Chapter 2
How the Diesel Aircraft Engine Functions

People who are familiar with the functioning of a gasoline aircraft engine need not have any difficulty in understanding how a high speed Diesel aircraft engine works. In size and outward appearance the two types of engines are similar as they both are internal combustion engines in which the fuel is burned inside the cylinder. Parts of the engines such as the crankcase, the cylinders, the crankshaft and the connecting rods are of the same design. The chief difference between the two types of engines is in the method used for admitting the air and the fuel into the engine cylinders and the method used for igniting the fuel. This difference in construction is necessitated by the use of nonexplosive fuel oil in the Diesel.

Feeding Fuel
Close examination reveals that the Diesel has no carburetor in which the air and the fuel can mix before being admitted to the cylinder. In the Diesel, the air containing the oxygen required for combustion is admitted through the inlet valve into the cylinder on the suction stroke of the piston. When the piston reaches the bottom of this stroke, the inlet valve closes and the air contained in the cylinder is compressed to a high pressure. The fuel, which consists of No. 2 furnace oil or its equivalent, is compressed to a still higher pressure in a small plunger-type injection pump and is forced through an injector into the engine cylinder. In this respect, the Diesel is similar to some of the latest gasoline aircraft engines which are equipped with direct fuel injection instead of a carburetor.

Igniting the Fuel
The method used to ignite the fuel charge in a Diesel is entirely different from that used in a gasoline engine. The Diesel has no magnetos, spark plugs or high-tension wires as it uses air heated by compression to a high temperature to ignite its fuel. In order to compress the air charge to this high temperature, the compression ratio in the cylinder of a Diesel is considerably higher than in a gasoline engine. Compression ratios in Diesel aircraft engines range from 14:1 to 17:1 which is sufficient to raise the temperature of the air charge to "red" heat or approximately 1,000 degrees Fahrenheit. When the fuel is injected in the form of a fine spray, it ignites readily and the gases of combustion expand as in a gasoline engine forcing the piston outward on its expansion or power stroke.

The ignition of the fuel charge in a Diesel by highly heated air is somewhat slower than the ignition of the combustible mixture in a gasoline engine by means of an electric spark. Higher peak pressures are encountered in the cylinder of a Diesel, however, due to the smaller size of its combustion chamber which results in more rapid pressure rise when the fuel ignites. For a time this rapid pressure rise necessitated heavier cylinder construction and made the Diesel too heavy for aviation. Now methods have been devised whereby the duration of the ignition delay period is reduced and this tends to cut down the rate of pressure rise.

Four-Cycle Diesels

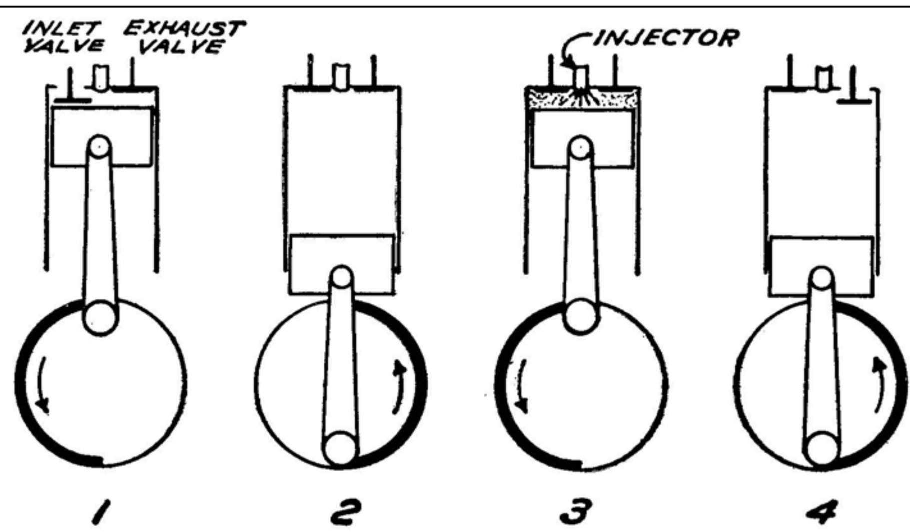

Fig. 16.—Sequence of events in a four-cycle Diesel.

