REPORT No. 102

PERFORMANCE OF A LIBERTY 12 AIRPLANE ENGINE

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Bureau of Standards

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RÉSUMÉ.

This report, on the complete performance test of the Liberty 12 airplane engine, was submitted for publication to the National Advisory Committee for Aeronautics by the Bureau of Standards. The tests described were conducted in the altitude chamber of the dynamometer laboratory of the Bureau of Standards. 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 that information which is considered of most importance in determining the value of an engine for aviation. 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 tests it was then returned to McCook Field for such flight tests as might be desired. Though the question of durability is of vital importance, it can be determined with much less equipment. Since an aviation engine is comparatively short lived, the tests were purposely made as short as was consistent with the securing of the above information so that the engine might be left in condition for many hours of flight tests.

The following tests were made:

1. A full power run at ground altitude at speeds from 1,200 to 2,000 revolutions per minute.

2. An altitude power run at full throttle and at speeds of 1,600 and 1,700 revolutions per minute from ground altitude 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 and engine throttle were so adjusted as to produce approximately the same engine load as would be imposed by a propeller at speeds from 1,200 revolutions per minute to the normal full load propeller speed of 1,700 revolutions per minute. 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 ground altitude and at 15,000 feet (4,570 meters).

RESULTS.

Some of the outstanding results are given in the accompanying tables. Correcting the results to the standard barometric pressure of 29.9 inches (76 centimeters) of mercury gives a maximum brake horsepower of about 440 (446 metric horsepower) at a speed of 1,900 revolutions per minute, and a maximum brake mean effective pressure of 124 pounds per square inch (8.7 kilograms per square centimeter) at 1,200 revolutions per minute. The mechanical efficiency varies from 90 per cent to 84 per cent from speeds of 1,200 revolutions per minute to 1,900 revolutions per minute, while the brake thermal efficiency, based on the lower calorific value of the fuel maintains a constant value of 25 per cent over the same speed range.

Above 15,000 feet (4,570 meters) altitude the carburetor altitude control is inadequate to maintain the proper mixture ratio. The effect of the rich mixture resulting is to cause a decrease in power below that which would be expected from the very nearly linear relation which brake horsepower and mean effective pressure bear to density as long as the mixture ratio can be adjusted for maximum power. The volumetric efficiency at 1,600 revolutions per minute decreases steadily with altitude from a value of 86 per cent at the ground to a value of 78 per cent at 20,000 feet altitude.

Under the conditions of this test at an air density of 0.0405 pound per cubic foot or 0.65 kilogram per cubic meter, the brake horsepower is about 42 per cent of that at the ground, and the indicated horsepower is approximately 47 per cent of that at the ground.

CONCLUSIONS.

Such information as is contained in a report of this kind is of most value when compared with similar tests of other engines. It then furnishes not only a basis for comparing the relative value of two engines, but also a means for explaining the causes of the superiority of one engine over another in any particular phase of performance. This test in itself, however, yields two conclusions that seem of primary importance:

1. The provision on the carburetors for adjusting the mixture ratio to suit altitude conditions is inadequate for altitudes above 15,000 feet (4,570 meters).

2. In making any changes in this engine to improve its altitude performance—that is, to decrease the rate at which the brake horsepower falls off with altitude—the two methods which offer most hope of success are to increase the mechanical efficiency by decreasing friction horsepower and to make such changes as will prevent the present decrease of volumetric efficiency with increase of altitude.

TABLE A.—*English units.*

Ground runs. Full power.

Approximate altitude (feet).	Revolutions per minute.	Brake mean effective pressure (pounds per square inch).	Brake horsepower.	Pounds of fuel per brake horsepower hour.	Carburetor air temperature (°F.).	Air density (pounds per cubic foot).	Volumetric efficiency (per cent).	Thermal efficiency (per cent).	Pounds air per pound fuel, ±0.2.
1,000	1,220	118.3	302	0.53	59	0.073	85	25	13.3
1,000	1,410	118.0	345	.53	59	.073	87	26	14.0
1,000	1,600	114.2	380	.54	54	.073	84	25	13.6
1,000	1,800	107.6	404	.54	59	.072	83	25	13.9
1,000	1,790	109.4	408	.52	59	.073	84	25	14.7
1,000	1,890	103.8	409	.55	60	.072	82	24	14.1
1,000	1,800	110.4	414	.53	59	.073	83	25	14.1
1,000	1,900	106.3	419	.54	59	.073	81	25	14.1
1,000	2,000	98.2	409	.61	59	.073	78	22	13.0

TABLE B.—*English units.*

Altitude runs. Full power.

