Universal Test Engine

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Engineers will generally agree, that despite the marvelous progress made in the development of high speed internal combustion engines during recent years, there still remains much to be accomplished toward increasing efficiencies and improving designs generally. The demands for better motive power previously brought forth new ideas effecting improvement so rapidly, that although many of the engines in use at present are of reputedly good design, there is scarcely any reliable and accurate scientific data which could be used in forming a proper basis for comparison.

One must take into account, however, that there are many influencing factors so dependent upon each other that an individual analysis of each source is practically impossible. Furthermore, engine designs are usually of such a varied nature that only the most pronounced differences in performance will permit of opinions regarding the effects of certain combinations. Nevertheless, something should be done as this lack of substantial data not only hinders scientific progress but generally leaves the engineer in a quandary in selecting the designs or combination of designs that should produce the results expected in a most efficient manner.

As a rule, the mechanical efficiency of an internal combustion engine is comparatively high. This is particularly true of the airplane engine, which is accurately constructed of very light weight parts made from the highest grades of material. Apparently little opportunity for improvement is afforded in this direction, but the marked differences between weight-power ratios, fuel consumptions, and other important performance characteristics clearly demonstrates the need for extensive development along other lines. One of the most important of these is undoubtedly the design and construction of the cylinder and its adjunct components.

Heretofore, the development of a cylinder has been carried out on a complete engine, but seldom produces satisfactory results as quickly as desired. Moreover, for multi-cylinder forms, such a method of development obviously entails considerable expense. Under normal conditions, one cylinder of an engine functions exactly like the others, and improvements in one effect improvements in all; hence, cylinder development can be carried out just as successfully, and with much less difficulty or expense, on a single-cylinder engine constructed for the purpose. A few test engines of this sort have been built, but in every case were intended only for one design and the field of experimentation was thus limited to that particular cylinder. Whenever it was required to develop other sizes or designs, new test engines had to be constructed. The Uni-

