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POWER FOR AIRCRAFT

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POWER FOR AIRCRAFT

EARLY in the Twentieth Century an engine was built and used to power an aircraft. Within two decades after this event the aircraft powerplant had been proved dependable. In 1929 I had the opportunity to help dramatize this dependability. During the quarter century that has passed since that occasion, sources of tremendous power, undreamed of then, have been discovered. Today we face the stark reality that this terrible power makes available to scientists and engineers on both sides of the globe a force capable of annihilating the human race. We must keep our slim margin of technical superiority until we find the way to use the power we now command to provide mankind with peace and prosperity.

Carl A. Spaatz
General, USAF (Ret)

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Foreword

Among the major events of this century only one other ranks with the invention of the powered aircraft. This event is the development of the engine which can release the power potentials of uranium atoms. The technological advances following in the train of these two events have created sociological conditions which demand immediate attention.

The young men and women of America must help the world adjust to the impacts of its inventions and discoveries. The Civil Air Patrol recognizes the task that this world adjustment places upon the youth of America. Its cadet program is designed to assist organized formal education in properly guiding young people toward the completion of this task.

The Civil Air Patrol aviation education series will help lay a foundation of basic understanding upon which can be built skills and attitudes essential to this task—that is to the solution of the problems spawned by technical acceleration.

WALTER R. AGEE
Major General, USAF
National Commander
Civil Air Patrol

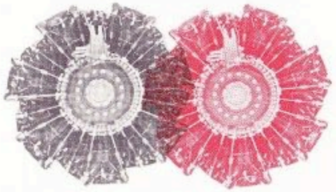
Preface

Power for Aircraft is one of a series of six pocket-sized books prepared for use in the aviation education program of the Civil Air Patrol. It is to be used with an instructional 35 mm. color, sound filmstrip which illustrates the concepts which it introduces.

The purpose of this book is to describe in terms of secondary-school student understandings the scientific principles basic to aircraft power plant operation. Descriptions and explanations are given of the methods by which the potential of a fuel is converted into energy, and straight line motion into propeller thrust. The operation of starting systems, fuel induction systems, and fuel ignition systems are explained. Cooling systems and lubricating systems are discussed. Simple explanations of thermal efficiency and mechanical efficiency are offered. The operation of jet-propelled engines is described. Power plant developments currently under way are briefly considered. Finally, the system of power plant controls the pilot uses is described. The book's treatment of the several areas with which it is concerned is sufficiently general to be of basic importance to all aviation career objectives. Yet, its content is detailed enough to challenge the interest of students and adults alike.

Although its first use will be with Civil Air Patrol cadets, it will be found of considerable value in science classes and any other class that stresses the role of scientific concepts related to engines and power plant systems.

The books and filmstrips of this series are not limited to use with Civil Air Patrol cadets only. They will be found of value to students and teachers in any aviation program. Those working with adults may also find this material helpful if the instructional or information goal is general education as it relates to aviation.



AIRCRAFT POWER PLANTS

Development

The history of aviation records achievements and development in the design and construction not only of airframes, but also of power plants. It is the aircraft power plant that makes sustained flight possible. Without a dependable power plant the airplane could not have been put to practical use.

A good many years before the Wright Brothers made the first powered flight, men had flown man-carrying gliders. Otto Lilienthal, a German, Octave Chanute, a Frenchman, and John Montgomery, an American, were among these men. Before 1903, the Wright Brothers themselves had built and flown soaring planes. It may be that the greatest accomplishment of the Wright Brothers was to design and build, with the help of Charles Taylor, the power plant for the airplane which they flew at Kitty Hawk.

Early aircraft power plants were not very reliable. However, by 1919 one had been built which would operate long enough to enable Alcock and Brown to fly non-stop from Newfoundland to Ireland. In 1927 Lindbergh flew non-stop from New York to Paris. And, in 1929, Spaatz * and Eaker kept the *Question Mark* aloft for over six days, finally demonstrating that during the twenty-three years following the advent of powered flight, the aircraft power plant had become dependable. A new transportation system could now emerge; the creation of a new military arm was destined; a new way of life was to open.

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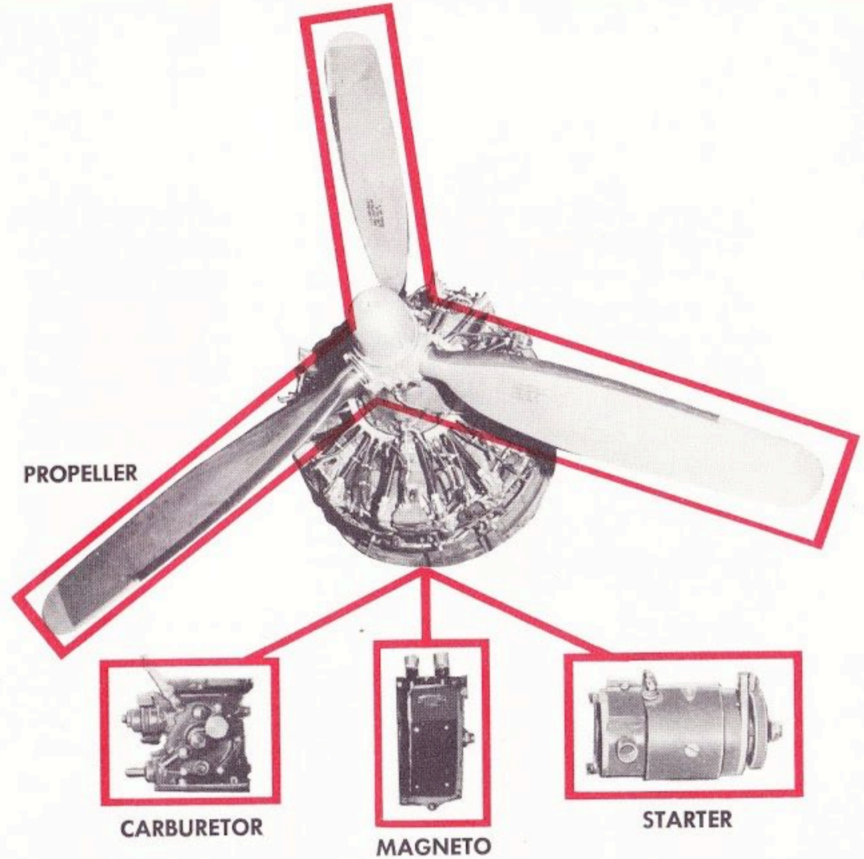
* Major Carl Spaatz and Captain Ira C. Eaker. Later both of these officers became generals of the United States Air Force. General Spaatz became its first Chief of Staff. From 1948 to 1956 he was Chairman of the National Board of the Civil Air Patrol.



Starter; Carburetor, Magneto, Propeller—Links in the chain of power.

Power Plant Systems

You have heard people call the airplane power plant an engine or perhaps a motor. As a matter of fact the engine is only one of the links in the chain of power. Sometimes the electric motor is another such link.

The engine proper changes heat energy into mechanical energy. In order to do this it must be assisted by a *carburetion system* which supplies fuel; by an *ignition system* which kindles fuel; by a *lubrication system* which reduces friction of its moving parts. To initiate the operation of a modern aircraft engine requires a *starting system*. To maintain effective operation of the engine requires a *control system* and *engine instruments*. Moreover, the power generated by a reciprocating engine is productive only when harnessed to an airplane propeller or helicopter rotor by a *transmission system*.

The aircraft engine is the most important of the power plant essentials, but other power plant equipment also requires study and understanding. Furthermore, beyond the engine must be a source of potential energy—a liquid fuel, such as gasoline; an unstable compound, such as gun-powder; or an element, such as uranium-238, capable of atomic fission.

The Simple Machines

So that you can better understand how heat energy is converted into mechanical energy and how such energy is put to work, it is necessary to learn about some simple machines. Some of these were discovered long ago. Men who lived in the dawn of civilization used them to increase the force they could apply with their muscles. Other men in later ages refined the early machines, using the principles of these machines to develop more complicated devices. Today we use the same basic principles to increase and to apply the force an engine generates. You will observe devices based upon them in use within hydraulic and electrical systems. In the aircraft power plant, they are found in rather complicated combinations. Sometimes in their adaptations, they are hard to recognize. There are six of these devices. They are the lever and fulcrum, the wheel and the axle, the pulley, the wedge, the inclined plane, and the screw.

The Lever and Fulcrum

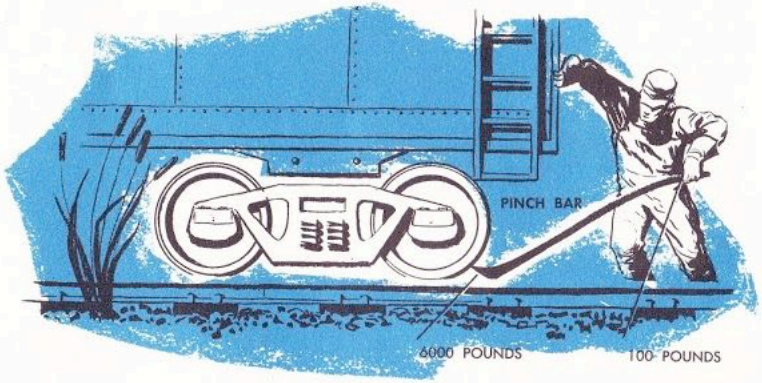
The child's teeter-totter on the playground is an example of the lever and its fulcrum (pivot-point) with which all are familiar. Many tools, in everyday use, illustrate this principle. The pinch-bar with which the railway worker can move a freight car is an example of a lever with a built-in fulcrum. A nutcracker, a pair of pliers, a wheelbarrow—all are adaptations of the lever for specific purposes. A gear may be regarded as a spinning lever.

Wheel and Axle

The wheel and axle may be exemplified by the steering wheel of an automobile and the shaft to which it is attached. Any twisting force applied to the outside of the steering wheel produces a greater twisting force on the shaft. On occasion, a single spoke of a wheel is used to obtain a similar result. The wheel then becomes a crank, but the principle remains the same. Consequently, a crankshaft is an adaptation of the wheel and axle.

The Pulley

You use an adaptation of the pulley whenever you adjust the drapes over the windows of a room. Other adaptations of this principle are employed whenever men sail ships, or operate the controls of airplanes.



A gain in force means a loss in distance.

Inclined Plane, Wedge, and Screw

The inclined plane, the wedge and the screw are closely related devices. When a truck driver wants to load a barrel of oil, he lays a plank from the edge of the truck-platform to the ground. He then rolls the barrel up the *inclined plane* thus formed.

The wedge is a movable inclined plane. In the instance in which the barrel was moved up the inclined plane, force was applied to the barrel. When the wedge is used, the initial force is applied to the wedge which in turn transmits this, magnified, to the object to be moved.

The screw may be regarded as an inclined plane wrapped around a shaft. Wood screws, cork screws, bolts and other familiar devices employ the principle of the screw. The aircraft propeller also makes use of this principle. In fact the English call an aircraft propeller an air-screw.

You will recognize characteristics of the six simple machines in the mechanisms of power-plant systems. As a matter of fact, to gain mechanical advantage, these six simple machines each employs the same, single, fundamental principle. The object of each machine is to accomplish work. In such instances, work is defined as force times distance. When one of these machines is used to increase a force, that force cannot move as far as the original smaller force moves. The force applied by the man who used a pinch bar to start the railway car rolling may have moved through a distance of three feet; the force transmitted to the car in this instance may have moved through no more than a distance of one inch. Under such circumstance a pressure of 100-pounds at one end of a five-foot bar would be transmitted as a pressure of 6,000-pounds at the other. You will note that the gain in force meant a loss in distance. (See illustration, page 5.)

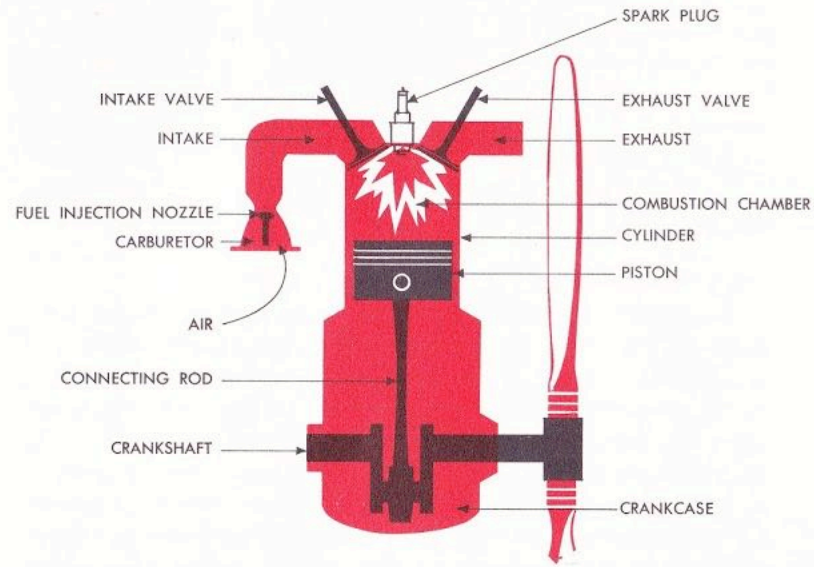
The Engine and Its Job

Potential and Kinetic Energy

The first task of any engine is to convert potential energy into kinetic energy. Energy is the capacity for performing work. Potential energy is stored energy—energy ready to act. Kinetic energy is energy in action. The one can be illustrated by a boulder poised on the edge of a canyon; the other by the moving boulder crashing down a canyon wall after its balance has been disturbed.