In a Diesel aircraft engine operating on the four-cycle principle, the sequence of events is similar to that in a four-cycle gasoline aircraft engine:
1. Suction stroke-intake of air charge through inlet valve.
2. Compression stroke-compression of air charge to a high temperature and injection of fuel charge just before top dead center.
3. Expansion stroke-ignition and combustion of fuel and expansion of gases transmitting power to the crankshaft,
4. Exhaust stroke-evacuation of burnt gases through exhaust valve.

These events can be seen in Fig. 16.

The four-cycle Diesel aircraft engine lends itself particularly well to air-cooled cylinders and poppet valves of conventional design. When supercharged, its power output can be increased by as much as 40 per cent as in the case of a gasoline aircraft engine. Refinements in design and metallurgy now permit air-cooled Diesels to be built weighing approximately the same as air-cooled gasoline engines of the same power Output (Fig. 17).

The Combustion Chamber

The design of the combustion chamber in a Diesel aircraft engine is very important and various kinds of open chambers, turbulence chambers and pre-combustion chambers can be used. The turbulence chamber used in conjunction with the Lanova combustion system is particularly interesting as it is used extensively in high-speed four-cycle automotive and marine Diesels and also is suitable for Diesel aircraft engines. The combustion chamber is in the form of a horizontal figure 8 with the inlet valve and the exhaust valve in the centers of the two lobes. The injector is on one side of the narrow portion of the chamber and injects a portion of the fuel charge into an energy cell opposite to it. The gas blast produced by the energy cell creates strong rotational turbulence in the two lobes of the chamber mixing the air charge with the remainder of the incoming fuel charge (Fig. 18).

Fig. 17.—Guiberson four-cycle Diesel in a Stinson "Reliant" monoplane.

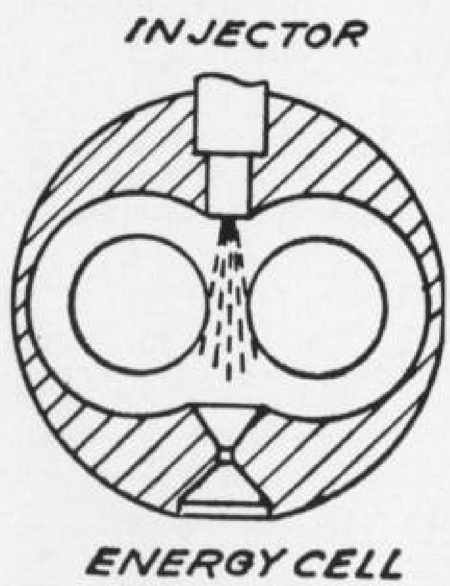

Fig. 18.—Combustion chamber for Lanova combustion system.

Referring back to the diagram in Fig. 16, it is seen that in a four-cycle engine the piston is productive during only one stroke out of four, or once during two complete revolutions of the crankshaft. It has to be driven by the crankshaft during the remainder of the period. From the viewpoint of efficiency, a better arrangement is to have the piston productive during one stroke out of two, or once during one complete revolution of the crankshaft. This last-mentioned arrangement is obtainable in a two-cycle engine.

Two-Cycle Diesels

In an engine functioning on the two-cycle principle, events happen twice as fast as in a four-cycle engine. Each up stroke of the piston is a compression stroke and each down stroke is an expansion stroke.

Exhaust or evacuation of the burnt gases and suction or intake of the new air charge have to take place during the brief interval when the piston is near bottom dead center. This kind of engine requires special valving so that the burnt gases can be evacuated rapidly and a new air charge admitted before the valves close and compression begins.

Small gasoline engines used in motorboats and motorcycles run quite well on the two-cycle principle. These engines are constructed so that the gasoline-and-air mixture is compressed in the crankcase to a pressure slightly above atmospheric. A deflector on top of the piston permits a new charge to be admitted into the cylinder through a transfer passage immediately after the exhaust port has been uncovered by the piston. Considerable pollution of the incoming charge naturally occurs and the engine does not function with very high efficiency. Obviously, such an arrangement is impracticable for a large multi-cylinder gasoline aircraft engine in which high specific power output and low specific fuel consumption are of paramount importance.

