TECHNICAL NOTES.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 12.

RECENT EFFORTS AND EXPERIMENTS IN THE CONSTRUCTION OF AVIATION ENGINES.

By

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Translated from
Technische Berichte Vol. III - Sec. 5,

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Paris Office, N.A.C.A.

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When war broke out in 1914, the mean power of the aviation engines at the disposal of the German Air Force was 100 to 120 H.P. on the ground. The unit weight of these engines, including the water and oil contained in them, was from 1.8 to 2 kg. per H.P. The flying efficiency attained with such power was supposed to be more than satisfactory, there being still believed to be absolute safety at an altitude of 1200 to 1500 m. from shots fired on the ground. At this period, aerial combat had not yet been thought of. Even competent authorities scarcely considered it credible that the arming of aircraft would ever be a matter of grave importance.

It soon became evident, however, that ever-increasing demands would be made on the climbing powers of aircraft, in proportion to the progress achieved by the defensive artillery in the technics of firing. Not only was it requisite that climbing efficiency should reach the highest possible point; climbing speed would also have to be raised higher and higher in proportion. With this end in view, increased engine power was the first point taken into consideration. Engines with 150 and 160 H.P. on the ground were consequently obtained and there are many cases, even at the present time, in which such engines give results that may be considered to be satisfactory.

Another difficulty then arose. The increasing number of the duties devolving on the pilot led to a corresponding increase in the weight of the load carried by the airplane. We need only mention, for instance, armor consisting of one or more machine-guns with ammunition, bombs and bomb-dropping devices, photographic apparatus and radio, according to the functions of the machine in question; and it was essential that good climbing power and speed should be attained notwithstanding such additional weight. This led to the need for still higher engine powers,

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* Extract from a lecture given at the General Meeting of the Scientific Association for the Technics of Aviation, at Hamburg, April 19, 1918.

and engines with 180, 200, 220 and 260 H.P. were produced. The unit of weight of these engines was reduced, in the case of those with 100 and 120 H.P., by 1.5 kg. to 1.8 kg. per H.P. Flying efficiency did not, however, keep pace with increasing engine power to the extent generally expected, in spite of the effort that was made to construct special aircraft for each particular purpose and to equip such aircraft for that purpose alone, so as to reduce its weight and load to the lowest possible amount.

The ever-increasing demands created by aerial warfare causing the need for a still higher degree of flying efficiency, it became more and more evident that the development of aviation engines must be carried out along new lines, and that increased efficiency alone would not suffice to ensure the desired end, the more so because high-powered engines were inconvenient from a flying viewpoint, by reason of their heavy weight and great length, which were unfavorable to the turning facility of aircraft equipped with such engines. Recent efforts in the construction of aviation engines have been developed along two different lines, which may be defined as follows: "Light-weight Construction" and the "Adaptation of the Aviation Engine to the Requirements of its Utilization."

In the spring and summer of 1916, the flying efficiency attained, through the reduction of the number of revolutions of the propeller used on the engine from 1400 to about 900 r.p.m., by the Mercedes 220 H.P. engine was so good that it seemed desirable that all aviation engines should be equipped with similar gear. This idea was justified, as propeller efficiency can be considerably improved by means of such reduction gear. It was most effective on the Mercedes 220 H.P. engine with its 8 cylinders placed tandem-wise, but it gave rise to so much difficulty on 6-cylinder engines that the experiments made on the latter, with the gear, had to be given up for more urgent tests.

In spite of this, the Aviation Inspection Department still pushed on the use of reduction gear in Aviation engine factories. As early as autumn, 1916, the Department decided upon the utilization of high piston velocity and a high number of revolutions as the standard for geared engines. Constructional work was then zealously started on all sides and the 8-cylinder Vee engine, with power from 180 to 240 H.P., was ordered at several factories asthe best high-speed engine from the flying standpoint. The unit weight of this engine, including the water and oil carried, was established at 1.25 to 1.35 kg. per H.P., - figures which can be obtained without difficulty, as has been seen in the case of different engines of the same constructional type now ready for quantity production.

The enemy had also been pushing engine development along similar lines, at a somewhat earlier period. In the winter of 1916-17, the French produced their first Vee high-speed engine at the Front, although it had long been known among German aviation experts. The engine in question is the 8-cylinder Hispano-Suiza from which the French, according to accounts given by prisoners, expected marvelous achievements. The early models of this engine were not yet supplied with gear. Their

H.P. was 140, with 1400 r.p.m., and their unit weight was 1.295 kg. per H.P., including water and oil. This engine gives an excellent impression at the first glance, with regard to its construction. It was also so exceptionally highly finished that it attracted a good deal of attention in German aeronautical circles. Many efforts were made to ensure the further production of the engine without other alteration, but this was not done on account of various weak points in its construction, and because German high-speed engines had already been in process of construction before the capture of the first of the French engines.

The examination of the above-mentioned engine at the test-bench (see Fig. 1)gave re markable results: To begin with, the engine proved to be a distinctly high-speed type, its maximum power being at about 2400 r.p.m. and consequently by no means fully utilized with 1400 r.p.m. and 140 H.P. as at the outset. Secondly, however, the engine was found to have considerable constructive shortcomings. Mention need only be made, for instance, of the defective cooling of the exhaust valve, which was burnt up each time at the end of 6 or 8 hours. The construction of the engine was, nevertheless, most instructive and interesting to German manufacturers, and it soon became accessible to them, as it was captured in large numbers. The carburetor, which has already been described in TECHNICAL REPORTS, (Vol. III, No.4, p.112) is particularly interesting.