Energy cannot be created nor destroyed, but potential energy can be converted into kinetic energy. A mixture of a fuel, such as gasoline and air, has potential energy. When this mixture is ignited, the combustion generates gases that have kinetic energy and perform work.

Another characteristic of energy is that although it cannot be created, nor destroyed, it can be transformed. Heat energy can be changed into mechanical energy; mechanical energy and chemical energy into electrical energy; electrical energy, in turn, into chemical, heat, or mechanical energy.



The engine releases stored energy.

The Combustion Chamber

The first task of any engine is to release the potential heat energy of a fuel. In order to transform the potential of a fuel into heat; an engine employs a combustion chamber. Fuel is introduced into this chamber, is ignited, and burned there. An external combustion engine, such as a steam engine, burns its fuel outside the engine to change water into steam under pressure. This steam is used to operate the engine's movable parts—piston or turbine. The engine with which we are most greatly concerned is called the internal combustion engine. Airplane engines, whether reciprocating, jet, or turbo-prop are internal combustion engines and burn their fuel within an integral part of themselves.

Heat and Mechanical Energy

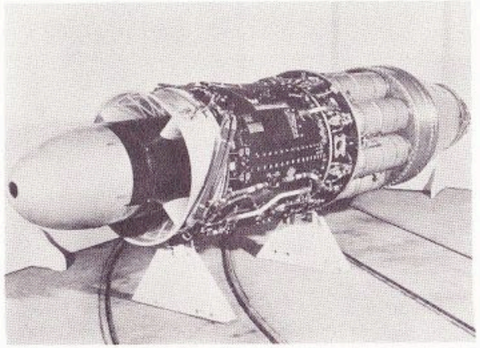
The second task of any engine is to transform heat energy into mechanical energy. As far as the internal combustion engine is concerned, some relationships discovered by two scientists who lived many years ago help us to understand how this is done. Robert Boyle, who lived about the middle of the sixteen-hundreds (1627-1691), discovered that the volume of a gas kept at a uniform temperature varied inversely as the pressure varied. That is, when we double the pressure of a gas, we reduce its volume by one-half, or if we treble the pressure, we reduce its volume to one-third of the original volume. Jacques Charles, who lived a century after Boyle, discovered that the pressure of a confined gas is directly proportional to its temperature. (Incidentally, Charles in 1783 was the first man ever to make a balloon ascension.)

Internal Combustion

The internal combustion engine puts to practical use the two principles discovered by Boyle and Charles. The mixture of fuel and air inducted into an engine cylinder, or combustion chamber, is therein compressed, ignited, and burned. It gives off heat which raises the temperature of the gas in the cylinder or chamber. As the temperature of the gas increases, it expands and its pressure increases. The higher its temperature, the more pressure it exerts. This pressure acts on the head of the piston in a reciprocating engine, on the vanes of a turbine in a turbine engine, and on the chamber walls of the jet engine.

Internal combustion engines are classified in a number of ways. Reciprocating engines, turbine engines, and ram engines depend for their operation upon oxygen contained in the atmosphere. Rocket engines carry their own oxygen, hence are independent of the atmosphere. There are over-lappings of engine classifications. For example, a turbo-prop and a turbo-jet are both turbine engines. Yet a turbo-prop is a combination, external-internal reaction engine in that some of the power it generates is transmitted to its propeller and some of it is converted into direct thrust.

Ram engines and rocket engines are internal reaction engines, yet ram engines are atmospheric-dependent while rocket engines are atmospheric-independent.



CHAPTER TWO

INTERNAL COMBUSTION ENGINES

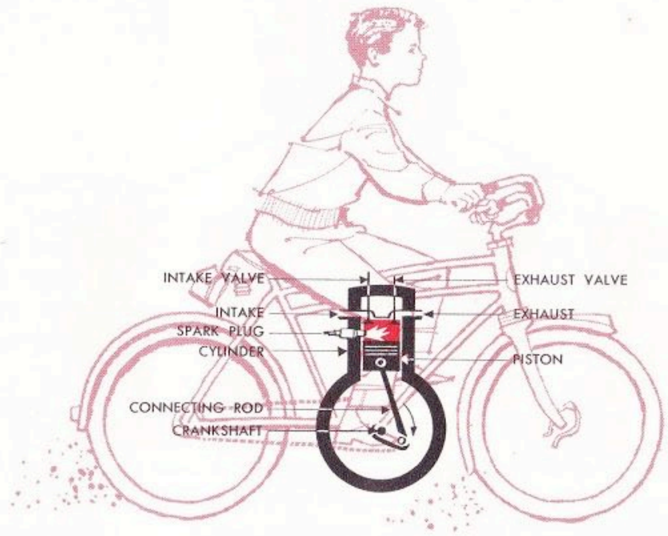
THE RECIPROCATING ENGINE

It appears likely that reciprocating engines will be used as the principal element of light airplane and helicopter power plants for many years to come. However, the turbo-jet engine, which in some respects is less complicated than a reciprocating engine, appears to be rapidly replacing the latter as an aircraft engine, particularly in military aircraft. In any event, a general knowledge of reciprocating engines, as background information, will help you better understand current research and development in aircraft propulsion.

The most simple reciprocating engine consists of a *cylinder*, a *piston*, a *connecting rod*, and a *crankshaft*. The ends (journals) of the crankshaft are mounted in oiled bearings. At one end of the crankshaft there may be a *fly wheel*. If there is no fly wheel, some other counter balancing device will be used. There are valves or ports in the cylinder which provide both an entrance for the air-fuel mixture and an exhaust for the burned products of this mixture. There is also provision for the ignition of the air-fuel mixture inside the cylinder.

Cylinder and Piston

The cylinder is a hollow tube closed at one end (the cylinder head). The piston is a second, shorter, hollow tube closed at one end (the piston head) which slides freely within the cylinder. Its walls are grooved to accommodate rings which fit closely against the cylinder walls and help seal the open end of the cylinder against escaping gases.



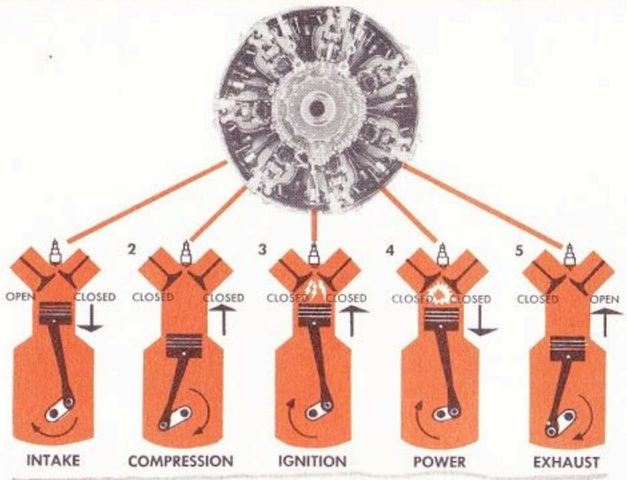
From straight-line motion to rotary motion.

Connecting Rod and Crankshaft

The connecting rod is a straight rod which helps convert the straight-line motion of the piston to the rotary motion of the crankshaft. It is attached at one end to the piston by means of a wrist pin and a bearing. It is attached at the other end to the offset portion (the crank) of the crankshaft by means of a bearing. The crankshaft is actually an adaptation of one of the simple machines—the wheel and axle. The moving piston, through its connecting rod, applies force to the crank in much the same may that the muscles of a bicycle rider, through his legs, apply force to the bicycle pedal.

The Flywheel

If you have ever ridden a bicycle you will remember that, if you did not release the pressure on one pedal at about the time you began to exert pressure on the other, the pedal crank would stop at the lowest point of its circular path. To prevent an engine crankshaft stopping in this fashion, it is equipped with a flywheel or counterweights. Once the wheel is set in motion and the pressure on the top of the piston is spent, the inertia of the flywheel or counterweights will carry the crank past its lowermost position and make possible the continuing operation of the engine.



Five events happen during the four-stroke cycle.

The Four-Stroke-5-Event-Cycle-Engine

A cycle is a series of events that repeats itself. An engine cycle is the series of events performed by an engine delivering power. When the term stroke is used in relation to the engines, it means the distance a piston travels from top dead center (TDC) to bottom dead center (BDC). Top dead center is the position of the piston just before it begins its downward stroke; bottom dead center is the position of the piston at the completion of this stroke. Although some engines complete a cycle of events in two-strokes, reciprocating air-craft-engines employ four strokes to complete a five-event series.

Intake Stroke

The first event of the engine cycle is the intake stroke. During this stroke, the fuel mixture is admitted through a valve opened by a projecton (a cam) on a shaft (cam shaft) operated by gears driven by the engine crankshaft. At the completion of the intake stroke, the cam shaft has revolved sufficiently to allow a spring to close the valve.

Compression and Ignition

The second event is the compression stroke. The rotation of crank-shaft forces the piston toward the top of the cylinder. During this stroke, both intake and exhaust valves are closed. As the piston approaches the top of the stroke (TDC) the fuel-air mixture is ignited by an electric spark. This is the third event—the ignition event.

Power Stroke

During the fourth event, the air-fuel mixture is ignited and burns. As this mixture burns, its temperature rises; it expands and drives the piston downward. This event is called the power stroke. Throughout the stroke, both valves remain closed, as they did throughout the compression stroke.

Exhaust Stroke

The fifth event is the result of the exhaust stroke. The exhaust valve is opened by action of the cam shaft, or other cam operating mechanism. The moving piston then forces through the exhaust valve opening the burned and burning gases left in the cylinder at the end of the power stroke. This leaves the cylinder ready to begin the cycle all over again. As long as the engine remains in good mechani-cal condition and unless fuel supply or ignition switch is turned off, each event of the cycle will take place in proper sequence.

The Two-Stroke-Cycle-Engine

Instead of valves, the two-stroke-cycle engine makes use of open-ings in the cylinder called ports. These are opened or closed as a result of piston movement. The piston head is constructed so that the exhaust port is opened before the intake port is opened and is closed before the intake valve is closed. During the first part of the compression stroke, both intake and exhaust events occur. The com-pression event takes place during the second part of this upward stroke. An arrangement of fuel intake and crank case makes it possible for the compression stroke also to draw an air-fuel mixture into the crank case.

Following the ignition event, the downward stroke—the power event—occurs. During this stroke, action of the piston also builds up pressure in the crank case which helps to force the fuel-air mixture through the intake part. Although the two-stroke-cycle engine is sometimes used in aviation to operate related and auxiliary equip-ment, in the main it has proven of no practical value as an aircraft power unit.

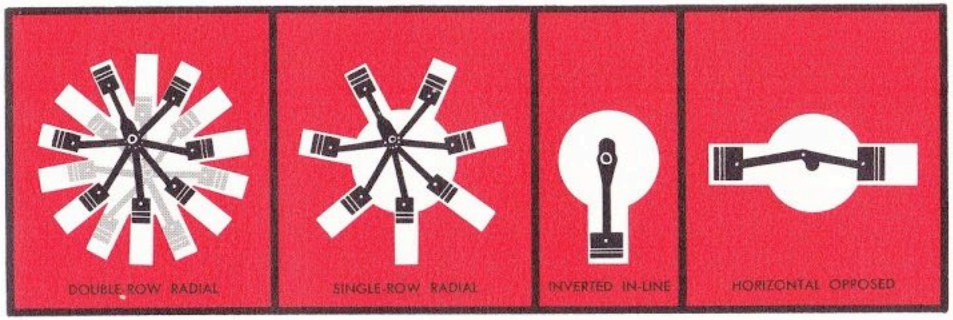
The Diesel-Engine

Most diesel-engines employ the four-stroke cycle. However, no fuel is mixed with air drawn into the cylinder during the intake event. The fuel is injected into the cylinder under very high pressure as the piston approaches TDC on the compression event. You will remember that Boyle's law states that the pressure of a gas is inversely proportional to its volume, if its temperature is held constant. However, under ordinary circumstances, it is not possible to compress a gas without raising its temperature. Consequently, at the end of the diesel-engine compression stroke, the compressed air in the cylinder is hot enough to ignite the injected and atomized fuel. Therefore, the diesel-engine uses no spark plugs. The diesel compresses the air within its cylinders to approximately one-half the volume of the compressed fuel-air mixture of the conventional four-stroke cycle engine. High pressures and high temperature of the diesel-engine require that it be of heavy construction. Consequently, since an aircraft engine must be of comparatively light weight, little use is made of the diesel as a power plant unit for aircraft.

