REPORT No. 103

PERFORMANCE OF A 300-HORSEPOWER HISPANO-SUIZA AIRPLANE ENGINE

By S. W. SPARROW and H. S. WHITE
Bureau of Standards

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RÉSUMÉ.

The following report of a complete performance test of a 300-horsepower Hispano-Suiza engine was submitted for publication to the National Advisory Committee for Aeronautics by the Bureau of Standards. The test described in the report was conducted in the altitude chamber of the Bureau of Standards under the joint supervision of the technical staff of the Bureau of Standards and the Engineering Division of the Air Service. The program of tests was planned in cooperation with the Engineering Division of the Air Service of the United States Army so as to yield enough data to determine adequately the characteristics of the engine for aviation purposes without operating it for so long a time as to prevent extensive flying tests from being carried out with the same engine later. The particular engine used in these tests was assembled by the Engineering Division at McCook Field and subjected to the standard dynamometer test for operation at ground level, then shipped to the Bureau of Standards and mounted in the altitude chamber without overhaul. After the altitude test it was returned to McCook Field for such flight tests as might be desired.

A prime requisite of the aviation engine is durability, but it is evident that the long runs necessary to determine this are more properly made with less costly and elaborate equipment than that of the altitude chamber.

The following tests were made:

1. A full power run at ground altitude at speeds from 1,400 to 2,200 r. p. m.
2. An altitude-power run at full throttle and at speeds of 1,600 and 1,800 r. p. m. from the ground to 25,000 feet (7,620 meters) in steps of 5,000 feet (1,520 meters).
3. Propeller load runs, in which the dynamometer load was so adjusted as to produce approximately the same engine load as would be imposed by the propeller at speeds from 1,400 r. p. m. to the normal propeller speed of 1,800 r. p. m. These were taken at altitudes of 5,000, 10,000, and 15,000 feet. (1,520, 3,050, 4,570 meters.)
4. Friction horsepower runs at the ground and at 15,000 feet. (4,570 meters.)

RESULTS.

Some of the outstanding results are given in the tables accompanying this résumé. Correcting the results to a standard barometric pressure of 29.9 inches (76.0 cm.) of mercury gives a brake horsepower at 2,200 r. p. m. of 352 (357 metric horsepower), and a maximum brake mean effective pressure of 128 pounds per square inch (9 kg. per sq. cm.) at about 1,600 r. p. m. The mechanical efficiency varies from 88 per cent to 83 per cent from speeds of 1,400 r. p. m. to 2,200 r. p. m., while the brake thermal efficiency, based on the lower calorific value of the fuel maintains a constant value of 26 per cent over the same range.

Due to lack of an adequate altitude control on the carburetor, the mixture became extremely rich at altitudes of 20,000 feet (6,040 meters) and higher. Below this altitude, where the air fuel ratio could be adjusted to give minimum fuel consumption consistent with maximum brake

horsepower, the brake horsepower and brake mean effective pressure were found to bear a straight line relation to carburetor air density. At 1,800 r. p. m. and at a density of 0.040 pounds per cubic foot (0.64 kg. per cu. m.), the brake horsepower is about 42 per cent of that at the ground and the indicated horsepower is about 47 per cent of that at the ground.

CONCLUSIONS.

The information in such a report as this will be of most value when compared with results of similar tests on other engines. It then serves as a basis for comparing the relative merits of the two engines and as a means of explaining the superiority of one engine to another in any particular phase of performance.

The test shows the inadequacy of the carburetor altitude control of air-fuel ratio for heights above 20,000 feet (6,040 meters). It also shows how the relative importance of high mechanical efficiency increases with altitude.

TABLE A.—*English units.*

Ground runs. Full power.

Approximate altitude in feet.	R. P. M.	B. m. e. p., lb./sq. in.	B. H. P.	Lb. of fuel per b. h. p. hr.	Carb. air temp. °F.	Air density, lb./cu. ft.	Volumetric efficiency, per cent.	Thermal efficiency, per cent.	Lb. air/lb. fuel ±0.2.
500	1,420	122.6	248	0.52	59	0.075	90	26	14.6
500	1,640	124.7	292	.51	59	.075	89	26	14.5
500	1,840	122.9	317	.52	60	.075	90	26	14.3
500	1,980	117.4	330	.51	59	.075	89	26	15.2
500	2,190	110.0	342	.52	59	.074	87	26	15.2

TABLE B.—*English units.*

Altitude runs. Full power.

Approximate altitude in feet.	R. P. M.	B. m. e. p., lb. per sq. in.	B. H. P.	Lb. of fuel/b. h. p. hr.	Carb. air, temp. °F.	Air density, lb./cu. ft.	Volumetric efficiency, per cent.	Thermal efficiency, per cent.	Lb. of air per lb. of fuel ±0.2.
Ground.	1,600	124.5	283	0.53	59	0.072	91	25	14.3
Ground.	1,800	123.6	316	.54	60	.075	91	25	13.9
5,000	1,610	105.1	241	.53	58	.064	91	25	14.2
5,000	1,790	103.1	264	.54	41	.066	90	25	14.7
10,000	1,600	84.7	193	.60	26	.056	89	23	13.6
10,000	1,810	84.0	216	.56	26	.056	89	24	14.6
15,000	1,590	68.3	155	.61	22	.047	91	22	14.2
15,000	1,790	66.6	170	.59	19	.047	87	23	14.2
20,000	1,620	46.1	107	.86	13	.039	88	16	12.0
20,000	1,820	51.4	133	.69	11	.040	88	19	13.5
25,000	1,780	29.9	76	1.18	12	.033	89	11	11.5
25,000	1,600	31.5	72	1.12	11	.033	91	12	11.6

TABLE C.—*English units.*

Ground runs.

R. P. M.	B. H. P.	F. H. P.	I. H. P.	Mechanical efficiency, per cent.	Air density, lb. per cu. ft.
1,400	243	34	277	88	0.075
1,600	284	43	328	87	.075
1,800	315	53	368	85	.075
2,000	334	62	396	84	.075
2,200	343	72	415	83	.075

TABLE D.

Altitude runs.

Air density, lb. per cu. ft.	B. H. P.	F. H. P.	I. H. P.	Mechanical efficiency.	R. P. M.	B.h.p.÷(b.h.p. at 0.075 density).
0.075	318	53	371	86	1,800	1.00
.065	263	50 30	313	84	1,800	.83
.055	210	46	256	82	1,800	.66
.045	158	43	201	78	1,800	.50
.040	131	42	173	76	1,800	.41
.035	96	40	136	71	1,800	.30

TABLE A.—*Metric units.*

Ground runs. Full power.

Approximate altitude in meters.	R. P. M.	B.m.e.p. kg. per sq. cm.	B. H. P.	Kg. of fuel per b. h. p. hr.	Carb. air, temp. °C.	Air density, kg. per cu. m.	Volumetric efficiency, per cent.	Thermal efficiency, per cent.	Kg. air per kg. fuel ±0.2.
152	1,420	8.6	251	0.23	15	1.20	90	26	14.6
152	1,640	8.8	296	.23	15	1.20	89	26	14.5
152	1,840	8.6	322	.23	15	1.20	90	26	14.3
152	1,980	8.2	335	.23	15	1.20	89	26	15.2
152	2,190	7.2	347	.23	15	1.19	87	26	15.2

TABLE B.—*Metric units.*

Altitude runs. Full power.

Approximate altitude in meters.	R. P. M.	B.m.e.p. kg. per sq. cm.	B. H. P.	Kg. of fuel per b. h. p. hr.	Carb. air, temp. °C.	Air density, kg. per cu. m.	Volumetric efficiency, per cent.	Thermal efficiency, per cent.	Kg. air per kg. of fuel ±0.2.
Ground.	1,600	8.8	287	0.24	15	1.16	91	25	14.3
Ground.	1,800	8.7	320	.24	16	1.20	91	25	13.9
1,520	1,610	7.4	244	.24	14	1.02	91	25	14.2
1,520	1,790	7.2	268	.24	5	1.06	90	25	14.7
3,050	1,600	6.0	195	.27	− 3	.90	89	23	13.6
3,050	1,810	5.9	219	.25	− 3	.90	89	24	14.6
4,570	1,590	4.8	157	.27	− 6	.76	91	22	14.2
4,570	1,790	4.7	173	.26	− 7	.76	87	23	14.2
6,040	1,620	3.2	109	.38	−11	.63	88	16	12.0
6,040	1,820	3.6	135	.31	−12	.64	88	19	13.5
7,620	1,780	2.1	77	.53	−11	.53	89	11	11.5
7,620	1,600	2.2	73	.50	−12	.53	91	12	11.6

TABLE C.—*Metric units.*

Ground runs.

R. P. M.	B. H. P.	F. H. P.	I. H. P.	Mechanical efficiency, per cent.	Air density, kg. per cu. m.
1,400	246	34	280	88	1.20
1,600	288	44	332	87	1.20
1,800	319	54	373	85	1.20
2,000	339	63	402	84	1.20
2,200	348	73	421	83	1.20

TABLE D.—*Metric units.*

Altitude runs.