The possibility of constructing high-speed internal combustion engines depends more upon piston velocity and inertia stresses than upom the cross-section of the valve. The piston velocity can easily be carried up to 10 and 15 m/sec., engines having already been constructed successfully with about 17 m/sec. piston velocity, as, for instance, in the case of the French Despujol racing boat engine. The possibility of adopting the largest cross-sectional area of gas-passage is, on the other hand, limited, especially if great importance be attached to the advantageous form of the combustion on account of the high piston velocity, so that the valve must be suspended at the bottom of the chamber. It is desirable that mean gas velocities of 40 to 60 m/sec. should be obtained in the fully opened valves. In such cases, when the inlet pipes are well made and the engine otherwise satisfactorily constructed, a mean effective pressure of 8 to 9.5 may easily be obtained. The power curve of a 6-cylinder Benz aviation engine may be taken as an example (see Fig.2) with 185 nominal H.P. With 1400 r.p.m., this engine produces 197.5 H.P. normal efficiency at a mean effective pressure of 8.4 and 1150 r.p.m. with 8.75 as maximum value of the mean effective pressure.

A noticeable feature of this engine is that its unit weight, including water and oil, is only about 1.36 kg/H.P. with perfect safety in working, although it is not a so-called high-speed engine. In contrast to the first high-speed enemy engines produced at the Front, which had no gear at all and a comparatively low number of revolutions, our 8-cylinder high-speed Vee engines were all designed with gear from the beginning. Tests made with the first working models soon showed that the gear itself caused serious difficulties. It was therefore also decided in France that the engine should be constructed without gear for the time being; and foreign high-speed engines still show the question of gear to be by no means satisfactorily solved, as almost every factory licensed to construct the Hispano-Suiza has different dimensions for the spur wheel gear selected for their engines.

The fact of a utilizable high-speed engine needing almost one year and a half for its development in our case is in no respect due to a lower productive capacity on the parts of German engine manufacturers, but is the result of the far higher standard of working safety required by us. Not a single foreign engine has so far been able to stand the 60 hours' duration test which must be passed by every German fixed engine before it is considered fit for service at the Front.

The first high-speed engine issued in quantity production in Germany was the Benz 195 H.P. 8-cylinder high-speed Vee engine with 125 mm. bore, 140 mm. stroke, and 1700 r.p.m. at the crankshaft, producing 225 H.P.

With a view to bringing it to technical perfection as soon as possible, the idea of producing it only when equipped with gear has been abandoned, as in the case of the Hispano-Suiza engine, and it has accordingly been mounted without gear, in a limited number, on model airplanes. It is especially suitable for the purpose on account of its high power at 1400 to 1500 r.p.m., as may be seen from the power curve given in Fig. 3.

In the meantime, a rotary gear with a satisfactory safety factor has been successfully constructed for this engine, its maximum efficiency being increased, at the same time, to 260 H.P. The construction of this gear somewhat resembles that of the Rolls Royce, which appears to be the best of all the enemy gear. The slightly excessive weight of the structure may therefore be adopted without hesitation in consideration of the simplicity of the spur wheel gearing.

Water and oil included, the engine weighs about 325 kg., which corresponds to 1.25 kg. per H.P. Although this is not less than the unit weight of the 200 H.P. Hispano Suiza engine with gear, the advantage is still on the side of the Benz engine if we compare it to the total engine plant of a Spad airplane with 200 H.P. Hispano Suiza engine, including fuel for 1-1/2 hours, and to the equivalent engine plant of a fighting monoplane; and the comparison is even more favorable to the Benz engine in flights of longer duration, on account of its low consumption of fuel.

Another high-speed German engine of good power and weight, and which has probably also been issued in quantity production by this time, is KÖRTING BROS.' 8-cylinder High-speed Vee engine. Its form is particularly pleasing. With 2 150 r.p.m. at the crankshaft, it produces 185 to 195 H.P. at the shaft of the spur gear and weighs about 252 kg. with water and oil, - that is, about 1.33 kg. per H.P.

According to statements made at the factory, the gear caused no special difficulty, being in that respect unlike other engines in which even simple spur gear could not be made to work perfectly although the demands made upon the teeth were generally less than in the case of foreign engines.

The constructive methods of DAIMLER and ARGUS resemble that of the KÖRTING engine. No reports can as yet be given of their results.

The ADLER Works have selected a cylinder system differing from the ordinary method, in the construction of their high-speed engine. In order to obtain a more compact style of construction, two crankshafts are located in one gear box. They rotate in opposite directions, being geared together by toothed wheels, and they work on four cylinders each. The engine works remarkably smoothly and its power output is 225 H.P. at the propeller shaft with 2000 to 2100 r.p.m. at the crankshaft. The propeller runs at 1050 to 1150 r.p.m. The locating of both crankshafts in one case entails no actual increase in weight, as the united weights of the crankshafts is only 24 kgs., whereas the Hispano Suiza crankshaft weighs 21 kg. The unit weight of this engine amounts to about 1.24 kg./H.P. Gearing difficulties were also originally found in this engine, but they were done away with by a special construction of the toothed wheels.

In addition to the above-named factories, the OBERURSEL Works are also constructing a high-speed engine designed by Engineer Dr. Becker, Assistant Professor at the Imperial Technical High School in Berlin, which shows some novel details. It differs from previously known models, particularly with regard to the mechanism driving the camshaft; the inauguration of such mechanism would bring the maximum power to the region of 2800 r.p.m. The unit weight of the engine is also a very good feature. With 240 normal H.P., relatively equal to 2100 to 2200 r.p.m. at the crankshaft, it weighs 260 kg., that is, only 1.08 kg. per H.P. This is not due to the utilization of specially high-class material, but is attained solely by the disposition and selection of dimensions of the engine. The total stress value is even lower than the usual values. No further details can be given, test reports not being available.

In all these 8-cylinder high-speed engines, the greatest importance is attached to the reduction of their constructional length. For this reason, the magnetos are usually located in front, over the gearbox, with a view to utilizing that space, and economizing space in the rear.

Although the 8-cylinder Vee engine may not be quite equal to the 6-cylinder engine series in equilibrium, the latter series being perfect in that respect, the inertia forces, which chiefly occur in a horizontal plane, caused no noticeable derangement with the dimensions selected. The compensating device which was proposed for the engine was therefore dispensed with for weight-saving reasons, without any detriment to the smooth running of the engine.