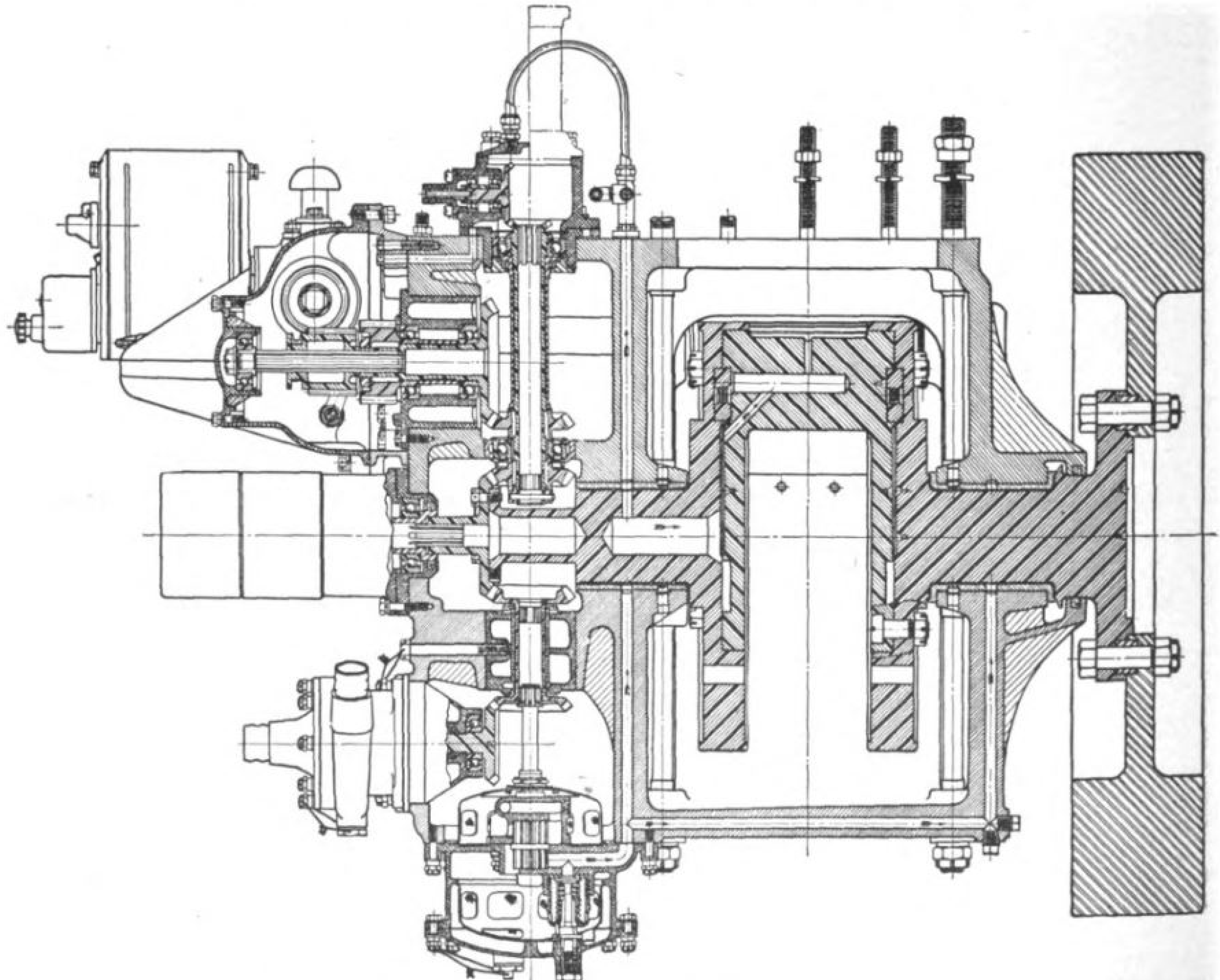

FIG. 1. LONGITUDINAL CROSS-SECTION OF UNIVERSAL TEST ENGINE

versal Test Engine surmounts this difficulty, as it is so designed that most any cylinder can be tested on it, but before describing this engine it would be well to briefly explain the specific reasons for its design.

Immediately following the signing of the armistice, the organization of the Governmental Experimental Airplane Station at McCook Field, Dayton, Ohio, began to rapidly adjust itself to the new duties, which included principally the perfecting of certain airplanes and engines then on hand, and as a technical division to accumulate data and prepare designs for future construction which should place this country in its proper rank in the science of military aeronautics.

Since engine development should precede plane development by one year or more, it was clearly evident that a good engine program was of the utmost importance. Only a few American designs were considered of military value and so besides immediately undertaking the necessary improvements on these engines, the design of other types found to be needed was also placed under careful consideration.

For future designs it was very apparent that the former methods of development were entirely inadequate, and the desired results could hardly be expected with the limited amount of money available for this work. It was therefore decided to construct some sort of engine which would allow for accurately testing different sizes and designs of cylinders under varying conditions, so that the performance and consequently the value of any particular design could be determined before

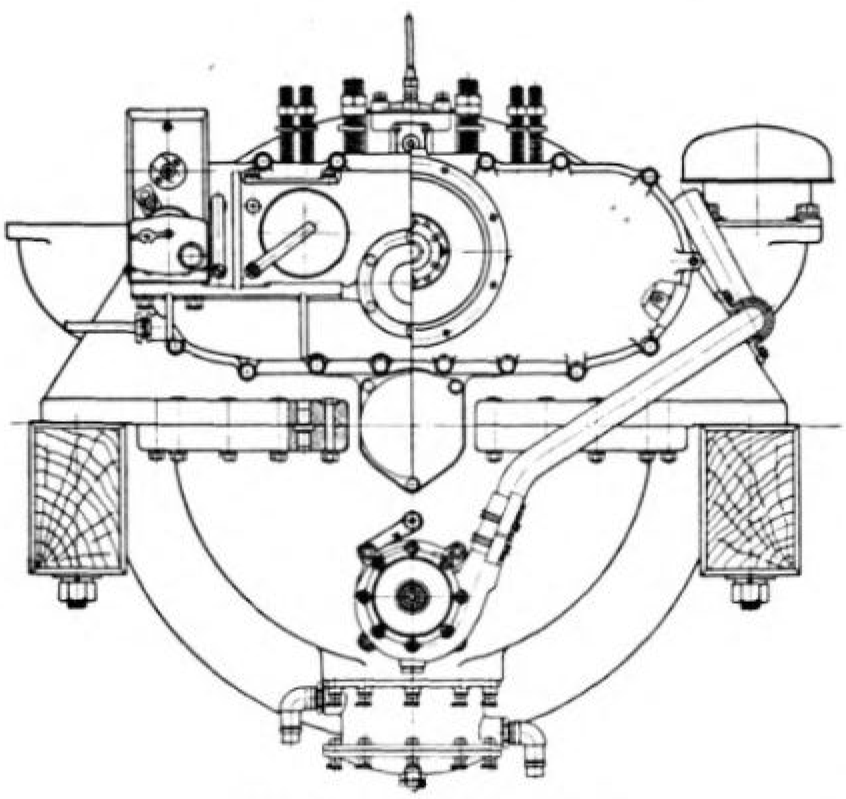

Fig. 2. Timing End View

constructing an entire engine. Furthermore, the Engineering Division could become acquainted with the exact performance of any cylinder submitted by the manufacturer of an experimental engine prior to purchasing the complete unit.

