[redacted]

[redacted]

[redacted]

TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 211

AIRCRAFT ENGINE DESIGN.

By E. E. Wilson,
Bureau of Aeronautics, Navy Department.

January, 1925.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL NOTE NO. 211.

AIRCRAFT ENGINE DESIGN.*

By E. E. Wilson.

The subject of this paper is so broad in scope that a large volume might be devoted to it. At the same time development is so rapid that such a volume would be obsolete before it got off the press. In a short paper of this kind it is possible simply to sketch in the high lights of aircraft engine design showing the developments to date, the possibilities of the future, and the underlying fundamental principles.

It is a truism that the aircraft is no better than its power plant. From the beginning of man's efforts to fly he has needed only a suitable means of propulsion to make mechanical flight possible. Once he has succeeded in flight he can continue to fly, only so long as he has means of propulsion.

The history of aircraft engine design has been concentrated into the last twenty years. In order to survey this development, we will consider a number of engines, confining ourselves chiefly to American developments and proved types which have been or are going into production. The first engine to fly was the Wright 4-cylinder in line 30-35 HP. engine (Fig. 1). Influenced by tendency of automobile design, it was water-cooled and at $5\frac{1}{2}$ lb./HP. was too heavy. Progress in flight was temporarily held up pending the development of new en-

* Lecture before the post-graduate students, U. S. Naval Academy, October 22, 1924.

gines. On the score of lightness of construction, attention was centered on the air-cooled engine, of which the Gnome and Le Rhone (Figs. 2 and 3), both foreign types, are early examples. To these engines, weighing about $3\frac{1}{2}$ lb./HP., may be ascribed the first important progress in aircraft. In this type the shaft is fixed and the cylinders rotate.

Certain inherent difficulties, such as the fan resistance and the gyroscopic effect of the rotating cylinders, led to a return in this country to the water-cooled type of which the Curtiss OX, developing 90 to 100 HP. and weighing about 3.75 - 4.25 lb./HP. dry, is a good example. This engine is an 8-cylinder 90° Vee (Fig. 4).

Close on the heels of the OX is the Hispano-Suisa at 150 HP. (Fig. 5). This was a water-cooled 8-cylinder 90° Vee type weighing, dry, about 3.2 lb./HP. About this time came the demand for more power and, with the entry of the United States into the World War, the Liberty engine project. It was originally intended to build this engine in three types, the 6-cylinder in line, the 8-cylinder Vee, and the 12-cylinder Vee. By the time the engine was developed, however, the necessity for the smaller types had disappeared and the Liberty in its final form is a 12-cylinder 45° engine developing about 400 HP. and weighing at that power about 2.2 lb./B.HP. (Fig. 6). We see here the steady increase in power and the steady decrease in weight per horsepower. The vision which prompted the Liberty program, the rapidity with which it was executed, and the success that attended it, after some minor difficulties at the outset, are outstanding achievements in aeronautic engineering.

Engine development stagnated for a time after the close of the war because of the large number of war time engines on hand. Shortly afterward, however, work was resumed and the first result is the Curtiss D-12 developing 325 to 400 HP. on a dry weight of 698 lb. and weighing, at 400 HP., 1.75 lb./B.HP. dry (Fig. 7). Owing to the insistent demand for greater power, particularly for torpedo airplane service, the Wright "T" type followed the D-12 and now exists as a 500 to 600 HP. engine weighing, dry, about 1180 lb. which at 650 HP. makes it weigh about 1.8 lb./HP. (Fig. 8). Since the Liberty is restricted by its physical characteristics to speeds of about 1700 R.P.M., it was necessary to develop the Packard 1A-1500 in the 400-500 HP. class. This engine weighs 735 lb. dry and at 440 HP. weighs 1.67 lb./HP. Following the "T" type in the heavy duty field is the Packard 2500 engine which is just now going through its tests. On about 1100 lb. it is developing 800 HP., which makes it weigh about 1.4 lb./HP. (Fig. 9).

This outline covers the water-cooled field. Air-cooled development has been much less rapid owing to certain inherent difficulties, but simultaneous with this water-cooled development has been produced the 9-cylinder Wright-Navy Model "J" static radial type, developing about 200 HP. on a weight of about 470 lb. (Fig. 10). This makes the engine weight 2.35 lb./HP. or exactly the dry weight of the Model E-4 water-cooled of similar power. This emphasizes the necessity for comparing engines, not on the "dry" or "wet" basis, but rather in the condition "ready to fly" (Fig. 11). On this basis the relatively undeveloped air-cooled engine weighs about 3/4 as much as the very best development of the water-cooled type in the same power. In the 400 HP. air-cooled field, we are now developing the Wright P-1 which, at 400 HP., will weigh about 800 lb. or 2 lb./HP. ready to fly, as contrasted with the Liberty at 3 lb./B.HP. with the radiator and cooling system included. The "J" and "P" models are static radials, i.e., fixed-cylinder engines as contrasted to the early radials of the rotary type.

Summarizing this development and referring to the graph (Fig. 1), we see that there is now a water-cooled engine in every power from 150 to 800 HP. and an air-cooled engine in the 200 to 400 HP. classes. A 1000 HP. water-cooled engine is to be had for the asking. The air-cooled field will be expanded as necessity arises.

One may readily ask why the need for so many engines, and to obtain the answer one must visualize the types of aircraft now in use. In general, the Navy requires Fighting, Observation, Bombing, Scouting, Torpedo and Patrol airplanes. The Fighter is a high-speed job of small radius of action but high rate of climb and high ceiling. The Observation for spotting has medium radius, medium ceiling and medium rate of climb. The Bombing, Scouting and Torpedo airplanes are grouped in one type of three-purpose machine. These are: slow, heavy duty jobs, of relatively low ceiling and rate of climb but large useful load. The Patrol airplane takes the form of the large flying boat, usually multi-motored, capable of considerable radius of action over the sea, slow rate of climb and low ceiling.

The Fighter demands from 300 to 500 HP. and utilizes high rotative speeds. The Observation airplane takes from 200 to 400 HP. and is a medium duty job. The three-purpose Bomber-Scout-Torpedo airplane required from 400 to 800 HP. in a single engine. The Patrol airplane requires from 800 to 1200 HP. in at least two engines. The air-cooled engine is useful particularly in Fighters and Observation airplanes because of its smaller vulnerability.

One need only consider the requirements of these craft to realize the demand on the aircraft engine. The engine must be capable of its maximum power output for long periods and yet must have the minimum weight per unit of power. It must have the maximum dependability and maximum endurance and at the same time the minimum expenditure of fuel. The engine must be flexible and readily controlled throughout the full range of speed from idling to full throttle. All the parts must be readily accessible and the engine easy of maintenance. The engine must be exceptionally free from vibration. It must be capable of production in quantity. The parts must be readily interchangeable. And with all this, the engine must occupy the minimum volume so as to produce the minimum head resistance and to make cowling easy. It will be noted that these requirements are diametrically opposed in many cases and the result is a compromise.

Before going into the method of obtaining the different results required, it is of interest to define a number of terms common in aero engine parlance. The brake horsepower is, of course, the power output of the engine measured on a dynamometer. The brake mean effective pressure is derived from the brake horsepower and represents the average effective pressure which, applied to the piston in each cylinder, would produce the given horsepower. It is useful as a measure of the effectiveness of a given cylinder displacement. Specific fuel consumption is the weight of fuel per brake horsepower hour consumed by the engine (Fig. 13). The volumetric efficiency of an engine is the ratio of the charge drawn in to the displacement available for charging. The compression ratio is the ratio of the clearance volume to the total cylinder volume. Preignition is the ignition in advance of the allotted time resulting from some cause outside the regular ignition apparatus. Detonation is a high order explosion resulting from peculiar cylinder conditions and depending upon the kind of fuel used and the compression ratio. Detonation readily results in high local heating which gives rise to preignition. As we go along, it will be seen that the brake horsepower, brake mean effective pressure, and specific fuel consumption are markedly dependent upon the compression ratio which in turn is limited by detonation.

The heart of the airplane is its power plant, and the heart of the power plant is its cylinder. The cylinder must measure the mixture to be burned, must burn that mixture, must act as a guide for the piston which transmits the energy to the crankshaft, and must at the same time transfer a great quantity of heat at a very rapid rate to the cooling medium. In general, the power output per unit of volume of a cylinder, and the efficiency increase with cylinder size. Aircraft engine cylinders take two general forms - the individual cylinder (Fig. 14) as exemplified in the Liberty, and the block construction (Fig. 15) as emphasized in the Hispano-Suiza and the Curtiss D-12.

Of primary interest in the cylinder construction is the form of the combustion chamber. This chamber must maintain the fuel at its maximum turbulence to produce complete combustion. It must permit the location of the spark plug in such a place as to reduce the tendency to detonate or to preignite. It must be devoid of gas pockets and hot spots, and must permit the free entry of the gases in order to produce a high volumetric efficiency. It would be interesting to point out the method by which these features are obtained, had we time to do so.