For higher powers, the 12 or 10 cylinder Vee engine should certainly be the given method of construction because of the free inertia forces of the 8-cylinder Vee type. Considering the great importance attached to facility in turning airplanes, it will be necessary that the engine should be still further shortened for combat one-seaters; for this reason, the 8-cylinder engine has a successor in the fan engine, which is being experimentally constructed in a three-radii type with 9 cylinders, by OPEL of Rüsselsheim. The next step should be from the fan type to the star engine with a view to obtaining the perfect fixed high-speed engine for single-seater airplanes. This type also gives promise of future developments in respect of higher powers. The star engine also has the great advantage, now that the armor of aircraft is ever on the increase, of being armed with the least weight possible.

The endeavor to obtain a high number of revolutions in connection with gearing has also been extended to the rotary engine. After having already brought out a 110 H.P. rotary engine with transmission gear, SIEMENS & HAISKE lately issued a 160 H.P. 11-cylinder rotary engine. The reduction of the number of revolutions in the propeller is attained in the latter type by making the crankshaft and cylinder block work in opposite directions. They both revolve at 900 r.p.m. in opposite directions, so that the cylinder block attains 1800 r.p.m. as compared to the crankshaft. This type has the advantage over earlier rotary engines not only on account of its low unit weight due to high liter power, but also because the low number of revolutions of the cylinder star diminishes the unpleasant gyratory motion usually found in powerful rotary engines, so that the effect isno longer disagreeable. The exceptionally short climbing time attained by this engine (see Fig. 4) is due not only to the transmission device, but also to other qualities which will be described later on.

The effort made to obtain the highest possible power with the lowest cylinder capacity, that is, with the least possible weight, has also led to the bestowal of more attention on the two-cycle stroke. In spite of the evident advantages it offers, the development of the two-stroke cycle system has been neglected in comparison to the 4-stroke cycle engine, chiefly because of the great supply of heat in the cylinder and the high number of revolutions to be considered , which caused serious difficulties. The quantity of heat supplied to the cylinder wall and the piston head at the time of combustion is surprisingly large. Calculated on the base of the area unit, it is, for instance, ten times as great as that of the fire-box of a locomotive. This explains the necessity for such a high degree of durability in the cylinder and piston of many types of engine. In the two-cycle engine, these difficulties are even greater, twice as many combustions taking place with the same number of revolutions, so that twice the amount of calorific heat must be applied to the same cylindrical dimensions per unit of surface. Prof. JUNKERS has now developed the portions subjected to the influence of the hot gases in such a way that those portions can be effectively cooled . Another difficulty to be encountered is the scavenging of high-speed two-cycle engines. Mixed scavenging is not successful in most cases. Pure air scavenging necessitates, on the other hand, the direct injection of the fuel into the cylinder. The constructive difficulties thereby entailed have been overcome by JUNKERS' high-pressure fuel pump, which regulates the quantity of the mixture.

Prof. JUNKERS' aviation engine is constructed with pistons placed in opposite directions, as in the case of the well-known JUNKERS oil-engines. Two pistons move in opposite directions in one cylinder, the combustion chamber being enclosed in their inner dead center. Near the outer dead center, the pistons control ports in the cylinder wall, through which fresh combustion air is let in and the consumed gases exhausted. Several cylinders of this kind lie parallel to one another. All the pistons lying in the same direction drive a common crankshaft. The regular working of the pistons and the accuracy of their intake and exhaust control is ensured by coupling the crankshafts by means of spur wheels. The engine power is supplied through the projected shaft of the middle spur wheel, on which the propeller is generally fixed. This arrangement has the additional advantage of enabling the best number of revolutions to be given to the propeller shaft, by alteration of the transmission in the spur wheels, independent of the number of revolutions of the engine.

The crank gear is disposed in two cases, which fill up the outer longitudinal side of the machine. The spur gear is entirely enclosed in a separate case closely adjoining the charging pump, which is projected to form a gyratory piston pump for the admission of fresh air. The pipes for the inlet of scavenging and charging air and for the outlet of exhaust gases also extend over the cylinders, the first-named pipe being constructed on the case of the charging-pump.

The pistons are equipped with a singular cooling device. The cavity of the piston is partly filled with heavy oil fluid which is not renewed in working and is violently dashed backwards and forwards by the motion of the piston. The fluid thereby absorbs the heat of the piston head and discharges it on the cylindrical portion of the piston, which conducts it into the cooled cylinder jacket.

The efficacy of this piston cooling has been proved by measurements taken with thermo-elements. Fig. 5 shows how the temperature of the piston-head gradually rises and attains the inertia condition after 19 min. This cooling system held good at speeds amounting to 2000 r.p.m. and also during longer periods of working.

The JUNKERS engine has another peculiarity, namely, that all the valves that cause great difficulties in high-speed engines with increasing cylinder capacity and thereby limit the working of the cylinder to some extent, are avoided by means of distribution through port-holes.

The valveless method of construction thereby makes it possible to construct reliable light engines with high cylinder power.

The balancing of the masses attained by the disposal of the pistons in such a manner that they work in opposite directions is of importance with regard to the utilization of the light-weight engine, and it can easily be brought to perfection by the requisite disposition of the pistons. Combined with the good conditions under which the cylinder charge is renewed, it becomes possible, with such favorable balancing of the masses, to obtain a high number of revolutions and to reduce the unit weight still further in consequence. As compared to other two-stroke engines, the JUNKER has the advantage of being able to attain high mean pressures and , in consequence, high powers with given dimensions. This is seconded by the complete scavenging of the cylinders and the high compression of the charge, which can, by reason of the absence of overheated portions of the combustion chamber, be admitted to the advance ignition without risk. Another favorable point is the slight loss of heat due to the smallness of the cooling surface of the combustion chamber.

