TECHNICAL NOTES.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No.15.

TESTS OF THE DAIMLER D-IVa ENGINE AT A HIGH ALTITUDE TEST BENCH.

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Translated from
Technische Berichte Vol. III - Sec 1,

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The following translation was made by the Paris Office of the National Advisory Committee for Aeronautics in view of the general interest that has been evidenced in connection with numerous engine tests conducted for the National Advisory Committee for Aeronautics in the Altitude Chamber of the Bureau of Standards, the results of which have appeared in the Committee's reports.

With a view to investigating the power decrease of a 260 H.P. Daimler engine at altitudes, and the behavior of that engine when fresh air is inducted, tests were made at the high altitude test bench (vacuum chamber) at Friedrichshafen from November, 1917, to February, 1918. The last few tests were specially intended to decide what increase of power may be gained and what conditions of work are realized when fresh air is supplied to the engine through a blower. The present author first made the proposal in January, 1917, that normal aircraft should be equipped with a centrifugal blower for that purpose and that it should either be directly coupled or - especially in the case of giant airplanes with several engines - be worked by the main shaft or by a special engine.

The vacuum chamber, which enabled the above-mentioned tests to be made on the ground under conditions considerably like those at a certain altitude, was lent for the purpose by the Zeppelin Aircraft Works at Friedrichshafen. The inbuilding of the engine and the entire preparations and measuring gear were taken care of by the Experimental Department of the Zeppelin Works, under the direction of Engineer Leitmann, whose invaluable support and collaboration are hereby gratefully acknowledged. The engine was furnished by the Rea Equipment Depot at Doberitz. The idea of supplying fresh air by external pressure, or by means of a blower, originated with the present writer, as also the alterations entailed, in consequence, in the engine and in the fuel supply. The centrifugal blower was one of those intended to be mounted, by way of experiment, in the 1000 H.P. giant aircraft. It was constructed by Brown, Boveri & Co., in close collaboration with the writer.

I. THE VACUUM CHAMBER.

The vacuum chamber of the Zeppelin Dirigible Worksat Friedrichshafen is constructed for the purpose of experimenting on engines and radio equipment with regard to their suitability for high altitudes, and also for investigating the adaptability of the crew in that respect.

It consists of a ferro-concrete building with a ground area of 8.5 by 4 sq.m., 3.4 m. at its highest pitch. A vacuum is created in the chamber by an ENCKE'S positive blower driven by electric power. The pressures are obtained by means of two automatic regulating valves which are subsequently replaced by an ordinary stop-valve. The exhaust gases are taken off through a capacious passage, where they are cooled by running water and exhausted by the positive blower. The test chamber communicates with the exhaust passage by small, adjustable orifices, so that there is equal pressure in both. The engine-power is measured by a water-brake, the fuel consumption by a calibrated measuring recipient. When the power is furnished by outside air and blowers, the fuel is weighed. The number of revolutions is recorded by an ordinary aircraft tachometer, and its work is repeatedly checked by a hand-tachometer. The temperature of the cooling water is regulated by the addition of fresh water. The exhaust pipes, and afterwards the under-side of the crankcase were cooled by means of water sluicing to enable duration tests to be made. The cooling water for engine and brake is likewise removed by means of a positive blower driven by electricity.

The chamber is provided with double doors and a sluice, thus supplying a means of exit when vacuum prevails in it. A dial telegraph serves as a means of communication from the inside of the chamber to the outside. As the centrifugal blower must be installed outside the vacuum chamber, orders are passed on by flash signals.

When a 260 H.P. engine is working and taking in its fresh air from the chamber, about 340 mm. mercury absolute, corresponding to an altitude of about 6500 m., may be maintained. If the whole of the fresh air for the engine be permitted to flow in from the outside, about 450 mm. mercury absolute only (about 4500 m.) can be attained. When tests were made in extremely rarefied air, the workers wore oxygen masks, and a large flask of oxygen is always kept in the chamber, near the fire grenades, for use in case of emergency.

It may here be mentioned that the chamber, in its present condition, is the result of long and costly experiments. Considering that it would scarcely be worth while for the majority of aviation engine manufacturers to construct altitude benches of their own, though future needs will make it urgently advisable to investigate engines with regard to altitude requirements, the Zeppelin Dirigible Works have offered their vacuum chamber and its measuring installation, for rent for such purposes.

II. THE ENGINE AT DECREASING ATMOSPHERIC PRESSURE.

The D. IVa engine, No.29609, was mounted on the test-bench for investigation, without any alterations. For the first series of experiments, fresh air was taken in from the experimental chamber and inducted through the air-passage of the crankcase in the usual manner. The engine ran with light gasoline, $\gamma = 0.708$ kg/dc^3 at 15°C. The time of consumption for every 3 dec.^{3} was registered by a stop-watch, the pressure in the chamber by two dirigible barometers. Whenever a variation in pressure was caused by the opening or closing of the regulating pressure valves in the chamber, normal regime conditions were set up and each reading was repeated several times. The powers were fixed for 1450 and 1550 r.p.m. alternatively.

The results of these tests are collectively given in Table 1. The same values, in terms of altitude, are shown in Fig. 1 (measured on the dirigible barometer), and in Fig. 2 in terms of atmospheric pressure (Curve 1).

There is a striking decrease of power at high altitudes. The tests were consequently made under altered conditions. The fresh air was again taken from the experimental chamber, but it was no longer inducted to the crankcase by the passage, being directly injected into the carburetor. Table 2, and the plotting of curve 2, Figs. 1 and 2, show that the powers resulting on this occasion were considerably higher and the consumption lower, and the explanation of this must be sought for in the different temperatures of the inducted air. The temperature of the air directly in front of the carburetor was not, unfortunately, measured at the first test, but we may safely assume that the air is heated to some extent by passing the hot crankcase; the more the atmospheric pressure decreases, and the mass of air in consequence, the more heated does the air become. As the crankcase was cooled by the intake air alone, during the first tests, it became hotter and hotter in proportion to the duration of the test and the decrease of atmospheric pressure, and this again increased the heating of the air still more. There was also a difference in the temperature of the air of the chamber from which the engine inducted air for the two tests : it amounted to 16° to 20° at the first test and 12° to 14° at the second.

If it were necessary to draw a conclusion from these tests as regards conditions during flight, the effect of temperature on the power or charging coefficient would have to be known, as also the chemical and thermal efficiency of the engines. Up to the present time, it was generally considered that the power might be set down in terms proportional to the temperature of the outer air. This supposition is sufficiently accurate so long as the differences in question are slight, but if the air becomes strongly heated on the way to the intake valve, it is only the temperature in front of the intake valve that can be taken as a standard. The dependency of the power on the temperature of the outer air, as resulting from a number of later tests with the D Iva engine, is shown in Fig. 3, which thus gives an approximate idea of the power curves at different temperatures with increasing atmospheric pressure.