While accomplishing the above results, a cylinder must be of the least possible weight. Early cylinders were of cast iron following automobile practice. The first step in reducing weight was to change from the cast iron water-jacket to a sheet-metal jacket welded on. Aluminum was tried as a substitute for cast iron and it was found that a steel sleeve had to be inserted to take the piston wear. The next move was to build a cylinder with a forged steel sleeve and weld the jacket on. Naturally, the forging of the head and valve seats was a difficult one and the final development uses a steel sleeve closed at the top with a water-cooled diaphragm to take the valve seats and having a sheet steel jacket welded on, with an aluminum head to form the intake and exhaust passages. In the air-cooled field, the first cylinders were steel with the fins turned on them. These were followed by aluminum cylinders with steel sleeve to take the wear. The finally accepted type is a steel cylinder open at the top with an aluminum head screwed on. The valve seats are inserted in the aluminum head and are made of aluminum bronze whose coefficient of expansion is theoretically such as to prevent the seats becoming loose (Fig. 16).

After the cylinders, next in importance is piston design. The piston transfers the energy of the explosion through the connecting rod to the crankshaft (Figs. 17 and 18). Since the chief friction in the engine is that of the pistons and the cylinder walls, this friction must be kept at a minimum. In order to reduce the reciprocating forces to a minimum, the pistons must be kept as light as possible. Since a large quantity of the heat generated must be transferred through the piston to the walls, the piston must fit closely enough and must be of such a form as to permit of a rapid heat transfer. Most of the heat is transferred through the rings but part of it passes through the skirts and part of it is dissipated to the lubricating oil underneath the piston. The piston and rings must be tight enough to prevent burned gases passing into the crankcase and must be designed to prevent too much oil getting back into the combustion chamber. For this purpose, in some cases scraper rings are fitted, and these force the oil back through holes in the piston and into the crankcase. The piston must be designed to give the wrist pin adequate bearing surface and to avoid its being deflected under load.

The first form of piston was the small trunk type with a rather thick head and tapered skirts. To reduce the piston friction, the slipper type, in which much of the skirt is cut away, has been evolved and, in a still later design, the piston and bearing surfaces are separated, there being a separate crown and slipper (Fig. 19). Piston rings are the ordinary cast iron snap rings of the Ramsbottom type made thin to reduce friction and peened on the underside to retain the initial tension.

Spark plug development in aircraft engines involves particular attention to cooling in order that high compression may be utilized without danger of preignition from a hot plug. Bearings of the sleeve type in aero engines consist of bronze shells with a thin layer of babbitt on the journal side, or they may be of some special metal such as Kelmet. One of the primary requirements is that the bearings be stiff in order to avoid deflection and local high pressures. This has resulted in the design of steel-backed babbitt bearings. Ball bearings and roller bearings are used for certain special purposes. The ball bearings are desirable particularly for taking up the thrust. One drawback is that exhaust gases collect in the crankcase and condense out to form water which will corrode a highly polished ball bearing unless it is adequately protected by oil. In aero engines, then, some roller and ball bearings require forced feed lubrication.

The chief consideration with regard to crankshafts is not only that they be strong enough to transmit their loads but also stiff enough to stand the torsional vibrations which result from firing impulses and whip. This limits the length of an engine. The crank-cases must be rigid enough to support the crankshaft and cylinders without deflection. In modern practice the bearings are supported in the upper half and the lower half is simply a pan (Fig. 20). This makes it possible to build the lower half very light.

Where the cylinders are staggered, as in the OX engine, two connecting rods ride side by side on the same crank pin. In order to shorten the crankshaft, however, the connecting rods on later engines are placed in the same plane. There are two types of rods, the forked type and the articulated type. On the former, the one rod is forked to receive the blade end of the other rod. In the latter, one rod becomes the master rod and the articulated rod is secured to this by a pin through a boss on the big end of the master rod.

Valves and accessory drives are actuated by gears driven off the crankshaft. Again the torsional vibrations in the crankshaft are the primary considerations in design; since gears, though strong enough to carry the direct load, may not withstand the shock loads due to vibration. Spur gears are preferred to beveled gears wherever these can be conveniently used, because spur gears do not need the adjustment for backlash necessary in the beveled gear type. Most aero engine camshafts are of the overhead type to reduce weight by eliminating push rods. In the Liberty, the camshaft housing was a small one and much too light. In the D-12 and T-2 we have the rugged camshaft housing which not only houses the camshaft but ties the cylinders securely together, stiffening the whole engine.

Valve springs may be of the ordinary spiral type, but flat coach springs and even nests of piano wire springs have been used successfully in water-cooled engines and volute springs or "watch springs" are being used in air-cooled work. Valve springs are usually in multiple to permit of better cooling, greater reliability, and better valve actuating. They must be designed to prevent fluttering at high speed and to permit low initial tension.

The valves themselves, particularly the exhaust valves which are subjected to high temperatures, are either mushroom or tulip type and must be carefully formed to permit a rapid transfer of heat to the cylinder walls and thus to the cooling water (Fig. 21). They must also resist deformation in order to remain tight. Special materials are used and of these, that known as Silchrome is in favor at the present time. An interesting development in cooling exhaust valves is that of the Packard 1500 in which the exhaust valve stem is cooled by circulating the oil (Fig. 22). Attempts have been made to cool the valves by the use of liquids which, boiling at the bottom of the valve, rise into the stem and are condensed and return to the bottom of the valve. When liquids are used for this purpose, excessive pressures are encountered inside the hollow valve stem.

This has resulted in the development of the salt-cooled valve in which certain metallic salts accomplish the same purpose without rise of pressure.

Lubrication in aircraft engines is of the full forced feed type. A dry sump is used for the reason that if oil is allowed to collect in the sump and the engine flows upside down, flooding of the cylinders will result. To bring about this dry sump condition, a gear-driven pump scavenges the sump and a separate gear-driven supply pump returns the oil from the tank to the engine. Suitable strainers must be fitted and a late development is an oil regulator in which the circulating water and the oil exchange heat through a cooler. In this manner, on starting up, the oil is rapidly warmed by the circulating water and is cooled by this water in normal operation. Lubricating oil is usually of two grades - winter and summer. In general, it is desired to obtain an oil which will flow in cold weather and, once warm, will still have sufficient viscosity to lubricate properly. To date no such oil has been obtained.

The requirements for carburetion of aircraft engines are, that the mixture furnished will give the maximum power for take-off and the maximum economy in flight (Fig. 23). To accomplish this, a mixture control device under the control of the pilot is fitted. This constitutes also a control for varying the mixture proportionality as altitude is attained. Even though carburetion may be perfect, there still remains the problem of distributing the mixture to the cylinders. Since this mixture, in the form of a fog, must travel through passages, these passages must be carefully designed to distribute to all cylinders the same quality of mixture. In general, we do not endeavor to deliver a mixture to more than three cylinders with the same carbureter. On a 12-cylinder engine, this involves either four single carbureters or two duplex carbureters. The problem of distribution is a complex one and it has not yet been solved. It is hoped, however, that rotary distribution in which the mixture is drawn from the carbureter and delivered to the cylinder by means of a high speed fan with a small supercharging effect, may relieve this. Rotary distribution must be differentiated from supercharging to sea-level conditions at high altitudes.

Two general types of ignition are in use: (1) the battery generator similar to that employed in automobiles, and (2) the magneto. Of these, we prefer the magneto (Fig. 24) type because of its simplicity and because it is not necessary to carry around a lot of lead in a storage battery. To date it has not been possible to get the high quality of workmanship in this country that magnetos require. In heavy duty work where electricity is required for landing lights, running lights, etc., the battery-generator system will probably be used. At any rate, the ignition system must be as rugged and reliable as possible. From the standpoint of the kind of spark furnished, there is nothing to choose so long as the spark is strong enough to ignite the mixture. All aircraft engine ignition is of the dual system, i.e., two complete and independent units are furnished.

Fuel is supplied to the carbureter by a gravity system whenever possible. In other cases, a pressure system is used either through an engine-driven fuel pump or an air-pressure pump. The air-pressure system is being abandoned because when an airplane crashes, a tank under pressure bursts, spreading gasoline over the engine, and produces a fire. To date, no pump has been developed which will lift gasoline under a reasonable suction head. This has resulted in a flexible drive off the engine with the pump located in a low position. Some trouble has been experienced in developing the flexible drive but the "Around-the-World" fliers used it successfully. A Navy experiment is the so-called Noble fuel system, which is an interesting hydraulic type and highly experimental. An actuator on the engine operates through the fuel supply line on a differential piston and a spring-actuated pump in the fuel tank. It is a sort of reverse ram-type pump.

Some means of starting an aircraft engine is absolutely necessary. With the smaller engines, a hand starter can be used successfully. We do not favor the electric type because of its weight and complication. The Navy has lately developed the so-called inertia type starter in which, by turning a crank rapidly, energy is stored in a small flywheel. By a mechanical device the flywheel is engaged with the crankshaft and the stored energy is utilized to turn the engine. This is apparently a very successful accessory.

As in marine practice, the engine speed is necessarily high to meet the requirements of economy and weight. Direct-driven propellers are, however, uneconomical except in very fast ships. This has resulted in the development of reduction gears. To date, the torsional vibrations in the crankshaft have made gearing unreliable and the additional weight absorbs most of the gain in propeller efficiency in all but very heavy duty work. A new gear, having a flexible coupling between the gear and crankshaft to absorb torsional vibrations, seems to have solved the problem, however, and new engines are being geared for heavy duty.

