Aircraft Powerplants

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Ninth Edition

Thomas W. Wild

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Aircraft Powerplants, Ninth Edition

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About the Author

Thomas W. Wild, Ph.D., is a retired professor in the Aviation Technology Department at Purdue University, where he taught and served for 37½ years. He holds or has held several FAA certifications, and was managing editor of the *Aviation Technician Education Council Journal* for 30 years. He has written many books and articles on aviation-related subjects and served on the boards of directors of aviation professional organizations.

Contents

Preface

Aircraft Powerplants, Ninth Edition, is designed to provide aviation students with both the theoretical and practical knowledge they need in the constantly changing and increasingly highly technical area of propulsion systems for aircraft. This text greatly exceeds the requirements to qualify students for certification as FAA powerplant technicians in accordance with the Federal Aviation Regulations (FAR). This edition is a revision designed to reflect not only the latest changes in FAR Part 147 but also the current and changing needs of the aircraft industry. Throughout the text, FAR Part 147 has been used for reference to ensure that FAA requirements have been met. The FAA Written Test Guide, Advisory Circular 65-22, has been reviewed carefully to ensure that all technical data that students will need in order to prepare for FAA written and oral examinations are included.

This edition of *Aircraft Powerplants* features expanded coverage of turbine-engine theory and nomenclature with some outdated material deleted. Additional current models of turbofan, turboprop, and turboshaft engines have been included. Information on turbine-engine fuel, oil, and ignition systems has been adjusted for currency and continues to be divided into separate chapters. Also added to the chapters is new information on turbine-engine health monitoring both in the air and ground-based stations. New materials used in turbine-engine components and manufacturing processes are described in detail. Review questions at the end of each chapter enable students to check their knowledge of the information presented.

Throughout the text, a special emphasis has been placed on the integration of information on how individual components and systems operate together. This text will provide maximum benefit when used in conjunction with the books *Aircraft Basic Science, Aircraft Maintenance and Repair*, and *Aircraft Electricity and Electronics*, which as a group encompass information on all phases of airframe and aircraft powerplant technology.

This book is designed to be used as a classroom text to provide the technician and the engineer with a background for a successful career in the aerospace field. Information contained in this book should not be used for actual maintenance performed on aircraft or substituted for that provided by manufacturers.

Thomas W. Wild

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Special thanks are given to my wife Louise Wild for her assistance in compiling this text.

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Aircraft
Powerplants

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 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 Gnome-Monosoupape, 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.

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 in order 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.

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.

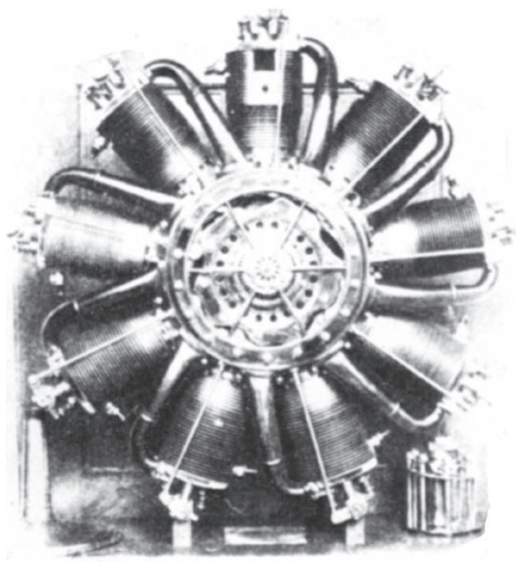

FIGURE 1-1 LeRhone rotary engine.

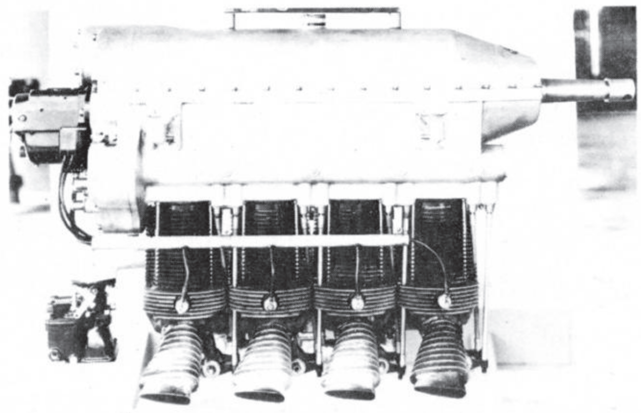

FIGURE 1-3 Inverted in-line engine.

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.

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.

FIGURE 1-2 Gnome-Monosoupape rotary engine.

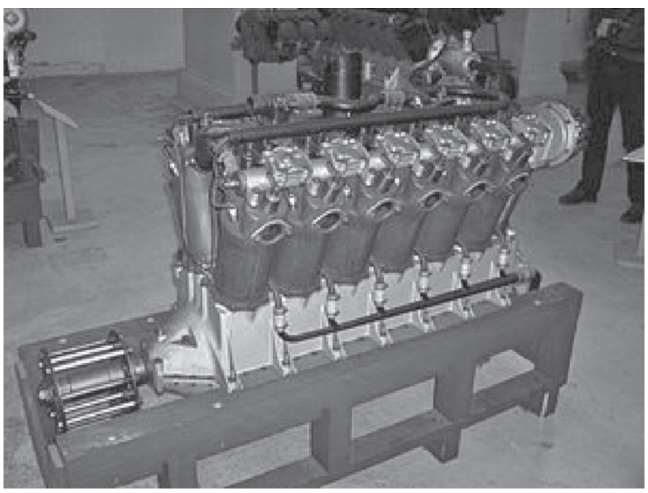

FIGURE 1-4 Liberty engine.

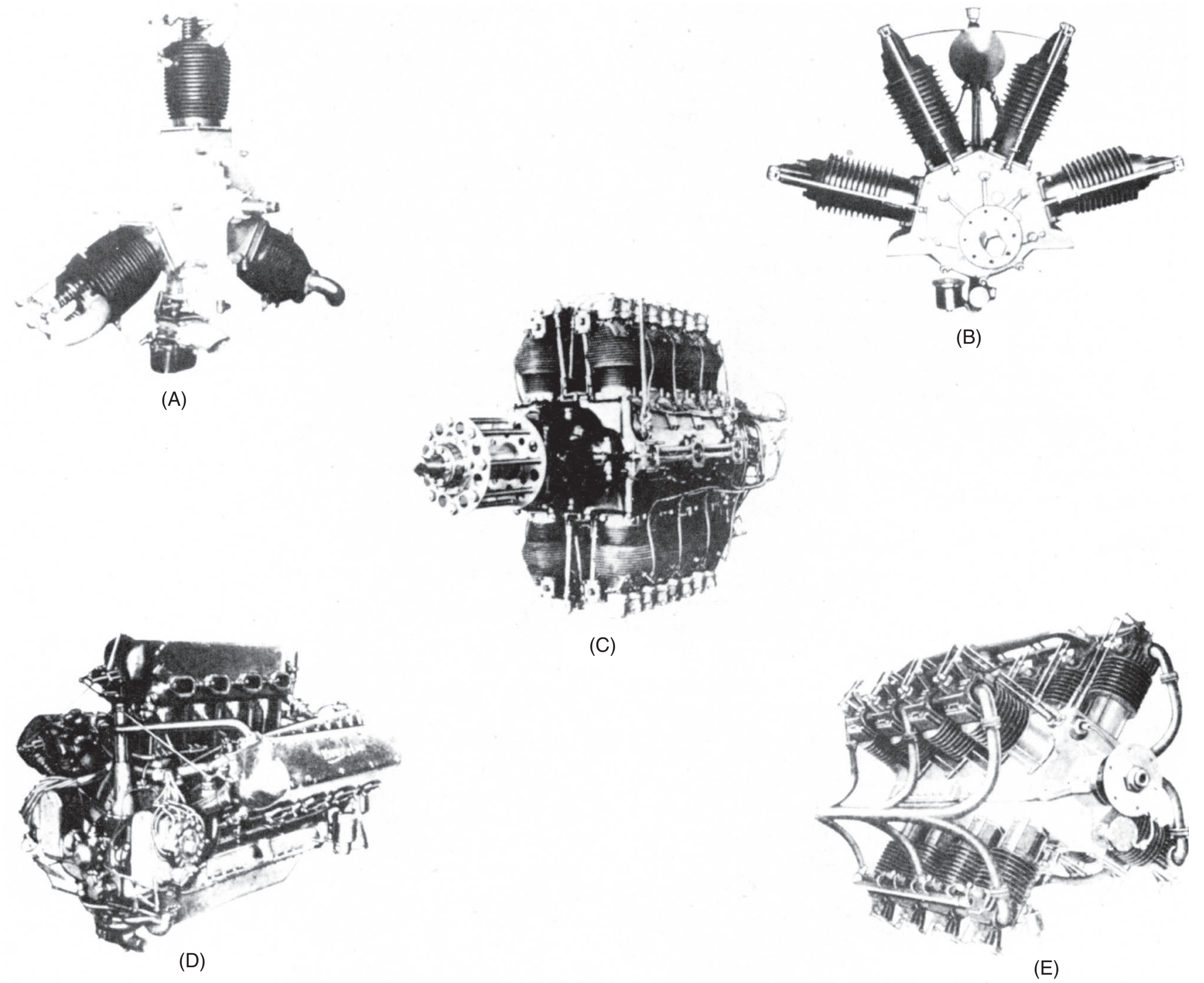

FIGURE 1-5 Different engine configurations developed after World War I. (A) Szekeley, three-cylinder radial. (B) Italian MAB, four-cylinder fan-type engine. (C) British Napier "Rapier," 16-cylinder H-type engine. (D) British Napier "Lion," 12-cylinder W-type engine. (E) U.S. Viking, 16-cylinder X-type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

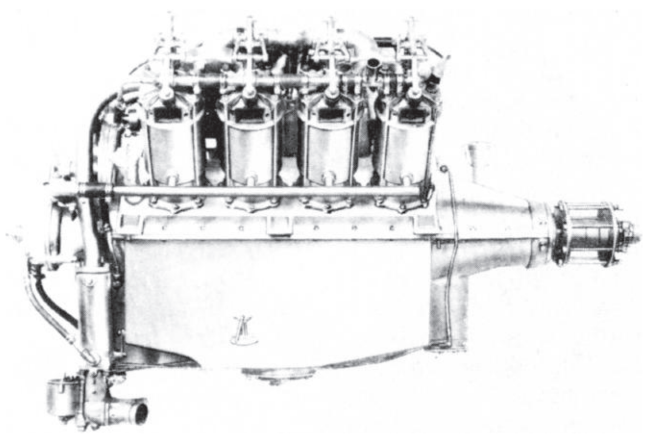

FIGURE 1-6 Curtiss OX-5 engine.

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 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.

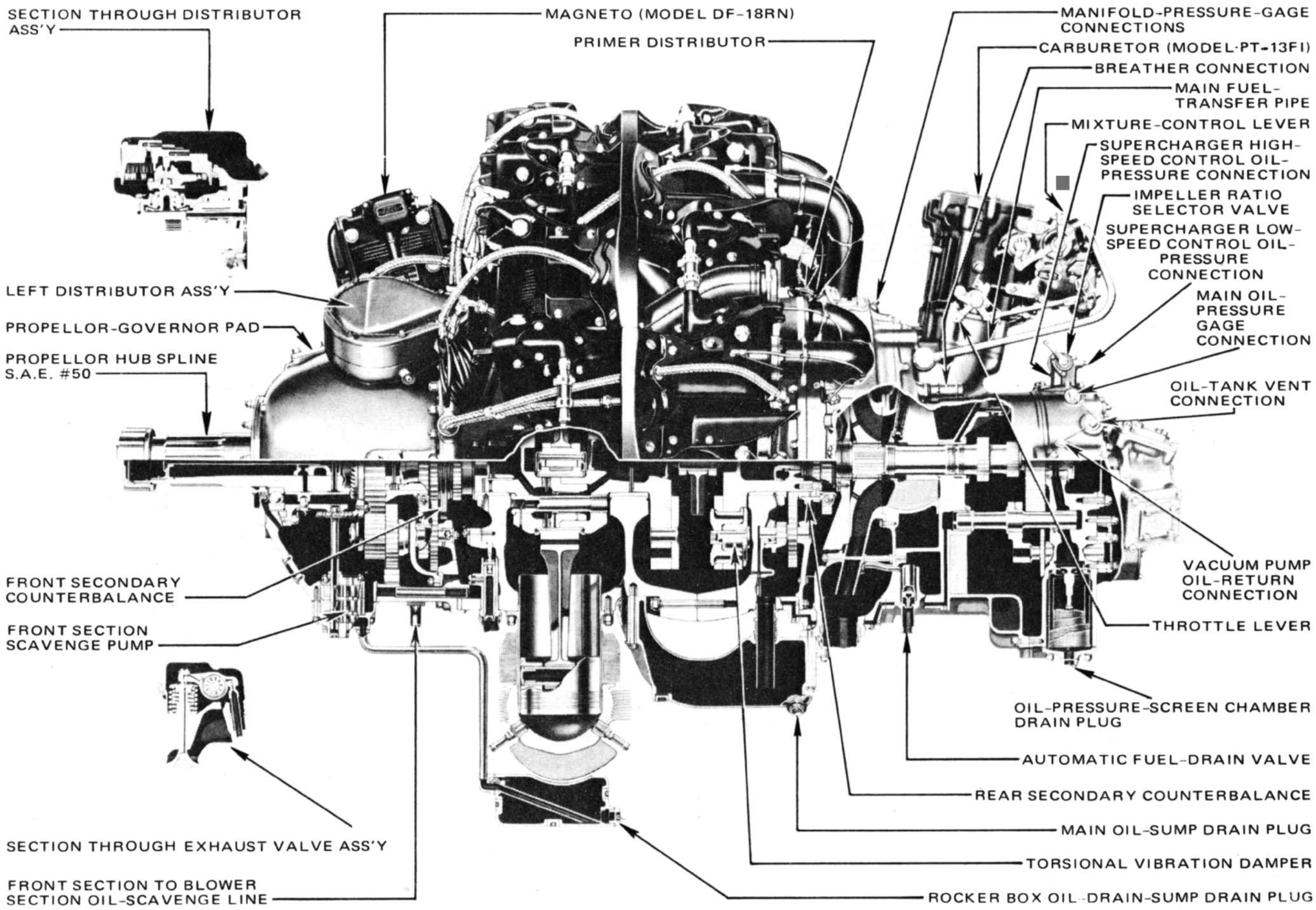

FIGURE 1-7 Double-row radial engine.

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.

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.

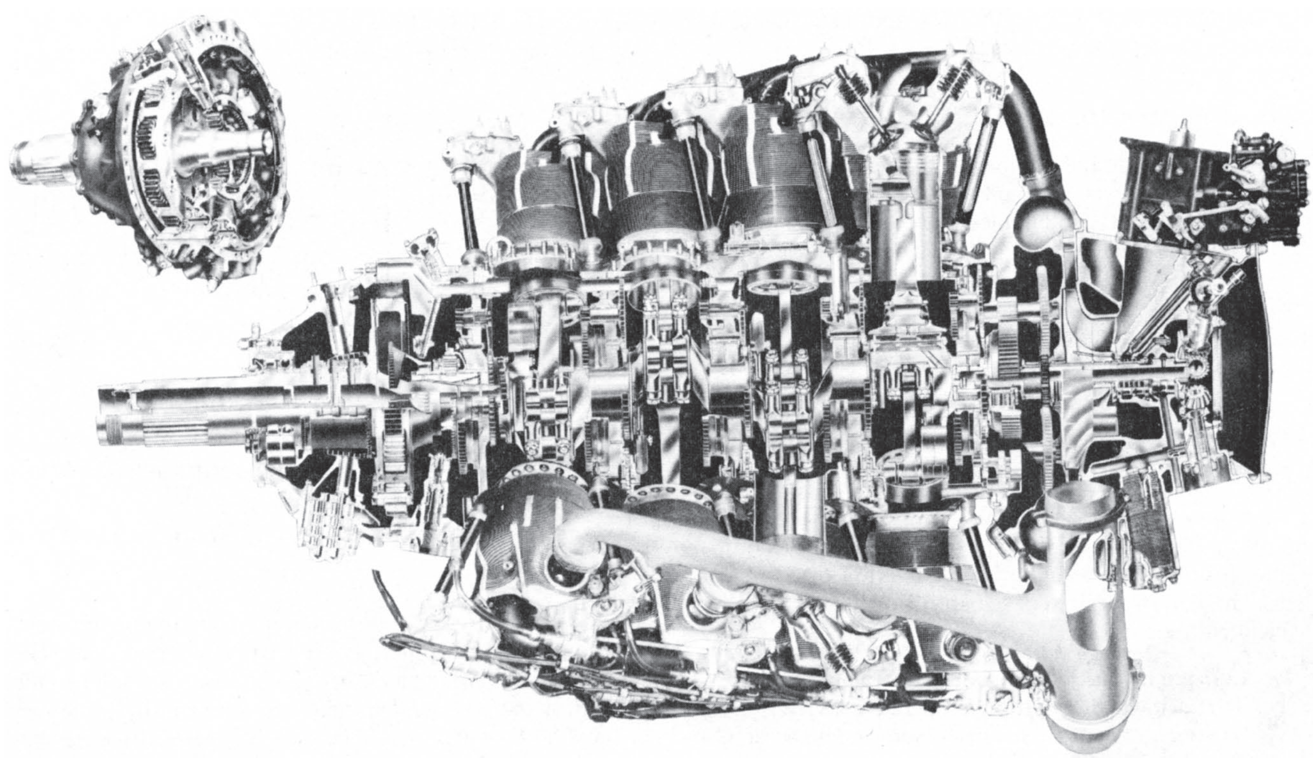

FIGURE 1-8 Pratt & Whitney R-4360 engine. (*Pratt & Whitney.*)

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.

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.

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.

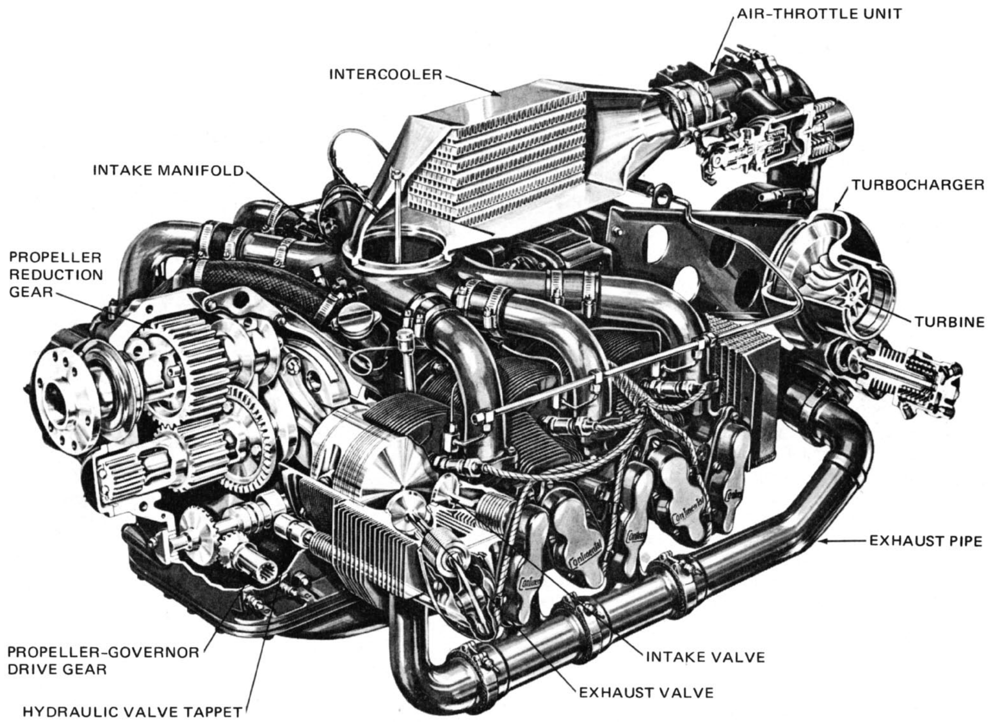

FIGURE 1-9 Teledyne Continental six-cylinder opposed engine. (*Teledyne Continental Motors.*)

The following letters usually indicate the type or characteristic shown:

- **L** **Left-hand rotation** for counterrotating propeller
- **T** **Turbocharged** with turbine-operated device
- **V** **Vertical** for helicopter installation with the crankshaft in a vertical position

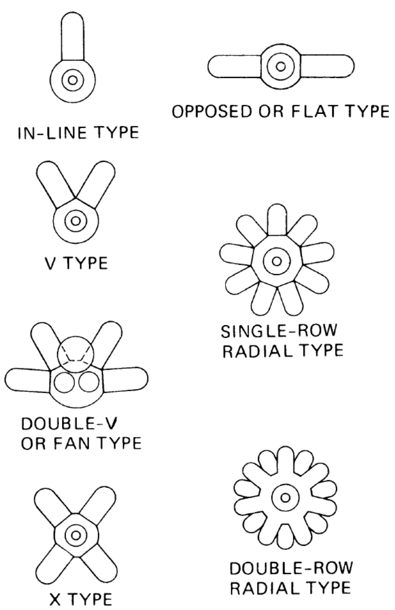

FIGURE 1-10 Engines classified according to cylinder arrangement.