The outside temperatures are here marked beside the test points, and the number of the test is also stated, in brackets. Although the values for higher and lower temperatures are distinctly different, these tests by no means suffice for the establishment of a perfectly faultless standard, owing to the fact that other variable factors enter into account in the above-named combination of test values, and that their influence on the engine power has not yet been explained and cannot, in consequence, be suppressed. These factors are, above all, the increase of temperature of the air, which varies with the density of the air and the temperature of the cooling water and affects the efficiency of the carburetor; and also the effect of differences between the intake and exhaust back-pressure.

Fig . 3 gives positive proof, however, of the fact that the engine still functions perfectly with an air temperature of 0° in front of the carburetor, and that it attains its highest power with very slightly increased fuel consumption, (see Table 3). Considering that the air is cooled from 20° to 25° - according to the richness of gasoline in the mixture - through the evaporation of the gasoline, it must be assumed that the carburetor heating, the warmth of the burnt gases remaining in the cylinder, the compression and the hot walls of the cylinder and valve suffice to evaporate the fuel. We must here observe that the intake pipes were thickly covered with ice during the tests, although the temperature of the surrounding air was $+10^{\circ}$ or more. In the airplane, the air was always inducted through the engine casing and was thus warmed again. By this means, the air should seldom reach the carburetor colder than in the tests in question, even in the case of the lowest temperatures, while the formation of the mixture and the burning should be faultless with sufficient carburetor heating.

Although there may be little difference between the conditions for actual airplanes and for tests, it appears to be desirable that a mean power curve should be plotted for various flying altitudes, in proportion to the absolute temperature, Curve 3, Fig. 1. It was assumed, in this case, that the air in the crankcase passage had been heated to 20°. The mean annual temperatures given by the Wagner Meteorological Tables for corresponding altitudes were taken as the temperatures of the air.

In establishing engine power for a given altitude, consideration must be given to the fact that such engine power is practically dependent on the atmospheric pressure, which may, however, vary greatly at a given altitude in the course of a year. More accurate values may therefore be deduced from the power curve if the powers be expressed in terms of atmospheric pressure, and the temperature and atmospheric pressure, at the altitudes in question, be calculated at a given time. Fig. 2 shows the powers in terms of pressure , and Fig. 4 represents tests 1 and 2 with the Daimler engine, the number of the tests being also set down. The upper curves are those of the same powers calculated at 760 mm. barometric pressure and 15° as induction temperature, according to the well-known formula:

$$N_r = N_o \cdot \frac{760}{b} \cdot \frac{273 + t}{288}$$

If the engine power were merely proportional to the pressure, that is, to the pressure and absolute temperature of the outside air, the above curves would result in horizontals. The rapid decline of the curves as compared to the straight lines, provides a standard for the "altitude characteristics" of the engine. In the tests in question, this rapid decline is due to the heating of the intake air. The hotter the crank-case becomes, and the lower the pressure, the greater is the influence on the efficiency of the engine.

The inadequate working of the carburetor is another factor, though influencing it in a secondary degree. It has been previously stated* that the supply of fuel in the carburetor diminishes less, with increased altitude, than the weight of air taken in with every stroke of the propeller. The result is an over-rich mixture, in which a large proportion of the fuel leaves the cylinder in an unused state and is consumed outside as exhaust flame. The thermal efficiency of the circulation is thereby considerably lowered, as may be seen from the increased specific fuel consumption represented in Tables 1 and 2. Improvement in this respect might be obtained by the use of a carburetor that could be regulated by means of an automatic or hand-worked nozzle-spray, according to the weight of inlet air.

Decrease of engine power is further influenced by mechanical efficiency. When the number of revolutions remains constant, the light running work of the engine scarcely diminishes at all, except for its being lessened by the decrease of working pressure, although its proportion to the brake power increases with altitude.

The future alone can show to what extent the altitude power of the normal Daimler engine may be improved by other carburetors, or how closely such decrease would approach a proportional decrease of pressure.

By way of comparison, the power curves of the Maybach Mb IVa and Mb H S Lu engines with 1450 r.p.m. are plotted in terms of altitude in Fig.5, on the basis of measurements previously taken at the Zeppelin Works. In Fig. 2, the values are also inscribed in Curves 3 and 4. In Fig. 5, Curves 1 to 3 relate to the Mb IVa engine, as follows: Curves 1 with light gasoline power (γ = 0.708), Curves 2 working with heavy gasoline (γ =0.750) and Curves 3 to benzol power, in which case the carburetor might remain constantly open. Curves 4 refer to the Mb H S Lu engine with light gasoline power. In Fig. 2, Curve 3 relates to the Mb IVa engine, and Curve 4 to the Mb H S Lu engine.

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* "Technische Berichte," Vol. II, No. 1; "The Decrease of Engine Power with Altitude," by H. C. Bader .

III. THE ENGINE WITH DECREASING OUTSIDE TEMPERATURE AND CONSTANT PRESSURE IN FRONT OF THE CARBURETOR.

These tests constitute a series preparatory to the working of the engine with compressors. Fresh air was inducted to the carburetor by outside piping instead of being admitted through a blower. The air pressure was therefore constant, while the pressure in the experimental chamber and the exhaust back pressure were capable of being regulated. The fuel tank and the float chamber were connected with the air passage of the carburetor by a pipe about 6 mm. in diameter. A receptacle containing about 1/2 liter was attached to the overflow pipe of the float, and fitted with a pet cock through which the overflow gasoline was drawn off. A cowl that can be screwed and unscrewed was fitted on the outlet of the float needle, and the valve spindle of the mixing throttle was made taut by means of a leather washer. The air is admitted directly under the carburetor in order to avoid its being heated by the crankcase. The air passage is not taut, however, as it communicates with the interior of the crankcase through the oil vapor exhaust ports. Air cooling being impossible on account of limited space, water was sprayed into the air passage to cool the crankcase.

These preparations were so adjusted practically that the engine worked satisfactorily from the commencement of the tests onwards. When there was depression in the chamber , fresh air could be let in, and the pressure gradually raised in front of the carburetor, by means of a valve located in the air passage leading to the carburetor. The engine showed no disturbance with abrupt increase of pressure, nor with gradual increase, such change being marked only by an increase in the number of revolutions; that is, by increased power. The mean pressure in front of the carburetor was about 720 mm. (Friedrichshafen is situated at an altitude of about 400 m., mean barometric pressure 730 mm.) 280 HP was the maximum brake power attained at an altitude of 4000 m. (see Table 3). The main object of this test was that of investigating the behavior of the engine and of the fuel supply with super-pressure .