Hellmuth HIRTH is now making tests with an engine that is quite unique in its way. It is a two-cycle engine, which has no actual scavenge or charging pump. The exhaust gases are drawn off through the hollow steel propeller, its peripheral speed being utilized for the production of a vacuum. This vacuum not only carries off the exhaust gases, but also simultaneously inducts the fresh charge into the cylinder. The obstacles to be overcome in the case of the engine consisted in the construction of a suitable steel propeller and in the transmission of the hot gases from the stationary cylinder to the rotating screw. Both points have been cleverly disposed of by HIRTH. The cylinders, disposed in star form, and the control are fundamentally similar to those of the JUNKERS engine, excepting that the cylinders are curved around the combustion chamber in such a manner that the courses of the pistons are parallel. The mechanism is so disposed that the pistons first expose the exhaust orifices and then the intake orifices. The cylinders being charged only by the vacuum produced by the peripheral speed of the propeller, it might be concluded that there would be difficulty in starting the engine. This is not the case, however. The screw is simply turned, at starting, in the direction contrary to the usual one; a depression is thereby produced, in the combustion chamber, which enables the combustion mixture to enter through the inlet orifice thereby exposed. This engine, too, is supposed to run at high speed with gear, with 2400 r.p.m. at the crankshaft. The weight of a 300 to 400 H.P. engine should amount to 0.75 to 0.8 kg/HP including the water and oil in the engine. The method of abducting the exhaust gases through the propeller may also be applied to 4-cycle engines. A better degree of admission can be obtained by this means, and higher mean pressure and power are attainable in consequence.

Although considerable improvement in flying efficiency may safely be expected, on account of the low unit weight of the above-named engines, the light-weight engine is not, in itself, a perfect aviation engine, as the latter would be required to supply consistently uniform power up to those altitudes in which the greater part of its existence is spent. In the case of the aviation engines hitherto constructed, power always decreases with altitude until, finally, no excess climbing power is available for the airplane and the limit of its climbing altitude is thus reached.

The reason for such decrease of power lies, above all, in the decrease of atmospheric pressure with increased altitude. The rotary impulse and the power depend upon the weight of air admitted into the engine, and upon the efficiency of the transformation of fuel energy into engine energy. If such efficiency were the same for all aviation altitudes, the engine power would actually depend upon the useful load of the engine and would follow the course of the atmospheric pressure. With constant horizontal speed on the part of the airplane, the number of revolutions of the engine would necessarily be the same at all altitudes. As it is, the number of revolutions decreases more or less with increased flying altitude. The efficiency of the transformation of the fuel energy into engine power is thereby necessarily lowered. Until quite recently, the decrease of power in its proportion to atmospheric pressure was considered to a sufficiently accurate basis. Recent tests have proved, however, that the actual decrease of power is considerably greater.

Further details were supplied by tests made in the vacuum chamber of the ZEPPELIN aircraft works at Friedrichshafen, as already reported in Technical Reports, Vol. III, No. 1, p.1. These tests gave striking proof of the fact that the power of engines does not keep proportional pace with the decrease of atmospheric pressure with increased altitude, and that fuel consumption increases with increasing altitude. The increase of fuel consumption therefore gives the course of the power curve.

High altitude tests made with a Daimler, a Maybach and a Benz engine - the results of which were published in Technical Reports, Vol. III, No. 1, p.15 - have shown how the increasing fuel percentage of the mixture affects the transformation of fuel energy into engine power. They also showed that the working of the engine deteriorated with increasing altitude. This leads to the conclusion that in developing altitude engines, the carburetor and, whenever possible, the efficiency of the transformation of energy should be improved, and that the air inlet should always take place at the same degree of pressure. The object of the improvement of the carburetor would be to supply a mixture of air and fuel that would remain constant under all conditions. In order to be able to do this, however, it would first of all be necessary to give some explanation of the manner in which the carburetor works. It may be assumed, as a leading principle, that air and fuel flow uniformly through nozzles working without friction. This is the case with short nozzles as well as with tapering nozzles, also with throttle valves with sufficiently large orifices. When the fluid passes through long narrow grooves and pipes, such conditions are no longer fulfilled. If special attention were paid to this point in constructing carburetors, it might at any rate be possible to ensure only a slight decrease in the number of revolutions of the engine at altitudes, such as is unavoidable on account of the light operating load.

So far as the improvement in the transformation efficiency of fuel energy into engine power is concerned, such efficiency largely depends upon the thermal efficiency. The latter rises with the compression, - that is, with the proportional cylinder volume of the engine + the volume of the compression chamber, as compared to the volume of the compression chamber. The compression ratio is, however, limited by the final temperature of compression and the temperature of the cylinder, if spontaneous combustion is to be avoided. For separate methods of engine construction, this limit depends upon the disposition of the cooling-water pipes and more particularly still upon the cooling of the ignition sparks.

These considerations entail the raising of the ratio of compression from normal 4.6 - 4.9 to 5.8 - 6.6, and to the introduction of the so-called over-compression engines. With such high-ratio of compression, spontaneous combustion occurs even below 2000 m., so that the engines must be throttled up to that altitude in order that they may not be worked at maximum power and that their temperature may be reduced.

In comparison with engines with normal compression, these engines attained considerably better climbing time. The first of the type was the Maybach 260 H.P. engine. Its success led to the subsequent construction of other engines for over-compression. Conclusive tests were made on several Benz 200 H.P. engines with regard to the effect of various ratios of compression (see Figs. 6 to 9). In Figs. 7 and 9, a comparison is drawn between the registered increase of the mean pressure Δ_{p_m} relative to the mean pressure p_{m_5}, the ratio of compression being $\epsilon_5 = 5$ and the increase theoretically calculated by raising the ratio of compression by means of the formula:

$$\frac{\Delta p_m}{p_{m_5}} \quad \frac{\epsilon_5^{k-1} - \epsilon^{k-1}}{I - \epsilon_5^{k-1}} \cdot 100$$

The result of this test is remarkable by reason of the fact that the maximum mean pressure increases when the number of revolutions increases (see Fig. 8). It may therefore be concluded that increased COMPRESSION RATIO is particularly propitious in the case of high-speed engines. The increase in the rapidity of consumption is also due to the fact that the mean effective pressure actually increases, with higher compression ratios, more than might be expected from the theoretical standpoint. In Fig. 10, the power, turning moments and fuel consumption of the Benz 200 H.P. engine, No. 32524, are shown with different compression ratios in terms of the number of revolutions. They show that the engine gives bad results with the maximum compression ratio 6, such results being due to spontaneous combustion and already signalled by the variable running of the engine and excessive fuel consumption.