In a Diesel aircraft engine operating on the two-cycle principle, the following events take place:
1. Compression stroke-intake of air charge, compression of air charge to a high temperature and injection of fuel charge just before top dead center.
2. Expansion stroke-ignition and combustion of fuel and expansion of gases transmitting power to the crankshaft, and evacuation of burnt gases with the aid of scavenging air under pressure.
These events can be seen in the diagram (Fig. 19).

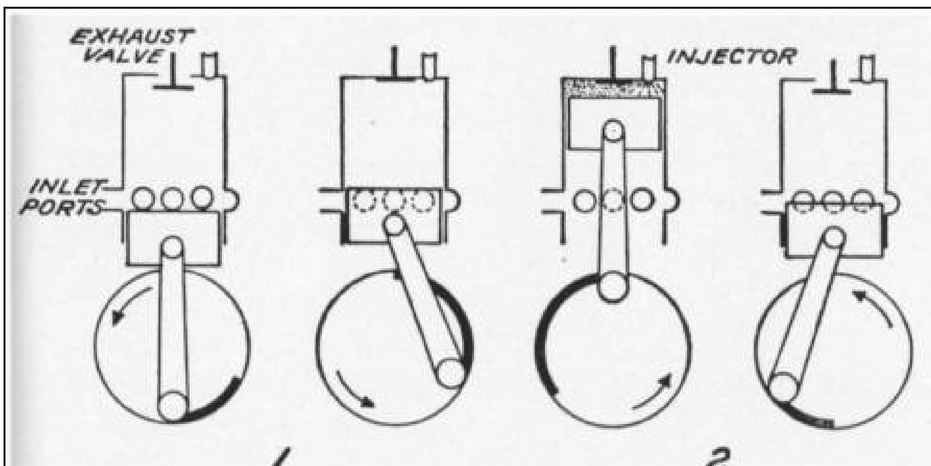

Fig. 19.—Sequence of events in a two-cycle Diesel.

The Diesel, whether it be small or large, functions with high efficiency on the two-cycle principle. Only air is contained in the cylinder prior to the injection of fuel near top dead center and this air can be compressed slightly by external means before it is admitted into the cylinder. A blower or supercharger is used on a two-cycle Diesel aircraft engine to provide the preliminary air pressure. The volume of the-air forced in during each intake period is in excess of the cylinder displacement so that sufficient air is available for scavenging as well as for charging the cylinder.

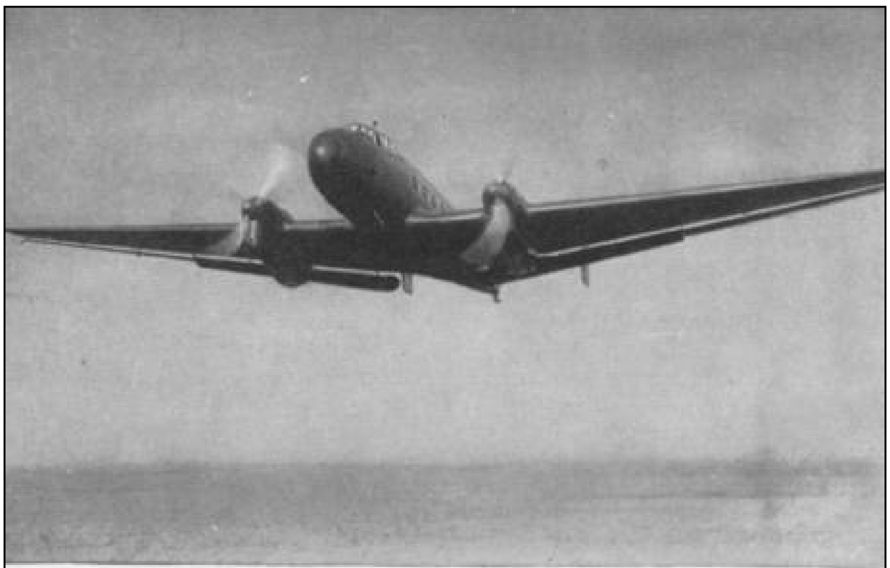

Fig. 20.—*Junkers two-cycle Diesels in a Junkers Ju 86 airliner.*

While it might appear that a two-cycle Diesel will develop twice as much power as a four-cycle Diesel because it has twice as many power strokes, such is not the case. Difficulty in evacuating the exhaust gases from a two-cycle Diesel necessitates opening the exhaust valve or port sooner and more of the power generated during the expansion stroke is lost. This power loss is not excessive and is only approximately 10 per cent more than in a four-cycle engine. A two-cycle Diesel therefore develops approximately 80 per cent more power than a four-cycle Diesel of the same displacement.