Air density, kg. per cu. m.	B. H. P.	F. H. P.	I. H. P.	Mechanical efficiency, per cent.	R. P. M.	B.h.p.÷(b. h.p. at 1.20 density).
1.20	322	54	376	86	1,800	1.00
1.04	267	50	317	84	1,800	.83
.88	213	47	260	82	1,800	.66
.72	160	44	204	78	1,800	.50
.64	133	42	175	76	1,800	.41
.56	97	41	138	71	1,800	.30

OBJECT OF TEST.

The test was made to determine the performance of a 300 horsepower Hispano-Suiza engine and was typical of the class of tests usually run on a new type engine in that some completeness was sacrificed in order to restrict the actual running time of the engine to an amount which would leave the engine in good condition for actual flight work.

DESCRIPTION OF ENGINE AND APPARATUS.

(*A*). *Engine and supplies.*

The engine used was a 300 horsepower Hispano-Suiza, S. C. No. 13481. This is a Vee type motor with eight water-cooled cylinders. It has a bore of 140 mm. (5.51 inches), stroke of 150 mm. (5.91 inches), and a compression ratio of 5.3. The Stromberg carburetor used is provided with a manually operated valve for controlling the air-fuel ratio at the different altitudes. Mobile B oil was used for lubrication and X gasoline for fuel. The X gasoline conforms to the Aircraft Production Board's Specification 3512 for Export Aviation Gasoline for the A. E. F., 1918. A distillation curve of the fuel is given on curve sheet 15.

(*B*). *Apparatus.*

The engine was tested in the Altitude Chamber of the Bureau of Standards. This chamber and apparatus is described in report No. 44 of the National Advisory Committee for Aeronautics (Bureau of Standards Automotive Power Plants Report No. 52). Provision is made for reducing the pressure of the air in the chamber to that of the altitude desired, while at the same time its temperature may be reduced to correspond with the temperature that prevails at that altitude. Outside the chamber there is ample equipment for measuring power, fuel consumption, and various temperatures and pressures.

PROGRAM OF TESTS.

(1) A run was made with wide-open throttle at ground altitude at speeds from 1,400 r. p. m. to 2,200 r. p. m. The spark advance was adjusted for maximum power at each speed. The carburetor was adjusted at each speed to give the least fuel consumption possible with maximum power. To secure this result the carburetor was first adjusted for maximum power and then the mixture was leaned until the torque dropped appreciably. The mixture was then again enriched until maximum torque was restored.

(2) A run was made with wide-open throttle at speeds of 1,600 r. p. m. and 1,800 r. p. m. at altitudes of ground, 5,000, 10,000, 15,000, 20,000, and 25,000 feet (1,520, 3,050, 4,570, 6,040, and 7,620 meters). At each speed and altitude the spark and carburetor were adjusted as for the ground run.

(3) A series of runs were made at altitudes of 5,000, 10,000, and 15,000 feet (1,520, 3,050, and 4,570 meters) at speeds of 1,400, 1,500, 1,600, 1,700, and 1,800 r. p. m. In these runs the dynamometer and throttle were so adjusted as to put a load on the engine at each speed equal to that which would be imposed by a propeller whose normal speed was 1,800 r. p. m. In runs of this type it is assumed that the horsepower of a propeller varies as the cube of the speed.

Thus, if 1,800 be the normal r. p. m. of the propeller, that is, the r. p. m. obtained with full power of the engine, then the horsepower at 1,400 r. p. m. will be $\frac{1400^3}{1800^3}$ times the horsepower at 1,800 r. p. m. In these runs the spark and carburetor were adjusted at 1,800 r. p. m. as in the above runs, but these adjustments were not altered for the other loads.

(4) A series of friction horsepower runs were made at speeds from 1,400 r. p. m. to 2,200 r. p. m. at altitudes of ground and 15,000 feet (4,570 meters.) In these runs the engine was operated under power until oil and water temperature became normal. It was then driven by the dynamometer and the power input measured.

METHOD OF OBTAINING RESULTS.

The results of the tests are given in Tables 1 to 9. A detailed record of the complete test procedure of the laboratory, both in securing data and computing results, is in preparation, so that a brief explanation here will suffice. The run numbers are those that were used on the original sheets to designate the different runs.

Altitude was determined from the curve sheet number 16, using the barometric pressure measured at the carburetor entrance. The engine torque was measured on a 21-inch arm on the dynamometer, and from this value the torque in pound-feet, brake mean effective pressure, and brake horsepower were calculated. The brake horsepower calculation, of course, required the speed which was obtained with a revolution counter. Temperatures were all measured with thermocouples and pressures with U type manometers.

The volume of air used per unit time was measured with a Venturi meter calibrated in place against a carefully tested Thomas meter. From measurements of temperature and pressure air density was figured, and then the weight of air used.

The volumetric efficiency is the ratio of the volume of air which the engine actually takes in per cycle of two revolutions to the total piston displacement of the engine. The air volume is computed at the temperature and pressure existing at the entrance to the carburetor.

The brake thermal efficiency is the ratio of the heat equivalent of brake horsepower to the heat equivalent of fuel supplied. Since the temperature in the engine cylinder is so high as to prevent the condensation of water vapor resulting from combustion, the heat that would be liberated in such a case (the difference between the upper and lower heating value of the fuel) can not be used by the engine. Hence in calculating thermal efficiencies the lower heating value is used which for X gasoline is 18,940 B. t. u. per pound (34,100 cal. per gram).

In calculating the heat distribution in Table 2, however, the higher heating value of the fuel (20,320 B. t. u. per pound (36,600 cal. per gram)) is used because in the calorimeter used for obtaining exhaust heat the water vapor resulting from combustion is condensed. Residual heat is obtained by difference. It includes, and in fact its chief element is, the heat equivalent of the unburned fuel which goes out of the exhaust. It will be noted that no consideration has been given to the power developed by the lubricating oil burned. The difficulties in determining just how much of the oil consumed is actually burned on the power stroke, together with the probability that this percentage is not greatly different for engines of similar type, have made it seem best to ignore this factor in heat balances up to the present time.

The brake horsepower and brake mean effective pressure obtained on the ground run are converted to values for standard barometric pressure by multiplying the values actually obtained by the ratio of 29.9 to the actual barometric pressure in inches of mercury.

The results shown in Table 9 are taken from the curves at even speeds. The indicated horsepower is obtained by adding the brake horsepower to the friction horsepower. The mechanical efficiency is obtained by dividing the brake horsepower by the indicated horsepower. In obtaining the value of friction horsepower at different densities, its value at the ground and at 15,000 feet (4,570 meters) was taken and it was assumed to vary linearly between these points. Previous tests justify this assumption.

RESULTS.

The more important results of the ground tests are shown on curve sheets 1 to 5, inclusive. Curve sheet 1 shows the maximum measured brake mean effective pressure to have been 124 pounds per square inch (8.7 kg. per sq. cm.) at a speed of about 1,600 r. p. m. The maximum brake horsepower measured was 343 (348 metric horsepower) at 2,200 r. p. m., with the indication that this would have increased slightly at higher speed. The atmospheric pressure was such as would be equivalent to an altitude of about 500 feet (150 meters) and the slightly higher results that would be expected under standard barometric pressure are given on curve sheet 2. This shows a maximum brake mean effective pressure of 128 pounds per square inch (9 kg. per sq. cm.) and a maximum brake horsepower of 352 (357 metric horsepower). Curve sheet 3 shows indicated horsepower, that is, the horsepower obtained by adding to the brake horsepower the friction horsepower at that speed, plotted against r. p. m. The lower curve shows the dependence of power upon charge weight by presenting at each speed the ratios of the indicated horsepower and pounds of air per hour at that speed to their values at 2,200 r. p. m. The mechanical efficiency is shown to vary from 88 per cent to 83 per cent over the speed range tested, while the brake thermal efficiency, based on the lower calorific value of the fuel, maintains a constant value of 26 per cent over the same range. In studying the curve of pounds of air per pound of fuel on sheet 4, it must be remembered that the carburetor was adjusted for each speed so that the shape of this curve does not indicate a carburetor characteristic. Curve sheet 5 shows the heat distribution. At 1,800 r. p. m., the normal speed of the engine, the heat in the fuel supplied is about 4.1 times that realized in brake horsepower and the heat in the jacket is about half that developed in brake horsepower. Under the same conditions the heat in the exhaust is about 1.7 times and the residual about equal to the heat equivalent of the brake horsepower. It should be remembered that the residual heat is the difference between the heat in the fuel and that which appears in brake horsepower, in the jacket, and as heat in the exhaust. Hence the residual heat includes and is chiefly composed of the heat value of the unburned fuel in the exhaust.

The curve sheets 6 to 8, inclusive, show the effect of change of altitude on engine performance. Since it is the change in density caused by change in altitude that is the fundamental cause of these changes, it is against air density that curves are plotted. That the results may be conveniently interpreted from a pressure standpoint vertical lines have been drawn upon which approximate barometric pressure are noted.