Approximate altitude (feet).	Revolutions per minute.	Brake mean effective pressure (pounds per square inch).	Brake horsepower.	Pounds of fuel per brake-horsepower hour.	Carburetor air temperature (°F.).	Air density (pounds per cubic foot).	Volumetric efficiency (per cent).	Thermal efficiency (per cent).	Pounds air per pound fuel, ±0.2.
Ground.	1,620	116.5	393	0.53	59	0.075	86	25	14.3
Ground.	1,700	117.0	414	.51	59	.075	85	26	14.5
5,000	1,690	100.0	352	.53	41	.066	83	25	14.3
5,000	1,610	101.2	339	.58	41	.066	85	23	13.0
10,000	1,600	82.3	273	.58	26	.057	83	23	13.5
10,000	1,690	74.6	262	.69	29	.056	81	20	12.2
10,000	1,710	79.2	282	.54	26	.057	81	25	14.5
15,000	1,690	59.8	209	.67	14	.048	76	20	12.5
15,000	1,590	65.2	216	.57	12	.048	81	23	14.3
20,000	1,570	50.9	166	.67	8	.040	76	20	12.2
20,000	1,700	44.3	157	.81	32	.038	77	16	11.1
25,000	1,700	24.8	88	1.41	19	.032	73	9	9.1
25,000	1,590	30.4	101	1.11	11	.033	74	12	10.0

TABLE C.—*English units.*

Ground runs.

Revolutions per minute.	Brake horse-power.	Friction horse-power.	Indicated horse-power.	Mechanical efficiency (per cent).	Air density (pounds per cubic foot).
1,200	295	33	328	90	0.073
1,400	344	43	387	89	.073
1,600	385	55	440	87	.073
1,800	415	69	484	86	.073
1,900	419	77	496	84	.073
2,000	410	90	500	82	.073

TABLE D.—*English units.*

Altitude runs.

Air density (pounds per cubic foot).	Brake horse-power.	Friction horse-power.	Indicated horse-power.	Mechanical efficiency (per cent).	Revolutions per minute.	B.h.p. ÷(b.h.p. at 0.076 density).
0.076	403	55	458	88	1,600	1.00
.066	336	54	390	86	1,600	.83
.057	276	52	328	84	1,600	.68
.048	216	51	267	81	1,600	.53
.040	163	50	213	77	1,600	.40
.033	96	49	145	66	1,600	.24

TABLE A.—*Metric units.*

Ground runs. Full power.

Approximate altitude (meters).	Revolutions per minute.	Brake mean effective pressure (kilograms per square centimeter).	Brake horse-power.	Kilograms of fuel per brake horse-power hour.	Carburetor air temperature (°C.).	Air density (kilograms per cubic meter).	Volumetric efficiency (per cent).	Thermal efficiency (per cent).	Kilograms air per kilogram fuel, ±0.2.
305	1,220	8.3	306	0.24	15	1.17	85	25	13.3
305	1,410	8.3	350	.24	15	1.17	87	26	14.0
305	1,600	8.0	385	.24	12	1.17	84	25	13.6
305	1,800	7.6	419	.24	15	1.15	83	25	13.9
305	1,790	7.7	414	.23	15	1.16	84	25	14.2
305	1,890	7.3	415	.25	16	1.16	82	24	14.1
305	1,800	7.8	420	.23	15	1.17	83	25	14.1
305	1,900	7.5	425	.24	15	1.17	81	25	14.1
305	2,000	6.9	415	.27	15	1.16	78	22	13.0

TABLE B.—*Metric units.*

Altitude runs. Full power.

