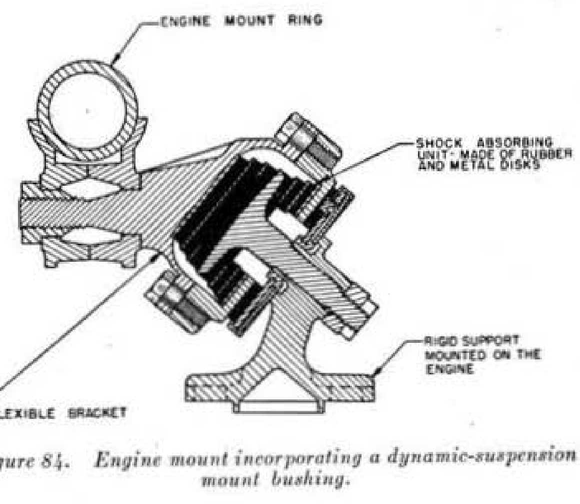


Figure 84. Engine mount incorporating a dynamic-suspension mount bushing.

SECTION IX

STORAGE AND SHIPMENT

57. GENERAL. It is necessary that the specific procedure outlined in Technical Orders be followed in treating any engine which is placed in storage. It is the responsibility of the maintenance division of each Air Technical Service Command activity to prepare aircraft engines for storage when necessary.

a. Susceptibility to corrosion. The parts of an airplane engine are manufactured to very close tolerances and are subjected to severe strains during operation. Even slight corrosion may damage some parts so that they will not function properly or may even cause them to fail completely during subsequent operation. Precautions must, therefore, be taken to prevent corrosion of the parts of an engine that is idle for even a short time.

b. Ethyl fluid. Modern high-output airplane engines require fuel that has an antiknock rating of 100-octane or above. Since it is impossible to produce pure octane in sufficient quantities to supply the demand, mixtures of similar fuels are used and tetra-ethyl lead is added to them to increase the octane rating. The tetra-ethyl lead produces corrosive substances when the fuel is burned in the cylinders. Ordinarily, the corrosive substances cause no serious damage. However, they will cause damage if preventive measures are not taken when the engine is allowed to remain idle.

c. Treatment of the engine. Airplane engines that are to remain idle for more than 1 day must be treated to prevent corrosion. The type of treatment required depends upon the length of time the engine is to remain idle. The specific treatments used vary for different types of engines. Therefore, the proper Technical Order should be consulted prior to the treatment of a particular engine.

58. FLYABLE AIRCRAFT STORAGE.

a. Length of time. All aircraft that will not be flown for an indefinite period are prepared for this type of storage. All aircraft in this type of storage must be maintained in a flyable status and require no preparation for flying service.

b. Treatment. Aircraft maintained under flyable aircraft storage are divided into two classes—those whose oil systems contain a mixture of corrosion-preventive compound and regular engine oil and those with no corrosion-preventive compound in the oil system.

(1) *Corrosion-preventive compound and engine-oil mixture.* The oil system is serviced with a mixture consisting of three parts of engine oil and one part of corrosion-preventive compound, as specified in Technical Orders, and a notation to this effect is made on Form 41B under the title "Remarks". The engine or engines will be given a ground run-up prior to placing the airplane in storage. On each *sixth day* the engines will be given a ground run-up. The ground run-up will consist of approximately a 15-minute operation at idling speeds (not to exceed 50 percent power) or until the oil-in temperature reaches normal operating temperature for the specific engine. Excessive ground operation and operation in sandy or dusty areas should be avoided. After 50 hours of engine-operating time the mixture will be drained and replaced with pure engine oil.

(2) *Engine oil.* In airplanes whose engines are not serviced with corrosion-preventive compound but contain only the regular engine oil, the engine or engines will be ground run-up (as described in paragraph 57) each *second day*.

59. TEMPORARY STORAGE.

a. Length of time. Temporary storage is used for engines that are to be idle for not more than 30 days.

b. Treatment. The following procedure will be followed when aircraft are placed in the temporary-storage status:

(1) *Oil system.* The engine-oil system will be serviced and given a ground run-up as described in paragraph 58b(1). Oil dilution will not be used during this preparation for storage. If the oil system has been previously serviced and the last engine operation has been with this mixture in the lubrication system, the ground run-up procedure will be eliminated. The mixture will remain in the lubrication system and oil sump.