IV. ENGINE WITH BLOWER.

A turbo-compressor was attached to the outlet airpipe. A detailed description of this compressor will be given later on. It was driven by a D II-engine, 120 HP, and it compressed 5200 kg. per hour with a total compression ratio of 1.75, corresponding to the quantity of air required by four 260 HP engines with a maximum of 1600 r.p.m., and by the turbo-engine. The compression ratio of 1.75 should be effected as soon as the airplane has reached an altitude of 4500 to 4800 m. and when the compression in front of the carburetor amounts to 1° constant absolute temperature. Only one engine being attached at the tests, and the blower being located outside the vacuum chamber, the compression ratio was obtained by throttles in the intake pipes.

In these tests, too, the working was faultless from the beginning so far as the combined working of engine and blower were concerned. The results of the tests (see Tables 4 and 5) and any statement of conclusions were put off for the time being, until a clear understanding could be arrived at on certain points. The power of an engine may be influenced in so many different ways that it is extremely difficult to distinguish single influences. In addition to the effect of the mixing temperature, heat of the cooling water, etc., the effect of the difference between the intake and exhaust back pressure must also be taken into account. During the compression of the blower, the engine functions in this case as a compressed air engine and the compression work of the blower is regained, the exhaust back pressure diminishing with altitude, so that the useful diagram surface is notably enlarged. At the same time, the exhaust back pressure is proportionally lessened. The cylinder efficiency is improved, and a sort of scavenging is obtained when the openings of the exhaust and inlet valves coincide.

All these conditions must necessarily bring about the increase of engine power with altitude .

An investigation was made of the manner in which the Daimler engine works when charged with fresh air, of its overload capacity, and also of the possibility of finding some substitute for the adjustable bladed propeller in the constant power engine.

The writer has proposed that propellers specially constructed for mean altitudes and for the atmospheric conditions and flying speeds therein prevailing should be used instead of adjustable bladed propellers. Larger pitch, and also, when it is possible, larger diameter, is thus obtained for the propellers than in the case of ordinary propellers with similar power. It is a known fact, however, that the power absorbed by the propeller varies with the third power of the number of revolutions, while the power of the engine varies, in the proximity of the maximum, with the first power of the number of revolutions.

In order to obtain constant power from a propeller in the region of 0 to 5000 m. altitude, the number of revolutions of the engine must therefore be altered from about 10% below the average to 10% above it. To obtain total power from the engine with this diminished number of revolutions, the blower must supply higher pressure, and a greater mixed charge must be injected through the blower.

Fig. 6 shows the course of curves of power, torque and consumption of the Daimler 260 HP engine for three different admission temperatures, pressures b, and exhaust back-pressures p_a in front of the carburetor. The values of Curves I are as follows: b = 830 mm. mercury, P_a = 736 mm. mercury, $t \sim 40^\circ$ C; Curves 2: b = 760 mm. mercury, p_a = 736 mm. mercury, $t \sim 30^\circ$; and Curves 3: b = 720 mm. mercury, p_a = 728 mm. mercury, $t \sim 8^\circ$. This shows that low compression suffices to produce considerable increase of power, so that increased torque can be realized without difficulty, with the reduced number of revolutions. There were no cases of breakdown, even with frequently repeated overloading, nor were there any sparking plug breakages observed, as in the case of super-compressed engines. The work of the engine was somewhat hard with powers of 300 to 320 HP, but there was no disturbance even with a duration test of half an hour.

Its capacity for overloading is of special advantage at starting in the case of heavily loaded aircraft or when there is a short starting run. The duration of overloading is a short one in both cases, and no danger is incurred, in consequence, by the engine.

The question of temperature is particularly important when working with compressors, The compression and internal losses (friction and leakages in the blower) are mostly converted into heat, so that the air is consequently more or less heated in proportion to the compression ratio. If fresh air is supplied through a blower driven separately, the pressure corresponding to the altitude of the time being must be produced by altering by hand the number of revolutions of the blowing engine. The highest compression ratio is then required at the highest altitude, and generally when the temperature of the air is lowest. The temperature of the air in front of the carburetor thus remains within acceptable limits. This is not the case for compressors coupled to the main engine or to the central gear, because the compressor always revolves at the same multiple of the number of revolutions of the engine. The pressures produced are therefore too high for the lower flying altitudes, and must consequently be throttled. As the highest temperatures generally prevail at these low altitudes, the compressed air reaches the air in a strongly overheated condition at low altitudes. It may be necessary, in such cases, to insert air-coolers between the compressor and the engine. The gain in power resulting from such cooling may be considerable, as has been seen from tests. Less stress is also put upon the cylinder, when better cylinder charging is effected by cooling, than by increase of pressure.

SUMMARY. Reports of tests of a Daimler IVa engine at the test-bench at Friedrichshafen, show that the decrease of power of that engine, at high altitudes, was established, and that the manner of its working when air is supplied at a certain pressure was explained. These tests were preparatory to the installation of compressors in giant aircraft for the purpose of maintaining constant power at high altitudes.

SUPPLEMENTARY NOTE. While the above report was in the Press, the Zeppelin Works made further tests with regard to the dependence of engine power on the temperature of the air, at different pressures in front of the carburetor, and valuable figures were thereby obtained. The results are collectively stated in Table 6, (tests Nos 150 to 158). In Fig. 7, those values are given with those of earlier tests. The numbers inscribed in the figure refer to the number of the test: Curve 1 to 730, Curve 2 to 760, and Curve 3 to 777 mm. mercury absolute in front of the carburetor. In all three cases, the exhaust back pressure amounted to 730 mm. mercury. Straight line 4 shows what the curve of power would be if it decreased in proportion to the increase of temperature.

Since that time, the first flying tests have also been made with a giant airplane of the Staaken type, with four D IVa engines, equipped with a compressor. The airplane attained almost 6000 m. on that occasion, as compared to its previous maximum altitude of less than 4000 m.

TABLE I.

D IVa ENGINE: FRESH AIR INDUCTED THROUGH AIR PASSAGE OF CRANKCASE.

