Aircraft
Powerplants

Powerplant Certification

Tenth Edition

Thomas W. Wild
John M. Davis

McGraw Hill

New York Chicago San Francisco Athens London Madrid
Mexico City Milan New Delhi Singapore Sydney Toronto

Contents at a Glance

Aircraft Powerplant Classification and Progress 1

INTRODUCTION

People have dreamed of flying ever since they first gazed into the sky and saw birds soaring overhead. Early attempts at flight often resulted in failure. This failure was not primarily due to airfoil design but instead was attributable to the lack of technology needed to produce a source of power sufficient to sustain flight.

The development of aviation powerplants has resulted from the utilization of principles that were employed in the design of earlier internal-combustion engines. During the latter part of the nineteenth century, a number of successful engines were designed and built and used to operate machinery and to supply power for "horseless carriages."

Since the first internal-combustion engine was successfully operated, many different types of engines have been designed. Many have been suitable for the operation of automobiles and/or aircraft, and others have been failures. The failures have been the result of poor efficiency, lack of dependability (owing to poor design and to materials which could not withstand the operating conditions), high cost of operation, excessive weight for the power produced, and other deficiencies.

The challenge to aviation has been to design engines that have high power-to-weight ratios. This was accomplished first with lightweight piston engines and then, more effectively, with gas-turbine engines.

In this chapter, we examine the evolution, design, and classification of various types of engines.

WORLD WAR I AIRCRAFT ENGINES

The extensive development and use of airplanes during World War I contributed greatly to the improvement of engines.

Rotary-Type Radial Engines

One type of engine that found very extensive use was the air-cooled **rotary-type radial engine**. In this engine the crankshaft is held stationary, and the cylinders rotate about the crankshaft. Among the best-known rotary engines were the LeRhone, shown in Fig. 1-1, the GnomeMonosoupape, shown in Fig. 1-2, and the Bentley, which has a similar appearance. In these engines, the crankshaft is secured to the aircraft engine mount, and the propeller is attached to the engine case.

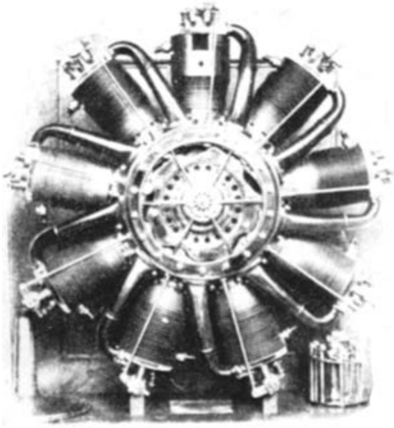


FIGURE 1-1 LeRhone rotary engine.

FIGURE 1-2 Gnome-Monosoupape rotary engine.

Even though the rotary engines powered many World War I airplanes, they had two serious disadvantages: (1) the torque and gyro effects of the large rotating mass of the engines made the airplanes difficult to control; and (2) the engines used castor oil as a lubricant, and since the castor oil was mixed with the fuel of the engine in the crankcase, the exhaust of the engines contained castor-oil fumes which were often nauseating to the pilots.

In-Line Engines

The cylinders of an in-line engine are arranged in a single row parallel to the crankshaft. The cylinders are either upright above the crankshaft or inverted, that is, below the crankshaft. The inverted configuration is generally employed. A typical inverted in-line engine is shown in Fig. 1-3. The engine shown is a Menasco Pirate, model C-4. The number of cylinders in an in-line engine is usually limited to six, to facilitate cooling and to avoid excessive weight per horsepower. There are generally an even number of cylinders to provide a proper balance of firing impulses. The in-line engine utilizes one crankshaft. The crankshaft is located above the cylinders in an inverted engine. The engine may be either air-cooled or liquid-cooled; however, liquid-cooled types are seldom utilized at present.

The use of the in-line-type engine is largely confined to low- and medium-horsepower applications for small aircraft. The engine presents a small frontal area and is therefore adapted to streamlining and a resultant low-drag nacelle configuration. When the cylinders are mounted in the inverted position, greater pilot visibility and a shorter landing gear are possible. However, the in-line engine has a greater weight-to-horsepower ratio than those of most other types. When the size of an aircraft engine is increased, it becomes increasingly difficult to cool it if it is the air-cooled in-line type; therefore, this engine is not suitable for a high-horsepower output.

