



AVIATION MECHANIC SERIES

POWERPLANT



Original Text by Dale Crane
FIFTH EDITION

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Original Text by Dale Crane
Keith Anderson, Technical Editor



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Aviation Mechanic Series: Powerplant
Fifth Edition
Based on the original text by Dale Crane

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Preface

Aviation maintenance technology has undergone tremendous changes in the past decades. Modern aircraft, with their advanced engines, complex flight controls and environmental control systems, are some of the most sophisticated devices in use today, and these marvels of engineering must be maintained by knowledgeable technicians. The Federal Aviation Administration, recognizing this new generation of aircraft, has updated the requirements for maintenance technicians and for the schools that provide their training. The FAA has also instituted an Aviation Maintenance Technician Awards Program to encourage technicians to update their training.

New technologies used in modern aircraft increase the importance of maintenance technicians having a solid foundation in such basic subjects as mathematics, physics, and electricity. The Aviation Mechanic Series has been produced by ASA to provide the needed background information for this foundation and to introduce the reader to aircraft structures, powerplants, and systems.

These textbooks have been carefully designed to assist a person in preparing for FAA technician certification, and at the same time serve as valuable references for individuals working in the field. The subject matter is organized into categories used by the FAA for the core curriculum in 14 CFR Part 147, Aviation Maintenance Technician Schools, and for the Subject Matter Knowledge Codes used in the written tests for technician certification. In some cases in the ASA series, these categories have been rearranged to provide a more logical progression of learning.

This textbook is part of the ASA series of coordinated maintenance technician training materials. The series consists of the Aviation Mechanic Series textbooks, *General*, *Airframe Structures*, *Airframe Systems*, and *Powerplant* textbooks with study questions, the test guides for aviation mechanics, exam software for Aviation Maintenance Technician tests, the *Aviation Mechanic Oral and Practical Exam Guide*, the *Dictionary of Aeronautical Terms*, and the *Aviation Mechanic Handbook*.

To supplement this fundamental training material, ASA reprints the FAA Advisory Circulars (ACs) 43.13-1 and 43.13-2 in *Aircraft Inspection, Repair, and Alterations: Acceptable Methods, Techniques, and Practices*, as well as the FAR-AMT, excerpts from the Federal Aviation Regulations that are applicable to the aviation maintenance technician.

Dale Crane

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About the Editorial Team

Fifth Edition

Based on the original text by Dale Crane

Dale Crane (1923–2010), the original author of this series, was involved in aviation for more than 50 years. He began his career in the US Navy as a mechanic and flight engineer in PBYS. After World War II, he attended Parks Air College. After college, he worked as an instrument overhaul mechanic, instrument shop manager, and flight test instrumentation engineer. Later he became an instructor and then director of an aviation maintenance school.

Dale was active as a writer of aviation technical materials, and as a consultant in developing aviation training programs. ATEC presented to Dale Crane their special recognition award for “his contribution to the development of aviation technicians as a prolific author of specialized maintenance publications.” He also received the FAA’s Charles Taylor “Master Mechanic” award for his years of service in and contributions to the aviation maintenance industry, and the recognition of his peers for excellence as a leader and educator in aircraft maintenance, and aviation safety advocate



Keith Anderson has over 40 years of experience in aviation as an A&P mechanic, authorized inspector (IA), commercial pilot, flight instructor, and aeronautical engineer. He has worked in Part 91, 121, and 135 operations, has held multiple DOM (director of maintenance) positions, and has taught at the university level. His pilot/mechanic experience includes 10 years of living and working in Central and South America and Africa. Keith has worked as a design engineer in aircraft design and certification and has held multiple leadership roles including engineering director and vice president positions that have included STC certifications and the type certification (TC) of a single-engine turboprop airplane.



DEVELOPMENT OF AIRCRAFT POWERPLANTS

1

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The first man-carrying flights were made in hot air balloons swept along by air currents and without means for the pilot to control the direction of flight. Aircraft had little practical utility until the development of engine-driven propellers. This development of the powerplant has made aviation the vital factor that it is today in the economic world.

The Principle of Heat Engines

All powered aircraft are driven by some form of heat engine. Chemical energy stored in the fuel is released as heat energy that causes air to expand. The expansion of this air is what performs useful work, driving either a piston or a turbine.

There are two basic types of heat engines: external-combustion and internal-combustion.