No knowledge concerning any former construction of this sort existed; consequently, the practicability of building an engine for these purposes demanded serious consideration. It was not until after the entire situation had been very carefully analyzed that design and construction was actually undertaken. It was proposed to obtain as wide a range of bore-stroke combinations as practically possible, provide for the operation of all types of cam and valve mechanisms, and at the same time allow for quick interchangeability of parts and easy means for testing.

The salient feature of the engine as it was finally worked out is the wide range of cylinder adaptation. Cylinders can be tested which have bore diameters from 4 to 8 in., inclusive, and strokes from 4 to 10 in., inclusive. This range includes all sizes of airplane engines that are at present in practical use, and allows for experimentation with large cylinders if future requirements so demand. Compression ratios can be readily varied, in most cases it being quite easy to obtain a range from 4 to 10. Obviously, high compression ratios can not be used continuously near the ground, but provision was made for

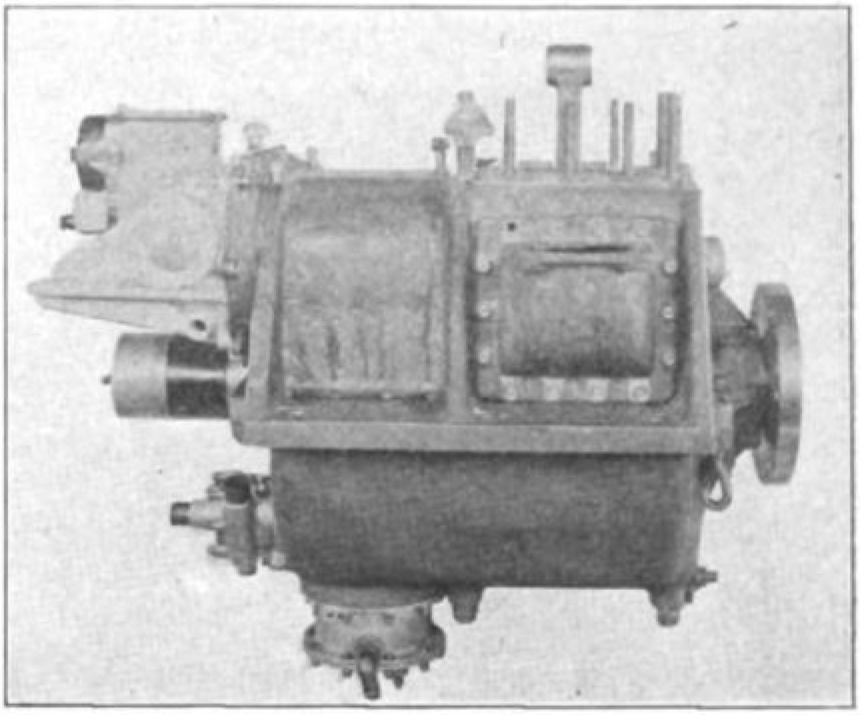

Fig. 3. Side View of Universal Test Engine

such cases when it might be desirable to determine the effects of different compressions at various altitudes by testing a cylinder in a vacuum altitude chamber. All other outstanding features can best be explained in the description of the various parts which immediately follows.

Crankcase

The crankcase is made in halves and divided along the horizontal crank center-line in the conventional manner. Both upper and lower halves contain the crankshaft bearings and the two are held together mainly by four long and sturdy bearing studs, together with the four shorter bearing bolts. There are also additional bolts through the outer flanges which give an oil tight joint. The walls, and in fact all sections, are made extremely heavy. The casting, which is made of iron, produces a very rigid frame member and should prevent serious damage in case any rotating part fails.

The crank and gear compartments are separated by a wall so that the gears are not exposed to the crankcase vapors. On either side of the crank compartment are large hand holes which permit inspection and the adjustment of connecting rod bolts. When the engine is in running condition these inspection holes are covered by breather elbows retaining screens which are to prevent oil vapor from being blown out or any foreign substance from entering the interior.

Crankshaft

A great deal of thought had to be given the design of a crankshaft for this engine on account of various lengths of strokes which were to be used. Individual crankshafts could