- **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:

G T S I O -520 -E 1 B 4 D

- D — DUAL MAGNETO
- 4 — MODE 4 COUNTERWEIGHTS
- B — B–TYPE ACCESSORY SECTION
- 1 — NO. 1 NOSE SECTION
- -E — E–TYPE CRANKCASE
- -520 — 520 IN^3 DISPLACEMENT [85.21 L]
- O — OPPOSED–TYPE ENGINE
- I — EQUIPPED WITH CONTINUOUS FUEL INJECTION
- TS — TURBOSUPERCHARGED ENGINE
- G — EQUIPPED WITH PROPELLER GEAR REDUCTION

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 complicate 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 feet (ft) [6096 meters (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

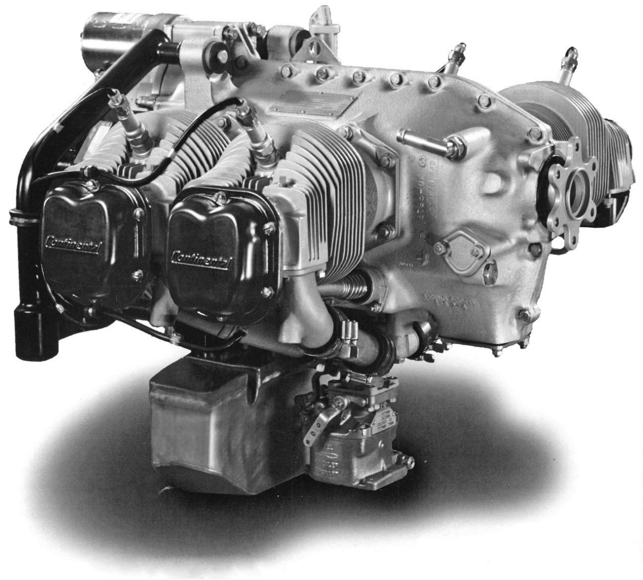

FIGURE 1-11 Continental Motors 200 series engine.

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.

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.

Lycoming Series Engines

Lycoming Four-Cylinder Series. The Lycoming four-cylinder series engines, shown in Fig. 1-15, are four-cylinder, direct-drive, horizontally opposed, air-cooled models. The cylinders are of conventional air-cooled construction with heads made from an aluminum-alloy casting and a fully machined combustion chamber. Rocker-shaft bearing supports are cast integral with the head, along with housings to form the rocker boxes. The cylinder barrels have deep integral cooling fins, and the inside of the barrels are ground and honed to a specified finish. The IO-360 and TIO-360 series engines are equipped with a fuel-injection

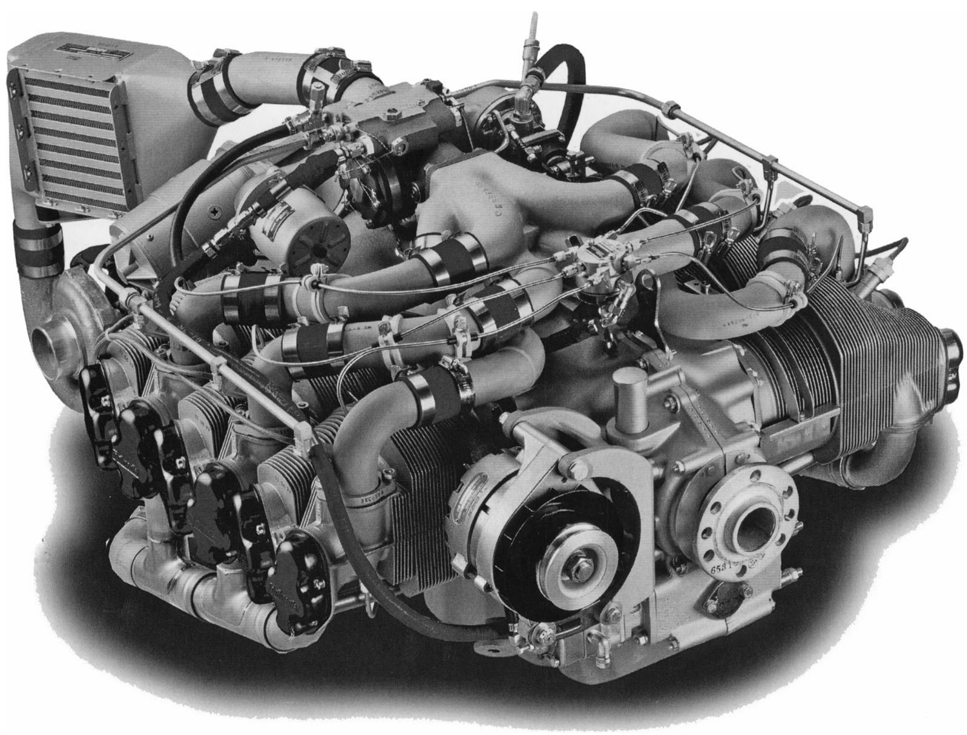

FIGURE 1-12 Continental Motors 300 series engine.

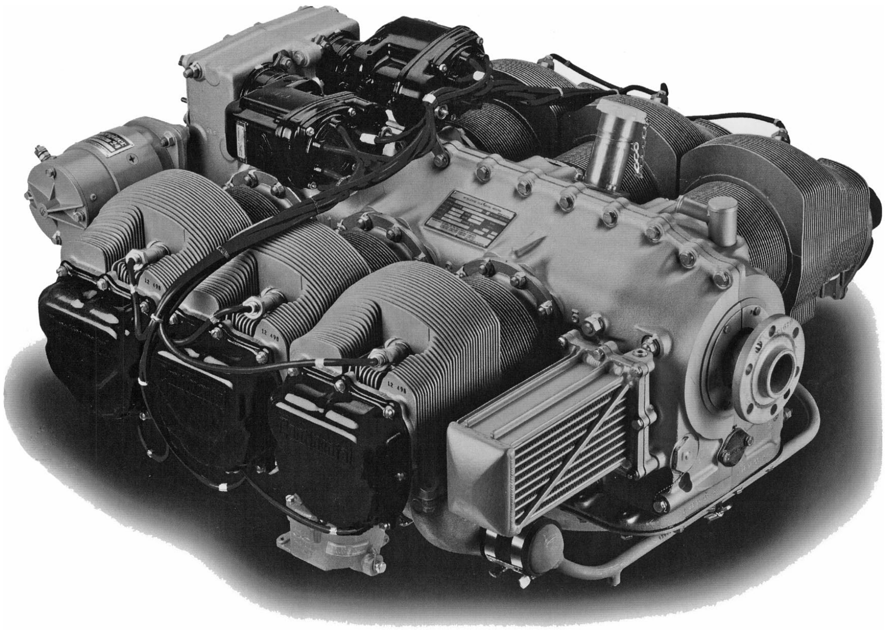

FIGURE 1-13 Continental Motors 400 series engine.

system, which schedules fuel flow in proportion to airflow. Fuel vaporization takes place at the intake ports. A turbocharger is mounted as an integral part of the TIO-360 series. Automatic waste-gate control of the turbocharger provides constant air density to the fuel-injector inlet from sea level to critical altitude. The following chapters will discuss all these engine components and details in great depth.

O-540 Series. The Lycoming O-540 series, shown in Fig. 1-16, engines are six-cylinder, direct-drive, horizontally opposed, air-cooled models. The cylinders are of conventional air-cooled construction with heads made from an aluminum-alloy casting and a fully machined combustion chamber. Rocker-shaft bearing supports are cast integral with the head, along with housings to form the rocker boxes as in the O-360 series. The cylinder barrels are ground and honed to a specified finish and are equipped with cooling fins. The IO-540 and TIO-540 (turbocharged) series engines are equipped with a fuel-injection system, which schedules fuel flow and delivers vaporized fuel at the intake ports in proportion to airflow. A turbocharger(s) is mounted as an integral part of the TIO-540 series. The turbocharger

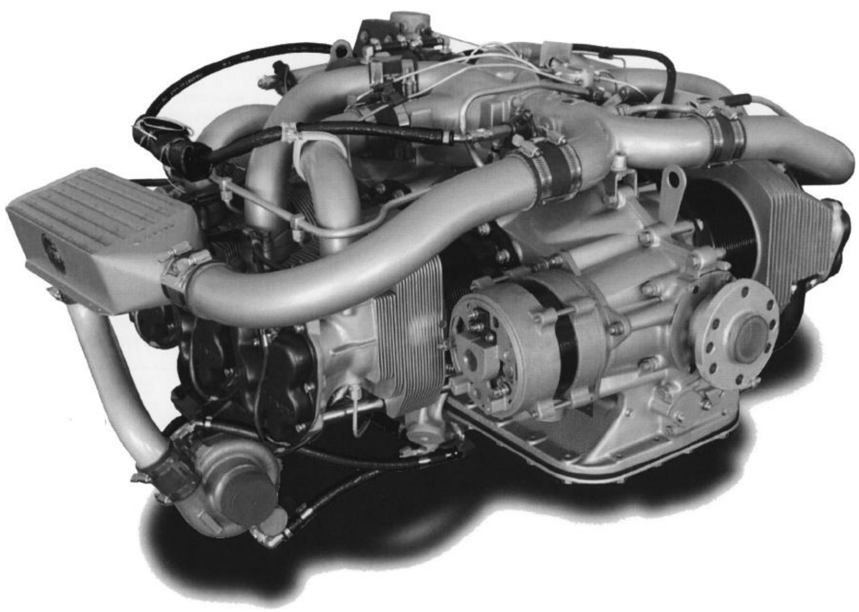

FIGURE 1-14 Continental Motors 500 series engine.

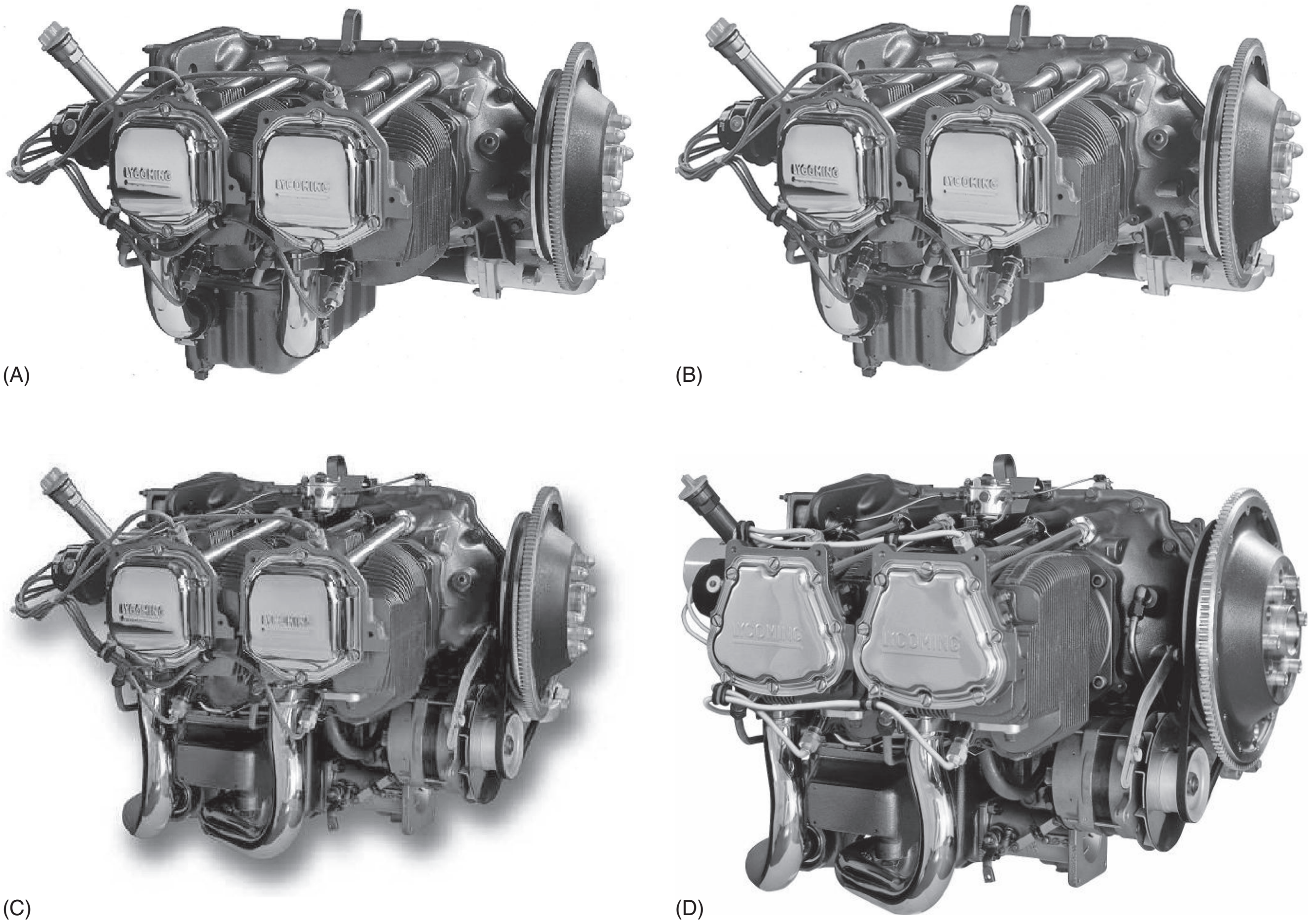

FIGURE 1-15 Four-cylinder Lycoming engines: (A) O-235, (B) O-320, (C) O-360, (D) O-390.

provides constant air density to the fuel-injector inlet. Some of the Lycoming series engines can be equipped with high compression heads, which increases the horsepower output.

IO-390 Series. The Lycoming IO-390 series engines are four-cylinder, direct-drive, horizontally opposed, air-cooled models. The engines are equipped with a fuel-injection system that schedules fuel flow in proportion to airflow. Fuel vaporization takes place at the intake ports. Implementing new technology in cylinder design proven by the performance of the 580 engine series to increase the displacement to 390 in^3, this model produces 210 hp

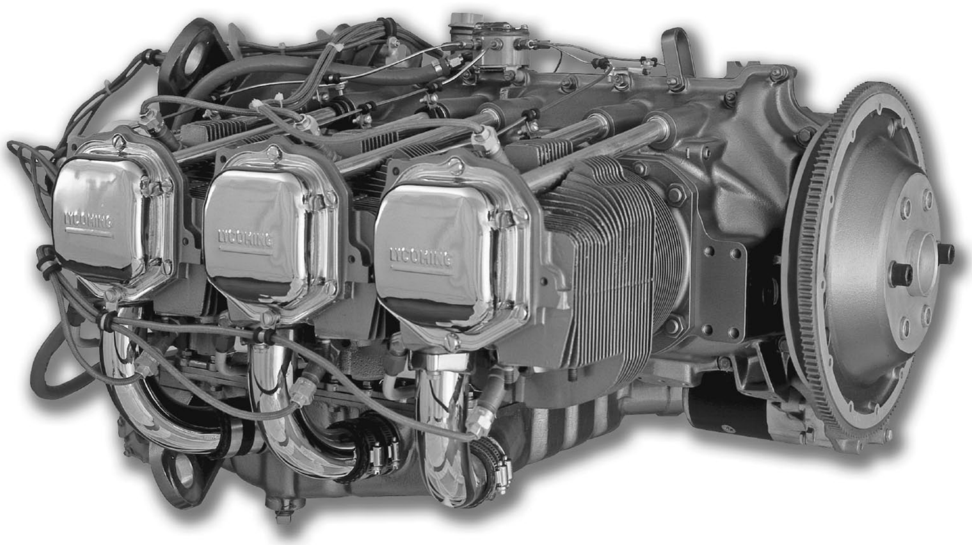

FIGURE 1-16 Six-cylinder IO-540 Lycoming engine.

at 2700 rpm and consumes 11.1 gal/h at 65 percent power. Designed to meet the growing demand for kit aircraft, the engine provides the required speed, payload, and low-fuel consumption.

IO-580 Series. The Lycoming IO-580 series engines are six-cylinder, direct-drive horizontally opposed, air-cooled models, see Fig. 1-17. The cylinders are of conventional air-cooled construction with heads made from an aluminum-alloy casting and a fully machined combustion chamber. The engines are equipped with a fuel-injection system. The fuel injector meters fuel in proportion to induction airflow to air-bled nozzles at individual cylinder intake ports. Manual mixture control and idle cutoff are provided. This engine has a bore of 5.319 in, a stroke of 4.375 in, and a piston displacement of 583 in^3.

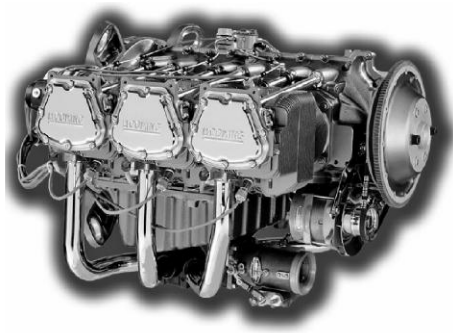

FIGURE 1-17 Six-cylinder AEIO-580 Lycoming engine fuel injected.

IO-720 Series. The Lycoming IO-720 series engines (see Fig. 1-18) are eight-cylinder, direct-drive, horizontally opposed, air-cooled models. The cylinders are of conventional air-cooled construction with heads made from an aluminum-alloy casting and a fully machined combustion chamber. The engines are equipped with a fuel-injection system that schedules fuel flow in proportion to airflow. Fuel vaporization takes place at the intake ports.

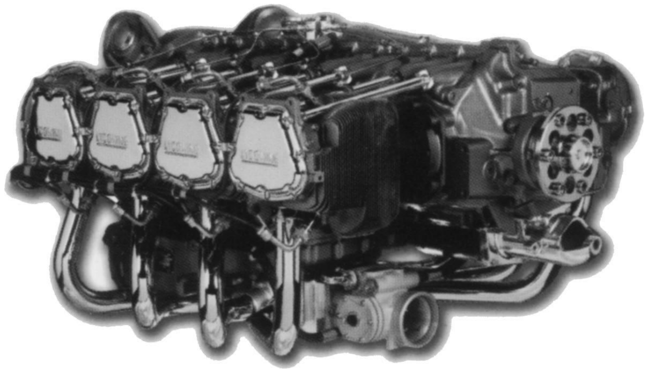

FIGURE 1-18 IO-720 Lycoming eight-cylinder opposed engine.

Lycoming Integrated Electronic Engine

The Integrated Electronic Engine (IEE or iE^2) is shown in Fig. 1-19. The iE^2 electronics have been “integrated” throughout the engine to optimize the systems operation, weight, and packaging. As a result, you have the benefit of an engine system that offers improved simplicity and reliability without sacrificing payload or performance.

In flight, the pilot can focus on flying the plane rather than managing the engine. Whether in takeoff, climb, or cruise, fuel leaning is automatic and optimized for each scenario. Monitoring CHTs, EGTs, and TITs is now a thing of the past as the engine condition is now managed electronically. Pilots need to set the desired power level to effectively control the engine. Engine data recording capability gives the mechanic insights into engine operation that were never available before. Approved technicians with the proper tools and training can quickly review engine data to make sure your engine is operating at peak performance.

The most demanding aviation environments were the primary considerations throughout the process of developing the Lycoming iE^2 series engines. Advanced computer logic allows key engine parameters to have double and even triple redundancy without the weight and cost of extra sensors. The automated preflight check evaluates system components and signals the pilot if any anomalies exist prior to takeoff. During flight, the reduced pilot workload allows the pilot to focus on flying the plane and maintaining situational awareness rather than managing the engine. Electronic knock detection allows the engine to automatically adjust to prevent damage caused by engine detonation. Integrated electrical power generation allows the engine to maintain its own power supply to ensure that the engine will be able to run regardless of the airframe’s power condition. The system even includes improved fuel consumption calculations to allow better estimates of fuel usage. In the event a problem is detected, the engine system alerts the pilot and keeps a record of the problem, allowing the technicians to quickly identify and remedy the issue.

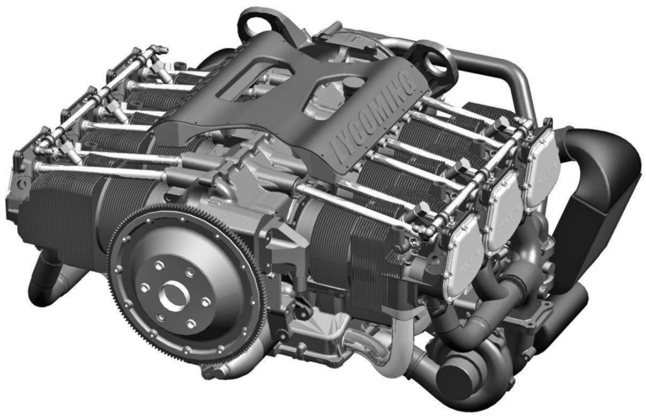

FIGURE 1-19 Lycoming six-cylinder iE^2 engine.