Tests	Altitude.	Barometer reading.	Room temperature	n	Brake load	Brake H.P.	Temperature of cooled water	Fuel consumption.			Air Density.
								4 l.=2.83 kg.			
No.	m.	mm. Q.-S.	t_o °C.	R.P.M./min.	kg.	HP	°C.	consumed in	kg/hr.	g/HP/hr.	kg/m^3
1	400	726	16	1450	171	249	57	2'57"	57.6	231	1.165
2	1000	672	17.2	1450	159	232	61				1.075
3	1000	672	17.2	1450	157	228	59	2'59"	56.8	249	1.075
4	2000	595	16.5	1450	138	200		3'10"	53.6	268	0.955
5	2500	560	19	1450	128	186	72	3'15.6"	52	279	0.89
6	3000	526	17.8	1450	118	171	71	3'24.2"	49.8	285	0.84
7	3000	527	19.5	1550	114	178	73	3'12.6"	52.8	296	0.838
8	3000	527	20	1550	113	175					0.836
9	3700	482	18.2	1450	105	152	66	3'31"	48.4	318	0.77
10	3700	482	18.5	1550	99	154		3'25"	50	325	0.769
11	4500	435	18.6	1450	90	131	72	3'41.8"	46	350	0.694
12	4500	436	18.7	1550	85	132	68	3'36"	47.2	357	0.696
13	5200	400	18.3	1450	76	110	68	3'56.6"	43.2	392	0.64
14	5200	400	18.4	1550	70	108		3'45.6"	45	416	0.639
15	6000	361	17.5	1450	51	74	61		41	555	0.578
16	6000	361	18.3	1550	46	72	56				0.577

TABLE II.

D IVa ENGINE: FRESH AIR DIRECTLY INJECTED INTO THE CARBURETOR.

Tests	Vacuum chamber			Carburetor.							Fuel consumption.			Air density.
	Altitude	Barometer reading	Room Temperature t_0	Difference of pressure	Abs. pressure	Temperature	n	Brake load	Brake H.P.	Temperature of cooled water	3 l. consumed in			
No.	m.	mm. Q.-S.	°C.	mm. Q.-S.	mm. Q.-S.	°C.	r.p.m./min.	kg.	H.P.	°C.		kg/hr	g/HP/hr.	kg/m^3
140	400	730	14	--	730	14	1450	179	259	60	2' 12"	54.7	211	1.18
141	400	730	14	--	730	13	1450	179	259	56	2' 9"	55.7	215	1.185
142	2000	602	14	--	602	14	1450	149	216	48				0.976
143	2000	602	13	--	602	14	1450	149	216	53	2' 21"	51.0	236	0.975
144	4000	471	13	--	471	14	1450	112	162	58	2' 42.8"	44.1	272	0.764
145	4000	471	13	--	471	14	1450	112	162	57	2' 39.6"	45.1	278	0.764
146	5000	414	13	--	414	13	1450	96	139	55	2' 53"	41.6	299	0.674
147	5500	389	13	--	389	13	1450	87	126	53	3' 3.2"	39.3	312	0.632
148	5800	378	12	--	378	12	1450	82	119					0.616
149	6000	365	12	--	365	12	1450	75	109	62	3' 2.5"	36.8	337	0.595

TABLE III.

DIVa ENGINE AT DECREASING ATMOSPHERIC PRESSURE AND VARIOUS PRESSURES BEFORE THE CARBURETOR.

Tests	Vacuum chamber			Carburetor.							Fuel consumption.			
	Altitude	Barometer reading	Room temperature	Difference of pressure	Abs. pressure	Temperature	n	Brake load	Brake H.P.	Temperature of cooled water				Air density.
			t_o											
No.	m.	mm. Q.-S.	°C.	mm. Q.-S.	mm. Q.-S.	°C.	r.p.m./min.	kg.	H.P.	°C.	consumed in	kg/hr	g/HP/hr.	kg/m³
21	400	731		-8	723	9.2	1450	169	245	63	3' 7.6"	57.5	235	1.191
22	1500	626		-6	620	8.2	1450	152	220	54	3' 24.6"	52.6	239	1.024
41	1500	626		+8.4	634.4	8.2	1450/ 1480	167	244					1.048
23	400	730	10	-6	724	8.2	1450/ 1480	169	246	51	3' 5"	58.4	237	1.195
24	400	730		-7	723	8.2	1450	171	250					1.194
42	2000	602					1450	146	212					
43	2000	600		+12	612	8.5	1450	151	220					1.012
44	1900	608		+118 (+120)	726	9	1450	177	256					1.195
25	2600	545		±0	545	9								0.898
26	400	729.5	8.5	-6	723.5	8	1450	171	248	49				1.195
27	400	730		-5	725	9	1450	176	255		3' 5.4"	58.4	229	1.195
28	1650	625	10.5	+2	627	10	1450	156	226	69	3' 22"	53.5	237	1.030
45	1720	618	11.5	+9.8	627.8	10.2	1450	182	265					1.029
46	1720	618		+104	722	10.5	1480	178	260					1.183
29	3000	530	13	±0	530	10.8	1450	132	191	52				0.868
47	3000	530	13	+198 (+195)	728	11	1450	177	258	63				1.192
30	3960	469	11	-3	466	11	1450	113	165	61				0.769

TABLE III (Contd.)

D IVa ENGINE: AT DECREASING ATMOSPHERIC PRESSURE AND VARIOUS PRESSURES BEFORE THE CARBURETOR.

Tests	Vacuum chamber			Carburetor.							Fuel consumption.			
	Altitude	Barometer reading	Room temperature	Difference of pressure	Abs. pressure	Temperature	n	Brake load	Brake H.P.	Temperature of cooled water	3 l. consumed in		g/HP/hr.	Air density
No.	m.	mm. Q.-S.	t_0 °C.	mm. Q.-S.	mm. Q.-S.	°C.	r.p.m./min.	kg.	H.P.	°C.		kg/hr		kg/m³
48	4000	468	14	+257	725	10.8	1450	175	254	62				1.188
49	5000	410	14.5	+12	422	11	1450	102	148	62				0.692
50	5000	410		+312	722		1450							
31	400	729	6.5	-5	724	-1	1450	172	250	47		62.8	251	1.238
51	1950	604	8.5	+5	609	±0	1450	152	221	49		57.6	261	1.037
52	1920	602	8.5	+118	720	-0.3	1450	187	271	53		63.5	234	1.228
53	3000	528	8.5	+7	535	-0.8	1450	132	191	50		53.6	281	0.914
54	3000	526	8.5	+193	719	±0	1450	187	271	51		63.4	234	1.225
32	4060	462	9	-7	455	±0	1450	109	159	46		50.5	318	0.775
55	4080	460	11	+258	718	±0	1450	189	275	53		63	229	1.222
33	400	727	8.5	-7	720	-3.6	1450	172	249	46				1.210
34	6000	362	11	+2	364	4.8	1450	83	120	48				0.606
56	4500	440	15	+275	715	4.8	1450	177	256	65		64.5	252	1.196
35	4000	464	14.5	+1	465	5.2	1450	115	167	53				0.778
57	4000	464	15.5	+249	713	4.8	1450	193	280					1.193

TABLE IV.