RECIPROCATING ENGINE DESIGN

Since aircraft which are built for different purposes differ from one another in design, so the engines of each type of aircraft are likely to differ in design. For example, the cylinders of an aircraft engine may vary in number and in plan of arrangement. The most common methods of arranging cylinders of aircraft engines are in-line, V-type, opposed, single-row radial, and multi-row radial.

An aircraft engine may be liquid-cooled or air-cooled. In-line and V-type engines are liquid-cooled. Radial-type engines are air-cooled. Excessive engine heat is undesirable. If the engine cylinder temperature becomes too great, pre-heating and pre-ignition of the fuel-air mixture will take place. Such premature combustion will cause detonation, or knocking, which in turn affects the engine adversely. Excess engine temperatures may weaken heat-treated, airplane parts or destroy the effectiveness of lubricating oil. Consequently, the cooling system is an important part of the aircraft power plant.



Different engine designs for different engine uses.

The cylinders of a radial engine branch out from a center in the same way that the spokes of a wheel spread out from an axle. Radial engines always have an odd number of cylinders. A single-row, radial engines may have five, seven, or nine cylinders. Multi-row, radial engines have two or more banks of seven or nine cylinders each.

From the outer surface of cylinders and cylinder heads, thin metal fins project. Air moving over and around these fins carries away excessive heat. A system of flaps (cowl flaps) hinged to the engine cowling (metal cover) is used to control this air flow and consequently, to regulate engine temperature.

Although the principles of operation are the same for all reciprocating engines used on modern aircraft, different engines may use different operating devices. For example, rather than a crankshaft with an offset for each connecting rod, a single-row, radial engine uses a crankshaft employing one crank with balancing counter-weights. A master rod is attached to the crankshaft, and all other connecting rods are attached to the master rod. Also the radial engine instead of a cam shaft must use a cam ring.

Those who design and build reciprocating aircraft engines are influenced in their work by several important, general, aircraft-engine requirements. The weight of the engine must be kept as low as possible so that a maximum useful load may be carried by the aircraft. It should be built as inexpensively as possible without sacrificing efficiency of performance. It should have a long performance life, a low fuel consumption at cruising speed, and ability to run smoothly and perform adequately at all its speeds under all variations of atmospheric conditions.

THE TURBO-JET

The principal advantage of jet-propulsion of aircraft is speed. Another advantage is its comparative simplicity. Air drawn into the front of the jet engine is compressed, fuel is added, and the fuel-air mixture set on fire. The ignited gases expand and discharge from the rear of the engine. The reaction to this discharge moves the airplane forward. The propeller of the reciprocating engine creates pressure differences by pushing the air backward; the expanding gases of the jet create pressure differences which move the aircraft forward as it blows the heated air mixture backward.

Jet and Rocket Development

The idea of the reaction engine is almost as old as recorded history. It is said that as early as 100 A.D., Hero of Alexander invented a device known as the Aeropile, which used the principle of jet propulsion. It consisted of a hollow sphere with nozzles on its surface mounted on an axle between two supports. When steam under pressure was introduced into the sphere and allowed to escape through the nozzles, the reaction caused the sphere to spin between its supports.

Centuries later in 1849 a man named Charles Golightly was granted a patent on an aircraft to be powered by a jet engine. It never got out of the design stage. The first jet propelled aircraft that actually flew was developed by a man named Campine, an Italian. Air Commodore Frank Whittle, of the R.A.F. (Royal Air Force), designed the first turbo-jet powerplant. An aircraft powered with this engine flew successfully in 1941. However, it was not until the Germans powered the buzz bombs which they used against England in World War II with a pulse jet engine that any practical use was made of jet propulsion.

Recent progress in jet and rocket propulsion has been the result of research and development efforts made by many people during

the last few years. Such research has discovered heat resisting alloys, new fuels, new lubricants, and more efficient designs for jet and rocket engines.

Principles of Jet Propulsion

Jet propulsion is based upon Newton's second and third laws of motion. The recoil of a gun or the reaction of a deflating toy balloon demonstrate in principle these laws of motion. One way to state Newton's second law of motion is to say that the force acting upon a body is equal to the mass times the acceleration of the body. One way to state Newton's third law is to say that for every action there is an equal and opposite reaction.

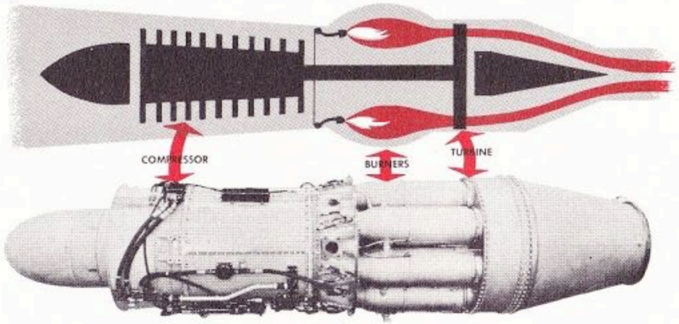
Another way to explain the operation of the jet is to say that its forward motion and that of the aircraft to which it is attached is a reaction to the force necessary to blow the burning air-fuel mixture out of the engine. This force is equal to the mass of the air blown out times its change of speed in relation to the jet engine.

A common application of jet propulsion is the rotating water sprinkler. Water under pressure enters the hollow shaft of the sprinkler which serves as an axis for the rotating sprinkler head. The water flows to the nozzles and, because of pressure, is ejected from each nozzle at high velocity. As a consequence, thrust-forces develop at each nozzle and cause the sprinkler head to rotate.

The turbo-jet employs a compressor which is somewhat like the turbo-supercharger used on some reciprocating aircraft engines. Its purpose is to compress the air which it acts upon much as a piston of a reciprocating engine compresses the air introduced into its cylinders, reducing its volume and increasing its density and pressure.

Guide vanes of the turbo-jet direct the course of the air into a compressor. From the compressor the air is discharged into the diffuser channels of the compressor casing. These channels slow down its velocity, increase its static pressure, and distribute the air evenly through adapters into the turbo-jet's combustion chambers.

The combustion chamber is equipped with removable liners. The air enters these through a series of holes, mixes with the fuel continuously injected into the combustion chamber, and is ignited. The resulting combustion causes heat which raises the temperature of the gases. The hot expanding gases escape with great force from the



A turbo-jet powerplant.

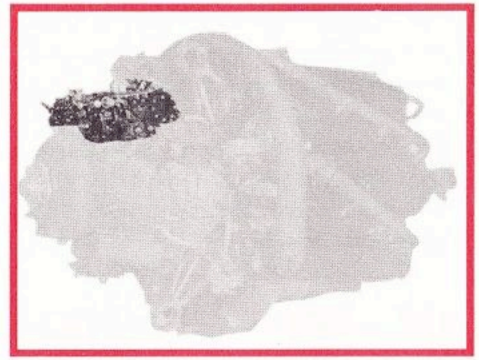
combustion chamber liners through the curved blades of the nozzle diaphragm and strike the curved blades of the turbine wheel, causing it to rotate.

The turbine wheel is attached to a shaft which drives the impeller wheel of the compressor. The operation of the turbine wheel takes much of the energy of the expanding gases. The remaining energy is transformed into forward thrust. One type of turbo-jet engine has an afterburner where extra fuel is injected into the escaping gases and ignited, giving added thrust to the engine.

EXPERIMENTAL ENGINES

Aircraft have been successfully powered by rocket engines. However, research must yet solve many engineering problems before such engines are generally used either in military or civil aviation. The use in aircraft operation of the tremendous power released by atomic fission is also contemplated. Research projects are now underway which very likely will produce an "atomic powered" aircraft. Again many practical problems confront research engineers and manufacturers who are working on these projects. An interesting experiment is also underway which would employ the jet principle to obtain lift as well as thrust, making the airplane wing unnecessary. An aircraft powered with this kind of jet engine would be a flying fuselage.

Whether or not engine projects now in the experimental stages prove practical, we can be certain that in the course of time research and development will produce new types of aircraft powerplants based upon newly discovered principles and practices.



CHAPTER THREE

HOW THE ENGINE GETS ITS FUEL

You have learned that the internal combustion engine, whether reciprocating or jet, makes use of the fact that when a gas is heated it expands. A fuel-air mixture enclosed in the cylinder of a reciprocating engine expands in one direction only, against the yielding piston. A fuel-air mixture entering the combustion chamber of a jet engine also expands in one direction, but the force of this expansion imparts movement to the engine itself. Before fuel can burn and release its potential heat energy, it must reach the engine cylinder or combustion chamber. Either a carburetion system, a fuel injection system, or some combination of these two introduces the fuel required for the engine's operation.

THE CARBURETION SYSTEM

A carburetor is used with reciprocating type engines that do not employ the fuel injection system. The carburetors first used by early aircraft engines were of the same type as those used by automobile engines. The carburetors used on modern reciprocating aircraft engines are still similar in principle to early carburetors. However, the modern aircraft engine carburetor is much more complex than the automobile carburetor, since it must function regardless of the attitude an aircraft assumes while in flight.

Aircraft carburetors may be classified as float type, diaphragm type, and injection types. All types of carburetors like all engines depend

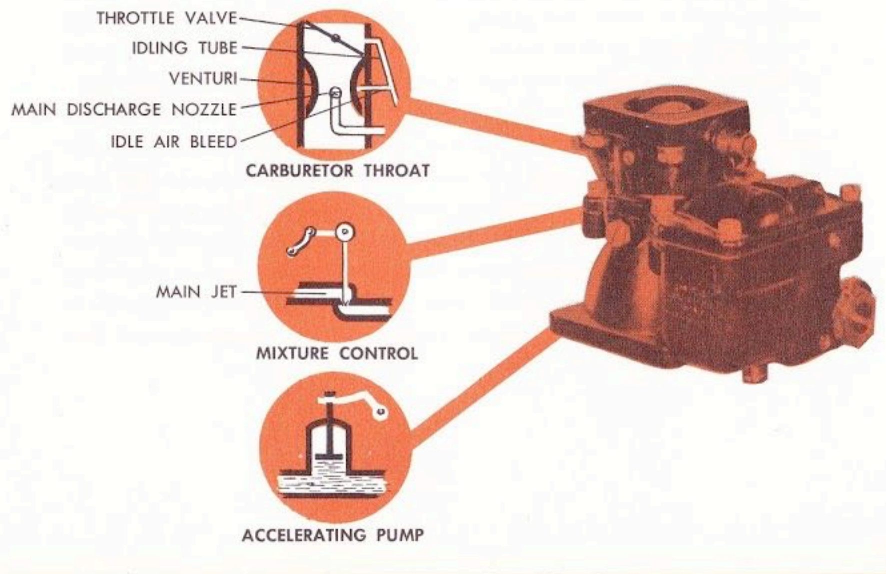
upon auxiliary equipment for proper operation; consequently, even the most simple carburetion system includes fuel tank, fuel line, strainers, fuel pump, and manifold. Gasoline from the fuel tank enters the carburetor through the fuel line. After the carburetor vaporizes the gasoline and mixes it with air, the manifold directs proper amounts of the mixture into each cylinder. More complex carburetion systems include superchargers which keep the manifold air pressure proper for engine-operation at high altitudes.

THE SIMPLE CARBURETOR AND ITS OPERATION

The first task of the carburetor is to meter (measure) the fuel. In the float type carburetor this measuring begins as the fuel enters the float chamber. A needle valve is operated by a float in the float chamber. When the level of the fuel in the float chamber rises, the float rises. As it rises, the needle attached to a level (the lever-fulcrum principle) lowers. When the proper fuel level is reached, the lowering needle cuts off the fuel flow through the fuel-inlet.

The second task of the carburetor is to atomize the fuel (break it into tiny particles and mix these with the air). To do this task the carburetor uses a fuel nozzle, an air intake, a venturi, and a throttle valve. (The illustration below shows these in their relation to each other and to other parts of the carburetion system.)

The principal parts of a float type carburetor.