(2) *Exhaust valves.* The exhaust valves are sprayed with a corrosion-preventive mixture. The spraying will be accomplished through the exhaust ports with the valves in the open position. On installations where the collector ring is not removed, the valves are sprayed through the spark-plug opening.

(3) *Cylinder walls.* The corrosion-preventive mixture is sprayed into each cylinder bore with the piston at bottom-dead-center so as to cover all interior surfaces. After all cylinders have been sprayed, respray each cylinder bore through the spark-plug opening making certain that the crankshaft is not rotated. If the crankshaft is rotated, respray all cylinder bores. Install cylinder dehydrator plugs into the spark-plug holes. (See fig. 85.) Consult Technical Orders for specific types of dehydrator plug for the engine.

(4) *Exhaust ports and carburetor intake.* The correct-size bag of silica gel is placed in each exhaust port and in the carburetor intake. The exhaust ports and the carburetor-intake opening are then covered with a moisture-resisting film and taped securely. All manifold joints must be sealed by placing tape over each joint.

(5) *Coolant systems.* In liquid-cooled engines the coolant system will be drained and the system will be refilled with clean water. The engine will then be operated until the water has thoroughly circulated through the system. The water is then drained. If

compressed air is available it will be introduced through the filler opening (drain plug removed) to dry out the system as much as possible. If the airplane is stored without removing the engine, the entire coolant system will be filled with the oil specified in Technical Orders. Red tape must be

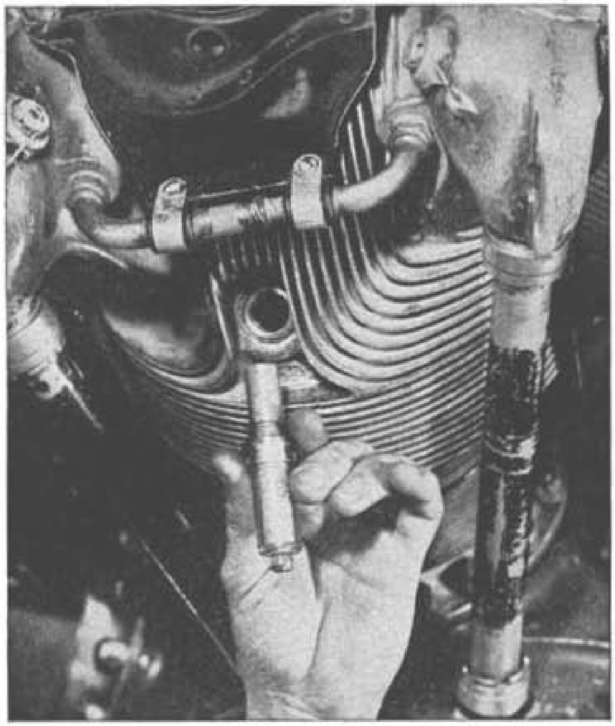


Figure 85. Installing dehydrating plug in the engine cylinder.

attached to the throttle-control lever of the airplane so treated. This is a reminder to maintenance and operating personnel that the engine is not to be operated until the oil is removed and cleaned from the system. The system is cleaned by removing the drain plug and introducing steam into the filler opening.

(6) *Vents and breathers.* All distributor vents, engine and supercharger breathers, and all other openings will be sealed with tape as specified in Technical Orders.

c. Inspection. All engine dehydrator plugs will be inspected weekly and replaced when their color indicates an unsafe condition for storage. If more than one-half of the dehydrator plugs are replaced, the dehydrator bags in the air-intake and exhaust manifolds must be replaced. Replacement of the dehydrator plugs or bags should not be made on highly humid or rainy days.

d. Preparation for service. When aircraft are removed from the temporary-storage status, they will be prepared for service as follows:

(1) *Engine openings.* Remove all dehydrator plugs, silica gel bags, cover plates, nipples, tape, and other means used to plug various openings.