Even the adoption of super-compression in connection with carburetors constructed for high altitudes does not finally settle the question of the adaptation of the aviation engine to its working requirements. An effort must be made to prevent any loss of power at all up to the customary flying altitudes. There are two ways in which this might be done, and which amount to practically the same thing: by inducting fresh air into the engine at constant pressure, - that is, at ground level pressure - or at the pressure prevailing at the altitudes up to which the power is to remain invariable. The first method entails the construction of a preliminary compressor in the form of a turbo or positive blower; the second entails the construction of an engine in which the cylinder dimensions are proportionally too large for the gear, and with its power throttled down to its nominal H.P. up to a certain altitude. This type of engine may be called "over-sized", or said to have dimensions specially adapted to high altitudes.

Preliminary compressors for aviation engines, in the form of turbo-compressors, are either being constructed or being tested in different places. The furthest advanced is that of BROWN, BOVERI & CO., who have constructed an installation for giant airplanes of 1000 to 1100 total H.P., at the request of the Board of Directors of the Air Service. The compressor was driven by a special Mercedes 130 H.P. engine of such dimensions that the total power of the installation remains constant up to an altitude of about 5000 m. Complete tests were carried out with regard to the combined working of a Mercedes 260 H.P. aviation engine and a preliminary compressor, in the vacuum chamber of the ZEPPELIN Airship Works at Friedrichshafen, and it was proved that the desired end could be perfectly well attained. Flying tests made since that time have also proved the utility of the installation.

About the time that the Administration of the Air Service entered into negotiations with BOVERI, BROWN & CO. concerning preliminary compressors for aviation engines, SCHWADE & CO., of Erfurth, brought out designs for a turbo-compressor to be directly coupled with a Mercedes 260 HP engine, and it has since been tested at the test-bench. The blower is worked from the rear end of the crankshaft, by means of centrifugal coupling, with 10000 to 11000 r.p.m. Such high wheel velocity is requisite in order to obtain the highest possible peripheral speed and to reduce, in consequence, the number of wheels; considering the slight quantity of air exhausted by the compressor, small wheel diameters must be selected to obtain wheels of the necessary practical size. The quantity of air supplied by the compressor is such that the engine power remains constant until an altitude of 3500 to 4000 m. has been attained. It was not considered advisable to proceed farther at the time, as it would have necessitated the use of propellers with adjustable blades in order to obtain the full benefit of the improvement, and it was not yet known if they could be successfully applied. In the case in question, propellers of larger pitch were to be used, running at low wheel velocity on the ground but gaining such a high torque that the engine should be as fully charged as at 1400 r.p.m. It is intended that the engine should be correspondingly overloaded by the super-compressor. The wheel velocity should increase with increased altitude and should attain 1500 to 1550 r.p.m. at the altitude at which the power remains constant. The advisability of such an overload depends entirely upon the strength and pressure of the surfaces or upon the frictional energy of the gear, by which the temperatures of combustion are not affected. The proof of the possibility of such overloading has been furnished by tests since carried out at different places. The SCHWADE blower was installed on an AEG-G-airplane for testing in the air. It is unfortunate that the machine was lost in a flying accident which was in no respect due to the location of the blower.

With a view to avoiding oscillations that might arise at the rear end of the crankshaft, in driving high-speed blowers, and which might threaten to cause the utility of the whole installation to be doubted under certain conditions, a blower of equally high power was simultaneously ordered at the SIEMENS-SCHUCKERT Works, to be driven by the screw end of the crankshaft. Tests made since that time with the SCHWADE blower show that it is evidently possible to avoid the influence of oscillation on the gear in using hand-coupling or coupling by centrifugal force, although the oscillation itself will not be done away with.

As in the case of fixed engines, tests are also made with turbo-compressors on rotary engines.

In order that the carburetor may be subjected to conditions similar to those of the sea level in the combined working of compressor and engine, the float chamber must be placed under blast pressure. When the gasoline is supplied under pressure, the tank is subjected to the pressure of the compressor as well as to the usual pressure of 0.25 to 0.3. It is preferable, however, that the tanks should not be subjected to pressure and that the gasoline should be supplied by means of pumps.

Fig. 11 shows the power absorbed by the above-mentioned turbo-compressor. In order to maintain constant engine power up to an altitude of 6000 m., 8.8% of the engine power was required. Being relatively small, that quantity can be taken from the engine without any difficulty, by means of overloading, Consideration must also be given to the fact that an increase of power at 6000 m. is added to the engine power on the ground because the engine only exhausts at an atmosphere of about 0.5, while it becomes charged at a pressure of 0.5, that is, during the time that the suction stroke acts as a compression engine. If, therefore, the pressure in front of the carburetor is to remain constant until high altitudes are reached, by preliminary compression, the engine power must not merely remain constant but must also increase. This has been positively proved by the results of tests carried out in the vacuum chamber at the ZEPPELIN Works at Friedrichshafen.

Over-sized engines prove to be more simply adjusted than those with preliminary compressors. All complementary building parts are unnecessary with the exception of a regulating device to be installed in front of the carburetor. There can be no doubt but that this engine will come to the fore in the future, although the preliminary compressor may have the preference for its comparatively high power at altitudes of 6000 and 7000 m. At the present early stage of development, it cannot yet be definitely stated at what altitude the preliminary compressor has the advantage as regards weight. Up to 4000 m., however, the over-sized engine is certainly preferable in respect of weight and constructor. The circumference of the cylinder stroke naturally increases with altitude in the case of the over-sized engine, until the altitude is attained at which the power is to remain constant (see Fig. 12).

In this figure, the necessary increase of volume of stroke is shown without the possibility of any additional super-compression being taken into consideration. If super-compression is employed at the same time, the volume of the strokes is materially diminished. Below 4000 m., the increase of weight through increased stroke volume, and the lengthening of the total construction thereby necessitated, would appear to exceed the weight of a preliminary compressor. The question cannot, however, be determined by considering the weight alone. For the present, greater safety in working and more convenient inbuilding may rather be expected of the over-sized engine than of the engine with preliminary compressor, as the latter requires to be driven with highly sensitive spur gear with high tooth velocities.