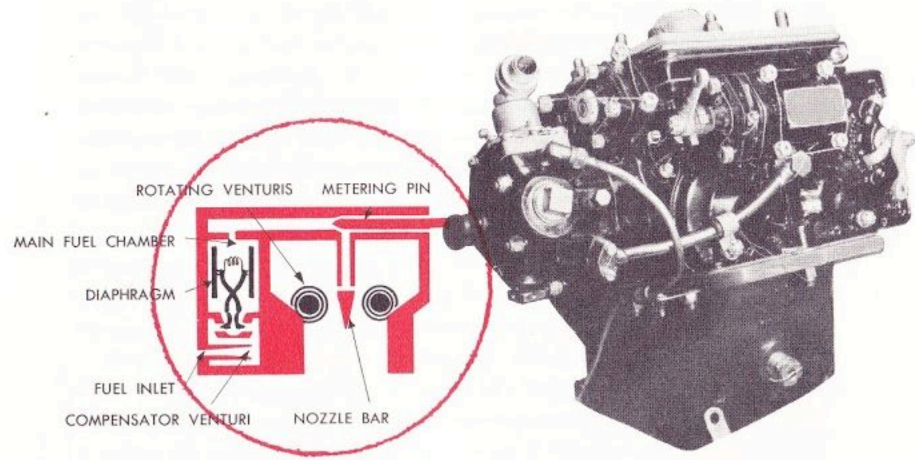
When the piston moves downward during the intake stroke, a partial vacuum is created within the cylinder. The decreased pressure occurring in the cylinder as a result of this action causes several things to happen. To fill the partial vacuum created, the fuel-air mixture from the manifold portion of the carburetion system rushes into the cylinder. Air from outside the carburetor is drawn by this lowered pressure into the air intake and through a constriction in the carburetor barrel called the Venturi section. The air passing through this narrow part of the carburetor barrel has to move faster than the air passing through the other sections of the barrel. Because of this, it has to use more of its energy for speed and as a result has less for pressure. (You remember the relationship of the velocity and pressure of gases.) Since the fuel nozzle enters the carburetor barrel at the Venturi section, when the pressure in this section lowers, the higher atmospheric pressure in the float chamber to which the fuel nozzle is connected causes the fuel to spray through the nozzle into the barrel of the carburetor. The butterfly valve, as it is opened or closed by throttle action, controls the amount of the fuel-air mixture entering the manifold for distribution to the cylinders.

In addition to the carburetor parts whose functions have been described above, the modern carburetor also requires an air bleed, an idling system (idle air bleed and idling jet), an accelerating pump, an economizer valve, and a mixture control. The *air bleed* permits air to be drawn into the discharge nozzle along with the fuel. By forming air bubbles in the fuel, it helps break the fuel into small particles as it is discharged through the nozzle. The idling system allows fuel to enter the carburetor barrel above the throttle valve (butterfly valve) so that, even with the throttle closed, a fuel supply sufficient for engine idling operation will be provided.

When the throttle is opened quickly and air and fuel are drawn into the carburetor, the heavier fuel does not move as rapidly as the lighter air. Consequently, the fuel-air mixture may become so lean (less fuel, more air) that the engine will not operate. *The accelerating pump,* under these conditions, forces extra fuel into the Venturi section. The *economizer valve* works in cooperation with the accelerating pump. At cruising speeds it remains closed. When the throttle is opened wide, its needle is raised and more fuel is permitted to flow

through the fuel nozzle. The *mixture control* keeps the amount of fuel flowing through the discharge nozzle in proper relation to the density of the air through which the aircraft flies.

You will remember that air at sea level is heavy enough to exert a pressure of 14.69 pounds per square inch. However, this pressure decreases as an aircraft increases its flight altitude, so that when an aircraft flys at 15,000 feet above sea level, the pressure exerted upon it is only half this amount. The mixture control makes it possible to reduce the amount of fuel flow to correspond to the weight of the air intake at high altitudes. (See illustrations, page 21.)



A diaphragm mechanism controls fuel flow.

The Diaphragm Carburetor

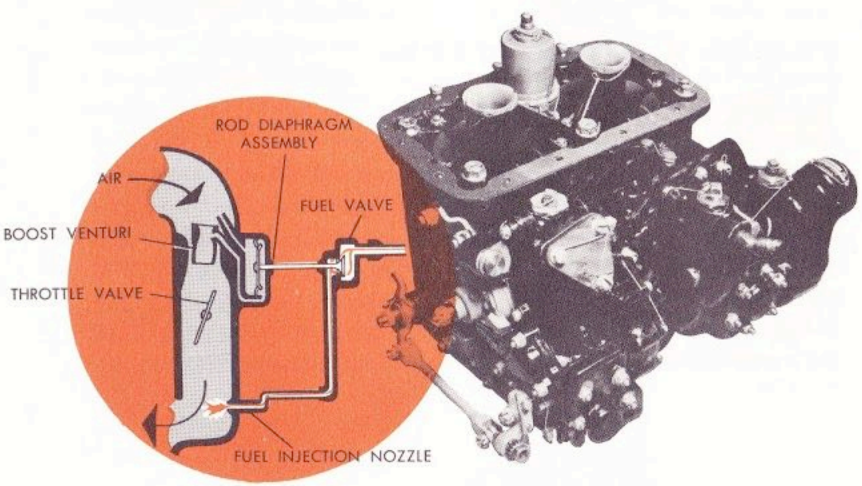
When the float system carburetor is used, any unusual change in the attitude of the aircraft will cause fuel to slosh around in the fuel chamber, interfering with proper fuel metering. To prevent such malfunctioning, aircraft engines are often equipped with the diaphragm type carburetor. The Venturi on this type carburetor is made of two parts shaped like half cylinders. These can be rotated to close the Venturi opening; consequently, no throttle valve is necessary.

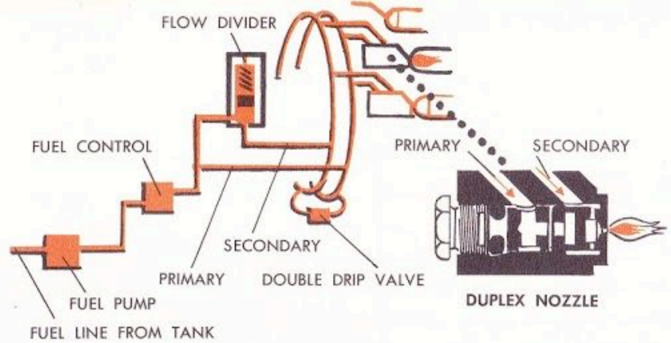
The diaphrams are made of metal disks set in larger, tough fabric disks. In the diaphragm type carburetor, diaphragms are placed one on each side of a cylindrical fuel chamber. They are joined together, yet held a certain distance apart, by a metal spring. Levers connected to them operate the fuel inlet valves. Fuel entering through these valves fills the chamber and, pressing against the diaphragms, forces them apart, thus closing the inlet valves. As the quantity of the fuel in the chamber is used and decreases, the diaphragms are pulled together by the action of the spring connecting them, thus opening the inlet valves. (See the illustration, page 23.)

The Injection Carburetor

There are two great problems which the aircraft engine carburetion system must solve. One is to assure a constant flow of fuel; the other is to prevent ice formation in the carburetor. For the ordinary carburetor is a miniature refrigerator. It changes the liquid fuel into a gas—vaporizes it. To vaporize a liquid requires heat. This heat is taken from the surrounding air. The decrease in air temperature which results may amount to 30° or 40° F. The lowered temperature causes the condensation and perhaps the freezing of water vapors which may be present in the air passing through the Venturi.

Fuel injection helps prevent carburetor icing.





A turbo-jet fuel system.

The rotating Venturi mentioned above helps prevent ice formation. Another effective method is to use the injection system of introducing the fuel into the carburetor. Three principal features set this carburetor apart from the ordinary carburetor: 1. Fuel under pressure from a fuel pump enters the fuel section of a cleverly designed fuel regulator. 2. The fuel regulator, by use of a small booster Venturi and a rod-diaphragm assembly, controls the amount of fuel injected into the carburetor. 3. Fuel enters the carburetor not at the Venturi throat, but beyond both this constriction and the throttle valve. (See the illustration, page 24.)

THE FUEL INJECTION SYSTEM

The fuel injection system discharges fuel in the form of a spray-jet into the intake manifold at the intake valve. Fuel is pumped into fuel jets by a plunger-cylinder arrangement activated by a gear and a cam operating off the main cam shaft. Obviously, the operation of the system must be synchronized with the intake event of the reciprocating engine.

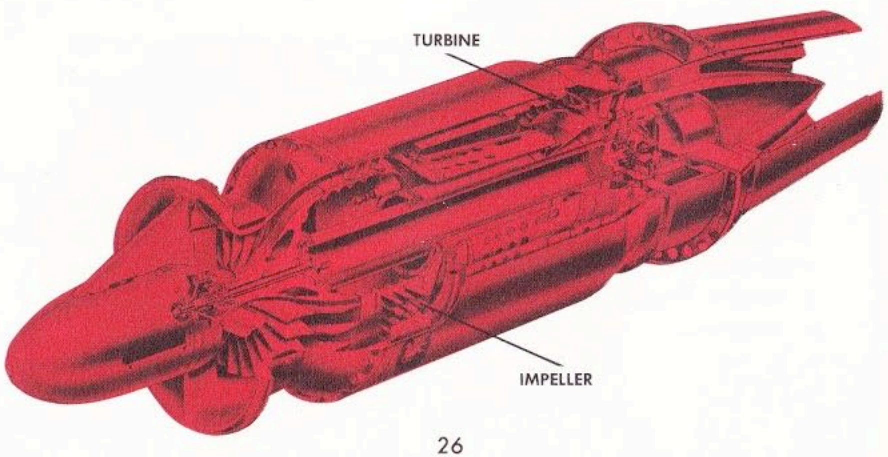
The fuel injection system eliminates completely the problem of ice formation, since fuel vaporization takes place at the intake valve where temperatures are normally quite high. The system also reduces fire hazards, is reported to give more power per unit of fuel, and functions equally well regardless of the attitude of the plane. Its principal disadvantage stems from the fact that when the system is adapted to a many-cylindered engine it is very complex. The jet engine uses a fuel-injection system, with these differences: 1. Fuel is injected directly into each combustion chamber. 2. The fuel flow is continuous.

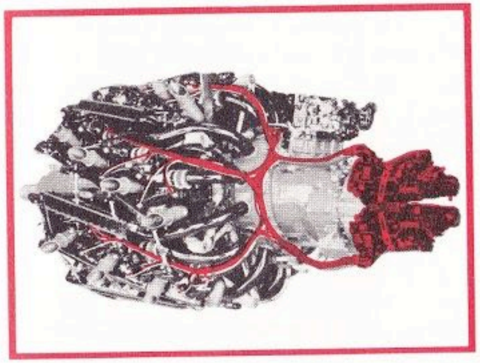
THE SUPERCHARGER

A supercharger is a type of air-compressor. Its purpose is to pump enough air into the carburetor or engine to assure efficient engine operation. You will remember that as altitude increases, air pressure decreases. This means that air at high altitude weighs less than air at low altitude. As a matter of fact, while at sea level 13 cubic feet of air weighs about one pound, at 18,000 feet it takes 26 cubic feet of air to weigh one pound. At 36,000 feet of air it takes about 52 cubic feet of air to weigh one pound.

Before an engine operating at 18,000 or 36,000 feet can attain sea-level operating efficiency, the supercharger must compress the fuel-air mixture as it enters the manifold, the air as it enters the carburetor intake, or both. All superchargers operate on the same principle. Revolving blades press the air into the carburetion system and consequently build up manifold pressure. The turbo supercharger impeller (or blower) is operated by a turbine driven by the exhaust gases from the engine. One type of supercharger is driven by means of shafts geared to the engine crankshaft. A method much like the transmission system of the modern automobile is used to drive the supercharger - impeller of the modern reciprocating engine. This method employs a fluid rather than a gear assembly as the driving mechanism.

Like the impeller of a turbo-jet, the impeller of the supercharger is driven by a turbine.





CHAPTER FOUR

POWER PLANT ELECTRIC SYSTEMS

After the fuel-air mixture drawn into the engine combustion chamber is compressed, it must be ignited, if the sequence of the engine's operating events takes place. That is to say, if the gases taken into the cylinders or combustion chambers are to expand, they must be set on fire. Of course, if a gas compressed is sufficiently reduced in volume, its temperature will rise high enough to ignite the vaporized fuel which it contains. The diesel engine uses this method of ignition. However, in aircraft engines most commonly used, it is found best to ignite the fuel-air mixture by means of an electric spark.

Starting the Engine

Before the operating cycle of an engine can get under way, some force outside the engine must be applied to "turn" the engine over. One way of starting the small engine of a light plane is by "swinging the prop." This method, which is rapidly being discontinued, requires that the propeller be used (as the crank of the early automobile was used) to start the engine cycle operating.