Prior to any careful analysis of the altitude curves the curves of pounds of fuel per brake horsepower hour on curve sheet 6 and pounds of air per pound of fuel on curve sheet 9 should be examined. The mixture will be seen to have been very rich at altitudes of 20,000 and 25,000 ft. (6,040 and 7,620 meters) due to the fact that the carburetor adjustment was not sufficient to permit the necessary decrease in fuel flow at those altitudes. Extreme richness, of course, manifests itself both in a reduction and fluctuation in speed and torque. Curve sheet 6 shows the brake mean effective pressure and brake horsepower to vary linearly with density up to the point where the mixture becomes abnormal. Curve sheet 7 shows that at 1,800 r. p. m. and at a density of 0.040 pounds per cubic foot (.6.4 kg. per cu. m.) the brake horsepower is about 42 per cent of that at the ground. This curve sheet also shows the percentage decrease in indicated horsepower for a reduced density to be considerably greater than the decrease in pounds of air used by the engine. On curve sheet 10 it should be borne in mind that it is the carburetion that is directly repsonsible for the high "heat in fuel over heat in brake horsepower" and "residual heat over heat in brake horsepower" values, and that indirectly it is responsible for the final high values of "heat in jacket over heat in brake horsepower" through the resulting low power.

Those curves on propeller load work on curve sheets 11 and 12 which show mixture ratios or fuel consumption are influenced primarily by carburetor characteristics, since its only adjustment was at the maximum speed, 1,800 r. p. m.

CONCLUSIONS.

The information in such a report as this will be of most value when compared with results of similar tests on other engines. It then serves as a basis for comparing the relative merits of the two engines and as a means of explaining the superiority of one engine over another in any particular phase of performance.

The test shows the inadequacy of the carburetor altitude control of air-fuel ratios for heights above 20,000 feet (6,040 meters). It also shows how the relative importance of high mechanical efficiency increases with altitude.

WASHINGTON, D. C., *May 12, 1920.*

TABLE I.—*English units.*

Ground runs. Full power.

Run No.	Approximate altitude in ft.	R. p. m.	Torque, lb. ft.	B. m. e. p., lb. per sq. inch.	B. h. p.	Lb. of fuel per hour.	Lb. of fuel per b. h. p. hour.
1 A	500	1,420	915	122.6	248	128	0.52
2 A	500	1,640	930	124.7	292	148	.51
3 A	500	1,840	917	122.9	317	166	.52
4 A	500	1,980	877	117.4	330	169	.51
5 A	500	2,190	820	110.0	342	179	.52

Run No.	Temperature, degrees F.					Oil pressure, lb. per sq. inch.	Manifold suction, inches hg.		Barometric pressure, inches hg.
	Oil inlet.	Oil outlet.	Jacket water inlet.	Jacket water outlet.	Carburetor air.		*R.*	*L.*	
1 A	96	136	87	110	59	65	1.0	1.0	29.4
2 A	123	159	88	106	59	63	1.2	1.1	29.3
3 A	124	170	88	110	60	63	1.5	1.3	29.2
4 A	....	162	87	110	52	65	1.8	1.5	29.1
5 A	....	166	92	107	59	63	1.9	1.8	29.0

TABLE II.—*English units.*

Ground runs. Full power.

Run No.	Heat distribution based on b. h. p.				Heat distribution based on heat in fuel.			
	Heat in fuel ÷(heat in b. h. p.).	Heat in jacket ÷(heat in b. h. p.).	Heat in exhaust ÷(heat in b. h. p.).	Residual heat ÷(heat in b. h. p.).	B. h. p., per cent.	Jacket, per cent.	Exhaust, per cent.	Residual, per cent.
1 A	4.1	0.41	1.9	0.8	24	10	46	20
2 A	4.0	.40	1.7	.9	25	10	42	23
3 A	4.2	.48	1.7	1.0	24	11	40	25
4 A	4.1	.55	1.9	.6	24	13	47	16
5 A	4.2	.39	2.0	.8	24	9	47	20

Run No.	Air density, lb per cu. ft.	Lb. air per hr.	Volumetric efficiency, per cent.	Thermal efficiency, per cent.	Lb. air per lb. of fuel, ±0.2.
1 A	0.075	1,870	90	26	14.6
2 A	.075	2,150	89	26	14.5
3 A	.075	2,380	90	26	14.3
4 A	.075	2,580	89	26	15.2
5 A	.074	2,770	87	26	15.2

TABLE III.—*English units.*

Altitude runs. Full power.

Run No.	Approximate altitude in ft.	R. p. m.	Torque, lb. ft.	B. m. e. p.	B. h. p.	Lb. of fuel per hr.	Lb. of fuel per b. h. p. hr.
11 A	Ground..	1,600	930	124.5	283	150	0.53
12 A	Ground..	1,800	938	123.6	316	171	.54
13 A	5,000	1,610	784	105.1	241	129	.53
14 A	5,000	1,790	772	103.1	264	142	.54
15 A	10,000	1,600	632	84.7	193	115	.60
16 A	10,000	1,810	628	84.0	216	122	.56
17 A	15,000	1,590	511	68.3	155	95	.61
18 A	15,000	1,790	499	66.6	170	101	.59
19 A	20,000	1,620	345	46.1	107	92	.86
20 A	20,000	1,820	383	51.4	133	92	.69
21 A	25,000	1,780	224	39.9	76	90	1.18
22 A	25,000	1,600	235	31.5	72	80	1.12

Run No.	Temperature, degrees F.					Oil pressure, lb. per sq. in.	Manifold suction, inches hg.		Barometric pressure, inches hg.
	Oil inlet.	Oil outlet.	Jacket water inlet.	Jacket water outlet.	Carburetor, air.		*R.*	*L.*	
11 A	104	141	91	117	59	66	1.3	1.2	29.4
12 A	124	164	92	111	60	64	1.5	1.4	29.3
13 A	113	151	88	108	58	66	1.1	1.1	24.9
14 A	115	157	91	107	41	66	1.2	1.2	24.9
15 A	121	152	92	111	26	64	.6	.8	20.7
16 A	124	158	94	111	26	64	.6	1.0	20.7
17 A	121	156	95	111	22	64	...	.6	17.2
18 A	121	157	97	112	19	64	.1	.6	17.0
19 A	118	151	94	107	13	65	.1	.6	14.0
20 A	120	152	98	111	11	65	...	.6	14.2
21 A	118	153	97	107	12	62	.1	.6	11.7
22 A	116	151	94	105	11	63	.2	.5	11.7

TABLE IV.—*English units.*

Altitude runs. Full power.

Run No.	Heat distribution based on b. h. p.				Heat distribution based on heat in fuel.			
	Heat in fuel ÷(heat in b. h. p.)	Heat in jacket÷(heat in b. h. p.)	Heat in exhaust÷(heat in b. h. p.)	Residual heat÷(heat in b. h. p.)	B. h. p., per cent.	Jacket, per cent.	Exhaust, per cent.	Residual, per cent.
11 A	4.2	0.59	2.0	0.6	24	14	48	14
12 A	4.3	.46	1.8	1.0	23	11	42	24
13 A	4.3	.54	1.8	.9	23	13	43	21
14 A	4.3	.45	1.8	1.0	23	10	43	24
15 A	4.8	.65	1.8	1.3	21	13	38	28
16 A	4.5	.57	1.8	1.1	22	13	41	24
17 A	4.9	.65	1.9	1.3	20	13	39	28
18 A	4.7	.64	1.9	1.2	21	14	40	25
19 A	6.8	.76	1.9	3.2	15	11	28	46
20 A	5.6	.67	2.1	1.8	18	12	38	32
21 A	9.4	.96	2.3	5.2	11	10	24	55
22 A	8.9	.98	2.0	4.9	11	11	22	56

Run No.	Air density, lb. per cu. ft.	Lb. air per hr.	Volumetric efficiency, per cent.	Thermal efficiency, per cent.	Lb. air per lb. of fuel, ±0.2.
11 A	0.072	2,150	91	25	14.3
12 A	.075	2,380	91	25	13.9
13 A	.064	1,840	91	25	14.2
14 A	.066	2,090	90	25	14.7
15 A	.056	1,570	89	23	13.6
16 A	.056	1,790	89	24	14.6
17 A	.047	1,340	91	22	14.2
18 A	.047	1,440	87	23	14.2
19 A	.039	1,100	88	16	12.0
20 A	.040	1,240	88	19	13.5
21 A	.033	1,030	89	11	11.5
22 A	.033	930	91	12	11.6

TABLE V.—*English units.*

Propeller load runs.