Approximate altitude (meters).	Revolutions per minute.	Brake mean effective pressure (kilograms per square centimeter).	Brake horse-power.	Kilograms of fuel per brake horse-power hour.	Carburetor air temperature (°C.).	Air density (kilograms per cubic meter).	Volumetric efficiency (per cent).	Thermal efficiency (per cent).	Kilograms air per kilogram fuel, ±0.2.
Ground.	1,620	8.2	399	94	15	1.20	86	25	14.3
Ground.	1,700	8.2	420	96	15	1.20	85	26	14.5
1,520	1,690	7.0	357	85	4	1.06	83	25	14.3
1,520	1,610	7.1	344	90	5	1.06	85	23	13.0
3,050	1,600	5.8	277	72	−3	.91	83	23	13.5
3,050	1,690	5.2	266	82	−2	.90	81	20	12.2
3,050	1,710	5.1	286	69	−3	.91	81	25	14.5
4,570	1,690	4.2	212	63	−10	.77	76	20	12.5
4,570	1,590	4.6	219	56	−11	.77	81	23	14.3
6,040	1,570	3.6	168	51	13	.64	76	20	12.2
6,040	1,700	3.1	159	58	0	.61	77	16	11.1
7,620	1,700	1.7	89	56	−7	.52	73	9	9.1
7,620	1,590	2.1	102	51	−12	.53	74	12	10.0

TABLE C.—*Metric units.*

Ground runs.

Revolutions per minute.	Brake horsepower.	Friction horsepower.	Indicated horsepower.	Mechanical efficiency (per cent).	Air density (kilograms per cubic meter).
1,200	299	33	332	90	1.17
1,400	349	44	393	89	1.17
1,600	391	56	447	87	1.17
1,800	421	70	491	86	1.17
1,900	425	78	503	84	1.17
2,000	416	91	507	82	1.17

TABLE D.—*Metric units.*

Altitude runs.

Air density (kilograms per cubic meter).	Brake horsepower.	Friction horsepower.	Indicated horsepower.	Mechanical efficiency (per cent).	Revolutions per minute.	B.h.p. ÷ (b.h.p. at 1.22 density).
1.22	409	56	465	88	1,600	1.00
1.06	341	54	395	86	1,600	.83
.91	280	53	333	84	1,600	.68
.77	219	52	271	81	1,600	.53
.64	165	51	216	77	1,600	.40
.53	97	50	147	66	1,600	.24

OBJECT OF TEST.

This test was made to determine the performance of a Liberty 12 airplane engine. The engine was operated under such conditions as would yield sufficient information to determine its value for aviation use. The test was typical of that ordinarily made on a new type of engine in that the completeness of the tests was sacrificed for the sake of reducing the actual running time of the engine. Such a procedure does not materially reduce the life of the engine, and leaves it in good condition for actual flight work.

DESCRIPTION OF ENGINE AND APPARATUS.

(*a*) *Engine.*—The engine used was a Liberty 12, U. S., No. 22, 519 standard in every respect. This is a V-type motor with 12 water-cooled cylinders. It has a bore of 5 inches (12.7 centimeters), stroke of 7 inches (17.8 centimeters), and compression ratio of 5.4. The Zenith carburetor used is provided with a manually operated valve for decreasing the fuel flow to maintain the correct mixture under altitude conditions. Mobile B oil was used on the full-power run on the ground and Liberty aero oil No. 3501 thereafter. Both oils were satisfactory, the reason for the change being of no importance in this test. The X gasoline used conforms to the Aircraft Production Board's Specification 3512 for the American Expeditionary Forces, 1918. A distillation curve of the fuel according to the standard Bureau of Mines method is given on curve sheet 15.

(*b*) *Apparatus.*—The engine was tested in the altitude chamber of the dynamometer laboratory of the Bureau of Standards. A complete description of this apparatus is given in report No. 44 of the National Advisory Committee for Aeronautics (No. 52 of the Bureau of Standards Automatic Power Plant Series). The air from this chamber can be exhausted until its pressure is reduced to that of the altitude desired, while at the same time the temperature of the air supplied to the engine can be reduced to approximately that prevailing at the given altitude. Outside the chamber, apparatus is provided for measuring power, fuel consumption, and all necessary temperatures and pressures.

PROGRAM OF TESTS.

1. A run was made with wide-open throttle at ground altitude at speeds from 1,200 to 2,000 revolutions per minute. At each speed the spark advance was adjusted for maximum power. The carburetor was adjusted at each speed to give the least fuel consumption possible with maximum power. This was accomplished by adjusting the carburetor until the speed and torque showed that the maximum power had been obtained. The mixture was then made so lean that the torque dropped appreciably and then enriched just enough to restore the maximum power.