D IVa ENGINE WITH BLOWER.

Tests	Vacuum chamber		Before the carburetor.								Fuel consumption			Blower			
	Altitude	Barometer reading	Difference of pressure	Abs. pressure	Temperature	n	Brake load	Brake H.P.	Temperature of cooled water	2 kg. consumed in				Pressure at Intake tube	Pressure at Discharge tube	Air density.
No.	m.	mm. Q.-S.	mm. Q.-S.	mm. Q.-S.	°C.	rpm/min	kg	H.P.	°C.		kg/hr.	g/hp/hr.	rpm/min.	mm. Q.-S	mm. Q.-S.	kg/m3
61		729	-5	724	+ 9	1450	176	255								1.192
62		729	+5	734	+26.5	1450	182	264					600	-115	+ 10	1.14
63		729	+0	729	+38	1450	177	257					980	-145	+ 6	1.088
64		729	-2	727	+61.5	1450	169	245					1360	-255	+ 4	1.015
65		729	+0	729	+74.5	1450	165	239					1450	-275	+ 4	0.975
66		729	-12	717	+ 4	1450	173	251								1.20
67		729	+12	741	+11.5	1450	184	267							+ 16	1.21
68		729	+28	757	+12	1450	189	275							+ 30	1.235
69		729	+54	784	+14.5	1450	192	279							+ 64	1.265
70	400	724	-4	720	+ 1	1450	174	252								1.22
71	400	724	+16	740	+11	1450	182	264								1.21
72	400	722	+42	764	+16.5	1450	192	278								1.23
73	400	722	+14	736	+11	1450	182	264								1.205
74	1000	670	+72	742	+12	1450	189	274								1.21
75	400	736	+28	764	+17	1450	192	279	44	1'56.2"	62	222		-5	+ 30	1.22
76	1000	683	+77	760	+25.5	1450	196	284	47	1'53.6"	63.3	223		-40	+ 30	1.18
77	1000	683	+92	775	+33	1450	191	277	44	1'53.3"	63.5	229		-100	+ 45	1.175
78	1000	683	+105	788	+48	1450	191	277	50	1'52.4"	64	231		-150	+ 60	1.14
79	1000	683	+80	763	+56.5	1450	176	255	44	1'55"	65	245		-200	+ 30	1.075
80	400	735	+28	763	+27	1450	192	279	53	1'58.8"	60.5	217		-18	+ 20?	1.18
81	400	730	+32	762	+ 21	1450	189	274	50	1'50"	64.9	237		--	--	1.205

TABLE IV (Contd.)

D IV ENGINE WITH BLOWER.

Tests No.	Vacuum chamber: Altitude m.	Vacuum chamber: Barometer reading mm. Q.S.	Before the carburetor: Difference of pressure mm. Q.S.	Before the carburetor: Abs. pressure mm. Q.S.	Before the carburetor: Temperature °C.	n rpm/min	Brake load kg.	Brake H.P. H.P.	Temperature of cooled water °C.	Fuel consumption: 2 kg. consumed in	Fuel consumption: kg/hr.	Fuel consumption: g/hp/hr	Blower: rpm/min	Blower: Pressure at Intake tube mm. Q.S.	Blower: Pressure at Discharge tube mm. Q.S.	Air density kg/m³
82	400	732	+27	759	+21	1450	187	271	47	1'55"	62.6	231		-57	+32	1.200
83	1000	680	+78	758	+29	1450	189	274	61	1'58"	61.1	223		-57	+32	1.165
84	1000	680	+83	763	+32.5	1450	187	271	50	1'57"	61.5	227		-60	+32	1.162
85	1000	680	+96	776	+42	1450	192	278	62	1'52.5"	63.9	230		-52	+50	1.145
86	1000	680	+125	805	+49	1450	197	286	--	1'52.5"	64	224		-52	+75	1.160
87	400	736	+27	763	+18	1450	189	274	52	1'59.6"	60.3	220		--	--	1.21
88	2000	605	+160	765	+42	1450	190	275	45	1'53.4"	63.5	231		-150	+30	1.13
89	2000	605	+180	785	+52	1450	197	285	60	1'52"	64.5	226		-140	+50	1.12
90	2000	605	+205	810	+62	1450	199	289	57	1'52"	64.2	222		-140	+75	1.12
91	3000	534	+226	760	+79	1450	184	267	51	1'53"	63.5	238		-205	+30	1.00
92	3000	534	+250	784	+87	1450	185	268	53	1'52.6"	63.7	238		-200	+50	1.00
93	3000	534	+274	808	+87	1450	191	277	53	1'52"	64.3	232		-205	+75	1.04
94	4000	470												-260	-26	
95	2500	500	+230	730	> 100	1450	165	240	50	2'10"	55.5	231		-230	+5	0.91
96	2000	602	+227	829	+76	1450	194	281	58	1'51"	65.0	231		-130	+100	1.10
97	2000	602	+283	885	+95	1450	190	276	58	1'53"	63.8	231		-130	+150	1.12
98	3000	532	+290	822	> 100	1450	180	261	48	1'50"	65.3	250		-200	? +100	1.02
132	1000	675	+48	723	+13	1450	182	264	60	2'6"	57.4	217		-55	+2	1.175
133	3000	527	+205	732	+54	1450	160	232	65	2'6"	57.0	246		-210	±0	1.04
134	1300	650	+170	820	+37	1450	221	320	60	1'57"	61.5	192		-85	+105	1.228
135	2000	592	+130	722	+36	1450	187	273	58	2'3.6"	58.2	213		-130	+5	1.086
136	3500	490	+295	785	+95	1450	185	268	65	1'53.2"	63.5	237		-235	+80	0.992
137	4000	462	? +260	722	? +105	1450	170	247	63	1'59"	60.5	245		-260	+15	0.888
138	4500	434	? +240	674	? +105	1450	155	225	58	2'5"	57.6	256		-280	-50	0.829

TABLE V.

DRIVE ENGINE WITH BLOWER.