The Maybach engine was not only the first super-compressed engine, but also the first over-sized engine, although its over-size was not so highly developed as in more recent types. The BAVARIAN ENGINE WORKS, Ltd., went a step further with their 185 H.P. It resembles the Mercedes 160 H.P. engine in weight and constructive parts, and its dimensions are such that its power remains constant up to almost 3000 m. The high degree of compression of this engine is remarkable. It attains 6.7 without the creation of any difficulties. This fact is probably to be ascribed to skillful induction of the cooling water into the cylinder-head. The SIEMENS and GOEBEL engines are examples of over-sized rotary engines. It was Professor JUNKERS who first recognized the advantages offered by over-sizing and obtained a patent for the same.*

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* D.R.P. No. 300007.

Engines with preliminary compressors and over-sized engines require constant regulation of the pressure in front of the carburetor while climbing. For engines with preliminary compressors, the inlet air or in the case of turbo-compressors, the air forced into the carburetor, can be throttled down or allowed to escape through a pressure-valve. In over-sized engines, the inlet piping must be equipped with a throttling device which so regulates the pressure in front of the carburetor that it always corresponds to the pressure of the altitude at which the power is to remain constant. It may be done by hand, according to readings of the altimeter, or it may be regulated automatically. The latter method is preferable in so far that there is then no risk of damage to the engine, at low altitudes, by inexpert handling.

These automatic regulators are constructed like barometric installations. Figs. 13 and 14 show a utilizable plan of the LORENZ type of propeller, which consists of an unloaded double-seated valve. It is worked by means of a caoutchouc membrane filled with air at the pressure prevailing at the altitude in question. This membrane is placed in the space in front of the carburetor, in which the pressure is to remain constant. As equilibrium always prevails while the gear is in action, there is similar pressure on both sides of the membrane, inside and outside, and consequently no stress is brought to bear upon it.

In the same way that the float case of the carburetor must be connected with the pressure chamber of the blower in the case of engines with preliminary compressors, so must the float case be connected with the space in front of the carburetor when the engine is an over-sized one. In the same manner, over-sized engines may be overloaded at the start, for a short time. If over-sized engines are also over-compressed, the overload can evidently only be carried to such a point as is compatible with safety from spontaneous combustion.

The construction of variable pitch propellers goes hand in hand with the development of altitude engines. Here, too, satisfactory progress has recently been made. A design has been furnished by Prof. REISSNER in which the pitch is regulated by hand and which has been shown to be utilizable when tested with overloading. The LORENZ PROPELLER type gives an automatic variable pitch propeller, in which a caoutchouc membrane inflated with air at 1° absolute temperature causes the pitch variation corresponding to the given altitude. This type of barometrical device has the advantage of enabling the requisite regulating power to be easily obtained by the relative dimensions of the membrane. To keep this power as low as possible, the axis of rotation is placed as nearly as possible in the center of pressure. Fluttering of the blades is prevented by an oil cataract.

The firm of GARUDA has also taken up the construction of variable pitch propellers and has a most interesting improvement now in hand, the pitch being so adjusted, by means of a centrifugal force regulator and a fore-coupled hydraulic Servo-engine, that the number of revolutions remains constant. The constructive system is extremely clear and summary. Such variable pitch propellers should be an acquisition on normal engines, as they render it possible to fly with a normal number of revolutions during the climb and thus to utilize the engine power to its full capacity. In time of war, the speed of the airplane can be accelerated by compression at the moment of danger just as well as at present, in spite of the constant number of revolutions, the propeller being simply automatically adjusted for larger pitch.

SUMMARY.

The development of aviation engine construction during the War will be fully described later on, the progressive adaptation of the aviation engine to the demands brought to bear upon it being especially pointed out as the main object to be attained by such development. The means available for that purpose will be stated and the results so far obtained will be discussed. In conclusion, reference will be made to the influence of engine construction on the development of the propeller.

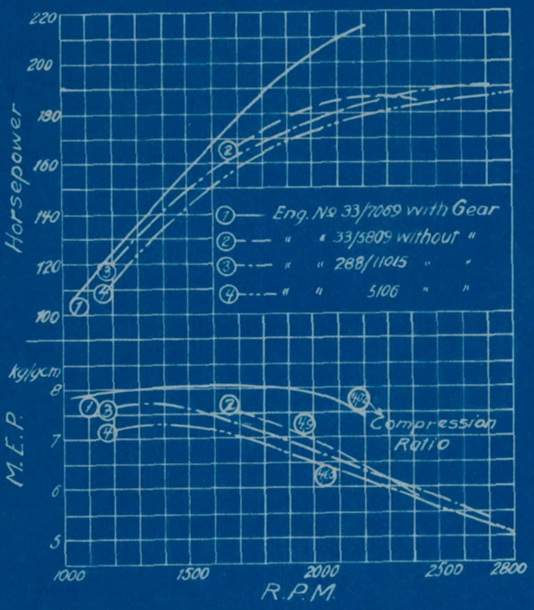

Fig. 1.

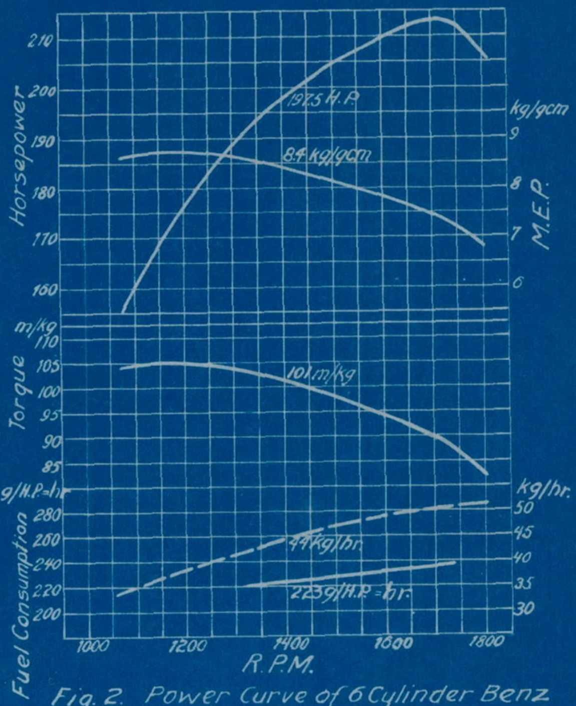

Fig. 2. Power Curve of 6 Cylinder Benz Engine Nominal Horsepower 185.