As aircraft reach higher altitudes, the decreased air density results in a falling off of engine power and a corresponding reduction in aircraft performance. To avoid this, compressors called "superchargers" have been used to a certain extent. These are either driven by gears off the engine shaft or by a gas turbine in the exhaust gas path. Of these, the gear type seems the only reliable one. By this device a fan compressor supplies air at sea-level pressure to the carbureter at high altitudes and increases the engine performance. The engine then speeds up at altitude and since the load on the propeller has been reduced by the decreased air density, the propeller runs away. This has resulted in the development of the variable pitch propeller by which the pilot can control the pitch at will. Both the supercharger and the variable pitch propeller are still experimental, however, and we are counting on using the supercharger idea mostly as a means of improving the distribution of fuel to the cylinders.

In the discussion above, we have mentioned air-cooled and water-cooled engines, the relative advantages of which are still controversial. The water-cooled engine is at present more highly developed than the air-cooled engine and the operating personnel are better acquainted with it than with the rather new mechanism of the static radial. This is an important consideration in any development. It takes time to learn how to run any engine. The water-cooled engine's chief handicap is weight and vulnerability of the cooling water system. The air-cooled engine's chief handicap is supposed to be its large frontal area and corresponding head resistance. When, however, one compares the drag due to radiators and the extra wing area to support the greater engine weight, this handicap disappears. To date, the higher cylinder temperatures in air-cooled engines have resulted in lower B.M.E.P. and lower economy, and rotative speeds have been limited by the connecting rod "big end" conditions of the static radial. For military purposes, if air and water-cooled engines are equal in every respect, the vulnerability of the water-cooled engine makes it inferior particularly for fighting purposes. The development of the two engines is, however, proceeding rapidly and it seems likely that we will find important uses for both types.

In the drive for higher power outputs and decreased weights, resort has been had in aircraft to numerous special classes of special materials. In general, the power output per unit of cylinder displacement is a function of the compression ratio. The higher this ratio the greater the unit of output and likewise the better the economy. There is a limit to the amount of compression. However, this limit is the compression at which the fuel tends to detonate. For instance, domestic aviation gasoline can be used for a compression ratio of about 5.3 to 1. For ratios of 6 and 6½ to 1, special fuels are required. Experiments have been made with such fuels as benzol and alcohol, and their blends with gasoline. Ethyl Fluid has also been used and tests are also being conducted with two special fuels known as Cyclo Gas and Stellarine. To date, no entirely satisfactory fuel has been obtained and service compression ratios are limited to 5.3.

In the matter of durability, considerable progress has been made. For a long time the average life of the Liberty engine between overhauls was considered to be fifty flying hours. Improvements in development have increased this time by nearly 100 per cent. In the newer types of engines this limit is greatly exceeded. There are two Wright T-2 engines in a PN-7 which have had over 300 hours of flying without major overhaul and they are still in excellent condition.

In the matter of dependability, considerable progress is being made. In so far as the engine itself is concerned, the problem is fairly well in hand. It is in the accessories that dependability is lacking. Fuel and water pump failures and ignition failures are common sources of trouble. Every effort is being made to improve the dependability of these important auxiliaries.

Experiments are being made with a so-called barrel-type engine somewhat similar in kind to the Waterbury Tool Gear, and with a cam engine in which a cam replaces the crankshaft. Nearly always these novel devices have some drawback which limits their application. It is necessary, however, to remain open-minded and assist the promising projects and at the same time to keep one's feet on the ground and devote our energies to the steady improvement of existing types.

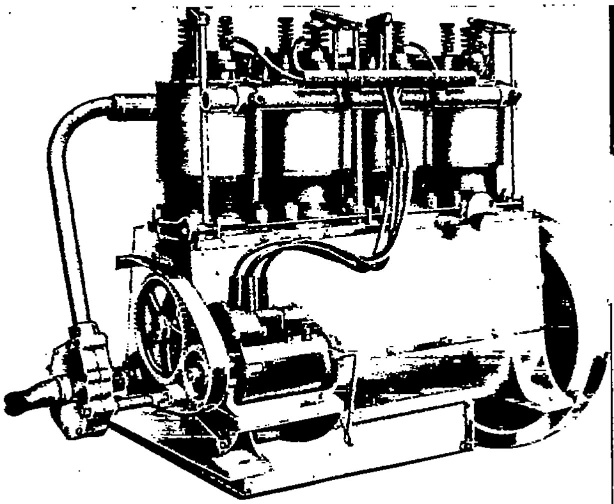
The indications are that existing engines will continue to develop along the lines of increased R.P.M. A year or two may very readily see an engine turning at 3000 R.P.M. and geared with a 2 to 1 ratio. Engine development is a long tedious process full of costly mistakes. It is not anticipated that the next five years will see any deviation from the present standard types and designs.

We have come to think of the water-cooled engine as being of necessity the in-line or Vee type. We also consider the air-cooled engine as of necessity a radial type. There are, however, in-line air-cooled engines such as an air-cooled Liberty, a radial water-cooled engine such as the French Salmson. The Liberty and the Packard 1500 have been run in an inverted position with success. As a matter of fact, the power output has been increased slightly by inversion. This has focused attention on the possibility of an X type engine which is nothing more than two Vee types opposed to one another. In this type, in 4-cylinder banks, are combined the short length of the radial and the multiple cranks of the in-line engine. This is a possibility of the future, especially in large sizes.

Aircraft engine development has been retarded rather than assisted by automobile development. Aircraft engines have followed conventional water-cooled lines. In 1901, Charles M. Manly designed and built an engine for Professor Langley, which is now in the Smithsonian. It was a water-cooled radial which actually developed 52.4 HP. at 950 R.P.M. for 10 hours, and at that low speed it has a dry weight of 2.36 lb./HP., or better than many modern engines (Fig. 25). Manly had to design and build his own carbureter, magneto, spark plug, and other accessories, because no such thing existed then. Starting with no traditions or conventions, he conceived a rational design which in many particulars corresponds to ideas we have developed after twenty-three years of trouble and grief. It is startling after you have painfully "discovered America" to find that Columbus was here in 1492.

From this brief summary, it is apparent that aircraft engine design is in a fluid state. The big idea of yesterday proves to be a dud today and the visionary solution of today is relegated to the scrap heap tomorrow. Behind it all, however, is plain common sense and broad service experience. We need less of invention and more of design.

In general, beauty and efficiency are synonymous. After all the experiments have been made, the final result is a thing of beauty. Any really successful engine proves to be of pleasing form. In the last analysis, all design work can be summed up in the question - How does it look? If it looks all right to the experienced eye, it will probably be all right and vice versa. As an example of the pleasing form a finished product takes, we have the latest water-cooled engine, the Packard 1A-2500 (Fig. 26), and the latest air-cooled engine, the Wright P-1 (Fig. 27). These are things of beauty. It is our sincere hope that, to the service at large, they may prove to be joys forever.



The Wright Four-Cylinder Engine.

Fig.1 The first engine to be flown.

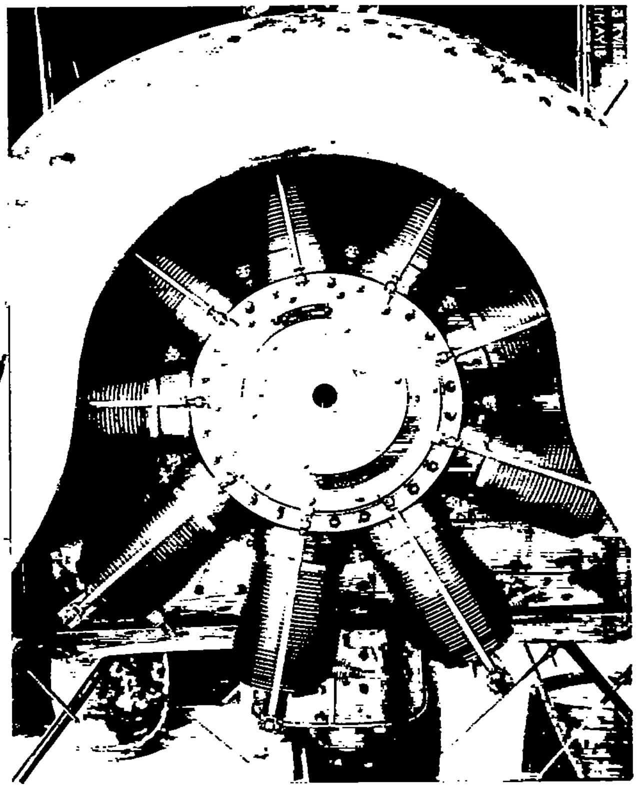
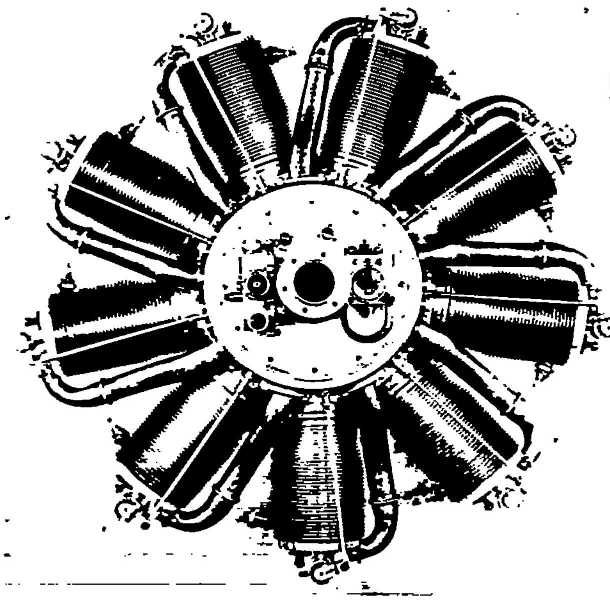


Fig.2 Gnome rotary 9-cylinder air-cooled engine 3-1/2 lb./HP. 80-100 HP. steel cylinder barrel and fins.