Tests No.	Altitude m.	Barometer reading mm. Q.-S.	Difference of pressure mm. Q.-S.	Working pressure mm. Q.-S.	Temperature °C.	n rpm/min	Brake load kg.	Brake H.P. H.P.	Temperature of cooled water °C.	2 kg. Consumed in	kg/hr.	g/HP. hr	Air density kg/m³	Calculated performance H.P	torsion moment cm/kg	Mean working pressure at
													b = 760 mm Q.-S.			
101	400	736	+22	758	+22	1450	187	271	46	1'59.2"	60.7	223	1.192	272	13400	7.7
102	400	736	+26	762	+23	1550	182	281	49	1'51.0"	65.0	231	1.195	280	12900	7.5
103	400	736	+34	770	+26	1550	186	289	43	1'54.6"	62.7	217	1.195	285	13200	7.7
104	400	736	+33	769	+26	1450	191	277	75	1'56.0"	62.0	224	1.195	274	13550	7.9
105	400	736	+26	762	+25	1350	192	259	60	2'14.0"	53.6	207	1.189	258	13700	7.95
106	400	736	+26	762	+25	1350	192	259	50	2'7.2"	56.7	219	1.189	258	13700	7.95
107	400	736	+25	761	+23	1250	195	244	58	2'27.8"	52.5	215	1.195	244	14000	8.1
108	400	736	+26	762	+24	1150	197	227	70	2'17.0"	52.4	231	1.192	226	14100	8.18
109	400	736	+25	761	+23	1050	195	205	52	2'46"	43.5	212	1.195	205	14000	8.1
													b = 830 mm. Q.-S.			
110	400	736	+96	832	+42	1450	206	299	54	1'57.4"	61.3	205	1.228	298	14750	8.55
111	400	736	+96	832	+42	1350	207	279	55	1'58"	61.1	219	1.228	278	14800	8.6
112	400	736	+94	830	+40	1250	211	264	54	2'11.6"	54.6	207	1.232	264	15100	8.75
113	400	736	+96	832	+38	1150	214	246	52	2'24.6"	50.0	203	1.243	245	15300	8.9
114	400	736	+92	828	+36	1050	210	221	52	2'31.6"	47.5	215	1.245	222	15050	8.7
115	400	736	+92	828	+40	1550	203	315	53	1'53.6"	63.5	201	1.230	316	14500	8.42

TABLE V (Cont.)

D IVa ENGINE WITH BLOWER.

No.	Vacuum chamber: Altitude m.	Vacuum chamber: Barometer mm. Q.-S.	Before the carburetor: Difference of pressure mm. Q.-S.	Before the carburetor: Abs. pressure mm. Q.-S.	Before the carburetor: Temperature °C.	n rpm/min.	Brake load kg.	Brake H.P. H.P.	Temperature of cooled water °C.	Fuel consumption: 2 kg. Consumed in	Fuel consumption: kg/hr.	Fuel consumption: g/H.P/hr	Air density kg/m³	Calculated performance H.P	Torsion moment cm/kg	Mean working pressure at
b = 720 mm Q.-S.																
116	400	728	-8	720	+10	1450	172	250	60	2' 7.4"	56.5	226	1.181	250	12320	7.15
117	400	728	-8	720	+ 8	1350	157	236	53	2'22.4"	50.7	215	1.190	236	12500	7.25
118	400	728	-6	722	+ 7	1150	179	206	65	2'41.6"	44.5	216	1.200	205	12800	7.40
119	400	728	-7	721	+ 5	1250	177	221	50	2' 32"	47.4	214	1.206	221	12650	7.35
120	400	728	-5	723	+ 5	1050	178	187	55	2'54.6"	41.2	220	1.209	186	12730	7.4
121	400	728	-12	716	+ 5	1550	172	267	60	2'4.6"	57.7	216	1.197	269	12300	7.15
b = 760 mm Q.-S.																
122	400	732	+28	760	+17	1450	192	278	52	2' 3.4"	58	209	1.218	278	13700	7.95
123	400	732	+29	761	+17	1450	192	278	56	2' 2.6"	58.6	211	1.220	278	13700	7.95
124	400	732	+28	760	+17	1350	195	263	60	2'15.3"	53.1	202	1.218	263	13950	8.1
125	400	732	+29	761	+17	1250	197	246	59	2'29.8"	48	195	1.220	246	14100	8.15
126	400	732	+29	761	+16	1150	197	227	59	2'36.8"	45.9	202	1.225	227	14100	8.15
127	400	732	+29	761	+15	1050	197	207	56	2' 53"	41.6	201	1.229	207	14100	8.15
128	400	732	+27	759	+17	1550	190	294	60	2' 54"	62.9	214	1.217	294	13530	7.85
129	400	732	+48	780	+22	1450	200	290	58	2' 6"	59.8	206	1.230	282	14300	8.3
130	400	732	+78	810	+28	1450	205	297	63	1'57.6"	61.2	206	1.250	279	14600	8.45
131	400	732	+165	897	+34	1450	224	325	58	1' 57"	61.4	189	1.357	275	16000	9.25

TABLE VI.

DIVa ENGINE TEST SHOWING DEPENDENCY OF POWER ON THE TEMPERATURE.

Tests No.	Vacuum chamber. Altitude m.	Barometer mmQ.-S	Before the carburetor. Difference of pressure mm. Q.-S.	Abs. pressure mm. Q.-S	Temperature °C.	n rpm/min.	Brake load kg.	Brake H.P. HP	Temperature of cooled water °C.	Fuel consumption. 2 kg. Consumed in	kg/hr	g/HP/hr.	Air density. kg/m^3
150	400	734	+26	760	+22	1450	188	273	47	2' 2.4"	59	215	1.20
151	400	734	26	760	38	1450	188	273	52	2' 6.6"	57	208	1.135
152	400	734	25	759	66	1450	178	258	55	2' 5.4"	57.5	223	1.04
153	400	734	26	760	81	1450	173	251	60	2' 6.2"	57	227	1.00
154	400	734	26	760	88	1450	171	248	63	2' 8.0"	56.4	227	0.98
155	400	734	43	777	31	1450	193	280	55	2' 4.0"	58	207	1.19
156	400	734	43	777	48	1450	190	275	66	2' 4.0"	58	211	1.13
157	400	734	43	777	65	1450	186	269	58	2' 6.4"	57	212	1.07
158	400	734	43	777	82	1450	179	259	59	2' 6.0"	57	221	1.02