(2) *Cylinders and spark plugs.* First remove any excessive corrosion-preventive mixture by draining or by using a hand suction pump. Rotate the propeller shaft by means of a propeller-shaft wrench to check for sticking valves. Lubricate the sticking valves with a gasoline and engine-oil mixture. If the valves continue to stick, perform the necessary maintenance to eliminate this condition. Install the proper spark plugs.

(3) *Preoiling.* Preoil the engine as directed in the specific Technical Order.

(4) *Engine starting.* Before starting the engine, rotate the crankshaft by hand four or five revolutions, as a final check, to determine that liquid lock has been eliminated.

60. EXTENDED STORAGE.

a. Length of time. Extended storage is used for engines that are to be idle for more than 30 days.

b. Treatment. The treatment of the aircraft treated in extended storage follows:

(1) *Oil system.* The engine oil system will be serviced and given a ground run-up as described in paragraph 59b(1).

(2) *Coolant system.* The coolant system of liquid-cooled engines will be serviced according to paragraph 59b(5).

(3) *Oil coolers.* Oil cooler must be blanked off or by-passed to produce the mixture *outlet* temperature specified in Technical Orders.

(4) *Oil sump.* Drain the mixture from the engine-oil sump while the sump is still warm. Do not drain the mixture from the oil tank. Replace the sump plug with properly specified dehydrator plug. (See fig. 86.)

(5) *Carburetor.* Drain the fuel from the carburetor. Reinstall the drain plugs and remove the pipe plugs from the top of the regulator. Pour the specified oil into the opening until the oil runs out of the front chamber or from the discharge nozzle. Reinstall the plugs and safety them. Carburetor openings will be sealed with suitable pipe plugs and the throttle valves will be locked in the open position. A bag of silica gel is placed in the carburetor intake and the opening is then sealed with a moisture-resisting film and taped securely.

(6) *Fuel pumps.* Fuel must be drained from all fuel pumps and the specified lubricating oil injected into the pumps while the propeller shaft is being rotated. The lines of the fuel system will be disconnected and the lines will be sealed with suitable plugs or tape.

(7) *Exhaust ports and manifolds.* With the exhaust valves open each exhaust port is sprayed with corrosion-preventive mixture. A bag of silica gel will be placed in the exhaust outlets. The openings are then covered with moisture-resisting film and taped securely.

(8) *Cylinder walls.* Treat as specified in paragraph 59b(3).

(9) *Vents, openings, and breathers.* Seal all openings, vents, and breathers with the properly specified tape.

(10) *Propeller shaft.* Spray the interior of the propeller shaft. The exterior of the shaft must be covered with the compound as specified in Technical Orders. Install a propeller-shaft thread protector.