System Operation

The first advantage of operation is the simplicity of the iE^2 single-lever engine controls. Mixture and propeller controls are now managed electronically, eliminating the need for additional cockpit levers. The engine starts easily and reliably, hot or cold, with a single button, bringing to mind today's modern automobiles. Engine preflight is automatic and starts with the push of a button. Within seconds, engine operations are checked then rechecked in the dual redundant system with the pilot receiving the "green light" when the sequence is successfully completed.

Conventional magneto and propeller control checks are now a "push of a button" process—set the engine to the appropriate rpm and push the "Preflight Test" button. A "Preflight Test" lamp will illuminate to let you know the process is underway. As the test progresses, you will notice variations in engine rpm and prop pitch as the system automatically checks the ignition, fuel, and turbo systems, as well as the propeller control system. The iE^2 electronics are designed to constantly monitor every sensor and actuator within the system. Each sensor and actuator is monitored for proper operation and even "cross-checked" with other sensors to verify accuracy. The data provided by each sensor is also monitored to identify potential issues that may have developed in other parts of the engine or aircraft. In the event a problem is found, the pilot is notified through one of the in-dash warning lamps. An electronic fault code is then stored in the system memory where it can be retrieved by a Lycoming Authorized Service Center to help in the repair process. The iE^2 engine uses a separate data logger to record a 30-minute detailed record of as many as 45 different engine parameters as well as a historic data trend of each parameter for the life of the engine. This data is available to mechanics with the appropriate training and equipment, and it can be used to greatly simplify the service and maintenance of the engine.

Types of Light-Sport and Experimental Engines

NOTE: All information in this text is for educational illustrational purposes and is not to be used for actual aircraft maintenance. This information is not revised at the same rate as the maintenance manual; always refer to the current maintenance information when performing maintenance on any engine.

Light-Sport Aircraft Engines

Light-sport/ultralight aircraft engines can be classified by several methods, such as by operating cycles, cylinder arrangement, and air or water cooled. An in-line engine generally has two cylinders, is two-cycle, and is available in several horsepower ranges. These engines may be either liquid-cooled, air-cooled, or a combination of both. They have only one crankshaft that drives the reduction gearbox or propeller directly. Most of the other cylinder configurations used are horizontally opposed, ranging from two to six cylinders from several manufacturers. These engines are either gear reduction or direct drive.

Two-Cycle, Two-Cylinder Rotax Engine: Single-Capacitor Discharge Ignition (SCDI), Dual-Capacitor Discharge Ignition (DCDI)

Rotax 447 UL (SCDI) and Rotax 503 UL (DCDI). The Rotax in-line cylinder arrangement has a small frontal area and provides improved streamlining (Fig. 1-20). The two-cylinder, in-line two-stroke engine, which is piston ported with air-cooled cylinder heads and cylinders, is available in a fan or free air-cooled version. Being a two-stroke cycle engine, the oil and fuel must be mixed in the fuel tank on some models. Other models use a lubrication system, such as the 503 oil injection lubrication system. This system does not mix the fuel and oil as the oil is stored in a separate tank.

As the engine needs lubrication, the oil is injected directly from this tank. The typical ignition system is a breakerless ignition system with a dual ignition system used on the 503, and a single ignition system used on the 447 engine series. Both systems are of a magneto capacitor discharge design.

The engine is equipped with a carburetion system with one or two piston-type carburetors. One pneumatic driven fuel pump delivers the fuel to the carburetors. The propeller is driven via a flange connected gearbox with an incorporated shock absorber. The exhaust system collects the exhaust gases and directs them overboard. These engines come with an integrated alternating current (AC) generator (12 V 170 W) with external rectifier-regulator as an optional extra.

Rotax 582 UL DCDI. The Rotax 582 is a two-stroke engine, two cylinders in-line with a rotary valve inlet, and has liquid-cooled cylinder heads and cylinders that use an integrated water pump (Fig. 1-21). The lubrication system can be a fuel/oil mixture or oil injection lubrication. The ignition system is a dual ignition using a breakerless magneto capacitor discharge design. Dual-piston-type carburetors and a pneumatic fuel pump deliver the fuel to the cylinders. The propeller is driven via the prop flange connected gearbox with an incorporated torsional vibration shock absorber. This engine also uses a standard version exhaust system with an electric starter or manual rewind starter.

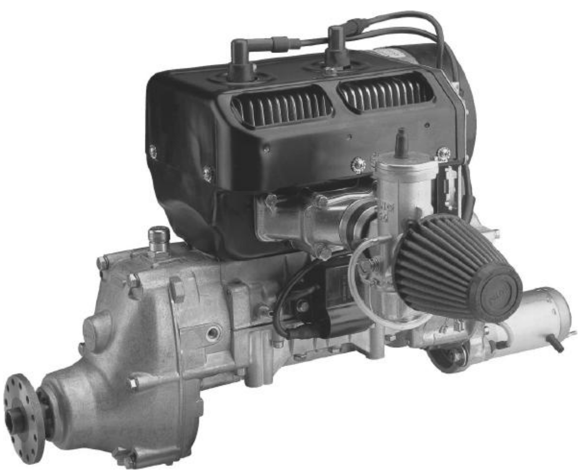

FIGURE 1-20 Rotax in-line cylinder arrangement.

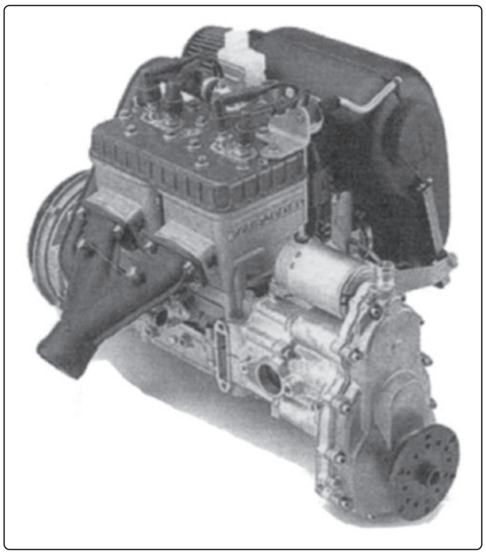

FIGURE 1-21 Rotax 582 engine.

Description of Systems for Two-Stroke Engines

Cooling System of Rotax 447 UL SCDI and Rotax 503 UL DCDI. Two versions of air cooling are available for these engines. The first method is free air cooling, which is a process of engine cooling by an airstream generated by aircraft speed and propeller. The second is fan cooling, which is cooling by an airstream generated by a fan permanently driven from the crankshaft via a V-belt.

Cooling System of the Rotax 582 UL DCDI. Engine cooling for the Rotax 582 is accomplished by liquid-cooled cylinders and cylinder heads (Fig. 1-22). The cooling system is in a two-circuit arrangement. The cooling liquid is supplied by an integrated pump in the engine through the cylinders and the cylinder head to the radiator. The cooling system has to be installed, so that vapor coming from the cylinders and the cylinder head can escape to the top via a hose, either into the water tank of the radiator or to an expansion chamber. The expansion tank is closed by a pressure cap (with excess pressure valve and return valve). As the temperature of the coolant rises, the excess pressure valve opens, and the coolant flows via a hose at atmospheric pressure to the transparent overflow bottle. When cooling down, the coolant is sucked back into the cooling circuit.

Lubrication Systems

Oil Injection Lubrication of Rotax 503 UL DCDI and 582 UL DCDI. Generally, the smaller two-cycle engines are designed to run on a mixture of gasoline and 2 percent oil that is premixed in the fuel tank. The engines are planned to run on an oil-gasoline mixture of 1:50. Other engines use oil injection systems that use an oil pump driven by the crankshaft via the pump gear that feeds the engine with the correct amount of fresh oil. The oil pump is a piston-type pump with a metering system. Diffuser jets in the intake inject pump supplied two-stroke oil with the exact proportioned quantity needed. The oil quantity is defined by the engine rotations per minute and the oil pump lever position. This lever is actuated via a cable connected to the throttle cable. The oil comes to the pump from an oil tank by gravity.

NOTE: In engines that use oil injection, the carburetors are fed with pure gasoline (no oil/gasoline mixture). The oil quantity in the oil tank must be checked before putting the engine into service as the oil is consumed during operation and needs to be replenished.

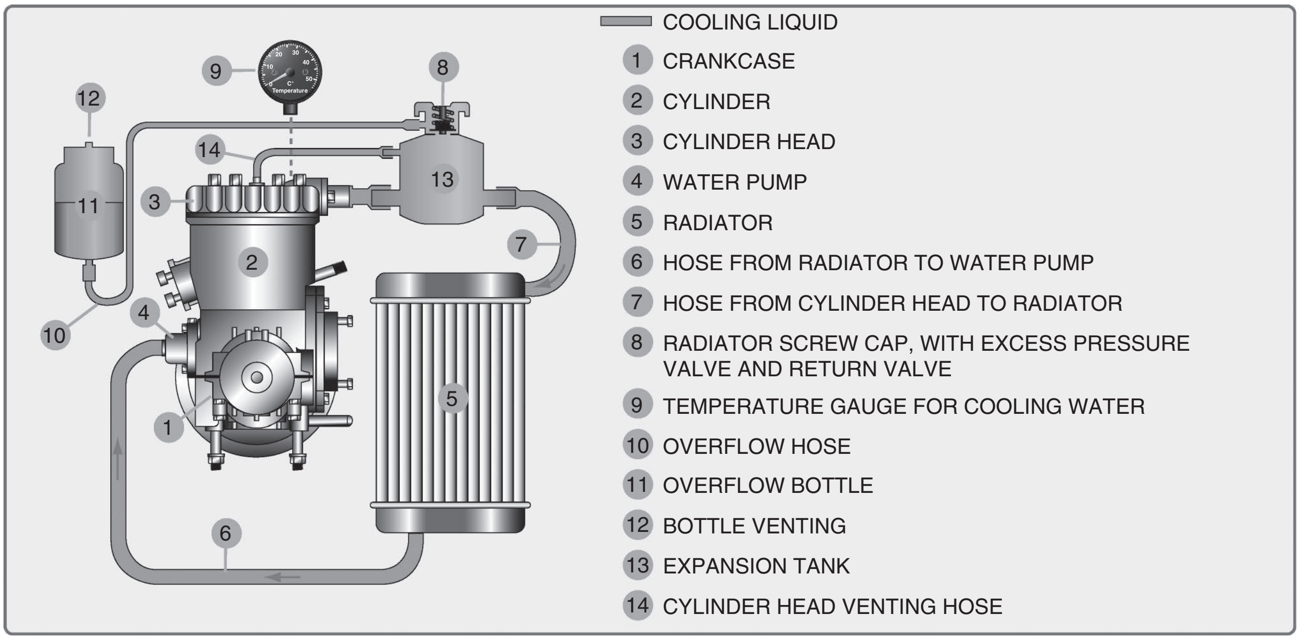

FIGURE 1-22 Rotax 582 cooling system.

Electric System

The 503 UL DCDI and 582 UL DCDI engine types are equipped with a breakerless, SCDI unit with an integrated generator (Fig. 1-23). The 447 UL SCDI engine is equipped with a breakerless, SCDI unit with an integrated generator. The ignition unit is completely free of maintenance and needs no external power supply. Two charging coils are fitted on the generator stator, independent from each other, each feeding one ignition circuit. The energy supplied is stored in the ignition capacitor. At the moment of ignition, the external triggers supply an impulse to the control circuits and the ignition capacitors are discharged via the primary winding of the ignition coil. The secondary winding supplies the high voltage for the ignition spark.

Fuel System

Due to higher lead content in aviation gas (avgas), operation can cause wear and deposits in the combustion chamber to increase. Therefore, avgas should only be used if problems are encountered with vapor lock or if the other fuel types are not available. Caution must be exercised to use only fuel suitable for the relevant climatic conditions, such as using winter fuel for summer operation.

Fuel/Oil Mixing Procedure. The following describes the process for fuel/oil mixing. Use a clean approved container of known volume. To help predilute the oil, pour a small amount of fuel into the container. Fill known amount of oil [two-stroke oil ASTM/Coordinating European Council (CEC) standards], API-TC classification (e.g., Castrol TTS) mixing ratio 1:50 (2%), into container. Oil must be approved for air-cooled engines at 50:1 mixing ratio. Agitate slightly to dilute oil with gasoline. Add gasoline to obtain desired mixture ratio; use a fine mesh screen. Replace the container cap and shake the container thoroughly. Then, using a funnel with a fine mesh screen to prevent the entry of water and foreign particles, transfer the mixture from the container into the fuel tank.

WARNING: *To avoid electrostatic charging at refueling, use only metal containers and ground the aircraft in accordance with the grounding specifications.*

Opposed Light-Sport, Experimental, and Certified Engines

Many certified engines are used with light-sport and experimental aircraft. Generally, cost is a big factor when considering this type of powerplant. The certified engines tend to be much more costly than the noncertified engines.

Rotax 912/914

Figure 1-24 shows a typical four-cylinder, four-stroke Rotax horizontally opposed engine. The opposed-type engine 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. The engine cylinder heads are both liquid-cooled and air-cooled; the air cooling is mostly used on the cylinder. It is generally mounted with the cylinders in a horizontal position.

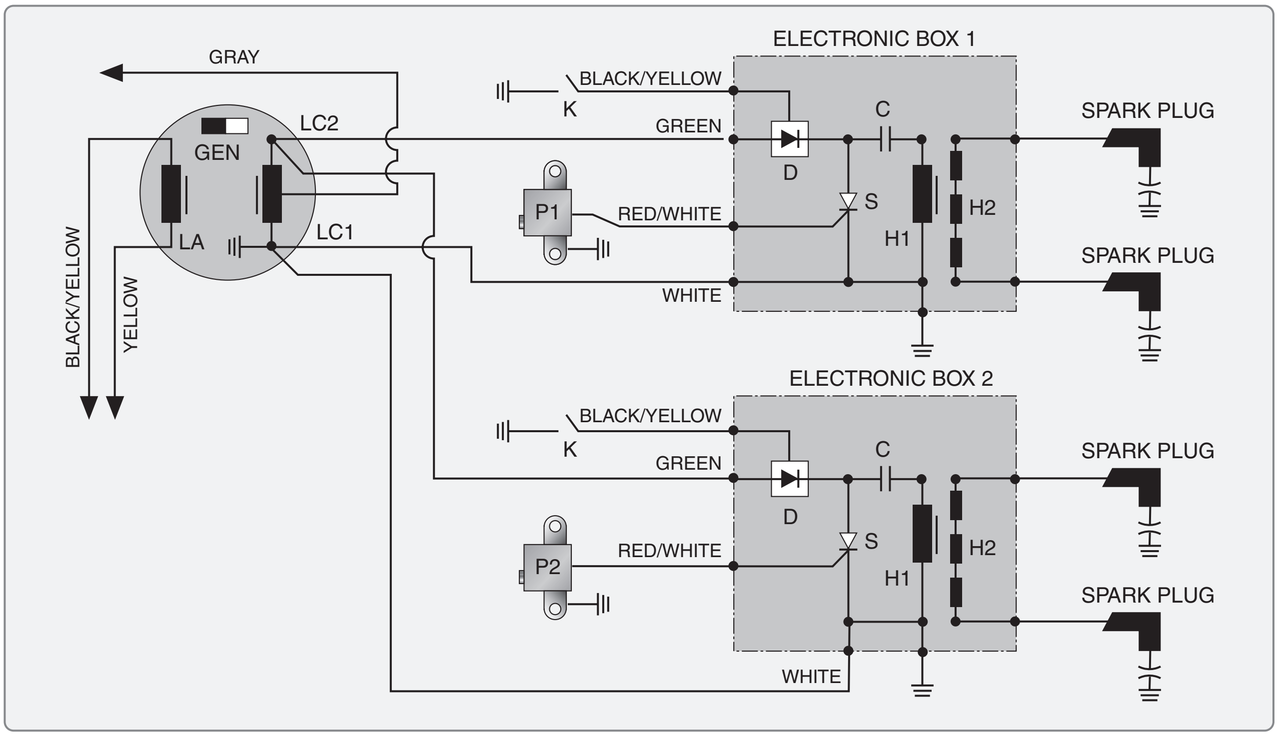

FIGURE 1-23 Rotax 503 and 582 electrical system.

FIGURE 1-24 Typical four-cylinder, four-stroke horizontally opposed engine.

The opposed-type engine has a low weight-to-horsepower ratio, and its narrow silhouette makes it ideal for horizontal installation on the aircraft wings (twin-engine applications). Another advantage is its low vibration characteristics. It is an ideal replacement for the Rotax 582 two-cylinder, two-stroke engine, which powers many of the existing light aircraft, as it is the same weight as the Rotax 582. These engines are ASTM approved for installation into light-sport category aircraft, with some models being FAA-certified engines.

Description of Systems

Cooling System. The cooling system of the Rotax 914, shown in Fig. 1-25, is designed for liquid-cooling of the cylinder heads and ram-air cooling of the cylinders. The cooling system of the cylinder heads is a closed circuit with an expansion tank (Fig. 1-26). The coolant flow is forced by a water pump driven from the camshaft, from the radiator, to the cylinder heads. From the top of the cylinder heads, the coolant passes on to the expansion tank (1). Since the standard location of the radiator (2) is below engine level, the expansion tank located on top of the engine allows for coolant expansion.

The expansion tank is closed by a pressure cap (3) (with an excess pressure valve and return valve). As the temperature of the coolant rises, the excess pressure valve opens and the coolant flows via a hose at atmospheric pressure to the transparent overflow bottle (4). When cooling down, the coolant is sucked back into the cooling circuit. Coolant temperatures are measured by means of temperature probes installed in the cylinder heads 2 and 3. The readings are taken on measuring the hottest point of cylinder head depending on engine installation.

Fuel System. The fuel flows from the tank (1) via a coarse filter/water trap (2) to the two electric fuel pumps (3) connected in series (Fig. 1-27). From the pumps, fuel passes on via the fuel pressure control (4) to the two carburetors (5). Parallel to each fuel pump is a separate check valve (6) installed via the return line (7) that allows surplus fuel to flow back to the fuel tank. Inspection for possible constriction of diameter or obstruction must be accomplished to avoid overflowing of fuel from the carburetors. The return line must not have any resistance to flow. The fuel pressure control ensures that the fuel pressure is always maintained approximately 0.25 bar [3.63 pounds per square inch (psi)] above the variable boost pressure in the air box and thus, ensures proper operation of the carburetors.

Lubrication System. The Rotax 914 engine is provided with a dry, sump-forced lubrication system with a main oil pump with an integrated pressure regulator and

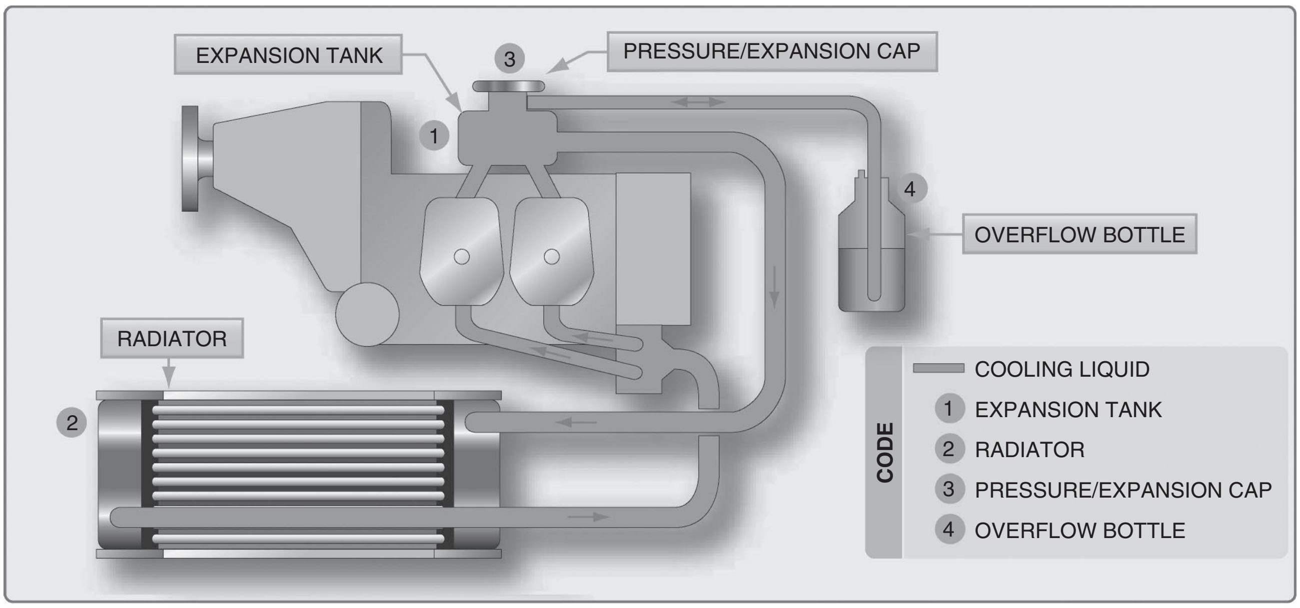

FIGURE 1-25 Rotax 914 cooling system.