Fig. 21.—*Single-unit fuel injection pumps on Zbrojovka ZOD 260-B Diesel.*

The two-cycle Diesel aircraft engine offers an attractive solution of the need for a high-powered, high-efficiency power plant for aviation. Its torque is considerably smoother than that of a four-cycle engine due to the more frequent but less violent power impulses transmitted to the crankshaft. Due to the more frequent generation of beat in its cylinders, the two-cycle Diesel aircraft engine usually is water-cooled or liquid-cooled (Fig. 20). Provided good combustion is obtained by imparting rotational swirl to the air charge so that it mixes with the fuel rapidly, the Diesel has a higher thermal efficiency than a gasoline aircraft engine. The fuel consumption of the Diesel is appreciably less than that of the gasoline engine as more of the heat units in its fuel are converted into mechanical energy.

The Fuel Injection System

The choice of a fuel injection system for a Diesel aircraft engine depends to a great extent upon the cycle upon which the engine functions, the arrangement of the engine cylinders and the injection equipment which is available on the market. The Bosch fuel injection system which has been used on a number of Diesel aircraft engines is typical of a high-pressure solid injection system in which the fuel is sprayed into the engine cylinders in the form of minute solid particles. The equipment required for each cylinder of the engine consists of an injection pump, an injector and a length of high-pressure tubing.