Fig. 4. Upper Half of Crankcase

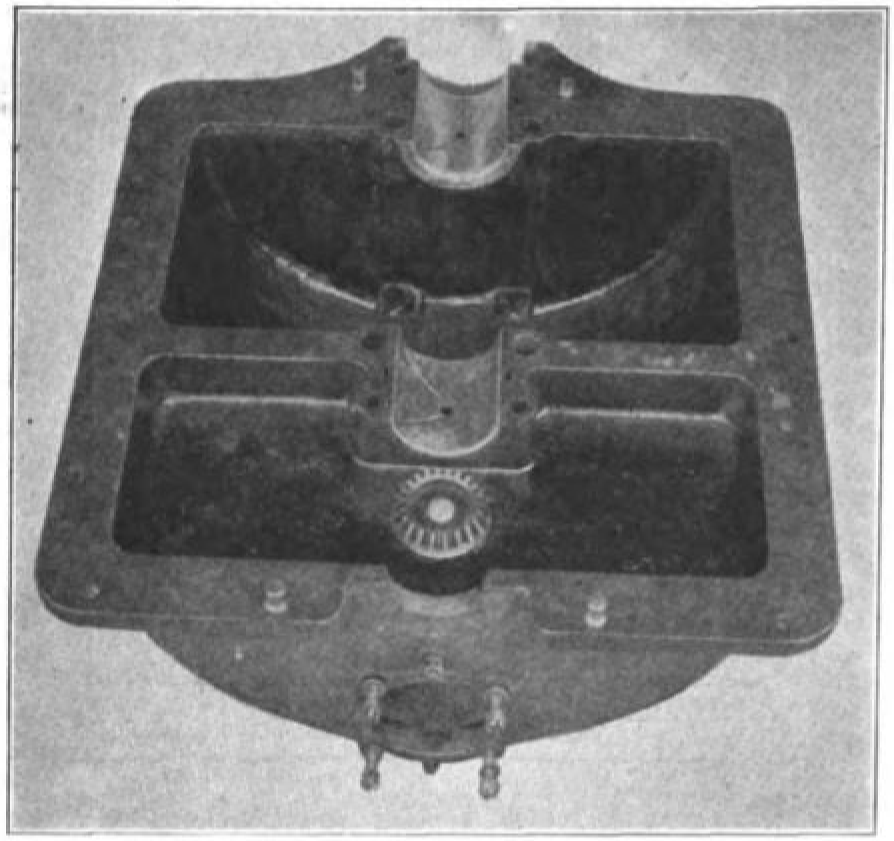

Fig. 5. Lower Half of Crankcase

have been made for each length of stroke, but this undoubtedly would have introduced difficulties later on. Bearings would have to be refitted almost every time a shaft was changed, and a conventional shaft design, in order to be strong enough for the large bore-stroke combination, would not be well proportioned for the smaller combinations. Furthermore, the attachment of counterweights to every shaft would each time introduce vital design problems.

The built-up crankshaft construction, shown on Fig. 6, eliminates the disadvantages referred to, and has another feature in that it serves to supplement the action of the regular flywheel and thereby helps to maintain a more uniform speed of rotation.

The crankshaft assembly consists mainly of three major parts. The two end portions include the main journals internally attached to the large discs which have eccentric recesses for receiving the intermediate piece. One end portion has a flange for attaching a flywheel and the other a flange for a bevel gear which drives the various auxiliary units. The intermediate section comprises a crankpin on the ends of which are eccentrically formed similar and integral discs of the proper diameter to fit flush into the recesses provided in the larger discs of the end sections. The eccentricity of the recess is the mean of the maximum and minimum crank radii required to give strokes previously specified. By angular adjustment of the intermediate section it is clearly evident that varying crank radii can be readily secured.

The three crank sections are held together as one assembly by a total of 12 bolts, 6 on each side. These bolts have countersunk heads, set in flush to the inner surfaces so as to avoid any interference with the connected rod, and are retained by slotted nuts and cotter pins. The bolts are not in shear, as the driving torque is carried by blocks or dowels which fit snugly into small recesses on both sides. To facilitate removal, each dowel is provided with a tapped hole.

Counterweights are bolted on the crankpin side of the large discs of the end sections by means of holes provided in those portions outside the eccentric recesses. The holes are unevenly spaced so that it becomes impossible to incorrectly attach counterweights from some predetermined location. The weights are of such proportions and the centers of gravity are so located from the crank center, that the crankshaft assembly in addition to being in static balance provides for the balance of half of the reciprocating inertia forces. As is generally understood, partial balancing of this sort on a single cylinder engine can be accomplished only at the expense of introducing an unbalanced component of equal magnitude along the horizontal. However, as a result, the forces are least if considered in every direction.

A variable throw crankshaft is apparently very difficult and expensive to produce, but once made, it has an indefinite period of usefulness. And when supplied with an additional intermediate section for strokes in half inches, it serves for testing purposes much better than would fourteen or in other words the equivalent number of crankshafts necessary to give that many stroke lengths. Even without any special tooling, the first crankshaft of this design was so accurately machined, that when assembled it had much better bearing alignment than the average crankshaft made in one piece.

Connecting Rods

It became necessary to provide for more than one length of connecting rod on account of the limits to which a piston can overrun the cylinder skirt, but it was found that only one rod was needed for each even inch stroke length. The body of the rod for each particular length of stroke was established by the section required to keep the stresses within safe limits with the largest diameter cylinders which were likely to be used, and also clear the skirt of the smallest cylinders, whose diameters in each case should not be less than the stroke length.