110 H.P. LE RHONE
Fig. 3

Fig.3 Le Rhone rotary 9-cylinder air-cooled engine 3-1/2 lb./HP. 110 HP. steel cylinder barrel and fins.

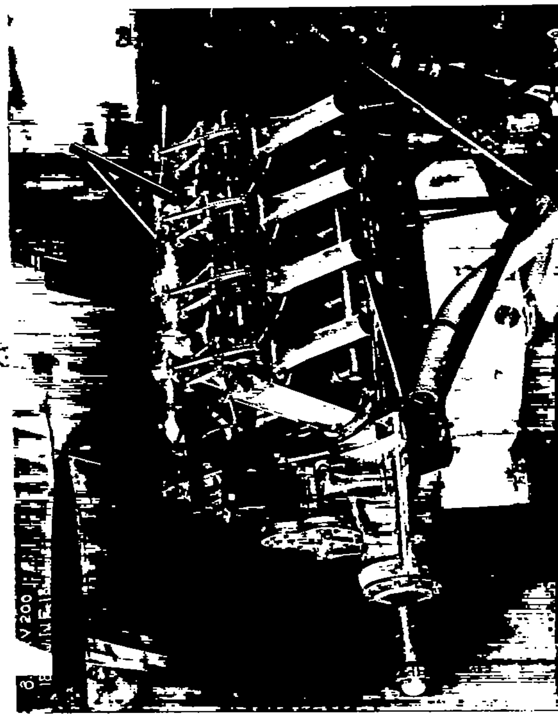


Fig.4 Curtiss OXX 8-cylinder 90° vee water cooled engine 4 lb./HP. 100 HP. individual cylinders.

11906 A.S.

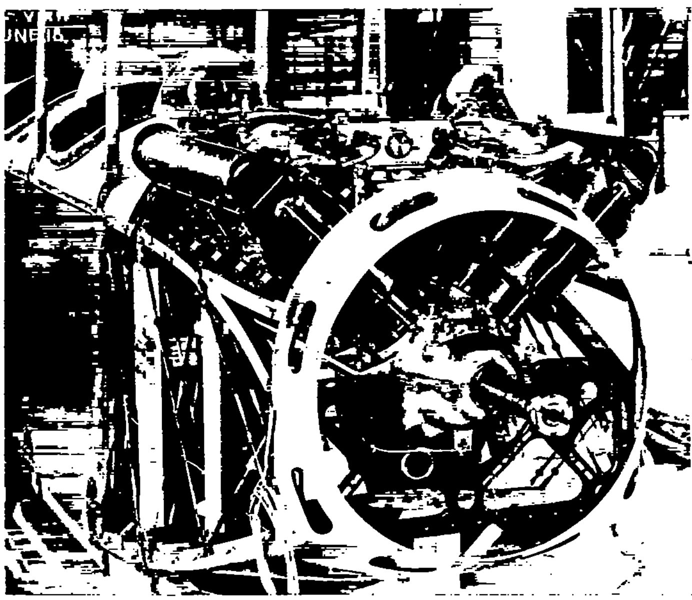


Fig.5 Hispano-Suiza 8-cylinder 90° vee water-cooled engine 3.2 lb./HP. 150 HP. block cylinder construction, dry sleeves.

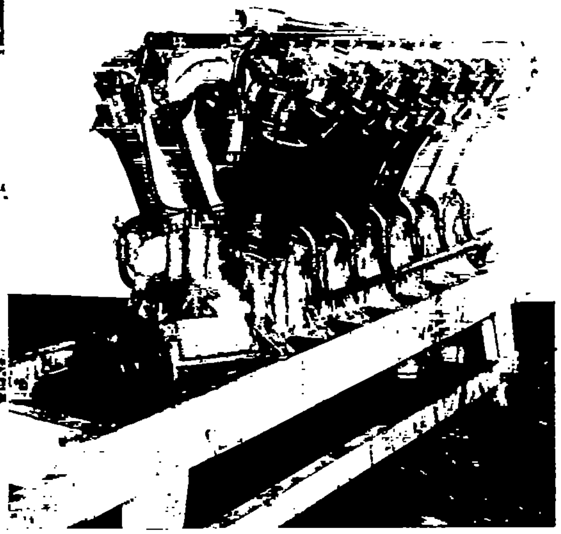


Fig.6 Liberty 12-cylinder 45° vee water-cooled engine 2.2 lb./HP. 400 HP. individual cylinders - wet sleeves.

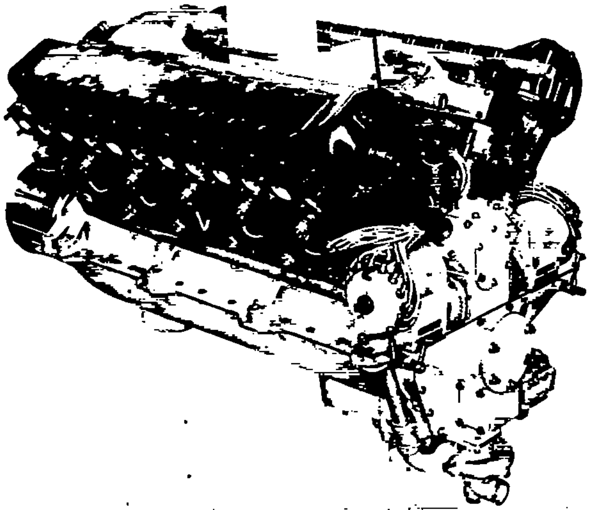


Fig.7 Curtiss D-12 12-cylinder 60° vee water-cooled engine 1.75 lb./HP. 400 HP. block cylinder construction - wet sleeves.

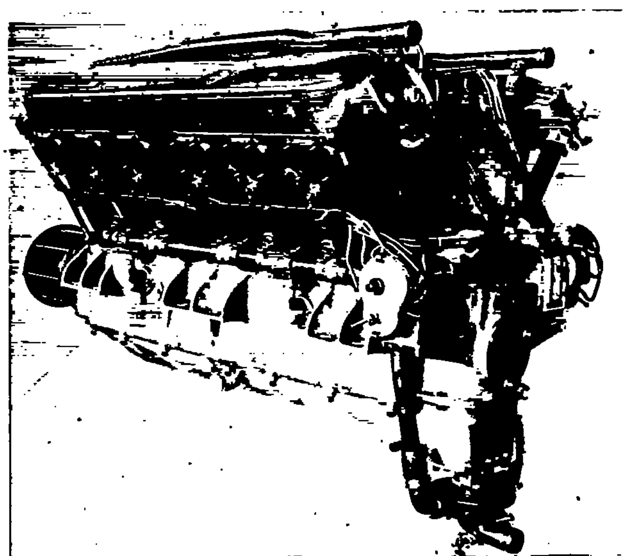


Fig.8 Wright T 12-cylinder 60° vee water-cooled engine 1.8 lb./HP. 650 HP. block cylinder construction, dry sleeves.

11907 A.S.

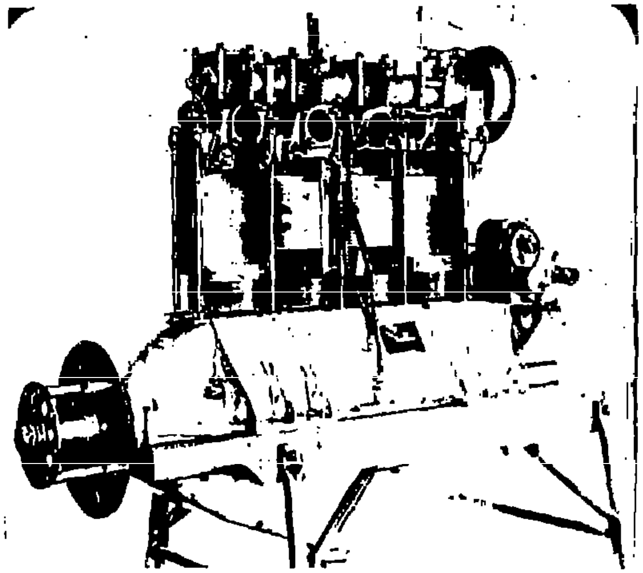


Fig.14 Hall Scott 4-cylinder engine showing individual cylinder construction.

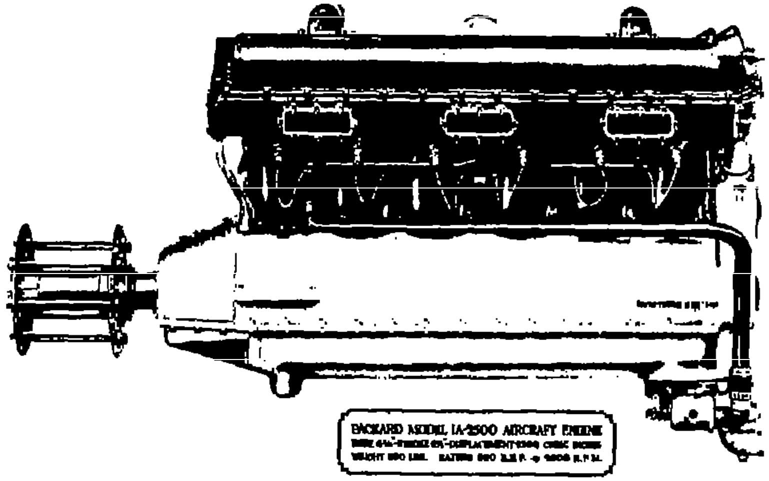


Fig.9 Packard 1A-2500 12-cylinder 60° vee water-cooled engine 1.4 lb./HP. 800 HP. individual cylinders - block heads - dry sleeves.