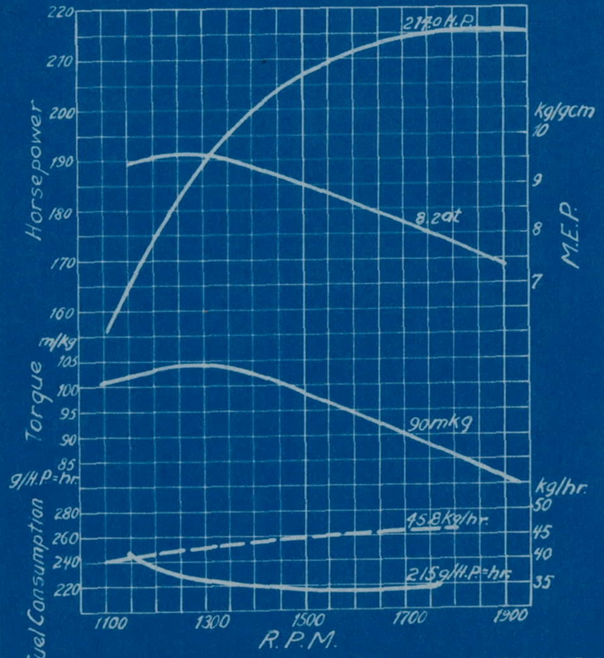

Fig. 3. Power Curve of Benz 195 H.P. 8 Cylinder High-Speed Vee Engine.

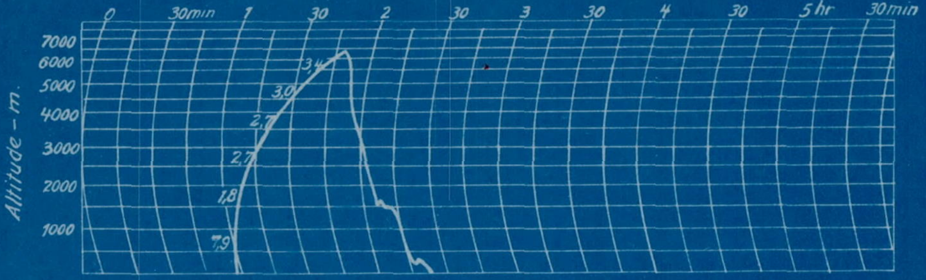

Fig.4.

Figs. 6&8.
Relation between
M.E.P. and R.P.M.

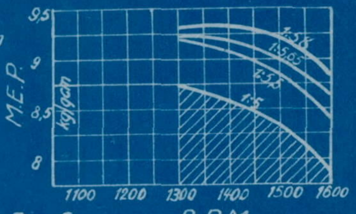

Fig. 6.

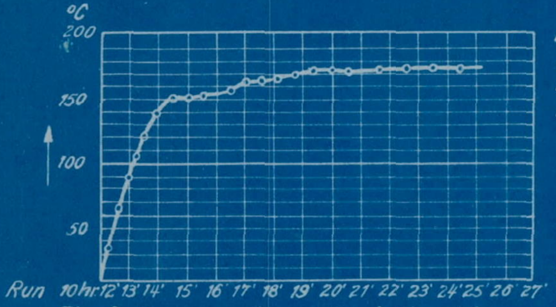

Fig. 5. Temperature Variation of Pistonhead.

Figs. 6&7.
Test on 200H.P.
Benz Engine
Nº 30,656.

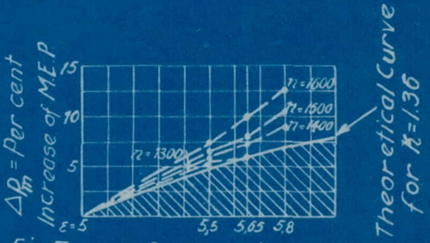

Fig.7.

Figs. 8 & 9.
Test on 200H.P.
Benz Engine
Nº 32524.

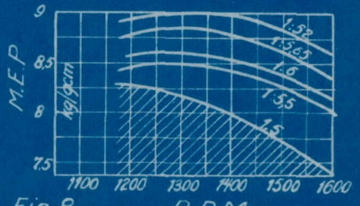

Fig. 8.

Figs. 7&9.
Comparison of the Actual and Theoretical Increase
of M.E.P. with Increase of Compression Ratio.

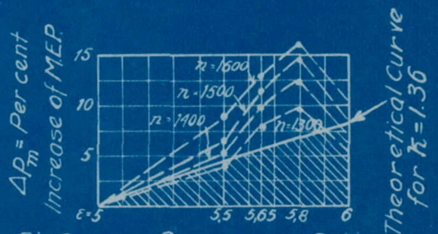

Fig.9.