As a matter of fact, detachable cranks are still used in starting some types of aircraft engines. One method of starting aircraft engines employs the crank *directly*; another method uses the crank to assist in *inertia starting*. In direct starting, the crank turns a clutch which engages the rear end of the crankshaft. In inertia starting, the crank turns a flywheel, causing it to rotate at high velocity. When the flywheel reaches a proper high speed, it engages the crankshaft, also by means of a clutch arrangement. The energy of the spinning flywheel then rotates the engine several times, putting it into operation. However, as the application of electricity provides the most satisfactory ignition system, so does the application of electricity provide the most satisfactory aircraft engine starting systems.

Some Essential Facts About Electricity

To help you understand the operation of aircraft engine ignition systems and starting systems, it is necessary to explain some simple facts that will help you understand how electricity is generated:

1. A magnetic field composed of magnetic lines of force surrounds any magnet.
2. A current flowing through a conductor sets up a magnetic field around that conductor.
3. Magnetic lines of force (or lines of flux) take the path of least resistance through a conductor.
4. When a conductor of electricity (a wire) is moved through a magnetic field, a current will flow through the conductor.
5. If the magnetic field is moved across the conductor, the effect is the same as that which occurs when the conductor is moved through the magnetic field.

The generating of electricity for any purpose makes use of these facts. Electric generators produce electric currents either by moving properly arranged conductors through a stationary magnetic field or by moving a magnet so that the magnetic field moves across the stationary conductors.

Igniting the Air-Fuel Mixture

Ignition systems are of two types: battery and magneto. Each system has a source of electrical energy, an induction coil, an interrupter, a condenser, a distributor, wiring, and control switches. Both systems are shielded to reduce electrical interference with radio communication. Modern aircraft engines are equipped with dual magneto ignition systems which assure both greater variety and greater efficiency of engine operation. However, on aircraft using magnetos, the source of electricity for purposes other than ignition is provided by electric generators and batteries.

The Magneto

A magneto is a special kind of generator. As it operates, magnets are rotated between "pole shoes" by means of an accessory shaft geared to the engine crankshaft. The pole shoes are joined by a core around which are wound the primary and secondary coils.

The primary and secondary coils of the magneto serve as the induction (or spark) coil. An induction coil is really a transformer which steps up the voltage (electric pressure) so that it is great enough to cause a spark to jump between the spark plug electrodes (wires).

When the magnets turn, the lines of flux of their magnetic fields move along the path of least resistance, the pole shoes and the soft iron bar which joins them. As a consequence, a voltage is introduced in the primary coil—the comparatively few turns of heavy copper wires wrapped around the bar between the pole shoes. Interrupting the flow of electricity through the primary coil induces a voltage in the secondary coil. (See Essential Facts About Electricity, p. 29.)

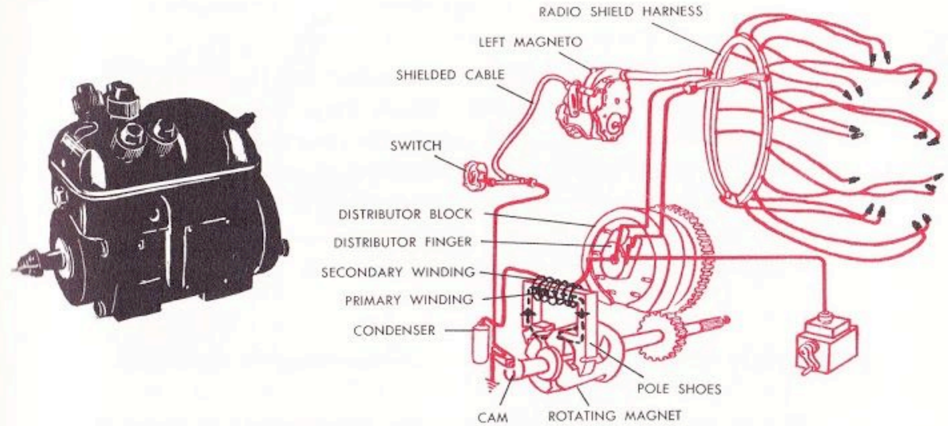
The magnitude of the voltage induced in the secondary coil depends in great part upon the comparative number of turns of wire that it has. If a primary coil which has 50 turns of wire produces 12 volts, its secondary coil which has 500 turns will produce 120 volts. Since the average magneto produces 20,000 volts, the secondary coil of such a magneto will be made up of thousands of turns of wire.

Remember that a changing current through one coil can induce a current in a second coil only when wires of the secondary cut the lines of flux in the magnetic field of the primary. Consequently, a current will flow in the secondary circuit only when the current in the primary circuit is building up from zero to its maximum or collapsing (when the primary circuit is broken) from its maximum to zero. This explains the purpose of the interrupter or circuit breaker. Its action makes it possible for the secondary windings to be cut by the lines of flux of the primary coil as these build up or collapse. (See illustration, page 31.)

One type of magneto, the low tension magneto, does not "step up" the voltage of the primary circuit. When this type of magneto is employed, an induction coil (secondary coil) is used with each spark plug to obtain the voltage needed for the "spark-jump."

The Condenser

The purpose of the condenser of an ignition system is to store up or accumulate electricity. Conducting bodies which are separated by insulation are able to do this. Consequently, condensers may be made of alternate layers of a metallic foil and waxed paper, rolled



The magneto is a special kind of electricity-generator.

into a cylindrical shape and inclosed in a moisture-proof container. A condenser does not provide a path for the transmission of an electrical current. Its chief purpose is to help make the collapse of the primary circuit instantaneous and, as a consequence, increase the voltage produced by the secondary coil. That is to say, it helps build up voltage for the "spark-jump."

The Distributor

From the secondary windings the current passes to the distributor. The distributor is a revolving contact point which passes over a circle of other stationary contact points. There is one of these for each engine cylinder. As the revolving contact point passes over a stationary contact point, a spark jumps the gap between the two electrodes of the appropriate spark plug. It is important that the timing mechanism of an engine is adjusted so that this ignition event occurs in each cylinder at the proper time. (See illustration, above.)

It is necessary to supplement the magneto with a booster coil which furnishes sparks for starting the engine. Until the engine rpm builds up, magnetos cannot furnish the necessary spark.

Jet Ignition

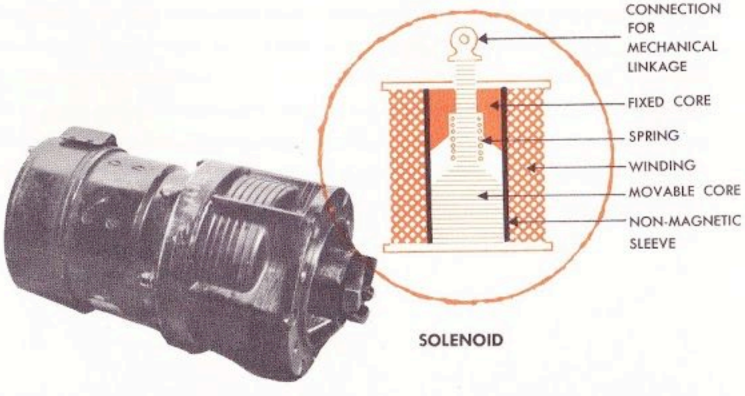
The ignition system of the jet engine is much less complicated than that of the reciprocating engine. Spark plugs are used to ignite the fuel-air mixture in two of the combustion chambers, as the engine is started. Cross ignition tubes connecting these with other combustion chambers ignite the fuel-air mixture of the remaining combustion chambers. A battery is used as the source of voltage. An induction coil steps up the voltage to produce the essential spark.

Electric Starting

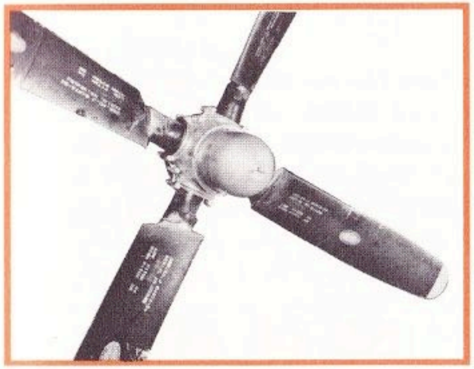
Electric starting uses an electric motor whose source of electricity is produced by a generator and stored in an electric battery. As a matter of fact, an electric motor is a generator operating in reverse. Mechanical energy converted into electrical energy can be recovered as electrical energy is converted back into mechanical energy. The device that generates electricity can, by using electricity, generate mechanical energy.

The mechanical energy of the electric starting motor can be applied directly or indirectly. In this latter instance it turns the flywheel of the inertia starter which engages the crankshaft. However, direct electric starting is the most widely used of all starting systems. Solenoids (coils with moveable cores) are used both as starting switches and as mechanical hands to mesh the starter gears of motor and crankshaft. (See illustration, below.)

The turbo-jet employs an electric starting system which operates the turbine wheel and compressor until necessary air-fuel density is built up in the compression chambers.



SOLENOID



CHAPTER FIVE

THE USE AND LOSS OF HEAT

You know that the internal combustion engine is a heat engine. This is true whether the engine be a reciprocating, a turbine, or a jet propulsion type. The principle of operation of the aircraft engine is based upon the fact that heat energy can be changed into mechanical energy. An English physicist named Joule demonstrated many years ago that it was possible also to transform a certain amount of work (mechanical energy) into the same amount of heat. The controlled observations of Joule and other scientists led to the definition of the first law of thermodynamics (the principle of the conservation of energy). The law states that although energy may change its form, no energy is ever destroyed.

HEAT AND MECHANICAL ENERGY

So that calculations involving heat energy and mechanical energy can be made, it is necessary to establish units of heat and units of work, and to describe the relation of these one to another. The unit of heat is called the *British thermal unit*. It is defined as the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit (F). The unit of work is the foot-pound. It is defined as the amount of mechanical energy required to move a one-pound weight a distance of one foot. It has been learned that if all the heat energy in one B.t.u. could be salvaged it would produce 778 ft./lbs. of work.

Thermal Efficiency

It has been learned that one pound of gasoline has a potential heat energy content of 20,000 B.t.u. This means that when we mix one pound of fuel with fifteen pounds of air and set fire to the mixture, 20,000 B.t.u. are given off. An internal-combustion engine which can transform all this heat into mechanical energy will be able to produce from one pound of fuel, 778 x 20,000 or 15,560,000 ft./lbs. of work. Such an engine would be 100% effective. Engineers would say that its *thermal efficiency* was 100%.

Thermal efficiency is the ratio (numerical expression of relationship) of the useful work developed by an engine to the heat energy produced. Unfortunately, no engine yet manufactured can turn into useful work more than 35% of the heat energy produced by the combustion of the fuel-air mixture. (See illustration, page 36.)

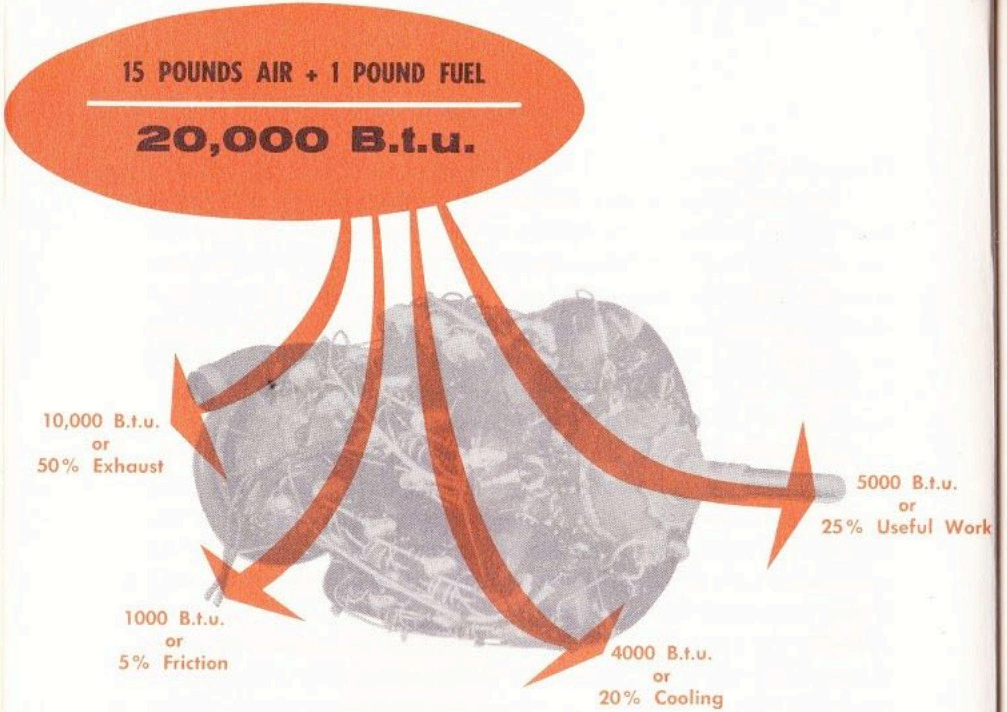
You remember that in the reciprocating engine the heat made available for conversion to work takes the form of pressure upon the piston head. The high speed of the reciprocating engine's operation forces the burned gases out of the exhaust port while their temperatures are still very high (approximately 2000° F). About half of the total heat produced during the engine operation is expended through the exhaust process.