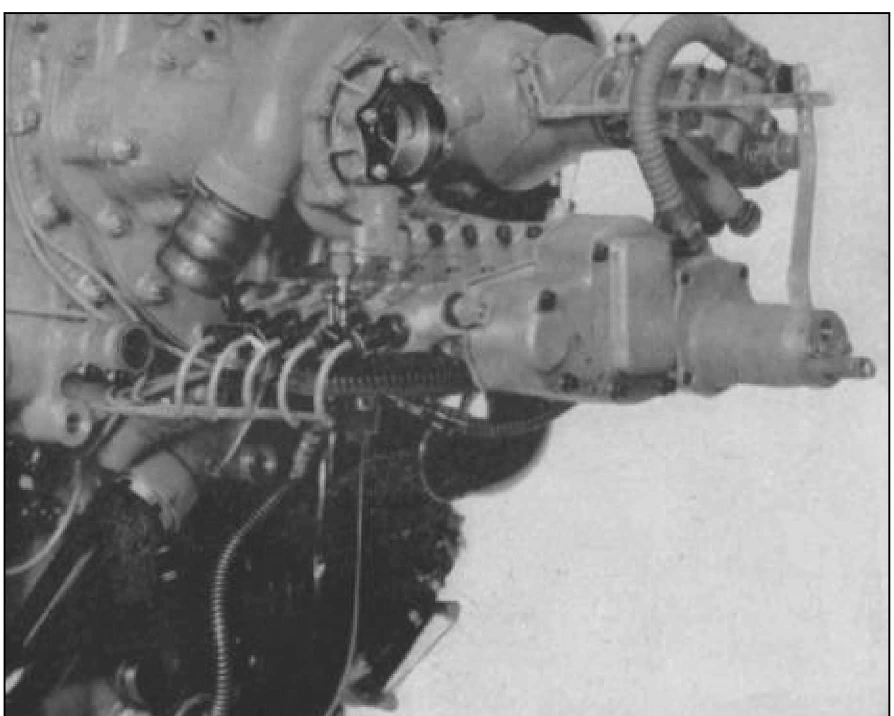

Fig. 22.—*Multi-unit fuel injection pump on B.M.W.-Lanova 114 V-4 Diesel.*

Bosch injection pumps are manufactured in both the individual type containing one or two pump units in one housing, and in the multi-unit type containing several pump units in one housing. On the Zbrojovka ZOD 260-B Diesel aircraft engine, nine individual Bosch pumps are mounted around the crankcase to supply fuel to the nine cylinders of this air-cooled radial (Fig. 21). A multi-unit Bosch pump containing nine pump units, on the other hand, is flange-mounted on the accessory section of the nine-cylinder B.M.W.-Lanova 114 V-4 Diesel aircraft engine where it is shaft-driven (Fig. 22). On Diesel aircraft engines with sixteen in-line cylinders arranged in two banks such as the Mercedes-Benz DB 602, four multi-unit injection pumps each containing four pump units can be mounted on brackets at the rear of the crankcase (Fig. 23). Sixteen individual injection pumps could also be used on the last-mentioned type of Diesel aircraft engine.

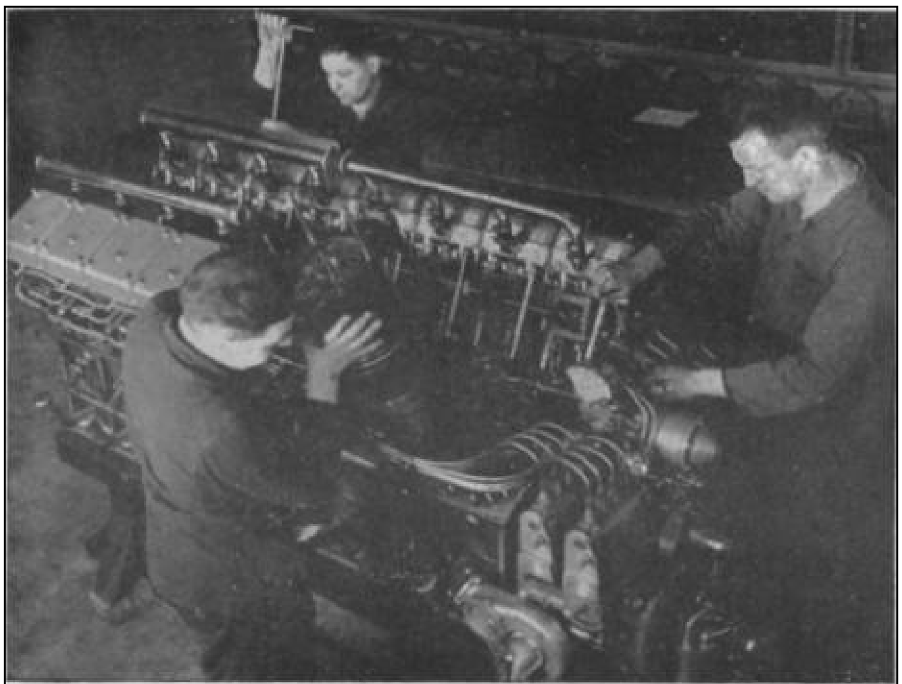

Fig. 23.—Four four-unit fuel injection pumps on Mercedes-Benz DB 602 Diesel.

Bosch injection pumps are of the constant-stroke plunger type. The length of the plunger stroke is constant at all times and is not varied to control the size of the fuel charge. Control of the quantity of fuel injected into the engine cylinder is obtained by turning the plunger slightly in the barrel of the pump so as to vary the moment of pressure release in the pressure chamber. The plunger is cam-actuated by a cam ring or camshaft inside the engine in the case of an individual pump, or by a small camshaft inside the pump housing itself in the case of a multi-unit pump.

How the Injection Pump Functions

The functioning of a Bosch injection pump unit is the same whether it is contained in an individual housing or in a multiple housing (Fig. 24). The fuel enters a sump in the upper part of the housing and on the down stroke of the plunger it rushes into the barrel as soon as the top of the plunger comes below the two radially-opposed ports in the barrel. During the first part of the up stroke of the plunger, excess fuel in the barrel is displaced back into the sump through the ports until the latter are completely covered by the rising plunger. Then the fuel contained in the pressure chamber above the plunger is compressed highly and the spring-loaded non-return delivery valve is lifted off its seat so that the fuel can be forced through the highpressure or discharge tubing into the injector. Finally the fuel opens the spring-loaded non-return valve in the injector and sprays into the engine cylinder.