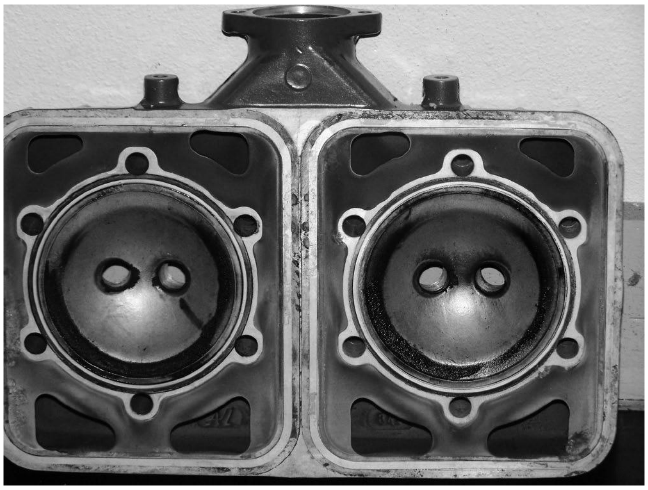

FIGURE 1-26 Water-cooled heads.

an additional suction pump (Fig. 1-28). The oil pumps are driven by the camshaft. The main oil pump draws oil from the oil tank (1) via the oil cooler (2) and forces it through the oil filter to the points of lubrication. It also lubricates the plain bearings of the turbocharger and the propeller governor. The surplus oil emerging from the points of lubrication accumulates on the bottom of crankcase and is forced back to the oil tank by the blow-by gases. The turbocharger is lubricated via a separate oil line (from the main oil pump). The oil emerging from the lower placed turbocharger collects in the oil sump by a separate pump and is pumped back to the oil tank via the oil line (3). The oil circuit is vented via the bore (5) in the oil tank. There is an oil temperature sensor in the oil pump flange for reading of the oil inlet temperature.

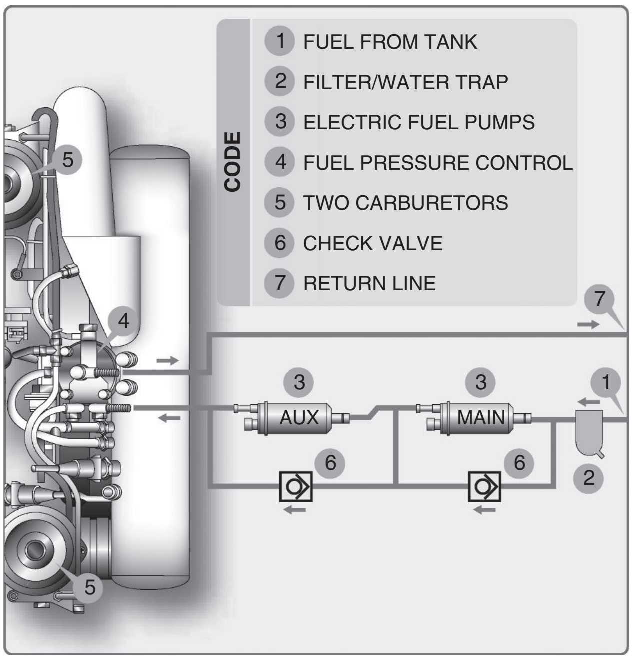

FIGURE 1-27 Fuel system components.

Electric System. The Rotax 914 engine is equipped with a dual ignition unit that uses a breakerless, capacitor discharge design with an integrated generator (Fig. 1-29). The ignition unit is completely free of maintenance and needs no external power supply. Two independent charging coils (1) located on the generator stator supply one ignition circuit each. The energy is stored in capacitors of the electronic modules (2). At the moment of ignition, two each of the four external trigger coils (3) actuate the discharge of the capacitors via the primary circuit of the dual ignition coils (4). The firing order is as follows: 1–4–2–3. The fifth trigger coil (5) is used to provide the revolution counter signal.

Turbocharger and Control System. The Rotax 914 engine is equipped with an exhaust gas turbocharger making use of the energy in the exhaust gas for compression of the intake air or for providing boost pressure to the induction system. The boost pressure in the induction system (air box) is controlled by means of an electronically controlled valve (waste gate) in the exhaust gas turbine. The waste gate regulates the speed of the turbocharger and consequently the boost pressure in the induction system. The required nominal boost pressure in the induction system is determined by the throttle position sensor mounted on the carburetor $\frac{2}{4}$. The sensor's transmitted position is linear 0 to 115 percent, corresponding to a throttle position from idle to full power (Fig. 1-30). For correlation between throttle position and nominal boost pressure in the induction, refer to Fig. 1-31. As shown in the diagram, with the throttle position at 108 to 110 percent results in a rapid rise of nominal boost pressure.

To avoid unstable boost, the throttle should be moved smoothly through this area either to full power (115%) or at a reduced power setting to maximum continuous power. In this range (108–110% throttle position), small changes in throttle position have a big effect on engine performance and speed. These changes are not apparent to the pilot from the throttle lever position. The exact setting for a specific performance is virtually impossible in this range and has to be prevented, as it might cause control fluctuations or surging. Besides the throttle position, overspeeding of the engine and too high intake air temperature have an effect on the nominal boost pressure. If one of the stated factors exceeds the specified limits, the boost pressure is automatically reduced, thus protecting the engine against overboost and detonation.

The turbo control unit (TCU) is furnished with output connections for an external red boost lamp and an orange caution lamp for indications of the functioning of the TCU. When switching on the voltage supply, the two lamps are automatically subject to a function test. Both lamps illuminate for 1 to 2 seconds, then they extinguish. If they do not, a check per the engine maintenance manual is necessary. If the orange caution lamp is not illuminated, then this signals that the TCU is ready for operation. If the lamp is blinking, this indicates a malfunction of the TCU or its periphery systems. Exceeding of the admissible boost pressure activates and illuminates the red boost lamp continuously.

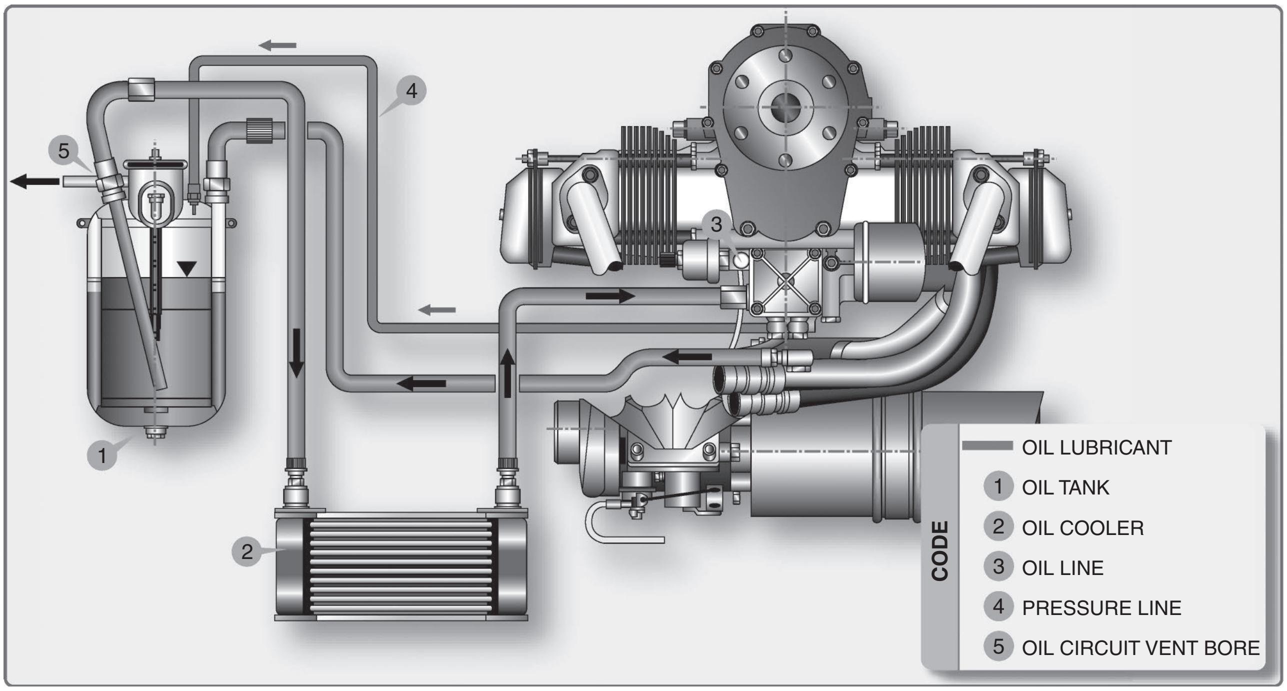

FIGURE 1-28 Lubrication system.

The TCU registers the time of full throttle operation (boost pressure). Full throttle operation for longer than 5 minutes, with the red boost light illuminated, makes the red boost lamp start blinking. The red boost lamp helps the pilot to avoid full power operation for longer than 5 minutes or the engine could be subject to thermal and mechanical overstress.

HKS 700T Engine

The HKS 700T engine is a four-stroke, two-cylinder turbocharged engine equipped with an intercooler (Fig. 1-32). The horizontally opposed cylinders house four valves per cylinder, with a piston displacement of 709 cc. It uses an electronic control fuel injection system. A reduction

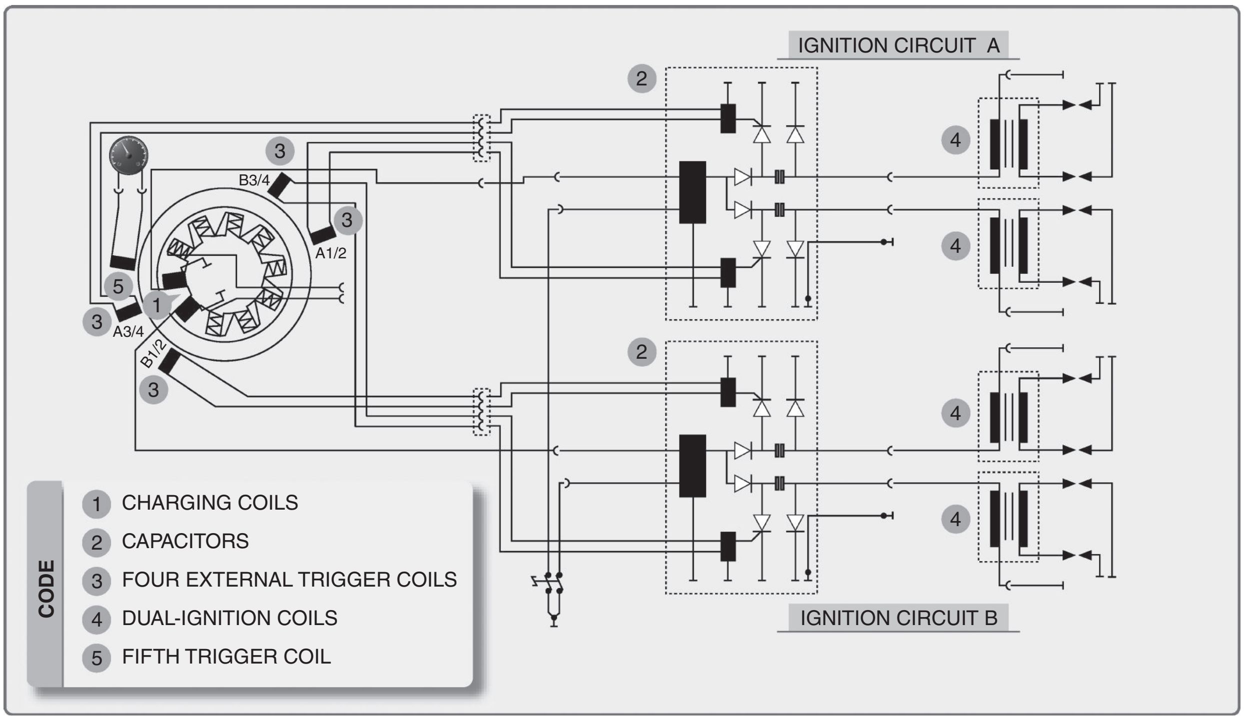

FIGURE 1-29 Electric system.

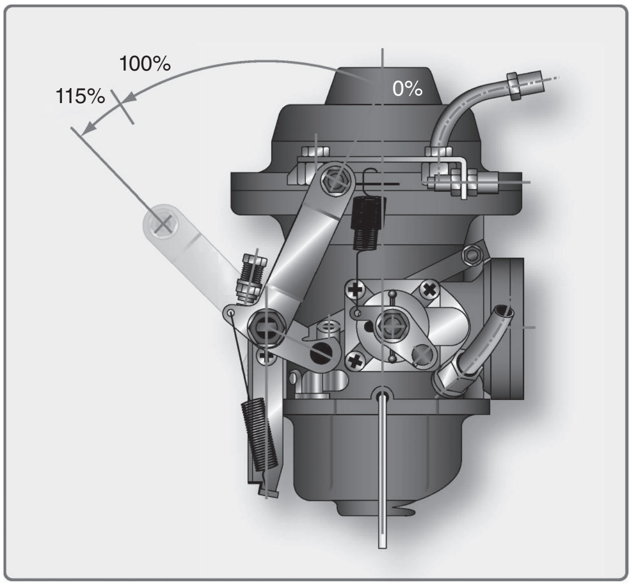

FIGURE 1-30 Turbocharger control system throttle range and position.

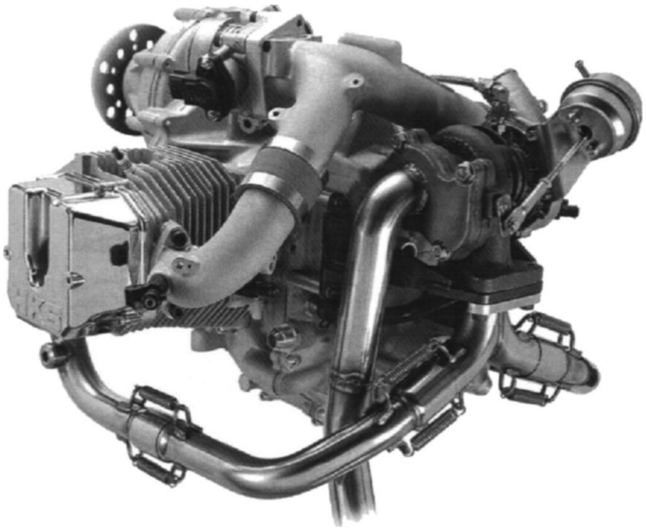

FIGURE 1-32 HKS 700T engine.

gearbox is used to drive the propeller flange at a speed reduction ratio of 2.13 to 1. The engine is rated at 77 hp continuous and 80 hp takeoff (3 minutes) at 4900 and 5300 rpm, respectively. A total, engine weight of 126 lb provides a good power-to-weight ratio. The 700T has a TBO of 500 hours.

Jabiru Light-Sport Engines

Jabiru engines are designed to be manufactured using the latest manufacturing techniques (Fig. 1-33). All Jabiru engines are manufactured, assembled, and ran on a Dynometer, then calibrated before delivery. The crankcase halves, cylinder heads, crankshaft, starter motor housings, gearbox cover (the gearbox powers the distributor rotors), together with many smaller components are machined from solid material.

The sump (oil pan) is the only casting. The cylinders are machined from bar 4140 chrome molybdenum alloy steel, with the pistons running directly in the steel bores. The crankshaft is also machined from 4140 chrome molybdenum alloy steel, the journals of which are precision ground prior to being Magnaflux inspected. The camshaft is manufactured from 4140 chrome molybdenum alloy steel with nitrided journals and cams.

The propeller is direct crankshaft driven and does not use a reduction gearbox. This facilitates its lightweight design and keeps maintenance costs to a minimum. The crankshaft features a removable propeller flange that enables the easy replacement of the front crankshaft seal and provides for a propeller shaft extension to be fitted, should this be required for particular applications. Cylinder heads are machined from a solid aluminum billet that is purchased directly from one company, thereby providing a substantive quality control trail to the material source. Connecting rods are machined from 4140 alloy steel and the 45-mm big end bearings are of the automotive slipper type. The ignition coils are sourced from

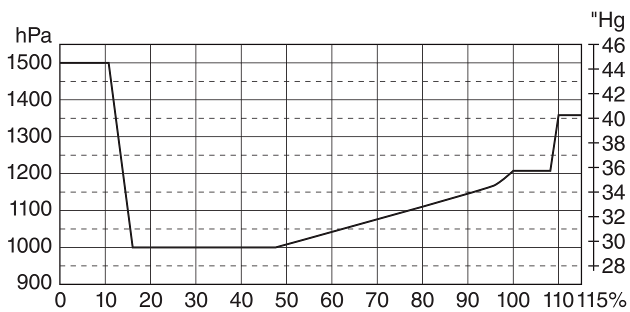

FIGURE 1-31 Correlation between throttle position and nominal boost pressure.

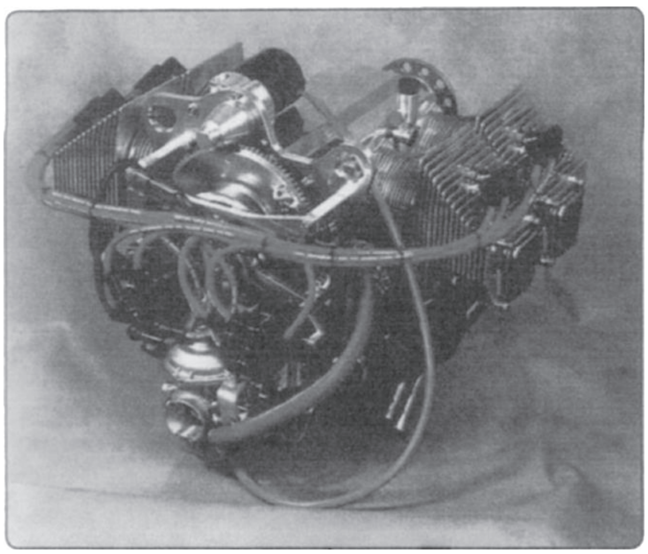

FIGURE 1-33 Jabiru engine.

outside suppliers and are modified by Jabiru for their own particular application.

An integral alternator provides AC rectification for battery charging and electrical accessories. The alternator is attached to the flywheel and is driven directly by the crankshaft. The ignition system is a transistorized electronic system; two fixed coils mounted adjacent to the flywheel are energized by magnets attached to the flywheel. The passing of the coils by the magnets creates the high-voltage current, that is transmitted by high-tension leads to the center post of two automotive type distributors, which are simply rotors and caps, before distribution to automotive spark plugs (two in the top of each cylinder head). The ignition system is fixed timing and, therefore, removes the need for timing adjustment. It is suppressed to prevent radio interference.

The ignition system is fully redundant, self-generating, and does not depend on battery power. The crankshaft is designed with a double bearing at the propeller flange end and a main bearing between each big end. Thrust bearings are located fore and aft of the front double bearing, allowing either tractor or pusher installation. Pistons are remachined to include a piston pin, circlip, and groove. They are all fitted with three rings, the top rings being cast iron to complement the chrome molybdenum cylinder bores. Valves are 7 mm (stem diameter) and are manufactured specifically for the Jabiru engine. The valve drive train includes pushrods from the camshaft followers to valve rockers. The valves are Computer Numerical Control (CNC) machined from steel billet, induction hardened, polished on contact surfaces, and mounted on a shaft through Teflon coated bronze-steel bush. Valve guides are manufactured from aluminum/bronze. Replaceable valve seats are of nickel steel and are shrunk into the aluminum cylinder heads. The valve train is lubricated from the oil gallery. Engines use hydraulic lifters that automatically adjust valve clearance. An internal gear pump is driven directly by the camshaft and provides engine lubrication via an oil circuit that includes an automotive spin-on filter, oil cooler, and built-in relief valve.

The standard engines are supplied with two ram-air cooling ducts, that have been developed by Jabiru to facilitate the cooling of the engine by directing air from the propeller to the critical areas of the engine, particularly the cylinder heads and barrels. The use of these ducts removes the need to design and manufacture baffles and the establishment of a plenum chamber, which is the traditional method of cooling air-cooled, aircraft engines. The fact that these baffles and plenum chamber are not required also ensures a cleaner engine installation, which in turn facilitates maintenance and inspection of the engine and engine components.

The engine is fitted with a 1.5-kW starter motor that is also manufactured by Jabiru and provides very effective starting. The engine has a very low vibration level; however, it is also supported by four large rubber shock mounts attached to the engine mounts at the rear of the engine. The fuel induction system uses a pressure compensating carburetor. Following the carburetor, the fuel/air mixture is drawn through a swept plenum chamber bolted to the sump casting, in which the mixture is warmed prior to entering short induction tubes attached to the cylinder heads.

An effective stainless steel exhaust and muffler system is fitted as standard equipment ensuring very quiet operations. For owners wanting to fit vacuum instruments to their aircraft, the Jabiru engines are designed with a vacuum pump drive direct mounted through a coupling on the rear of the crankshaft.

Jabiru 2200 Aircraft Engine. The Jabiru 2200 cc aircraft engine is a four-cylinder, four-stroke horizontally opposed air-cooled engine. At 132 lb (60 kg) installed weight, it is one of the lightest four-cylinder, four-stroke aircraft engines. Small overall dimensions give it a small frontal area width (23.46 in or 596 mm) that makes it a good engine for tractor applications. The Jabiru engine is designed for either tractor or pusher installation. The Jabiru engine specifications are listed in Fig. 1-34.