The temperatures (2000° F) resulting as the fuel-air mixture burns are so high that metals used in engine construction cannot withstand them. For this reason the engine must employ a cooling system. (See Chapter VI.) The cooling system carries away about 20% of the total heat produced during the engine operation.

Friction (the rubbing together of the engine's moving parts) raises the temperature of the metals involved. This temperature rise is made possible only by using the nearest source of heat. The burning gases of the engine cylinders supply an easy source and ample amount of heat. About 5% of the total heat produced by the reciprocating engine is expended because of friction.

Horsepower

Mechanical efficiency is the ratio of the ft.-lbs. of work actually delivered to the propeller to the ft.-lbs. of work produced by the engine. Generally the ratio is expressed in horsepower and is stated



Where the heat goes.

as the ratio of the useful horsepower to the total horsepower produced.

James Watt established *horsepower* as the unit of measurement to describe the power of his steam engine. He concluded that the largest weight that could be raised in one minute by a draft horse was 33,000 pounds. Consequently, one horsepower came to be defined at 33,000 ft.-lbs./min. (33,000 foot pounds per minute). This fact accounts for the figure 33,000 in the formula used to calculate horsepower.

You must remember that to find the total horsepower of an engine, the horsepower of one cylinder is multipled by the number of the engine's cylinders. The result of this multiplication is called the *indicated horsepower*. However, friction not only causes the expenditure of heat energy, it also causes an expenditure of mechanical energy. The amount of horsepower needed to overcome friction

is called *friction* horsepower. In order to learn how much horsepower is left to turn the propeller, *friction horsepower* is subtracted from *indicated horsepower*. The remainder is called *brake horsepower*. The relationship between the brake horsepower and the indicated horsepower, expressed in percent, is the mechanical efficiency of the engine.

One way to discover the brake horsepower of an engine is to use a device called a *Prony brake*. This device uses a flywheel which is fastened to the shaft of the engine. The flywheel is then clamped between two blocks. As the engine operates, the flywheel tends to twist the blocks. This torque (the force of the twisting movement) is measured on a scale by a pointer attached to the block assembly. The scale is assumed to record the brake horsepower.

Horsepower Factors

In order to learn how much indicated horsepower an engine will produce, it is necessary to know a number of things:

1. We need to know the pressure of the expanding gases in the cylinder. The average value of this pressure expressed in pounds per square inch, called the *mean effective pressure* (m.e.p.), is the value used in the horsepower formula. In order to find this value, an indicator card (pressure, volume diagram) of the engine in question is used. This card shows the rise and drop of pressure during the piston strokes. An approximation of the m.e.p. value can be determined by taking an average of pressure values plotted on the indicator card.
2. We need to know the stroke of the piston (distance of piston travel) since this is the distance through which the force on the piston head is exerted.
3. We need to know the area of the piston head, since m.e.p. is expressed in lbs./sq. in.
4. We need to know how many times the crankshaft turns each minute (r.p.m.). In the four-stroke-cycle engine, this value must be divided by two because the power stroke lasts only one half of one revolution and the crankshaft makes two complete revolutions for each complete four-stroke cycle.
5. We need to know the number of cylinders of our engine.

By using a formula we can learn from this information the indicated horsepower of our engine.

The formula is $\frac{PLANK}{33,000} = IHP$

P = m.e.p.; L = the length of the stroke;
A = the area of the piston head, or cylinder bore;
N = the number of r.p.m. divided by 2;
K = the number of cylinders; 33,000 is the weight in lbs. that can be raised by 1 HP in 1 min. (See page 36.)

Let us assume that the m.e.p. of our engine is 110 lbs./sq. in.; that its stroke is 3.5 inches; its bore diameter 3 inches; that its r.p.m. is 2000; and that it has 9 cylinders. Substituting these values for the symbols in the horsepower formula we have:

$$\frac{110 \times 3.5 \times \pi\left(\frac{3}{2}\right)^2 \times \frac{2000}{2} \times 9}{33,000} = IHP$$

$$\text{or } \frac{110 \times 3.5 \times 7 \times 9}{33} = 735 \text{ IHP}$$

After completing the necessary multiplication and division we find the IHP (indicated horsepower) of our engine to be 735.

Thrust

The power developed by jet propulsion engines is expressed in pounds of thrust rather than horsepower. Since the thrust delivered by the reaction type engine is constant, its power is in proportion to its speed. If the speed of a jet aircraft is 375 m.p.h., one pound of thrust will equal 1 horsepower; if it is 750 m.p.h., one pound of thrust will equal 2 horsepower. For example, a jet engine of 4000 pounds thrust develops 4000 horsepower at 375 m.p.h. and 8000 horsepower at 750 m.p.h.

In theory, if a jet propelled airplane was flown in a perfect vacuum, its forward velocity would equal the velocity of the jet its engine produced. Consequently, under certain conditions, the less dense the atmosphere through which it flies and the greater the speed at which it flies, the better will be the jet engine's performance.

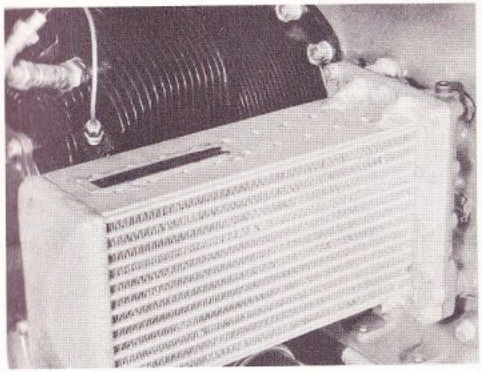
The jet engine has a comparatively high rate of fuel consumption. A jet developing 4000 pound thrust may use as much as 5000 pounds of fuel in one hour. Obviously, although research brings about almost daily improvement in the performance of jet engines, their thermal efficiency is low when compared with that of reciprocating engines.

The Fuel the Engine Uses

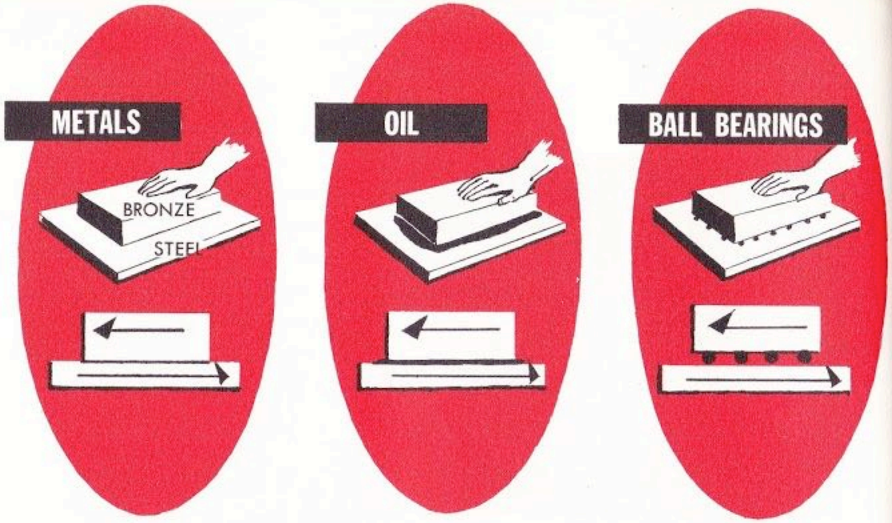
Crude petroleum is the source of modern aviation fuels. Petroleum belongs to a chemical family called hydrocarbons. *Hydrocarbons* are formed by the chemical elements, hydrogen and carbon. After the crude oil is pumped from wells it is piped to refineries where a process called *fractional distillation* takes substances from it, such as gasoline, kerosene, and lubricating oils. Fractional distillation is possible because each of these different substances has a different boiling point, and all vaporize at different temperatures. Consequently, when crude oil is raised to one temperature, gasoline is evaporated; when raised to a higher temperature, kerosene is evaporated, etc. After a substance is vaporized, it is then cooled to its condensation point and is ready for use.

Fuel for the modern high-speed, high-compression, reciprocating engine must meet certain standards. Volatility (its ability to turn readily into vapor) is one of these. Its antidetonation (antiknock) value, or octane rating, is another.

Rapid burning of fuel vapors in the combustion chamber means not only detonation, but also a sudden rise in pressure followed by an immediate decrease in pressure. As a result, the average pre-sure during the power stroke (mean effective pressure, m.e.p.) is comparatively low. The octane rating is an index to the slow-burning quality of a fuel. Slow burning aviation gasolines have octane ratings from 90 to 120.



CHAPTER SIX



How friction is reduced.

LUBRICATION AND COOLING

When two surfaces move across one another there is always a resistance to this motion. The resistance is called friction. It causes the temperatures of the surfaces involved to rise. This rise in heat, due to the friction of the engine's moving parts not only causes a loss of thermal efficiency, but also may weaken these parts. Furthermore, friction also reduces the engine's mechanical efficiency.

If friction can be reduced, the deterioration of the engine parts which rub against each other can be prevented, friction horsepower of the reciprocating engine will be made less, and mechanical efficiency will be increased. There are three ways of reducing friction. In practice these are generally used in combination.

1. Since it has been learned that friction is less when the moving parts in contact are of different metals, it is customary to make plain bearings of metals or metal alloys which are unlike their journals. (Journals used in this sense means the shaft, spindle, or rod which turns within the bearing.)

2. Since balls or rollers offer less resistance than a metal block when moving across a surface, ball bearings and roller bearings are used to reduce friction. (See illustration, above.)

3. Since oil placed between moving surfaces reduces friction, engine lubrication systems are used on all types of aircraft engines.

Lubrication

The use of oil between surfaces that rub together changes dry friction to fluid friction. The molecules of fluids (liquids and gases) are not held so closely together as those of solids; hence, they slide more easily. Oil molecules are also long and flat, and when placed between moving parts, they tend to form a layer only one molecule deep. This is known as a monomolecular layer.

Through experimenting with different kinds of oils (animal, vegetable, and mineral) it has ben learned that mineral oil (petroleum) is best for aircraft engine lubrication.

Petroleum is a member of the great hydrocarbon family. There are different kinds of petroleum. Petroleums from the eastern oil fields are designated as paraffin-base crudes, those from California and the Gulf Coast oil fields as asphalt base crudes.

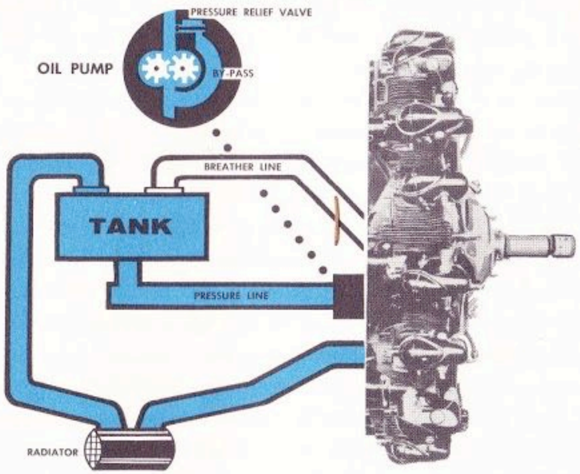
Many different kinds of lubricants and lubricating oils are made from crude oils. The purpose for which they are made has a lot to do with their characteristics. For example, the oil you use in your automobile engine would not serve for your aircraft engine. Aircraft engine pistons are of aluminum alloy construction; they operate at higher temperatures than do automobile engines; these pistons are twice as large as automobile pistons; they expand more; there are larger clearances between them and their cylinder walls.

Lubricant Tests

To make sure that an oil is right for a certain type of engine, it is put through a series of tests. The test measures *viscosity, flash point, pour point, carbon residue,* and *sulfur content.*

Viscosity is used as the measure of ability of an oil to flow at certain temperatures. (For an explanation of viscosity see *Aircraft in Flight,* p. 18.) A heavy-bodied oil has a *high viscosity.* A thin-bodied oil has a *low viscosity.* The higher the viscosity of an oil, the greater the weight it can support without breaking. The lower the viscosity of an oil, the less drag it adds to moving engine parts. Viscosity is affected by temperature. The S.A.E. (Society of Automotive Engineers) rating for viscosity is found by heating the oil to a temperature of 100° C. or 212° F., then finding how long it takes for 60cc. of it to flow from a container through a hole of a specified size.