Since the crankpin diameter is never changed, the crankpin bearing is the same for all rods and make of sufficient length to satisfy all conditions. The upper end of the rod is likewise made amply large and a bushing inserted to give the desired diameter of piston pin bearing. The width of the upper end is limited by the length of bearing required in the smallest piston that would probably be used with each stroke, and by careful analysis it was found possible to so proportion these bearings that at no time were practical unit bearing pressures exceeded.

Camshafts

It was necessary to provide two camshafts in order to test all types of L or T head, or in fact any cylinder designs, whose valve gear is operated through push rods from a camshaft mounted in the crankcase. These camshafts were symmetrically located on each side of the case, and at a distance from the center sufficient to allow for operating the valve gear of the largest cylinder which could be tested. The shafts are driven through spur gears, as will be noted from Fig. 7. An idler gear is mounted on a stud between the driving and driven gears, and can be easily removed when the particular camshaft which it drives is not to be used. The camshaft gear is held to a flange on the shaft by three screws. By providing a certain different odd number of holes in each piece, a very fine degree of adjustment for timing purposes is had.

The shaft is supported in three split aluminum bearings which are assembled onto the shaft before it is inserted into the crankcase from the end. When the assembly is in place the bearings are held from turning by the hollow studs, through which oil is supplied under pressure.

That part of the shaft extending into the crank compartment is splined for the purpose of driving cams. Individual cams of any desired shape or size having the proper splined hole may be attached. These are held in the correct longitudinal positions by spacing sleeves which slip over the outside of the splines. The whole assembly is then clamped together by means of a nut drawn up tightly against the steel collar which serves as the rear bearing of the camshaft.

Push rod guides are usually of special design depending of course upon the particular requirements. The push rod guide housings are bolted on top of the crankcase, over a hole directly above the camshaft. When these housings are not to be used the holes are covered by plates.

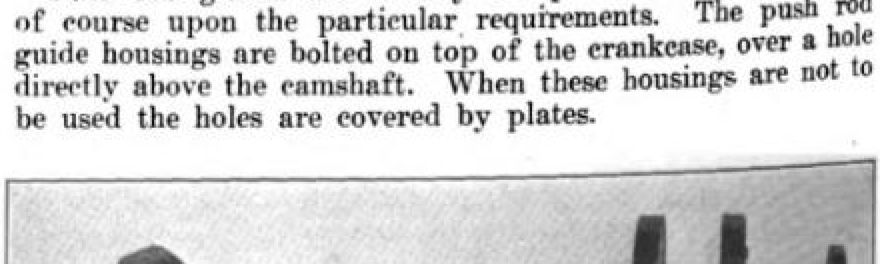

Fig. 6. The Built-Up Crankshaft Construction

Overhead camshafts are to be considered as a part of the cylinder design, and therefore need no description here. However, attention should be directed to the fact that the scheme for attaching cams is again carried out, even so far as to use the same size of splines, thus making it possible to adapt the same cams in either place.

Flywheel

The purpose of the flywheel as is quite generally known is to contribute toward smoother running and lower rotative speeds, and comes as the result of storing the energy created during periods of high torque to compensate for the low torque periods. We have in this engine the possibilities of comparatively high and low torque magnitudes and also a wide speed range, if considered as controlled by the so-called limiting piston speeds. A flywheel having a sufficient moment of inertia to handle the greatest torque periods, if made very large in diameter, would undoubtedly have prohibitive peripheral speeds in certain cases. It was found possible, however, after several trial computations, to satisfy all conditions with only two sizes of flywheels. These were so designed, that at no time should the engine be prohibited from running at its lowest speeds more than 300 r.p.m.

Lubrication

Lubrication is of the force feed dry sump type, oil pressure being maintained by a slightly altered Liberty oil pump mounted on the lower part of the crankcase. The only alteration on the pump is the addition of an exterior adjustment for varying the pressure of the relief valve spring. This provides simple means for regulating the oil pressure which is maintained in the line serving the crankshaft journals. Sufficient outside connections were incorporated so that oil could be led to any one or all of the camshafts, the tachometer gear housing, the gears and bearings used in conjunction with driving all of the various units and also to an oil gauge.

Ignition

Either battery or magneto ignition may be employed. A Liberty generator is supported on the crankcase and driven through splines at the end of the crankshaft, and when not in use is to be replaced by a cover plate which fits its mounting flange. Distribution for battery ignition is taken care of by magneto replacement units mounted on the magneto base flanges.