External-Combustion Engines

External-combustion engines are most familiar to us as steam engines. Energy released in coal- or gas-fired furnaces or in nuclear reactors is transferred into water, changing it into steam that expands and drives either a piston or a turbine.

Steam engines were used to power experiments in flight made during the late 1800s. Dr. Samuel Langley of the Smithsonian Institution in Washington, D.C. used small steam engines to power a successful series of unmanned machines he called Aerodromes. In 1896, Dr. Langley made a number of powered flights with these models. The most successful had tandem wings with a span of 14 feet, weighed 26 pounds, and was powered by a one-horsepower steam engine. It was launched from a catapult atop a houseboat on the Potomac river, and flew for 90 seconds, traveling more than half a mile.

There was one successful but impractical aircraft steam engine developed in America in 1933 by the Besler brothers, manufacturers of logging locomotives. This 150-horsepower engine, using an oil-fired boiler and having a total installed weight of approximately 500 pounds, was used to power a Travel Air 2000 biplane.

Internal-Combustion Engines

The concept of releasing energy from fuel directly inside an engine to heat and expand the air has challenged engineers since the late 1700s. The expanding air can drive reciprocating pistons or spin turbines.

Coal dust, gunpowder, and even turpentine vapors have been exploded inside cylinders, but it was not until 1860 that the French engineer Etienne Lenoir actually built a practical engine that could use illuminating gas as its fuel.

In 1876, Dr. Nikolaus Otto of Germany made practical engines using the four-stroke cycle that bears his name, and it is the principal cycle upon which almost all aircraft reciprocating engines operate. This cycle of energy transformation is discussed in detail in Chapter 2.

Gas turbine engines in the form of turbojet, turbofan, turboprop, and turboshaft engines have revolutionized aviation, and their principle of operation is discussed in Chapter 10.

powerplant. The complete installation of an aircraft engine, propeller, and all accessories needed for its proper function.

heat engine. A mechanical device that converts chemical energy in a fuel into heat energy, and then into mechanical energy.

piston. The movable plug inside the cylinder of a reciprocating engine.

turbine. A wheel fitted with vanes or airfoils radiating out from a central disc. Used to extract energy from a stream of moving fluid.

external-combustion engine. A form of heat engine in which the fuel releases its energy outside of the engine.

Aerodrome. The name given by Dr. Samuel Langley to the flying machines built under his supervision between the years of 1891 and 1903.

cylinder. The component of a reciprocating engine which houses the piston, valves, and spark plugs and forms the combustion chamber.

internal-combustion engine. A form of heat engine in which the fuel and air mixture is burned inside the engine.

Otto cycle of energy transformation. The four-stroke, five-event, constant-volume cycle of energy transformation used in a reciprocating engine.

gas turbine engine. An internal combustion engine that burns its fuel in a constant-pressure cycle and uses the expansion of the air to drive a turbine which, in turn, rotates a compressor. Energy beyond that needed to rotate the compressor is used to produce torque or thrust.

reciprocating engine. A type of heat engine that changes the reciprocating (back-and-forth) motion of pistons inside the cylinders into rotary motion of a crankshaft.

brake horsepower. The actual horsepower delivered to the propeller shaft of an aircraft engine.

turboshaft engine. A turbine engine in which energy extracted from the accelerated gases is used to drive helicopter rotors, generators, or pumps.

dirigible. A large, cigar-shaped, lighter-than-air flying machine. Dirigibles differ from balloons in that they are powered and can be steered.

Aircraft Reciprocating Engines

Throughout the history of aviation, progress has always been dependent upon the development of suitable powerplants.

Aviation as we know it today was born at the beginning of the 1900s with powered flights made by Wilbur and Orville Wright. The Wright brothers approached the problems of flight in a sensible and professional way. They first solved the problem of lift with kites, then the problem of control with gliders, and finally by 1902, they were ready for powered flight. First they painstakingly designed the propellers and then began their search for a suitable engine. Their requirements were for a gasoline engine that would develop 8 or 9 brake horsepower and weigh no more than 180 pounds. No manufacturer had such an engine available, and none were willing to develop one for them. Their only recourse was to design and build it on their own.

The engine, built to their design by Mr. Charles Taylor, had four cylinders in-line and lay on its side. It drove two 8½-foot-long wooden propellers through chain drives and developed between 12 and 16 horsepower when it turned at 1,090 RPM. It weighed 179 pounds.