V-Type Engines

World War I saw the development of several **V-type engines**, including the Rolls-Royce V-12 engine, the U.S.-made Liberty V-12 engine, shown in Fig. 1-4, and several German engines. The V-type engine has the cylinders arranged on the crankcase in two rows (or banks), forming the letter V, with an angle between the banks of 90, 60, or 45°. There is always an even number of cylinders in each row.

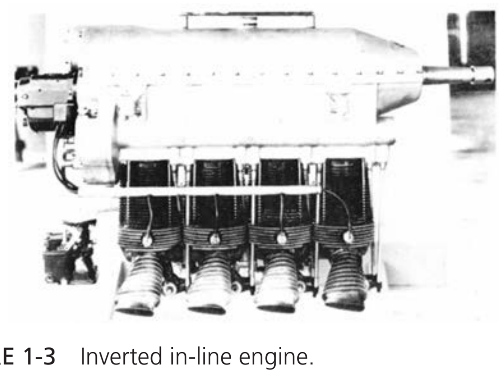


FIGURE 1-3 Inverted in-line engine.

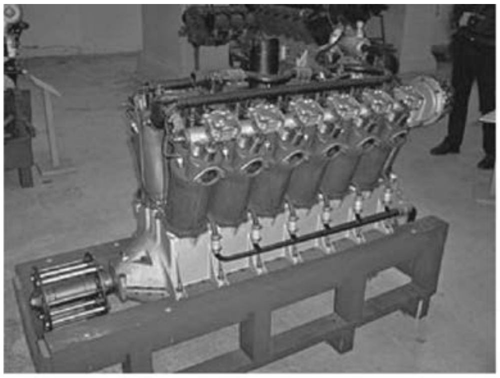


FIGURE 1-4 Liberty engine.

Since the two banks of cylinders are opposite to each other, two sets of connecting rods can operate on the same crankpin, thus reducing the weight per horsepower as compared with the in-line engine. The frontal area is only slightly greater than that of the in-line type; therefore, the engine cowling can be streamlined to reduce drag. If the cylinders are above the crankshaft, the engine is known as the **upright-V-type engine**, but if the cylinders are below the crankshaft, it is known as an **inverted-V-type engine**. Better pilot visibility and a short landing gear are possible if the engine is inverted.

POST–WORLD WAR I ENGINES

After World War I, many different engine designs were developed. Some of those with rather unusual configurations are shown in Fig. 1-5.

A popular U.S. engine was the Curtiss OX-5 engine manufactured during and after World War I. This engine powered the Curtiss Jennie (JN-4) trainer plane used for training U.S. military aviators. After the war, many were sold to the public, and the majority were used in the early barnstorming days for air shows and passenger flights. An OX-5 engine is shown in Fig. 1-6.

Other engines developed in the United States between World War I and World War II were the Wright Hisso (a U.S.-built Hispano-Suiza), the Packard V-12, the Curtiss D-12 (a V-12 engine), the Wright Whirlwind and radial engines, and the Pratt & Whitney Wasp and Hornet engines, which are air-cooled radial types. Numerous smaller engines were also designed and built, including radial, opposed-cylinder, and in-line types.

Radial Engines

The **radial engine** has been the workhorse of military and commercial aircraft ever since the 1920s, and during World War I, radial engines were used in all U.S. bombers and