The gear case cover provides space for mounting and driving four magnetos or four magneto replacement units as desired. It is reasonable to believe that as cylinder bore dimensions are increased the use of more spark plugs per cylinder should improve performance as a result of the better flame propagation. By supplying at least four spark bosses per cylinder, it will be possible to verify the relative values of the different numbers of sparks. Also, the proper location of spark plugs in any particular cylinder design may be determined by running tests with plugs in various positions. It is a comparatively simple matter, during the test of cylinders using dual ignition, to have both magneto and battery systems connected up, and by switching from one to the other note the effects and make comparisons as to the merits of the two systems under identical conditions. It is also proposed in connection with this engine to run tests to determine the values of various intensities of spark.

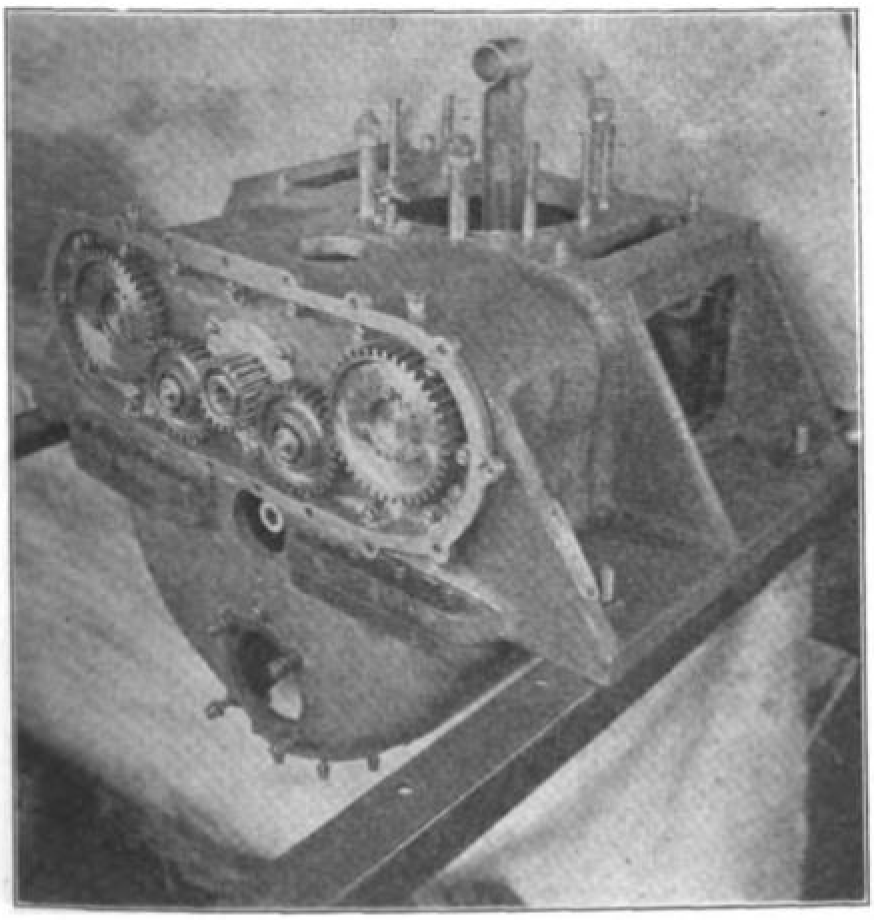

Fig. 7. Timing End with Magneto Housing Removed

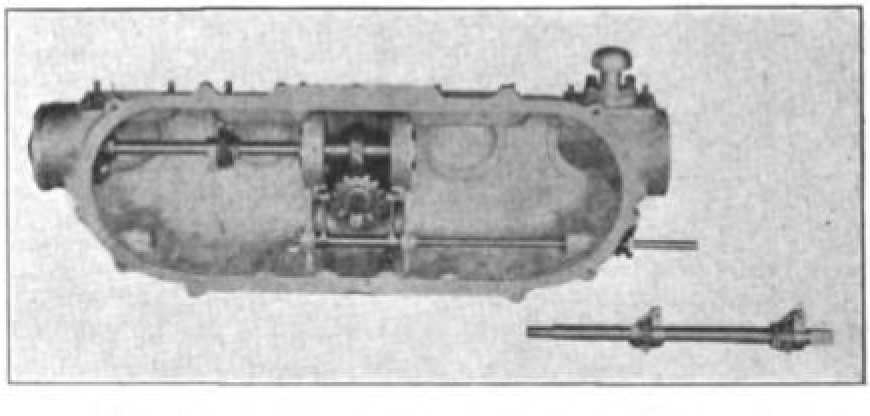

Fig. 8. Interior View of Magneto Housing

In order to derive full benefit from multiple ignition, it becomes important to have the sparks occur simultaneously. All magnetos, therefore, should be advanced together from a common point, and the advancing apparatus should have no slackness in its movements. All magnetos are driven through bevel gears from cross shafts whose squared ends engage with a central and permanently mounted shaft having an integral spiral gear. The angular positions of the three in line shafts are varied by sliding the driving spiral gear forward and back on the driving splined shaft. The driving gear is operated by a yoke which is pinned to a small shaft extending just outside of the housing for hook up to an instrument board.