The Jabiru 3300 (120 hp) engine features (Fig. 1-35):

- 4-stroke
- 3300 cc (200 in^3) engine
- 6-cylinder horizontally opposed
- 1 central camshaft
- Fully machined aluminum-alloy crankcase
- Overhead valves (OHV)—pushrod operated
- Ram-air cooled
- Wet sump lubrication—4 liter capacity
- Direct propeller drive
- Dual transistorized magneto ignition
- Integrated AC generator
- Electric starter
- Mechanical fuel pump
- Naturally aspirated—1 pressure compensation carburetor

Aeromax Aviation 100 (IFB) Aircraft Engine. Aeromax Aviation produces a version of a 100-hp engine. The engine features a special made integral front bearing (Fig. 1-36). The engine uses an integral permanent magnet 35-amp alternator, lightweight starter, and dual ignition. The compact alternator and starter allow for a streamlined and aerodynamic cowl which improves the fuel efficiency of an experimental aircraft. The Aeromax aircraft engine is an opposed six-cylinder, air-cooled, and direct drive. Being a six-cylinder engine, it has smooth operation. The Aeromax engines are known for their heat dissipation qualities, provided the proper amount of cooling air is provided.

It features a crank extension supported by a massive integral front bearing (IFB) and bearing housing. These engines start out as a GM Corvair automobile core engine. These basic core engines are disassembled and each component that is reused is refurbished and remanufactured. The crankshaft in the Areomax 100 IFB aircraft engine is

Specifications: Jabiru 2200 cc 85 HP Aircraft Engine	
Engine Features	Four-stroke
	Four-cylinder horizontally opposed
Opposed	One central camshaft
	Pushrods
	Overhead valves (OHVs)
(OHV)	Ram-air cooled
	Wet sump lubrication
	Direct propeller drive
	Dual transistorized magneto ignition
Magneto Ignition	Integrated AC generator 20 amp
Generator 20 *Amp*	*Electric starter*
	Mechanical fuel pump
	Naturally aspirated - 1 pressure compensating carburetor
Pressure Compensating Carburetor	Six-bearing crankshaft
Displacement	2200 cc (134 cu. in.)
Bore	97.5 mm
Stroke	74 mm
Compression Ratio	8:1
Directional Rotation of Prop Shaft	Clockwise - pilot's view tractor applications
Ramp Weight	132 lb complete including exhaust, carburetor, starter motor, alternator, and ignition system
Ignition Timing	25° BTDC
Firing Order	1–3–2–4
Power Rating	85 hp @ 3300 rpm
Fuel Consumption at 75% Power	4 US gal/h
Fuel	Avgas 100 LL or autogas 91 octane minimum
Oil	Aeroshell W100 or equivalent
Oil Capacity	2.3 quarts
Spark Plugs	NGK D9EA - automotive

FIGURE 1-34 Jabiru 2200 cc specifications.

thoroughly inspected, including a magnaflux inspection. After ensuring the crank is free of any defects, it is extended by mounting the crank extension hub on its front. Then, the crank is ground true, with all five bearing surfaces (four original and the new-extended crank's front bearing), being true to each other and perpendicular to the crank's prop flange (Fig. 1-37).

All radiuses are smooth with no sharp corners where stress could concentrate. Every crankshaft is nitrated, which is a heat/chemical process that hardens the crank surfaces. The crank reinforcement coupled with the IFB is required to counter the additional dynamic and bending loads introduced on the crank in an aircraft application. The engine case is totally refurbished and checked for wear. Any studs or bolts that show wear are replaced. The engine heads are machined to proper specifications and all new valves, guides, and valve train components are installed. A three-angle valve grind and lapping ensure a good valve seal.

Once the engine is assembled, it is installed on a test stand, prelubricated, and inspected. The engine is, then, run

Jabiru 3300 cc Aircraft Engine	
Displacement	3300 cc (202 cu. in.)
Bore	97.5 mm (3.838")
Stroke	74 mm (2.913")
Aircraft Engine	Jabiru 3300 cc 120 hp
Compression Ratio	8:1
Directional Rotation of Prop Shaft	Clockwise - Pilot's view tractor applications
Ramp Weight	178 lb (81 kg) complete including exhaust, carburetor, starter motor, alternator, and ignition system
Ignition Timing	25° BTDC fixed timing
Firing Order	1–4–5–2–3–6
Power Rating	120 hp @ 3300 rpm
Fuel Consumption at 75% Power	26 l/hr (6.87 US gal/h)
Fuel	Avgas 100 LL or autogas 91 octane minimum
Oil	Aeroshell W100 or equivalent
Oil Capacity	3.51 (3.69 quarts)
Spark Plugs	NGK D9EA - automotive

FIGURE 1-35 Jabiru 3300 cc aircraft engine.

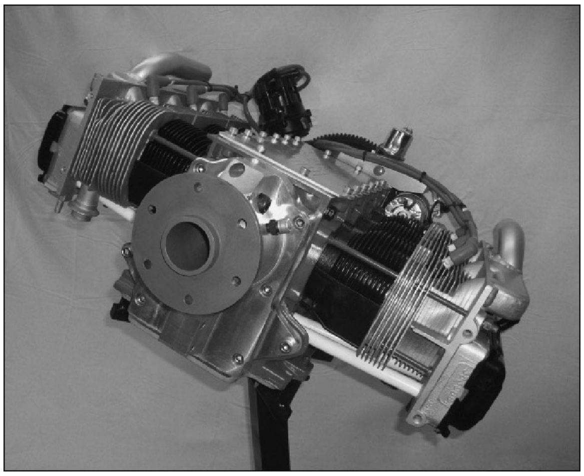

FIGURE 1-36 Aeromax direct-drive, air-cooled, six-cylinder engine.

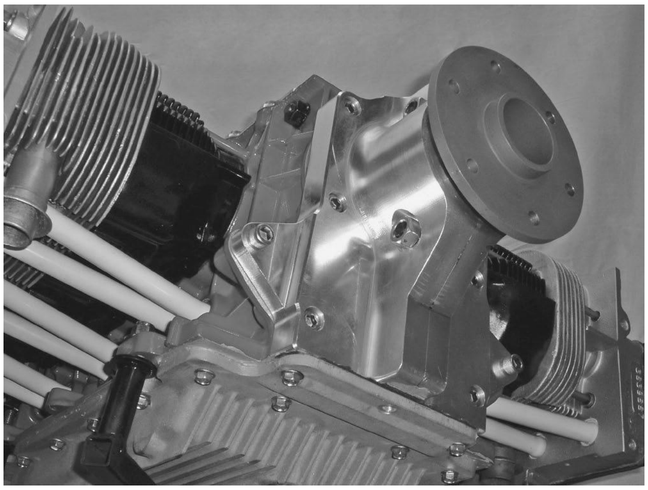

FIGURE 1-37 Front-end bearing on the 1000 IFB engine.

several times for a total of 2 hours. The engine is carefully inspected after each run to ensure that it is in excellent operating condition. At the end of test running the engine, the oil filter is removed and cut for inspection. Its internal condition is recorded. This process is documented and kept on file for each individual engine. Once the engine's proper performance is assured, it is removed and packaged in a custom built crate for shipping. Each engine is shipped with its engine service and operations manual. This manual contains information pertaining to installation, break-in, testing, tune-up, troubleshooting, repair, and inspection procedures. The specifications for the Aeromax 100 engine are outlined in Fig. 1-38.

Direct Drive VW Engines

Revmaster R-2300 Engine

The Revmaster R-2300 engine maintains Revmaster's systems and parts, including its RM-049 heads that feature large fins and a hemispherical combustion chamber (Fig. 1-39). It maintains the earlier R-2200 engine's top horsepower (82)

Aeromax 100 Engine Specifications	
Power output: 100 hp continuous at 3200 rpm	Air-cooled
Displacement: 2.7 L	Six cylinders
Compression: 9:1	Dual ignition–single plug
Weight: 210 lb	Normally aspirated
Direct Drive	CHT max: 475 F
Rear lightweight. Starter and 45 amp alternator	New forged pistons
Counterclockwise rotation	Balanced and nitrated crankshaft
Harmonic balancer	New hydraulic lifters
Remanufactured case	New main/rod bearings
Remanufactured heads with new guides, valves, valve train, intake	New all replaceable parts
Remanufactured cylinders	New spark plug wiring harness
New lightweight aluminum cylinder - optional	Remanufactured dual-ignition distributor with new points set and electronic module
New high-torque cam	New oil pump
New CNC prop hub and safety shaft	New oil pan
New Aeromax top cover and data plate	Engine service manual

FIGURE 1-38 Aeromax 100 engine specifications.

at 2950 rpm continuous (Fig. 1-40). Takeoff power is rated at 85 to 3350 rpm. The additional power comes from a bore of 94 mm plus lengthening of the R-2200's connecting rods, plus increasing the stroke from 78 to 84 mm. The longer stroke results in more displacement, and longer connecting rods yield better vibration and power characteristics. The lower cruise rpm allows the use of longer propellers, and the higher peak horsepower can be felt in shorter takeoffs and steeper climbs.

The Revmaster's four main bearing crankshaft runs on a 60-mm center main bearing, is forged from 4340 steel, and uses nitrided journals. Thrust is handled by the 55-mm #3 bearing at the propeller end of the crank. Fully utilizing its robust #4 main bearing, the Revmaster crank has built-in oil-controlled propeller capability, a feature unique in this horsepower range; nonwood props are usable with these engines.

Moving from the crankcase and main bearings, the cylinders are made by using centrifugally cast chilled iron. The pistons are forged out of high-quality aluminum-alloy, machined and balanced in a set of four. There are two sizes of pistons, 92 and 94 mm, designed to be compatible with 78- to 82-mm stroke crankshafts. The cylinder set also contains piston rings, wrist pins, and locks. The direct-drive R-2300 uses a dual CDI ignition with eight coil spark to eight spark plugs, dual 20-amp alternators, oil cooler, and its proprietary Rev-Flo carburetor, while introducing the longer cylinders that do not require spacers. The automotive-based bearings, valves, valve springs, and piston rings (among others) make rebuilds easy and inexpensive.

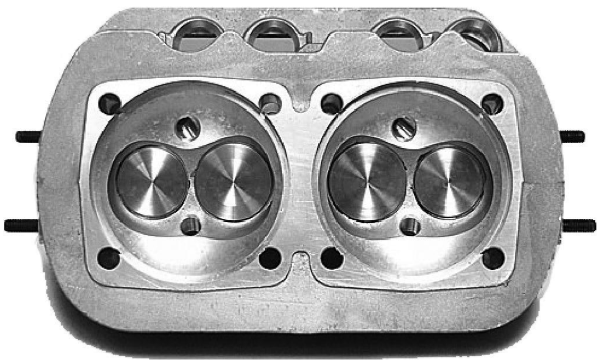

FIGURE 1-39 Hemispherical combustion chamber within the Revmaster R-2300 heads.

FIGURE 1-40 Revmaster R-2300 engine.

Great Plains Aircraft Volkswagen (VW) Conversions

Great Plains Aircraft is one company that offers several configurations of the Volkswagen (VW) aircraft engine conversion. One very popular model is the front-drive long block kits that offer a four-cycle, four-cylinder opposed engine with horsepower that ranges from approximately 60 to 100 (Fig. 1-41). The long block engine kits, which are complete, can be assembled in the field or shipped completely assembled, and are available from 1600 cc up through 2276 cc. All the engine kits are built from proven time-tested components and are shipped with a Type 1 VW Engine Assembly Manual. This manual was written by the manufacturer, specifically for the assembly of their engine kits. Also included are how to determine service and maintenance procedures and many tips on how to set up and operate the engine correctly. The crankshaft used in the 2180- to 2276-cc engines is an 82-mm crankshaft made from a forged billet of E4340 steel, machined and magnafluxed twice. The end of the crankshaft features a $\frac{1}{2}$-in fine thread versus a 20-mm thread found on the standard automotive crank.

Teledyne Continental O-200 Engine

The O-200 series engine has become a popular engine for use in light-sport aircraft. The O-200-A/B is a four-cylinder, carbureted engine producing 100 bhp and has a crankshaft speed of 2750 rpm (Fig. 1-42). The engine has horizontally opposed air-cooled cylinders. The engine cylinders have an overhead valve design with updraft intake inlets and downdraft exhaust outlets mounted on the bottom of the cylinder. The O-200-A/B engines have a 201-in^3 displacement achieved by using a cylinder design with a 4.06-in-diameter bore and a 3.88-in. stroke. The dry weight of the engine is 170.18 lb without accessories. The weight of the engine with installed accessories is approximately 215 lb. The engine is provided with four integral rear engine mounts. A crankcase breather port is located on the 1-3 side of the crankcase forward of the #3 cylinder. The engine lubrication system is a wet sump, high-pressure oil system. The engine lubrication system includes the internal engine-driven pressure oil pump, oil pressure relief valve, pressure oil screen mounted on the rear of the

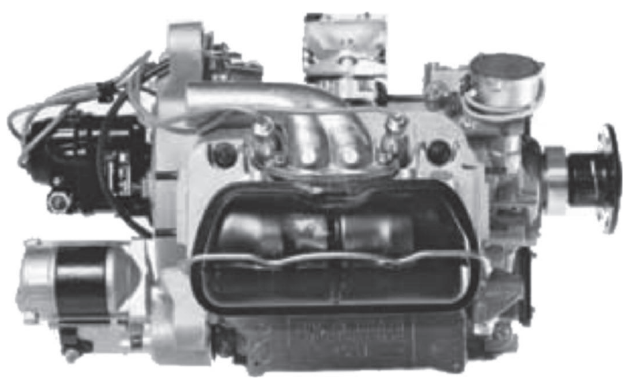

FIGURE 1-41 Great Plains' Volkswagen conversion.

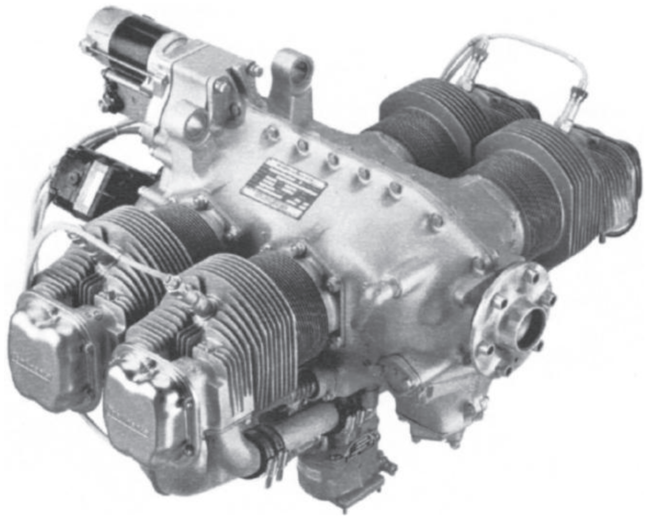

FIGURE 1-42 O-200 Continental engine.

accessory case and pressure instrumentation. A fitting is provided at the 1-3 side of the crankcase for oil pressure measurement. The oil sump capacity is 6 quarts maximum. The O-200-A/B induction system consists of an updraft intake manifold with the air intake and throttle mounted below the engine. Engine manifold pressure is measured at a port located on the 2-4 side of the intake air manifold. The O-200-A/B is equipped with a carburetor that meters fuel flow as the flight-deck throttle and mixture controls are changed.

Lycoming O-233 Series Light-Sport Aircraft Engine

Lycoming Engines, a Textron Inc. company, produces an experimental noncertified version of its 233 series light-sport aircraft engine (Fig. 1-43). The engine is light and capable of running on unleaded automotive fuels, as well as avgas. The engine features dual CDI spark ignition, an optimized

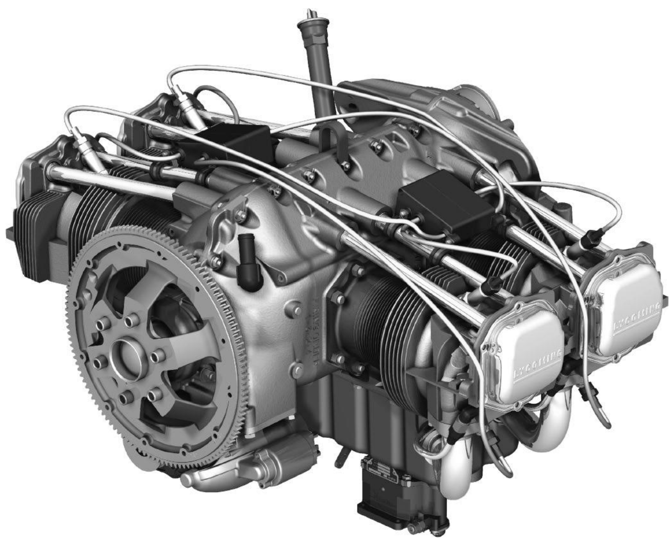

FIGURE 1-43 Lycoming O-233 engine.

FIGURE 1-44 Gemini diesel engine. (*Superior Air Parts.*)

oil sump, a streamlined accessory housing, hydraulically adjusted tappets, a lightweight starter, and a lightweight alternator with integral voltage regulator. It has a dry weight of 213 lb (including the fuel pump) and offers continuous power ratings up to 115 hp at 2800 rpm. In addition to its multi-gasoline fuel capability, it has proven to be very reliable with a TBO of 2400 hours. The initial standard version of the engine is carbureted, but fuel-injected configurations of the engine are also available.

Superior Air Parts is producing a 100-hp compression ignition diesel for experimental and light sport aircraft called the Gemini 100 (Fig. 1-44). The engine will feature a cast aluminum block and iron piston sleeves. It has a simplistic configuration which uses six horizontal opposed pistons housed in three cylinders, each sharing a common fuel injector and glow plug. The engine is a two-stroke supercharged liquid-cooled engine which weighs about 200 lb. The projected fuel consumption is 4.5 gal/h fuel burn at 75 percent power. The basic engine will be for experimental aircraft, followed by ASTM approval for light-sport aircraft (LSA) and finally for part 33 (the FAR that sets standards for FAA engine certification). Time before overhaul is projected to be 2000 hours.

Most diesel aircraft engines are water-cooled and turbocharged, and employ a single-lever digital engine management system (FADEC). This feature provides for one-lever operation, which simplifies engine management. The Centurion diesel engine (Fig. 1-45) uses jet A fuel, and has a high compression ratio and a digitally controlled fuel injection system.

The Centurion series is always equipped with a constant-speed propeller, which allows the engine to be operated at optimum speed. The engine requires a reduction gearbox to lower propeller rpm to an expectable propeller tip speed. The constant-speed propeller and reduction gearbox result in a propeller tip speed that is 10 to 15 percent lower. The diesel engine's high compression results in better thermal efficiency.

Diesel Engines

A Centurion engine, complete with CSU, reduction gearbox, turbocharger, and FADEC, is considerably heavier than the more conventional Continental and Lycoming engines with which it competes, but this weight disadvantage is compensated for by the Centurion's lower fuel consumption. Designed as a larger engine to replace 300-hp (224-kW) gasoline engines, this new V8 design produces 350 hp (261 kW).

Jet Propulsion History

During World War II, the demand for increased speed and power expedited the progress which was already taking place in the development of jet propulsion powerplants. As a result of the impetus given by the requirements of the War and Navy departments in the United States and by similar demands on the part of Great Britain, engineers in England and the United States designed, manufactured, and tested in flight an amazing variety of jet propulsion powerplants. Also note that the government was not trailing behind in the jet propulsion race, because the first flight by an airplane powered with a true jet engine was made in Germany on August 27, 1939. The airplane was a Heinkel He 178 and was powered by a Heinkel HeS 3B turbojet engine.

The first practical turbojet engines in England and the United States evolved from the work of Sir Frank Whittle in England. The success of experiments with this engine led to the development and manufacture of the Whittle W1 engine.