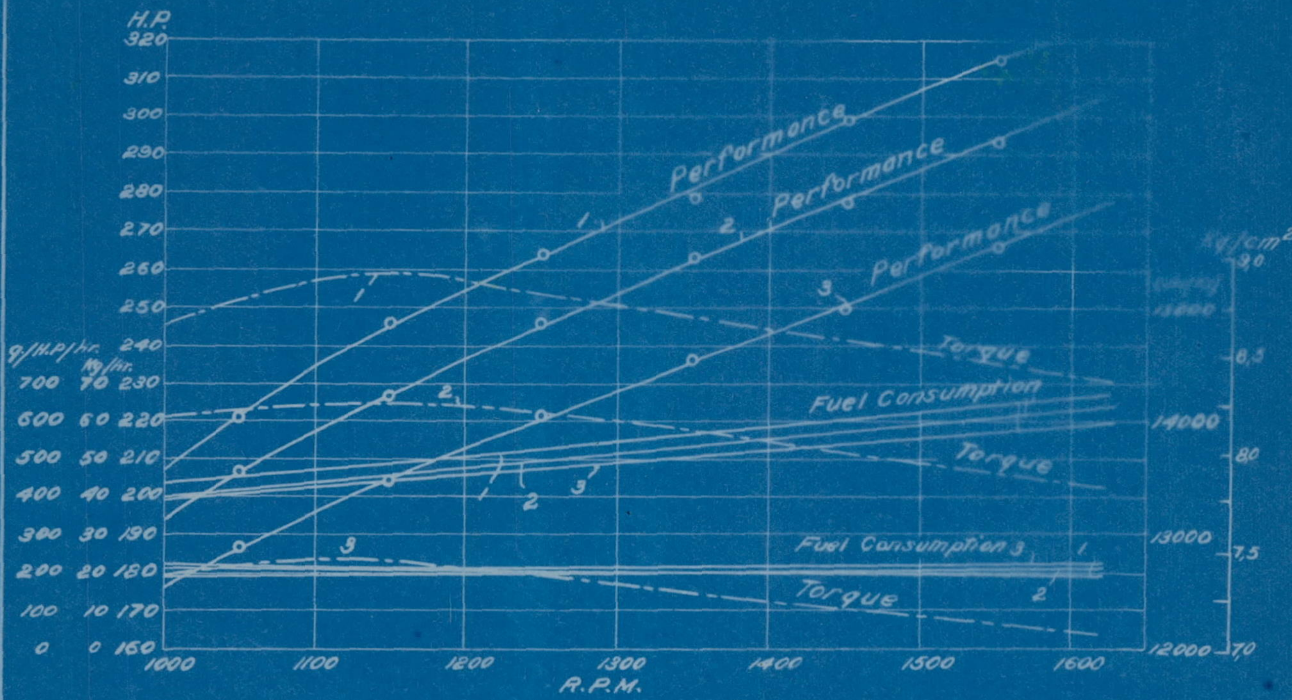

Fig. 6. Performance torque and gas consumption of the D IVa engine for three different intake and exhaust pressures and intake temperatures before the carburator at increasing engine speeds.

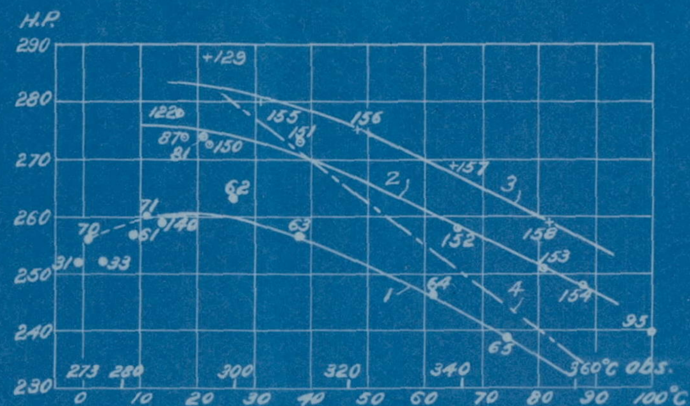

Fig. 7. Dependence of engine performance on intake temperature at 1450 R.P.M. with various pressures before the carburator and at constant exhaust pressure.

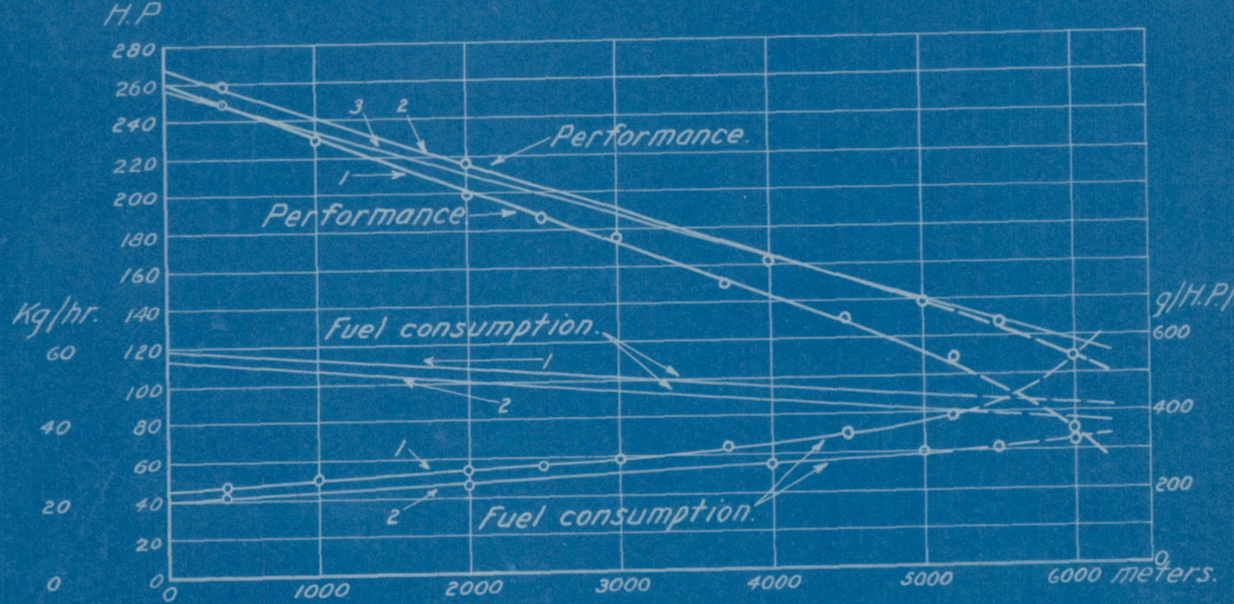

Fig. 1. Performance and gas consumption of DIVa engine running at 1450 r.p.m. at various altitudes.