On December 17, 1903, this engine powered the Wright *Flyer* on its historic flight of 59 seconds, covering a distance of 852 feet on the wind-swept sand at Kitty Hawk, North Carolina.

Because of Dr. Langley's success with his Aerodromes, the US government gave him a contract to build a full-scale man-carrying machine. The steam engines used in the models could not be effectively scaled up to power this aircraft, so a better means of propulsion had to be found.

Charles Manly, Dr. Langley's assistant, searched without success, both in the United States and Europe, for a suitable powerplant. The best he found was a three-cylinder rotary radial automobile engine built by Stephen Balzer in New York. This engine was not directly adaptable to the Aerodrome, but Manly, building upon Balzer's work, constructed a suitable engine for it. The Manly-Balzer engine was a five-cylinder, water-cooled static radial engine that produced 52.4 horsepower at 950 RPM and weighed 207.5 pounds complete with water.

On October 7, 1903, the full-scale Aerodrome with Manly as the pilot was launched from atop the houseboat. As the aircraft neared the end of the catapult, it snagged part of the launching mechanism and was dumped into the river. But Manly's engine, which was far ahead of its time, functioned properly and was in no way responsible for the failure of the Aerodrome to achieve powered flight.

Glenn Curtiss was a successful motorcycle builder and racer from western New York state. The use of one of his motorcycle engines in a dirigible in 1907 got Curtiss interested in aviation, and as a result, he became involved in furnishing the powerplants for Dr. Alexander Graham Bell's Aerial Experiment Association. A number of successful aircraft, including the first aircraft to fly in Canada, came from this group.

Curtiss's own company designed and built some of the most important engines in America in the periods before and during World War I and up until 1929, when the Curtiss Aeroplane and Motor Corporation merged

with the Wright Aeronautical Corporation to form the giant Curtiss-Wright Corporation.

World War I, between 1914 and 1918, was a time of rapid growth in aviation. The British, French, Germans, and Americans all developed aero engines.

One of the most popular configuration of engines built in this era was the rotary radial engine. With this engine, the crankshaft was attached rigidly to the airframe, and the propeller, crankcase, and cylinders all spun around. Clerget, Gnome, and Rhone in France, Bentley in Britain, Thulin in Sweden, and Oberursel, BMW, Goebel, and Siemens-Halske in Germany all built rotary radial engines. These engines had 5, 7, 9, 11, or 14 cylinders and produced between 80 and 230 horsepower.

The Germans used some very efficient 6-cylinder in-line water-cooled engines built by the Mercedes, Maybach, BMW, Benz, and Austro-Daimler companies. Some of these engines developed up to 300 hp.

Some of the most popular V-8 engines of this time were the French-built 150- to 300-horsepower Hispano-Suizas. These engines were also built under license agreements in Great Britain and the United States.

There were only two aircraft engines designed and built in quantities in the United States during this time, and both were V-engines. Glenn Curtiss's Company built the 90-horsepower, water-cooled V-8 Curtiss OX-5 engine in great numbers, and various automobile manufacturers built the 400-horsepower water-cooled V-12 Liberty engine.

The years between World Wars I and II are called the golden years of aviation because of the tremendous strides made during this era. Powerplant development was largely responsible for this progress.

At the end of hostilities in 1918, the aviation market was flooded with surplus Curtiss Jennies and Standard J-1s, with their Curtiss OX-5 engines and DeHaviland DH-4 airplanes with Liberty V-12 engines. These airplanes and engines, while limited in utility, were so abundant and cheap that manufacturers were discouraged from developing new engines until these were used up.

Aviation did not become a viable form of transportation until a dependable engine was developed. Beginning in about 1923, Charles Lawrance built a 9-cylinder radial engine that was developed by the Wright Aeronautical Corporation into their famous Whirlwind series of engines, the most famous of which was the 220-horsepower Wright J-5. This is the engine that powered Charles Lindbergh's *Spirit of St. Louis* on its successful 33-hour nonstop flight from New York to Paris in May of 1927. About two weeks later, Clarence Chamberlain, flying a Bellanca, also powered by a Wright J-5 engine, flew nonstop from New York to Germany in 43 hours.

Small 3-, 5-, and 7-cylinder radial engines powered the light airplanes of the 1930s and 1940s, and 7-, 9-, and 14-cylinder radial engines powered the faster private and business airplanes, as well as military and airline aircraft.