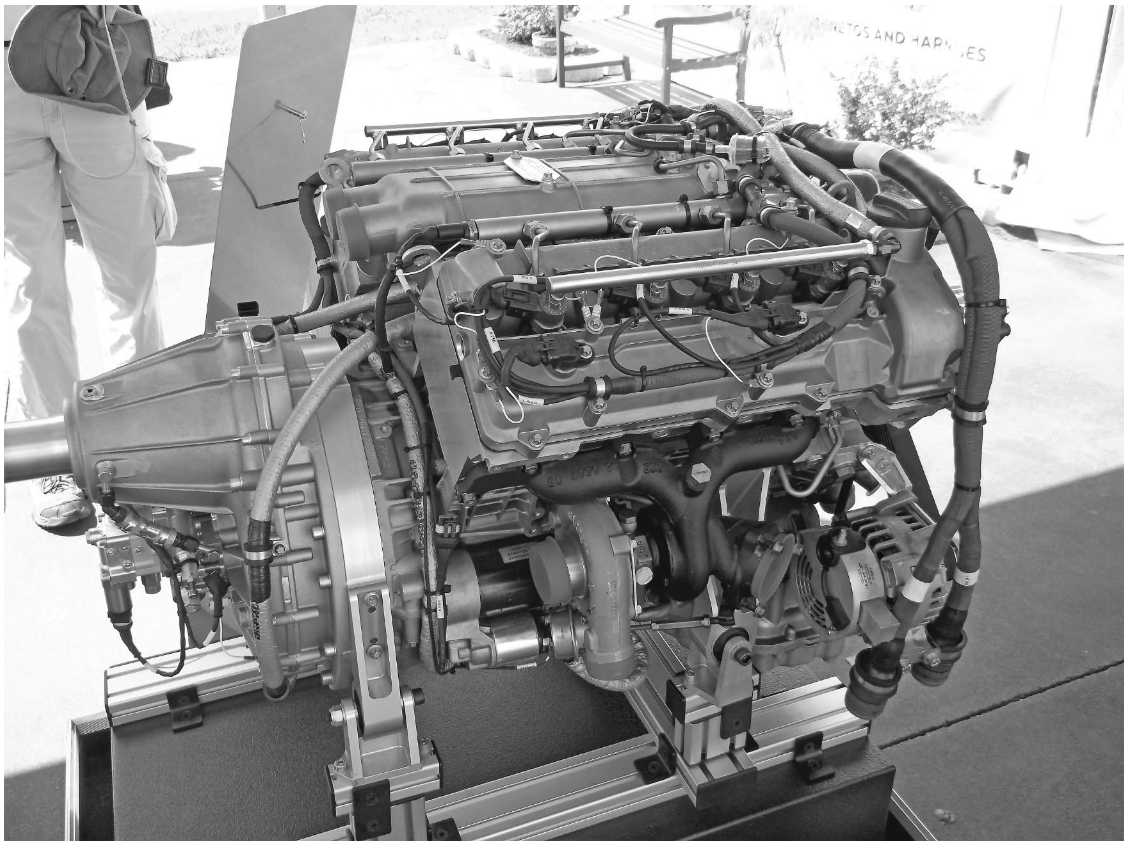

FIGURE 1-45 Centurion 4.0.

Under agreement with the British government, the United States was authorized to manufacture an engine of a design similar to the W1. The General Electric Company was given a contract to build the engine because of its extensive experience with turbine manufacture and with the development of turbosuperchargers used for military aircraft in World War II. Accordingly, the General Electric GE I-A engine was built and successfully flown in a Bell XP-59A airplane.

The successful development of jet propulsion is beyond question the greatest single advance in aviation since the Wright brothers made their first flight. The speed of aircraft has increased from below Mach 1, the speed of sound, to speeds of more than Mach 4. Commercial airliners now operate at more than 600 miles per hour (mph) [965.6 kilometers per hour (km/h)] rather than at speeds of around 350 mph (563.26 km/h), which is usually about the maximum for conventional propeller-driven airliners.

Gas-Turbine Engine Progress

The gas-turbine engine can be used as a **turbojet engine** (thrust developed by exhaust gases alone), a **turbofan engine** (thrust developed by a combination of exhaust gases and fan air), a **turboprop engine** (in which a gas-turbine engine turns a gearbox for driving propellers), and a **turboshaft engine** (which drives helicopter rotors). Small gas-turbine engines called **APUs** (auxiliary power units) have been developed to supply transport-category aircraft with electrical and pneumatic power. Although these units can be used both on the ground and in the air, they are mainly used on the ground.

Gas-turbine engines are used for propulsion in many different types of aircraft. These aircraft include airliners, business aircraft, training aircraft, helicopters, and agricultural aircraft. During the development of the gas-turbine engine, many challenges have faced designers and engineers. Some of the concerns which designers are constantly striving to improve on gas-turbine engines are performance, sound levels, fuel efficiency, ease of maintenance, dependability, and reliability. Many different types of gas-turbine engines have been developed to meet the overall propulsion needs of the aviation community. An example of an engine which incorporates many of the learned technologies needed to provide excellent fuel consumption, low emissions, and many of the characteristics mentioned earlier, is the GE LEAP engine, shown in Fig. 1-46. This engine is a **high-bypass turbofan engine**, which incorporates much new technology. The LEAP engine features an advanced combustor as well as use of ceramic matrix composites on many engine components, especially in hot sections of the engine. This new combustor design will reduce emissions from the combustion process. New types of composite fan blades reduce weight and increase efficiency by reducing the number of blades needed.

FIGURE 1-46 LEAP high-bypass propulsion system. (*General Electric*.)

This improved technology will allow longer engine life with easier maintenance.

The largest increase in turbine technology has been the use of electronic engine control systems for full authority engine control. This also allowed for full integration with aircraft monitoring systems. The huge amount of thrust developed by each engine can be (well over 100 000 lb of thrust) has allowed for heavier aircraft with fewer engines. The engine electronic control system automatically monitors and controls several separate systems during engine operation. Some examples of these systems are engine starting, relighting following flame-out detection, total control of fuel control as per pilot input, variable inlet guide vane/variable stator vanes position, compressor bleed valves, engine oil/fuel heat management, gearbox cooling airflow, turbine case cooling airflow, high-pressure valve for aircraft cabin air, probe heater control, thrust reverser, and turbine overheat data. These systems and more will be explained in detail in the chapters on turbine engines later in this text.

REVIEW QUESTIONS

1. List the advantages of the in-line engine.
2. Describe the difference between upright-V-type and inverted-V-type engines.
3. What type of reciprocating engine design provides the best power-to-weight ratio?
4. List the advantages of the opposed-type engine design.
5. Conventional piston engines are classified according to what characteristics?
6. Name four common engine classifications by cylinder arrangement.
7. The letter "O" in an engine designation is used to denote what?
8. The greatest single advance in aircraft propulsion was the development of what type of engine?
9. List the certified engines mentioned in this chapter.
10. List the light-sport engines mentioned in this chapter.
11. List the major components in an engine monitoring system.

Reciprocating-Engine Construction and Nomenclature 2

INTRODUCTION

Familiarity with an engine's components and construction is basic to understanding its operating principles and maintenance practices. In the construction of an aircraft reciprocating engine, reliability of the working parts is of primary importance. This need generally requires the use of strong, and at times heavy, materials which can result in a bulky and heavy engine. A major problem in the design of aircraft engine components lies in constructing parts strong enough to be reliable but light enough for use in an aircraft. Moving parts are carefully machined and balanced in an effort to minimize vibration and fatigue. In the construction of an aircraft engine, individual components must be designed and constructed in order to obtain a powerplant which has good reliability, weighs little, and is economical to operate.

This chapter describes the major components and construction principles of an aircraft reciprocating engine.

THE CRANKCASE

The **crankcase** of an engine is the housing that encloses the various mechanisms surrounding the crankshaft; therefore, it is the foundation of the engine. The functions of the crankcase are as follows: (1) it must support itself, (2) it contains the bearings in which the crankshaft revolves, (3) it provides a tight enclosure for the lubricating oil, (4) it supports various internal and external mechanisms of the powerplant, (5) it provides mountings for attachment to the airplane, (6) it provides support for the attachment of the cylinders, and (7) by reason of its strength and rigidity, it prevents the misalignment of the crankshaft and its bearings.

Crankcases come in many sizes and shapes and may be of one-piece or multipiece construction. Most aircraft engine crankcases are made of aluminum alloys because they are both light and strong. Although the variety of crankcase designs makes any attempt at classification difficult, they may be divided into three broad groups for discussion: (1) opposed-engine crankcases, (2) radial-engine crankcases, and (3) in-line and V-type engine crankcases.

Opposed-Engine Crankcase

The crankcase for a four-cylinder opposed engine is shown in Fig. 2-1. This assembly consists of two matching, reinforced aluminum-alloy castings divided vertically at the centerline of the engine and fastened together by means of a series of studs and nuts. The mating surfaces of the crankcase are joined without the use of a gasket, and the main-bearing bores are machined for the use of precision-type main-bearing inserts. Machined mounting pads are incorporated into the crankcase for attaching the accessory housing, cylinders, and oil sump, as shown in Fig. 2-2. Opposed engines with propeller reduction gearing usually incorporate a separate nose section to house the gears.

The crankcase of the opposed engine contains bosses and machined bores to serve as bearings for the camshaft. On the camshaft side of each crankcase half are the tappet bores which carry the hydraulic valve tappet bodies.

Essential portions of the lubricating system are contained in the crankcase. Oil passages and galleries are drilled in the sections of the case to supply the crankshaft bearings, camshaft bearings, and various other moving parts which require lubrication. During overhaul, the technician must make sure that all oil passages are free of foreign matter and that passages are not blocked by gaskets during assembly.

Radial-Engine Crankcase

Radial-engine crankcases (see Fig. 2-3) may have as few as three or as many as seven principal sections, the number depending on the size and type of the engine, although large engines usually have more sections than small ones. For the purpose of describing radial-engine crankcases, it is customary to assume that the typical radial-engine crankcase has four major sections, although this is not necessarily true.

The **front section**, or **nose section**, is usually made of an aluminum alloy, its housing is approximately bell-shaped, and it is fastened to the power section by studs and nuts or cap screws. In most cases, this section supports a propeller thrust bearing, a propeller-governor drive shaft, and a propeller reduction-gear assembly if the engine provides for propeller speed reduction. It may also include an oil scavenge pump and a cam-plate or cam-ring mechanism.

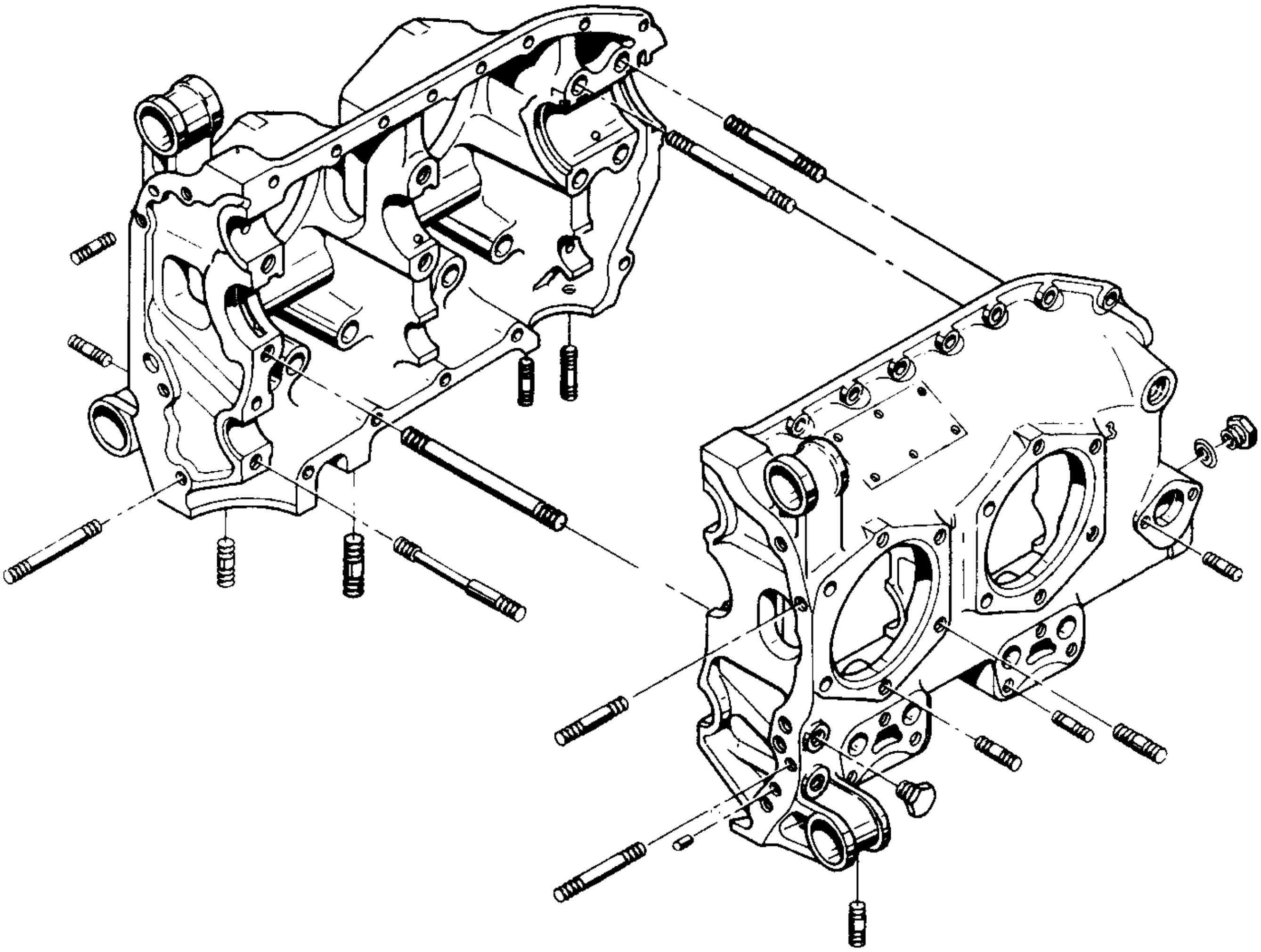

FIGURE 2-1 Crankcase for a four-cylinder opposed engine.

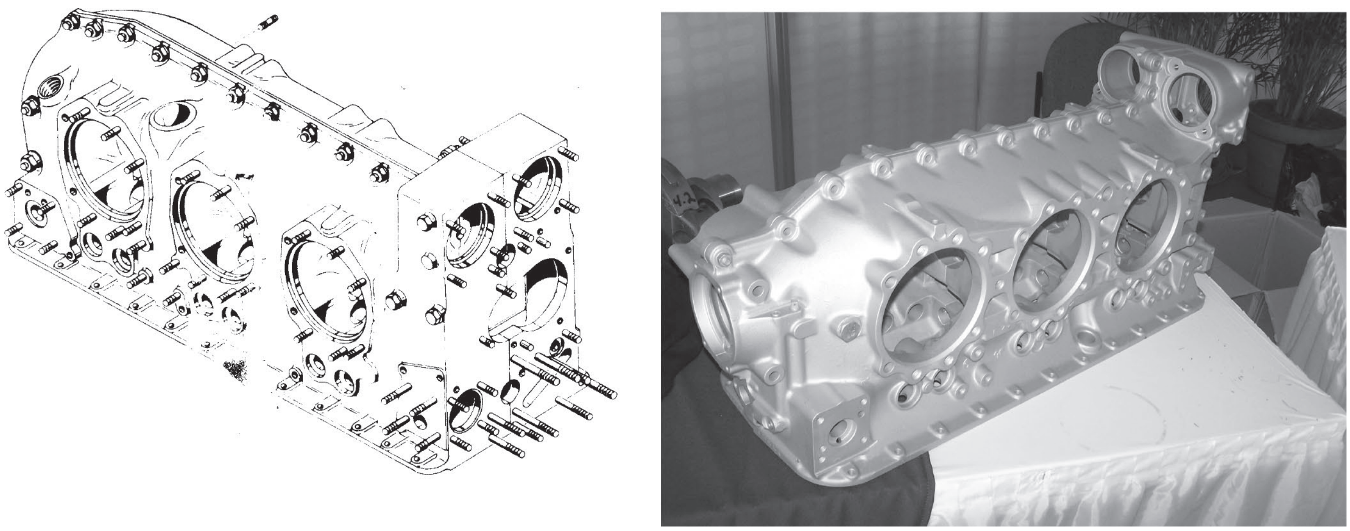

FIGURE 2-2 Crankcase machined mounting pads for a six-cylinder opposed engine.

This section may also provide the mountings for a propeller governor control valve, a crankcase breather, an oil sump, magnetos, and magneto distributors. The engines which have magnetos mounted on the nose case are usually of the higher power ranges. The advantage of mounting the magneto on the nose section is in cooling. When the magnetos are on the nose section of the engine, they are exposed to a large volume of ram air; thus, they are kept

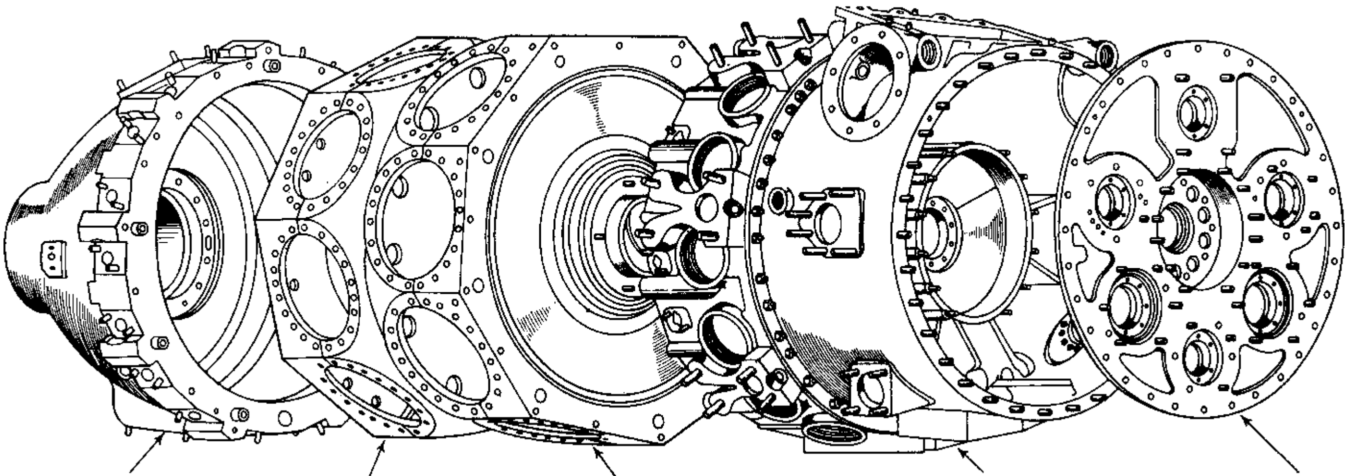

FIGURE 2-3 Crankcase for a twin-row radial engine.

much cooler than when they are mounted on the accessory section.

The **main power section** usually consists of one, two, or possibly three pieces of high-strength heat-treated aluminum-alloy or steel forgings, bolted together if there is more than one piece. The use of a two-part main power section for a radial engine makes it possible to add strength to this highly stressed section of the engine. The cam-operating mechanism is usually housed and supported by the main crankcase section. At the center of each main crankcase web section are crankshaft bearing supports. Cylinder mounting pads are located radially around the outside circumference of the power section. The cylinders are fastened to the pads by means of studs and nuts or cap screws. Oil seals are located between the front section and the main section. Similar seals are installed between the power section and the fuel induction and distribution section.

The **fuel induction and distribution section** is normally located immediately behind the main (power) section and may be of either one- or two-piece construction. It is sometimes called the **blower section** or the **supercharger section** because its principal function is to house the blower or supercharger impeller and diffuser vanes. There are openings on the outside circumference of the housing for attaching the individual induction pipes, a small opening for the attachment of the manifold pressure line, and internal passages which lead to the supercharger drain valve.

The **accessory section** provides mounting pads for the accessory units, such as the fuel pumps, vacuum pumps, lubricating oil pumps, tachometer generators, generators, magnetos, starters, two-speed supercharger control valves, oil filtering screens, Cuno filters, and other items of accessory equipment. In some aircraft powerplants, the cover for the supercharger rear housing is made of an aluminum-alloy or a magnesium-alloy casting in the form of a heavily ribbed plate that provides the mounting pads for the accessory units; but in other powerplants, the housing for the accessory units may be mounted directly on the rear of the crankcase. Regardless of the construction and location of the accessory housing, it contains the gears for driving the accessories which are operated by engine power.

In-Line and V-Type Engine Crankcases

Large in-line and V-type engine crankcases usually have four major sections: (1) the front, or nose, section; (2) the main, or power, section; (3) the fuel induction and distribution section; and (4) the accessory section.

The front, or nose, section is directly behind the propeller in most tractor-type airplanes. A **tractor-type airplane** is one in which the propeller "pulls" the airplane forward. The nose section may be cast as part of the main, or power, section, or it may be a separate construction with a dome or conical shape to reduce drag. Its function is to house the propeller shaft, the propeller thrust bearing, the propeller reduction-gear train, and sometimes a mounting pad for the propeller governor. In a very few arrangements where the nose section is not located close to the engine, the propeller is connected to the engine through an extension shaft and the reduction-gear drive has its own lubricating system. This same arrangement is found in some turboprop engines.

The main, or power, section varies greatly in design for different engines. When it is made up of two parts, one part supports one half of each crankshaft bearing and the other supports the opposite half of each bearing. The cylinders are normally mounted on and bolted to the heavier of the two parts of this section on an in-line engine, and the crankshaft bearings are usually supported by reinforcing weblike partitions. External mounting lugs and bosses are provided for attaching the engine to the engine mount.

The fuel induction and distribution section is normally located next to the main, or power, section. This section houses the diffuser vanes and supports the internal blower impeller when the engine is equipped with an internal blower system. The induction manifold is located between the fuel induction and distribution section and the cylinders. The housing of this section has an opening for the attachment of a manifold pressure gauge line, and it also has internal passages for the fuel drain valve of the blower case. The **fuel drain valve** is designed to permit the automatic drainage of excess fuel from the blower case.