2. A run was made with wide-open throttle at speeds of 1,600 revolutions per minute and 1,700 revolutions per minute at the ground, and at altitudes of 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 advance and carburetor were adjusted as for the ground run with the exception that carburetor limitations prevented the desired adjustment at the latter two altitudes.

3. A series of runs was made at altitudes of 5,000, 10,000, and 15,000 feet (1,520, 3,050, and 4,570 meters) at speeds of 1,700, 1,600, 1,500, 1,400, 1,300, and 1,200 revolutions per minute. 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 which would absorb the full power of the engine at 1,700 revolutions per minute. In runs of this type it is assumed that the horsepower of a propeller varies as the cube of the speed. Thus if 1,700 be the normal revolutions per minute of the propeller, the horsepower at 1,400 revolutions per minute will be $\frac{1400^3}{1700^3}$ times the horsepower at 1,700 revolutions per minute. In these runs the spark and carburetor were adjusted at 1,700 revolutions per minute at each altitude as in the preceding runs, but were not altered for the other speeds.

4. A series of friction horsepower runs was made at speeds from 1,200 to 2,000 revolutions per minute both at the ground and at an altitude of 15,000 feet (4,570 meters). In these runs the engine was operated under power until oil and water temperatures were normal, and then it was 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 by means of the pressure altitude relation adopted by the Aeronautical Instruments Section of the Bureau of Standards and given on curve sheet 16. The pressures used were measured at the carburetor entrance. The engine torque was measured on a 21-inch (53-centimeter) arm on the dynamometer, and from this value the torque in pounds feet, brake mean effective pressure, and brake horsepower are calculated. The brake horsepower calculation requires the speed which was obtained with a revolution counter and stop watch. Temperatures were all measured with thermo couples and pressures with U-type manometers.

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

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 per stroke. The volume of the air used is determined for the pressure and temperature measured at the carburetor entrance.

The thermal efficiency is the ratio of the heat equivalent of brake horsepower to the heat equivalent of fuel supplied. The lower heating value of the fuel is used, which for gasoline is 18,940 British thermal units per pound (34,100 calories per gram).

In calculating the heat distribution on Table 2, the higher heating value of the fuel (20,320 B. t. u. per pound; 36,600 calories per gram) is used.

Heat in the exhaust is obtained by an exhaust calorimeter method and the residual heat by difference. The latter includes the heat equivalent of the unburned fuel that goes out the exhaust. Power developed by the burning of the lubricating oil has been neglected in heat balances chiefly because of the difficulty in determining just how much of the oil consumed is actually burned on the power stroke.

The brake horsepower and brake mean effective pressure obtained on the ground run are converted to 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 given 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 friction horsepower at different densities its value at 1,600 revolutions per minute at the ground and at 15,000 feet (4,570 meters) was taken, and it was assumed to vary linearly with air density between these points. Previous tests show this to be close enough to the true relation to justify this assumption.

RESULTS.

The more important results of the ground tests are shown on curves 1 to 5, inclusive. The maximum brake mean effective pressure of about 118 pounds per square inch (8.3 kilograms per square centimeter) was attained at 1,200 revolutions per minute. The maximum brake horsepower occurs at about 1,900 revolutions per minute, which is the peak of the curve, the power falling off rapidly thereafter. The atmospheric pressure was such as would be equivalent to an altitude of about 1,000 feet (305 meters), and the results that would be expected under standard barometric pressure are shown on sheet 2. This shows a maximum brake mean effective pressure of 124 pounds per square inch (8.7 kilograms per square centimeter) and maximum brake horsepower of 440 (446 metric) horsepower. The reason for the "flattening out" or peaking of the brake horsepower speed curve is due usually to two major causes—the increase in friction horsepower with speed and the decrease in volumetric efficiency. A study of the indicated horsepower speed curve on sheet No. 3 shows a maximum at about 2,000 revolutions per minute. This curve was obtained by adding the friction horsepower to the brake horsepower at the different speeds, hence the flattening of this curve is due to decrease in volumetric efficiency. The curve at the bottom of the sheet shows how closely the power developed is related to the volumetric efficiency of the engine. On this curve the ratio of the indicated horsepower at each speed to the indicated horsepower at 2,000 revolutions per minute has been plotted, and also the ratio of pounds of air used per hour to the pounds of air used per hour at 2,000 revolutions per minute. The curves are practically identical. In studying the mixture-ratio curve plotted from values taken from curves of pounds of air per hour (sheet 4), it must be remembered that the mixture and pounds of fuel per hour were adjusted by hand at each speed, so that the shape of the curve and the values themselves in no way represent a carburetor characteristic. It is not clear at the present time why these values should be the ones to give maximum power and minimum fuel consumption, but the accumulation of data of this sort, together with further research based definitely on this subject, should furnish an explanation. On sheet 5 is shown the heat distribution. At 1,700 revolutions per minute, the normal speed of the engine, the heat in the fuel supplied is about 4.3 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 nearly 1.7 times and residual is about 1.1 times that realized in 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 in the exhaust. Hence the residual heat includes the heat value of the unburned fuel which goes out of the exhaust.