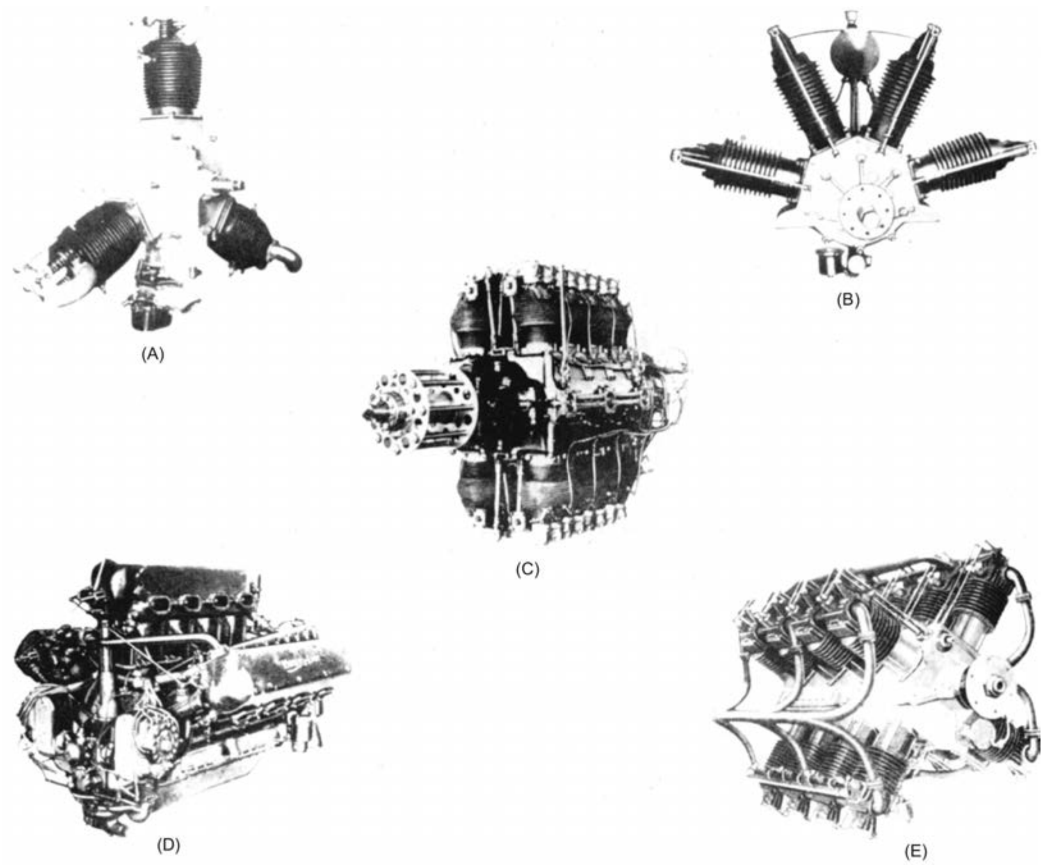


FIGURE 1-5 Different engine configurations developed after World War I. (A) Szekeley, three-cylinder radial. (B) Italian MAB, four-cylinder fan-type engine. (C) British Napier "Rapier," 16-cylinder H-type engine. (D) British Napier "Lion," 12-cylinder W-type engine. (E) U.S. Viking, 16-cylinder X-type engine.

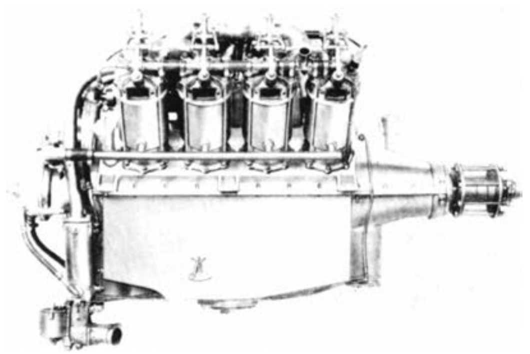


FIGURE 1-6 Curtiss OX-5 engine.

transport aircraft and in most of the other categories of aircraft. They were developed to a peak of efficiency and dependability; and even today, in the jet age, many are still in operation throughout the world in all types of duty.

A **single-row radial engine** has an odd number of cylinders extending radially from the centerline of the crankshaft. The number of cylinders usually ranges from five to nine. The cylinders are arranged evenly in the same circular plane, and all the pistons are connected to a single-throw 360° crankshaft, thus reducing both the number of working parts and the weight.

A **double-row radial engine** resembles two single-row radial engines combined on a single crankshaft, as shown in Fig. 1-7. The cylinders are arranged radially in two rows, and each row has an odd number of cylinders. The usual number of cylinders used is either 14 or 18, which means that the same effect is produced as having either two seven-cylinder engines or two nine-cylinder engines joined on one crankshaft. A two-throw 180° crankshaft is used to permit the cylinders in each row to be alternately staggered on the common crankcase. That is, the cylinders of the rear row are located directly behind the spaces between the cylinders in the front row. This allows the cylinders in both rows to receive ram air for the necessary cooling.