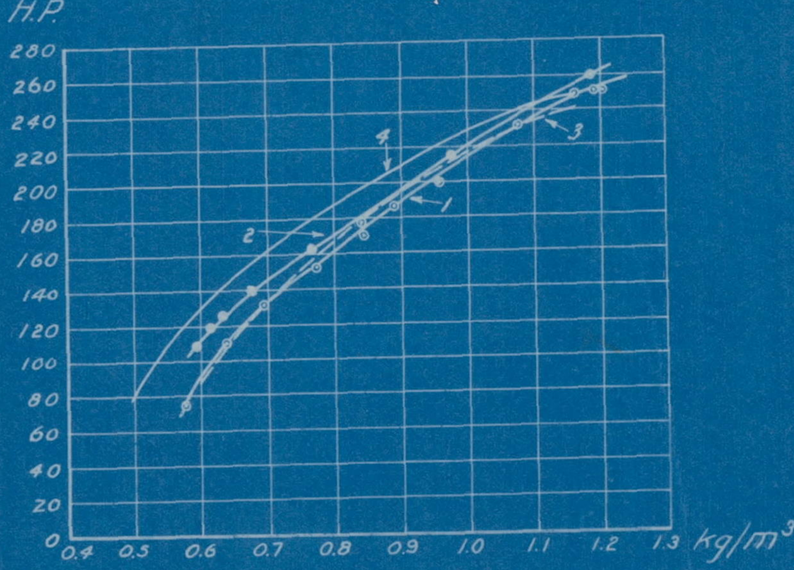

Fig. 2. Performance of DIVa engine running at 1450 r.p.m. for various air denisities.

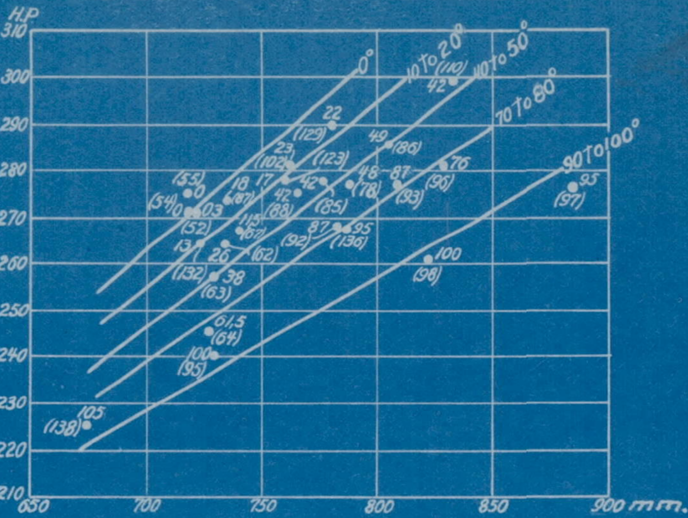

Fig. 3. Dependence of performance on the pressure and temperature of the intake air before the carberator.

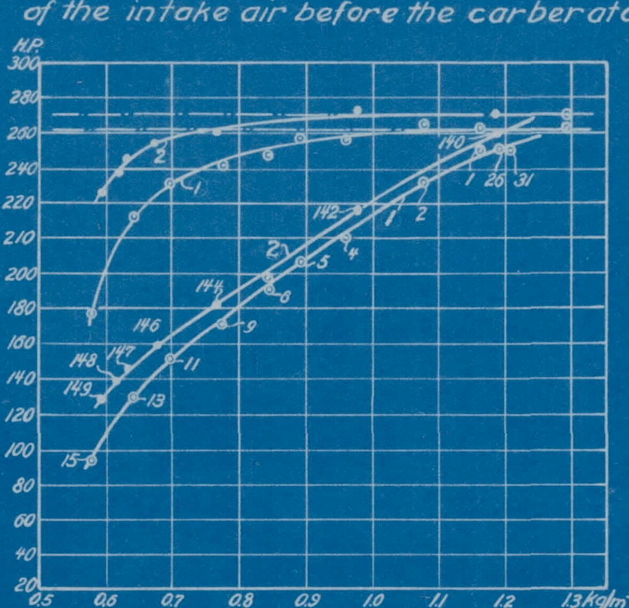

Fig. 4. Calculated performance of DVIa engine running at 1450 R.P.M. with various air densities.

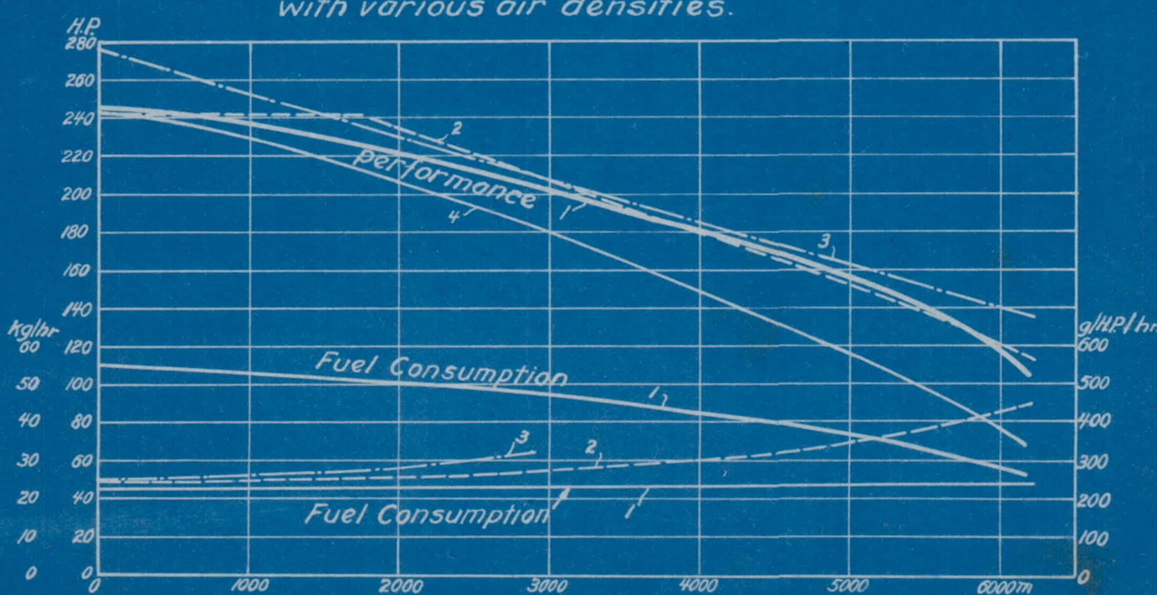

Fig. 5. Performance and gasoline consumption of the MbIVa and the Mb HSLu engines running at 1450 R.P.M. at various altitudes.