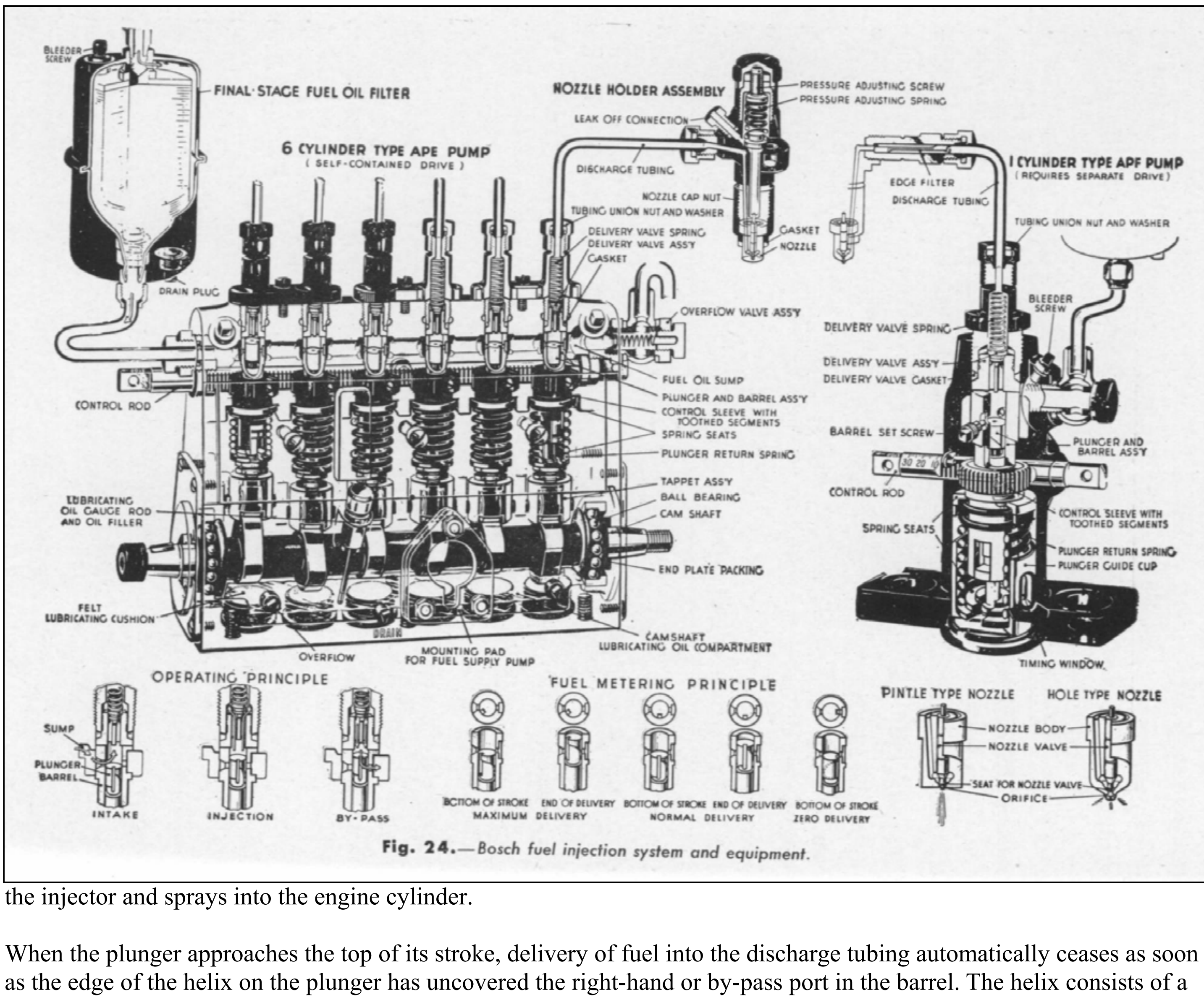

Fig. 24.—Bosch fuel injection system and equipment.