The cross shafts on either side of the center can be readily removed from the ends by first dismantling the covers which retain their ball bearings. This feature is important as two shaft and gear assemblies are supplied in order to operate magnetos having either crankshaft or half crankshaft speeds of rotation.

It will be noted from the interior view of the magneto housing shown on Fig. 8 that special means have been provided for accurately adjusting the magneto timing for spark synchronization. The magneto driving gear is not fastened to the armature shaft, but instead, floats on a hub that is keyed to this shaft. The drive is taken through the two adjusting screws, which are to be screwed up and locked in the correct position against an extension provided on the back of the gear.

When certain magnetos or magneto replacement units are not used, the hole through which these units are driven must be closed by a cover plate. This plate is held in position by a flat spring which at other times is turned back out of the way in a vertical position.

Cooling

For testing water-cooled cylinders, circulation is maintained by a centrifugal water pump identical to the one designed for the 4-cyl. Liberty engine. The outlet water from the pump is piped just beyond the first external crankcase rib, and from here connections are quite easily made to any desired point on a cylinder. In most every case it will be found that the capacity of this pump is greater than necessary; so, in order to assimilate the conditions under which a cylinder is cooled as a unit of a multi-cylinder form, means for regulating and measuring flow can be incorporated just outside the cylinder inlet.

When testing air-cooled cylinders, the water pump should be temporarily replaced by a special cover plate designed for this purpose. An air blast produced by a suitable blower is then directed against the cylinder walls for cooling. If suitable equipment is available, some very valuable data in regards to air cooling can be obtained in connection with regular cylinder tests.

Tachometer Drive

Whenever the dynamometer testing equipment does not include a tachometer, one may be attached and driven from the engine. The driving attachment is incorporated at the end of the gear and driving shaft shown mounted in the small housing on top of the crankcase directly above the gear compartment. This housing has three possible positions, allowing for drive toward the end of the engine, as shown on Fig. 2 or toward either side.

When side camshafts are used, the tachometer gear housing cover is in place and connected to the oil line for an original source of oil supply to the entire gear compartment. A flange containing a tube, which acts as the lower part of the telescoping housing around the camshaft driveshaft, is substituted for this cover whenever overhead camshafts are used. Oil is then supplied to the gear compartment by the overflow from the camshaft housing.

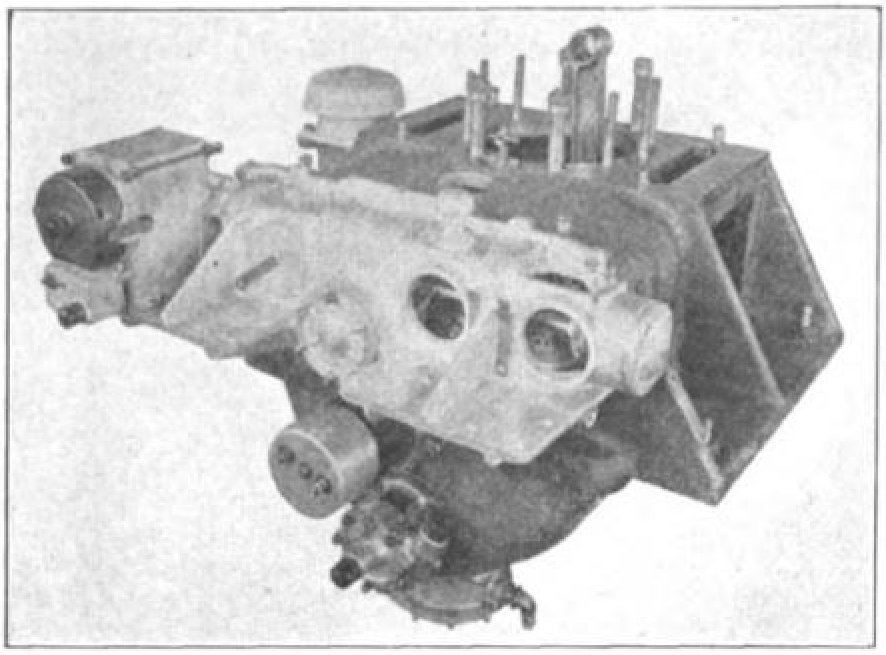

Fig. 9. Assembly Showing Magneto Housing, Oil Pump, Water Pump and Generator

Overhead Camshaft Drive

Overhead camshafts are always driven through bevel gears. The driving pinion is keyed to a vertical shaft, having splines at its lower end to engage with the vertical hollow shaft mounted in the case. Three lengths of vertical camshaft drive shafts are all that are needed, to take care of the variation in height of camshaft above the top of the crankcase as influenced by cylinder design and by differences in bore-stroke combinations and compression ratio. Since the camshaft housing is usually supported on the cylinder, the drive shaft housing can be made to telescope. This allows almost unlimited privileges in the matter of raising or lowering the cylinder for any purpose.