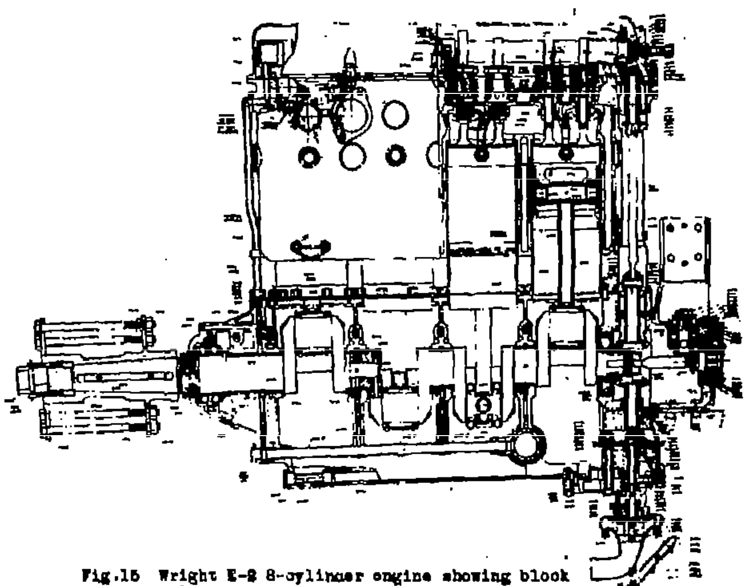


Fig.15 Wright E-2 8-cylinder engine showing block cylinder construction.

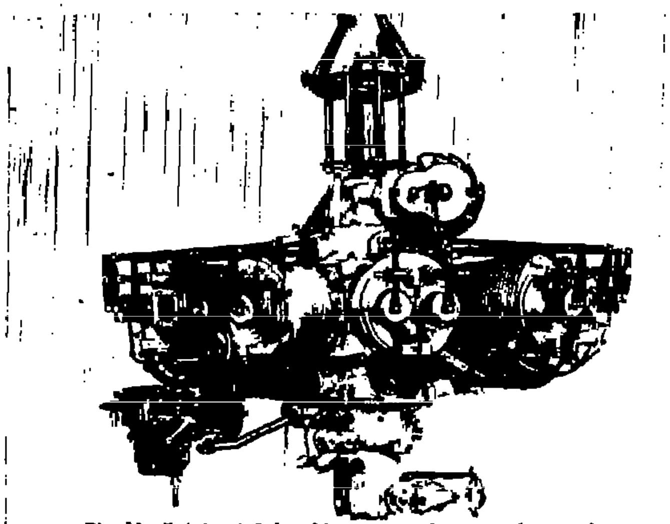


Fig.10 Wright J-3 9-cylinder radial air-cooled engine 2.35 lb./HP. 200 HP. - steel cylinder sleeves pressed in finned aluminum jackets.

11908 A.S.

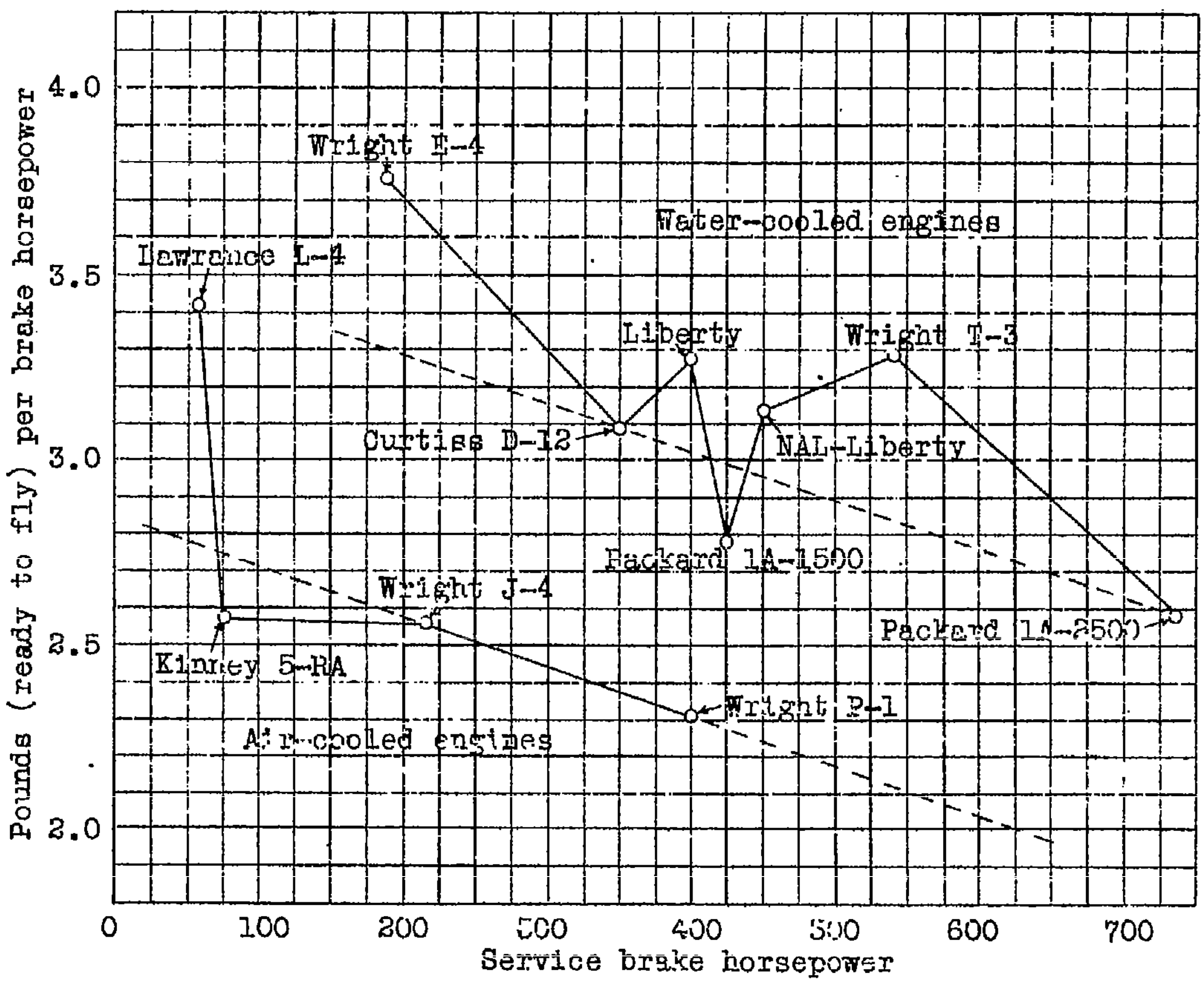


Fig.11 Weight of engines ready to fly less fuel and oil system.

Compression ratios.