Run No.	Approximate altitude in ft.	R. p. m.	Torque. lb. ft.	B. m. e. p., lb. per sq. in.	B. h. p.	Lb. of fuel per hr.	Lb. of fuel per b. h. p. hr.	Barometric pressure, inches hg.
1 B	15,000	1,790	283	66.2	168	100	0.59	17.2
2 B	15,000	1,680	253	58.9	142	86	.60	17.2
3 B	15,000	1,580	223	52.1	117	74	.63	17.1
4 B	15,000	1,500	199	46.3	100	72	.72	17.2
5 B	15,000	1,390	170	39.5	78	66	.84	17.2
6 B	10,000	1,790	358	83.7	214	117	.55	20.7
7 B	10,000	1,690	323	75.3	183	93	.51	20.8
8 B	10,000	1,620	288	67.5	155	89	.57	20.7
9 B	10,000	1,490	253	59.3	126	72	.57	20.7
10 B	10,000	1,420	221	51.7	104	71	.68	20.7
11 B	5,000	1,780	437	102.2	259	131	.51	24.9
12 B	5,000	1,700	394	92.1	223	110	.49	25.0
13 B	5,000	1,610	348	81.4	187	92	.49	25.0
14 B	5,000	1,510	318	74.4	160	85	.53	25.1
15 B	5,000	1,410	266	62.2	126	78	.62	25.0

TABLE VI.—*English units.*

Propeller load runs.

Run No.	Temperature, degrees F.					Manifold suction, inches hg.		Air density, lb. per cu. ft.	Lb. of air per hr.	Lb. of air per lb. of fuel, ±0.2.
	Oil inlet.	Oil outlet.	Jacket water inlet.	Jacket water outlet.	Carburetor, air.	*R.*	*L.*			
1 B	113	152	95	112	20	0.9	0.8	0.048	1,450	14.5
2 B	124	157	97	112	19	2.7	2.7	.048	1,180	13.7
3 B	123	155	95	110	19	3.7	4.0	.047	990	13.4
4 B	120	150	94	108	22	4.8	4.7	.047	870	12.1
5 B	116	146	95	110	14	5.5	5.4	.048	770	11.7
6 B	119	157	98	114	27	1.1	1.1	.057	1,690	14.4
7 B	122	158	97	113	27	2.7	2.9	.057	1,420	15.3
8 B	122	157	95	113	27	4.6	4.5	.056	1,230	13.9
9 B	117	151	94	108	27	5.9	5.8	.056	1,030	14.3
10 B	114	147	92	106	27	7.1	6.5	.056	900	12.7
11 B	120	158	97	118	43	1.3	1.2	.066	1,990	15.2
12 B	122	162	93	111	41	3.3	3.4	.066	1,680	15.2
13 B	119	157	92	111	41	5.7	5.5	.066	1,450	16.7
14 B	111	150	91	108	40	7.0	6.7	.066	1,250	14.8
15 B	108	144	89	105	41	8.2	8.4	.066	1,030	13.1

TABLE VII.—*English units.*

Friction horsepower.

Run No.	Approximate altitude, feet.	R. p. m.	Friction h. p.	Barometric pressure, inches hg.	Air density, lb. per cu. ft.
29 B	15,000	1,420	29	17.0	0.044
30 B	15,000	1,600	35	17.0	.044
31 B	15,000	1,800	42	17.1	.044
32 B	15,000	1,990	50	17.0	.044
33 B	15,000	2,170	58	17.1	.044
34 B	Ground	1,390	33	29.3	.076
35 B	Ground	1,610	43	29.2	.075
36 B	Ground	1,780	52	29.1	.075
37 B	Ground	1,980	61	29.1	.075
38 B	Ground	2,180	75	29.1	.075

Temperature, degrees F.

Run No.	Oil inlet.	Oil outlet.	Jacket inlet.	Jacket outlet.	Carburetor, air.
29 B	113	143	116	118	56
30 B	115	139	120	121	57
31 B	117	142	122	124	57
32 B	119	146	126	128	56
33 B	123	153	129	131	52
34 B	124	151	121	123	53
35 B	126	147	115	117	53
36 B	124	147	104	106	54
37 B	127	149	108	108	54
38 B	129	154	113	115	54

TABLE VIII.—*English Units.*

Ground and altitude runs.

R. p. m.	B. h. p.	F. h. p.	I. h. p.	Lb. air per hr.÷(lb. air per hr. at 2,200 r. p. m.).	I. h. p. ÷ (i. h. p. at 2,200 r. p. m.).	Mechanical efficiency, per cent.	Approximate air density, lb. per cu. ft.
1,400	243	34	277	0.66	0.66	88	0.075
1,600	284	43	327	.75	.79	87	.075
1,800	315	53	368	.84	.89	85	.075
2,000	334	62	396	.94	.96	84	.075
2,200	343	72	415	1.00	1.00	83	.075

Air density, lb. per cu. ft.	B. h. p.	F. h. p.	I. h. p.	Lb. air per hr.÷(lb. air per hr. at 0.075 density).	I. h. p. ÷ (i. h. p. at 0.075 density).	Mechanical efficiency, per cent.	R. p. m.	B. h. p. ÷ (b. h. p. at 0.075 density).
0.075	282	43	325	1.00	1.00	87	1,600	1.00
.065	235	41	276	.86	.85	85	1,600	.83
.055	189	38	227	.73	.70	83	1,600	.67
.045	141	36	177	.60	.54	80	1,600	.50
.040	116	34	150	.53	.46	77	1,600	.41
.035	83	33	116	.46	.36	71	1,600	.29
.075	318	53	371	1.00	1.00	86	1,800	1.00
.065	263	50	313	.86	.83	84	1,800	.83
.055	210	47	257	.73	.66	82	1,800	.66
.045	158	43	201	.59	.50	78	1,800	.50
.040	131	42	173	.52	.41	76	1,800	.41
.035	96	40	136	.46	.30	71	1,800	.30

TABLE I.—*Metric Units.*

Ground runs. Full power.

Run No.	Approximate altitude in meters.	R. p. m.	Torque, kg. meters.	B. m. e. p., kg. per sq. cm.	B. h. p.	Kg. of fuel per hr.	Kg. of fuel per b. h. p. hr.
1 A	150	1,420	126	8.6	251	58	0.23
2 A	150	1,640	128	8.8	296	67	.23
3 A	150	1,840	127	8.6	322	75	.23
4 A	150	1,980	121	8.2	335	77	.23
5 A	150	2,190	113	7.7	347	81	.23

Run No.	Temperature, degrees C.					Oil pressure, kg. per sq. cm.	Manifold suction, cm. hg.		Barometric pressure, cm. hg.
	Oil inlet.	Oil outlet.	Jacket water inlet.	Jacket water outlet.	Carburetor, air.		*R.*	*L.*	
1 A	35	58	31	43	15	4.6	2.5	2.4	74.7
2 A	50	71	31	41	15	4.4	3.0	2.9	74.4
3 A	52	76	31	43	15	4.4	3.7	3.4	74.3
4 A	....	72	31	43	15	4.6	4.6	3.8	74.0
5 A	....	74	33	42	15	4.4	4.9	4.5	73.7

TABLE II.—*Metric units.*

Ground runs. Full power.

Run No.	Heat distribution based on b. h. p.				Heat distribution based on heat in fuel.			
	Heat in fuel÷(heat in b. h. p.).	Heat in jacket ÷ (heat in b. h. p.).	Heat in exhaust ÷ (heat in b. h. p.).	Residual heat ÷ (heat in b. h. p.).	B. h. p., per cent.	Jacket, per cent.	Exhaust, per cent.	Residual, per cent.
1 A	4.1	0.41	1.9	0.8	24	10	46	20
2 A	4.0	.40	1.7	.9	25	10	42	23
3 A	4.2	.48	1.7	1.0	24	11	40	25
4 A	4.1	.55	1.9	.6	24	13	47	15
5 A	4.2	.39	2.0	.8	24	9	47	20

Run No.	Air density, kg. per cu. m.	Kg. air per hr.	Volumetric efficiency, per cent.	Brake thermal efficiency, per cent.	Kg. air per kg. of fuel, ±0.2.
1 A	1.20	850	90	26	14.6
2 A	1.20	970	89	26	14.5
3 A	1.20	1,080	90	26	14.3
4 A	1.20	1,170	89	26	15.2
5 A	1.19	1,260	87	26	15.2

TABLE III.—*Metric units.*

Altitude runs. Full power.

Run No.	Approximate altitude in meters.	R. p. m.	Torque in kg. meters.	B. m. e. p. kg. per sq. cm.	B. h. p.	Kg. of fuel per hour.	Kg. of fuel per b. h. p. hr.
11 A	Ground	1,600	128	8.8	287	68	0.24
12 A	Ground	1,800	130	8.7	320	78	.24
13 A	1,520	1,610	108	7.4	244	59	.24
14 A	1,520	1,790	107	7.2	268	64	.24
15 A	3,050	1,600	87	6.0	195	52	.27
16 A	3,050	1,810	87	5.9	219	55	.25
17 A	4,570	1,590	71	4.8	157	43	.27
18 A	4,570	1,790	69	4.7	173	46	.26
19 A	6,040	1,620	48	3.2	109	42	.38
20 A	6,040	1,820	53	3.6	135	42	.31
21 A	7,620	1,780	31	2.1	77	41	.53
22 A	7,620	1,600	32	2.2	73	36	.50

Run No.	Temperature, degrees C.					Oil pressure, kg. per sq. cm.	Manifold suction, cm. hg.		Barometric pressure, cm. hg.
	Oil inlet.	Oil outlet.	Jacket water inlet.	Jacket water outlet.	Carburetor air.		*R.*	*L.*	
11 A	40	61	33	47	15	4.6	3.4	3.0	74.6
12 A	51	73	33	44	16	4.5	3.8	3.6	74.4
13 A	45	66	31	42	14	4.6	2.7	2.7	63.3
14 A	46	69	33	42	5	4.6	3.1	3.1	63.3
15 A	49	67	33	44	−3	4.5	1.6	2.0	52.5
16 A	51	70	34	44	−3	4.5	1.5	2.5	52.5
17 A	50	69	35	44	−6	4.5		1.5	43.7
18 A	49	69	36	45	−7	4.5	.2	1.6	43.2
19 A	48	66	34	42	−11	4.6	.4	1.6	35.6
20 A	49	67	37	44	−12	4.6	.1	1.6	36.0
21 A	48	67	36	42	−11	4.4	.3	1.6	29.8
22 A	47	66	34	41	−12	4.4	.4	1.3	29.6

TABLE IV.—*Metric units.*

Altitude runs. Full power.