3001-29

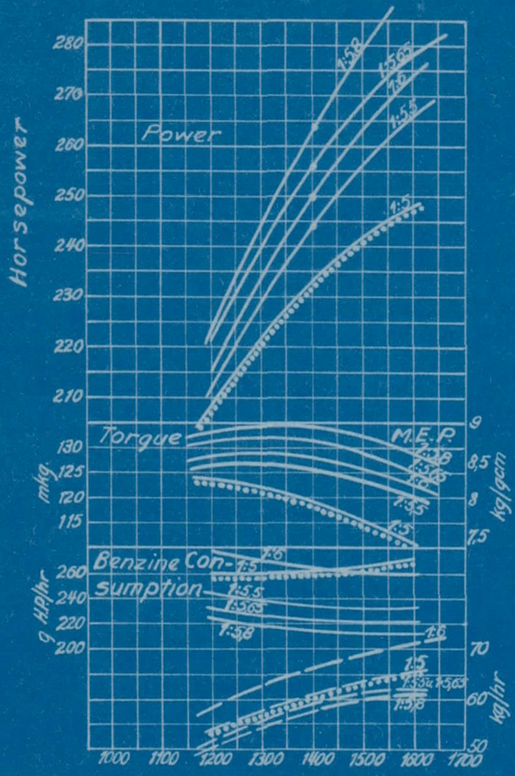

Fig. 10. Horsepower, Torque and Fuel Consumption of 200 H.P. Benz Engine No 32524.

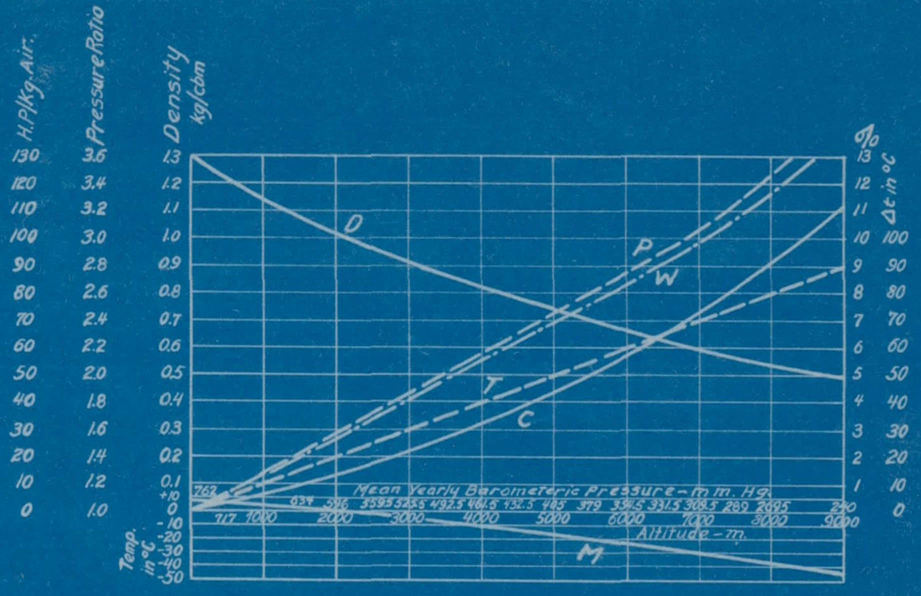

Fig. 11. Power absorbed by Turbo-Compressor.

D = Air Density.

P = Power absorbed from adiabatic compression in per cent of power out put.

W = Work of adiabatic compression.

T = Temperature at Altitudes Δt from adiabatic compression.

C = Compression Ratio $\frac{P760mm}{PH}$.

M = Mean Yearly Temperature.

Figs. 10 & 11.

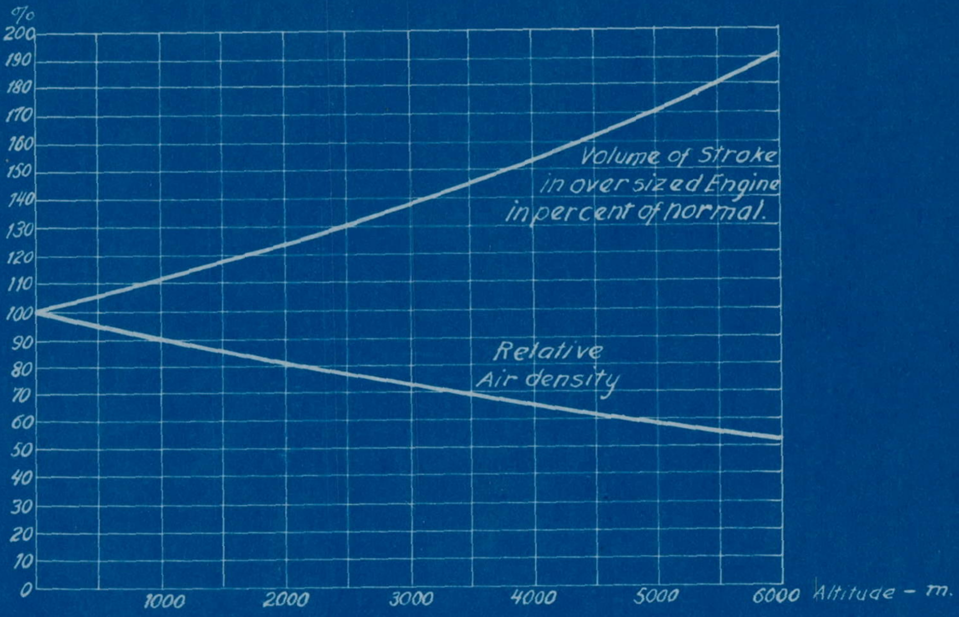

Fig. 12. Increase of Cylinder Stroke of an over-sized Engine with Altitude.

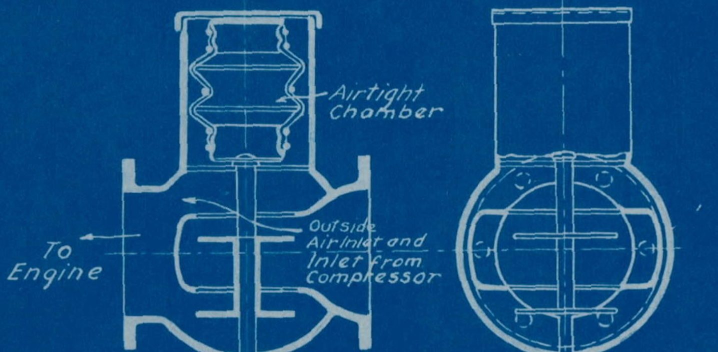

Fig. 13.

Fig. 14.

Figs. 13 & 14. Automatic Regulators for Altitude Engines of the Lorenz Type Propeller.