The curves from 6 to 10, inclusive, show the effect of change in altitude on engine performance. Since it is the change in air density with change in altitude which is the fundamental cause of these changes, it is against air density that these curves are plotted. For convenience in interpretation of the results, from the standpoint of barometric pressure, vertical lines have been drawn through the plotted points and the approximate barometric pressure noted.

For a proper understanding of the altitude curves, the curve of pounds of fuel per brake horsepower hour on curve sheet 6 and pounds of air per pound of fuel curve on sheet 9 should be noted. It will be observed that the mixture became extremely rich as the altitude was increased above 15,000 feet (4,570 meters), due to the fact that the adjustment was at its leanest position at this altitude, and it was impossible to secure the desired mixture beyond this point. The result of this richness of mixture of course manifested itself in extreme fluctuations of speed and torque, and excessive fouling of spark plugs. It will be noted on curve sheet 6 that the brake horsepower and brake mean effective pressure vary linearly with density up to the point where the abnormal mixture ratio results in their decrease. On curve sheet 7 is plotted the ratio of the indicated horsepower, pounds of air per hour and brake horsepower at a given density to their corresponding values at a density of 0.076 (approximately ground altitude). It is seen here, again, that as long as the mixture ratio was held within reasonable limits the percentage change in indicated horsepower was the same as the percentage change in weight of air received by the engine.

The rate of decrease of brake horsepower over indicated horsepower is more rapid with increase of altitude as the friction horsepower does not decrease nearly as rapidly as the brake horsepower and therefore becomes a greater and greater per cent of the brake horsepower. It is of interest to note that on this engine the volumetric efficiency drops steadily with altitude to the extent of a 12 per cent decrease at 25,000 feet (7,620 meters) over what it was at the ground, this, of course, being a vital factor in causing the decrease of power. In studying the curves on sheet 10, it must be remembered that it is the carburetor that is directly responsible 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 the exhaust over heat in brake horsepower" and "heat in jacket over heat in brake horsepower," through the resulting low power.

Comparison of the "Propeller load" curves on sheets 11 and 12 will show that fuel-consumption curve is influenced strongly by the carburetor characteristics as shown by pounds of air over pounds of fuel curve, it being remembered that the carburetor was only adjusted for 1,700 revolutions per minute in these cases.

CONCLUSIONS.

The greatest value of such data as is contained herein can only be realized by its comparison with a number of results obtained on other engines. This not only enables the engines to be judged as to their relative value for a given type of work but also indicates reasons for superiority in performance of one type over another.

There are two outstanding conclusions, however, to be drawn from the test itself—namely, that the carburetor control is inadequate above 15,000 feet (4,570 meters); that the most promising line of development for improved altitude performance lies in increased mechanical efficiency through decreased friction horsepower, and in such changes as will prevent the decrease in volumetric efficiency with increase in altitude.

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TABLE I.—*English units.*

Ground runs. Full power.