Run No.	Heat distribution based on b. h. p.				Heat distribution based on heat in fuel.			
	Heat in fuel ÷ (heat in b. h. p.).	Heat in jacket ÷ (heat in b. h. p.).	Heat in exhaust ÷ (heat in b. h. p.).	Residual heat ÷ (heat in b. h. p.).	B. h. p., per cent.	Jacket, per cent.	Exhaust, per cent.	Residual, per cent.
11 A	4.2	0.59	2.0	0.6	24	14	48	14
12 A	4.3	.46	1.8	1.0	23	11	42	24
13 A	4.3	.54	1.8	.9	23	13	43	21
14 A	4.3	.45	1.8	1.0	23	10	43	24
15 A	4.8	.65	1.8	1.3	21	13	38	28
16 A	4.5	.57	1.8	1.1	22	13	41	24
17 A	4.9	.65	1.9	1.3	20	13	39	28
18 A	4.7	.64	1.9	1.2	21	14	40	25
19 A	6.8	.76	1.9	3.2	15	11	28	46
20 A	5.6	.67	2.1	1.8	18	12	38	32
21 A	9.4	.96	2.3	5.2	11	10	24	55
22 A	8.9	.98	2.0	4.9	11	11	22	56

Run No.	Air density, kg. per cu. m.	Kg. air per hr.	Volumetric efficiency, per cent.	Thermal efficiency, per cent.	Kg. air per kg. of fuel, ±0.2.
11 A	1.16	970	91	25	14.3
12 A	1.20	1,080	91	25	13.9
13 A	1.02	830	91	25	14.2
14 A	1.06	950	90	25	14.7
15 A	.90	710	89	23	13.6
16 A	.90	810	89	24	14.6
17 A	.76	610	91	22	14.2
18 A	.76	650	87	23	14.2
19 A	.63	500	88	16	12.0
20 A	.64	560	88	19	13.5
21 A	.53	470	89	11	11.5
22 A	.53	420	91	12	11.6

TABLE V.—*Metric units.*

Propeller load runs.

Run No.	Approximate altitude in meters.	R. p. m.	Torque, kg. meters.	B. m. e. p., kg. per sq. cm.	B. h. p.	Kg. of fuel per hr.	Kg. of fuel per b. h. p. hr.	Barometric pressure. cm. hg.
1 B	4,570	1,790	39	4.6	170	45	0.27	43.8
2 B	4,570	1,680	35	4.1	144	39	.27	43.8
3 B	4,570	1,580	31	3.7	119	33	.28	43.5
4 B	4,570	1,500	27	3.2	101	33	.32	43.7
5 B	4,570	1,390	23	2.8	80	30	.38	43.7
6 B	3,050	1,790	50	5.9	217	53	.25	52.6
7 B	3,050	1,690	45	5.3	185	42	.23	52.7
8 B	3,050	1,620	40	4.7	157	40	.26	52.4
9 B	3,050	1,490	35	4.2	128	33	.26	52.5
10 B	3,050	1,420	31	3.6	106	32	.30	52.5
11 B	1,520	1,780	60	7.2	263	60	.23	63.3
12 B	1,520	1,700	54	6.5	227	50	.22	63.5
13 B	1,520	1,610	48	5.7	190	42	.22	63.6
14 B	1,520	1,510	44	5.2	162	38	.24	63.7
15 B	1,520	1,410	37	4.4	128	35	.28	63.5

TABLE VI.—*Metric units.*

Propeller load runs.

Run No.	Temperature, degrees C.					Manifold suction, cm. hg.		Air density kg. per cu. m.	Kg. of air per hour.	Kg. of air per kg. of fuel, ±0.2.
	Oil inlet.	Oil outlet.	Jacket water inlet.	Jacket water outlet.	Carburetor, air.	*Right.*	*Left.*			
1 B	45	67	35	45	−7	2.4	2.1	0.76	660	14.5
2 B	51	70	36	45	−7	6.9	6.9	.77	540	13.7
3 B	51	68	35	43	−7	9.4	10.6	.76	450	13.4
4 B	49	65	34	42	−5	12.2	12.0	.76	390	12.1
5 B	47	63	35	43	−10	14.0	13.6	.77	350	11.7
6 B	48	70	37	46	−3	2.8	2.8	.91	770	14.4
7 B	50	70	36	45	−3	6.9	7.4	.91	640	15.3
8 B	50	70	35	45	−3	11.6	11.4	.90	560	13.9
9 B	47	66	34	42	−3	15.1	14.7	.90	470	14.3
10 B	46	64	33	41	−3	18.0	16.4	.90	410	12.7
11 B	49	70	36	48	+6	3.4	3.0	1.05	900	15.2
12 B	50	72	34	44	+5	8.4	8.7	1.06	760	15.3
13 B	48	70	33	44	+5	14.4	14.0	1.06	660	16.7
14 B	44	65	33	42	+5	17.8	17.1	1.07	570	14.8
15 B	42	62	32	41	+5	22.5	21.4	1.06	460	13.1

TABLE VII.—*Metric units.*

Friction horsepower.

Run. No.	Approximate altitude, meters.	R. p. m.	Friction, h. p.	Barometric pressure, cm. hg.	Air density, kg. per cu. m.
29 B	4,570	1,420	29	43.3	0.70
30 B	4,570	1,600	35	43.3	.70
31 B	4,570	1,800	42	43.5	.70
32 B	4,570	1,990	51	43.3	.70
33 B	4,570	2,170	59	43.4	.71
34 B	Ground.	1,390	34	74.3	1.21
35 B	Ground.	1,610	44	74.2	1.21
36 B	Ground.	1,780	53	74.0	1.21
37 B	Ground.	1,980	62	73.8	1.20
38 B	Ground.	2,180	76	73.8	1.20

Temperature degrees C.

Run No.	Oil inlet.	Oil outlet.	Jacket inlet.	Jacket outlet.	Carburetor air.
29 B	45	62	47	48	13
30 B	46	60	49	49	14
31 B	47	61	50	51	14
32 B	48	63	52	53	13
33 B	50	67	54	55	11
34 B	51	66	50	51	12
35 B	52	64	46	47	12
36 B	51	64	40	41	12
37 B	53	65	42	42	12
38 B	54	68	45	46	12

TABLE VIII.—*Metric units.*

Ground and altitude runs.

R. p. m.	B. h. p.	F. h. p.	I. h. p.	Kg. air per hr. ÷ (kg. air per hour at 2,200 r. p. m.)	I h. p. ÷ (I. h. p. at 2,200 r. p. m.)	Mechanical efficiency, per cent.	Approximate air density kg. per cu. m.
1,400	246	34	280	0.66	0.66	88	1.20
1,600	288	44	332	.75	.79	87	1.20
1,800	319	54	373	.84	.89	85	1.20
2,000	339	63	402	.94	.96	84	1.20
2,200	348	73	421	1.00	1.00	83	1.20

Air density kg. per cu. m.	B. h. p.	F. h. p.	I. h. p.	Kg. air per hr. ÷ (kg. air per hour at 1.22 density).	I. h .p. ÷ (I. h. p. at 1.22 density).	Mechanical efficiency, per cent.	R. p. m.	B. h. p. ÷ (B. h. p. at 1.22 density).
1.20	286	44	330	1.00	1.00	87	1,600	1.00
1.04	238	41	279	.86	.85	85	1,600	.83
.88	192	39	231	.73	.70	83	1,600	.67
.72	143	36	179	.60	.54	80	1,600	.50
.64	118	35	153	.53	.46	77	1,600	.41
.56	84	33	117	.46	.36	71	1,600	.29
1.20	322	54	376	1.00	1.00	86	1,800	1.00
1.04	267	50	317	.86	.83	84	1,800	.83
.88	213	47	260	.73	.66	82	1,800	.66
.72	160	44	204	.59	.50	78	1,800	.50
.64	133	42	175	.52	.41	76	1,800	.41
.56	97	41	138	.46	.30	71	1,800	.30