During World War II the radial engine was the most popular configuration in the United States. Some fighter airplanes used liquid-cooled V-12 engines, but most aircraft were powered by 9-, 14-, and 18-cylinder radial engines, and by the end of the war, by a popular 28-cylinder engine (Figure 1-1).

rotary radial engine. A form of reciprocating engine in which the crankshaft is rigidly attached to the airframe and the cylinders revolve with propeller.

crankshaft. The central component of a reciprocating engine. This high-strength alloy steel shaft has hardened and polished bearing surfaces that ride in bearings in the crankcase. Offset throws, formed on the crankshaft, have ground and polished surfaces on which the connecting rods ride. The connecting rods change the in-and-out motion of the pistons into rotation of the crankshaft.

crankcase. The housing that encloses the crankshaft, camshaft, and many of the accessory drive gears of a reciprocating engine.

The cylinders are mounted on the crankcase, and the engine attaches to the airframe by the crankcase.

V-engine. A form of reciprocating engine in which the cylinders are arranged in two banks. The banks are separated by an angle of between 45° and 90°.

Pistons in two cylinders, one in each bank, are connected to each throw of the crankshaft.

Curtiss Jenny (Curtiss JN4-D). A World War I training airplane powered by a Curtiss OX-5 engine. It was widely available after the war and helped introduce aviation to the general public.

Standard J-1. A World War I training airplane powered by a Curtiss OX-5 engine.

DeHaviland DH-4. An English designed observation airplane built in large quantities in America during World War I. After the war, surplus DH-4s were used for carrying the US mail.

radial engine (static radial). A form of reciprocating engine in which the cylinders radiate out from a small central crankcase. The pistons in the cylinders drive a central crankshaft which in turn drives the propeller.



Figure 1-1. *The Pratt & Whitney R-4360 Wasp Major, with 28 air-cooled cylinders, weighed over 3,600 pounds and was manufactured in various configurations, producing up to 4,300 horsepower. This engine, with four rows of seven cylinders each, was the largest practical aircraft reciprocating engine. (Courtesy Pratt & Whitney Division, United Technologies Corp.)*

amateur-built aircraft. Aircraft built by individuals as a hobby rather than by factories as commercial products. Amateur-built or homebuilt aircraft do not fall under the stringent requirements imposed by the FAA on commercially built aircraft.

rotating combustion (RC) engine. A form of internal combustion engine in which a rounded, triangular-shaped rotor with sliding seals at the apexes forms the combustion space inside an hourglass-shaped chamber. Expanding gases from the burning air-fuel mixture push the rotor around and turn a geared drive shaft in its center. The RC engine was conceived in Germany by Felix Wankel in 1955.

The point of diminishing returns in reciprocating engine development was reached during World War II by the Lycoming XR-7755, a 5,000-horsepower 36-cylinder liquid-cooled radial engine. Fortunately the gas-turbine engine became functional at about this time.

Horizontally opposed engines first became popular as powerplants for very light aircraft in 2- and 4-cylinder models of less than 40 horsepower. This configuration has the advantage of smooth operation, small frontal area, light weight, and dependability. Because of these characteristics, they have been widely produced with 4-, 6-, and even 8-cylinders, with power output of up to 520 horsepower or more.

After World War II, horizontally opposed engines replaced radial engines for almost all reciprocating engine-powered private airplanes. Recently, however, there have been a several in-line and V-configured diesel engines marketed.

Private aviation in the United States has undergone drastic changes since the 1960s. The cost of private aircraft ownership skyrocketed because of the proliferation of product liability lawsuits, and commercial manufacturers virtually stopped producing reciprocating-engine-powered private aircraft in the 1980s. By the mid 1990s, changes in tort reform laws encouraged some manufacturers to re-enter the private aircraft field.

The amateur-built or homebuilt aircraft movement originally began because people wanted to build and fly ultra-simple aircraft without complex tooling, at minimum of cost. Today there are still some very basic designs yet there are also a number of homebuilt aircraft on the cutting edge of technology, costing hundreds of thousands of dollars. Freedom from some of the FAA constraints under which production aircraft are built and the accompanying reduction of the threat of product liability lawsuits allow private builders to exploit the limitless advantages of composite construction.