Wright E	5.3	Liberty		5.4
" J	5.0	Packard	1-A-1500	5.7
" T	5.3	"	1-A-2500	5.6

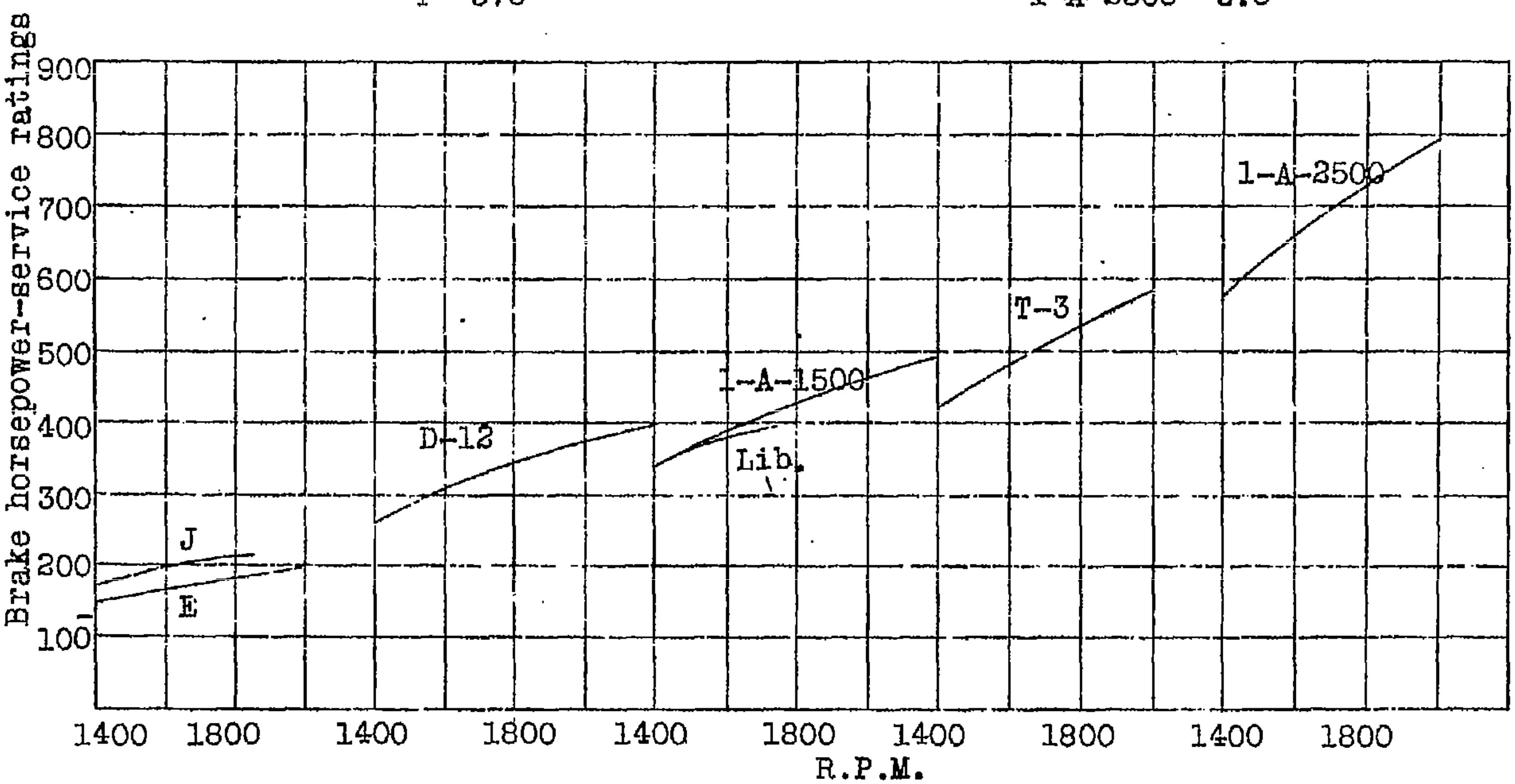


Fig.12 Service ratings of existing aircraft engines (1924).

Relative performance data showing Wright development from 1916 to 1923 on one type of engine.

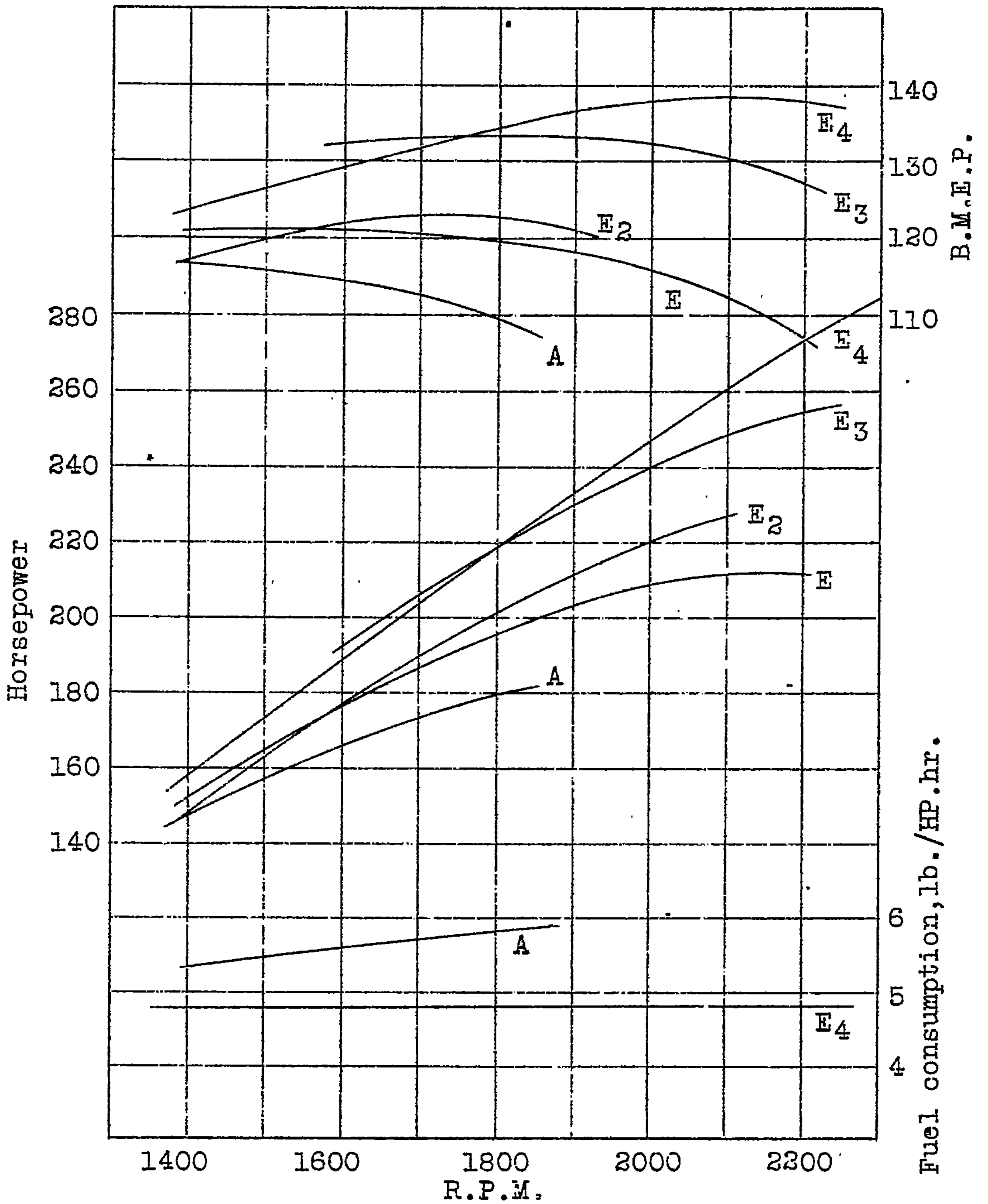
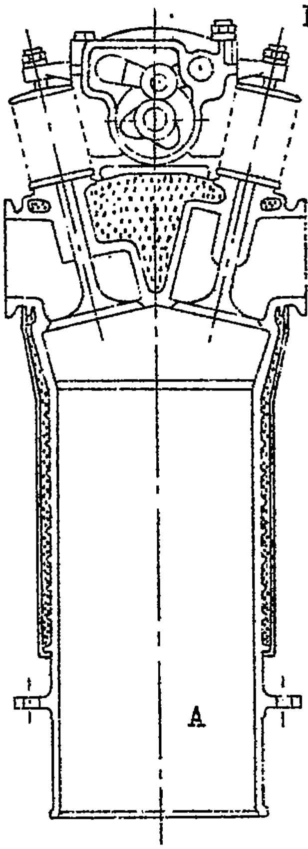
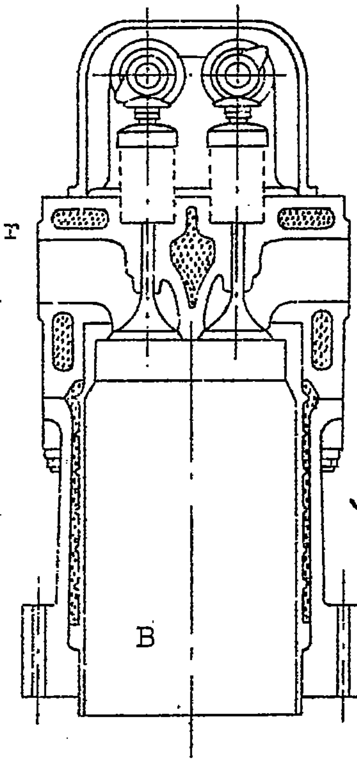


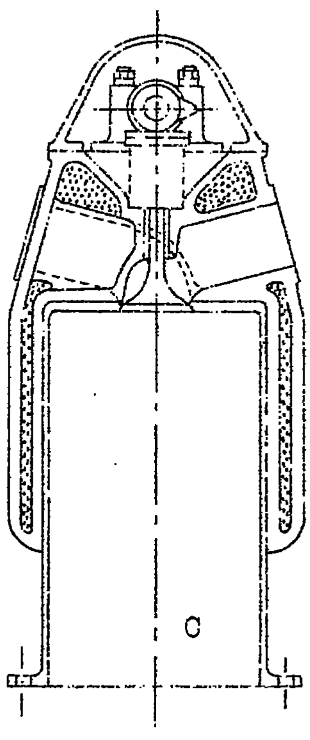
Fig.13 Power and fuel consumption development of Wright engines.



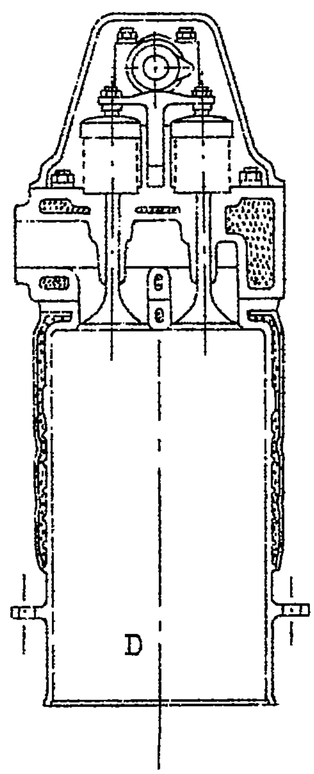
A - Liberty cylinder construction - wet cylinder barrel and welded on jacket.