The flash point test discovers the temperature at which an oil gives off inflammable vapor which will catch fire. The pour point test finds the lowest temperature at which an oil will flow when it is cold. The carbon residue test shows the amount of carbon which is precipitated from oil operating at high temperatures.



How oil gets between moving engine parts.

The Oil System

The oil system consists of an *oil storage tank*, an *oil pump*, *oil lines*, *a sump and scavenger pump*, an *oil filter*, and a *radiator*.

Because of the pressure put upon the moving parts of the aircraft engine, oil cannot flow between them unless forced to do so. The oil pump is used to feed the oil through the oil lines to the engine parts. After the oil has been forced through the engine, it collects in a sump from which the scavenger pump (which is actually another oil pump) forces the oil through a fiiter and radiator and back into the storage tank. (See illustration, above.)

The filter removes from the circulating oil any dirt, sludge, or metal particles accumulated by the oil as it passed through the engine. The radiator serves to regulate the oil temperature by dissipating excess heat taken from the engine. On some small engines the engine crank case serves as both sump and oil tank. Such engines are sometimes called wet-sump engines; other engines that have engine oil tanks separate from the engine are sometimes called dry-sump engines.

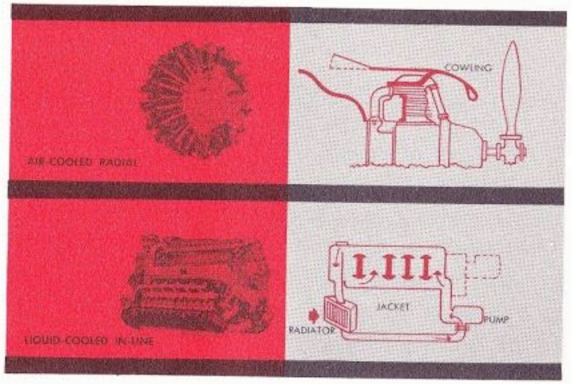
Cooling

Heat has been defined as the motion of the molecules of a substance. Heat causes the expansion of engine parts; excessive heat can cause the warping of engine parts; and heat in sufficient quantities can cause solid metals to melt (become liquid). It is for these reasons that means must be provided to dissipate the excess heat absorbed by the parts of internal combustion engines. As a result of compression and ignition, cylinder temperatures of an uncooled aircraft engine could reach 4500° F. Such temperatures would do damage to the engine.

Oil carries off a great amount of excess heat and dissipates this through the oil temperature regulator radiator. Strange as it may seem, a rich fuel mixture helps keep cylinders cool. (Remember what happens in the carburetor when fuel vaporizes.)

Two systems of engine cooling are in general use. *One of these uses a liquid and a radiator.* This works much as the cooling system of your car does. The coolant, generally a liquid such as ethylene glycol (popularly known as Prestone or by some other trade name), is circulated by means of a pump through a jacket which encloses the cylinders and a radiator. Air passing among the radiator tubes and fins actually carries away the heat.

The other cooling system uses cowlings to scoop up the air and baffle plates to direct air flow around the cylinder heads and barrels. The cylinders and the intake and exhaust ports are covered with fin-like metal projections. These projections serve to present a greater surface area to the inflowing air and, consequently, to speed



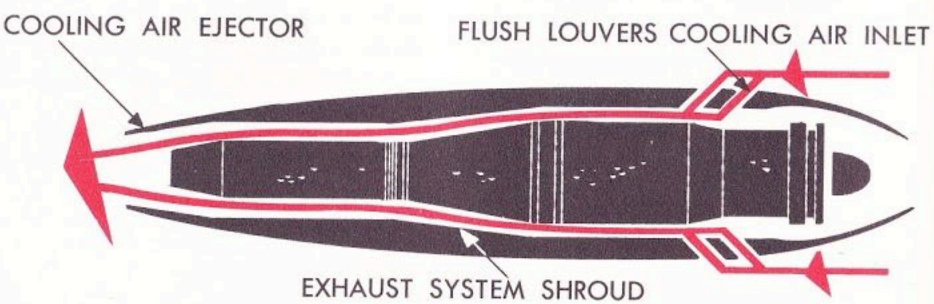
Liquid cooled and air cooled engines.

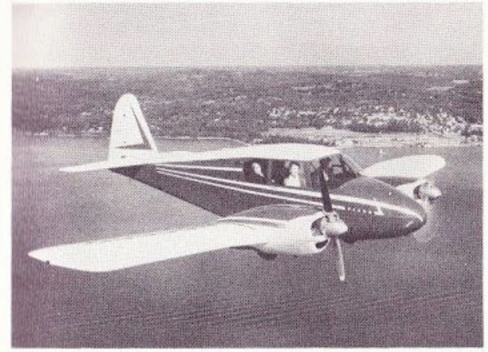
up the transfer of heat from the hot metal to the cold air. After passing around the cylinders, the hot air passes out of the rear of the engine cowling through cowl flaps. These can be opened or closed and are used to control the amount of air flowing over the engine during flight, thus regulating engine temperatures.

Liquid-cooled engines are usually in-line engines of one or another type, although some radial engines have been liquid cooled. Air-cooled engines are always radial or opposed cylinder type engines. (See illustration, above.) Jet engines are air cooled. Air enters the airplane through air inlet louvers and flows rearward between a stainless steel shroud and the hot surfaces of the power plant. In addition to cooling the engine, this device insulates the engine, exhaust cone, and tail pipe, and protects the fuselage structure from the high, exhaust-gas temperatures.

High-speed flight made possible by jet propulsion causes friction between aircraft and air, resulting in high temperatures which can be controlled only by a refrigerating system such as commonly used to preserve foods. (See *Aviation and You, page 34.*) However, there is no relationship between the situation causing heat in this instance and that causing excessive powerplant temperatures.

Jet engines also need cooling systems.





CHAPTER SEVEN

THRUST AND THE PROPELLER

To develop power and to convert this into thrust are the major purposes of the aircraft power plant. The jet engine virtually succeeds in combining these two tasks into one. In the jet, the potential chemical energy of the fuel-air mixture is converted into thrust directly. The reciprocating engine converts the potential energy of the fuel-air mixture into mechanical energy, which is applied through a transmission system to propeller operation. This difference between jet and reciprocating engines accounts for the methods of reporting power output of the two types. We speak of jet performance in terms of *pounds of thrust*; and of reciprocating engine performance in terms of *horsepower*.

The Propeller

The blade of a propeller is a type of airfoil, just as the aircraft wing is an airfoil. (See *Aircraft in Flight*, page 10.) Like the rotor of a helicopter, the propeller, in a sense, is a rotating wing. The helicopter, of course, uses its rotating airfoil to produce both vertical motion (lift) and forward motion (thrust). By changing the pitch of the helicopter rotor as it reaches a certain position during its turn, a difference of forces is obtained. The resultant of these forces controls the direction of the helicopter's movement.

The helicopter rotor (a rotating airfoil) can produce both lift and thrust. The propeller also has a double function: 1. It produces thrust which overcomes drag and pulls the airplane forward. 2. The forward movement of the airplane sets up the reaction between wing and wind and causes lift, which overcomes the force of gravity. The principle of propeller action is based on the fact that a decrease in pressure in any direction will cause the air to produce a force in that direction.

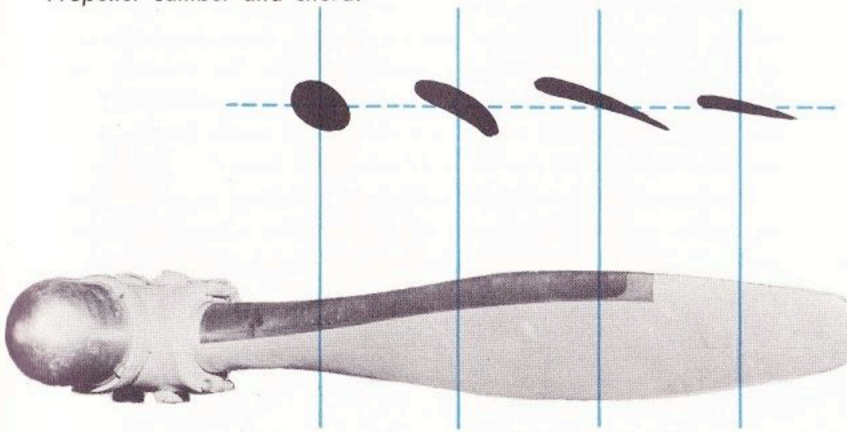
If a propeller blade is cut in cross section at any point, this cross section view will look very much like an airfoil section of an airplane wing. If the propeller blade is cut into several sections it will be noted that while each section retains the appearance of a wing section, the camber and chord of each section differ one from another. As a matter of fact, the aircraft propeller is not as simple in

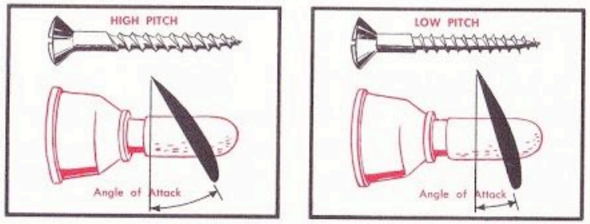
action as the aircraft wing. Whereas the wing has only one motion—forward, the propeller has two motions—forward and rotating. Since these two motions take place at the same time, the path of the motion is *helical* (shaped like a corkscrew). Also, each segment of the blade takes a path different from each other segment. Regardless of the length of a propeller blade, the tip section will travel, as it rotates, a distance twice as great as a section midway between propeller hub and tip.

Since the comparative rotary speed is different for every section of the propeller, the thrust produced by a propeller whose sections all have the same shape will decrease in value throughout propeller sections from tip to hub. Consequently, to equalize the thrust (forward lift) producing qualities of each propeller section, the blade elements toward the propeller tip decrease in chord length, upper camber, and angle of attack. (See illustration, below.) Since the amount and direction of thrust (forward lift) changes with each propeller element, propellers must be designed to produce a resultant force in the proper direction and amount.

There are different ways to classify propellers. For example, some are made of metal and some of wood, and are classified accordingly. Another classification is based upon whether or not the pitch of the propeller blade is *fixed* or *variable*.

Propeller camber and chord.





Blade pitch—the propeller's angle of attack.

The Fixed-Pitch Propeller

Blade pitch is defined as the angle made by the chord of the blade element and the plane in which the propeller rotates. When this angle is large, the blade takes a deeper *bite* into the air and is said to be in high pitch; when it is less, the blade takes a lesser bite and is said to be in low pitch. During take-off and climb , greater loads are placed upon the engine than during cruising flight; hence low propeller pitch is desirable for these operations. At cruising speed, high pitch is desirable. The fixed-pitch propeller is a compromise. It is neither the best possible for take-off nor for cruising.

The Variable-Pitch Propeller

There are two types of variable-pitch propellers; the adjustable and controllable. The adjustable is little better than the fixed-pitch propeller except, before take-off, the pitch may be changed to meet flight conditions anticipated.

The controllable-pitch propeller can be adjusted by the pilot in flight. Propellers used on modern aircraft have been improved so that they are not only controllable in flight, but are also automatic. They are called *constant-speed propellers* since they vary their pitch with varying power requirements of engine loads, keeping engine and propeller operating at a constant r.p.m.

Constant-speed propellers are of two principal types depending upon the system controlling their operation. One type uses a hydraulic system, the other, an electrical system. In both of these systems the propeller blades are attached to their shafts by means of bevel gears. Changes in pitch are effected by rotating these gears.

Both types of constant-speed propellers use a governor as the core of the automatic pitch control. As propeller speeds increase, the flyweights of the governor turn faster; as propeller speeds decrease, the flyweights turn more slowly. The flyweights, reacting to the centrifugal forces resulting, activate a control rod.