The radial engine has the lowest weight-to-horsepower ratio of all the different types of piston engines. It has the disadvantage of greater drag because of the area presented to the air, and it also has some problems in cooling. Nevertheless, the dependability and efficiency of the engine have made it the most widely used type for large aircraft equipped with reciprocating engines.

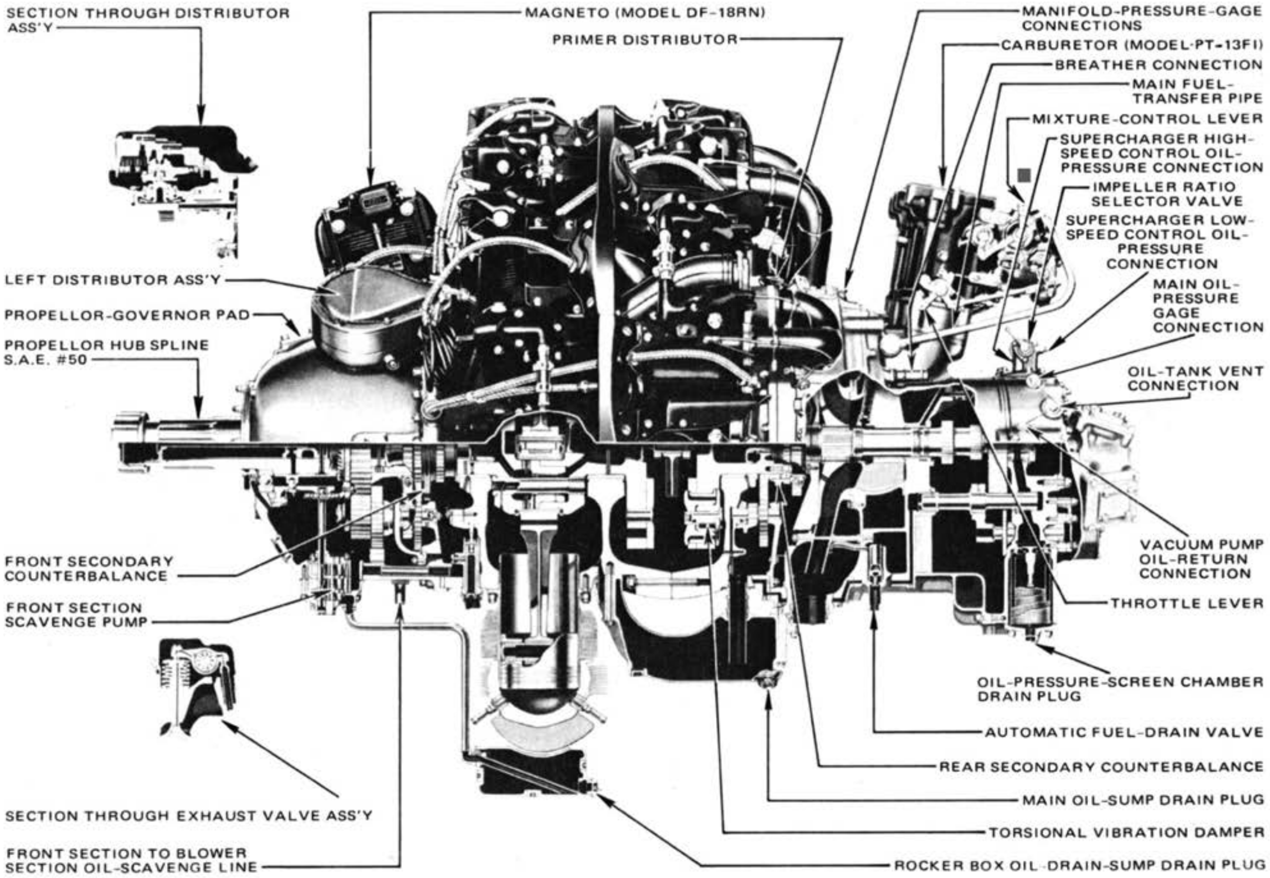


FIGURE 1-7 Double-row radial engine.