Run No.	Approximate altitude (feet).	Revolutions per minute.	Torque (pound feet).	Brake mean effective pressure.	Brake horsepower.	Pounds of fuel per hour.	Pounds of fuel per brake horsepower hour.	Temperature (° F.). Oil. Inlet.	Temperature (° F.). Oil. Outlet.	Temperature (° F.). Jacket water. Inlet.	Temperature (° F.). Jacket water. Outlet.	Temperature (° F.). Carburetor air.	Oil pressure (pounds per square inch).	Manifold suction (inches hg., cyl. 4-5-6 R.).	Barometric pressure (inches hg.).
5 A...	1,000	1,220	1,292	118.3	302	162	0.53	81	142	147	167	59	35	0.6	28.6
6 A...	1,000	1,410	1,289	118.0	345	182	.53	84	156	137	155	59	36	.8	28.6
7 A...	1,000	1,600	1,248	114.2	380	206	.54	88	164	150	165	54	40	1.0	28.3
8 A...	1,000	1,800	1,176	107.6	404	219	.54	88	164	134	151	59	41	1.3	28.1
9 A...	1,000	1,790	1,195	109.4	408	210	.52	88	162	133	151	59	41	1.1	28.3
10 A...	1,000	1,890	1,133	103.8	409	226	.55	98	175	138	152	60	41	1.3	28.3
1 B...	1,000	1,800	1,204	110.4	414	218	.53	80	160	143	162	59	43	1.1	28.5
2 B...	1,000	1,900	1,162	106.3	419	224	.54	91	176	145	163	59	40	1.3	28.4
3 B...	1,000	2,000	1,074	98.2	409	248	.61	98	194	147	165	59	41	1.4	28.3

TABLE II.—*English units.*

Ground runs. Full power.

Run No.	Heat distribution based on brake horsepower. 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.).	Heat distribution based on heat in fuel. Brake horsepower (per cent).	Jacket (per cent).	Exhaust (per cent).	Residual (per cent).	Air density (pound per cubic foot).	Pounds of air per hour.	Volumetric efficiency (per cent).	Thermal efficiency (per cent).	Pounds of air per pound of fuel ±0.2.
5 A....	4.3	0.57	1.8	0.9	23	13	42	22	0.073	2,140	85	25	13.3
6 A....	4.2	.53	1.7	1.0	24	13	40	23	.073	2,530	87	26	14.0
7 A....	4.3	.46	1.7	1.2	23	11	38	28	.073	2,800	84	25	13.6
8 A....	4.3	.53	1.8	.9	23	12	43	22	.072	3,030	83	25	13.9
9 A....	4.1	.56	1.9	.6	24	14	46	16	.073	3,100	84	25	14.7
10 A....	4.4	.44	1.8	1.2	23	10	41	26	.072	3,190	82	24	14.1
1 B....	4.2	.56	1.9	.8	24	13	44	19	.073	3,080	83	25	14.1
2 B....	4.3	.55	1.9	.8	23	13	45	19	.073	3,170	81	25	14.1
3 B....	4.8	.64	2.0	1.2	21	13	41	25	.073	3,220	78	22	13.0

TABLE III.—*English units.*

Altitude runs. Full power.

Run No.	Approximate altitude (feet).	Revolutions per minute.	Torque (pound feet).	Brake mean effective pressure (pounds per square inch).	Brake horsepower.	Pounds of fuel per hour.	Pounds of fuel per brake horsepower hour.	Temperature (° F.). Oil. Inlet.	Temperature (° F.). Oil. Outlet.	Temperature (° F.). Jacket water. Inlet.	Temperature (° F.). Jacket water. Outlet.	Temperature (° F.). Carburetor air.	Oil pressure (pounds per square inch).	Manifold suction (inches hg.). Cylinder 4-5-6 R.	Manifold suction (inches hg.). Cylinder 1-2-3 L.	Barometric pressure (inches hg.).
5 C..	Ground.	1,620	1,273	116.5	393	208	0.53	82	145	145	166	59	43	1.4	1.1	29.3
6 C..	Ground.	1,700	1,279	117.0	414	212	.51	85	164	143	163	59	41	1.2	1.2	29.2
7 C..	5,000	1,690	1,094	100.0	352	187	.53	91	164	135	153	41	39	1.0	.9	25.1
8 C..	5,000	1,610	1,106	101.2	339	198	.58	95	167	135	153	41	40	1.1	.6	25.0
9 C..	10,000	1,600	900	82.3	273	158	.58	95	166	130	146	26	38	.4	.5	20.8
10 C..	10,000	1,690	815	74.6	262	180	.69	85	156	133	149	29	42	.8	.3	20.8
1 D.	10,000	1,710	866	79.2	282	153	.54	74	142	137	149	26	45	1.0	.9	20.8
2 D.	15,000	1,690	653	59.8	209	13	.67	72	162	156	172	14	36	.9	1.0	17.2
3 D.	15,000	1,590	713	65.2	216	123	.57	74	165	138	155	12	34	.2	.4	17.1
4 D.	20,000	1,570	556	50.9	166	112	.67	93	165	144	154	8	30	.8	.8	14.2
5 D.	20,000	1,700	483	44.3	157	128	.81	83	158	156	170	32	34	.6	.6	14.2
6 D.	25,000	1,700	271	24.8	88	124	1.41	88	158	151	158	19	29	.6	.6	11.7
7 D.	25,000	1,590	332	30.4	101	113	1.11	92	164	149	156	11	28	.6	.5	11.9