The **accessory section** may be a separate unit mounted directly on the fuel induction and distribution section, or it may form a part of the fuel induction and distribution section. It contains the accessory drive-gear train and has mounting pads for the fuel pump, coolant pump, vacuum pump, lubricating oil pumps, magnetos, tachometer generator, and similar devices operated by engine power. The material used in constructing this section is generally either an aluminum-alloy casting or a magnesium-alloy casting.

BEARINGS

A **bearing** is any surface that supports or is supported by another surface. It is a part in which a journal, pivot, pin, shaft, or similar device turns or revolves. The bearings used in aircraft engines are designed to produce minimum friction and maximum wear resistance.

A good bearing has two broad characteristics: (1) it must be made of a material that is strong enough to withstand the pressure imposed on it and yet permit the other surface to move with a minimum of wear and friction, and (2) the parts must be held in position within very close tolerances to provide quiet and efficient operation and at the same time permit freedom of motion.

Bearings must reduce the friction of moving parts and also take thrust loads, radial loads, or combinations of thrust and radial loads. Those which are designed primarily to take thrust loads are called **thrust bearings**.

Plain Bearings

Plain bearings are illustrated in Fig. 2-4. These bearings are usually designed to take radial loads; however, plain bearings with flanges are often used as thrust bearings in opposed aircraft engines. Plain bearings are used for connecting rods, crankshafts, and camshafts of low-power aircraft engines. The metal used for plain bearings may be silver, lead, an alloy (such as bronze or babbitt), or a combination of metals. Bronze withstands high compressive pressures but offers more friction than babbitt. Conversely, **babbitt**, a soft bearing alloy, silver in color and composed of tin, copper, and antimony, offers less friction but cannot withstand high compressive pressures as well as bronze. Silver withstands compressive pressures and is an excellent conductor of heat, but its frictional qualities are not dependable.

Plain bearings are made with a variety of metal combinations. Some bearings in common use are steel-backed with silver or silver-bronze on the steel and a thin layer of lead then applied for the actual bearing surface. Other bearings are bronze-backed and have a lead or babbitt surface.

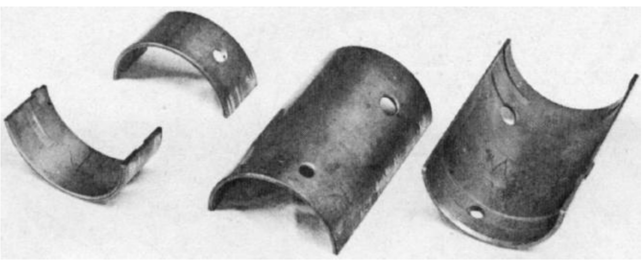

FIGURE 2-4 Plain bearings.

Roller Bearings

The **roller bearings** shown in Fig. 2-5 are one of the two types known as “antifriction” bearings because the rollers eliminate friction to a large extent. These bearings are made in a variety of shapes and sizes and can be adapted to both radial and thrust loads. Straight roller bearings are generally used only for radial loads; however, tapered roller bearings will support both radial and thrust loads.

The bearing **race** is the guide or channel along which the rollers travel. In a roller bearing, the roller is situated between an inner and an outer race, both of which are made of case-hardened steel. When a roller is tapered, it rolls on a cone-shaped race inside an outer race.

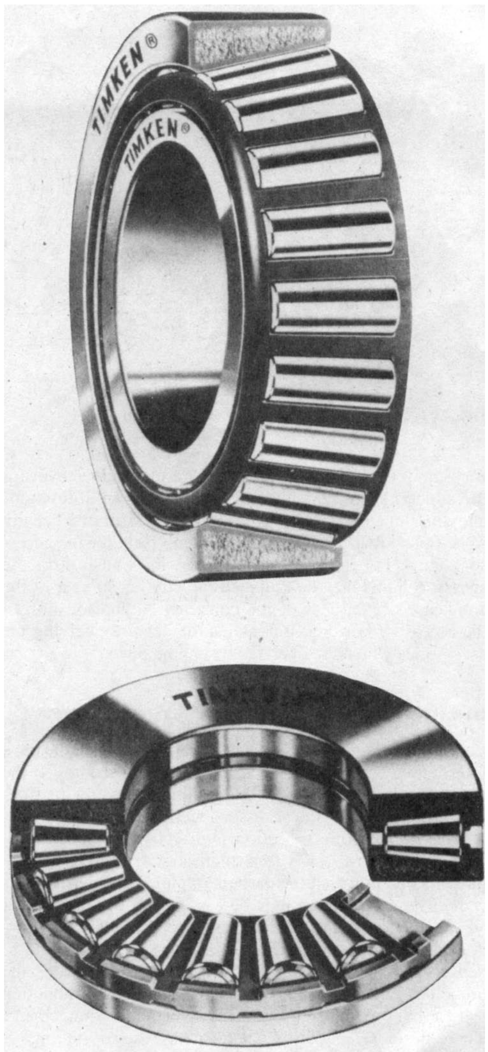

FIGURE 2-5 Roller bearings. (*Timken Roller Bearing Co.*)

Roller bearings are used in high-power aircraft engines as main bearings to support the crankshaft. They are also used in other applications such as turbine engines, where radial loads are high.

Ball Bearings

When a cylinder or sphere rolls over the surface of a plane object, the resistance to this relative motion offered by the surfaces is known as **rolling friction**.

Ball bearings provide less rolling friction than any other type. A ball bearing consists of an inner race and an outer race, a set of polished steel balls, and a ball retainer. Some ball bearings are made with two rows of balls and two sets of races. The races are designed with grooves to fit the curvature of the balls in order to provide a large contact surface for carrying high radial loads.

A typical ball-bearing assembly used in an aircraft engine is shown in Fig. 2-6. In this assembly, the balls are controlled and held in place by the ball retainer. This retainer is necessary to keep the balls properly spaced, thus preventing them from contacting one another.

Ball bearings are commonly used for thrust bearings in large radial engines and gas-turbine engines. Because of their construction, they can withstand heavy thrust loads as well as radial or centrifugal loads. They are also subject to gyroscopic loads, but these are not critical. A ball bearing designed especially for thrust loads is made with exceptionally deep grooves for the ball races. Bearings designed to resist thrust in a particular direction will have a heavier race design on the side which takes the thrust. It is important to see that this type of bearing is installed with the correct side toward the thrust load.

In addition to the large ball bearings used as main bearings and thrust bearings, many smaller ball bearings are found in generators, magnetos, starters, and other accessories used on aircraft engines. For this reason, the engine technician should be thoroughly familiar with the inspection and servicing of such bearings.

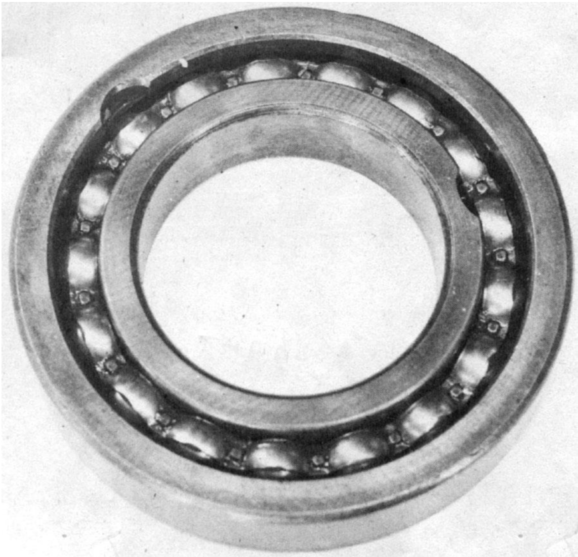

FIGURE 2-6 Ball-bearing assembly.

Many bearings, particularly for accessories, are prelubricated and sealed. These bearings are designed to function satisfactorily without lubrication service between overhauls. To avoid damaging the seals of the bearings, it is essential that the correct bearing pullers and installing tools be employed when the bearings are removed or installed.

THE CRANKSHAFT

The **crankshaft** transforms the reciprocating motion of the piston and connecting rod to rotary motion for turning the propeller. It is a shaft composed of one or more cranks located at definite places between the ends. These **cranks**, sometimes called **throws**, are formed by forging offsets into a shaft before it is machined. Since the crankshaft is the backbone of an internal-combustion engine, it is subjected to all the forces developed within the engine and must be of very strong construction. For this reason, it is usually forged from some extremely strong steel alloy, such as chromium-nickel-molybdenum steel (SAE 4340).

A crankshaft may be constructed of one or more pieces. Regardless of whether it is of one-piece or multipiece construction, the corresponding parts of all crankshafts have the same names and functions. The parts are (1) the main journal, (2) the crankpin, (3) the crank cheek or crank arm, and (4) the counterweights and dampers. Figure 2-7 shows the nomenclature of a typical crankshaft.

Main Journal

The **main journal** is the part of the crankshaft that is supported by and rotates in a **main bearing**. Because of this, it may also properly be called a **main-bearing journal**. This journal is the center of rotation of the crankshaft and serves to keep the crankshaft in alignment under all normal conditions of operation. The main journal is surface-hardened by nitriding for a depth of 0.015 to 0.025 in [0.381 to 0.635 millimeter (mm)] to reduce wear. Every aircraft engine crankshaft has two or more main journals to support the weight and operational loads of the entire rotating and reciprocating assembly in the power section of the engine.

Crankpin

The **crankpin** can also be called a **connecting-rod bearing journal** simply because it is the journal for a connecting-rod bearing. Since the crankpin is off center from the main journals, it is sometimes called a **throw**. The crankshaft will rotate when

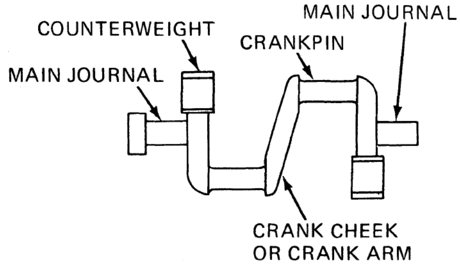

FIGURE 2-7 Nomenclature for a twin-row radial crankshaft.

a force is applied to the crankpin in any direction other than parallel to a line directly through the centerline of the crankshaft.

The crankpin is usually hollow for three reasons: (1) it reduces the total weight of the crankshaft, (2) it provides a passage for the lubricating oil, and (3) it serves as a chamber for collecting carbon deposits, sludge, and other foreign substances which are thrown by centrifugal force to the outside of the chamber where they will not reach the connecting-rod bearing surface. For this reason the chamber is often called the **sludge chamber**. Sludge chambers are not used on modern engines. On some engines a drilled passage from the sludge chamber to an opening on the exterior surface of the connecting rod makes it possible to spray clean oil on the cylinder walls.

Lubrication of the crankpin bearings is accomplished by oil taken through drilled passages from the main journals. The oil reaches the main journals through drilled passages in the crankcase and in the crankcase webs which support the main bearings. During overhaul the technician must see that all oil passages and sludge chambers are cleared in accordance with the manufacturer's instructions.

Crank Cheek

The **crank cheek**, sometimes called the **crank arm**, is the part of the crankshaft which connects the crankpin to the main journal. It must be constructed to maintain rigidity between the journal and the crankpin. On many engines, the crank cheek extends beyond the main journal and supports a counterweight used to balance the crankshaft. Crank cheeks are usually provided with drilled oil passages through which lubricating oil passes from the main journals to the crankpins.

Counterweights

The purpose of the **counterweight** is to provide static balance for a crankshaft. If a crankshaft has more than two throws, it does not always require counterweights because the throws, being arranged symmetrically opposite each other, balance each other. A single-throw crankshaft, such as that used in a single-row radial engine, must have counterbalances to offset the weight of the single throw and the connecting-rod and piston assembly attached to it. This type of crankshaft is illustrated in Fig. 2-8.

Dynamic Dampers

The purpose of **dynamic dampers** is to relieve the whip and vibration caused by the rotation of the crankshaft. They are suspended from or installed in specified crank cheeks at locations determined by the design engineers. Crankshaft vibrations caused by power impulses may be reduced by placing floating dampers in a counterweight assembly. The need for counterweights and dampers is not confined to aircraft engines. Any machine with rotating parts may reach a speed at which so much vibration occurs in the revolving mass of metal that the vibration must be reduced or else the machine will eventually destroy itself.

Dampers or **dynamic balances** are required to overcome the forces which tend to cause deflection of the crankshaft and torsional vibration. These forces are generated principally by the power impulses of the pistons. If we compute the force exerted by the piston of an engine near the beginning of the power stroke, we find that 8000 to 10000 lb [35585 to 44480 newtons (N)] is applied to the throw of a crankshaft. As the engine runs, this force is applied at regular intervals to the different throws of the crankshaft on an in-line or opposed engine and to the one throw of a single-row radial engine. If the frequency of the power impulses is such that it matches the natural vibration frequency of the crankshaft and propeller as a unit, or of any moving part of the engine, severe vibration will take place. The dynamic balances may be pendulum-type weights mounted in the counterweight (Fig. 2-9), or they may be straddle-mounted on extensions of the crank cheeks. In either case, the weight is free to move in a direction and at a frequency which will damp the natural vibration of the crankshaft. Dynamic balances are shown in Fig. 2-10.

The dynamic damper used in an engine consists of a movable slotted-steel counterweight attached to the crank cheek. Two spool-shaped steel pins extend into the slot and pass through oversized holes in the counterweight and crank cheek. The difference in the diameters between the pins and the holes provides a pendulum.

The effectiveness of a dynamic damper can be understood by observing the operation of a pendulum. If a simple pendulum is given a series of regular impulses at a speed

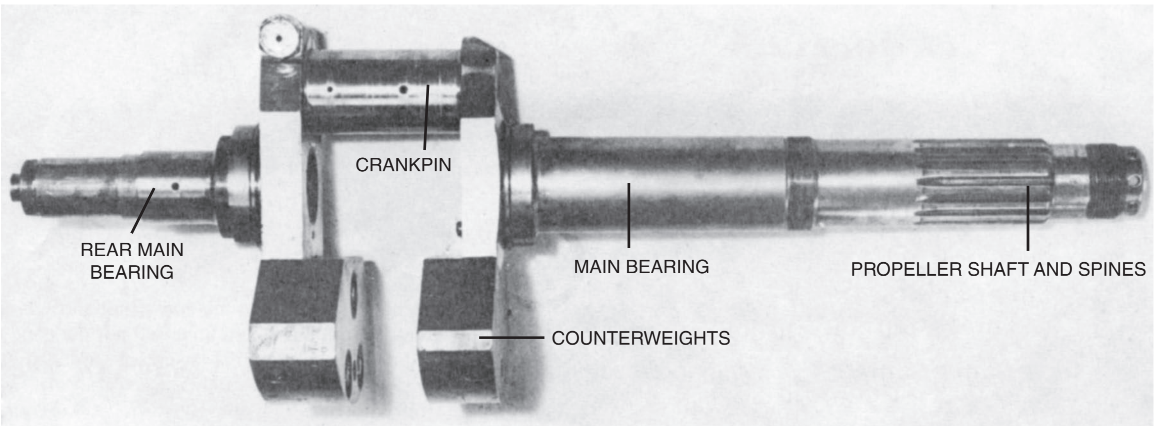

FIGURE 2-8 Single-throw crankshaft with counterweights.

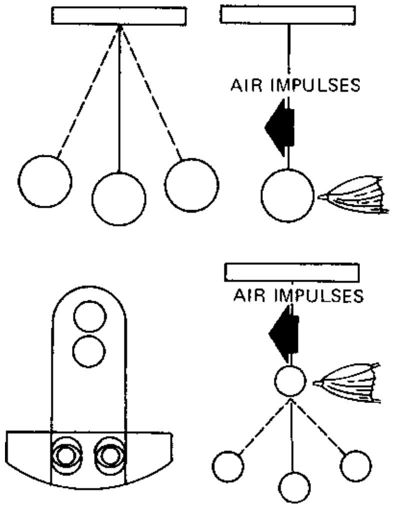

FIGURE 2-9 Dynamic balances and principles of operation.

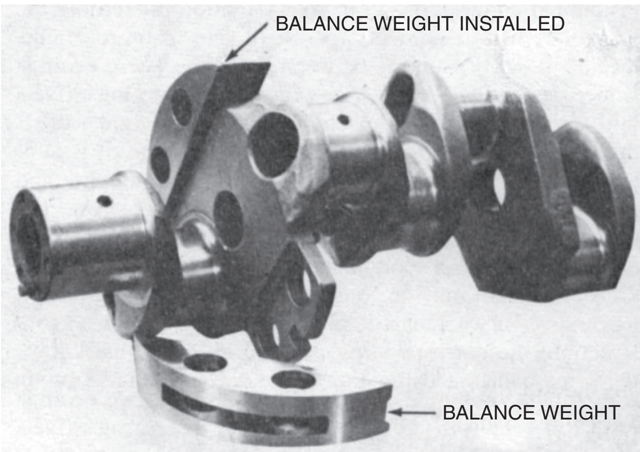

FIGURE 2-10 Dynamic-balance weights.

corresponding to its natural frequency, using a bellows to simulate a modified power impulse in an engine, it will begin swinging or vibrating back and forth from the impulses, as shown in the upper half of Fig. 2-9.

Another pendulum, suspended from the first, will absorb the impulse and swing itself, leaving the first pendulum stationary, as shown in the lower portion of Fig. 2-9. The dynamic damper, then, is a short pendulum hung on the crankshaft and tuned to the frequency of the power impulses to absorb vibration in the same manner as the pendulum illustrated in the lower part of the illustration. A **mode number** is used to indicate the correct type of damper for a specific engine.

Types of Crankshafts

The four principal types of crankshafts are (1) single-throw, (2) double-throw, (3) four-throw, and (4) six-throw. Figure 2-11 shows the crankshafts for an in-line engine, a single-row radial engine, and a double-row radial engine. Each individual type of crankshaft may have several configurations, depending on the requirements of the particular engine for which it is designed. An engine which operates at a high speed and power output requires a crankshaft more carefully balanced and with greater resistance to wear and distortion than an engine which operates at lower speeds.

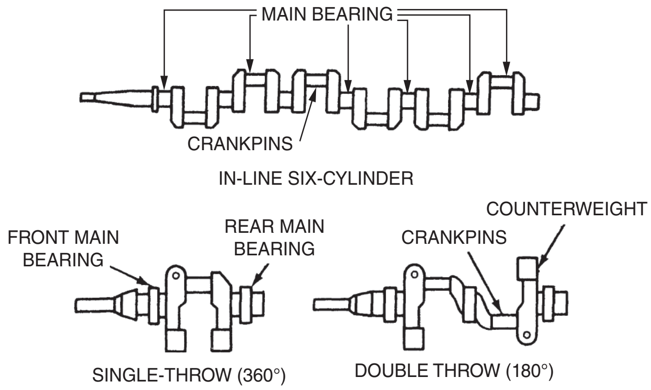

FIGURE 2-11 Three types of crankshafts.

Single-Throw Crankshaft

The type of crankshaft and the number of crankpins it contains correspond in every case to the engine cylinder arrangement. The position of a crank on any crankshaft in relation to other cranks on the same shaft is given in degrees.

The single-throw, or 360°, crankshaft is used in single-row radial engines. It may be of single- or two-piece construction with two main bearings, one on each end. A single-piece crankshaft is shown in Fig. 2-12. This crankshaft must be used with a master rod which has the large end split.

Two-piece single-throw crankshafts are shown in Fig. 2-13. The first of these (Fig. 2-13A) is a clamp-type shaft, sometimes referred to as a **split-clamp crankshaft**. The front section of this shaft includes the main-bearing journal, the front crank-cheek and counterweight assembly, and the crankpin. The rear section contains the clamp by which the two sections are joined, the rear crank-cheek and counterweight assembly, and the rear main-bearing journal. The spline-type crankshaft shown in Fig. 2-13B has the same parts as the clamp type, with the exception of the device by which the two sections are joined. In this shaft the

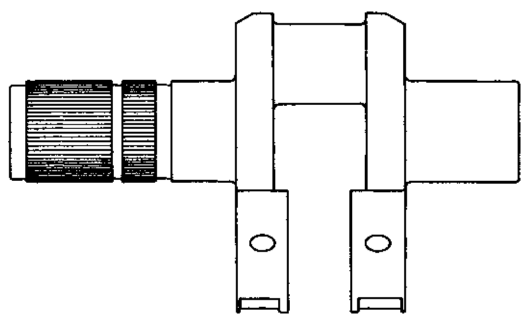

FIGURE 2-12 Single-piece crankshaft.