The Hydraulic Propeller

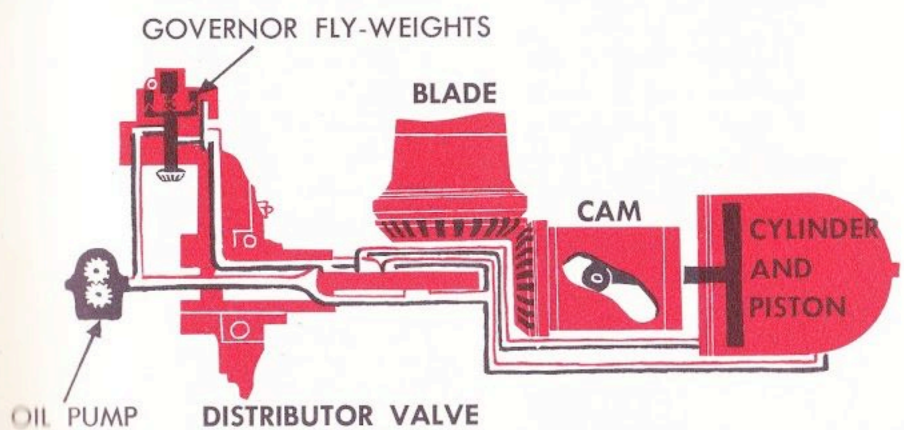
In the hydraulic propeller, the control rod opens or closes a pilot valve and also operates an oil pump. By means of its pilot valve and pump, the governor regulates and varies the oil pressure on either side of a piston in the dome section of the propeller assembly. (See illustration, below.) By changing the pressure on the piston, it is moved forward or backward, rotating a cam. The moving cam turns the propeller blades one direction when the piston moves forward, the opposite direction when the piston moves backward.

The Electric Propeller

In the electric propeller, the governor control-rod opens or closes an electric contact switch. Closing the switch completes a circuit with a reversible electric motor in the propeller hub. The pitch-control motor drives reduction gears, which in turn drive the bevel gears which change blade pitch.

Constant speed propellers are *full feathering,* which means that the blade pitch can be increased to 90°. Sometimes in case of an engine failure, in order to decrease propeller drag and windmilling

A governor is the core of automatic pitch control.



CONSTANT SPEED CONTROL

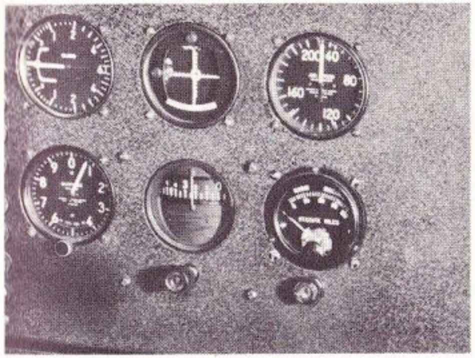
with their accompanying ill-effects, it is necessary to vary propeller pitch so that the sharp propeller edge is presented to the wind.

Reversible pitch propellers are often used on heavy aircraft. Upon landing the pilot can change the blades of such propellers so that they create a backward thrust. Reversing propeller pitch helps shorten the length of the landing run. The reversed propellers help brake the airplane to a stop.

The Contraprop Propeller

Some propellers are dual rotating. They are called contraprop propellers, since each propeller assembly really consists of two propellers, one behind the other, rotating in opposite directions. This contra-rotation is accomplished by a special type of reduction gear system. Contraprops have wide blade sections near the hubs which throw air into the engine to help in engine cooling.

Since some propellers have a rather large diameter, at high engine r.p.m., the tips of these would travel very rapidly. For example, if the diameter of a propeller is 16 feet, in one revolution the blade tip will travel 16 ft. x π or 50.24 ft. At 2000 r.p.m. the blade tip will travel 1674 feet per second, which is faster than the speed of sound at sea level (1100 ft./sec.). Propellers lose their effectiveness under such circumstances, consequently, a system of reduction gears must be used. Types of reduction gears differ, but their purpose is the same, to keep propeller tips operating below the speed of sound.



CHAPTER EIGHT

INSTRUMENTS AND CONTROLS

As aircraft engines have developed and become more complex, the number of instruments they use has increased. The purpose of the engine instruments is to keep the pilot informed of the operating conditions of his engine. The engines of comparatively low horsepower and low compression ratio used in the early days of aviation required only tachometer, oil temperature gauge, and water temperature gauge. The modern engine requires these and, in addition, gauges which show pressure of oil, fuel, and manifold. It also requires indicators which show the temperature of oil, air, the carburetor, and cylinder heads.

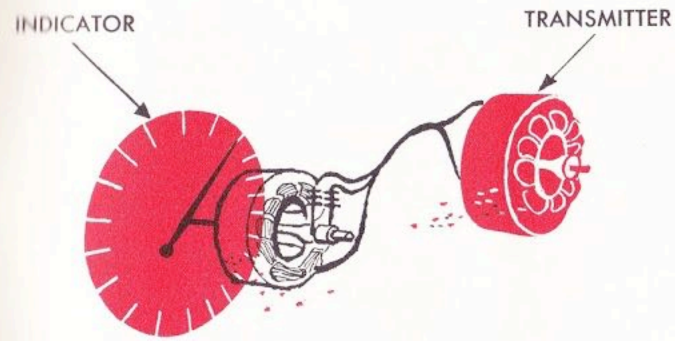
Pressure and Temperature Gauges

Pressure gauges operate either on the Bourdon-tube principle or on the aneroid principle. The temperature indicators may employ the principle of the Wheatstone bridge, the thermocouple, or the vapor-pressure type thermometer and Bourdon tube. The principles of the Bourdon tube, aneroid, thermocouple, and Wheatstone bridge have been explained. (See *Aircraft in Flight*, Chapter VI.)

The vapor-pressure type temperature indicator uses a bulb containing a highly volatile liquid such as methyl chloride, a capillary tube, and a Bourdon tube. The capillary joins the Bourdon tube, which is connected to the indicator needle by a linkage system, and the bulb, which is located at the point where the temperature is to be measured. As the temperature of the liquid in the bulb changes, the vapor pressure throughout the system changes, affecting the Bourdon tube and indicator needle.

Remote Indicating Systems

On large multi-engine aircraft where considerable distances separate the point where a measurement is to be made, and the instrument panel where the reading is taken, self-synchronizing, remote-indicating systems are in common use. These instruments are used to reveal fuel, oil, and manifold pressures and temperatures, fuel flow and levels, and engine r.p.m. They may also be used to indicate landing gear, flaps, and tail wheel positions.



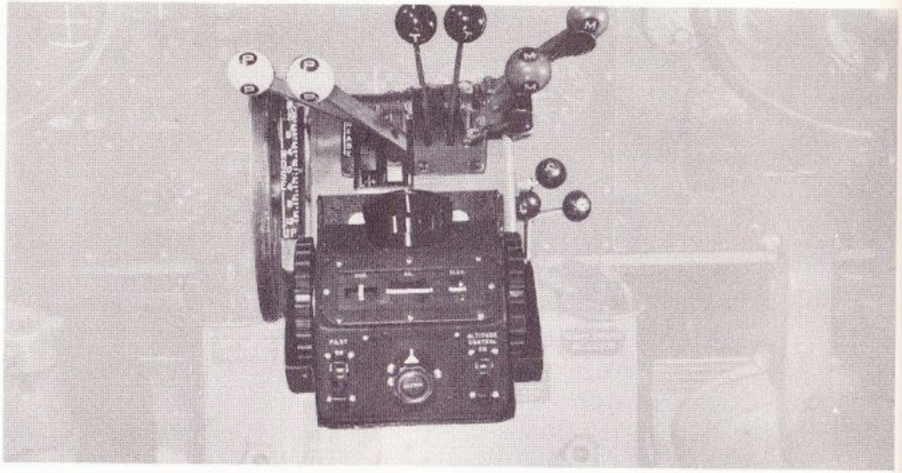
How information reaches the instrument panel.

The self-synchronizing system is an adaptation of the synchronous motor principle. The synchronous motor assembly consists of two separate motors which operate in exact timing one with the other. The self-synchronizing system differs from the synchronous motor assembly in that the rotors neither spin nor produce power. Their design is such that the rotor of the indicator moves only the distance required to match a movement of the rotor of the transmitter. (See illustration, above.)

Engine Control Systems

Engine control systems may be classified in accordance either with their construction or with their method of operation. In terms of construction there are two systems, the *push-pull tube control* and the *wire-and-cable control*. In terms of operating method, there are three classifications: the manually operated, the semi-automatic, and the automatic.

As engines have become more complex, semi-automatic and automatic controls have been adopted. However, some method of manual control is almost always kept as a safeguard in the event of failure of the automatic mechanisms. The principles underlying the operation of automatic controls are hydraulic, electric, or electronic. Electronic mechanisms are electric mechanisms which employ vacuum tubes.



Instrument panel and cockpit controls.

Reciprocatng engine controls include controls for throttle, fuel-air mixture, cowling flaps or radiator shutter, supercharger, supercharger intercooler shutters, oil coolers, and perhaps carburetor heat. One of the most important controls is the engine throttle; it helps the pilot govern the power of the engine and the speed of the airplane. Another important control is the fuel-air mixture control.

Engine controls often combine a control lever, which operates through a 90° arch (a *quadrant*, one fourth of a circle), and the base upon which these levers are mounted. The control pedestal is a frame secured to the floor of the cockpit which supports the control quadrants and control mechanisms.

Controls are identified, as by a letter T for throttle, or a letter M for fuel-air mixture. Control lever positions are marked on the quadrant. When the pilot wants to increase engine power, he moves the throttle control lever toward *open* position; should he want to reduce engine power, he moves this control toward *closed* position. On some aircraft the mixture control has four positions, *idle cut-out, automatic lean, automatic rich,* and *emergency rich.* A manually operated mixture control has any number of positions. It is by means of the mixture control that a proper relationship (by weight) of fuel to air is kept in the fuel-air mixture.

Jet engine controls are much less complicated than reciprocating engine controls. In this as in other respects the jet engine has the advantage of simplicity.

SUMMARY

Power for flight is produced by engines all of which convert potential chemical energy into heat energy. Reciprocating engines are internal combustion engines that use machine-principles to convert heat energy into mechanical energy. Jet engines are reaction engines that convert the pressure forces of expanding gases directly into thrust.

The engine is the most important of the power-plant systems. However before the engine can produce power and before this can be converted into thrust, other systems must be brought into play. These include the fuel, ignition, lubrication, control, and propeller systems. The reciprocating engines used by aircraft are four-stroke-cycle engines. This type of engine delivers power only one out of every four piston strokes, or two crankshaft revolutions. Turbo-jet and turbo-prop engines employ turbine wheel and compressor rather than piston to compress the fuel-air mixture. The purpose of the aircraft engine is to change, through the process of combustion, the potential energy of a fuel into heat and the heat energy into work.

Energy means the capacity to do work. There are several different kinds, such as chemical, heat, electrical, and mechanical. One kind of energy may be changed into another.

The law of conservation of energy states, in effect, that although energy can be changed from one form to another, it cannot be destroyed. However, no engine can convert all the heat energy it produces into mechanical energy. Some of the heat escapes through the exhaust, some through essential cooling, but none of it is destroyed.

Thermal efficiency is the ratio of heat an engine converts into useful work to the heat potential of the fuel used. Mechanical efficiency is the ratio of the brake horsepower an engine develops to its indicated horsepower.

The carburetor vaporizes the fuel used by reciprocating type engines and meters this to the cylinders. Some carburetors make use of the Venturi principle, others use an injection system to introduce fuel into the carburetor barrel. A jet engine uses a fuel injection system which feeds fuel directly into each of its combustion chambers.

The ignition system is an important part of the aircraft power plant. Generally, reciprocating engines use a magneto to provide the spark which sets fire to the fuel-air mixture drawn into its cylinders. The jet engine also uses a spark to ignite its fuel when starting. However, since jet engine combustion is continuous, jet engine ignition does not present engineers the difficult problems encountered by those who design ignition systems for reciprocating engines.

When two surfaces move over one another friction results. Since friction causes heat loss, the weakening of power plant parts, and other bad effects, it is necessary to reduce it as much as possible. To solve the problem of friction reduction, engines use special types of bearings and employ lubricating systems.

The propeller is the device which converts the power produced by the reciprocating aircraft engine into thrust. Propeller blades are actually airfoils that rotate. The pitch of the propeller blade can be compared with the angle of attack of the airplane wing. The propellers of large modern aircraft are controllable-pitch, constant-speed propellers. Their pitch changes automatically in flight, adjusting to the power-load placed upon the aircraft engine. Reduction gears are used with some propellers so that the tip speeds of the propeller blades do not exceed the speed of sound.

Men designing aircraft engines have met and solved many problems. Each day they meet and solve new problems in aircraft propulsion. The solutions of these problems require scientific understandings and technical skills. Each day adds to these understandings and skills. As a result, great improvements are being made in aircraft power plants. In military aviation, with some exceptions, jet aircraft are replacing aircraft powered by reciprocating engines. Even helicopters make use of jet power. As a matter of fact turbine engines (both turbo-jet and turbo-prop) are very much in the limelight. Research appears already to have developed turbine engines which are economically feasible from the commercial air-transport viewpoint. Turbo-props are now in use; turbo-jets have been ordered by airline companies. In the course of time, rocket engines and atomic engines will likely be used as sources of power for flight.

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