Compression Ratios

As hereinbefore stated, compression ratios from 4 to 10 are possible. The ratios are varied by raising or lowering the cylinder in respect the crank axis, and in order to obviate any changes in a cylinder flange shims are employed. The crankcase has a large hole above the crank compartment in order to adapt cylinders of 8-in. bore. As a result, each cylinder must be securely mounted on a special flange which fits the crankcase, and is held down by means of the long main bearing studs and six additional studs of smaller diameter. All of these studs extend above the case for some distance to allow for shimming.

It was found possible to obtain the desired range of compression ratios in comparatively small increments, by the use of one or more of the six shimming plates of different thicknesses that were designed for this purpose. These shims, which have the same shape as the cylinder flange are fitted over the studs before the flange is put into place. Calculations are always made to determine the compression ratios that will be had with the various shim combinations when used with any cylinder adaptation and are recorded for reference purposes during these tests.

The above description dealing with certain features of the Universal Test Engine explains fairly well the numerous possibilities afforded for cylinder testing. Any cylinder within the prescribed size limitations, if more or less conventional in design, can be adopted, and moreover, in such a way as to assimilate very closely the conditions under which it is to perform as a unit of some multi-cylinder type. The flexible characteristics are not confined to cylinder sizes, but extend over each functionary element. This feature has been carried out as far as all former indications seemed to warrant.

Practically all comparisons will have to be made on a basis of the type of cylinder construction and then if desired, various cylinders compared for the purpose of determining the best construction for some particular kind of work. In a general way, cylinders must be classified and their performance judged accordingly.

Since the mechanical efficiency of this engine is low and brake loads are not in the correct proportion to those of multi-cylinder forms, it becomes necessary to reduce all data to indicated readings, which after all is the correct way to make these comparisons. After making due allowance for distribution, the brake horsepower of any combination of cylinders may be approximately calculated by totaling the indicated horsepowers of that many cylinders and multiplying by the probable mechanical efficiency as would be found in other engines of the same type running at corresponding speeds.

One of the design factors which engineers seldom agree upon, is the bore-stroke ratio. It should be possible after a sufficient number of combinations have been tried on this engine to make some kind of definite statement in this regard. Compression ratios are limited in a certain degree by the type of cylinder and the work to be performed, nevertheless these should be accurately determined for every case. The valve and cam design, which ordinarily requires extensive experimenting can be easily worked out with full assurance that the design adopted is the best possible under the conditions. Ignition tests, particularly in regards to number and location of spark plugs, are simple to perform and the results should be conclusive. Tests on cooling, whether by means of water or air, can be scientifically conducted and the data made applicable to the engine of which the cylinder belongs. Unless it is manifolding and gas distribution, there is apparently very little development work on cylinders which cannot be completely and accurately accomplished on this engine.

Two test engines were constructed in the shops at McCook Field and satisfactory tests have already been made on a few cylinders. One engine is kept running most of the time, and when a test is finished, this engine is removed from the dynamometer for a new cylinder adaptation, and the other engine takes its place. As a result of careful planning it is possible to so arrange the order of these tests that very little work is required in changing cylinders.

Several cylinder assemblies have been completed and are ready for test while a number of others are in course of construction. The results so far obtained, leave no doubt as to the practicability of this procedure, either in developing one cylinder or obtaining useful data on cylinder design generally. As more tests are completed, the easier it will be to compare the data acquired and arrive at conclusions, which no doubt may have considerable influence on cylinder designs in the future.

The Engineering Division is desirous of cooperating with anyone particularly interested in developments of this nature, and will furnish additional information upon request.

San Francisco Aero Show

The following is a list of the exhibitors at the San Francisco Aeronautical Show to date:—

Curtiss Aeroplane and Motor Corp.
Goodyear Tire and Rubber Co.
Dayton-Wright Division, General Motors Co.
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Loughead Aircraft Corp.
Aeromarine Plane and Motor Co.
Boeing Airplane Co.
Hall-Scott Motor Car Co.
Wright Aeronautical Corp.
Standard Oil Co. of California.
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The Air Service of the United States Army and Navy will be represented by a very comprehensive exhibit.