Multiple-Row Radial Engine

The 28-cylinder Pratt & Whitney R-4360 engine was used extensively at the end of World War II and afterward for both bombers and transport aircraft. This was the largest and most powerful piston-type engine built and used successfully in the United States. A photograph of this engine is shown in Fig. 1-8. Because of the development of the gas-turbine engine, the very large piston engine has been replaced by the more powerful and lightweight turboprop and turbojet engines. Since it has few moving parts compared with the piston engine, the gas-turbine engine is more trouble-free and its maintenance cost is reduced. Furthermore, the time between overhauls (TBO) is greatly increased.

Opposed, Flat, or O-Type Engine

The opposed-type engine is most popular for light conventional aircraft and helicopters and is manufactured in sizes delivering from less than 100 hp [74.57 kW] to more than 400 hp [298.28 kW]. These engines are the most efficient, dependable, and economical types available for light aircraft. Gas-turbine engines are being installed in some light aircraft, but their cost is still prohibitive for the average, private airplane owner.

The **opposed-type engine** is usually mounted with the cylinders horizontal and the crankshaft horizontal; however, in some helicopter installations the crankshaft is vertical. The engine has a low weight-to-horsepower ratio, and because of its flat shape it is very well adapted to streamlining and to horizontal installation in the nacelle. Another advantage is that it is reasonably free from vibration. Figure 1-9 illustrates a modern opposed engine for general aircraft use.

ENGINE DESIGN AND CLASSIFICATION

Conventional piston engines are classified according to a variety of characteristics, including cylinder arrangement, cooling method, and number of strokes per cycle. The most satisfactory classification, however, is by cylinder arrangement. This is the method usually employed because it is more completely descriptive than the other classifications. Gas-turbine engines are classified according to construction and function; these classifications are discussed in Chap. 11.

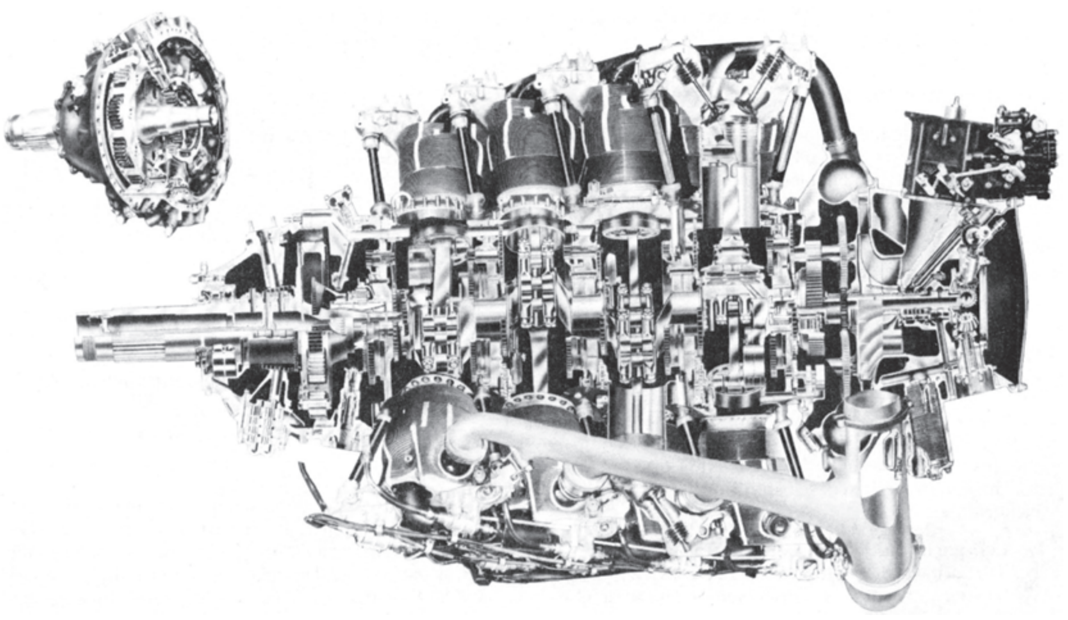


FIGURE 1-8 Pratt & Whitney R-4360 engine. (*Pratt & Whitney.*)