Amateur-built aircraft do not require FAA-certificated engines, and as a result, there is a strong movement in the conversion of automobile engines for aircraft use. Some converted automobile engines are truly state-of-the-art powerplants, with electronic ignition and fuel injection. The safety record for these engines is excellent, and it is quite possible that this will continue to be a viable means of developing engines for private aircraft in the future.

As aviation begins its second century, the gasoline reciprocating engine, in spite of its inefficiency, continues to be used, but not without competition. Practically all airline and military aircraft are turbine powered and will continue to be.

Air-cooled, horizontally-opposed gasoline engines will continue to dominate the piston-powered aircraft market for the foreseeable future. There have been, and continue to be, inroads made to develop more fuel-efficient powerplants, but none have risen to the forefront in any significant way to unseat the gasoline-fired mainstay. Some of the ongoing innovations include liquid-cooled gasoline engines, compression-ignition (CI) engines, rotating combustion (RC) engines developed from the Wankel engine, and cam (as opposed to crankshaft) engines.

The most significant of these improved engines has been the compression-ignition engine, better known as the diesel engine. The diesel or CI engine is about 10% to 15% more fuel efficient than the gasoline engine. This could be a significant savings if that were the only consideration, but the CI engine is considerably heavier than the gasoline-fired engine. This aspect in itself produces considerable inefficiencies when cost per mile is concerned; the search for ideas for more efficient piston engine power therefore continues.

Figure 1-2 highlights the progress made in aircraft reciprocating engines. In only 40 years, engines progressed from almost 15 pounds per horsepower to slightly less than one pound per horsepower.

Manufacturer and Name	Year	Configuration	Horsepower	Weight
Wright <i>Flyer</i>	1903	4 I L	12-16	179
Manly-Balzer	1903	5 R L	52.4	207
Curtiss OX-5	1910	8V L	90	400
Le Rhone J	1916	9 Ro A	120	323
Liberty V-12	1918	12 V L	400	900
Wright J-5	1925	9 R A	220	510
Pratt & Whitney R-1830	1932	14 R A	1,200	1,467
Wright Turbocompound	1940	18 R A	3,700	2,779
Pratt & Whitney R-4360	1943	28 R A	4,300	3,600
Engines for Private Aircraft				
Continental A-65	1938	4 O A	65	170
Lycoming TIGO-541	1959	6 O A	450	396

I = Inline, R = Radial, V = V, Ro = Rotary, O = Horizontally opposed, L = Liquid cooled, A = Aircooled

Figure 1-2. Progress made in aircraft reciprocating engines.

Aircraft Turbine Engines

The principle of using a turbine as a source of power has been known for more than 400 years, since the days of Leonardo da Vinci. Wind-driven turbines in the form of windmills have converted much of the arid wasteland in the western United States into profitable farms and ranches.

Water-driven turbines are used to generate electricity in the huge hydroelectric powerplants, and steam turbines are used to drive electrical generators and propel ocean-going ships.

The first practical use of turbines in aviation was the turbosupercharger developed by Dr. Sanford Moss during World War I. A turbine spun by exhaust gases leaving the engine drove a centrifugal compressor that increased the pressure of the air entering the cylinders. Turbosuperchargers allow reciprocating engines to maintain their sea-level power to a high altitude.

turbosupercharger. A centrifugal air compressor driven by exhaust gases flowing through a turbine. The compressed air is used to increase the power produced by a reciprocating engine at altitude.

centrifugal compressor. An air compressor that uses a scroll-type impeller. Air is taken into the center of the impeller and slung outward by centrifugal force into a diffuser where its velocity is decreased and its pressure is increased.



POWERPLANT

Powerplant, the last textbook in Dale Crane's four-part Aviation Mechanic Series, covers the technical maintenance of turbine and reciprocating engines, theory and construction of aircraft engines, aircraft powerplants, and powerplant auxiliary systems. The content meets FAA aviation maintenance technician school curriculum requirements and prepares applicants for the Powerplant FAA Knowledge Exam.

Also in the **Aviation Mechanic Series:**



This new fifth edition features updated content reflecting new regulations and changes affecting aviation mechanic certification. Originally written by Dale Crane in 1996, this textbook has been reviewed and updated by an editorial team consisting of aviation mechanics, university professors, and pilots.

ASA's Aviation Mechanic Series is a current, comprehensive, and effective learning resource for aviation mechanic training. Designed for use in classrooms and for independent study, these textbooks feature color figures, study questions with answer keys, and extensive glossaries and indexes.



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