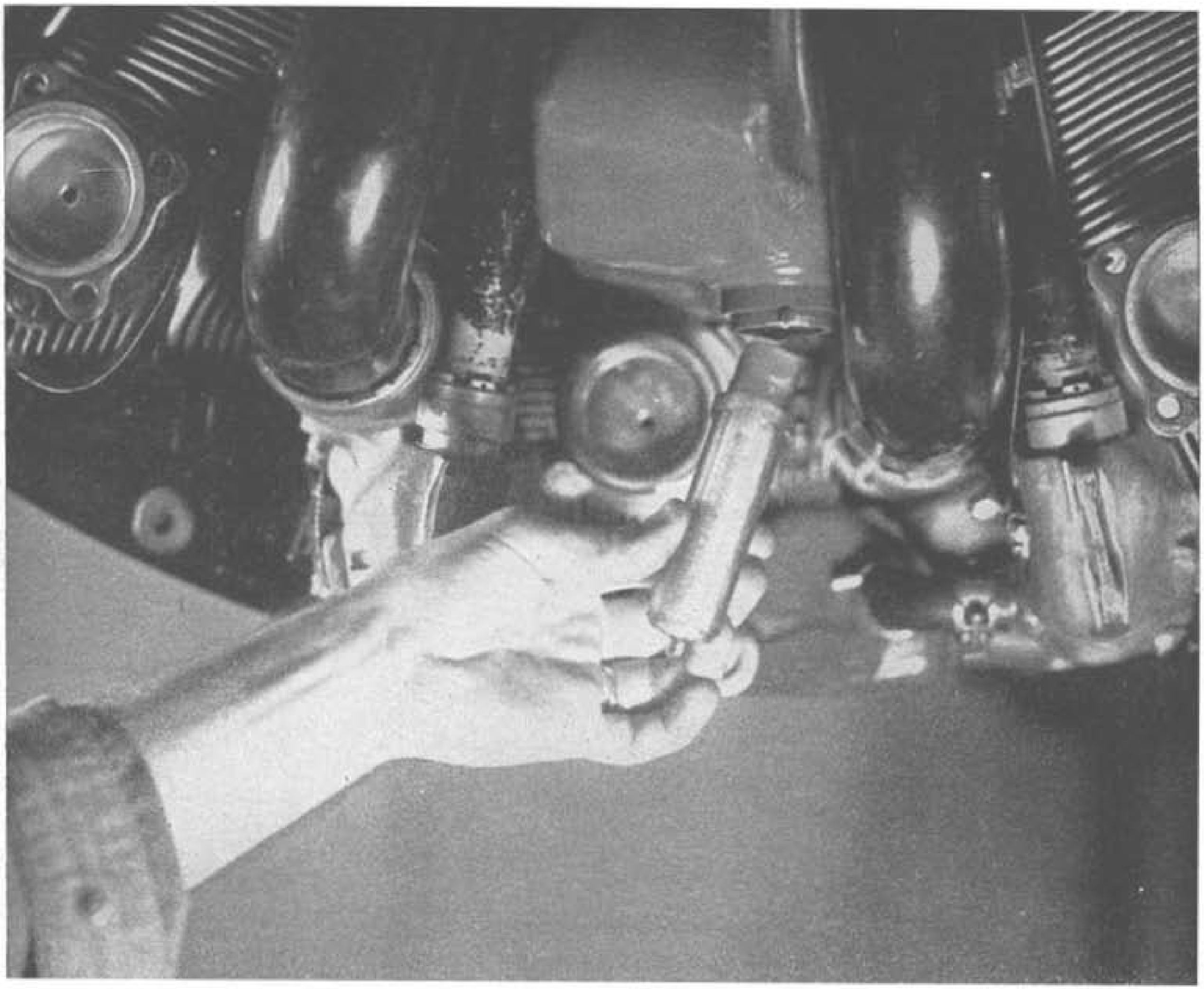


Figure 86. Installing dehydrating plug in the oil sump.

These instructions are followed only when the propeller is stored separately.

(11) *Magnetos.* All openings in the magneto will be sealed with tape.

(12) *Entire engine.* Install covers on all openings in the engine and fasten them securely.

c. Inspection. Inspect according to paragraph 59c.

d. Preparation for service.

(1) *Engine openings.* Remove all dehydrator plugs, silica-gel bags, plates, tape, nipples, plugs, and other such items which have been used to seal the openings.

(2) *Oil and fuel lines.* Properly install all oil and fuel lines.

(3) *Engine cylinders.* Follow instructions listed in paragraph 59d(2).

(4) *Propeller and propeller shaft.* Clean the propeller shaft and the propeller. Mount the propeller on the propeller shaft.

(5) *Cuno oil filter.* The Cuno oil filter will be removed and cleaned by washing it in a solvent such as kerosene, gasoline or a half-and-half mixture of carbon tetrachloride and benzol. Rotate the filter while it is immersed in the cleaning solvent to make certain that all foreign material is removed. Do not use any hard tool to scrape or pick the material from the cartridge. An air jet must not be used in cleaning the cartridge. After washing, immediately lubricate the cartridge by immersing it into clean engine oil.

(6) *Screens.* All oil screens shall be removed, cleaned in gasoline, dried, reoiled and reinstalled.

(7) *Preoiling.* Prior to ground testing the engine preoil the engine as directed in the specific Technical Order.

(8) *Spark plugs.* Before installing the spark plugs rotate the propeller four or five times to make certain that liquid lock (due to excessive corrosion-preventive mixture in the cylinders) has been eliminated. Install the spark plugs and tighten them to the correct torque.