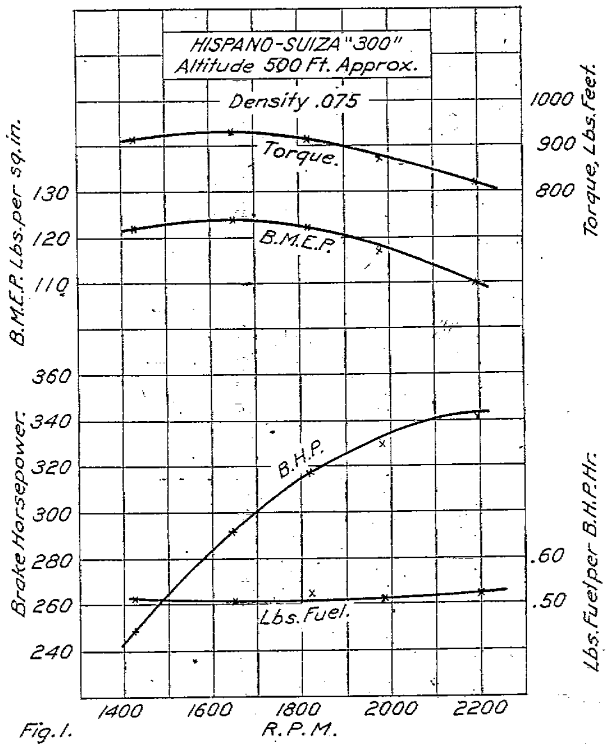

Fig. 1.

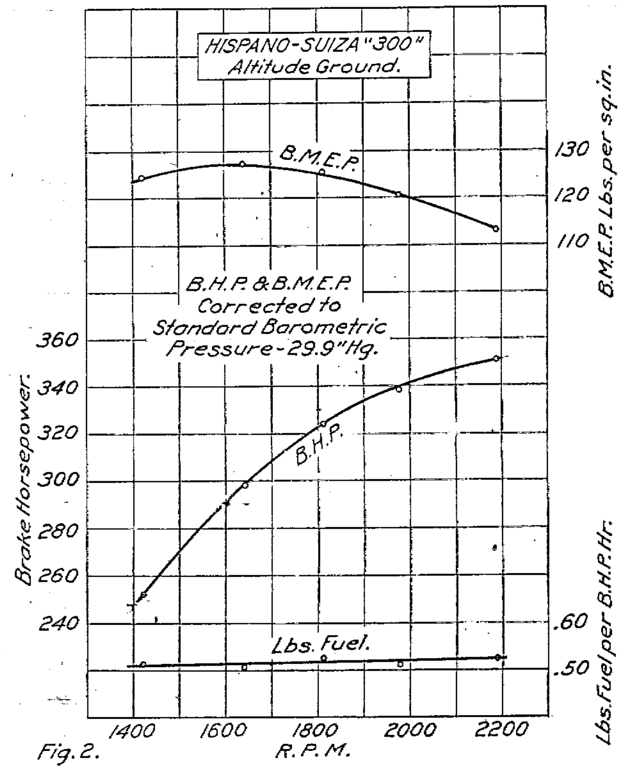

Fig. 2.

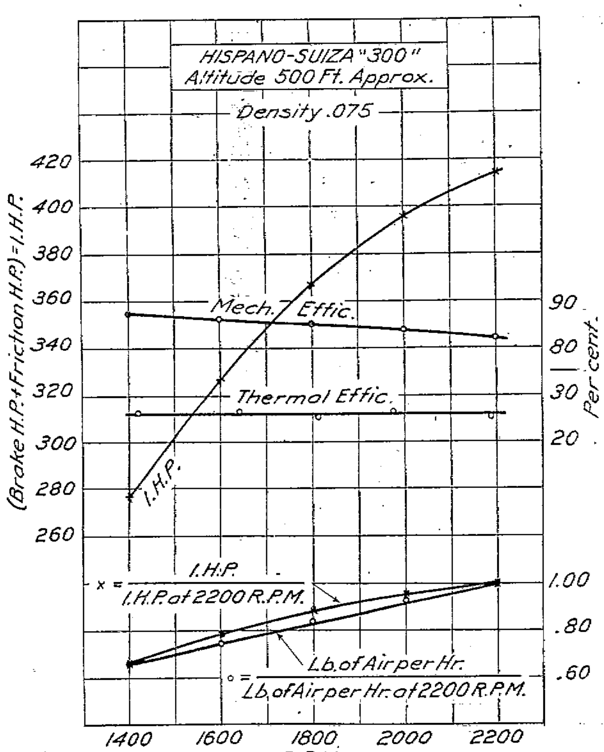

Fig. 3.

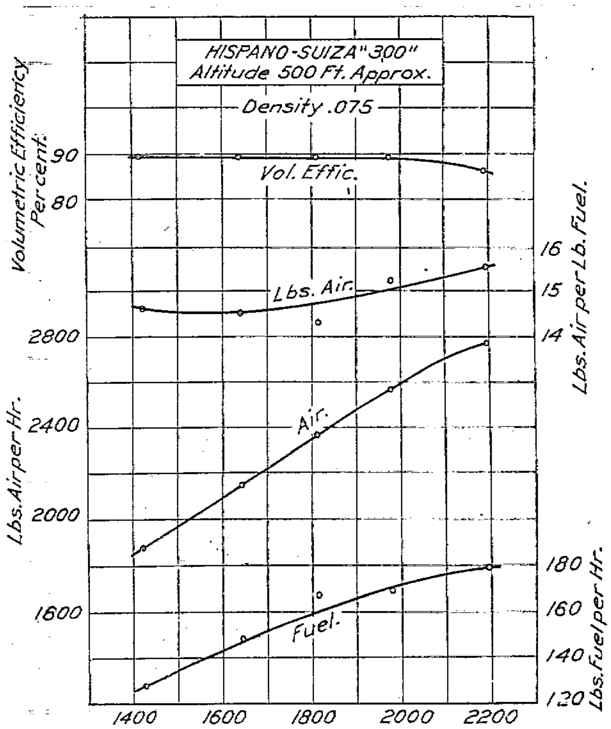

Fig. 4.

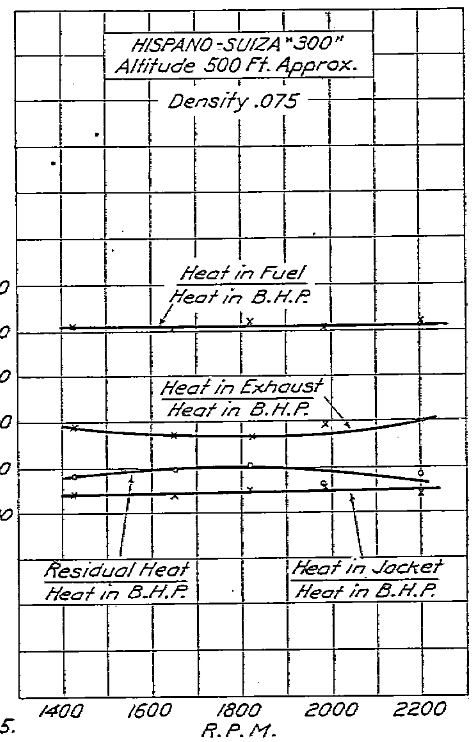

Fig. 5.

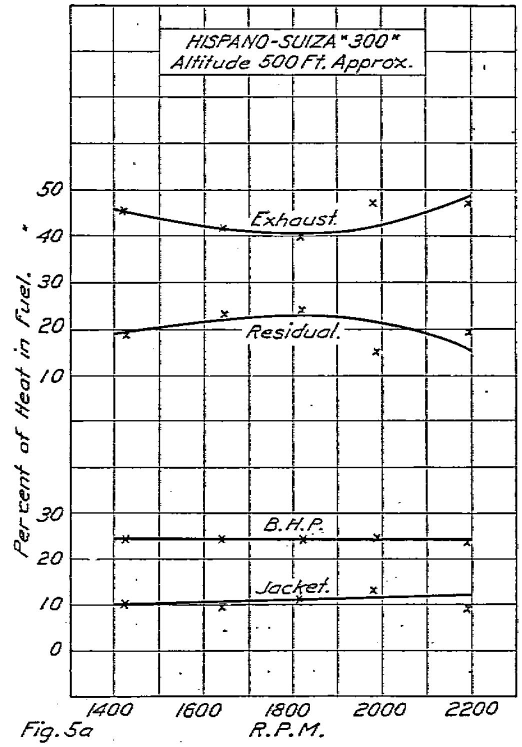

Fig. 5a

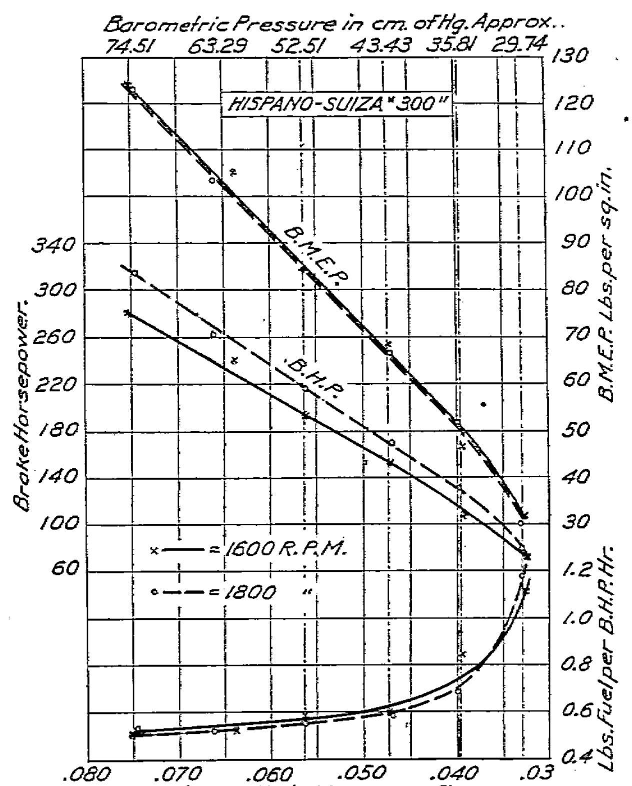

Fig. 6.