B - Curtiss D-12 cylinder construction - wet cylinder barrel and cast aluminum jacket.



C - Wright E and H cylinder construction - dry cylinder barrel and cast aluminum jacket.



D - Packard 1500 and 2500 cylinder construction - wet cylinder barrel and welded on jacket.

Fig.16

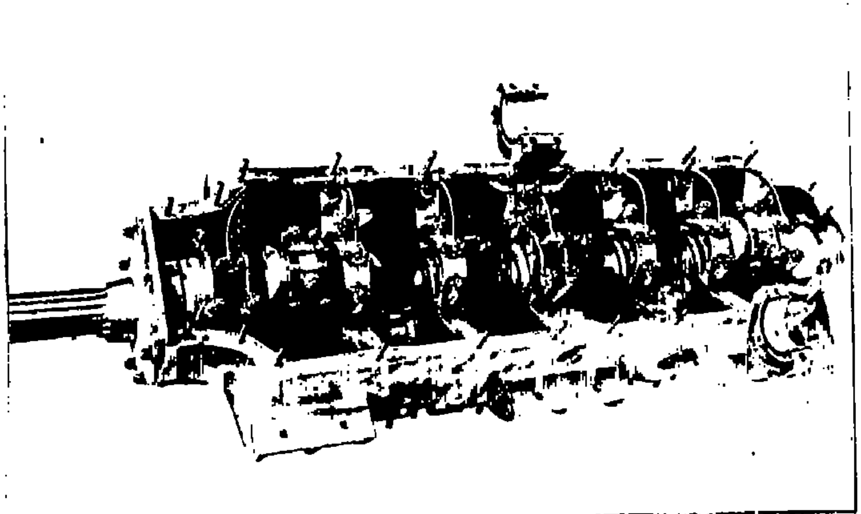


Fig.20 Wright T-3 crankcase with crankshaft.

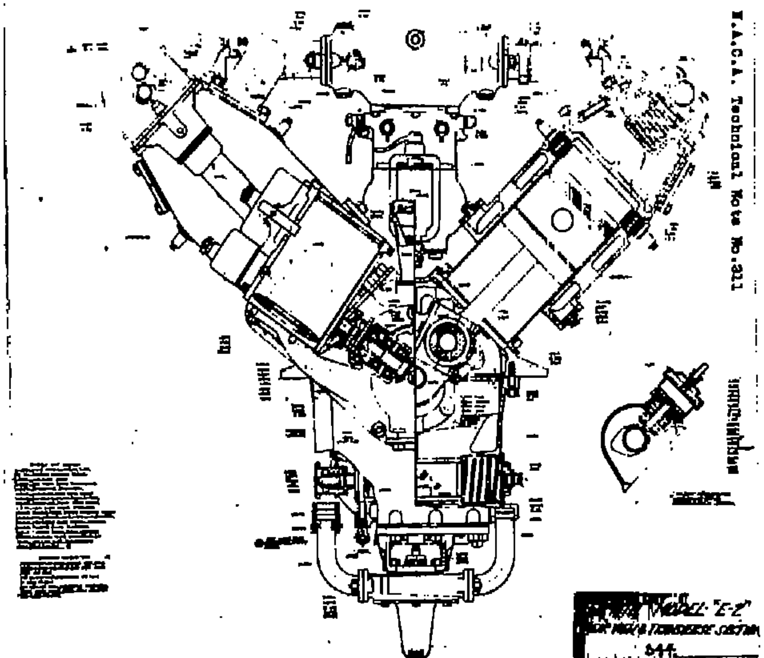


Fig.17 Wright E-2 8-cylinder engine showing piston connection rod and crankshaft relation.

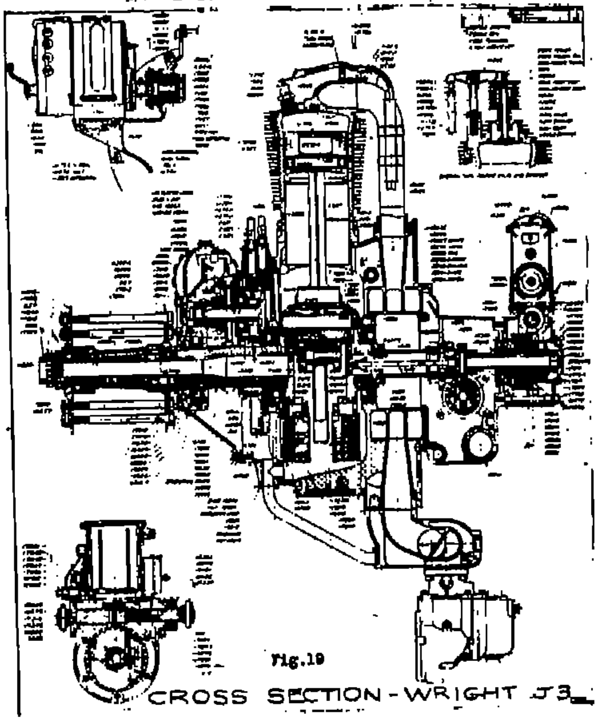


Fig.19

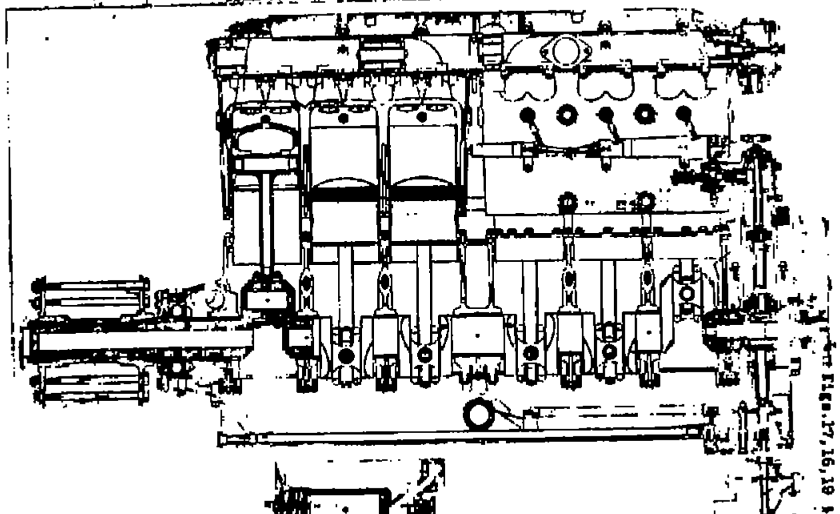


Fig.18 Wright T-2 12-cylinder engine - longitudinal section.

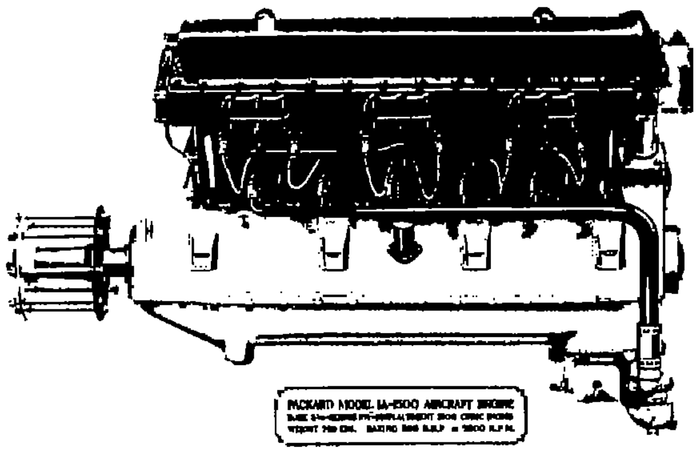


Fig.26 Packard 1A-1500 12-cylinder, water-cooled engine 1.75 lb./HP. 450 HP.

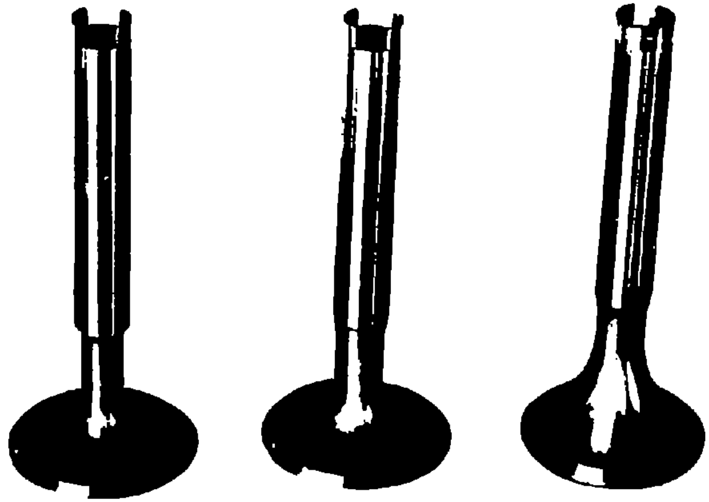


Fig.21 Evolution in valve design - Wright E engine.