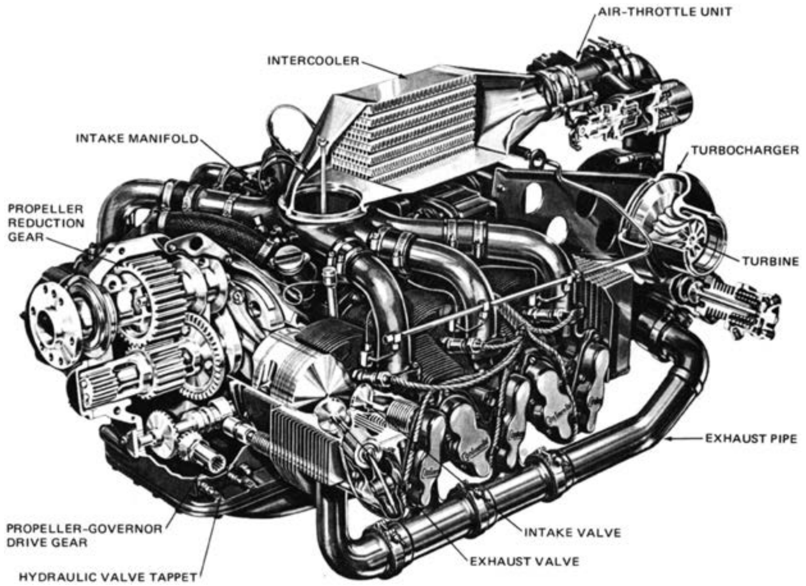


FIGURE 1-9 Teledyne Continental six-cylinder opposed engine. (*Teledyne Continental Motors.*)

Cylinder Arrangement

Although some engine designs have become obsolete, we mention the types most commonly constructed throughout the history of powerplants. Aircraft engines may be classified according to cylinder arrangement with respect to the crankshaft as follows: (1) in-line, upright; (2) in-line, inverted; (3) V type, upright; (4) V type, inverted; (5) double-V or fan type; (6) X type; (7) opposed or flat type; (8) radial type, single-row; (9) radial type, double-row; (10) radial type, multiple-row or "corncob." The simple drawings in Fig. 1-10 illustrate some of these arrangements.

The double-V- or fan-type engine has not been in use for many years, and the only piston engines in extensive use for aircraft in the United States at present are the opposed and radial types. A few V-type and in-line engines may still be in operation, but these engines are no longer manufactured in the United States for general aircraft use.

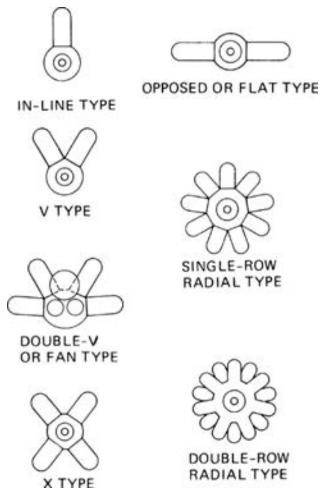


FIGURE 1-10 Engines classified according to cylinder arrangement.

Early Designations

Most of the early aircraft engines, with the exception of the rotary types, were water-cooled and were of either in-line or V-type design. These engines were often classified as liquid-cooled in-line engines, water-cooled in-line engines, liquid-cooled V-type engines, or water-cooled V-type engines. As air-cooled engines were developed, they were classified in a similar manner (air-cooled in-line, air-cooled V-type, etc.).

Classification or Designation by Cylinder Arrangement and Displacement

Current designations for reciprocating engines generally employ letters to indicate the type and characteristics of the engine, followed by a numerical indication of displacement. The following letters usually indicate the type or characteristic shown:

- **L** **Left-hand rotation** for counter-rotating propeller
- **T** **Turbocharged** with turbine-operated device
- **V** **Vertical** for helicopter installation with the crankshaft in a vertical position
- **H** **Horizontal** for helicopter installation with the crankshaft horizontal
- **A** **Aerobatic**; fuel and oil systems designed for sustained inverted flight
- **I** **Fuel injected**; continuous fuel injection system installed
- **G** **Geared** nose section for reduction of propeller revolutions per minute (rpm)
- **S** **Supercharged**; engine structurally capable of operating with high manifold pressure and equipped with either a turbine-driven supercharger or an engine-driven supercharger
- **O** **Opposed cylinders**
- **R** **Radial engine**; cylinders arranged radially around the crankshaft