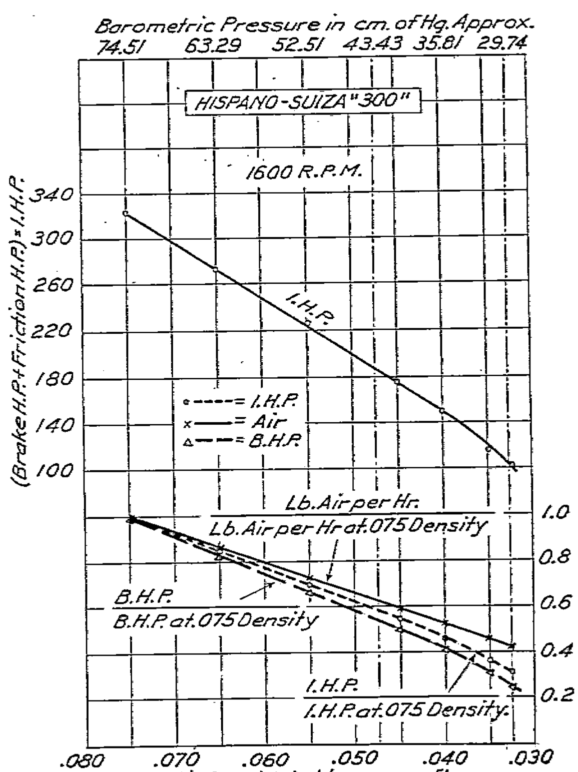

Fig. 7.

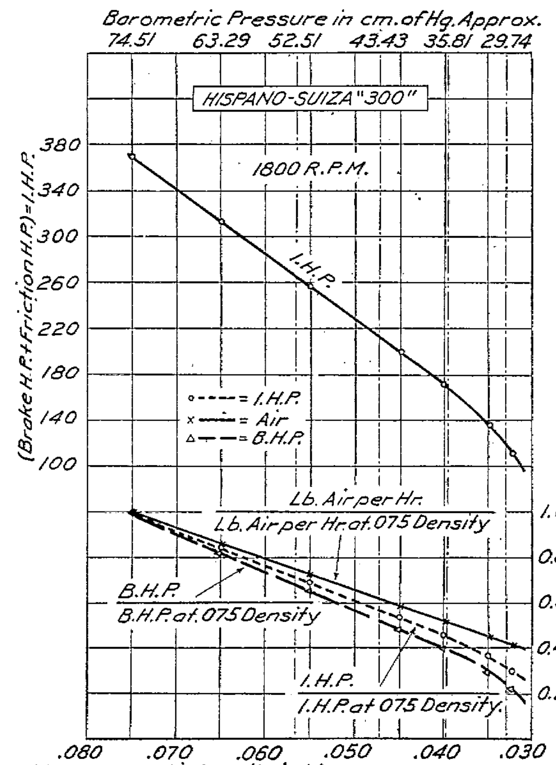

Fig. 7a. Air Density in Lbs. per cu. ft.

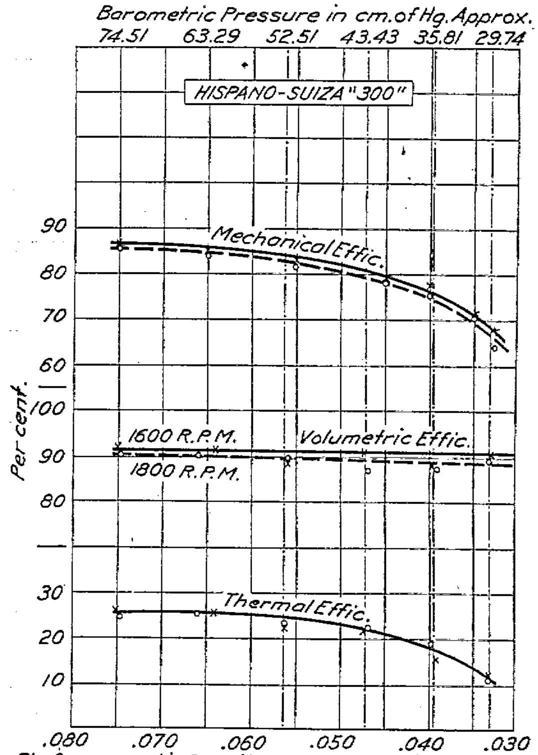

Fig. 8. Air Density in Lbs per cu. ft.

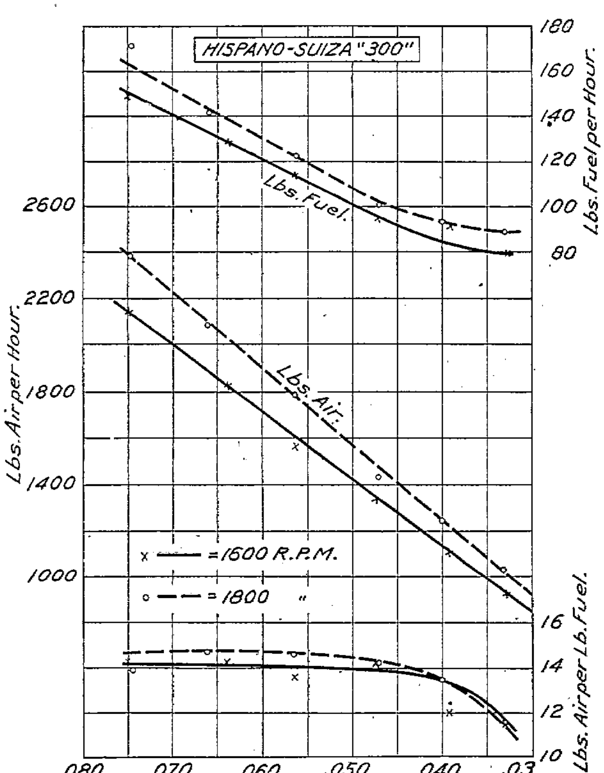

Fig. 9. Air Density in Lbs. per cu. ft.

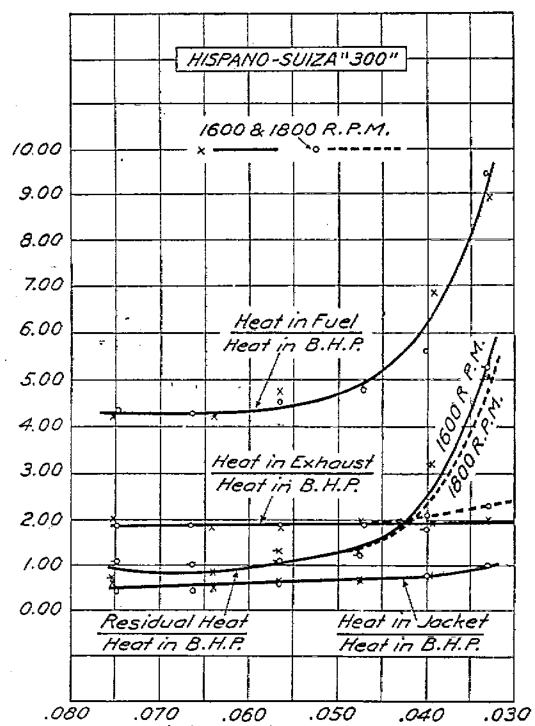

Fig. 10. Air Density in Lbs. per cu. ft.