When the plunger approaches the top of its stroke, delivery of fuel into the discharge tubing automatically ceases as soon as the edge of the helix on the plunger has uncovered the right-hand or by-pass port in the barrel. The helix consists of a recess with an edge of special contour cut in the upper part of the plunger. It is connected with the top of the plunger by means of a vertical slot. At this moment, the pressure chamber communicates with the sump in the housing by way of the helix and the remainder of the fuel not yet forced through the delivery valve by-passes into the sump due to the drop in pressure. At the same time the discharge valve snaps shut.

In the Bosch injection pump, termination of fuel delivery controls the pump output and the quantity of fuel delivered by the plunger on each stroke. For maximum fuel delivery, the plunger is turned slightly in the barrel by means of a toothed control rod so that the helix does not uncover the by-pass port until very late in the stroke. For zero delivery, the plunger is turned until the helix communicates with the by-pass port during all positions of plunger stroke and the fuel is not compressed sufficiently in the pressure chamber to open the discharge valve. The plunger and its barrel are carefully lapped and matched in pairs so that they are a very close fit.

In addition to controlling the quantity of fuel injected into the cylinders of a Diesel aircraft engine it is also necessary to control the timing of the commencement of fuel injection which corresponds roughly to the moment of firing in a gasoline aircraft engine. In the case of individual injection pumps actuated by a cam ring or a camshaft means are devised by the engine manufacturer for varying the timing of the cams. When a multi-unit injection pump containing its own camshaft is used the timing of the camshaft can be varied by interposing a special device with sliding helical splines between the camshaft and the drive shaft from the engine.

A single-unit injection pump of suitable capacity is sufficient for each cylinder of a Diesel aircraft engine. It is sometimes found desirable, however, to use two pump units in one housing or two individual single-unit pumps together with two or more injectors for each cylinder in order to improve the injection characteristics. In the latter case, each pump unit is designed to have sufficient capacity to supply the cylinder under full load. Single-unit and two-unit (duplex) injection pumps are flange-mounted on the crankcase of the engine where they can be actuated conveniently by a cam ring or camshaft. The cam profile has to be designed with great care in order to attain the best injection characteristics and engine performance.

On four-cycle Diesel aircraft engines the injection pumps are driven at one-half crankshaft speed while on two-cycle engines they are driven at crankshaft speed. Operating speeds as high as 3,000 r.p.m. are now permissible for the latest types of injection pumps. The manufacturers of Bosch injection equipment recommend that the maximum injection pressure should not exceed 3,500 lb. per sq. in. to insure long life of the actuating and moving parts. They also recommend that the high pressure tubings connecting the injection pumps and the injectors should be of the same length so that each cylinder of the engine will develop approximately the same power.

The Injectors

Bosch injectors comprise two main parts-the nozzle body and the nozzle valve. These two parts are carefully lapped and matched in pairs and are contained in a nozzle holder made of steel or duralumin. The injector is of the closed type with a spring-loaded nozzle valve which seats in an orifice in the bottom of the nozzle body. The movement of the nozzle valve is controlled hydraulically by the pressure of the fuel against its tapered end when the fuel is admitted through the discharge tubing from the injection pump.

Two basic types of nozzles are used in Bosch injectors. These are the hole-type nozzle which is suitable for Diesel aircraft engines having open combustion chambers and the pintle nozzle which is suitable for engines constructed with high-turbulence combustion chambers or pre-combustion chambers. (See Fig. 24.)

The hole-type nozzle injects the fuel in one or more sprays according to the number of holes in the nozzle body. The shape and penetration of the sprays depend upon the diameter and length of the holes. The holes are arranged symmetrically at suitable angles in the bulbous end of the nozzle body so that the sprays will penetrate in the desired directions.

The pintle-type nozzle has a nozzle valve with a short pin or pintle on its tip which protrudes through the circular orifice in the bottom of the nozzle body. The pintle is appreciably smaller in diameter than the orifice and when the nozzle valve lifts from its seat the fuel strikes the pintle with considerable force as it emerges and produces a hollow cone-shaped spray by refraction. The shape and penetration of the spray depend upon the diameter and length of the orifice and the clearance space between the orifice and the pintle.