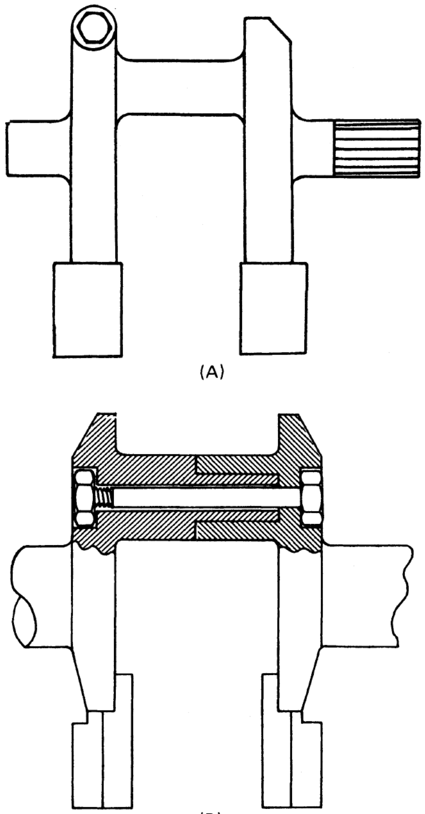

FIGURE 2-13 Two-piece single-throw crankshafts.

crankpin is divided, one part having a female spline and the other having a matching male spline. When the two parts are joined, they are held securely in place by means of a steel-alloy bolt.

Double-Throw Crankshaft

The double-throw, or 180°, crankshaft is generally used in a double-row radial engine. When used in this type of engine, the crankshaft has one throw for each row of cylinders. The construction may be one- or three-piece, and the bearings may be of the ball type or roller type.

Four-Throw Crankshaft

Four-throw crankshafts are used in four-cylinder opposed engines, four-cylinder in-line engines, and V-8 engines. In the four-throw crankshaft for an in-line or opposed engine, two throws are placed 180° from the other two throws. There may be three or five crankshaft main journals, depending on the power output and the size of the engine. The bearings for the four-cylinder opposed engine are of the plain, split-shell type. In the four-throw crankshaft, illustrated in Fig. 2-14, lubrication for the crankpin bearings is provided through passages drilled in the crank cheeks. During operation, oil is brought through passages in the crankcase webs to the main-bearing journals. From the main-bearing journals, the oil flows through the crank-cheek passages to the crankpin journals and the sludge chambers in the journals.

Six-Throw Crankshaft

Six-throw crankshafts are used in six-cylinder in-line engines, 12-cylinder V-type engines, and six-cylinder opposed engines. Since the in-line and V-type engines are not in general use in the United States, we limit our discussion to the type of shaft used in the six-cylinder opposed engine.

A crankshaft for a Continental six-cylinder opposed aircraft engine is shown in Fig. 2-15. This is a one-piece

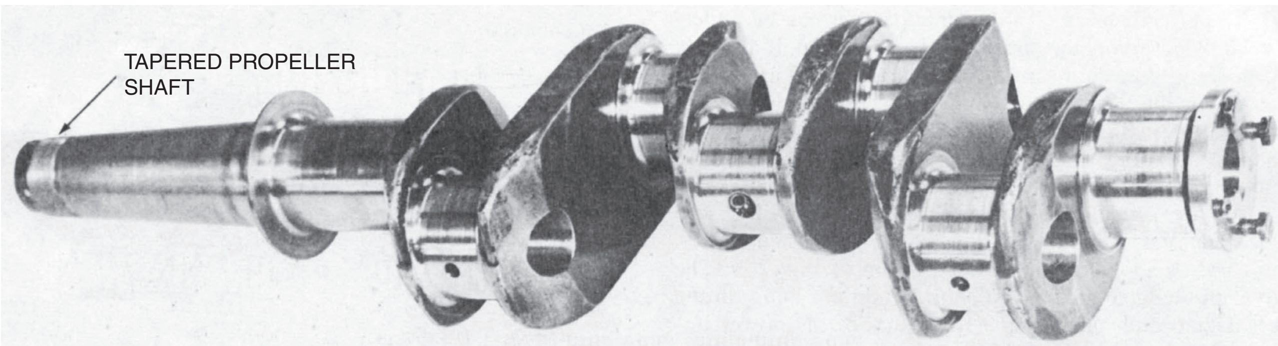

FIGURE 2-14 Four-throw crankshaft with a tapered propeller shaft.

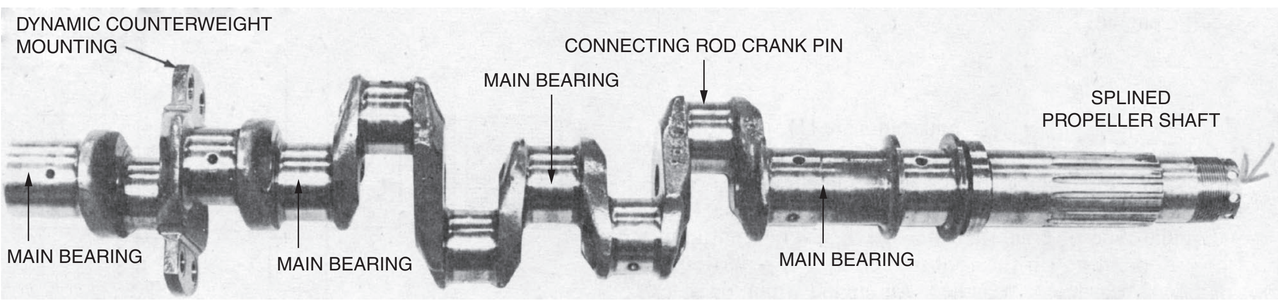

FIGURE 2-15 Crankshaft for a six-cylinder opposed engine with a splined propeller shaft.

six-throw 60° crankshaft machined from an alloy-steel (SAE 4340) forging. It has four main journals and one double-flanged main-thrust journal. The shaft is heat-treated for high strength and nitrided to a depth of 0.015 to 0.025 in [0.381 to 0.635 mm], except on the propeller splines, for maximum wear. The crankpins and main-bearing journals are ground to close limits of size and surface roughness. After grinding, nitriding, and polishing, the crankshaft is balanced statically and dynamically. Final balance is attained after assembly of the counterweights and other parts.

As shown in Fig. 2-15, the crankshaft is provided with dynamic counterweights. Since the selection of the counterweights of the correct mode is necessary to preserve the dynamic balance of the complete assembly, they cannot be interchanged on the shaft or between crankshafts. For this reason, neither counterweights nor bare crankshafts are supplied alone.

The crankshaft is line-bored the full length to reduce weight. Splined shafts have a threaded plug installed at the front end. The crankpins are recessed at each end to reduce weight. Steel tubes permanently installed in holes drilled through the crank cheeks provide oil passages across the lightening holes to all crankpin surfaces from the main journals. A U-shaped tube, permanently installed inside the front end of the shaft bore, conducts oil from the second main journal to the front main-thrust journal.

Propeller Shafts

Aircraft engines are equipped with one of three types of propeller mounting shafts: taper shafts, spline shafts, or flange shafts. In the past, low-power engines often were equipped with **tapered propeller shafts**. The propeller shaft is an integral part of the crankshaft (Fig. 2-14). The tapered end of the shaft forward of the main bearing is milled to receive a key which positions the propeller in the correct location on the shaft. The shaft is threaded at the forward end to receive the propeller retaining nut.

Crankshafts with **spline propeller shafts** are shown in Figs. 2-8 and 2-15. As can be seen in these illustrations, the splines are rectangular grooves machined in the shaft to mate with grooves inside the propeller hub. One spline groove may be blocked with a screw to ensure that the propeller will be installed in the correct position. A wide groove inside the propeller hub receives the blocked, or "blind," spline. The propeller is mounted on the spline shaft with front and rear cones to ensure correct positioning both longitudinally and radially. A retaining nut on the threaded front portion of the shaft holds the propeller firmly in place when the nuts are properly torqued. The installation of propellers is described in other chapters of this text.

Note that the propeller shaft in Fig. 2-8 is threaded about halfway between the forward end and the crank throw. This threaded portion of the shaft is provided to receive the thrust-bearing retaining nut, which holds the thrust bearing in the nose case of the engine. The shaft in Fig. 2-15 is not threaded aft of the splines because the design of the engine case eliminates the need for a thrust nut.

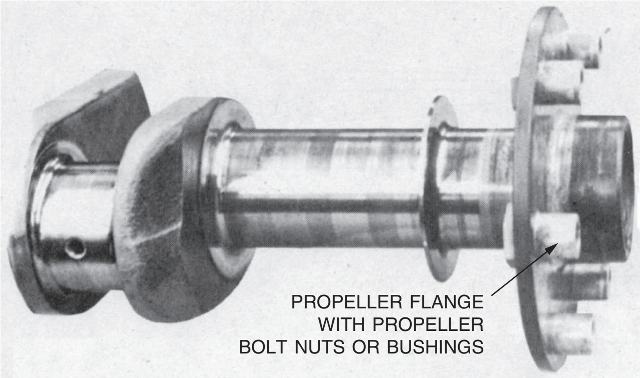

FIGURE 2-16 Flange-type propeller shaft.

Spline propeller shafts are made in several sizes, depending on engine horsepower. These sizes are identified as SAE 20, 30, 40, 50, 60, and 70. High-power engines have shafts from SAE 50 to SAE 70, and low-power engines are equipped with shaft sizes from SAE 20 to SAE 40.

Flange-type shafts are used with many modern opposed engines with power ratings up to 450 hp [335.57 kW]. Figure 2-16 shows a shaft of this type. A short stub shaft extends forward of the flange to support and center the propeller hub. Six high-strength bolts or studs are used to secure the propeller to the flange. In this type of installation, it is most important that the bolts or studs be tightened in a sequence which will provide a uniform stress. It is also necessary to use a torque wrench and to apply torque as specified in the manufacturer's service manual.

Some aircraft utilize **propeller-shaft extensions** to move the propeller forward, thus permitting a more streamlined nose design. Special instructions are provided by the aircraft manufacturer for service of such extensions.

Propeller-shaft loads are transmitted to the nose section of the engine by means of thrust bearings and forward main bearings. On some opposed-type engines, the forward main bearing is flanged to serve as a thrust bearing as well as a main bearing. The nose section of an engine either is a separate part or is integral with the crankcase. For either type of design, the nose section transmits the propeller-shaft loads from the thrust bearing to the crankcase, where they are applied to the aircraft structure through the engine mounts.

CONNECTING-ROD ASSEMBLIES

A variety of connecting-rod assemblies have been designed for the many different types of engines. Some of the arrangements for such assemblies are shown in Fig. 2-17. The **connecting rod** is the link which transmits forces between the piston and the crankshaft of an engine. It furnishes the means of converting the reciprocating motion of the piston to a rotating movement of the crankshaft in order to drive the propeller.

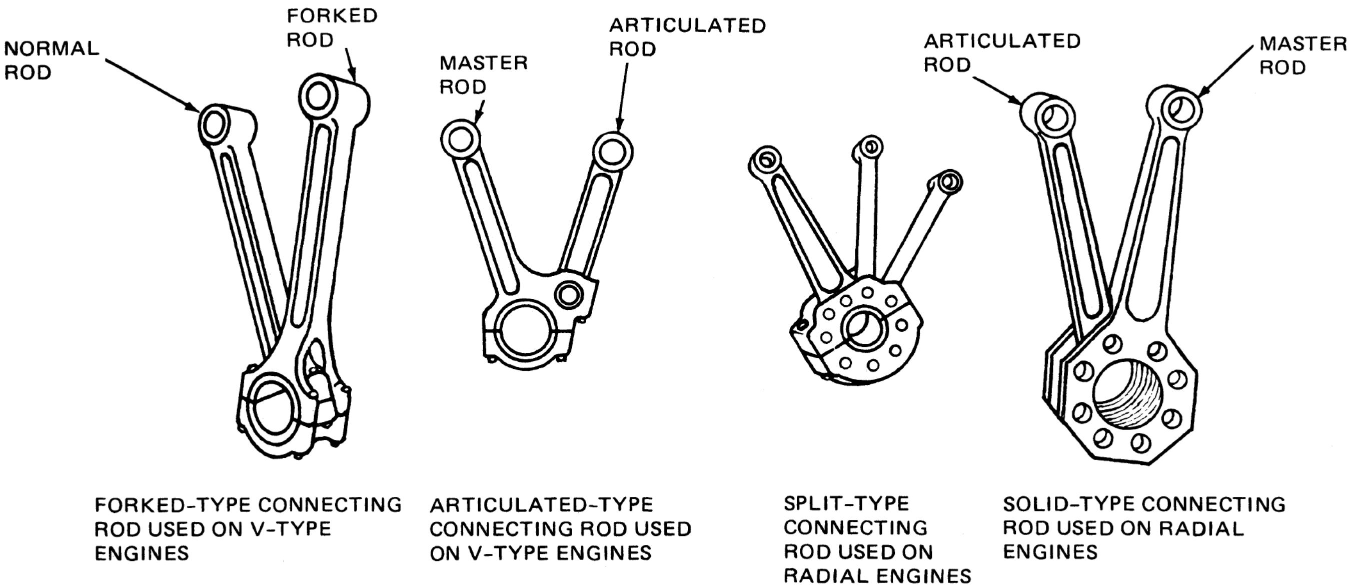

FIGURE 2-17 Connecting-rod assemblies.

A tough steel alloy (SAE 4340) is the material used for manufacturing most connecting rods, but aluminum alloys have been used for some low-power engines. The cross-sectional shape of the connecting rod is usually like either the letter H or the letter I, although some have been made with a tubular cross section. The end of the rod which connects to the crankshaft is called the **large end**, or **crankpin end**, and the end which connects to the piston pin is called the **small end**, or **piston-pin end**. Connecting rods, other than tubular types, are manufactured by forging to provide maximum strength.

Connecting rods stop, change direction, and start at the end of each stroke; therefore, they must be lightweight to reduce the inertial forces produced by these changes of velocity and direction. At the same time, they must be strong enough to remain rigid under the severe loads imposed under operating conditions.

There are three principal types of connecting-rod assemblies: (1) the plain type, shown in Fig. 2-18, (2) the fork-and-blade type, shown in Fig. 2-19, and (3) the master and articulated type, shown in Fig. 2-20.

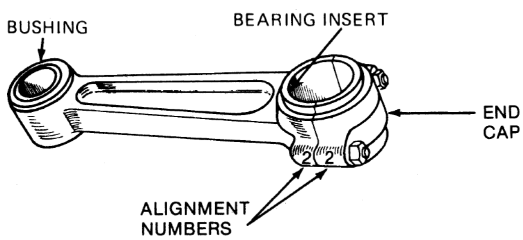

FIGURE 2-18 Plain-type connecting rod.

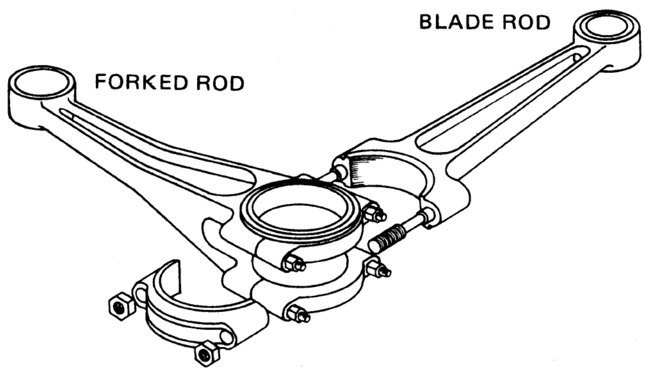

FIGURE 2-19 Fork-and-blade connecting rod.

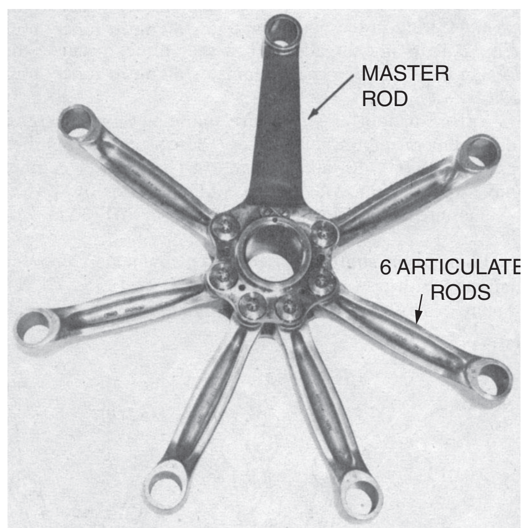

FIGURE 2-20 Master and articulated connecting-rod assembly.

Plain Connecting Rod

The plain connecting rod, the most widely used in modern engines, is used in in-line engines and opposed engines. The small end of the rod usually has a bronze bushing that serves as a bearing for the piston pin. This bushing is pressed into place and then reamed to the proper dimension. The large end of the rod is made with a cap, and a two-piece shell bearing is installed. The bearing is held in place by the cap. The outside of the bearing flange bears against the sides of the crankpin journal when the rod assembly is installed on the crankshaft. The bearing inserts are often made of steel and lined with a nonferrous bearing material, such as lead bronze, copper lead, lead silver, or babbitt. Another type of bearing insert is made of bronze and has a lead plating for the bearing surface against the crankpin.

The two-piece bearing shell fits snugly in the large end of the connecting rod and is prevented from turning by dowel pins or by tangs which fit into slots cut into the cap and the connecting rod. The cap is usually secured on the end of the rod by bolts; however, some rods have been manufactured with studs for holding the cap in place.

During inspection, maintenance, repair, and overhaul, the proper fit and balance of connecting rods are obtained by always replacing the connecting rod in the same cylinder and in the same relative position as it was before removal.

The connecting rods and caps are usually stamped with numbers to indicate their positions in the engine. The rod assembly for the no. 1 cylinder is marked with a 1, the assembly for the no. 2 cylinder is marked with a 2, and so on. The caps are also marked and must be assembled with the numbers aligned, as shown in Fig. 2-18.

Fork-and-Blade Connecting-Rod Assembly

The fork-and-blade connecting rod, illustrated in Fig. 2-19, is generally used in V-type engines. The **forked rod** is split on the large end to provide space for the **blade rod** to fit between the prongs.

One two-piece bearing shell is fastened by lugs or dowel pins to the forked rod. Between the prongs of the forked rod, the center area of the outer surface of this bearing shell is coated with a nonferrous bearing metal to act as a journal for the blade rod and cap.

During overhaul or maintenance, the fork-and-blade connecting rods are always replaced on the crankshaft in the same relative positions they occupied in their original installation. This ensures the proper fit and engine balance.

Master and Articulated Connecting-Rod Assembly

The **master and articulated connecting-rod assembly** is used primarily for radial engines, although some V-type engines have employed this type of rod assembly. The complete rod assembly for a seven-cylinder radial engine is shown in Fig. 2-20.

The **master rod** in a radial engine is subjected to some stresses not imposed on the plain connecting rod; therefore, its design and construction must be of the highest quality. It is made of an alloy-steel forging, machined and polished to final dimensions and heat-treated to provide maximum strength and resistance to vibration and other stresses. The surface must be free of nicks, scratches, or other surface damage which may produce stress concentrations and ultimate failure.

The master rod is similar to other connecting rods except that it is constructed to provide for the attachment of the articulated rods (link rods) on the large end. The large end of the master rod may be a two-piece type or a one-piece type, as shown in Fig. 2-21.

If the large end of the master rod is made of two pieces, the crankshaft is one solid piece. If the rod is one piece, the crankshaft may be of either two- or three-piece construction.

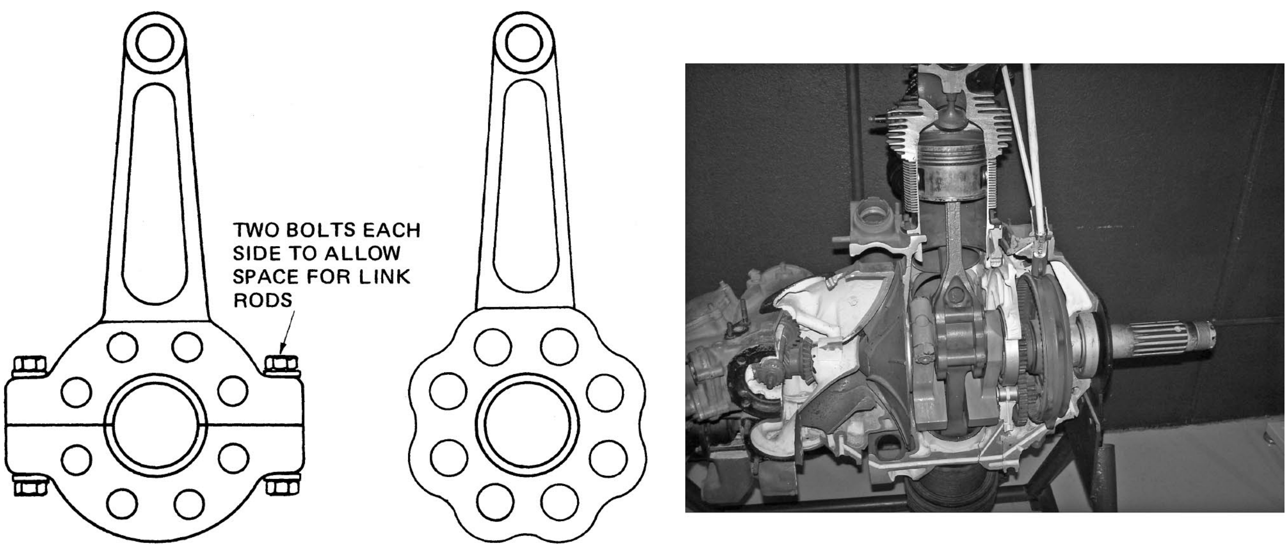

FIGURE 2-21 Types of master rods.