TABLE IV.—*English units.*

Altitude runs. Full power.

Run No.	Heat distribution based on brake horsepower.				Heat distribution based on heat in fuel.				Air density (pound per cubic foot).	Pounds of air per hour.	Volumetric efficiency (per cent).	Thermal efficiency (per cent).	Pounds of air per pound of fuel, ±0.2.
	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.).	Brake horsepower (per cent).	Jacket (per cent).	Exhaust (per cent).	Residual (per cent).					
5 C.....	4.2	0.62	2.0	0.6	24	15	47	14	0.075	2,980	86	25	14.3
6 C.....	4.1	.58	1.9	.6	24	14	46	16	.075	3,070	85	26	14.5
7 C.....	4.3	.61	1.9	.7	23	14	45	18	.066	2,690	83	25	14.3
8 C.....	4.6	.60	1.8	.7	21	13	39	27	.066	2,560	85	23	13.0
9 C.....	4.6	.66	1.9	1.0	22	14	42	22	.057	2,130	83	23	13.5
10 C.....	5.5	.71	1.9	1.9	18	13	34	35	.056	2,180	81	20	12.2
1 D....	4.3	.61	1.8	1.0	23	12	42	23	.057	2,220	81	25	14.5
2 D....	5.3	.63	1.9	1.5	19	17	35	29	.048	1,740	76	20	12.5
3 D....	4.6	.85	2.1	1.1	22	19	45	14	.048	1,750	81	23	14.3
4 D....	5.3	.65	1.8	1.9	19	12	33	36	.040	1,360	76	20	12.2
5 D....	6.5	.64	1.9	2.5	15	16	29	40	.038	1,420	77	16	11.1
6 D....	11.2	.95	2.6	6.7	9	8	23	60	.032	1,130	73	9	9.1
7 D....	8.9	.80	2.3	4.8	11	9	25	55	.033	1,120	74	12	10.0

TABLE V.—*English units.*

Propeller load runs.

Run No.	Approximate altitude (feet).	Revolutions per minute.	Torque (pound feet).	Brake mean effective pressure.	Brake horsepower.	Pounds of fuel per hour.	Pound of fuel per brake horsepower hour.	Barometric pressure (inches hg.).
8 D.....	15,000	1,710	538	59.3	212	142	0.67	17.2
1 E.....	15,000	1,640	599	54.7	186	107	.57	17.4
2 E.....	15,000	1,530	514	47.1	150	77	.51	17.2
3 E.....	15,000	1,400	447	40.9	119	69	.58	17.3
4 E.....	15,000	1,300	391	35.7	97	61	.63	16.9
5 E.....	15,000	1,210	331	30.3	76	54	.71	17.4
6 E.....	10,000	1,690	870	79.6	280	164	.58	20.7
7 E.....	10,000	1,610	769	70.3	236	121	.51	20.8
8 E.....	10,000	1,460	665	60.8	184	92	.50	20.5
9 E.....	10,000	1,390	580	53.1	153	71	.46	20.6
10 E.....	10,000	1,300	506	46.3	126	62	.49	20.7
11 E.....	10,000	1,190	430	39.4	98	53	.55	20.7
12 E.....	5,000	1,690	1,051	96.1	338	167	.49	25.0
13 E.....	5,000	1,620	975	89.2	300	146	.49	25.1
14 E.....	5,000	1,510	865	79.1	249	121	.48	24.9
15 E.....	5,000	1,410	749	67.7	199	97	.49	25.0
16 E.....	5,000	1,320	656	60.0	165	82	.49	24.9
17 E.....	5,000	1,200	544	49.8	124	63	.51	24.9

TABLE VI.—*English units.*

Propeller load runs.