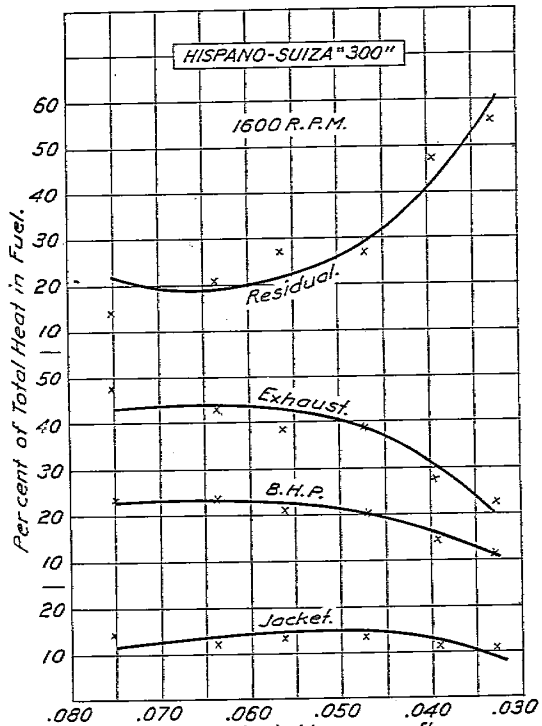

Fig. 10a.

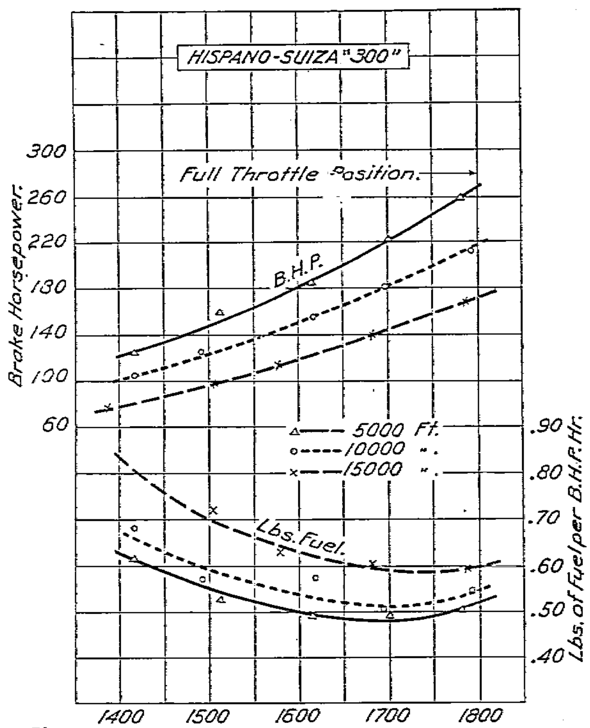

Fig. 11.

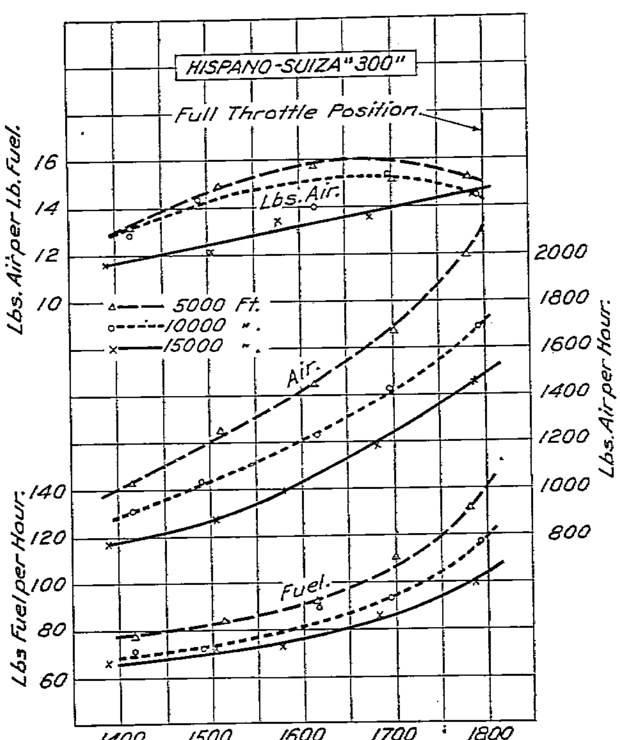

Fig. 12.

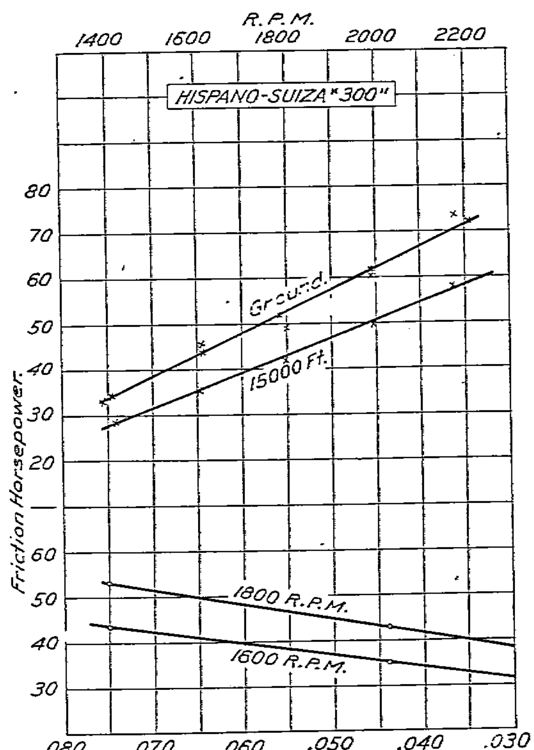

Fig. 13.

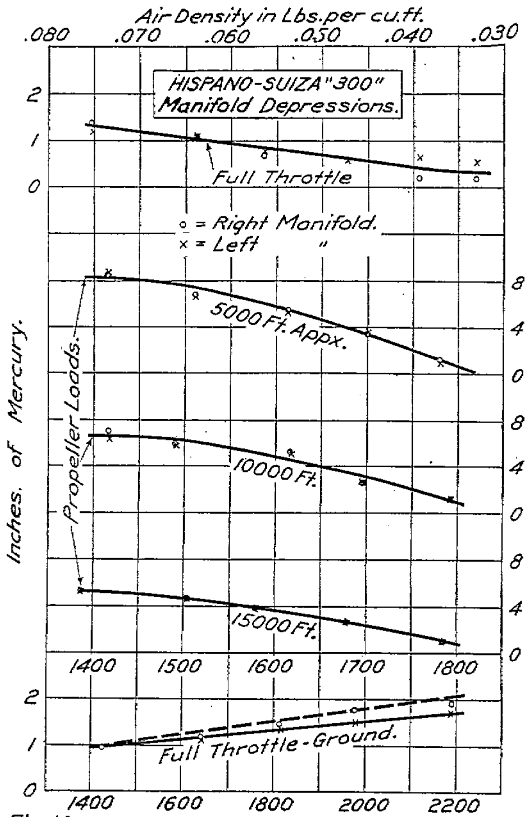

Fig. 14.

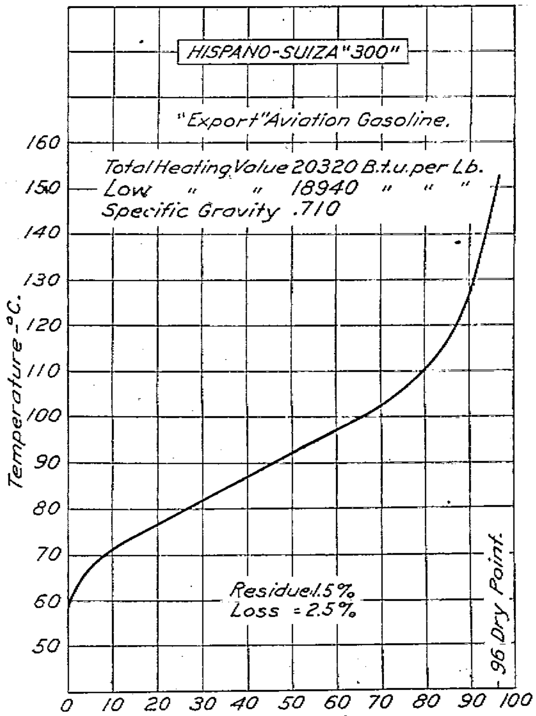

Fig. 15.

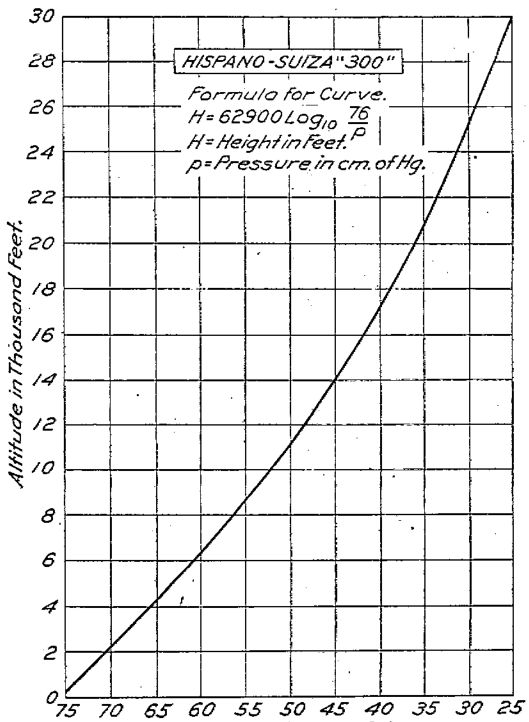

Fig. 16.