There is also a throttling nozzle which is a variety of the pintle nozzle with a longer pintle in the shape of an inverted cone. It is designed to control the rate of fuel injection so that only a small quantity of fuel is sprayed into the engine cylinder at the beginning of the injection period. The main fuel charge is injected when the lift of the nozzle valve is increased by the pressure of the initial fuel charge as it emerges. This type of nozzle prevents excessive accumulation of fuel in the combustion chamber prior to ignition and helps to reduce the rate of pressure rise in the engine cylinder.

The High-Pressure Tubing

The high-pressure discharge tubing used on Diesel aircraft engines is made of low carbon steel cold-drawn without seams. Tubing such as that manufactured by Summerill is satisfactory as it can be bent and swaged cold without cracking and will withstand pressures as high as 9,000 lb. per sq. in. The inside wall of the tubing should be perfectly smooth to prevent undue restriction to fuel flow.

Engine Accessories

Many of the accessories required for a Diesel aircraft engine are similar to those used on a gasoline aircraft engine. The transfer pumps used to transfer the fuel oil from the tanks in the airplane to the injection pumps on the engine usually are of the rotary-vane or oscillating plunger type. The lubrication system is handled by a pressure-feed pump and two or more scavenge pumps in single or multiple housings of the rotary-gear type. The lubricating oil filter is of the metal disc type with or without a hydraulic motor to rotate the filtering element. A centrifugal pump is provided for each bank of cylinders in the case of a water-cooled or a liquid-cooled engine.

The fuel filtering system is considerably more elaborate on a Diesel aircraft engine than on a gasoline aircraft engine equipped with a carburetor. The fuel oil has to be filtered very carefully before it enters the injection pumps and injectors so that it will not contain impurities in suspension which might score the closely fitted plungers and barrels, and nozzle valves and nozzle bodies of these precision instruments. On most Diesel aircraft engines a fuel filtering system comprising a first-stage filter of the metal-disc type followed by a final stage filter of the paper-element type in a sealed case is sufficient for the purpose (Fig. 25).

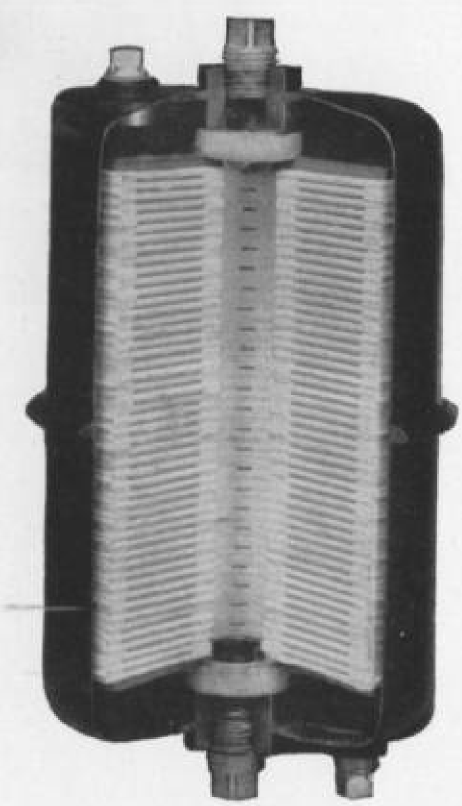

Fig. 25.—American Bosch final-stage filter for fuel oil.

A supercharger of the centrifugal type is highly desirable for a four-cycle Diesel aircraft engine and an absolute necessity for one functioning on the two-cycle principle. The supercharger may be of the gear-driven, single-speed type which absorbs from 10 per cent to 15 per cent of the power output of the engine for its drive, or it may have two speeds or two stages and absorb still more power from the engine. An exhaust-driven supercharger is more advantageous as it absorbs practically no power and has an output equivalent to that of a two speed gear driven supercharger. The exhaust-driven supercharger is particularly, adaptable to the Diesel as the exhaust gases emerge from the latter at a lower temperature than from a gasoline engine and consequently the turbine wheel and its blades are not subjected to unduly high temperatures and stresses.

Starting a Diesel aircraft engine does not present any difficulty despite its high compression. A hand and electric inertia starter such as the Eclipse or a cartridge starter such as the Breeze (Coffman) can be installed as on a gasoline aircraft engine but it may have to be the next size larger for a Diesel engine. A compressed air starting system also can be used with a distributor driven from the engine and air injection valves in one bank or row of cylinders.