61. STORAGE TREATMENT OF REPARABLE ENGINES. The preparation of reparable engines includes those that can be operated without further damage and those which cannot be operated.

a. Operable engines. An engine in this class can be operated without damage to the engine itself or any of its parts. The procedure for storage treatment of operable engines is specifically outlined in Technical Orders.

(1) *Oil system.* Treat as specified in paragraph 58b(1).

(2) *Coolant system.* Drain the coolant out of liquid-cooled engines.

(3) *Rocker boxes.* Remove the rocker-box covers and clean and spray each rocker box with corrosion-preventive mixture. Replace the covers and gaskets to form an airtight seal.

(4) *Exhaust ports and manifolds.* With the exhaust valve open spray the exhaust valves and exhaust ports. Seal the openings with the properly specified plates and tape.

(5) *Accessory drive.* Remove the accessory-drive cover plates, spray the drives, and reinstall the cover plates securely.

(6) *Propeller.* The propeller will be removed. The thrust-bearing propeller plates, if provided, will be removed and the thrust bearing will be thoroughly sprayed. The cover plate must be reinstalled.

(7) *Carburetor.* Treat as specified in paragraph 60b(5).

(8) *Oil inlet, outlet, and breathers.* The oil inlet and outlet will be sealed with locally manufactured oil-resistant or moisture-resistant blank caps or tape.

(9) *Crankcase.* Remove the oil-sump plug and replace it with the properly specified dehydrator plug. Attach the sump plug to the sump with safety wire.

(10) *Magnetos.* Seal all external openings with the properly specified tape. Coat the cam breaker mechanism with oil, as specified in Technical Orders.

(11) *Propeller shaft.* Treat as specified in paragraph 60b(10).

(12) *Cylinder bores.* Treat as specified in paragraph 59b(3).

(13) *Other engine openings.* Seal all openings with tape or other suitable moisture-resistant seals as specified in Technical Orders.

(14) *Packing procedure.* Silica gel and the engine envelope will be applied as described in the particular Technical Order.

b. Engines that cannot be operated. Engines which cannot have their crankshafts rotated will be treated as near to the procedure listed in a above as practicable. Utmost care must be applied to make certain that all interior surfaces are sprayed or covered with corrosion-preventive mixture. These engines will not have the run-out protection of the engines that can be operated.

62. PREPARING SERVICEABLE ENGINES FOR SERVICE. Serviceable engines to be installed in aircraft will be prepared for service according to the detailed procedure listed in Technical Orders. A brief outline of the procedure follows:

a. Engine envelope. Carefully open the engine envelope without unnecessary tearing and fold the envelope down over the sides of the engine. Remove the engine from the mounting plate. After removing the engine, the envelope will be carefully cleaned and folded for reuse.

b. Silica-gel bags, seals, and dehydrator plugs. Remove all silica-gel bags, all seals and inclosures, and all dehydrator plugs.

c. Cuno oil strainer. See paragraph 60d(5).

d. Supercharger fuel-drain valve. If the unit is installed, clean and check it for proper operation. Lubricate with engine oil and reinstall.

e. Engine cylinders and valves. Service as specified in paragraph 59d(2).

f. Blower (impeller) section. When installing a radial engine, the corrosion-preventive compound is allowed to drain into the lower intake pipes for at least 24 hours with the engine in a flying position. This may be done by placing it in position on the airplane, suspending it, or by laying the packing box or crate on its side. After draining, remove the intake pipes, remove the liquid, and reinstall the pipes.

g. Spark plugs. See paragraph 60d (8).

h. Preoiling the engine. Before ground testing, preoil the engine according to instructions in Technical Orders.

63. AIRCRAFT SUBJECTED TO SEA-WEATHER CONDITIONS DURING SHIPMENT. Engines installed in aircraft that are loaded aboard ships and subjected to sea-weather conditions will be treated for extended storage status. In addition, the following procedures must also be included.

a. Exterior engine surfaces. All exterior engine surfaces, parting lines of the crankcase, clamps, studs, and nuts will be sprayed with the properly specified solvent. (See Technical Orders.)

b. Oil regulators and radiators. The oil regulators and radiators must be sprayed with a light coat of corrosion-preventive mixture to prevent corrosion from salt spray.

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