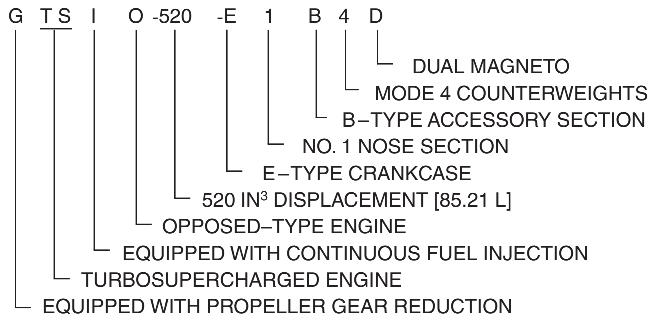
However, note that many engines are not designated by the foregoing standardized system. For example, the Continental W-670 engine is a radial type, whereas the A-65, C-90, and E-225 are all opposed-type engines. V-type engines and inverted in-line engines have such designations as V and I. In every case, the technician working on an engine must interpret the designation correctly and utilize the proper information for service and maintenance.

The two- or three-digit numbers in the second part of the engine designation indicate displacement to the nearest 5 in^3. An engine with a displacement of 471 in^3 [7.72 liters (L)] is shown as 470, as is the case with the Teledyne Continental O-470 opposed engine.

In some cases, the displacement number will end with a figure other than zero. In such a case, this is a special indication to reveal a characteristic such as an integral accessory drive.

Radial engines generally employ only the letter R followed by the displacement. For example, the R-985 is a single-row radial engine having a displacement of approximately 985 in^3 [16.14 L].

An example of the standard designation for an engine is as follows:



A system of suffix designations has also been established to provide additional information about engines. The first suffix letter indicates the type of power section and the rating of the engine. This letter is followed by a number from 1 to 9, which gives the design type of the nose section. Following the nose-section number is a letter indicating the type of accessory section, and after this letter is a number which tells what type of counterweight application is used with the crankshaft. This number indicates the mode of vibration, such as 4, 5, or 6. The mode number is found on the counterweights or dynamic balances on the crankshaft.

The final character in the designation suffix may be a letter indicating the type of magneto utilized with the engine. The letter D indicates a dual magneto.

Engine Classification by Cooling Method

Aircraft engines may be classified as being cooled either by air or by liquid; however, few liquid-cooled engines are in operation. Most aircraft engines are cooled by passing air over the engine's cylinders; through the convection process, excessive heat generated by the engine's combustion process is removed from the engine. In a liquid-cooled engine, the liquid is circulated through the engine areas that require heat removal. After the heat has been transferred to the liquid, the liquid passes through a heat exchanger which cools the liquid, and the cycle repeats. A complete discussion of engine cooling systems is presented in Chap. 5.

Progress in Design and Types of Current Reciprocating Engines

Engineers who specialize in the design of aircraft powerplants have used light alloy metals for construction of the engines and have adopted weight-saving cylinder arrangements, with the result that today the weight per horsepower on several engines is below 1.2 lb [0.54 kg] and on some less than 1 lb [0.45 kg].

Airplanes have increased in size, carrying capacity, and speed. With each increase has come a demand for more power, and this has been met by improvements in engine and propeller design and by the use of gas-turbine and turboprop engines. As piston engines increased in power, they became more complicated. The early powerplant engineers and mechanics had only a few comparatively simple problems to solve, but the modern powerplant specialist must be familiar with the principles of the internal-combustion engine; the classification, construction, and nomenclature of engines; their fuel and carburetion systems; supercharging and induction systems; lubrication of powerplants; engine starting systems; ignition systems; valve and ignition timing; engine control systems; and propellers.

Fundamentally, the reciprocating internal-combustion engine that we know today is a direct descendant of the first Wright engine. It has become larger, heavier, and much more powerful, but the basic principles are essentially the same. However, the modern reciprocating aircraft engine has reached a stage in its development where it is faced with what is commonly called the **theory of diminishing returns**. More cylinders are added to obtain more power, but the resulting increase in size and weight complicates matters in many directions. For example, the modern reciprocating engine may lose more than 30 percent of its power in dragging itself and its nacelle through the air and in providing necessary cooling.