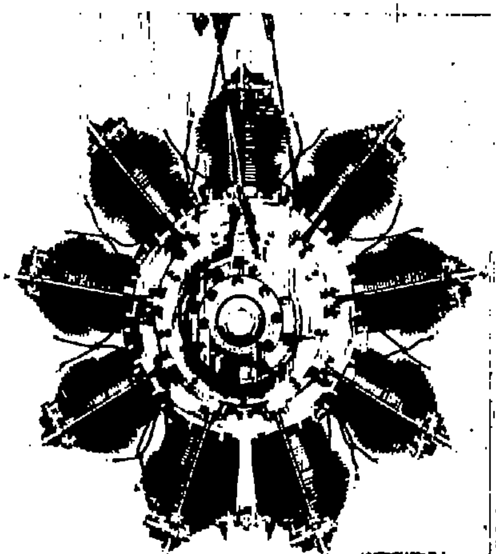


Fig. 27 Wright P-1 9-cylinder radial air-cooled engine. 2 lb./HP. 400 HP.
Steel cylinder sleeve, steel fins, & aluminum head.

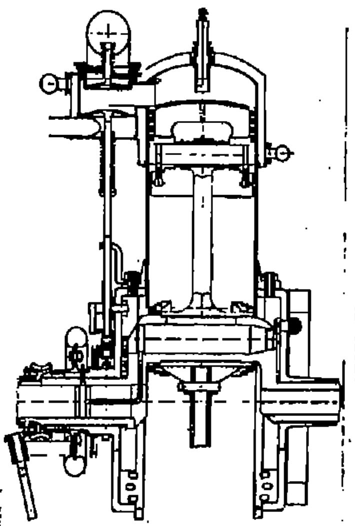


Fig. 23 Manly 5-cylinder, water-cooled engine.
2.36 lb./HP., dry weight.
52.4 HP. at 950 R.P.M.

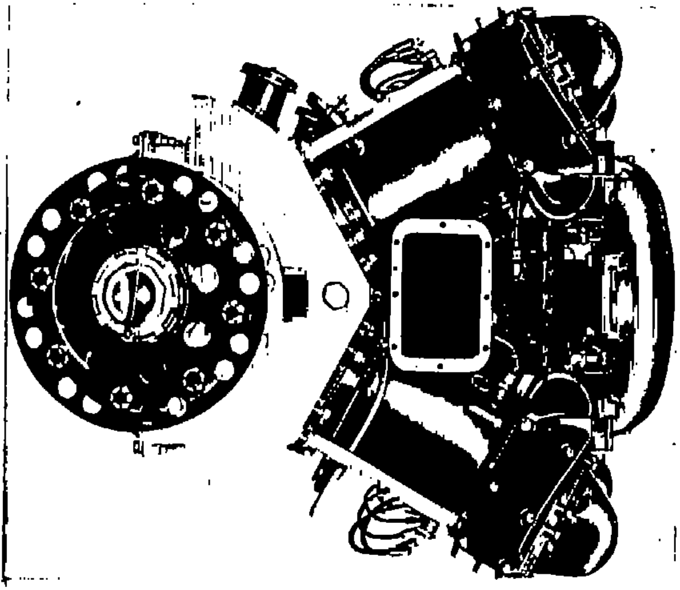


Fig.25 Packard 1A-2500, 12-cylinder engine showing carburetor installation.

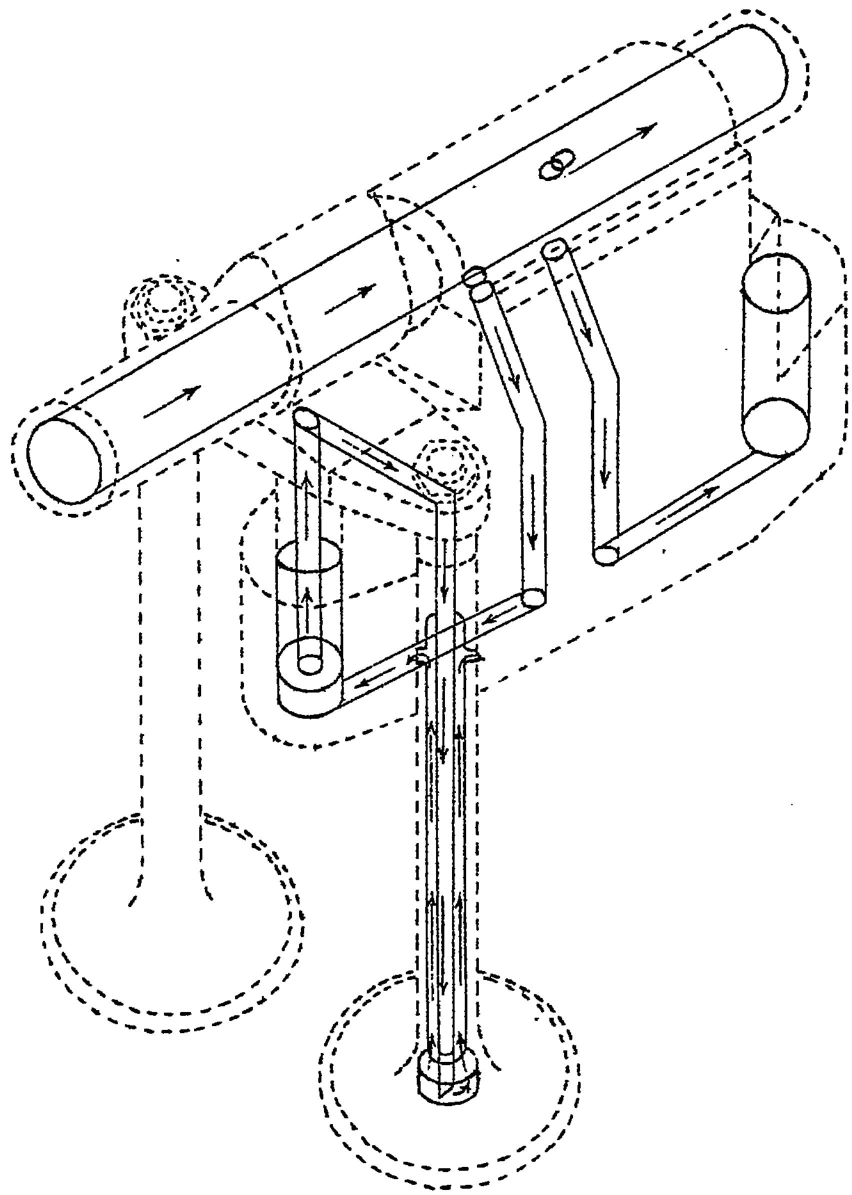


Fig.22 Packard 1A-1500 oil cooled exhaust valve.

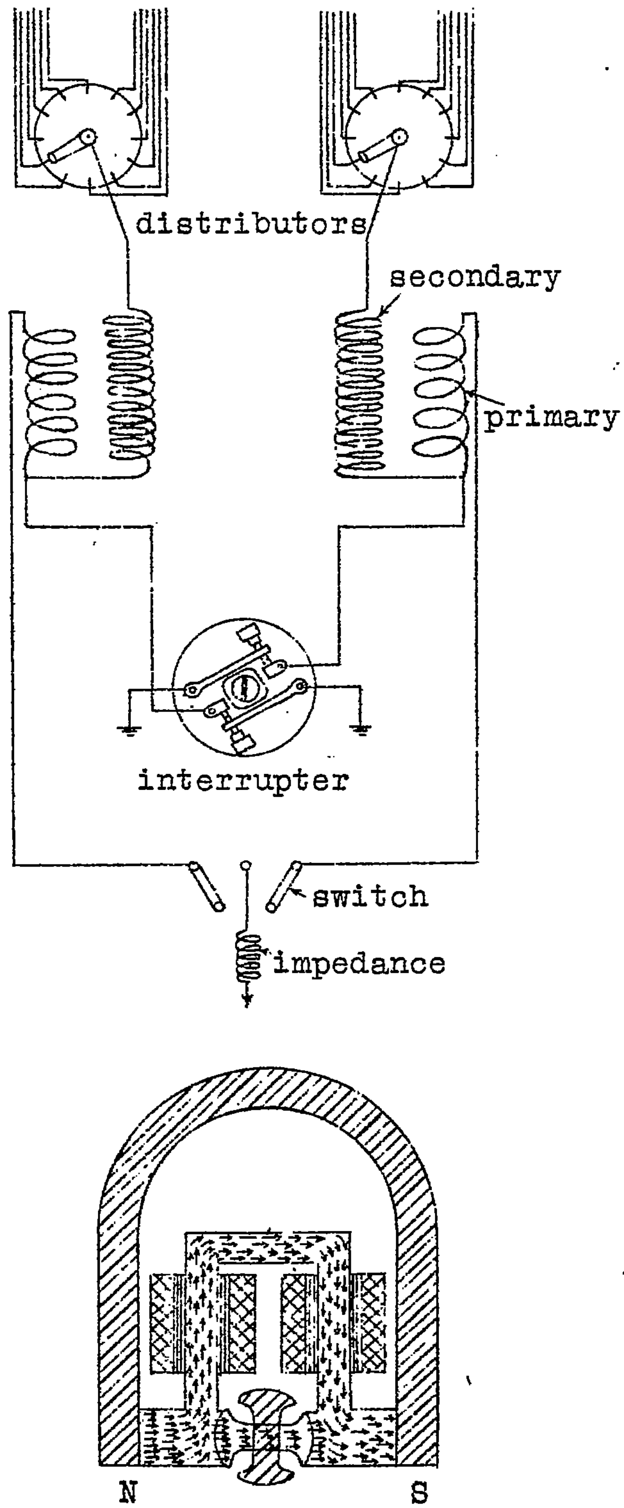


Fig.24 Single magneto with double distributor used on Packard 1A-1500 and 2500 engines.