The improvement in reciprocating engines has become quite noticeable in the smaller engines used for light aircraft. This has been accomplished chiefly with the opposed-type four- and six-cylinder engines. Among the improvements developed for light engines are geared propellers, superchargers, and fuel-injection systems. Whereas light airplanes were once limited to flight at comparatively low altitudes, today many are capable of cruising at altitudes of well over 20 000 ft [6096 m].

Examples of Certified Reciprocating Engines

Many modern reciprocating engines for light certified aircraft (certificated under FAR part 33) are manufactured by Continental Motors, Inc. and Lycoming, a division of AVCO Corp. Although over time engine types can vary somewhat, some basic engine series will be presented.

Continental Motors Series Engines

200 Series. The first series for the continental engines is the 200 series shown in Fig. 1-11. This series of engines has been providing aircraft power for decades. The Continental's 200 series tuned induction system provides improved cylinder to cylinder intake-air distribution for smoother operation and increased fuel efficiency. The lightweight O-200-D engine weighs 199 lb and develops 100 continuous horsepower at 2750 rpm. Another version of the 200 series is the O-200-AF (alternative fuel) developed for use with lower octane/unleaded fuels for international markets.

300 Series. Some of Continental's 300 series engines top the horsepower charts at an impressive 225 hp in turbocharged, (used to boost horsepower) and intercooled form. All 360s have six smooth-running cylinders. And every 360 engine is fuel injected for outstanding efficiency and range. At 283 lb the TSIO-360-A, shown in Fig. 1-12, rates among the lightest of all six-cylinder aircraft powerplants. The Continental's 300 series designs are used in many different aircraft.

400 Series. The main engine in the 400 series is the O-470 powering many Cessna aircraft. Ranging in output from 225 to 260 hp, the 470 engines come equipped with either a carburetor or Continental's continuous-flow fuel-injection system. The 400 series uses a six-cylinder design and has many hours of successful operation and is used in several configurations. The O-470 series engines can be seen in Fig. 1-13.

FIGURE 1-11 Continental Motors 200 series engine.

FIGURE 1-12 Continental Motors 300 series engine.

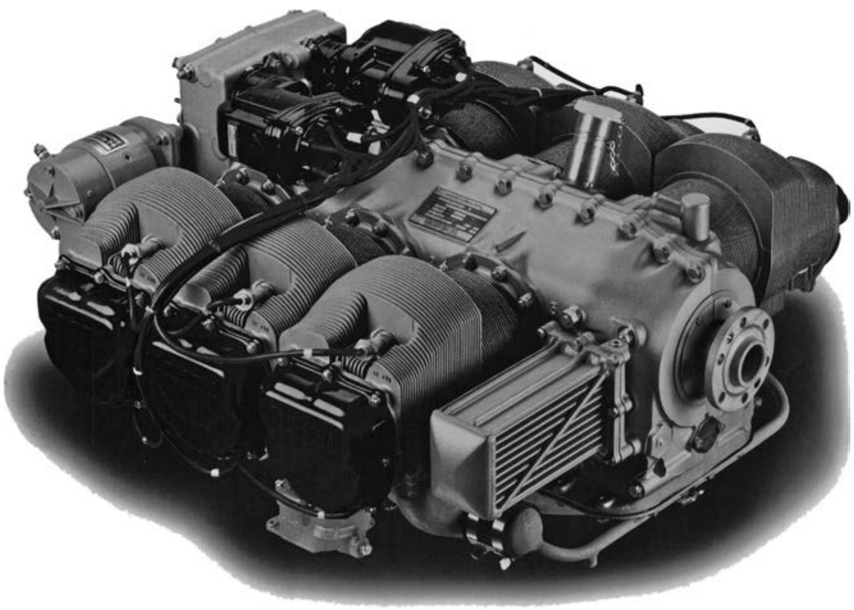


FIGURE 1-13 Continental Motors 400 series engine.

500 Series. A family of engines that ranges in power from 285 to 375 hp is the Continental Motors 500 series. Continental Motors introduced the first 500 series engine in the Beech Bonanza and the Cessna Centurion in 1964. The 500 series, shown in Fig. 1-14, includes both 520 and 550 in^3 models in either naturally aspirated or turbocharged configurations. There is even a geared variant that exceeds horsepower-to-displacement standards—a stunning 375 hp from 520 in^3. With the right combination of thrust and efficiency, the 500 series engines have powered many aircraft in general aviation.