Run No.	Temperature (°F.).					Manifold suction (inches hg.).		Air density (pound per cubic foot).	Pounds of air per hour.	Pounds of air per pound of fuel, ±.02.
	Oil.		Jacket water.		Carburetor air.	Cylinder 4-5-6 R.	Cylinder 1-2-3 L.			
	Inlet.	Outlet.	Inlet.	Outlet.						
8 D....	88	158	144	158	30	0.7	0.7	0.047	1,750	12.4
1 E....	75	139	144	158	25	1.1	2.1	.047	1,610	15.0
2 E....	87	155	142	155	14	2.0	3.3	.048	1,430	18.6
3 E....	88	156	147	159	14	2.2	6.5	.048	1,110	16.1
4 E....	80	145	150	163	25	5.3	4.9	.046	890	14.5
5 E....	82	147	140	151	16	6.0	7.1	.048	776	14.1
6 E....	88	162	147	163	26	.8	.8	.056	2,170	13.3
7 E....	93	165	137	152	28	1.5	2.1	.056	1,930	16.0
8 E....	95	165	143	158	29	3.3	4.8	.056	1,520	16.5
9 E....	91	166	153	168	26	4.9	4.5	.056	1,300	18.3
10 E....	76	126	129	143	27	6.2	5.3	.057	1,090	17.6
11 E....	77	139	156	166	25	6.4	8.1	.057	940	17.7
12 E....	85	160	145	162	42	1.0	1.0	.066	2,610	15.7
13 E....	89	164	139	156	41	2.1	1.8	.066	2,330	16.0
14 E....	91	162	136	152	42	3.0	2.6	.067	1,970	16.3
15 E....	92	160	138	154	40	4.4	3.9	.066	1,720	17.7
16 E....	90	157	137	152	41	5.9	5.3	.066	1,490	18.2
17 E....	88	153	144	158	41	8.4	7.1	.066	1,200	19.0

TABLE VII.—*English units.*

Friction horsepower.

Run No.	Approximate altitude (feet).	Revolutions per minute.	Friction horsepower.	Barometric pressure inches Hg.	Air density (pound per cubic foot).	Temperature, (° F.). Oil. Inlet.	Oil. Outlet.	Jacket water. Inlet.	Jacket water. Outlet.	Carburetor air.
26 E.....	15,000	1,210	30	17.2	0.046	91	170	154	155	32
27 E.....	15,000	1,410	41	17.5	.047	92	156	157	158	29
28 E.....	15,000	1,610	52	17.1	.047	94	156	162	163	28
29 E.....	15,000	1,790	61	17.1	.047	100	162	165	166	27
30 E.....	15,000	1,980	70	17.1	.047	107	173	151	168	28
31 E.....	Ground.	1,200	33	....	.071	99	151	166	167	90
32 E.....	Ground.	1,400	43	....	.071	96	155	167	168	93
33 E.....	Ground.	1,600	55	....	.070	95	157	167	168	97
34 E.....	Ground.	1,800	69	....	.069	97	159	171	172	100

TABLE VIII.—*English units.*

Ground and altitude runs.

Revolutions per minute.	Brake horsepower.	Friction horsepower.	Indicated horsepower.	Lb. air per hour ÷ (lb. air per hour at 2,000 r.p.m.).	I. h. p. ÷ (i.h.p. at 2,000 r.p.m.).	Mechanical efficiency (per cent).	Approximate air density (pound per cubic foot).	Air density (pound per cubic foot).	Brake horsepower.	Friction horsepower.	Indicated horsepower.	Lb. air per hour ÷ (lb. air per hour at 0.076 density).	I.h.p. ÷ (i. h. p. at 0.076 density).	Mechanical efficiency (per cent).	Revolutions per minute.	B. h. p. ÷ (b. h. p. at 0.076 density).
1,200	295	33	328	0.64	0.66	90	0.073	0.076	403	55	458	1.00	1.00	88	1,600	1.00
1,400	344	43	387	.78	.77	89	.073	.066	336	54	390	.85	.86	86	1,600	.83
1,600	385	55	440	.87	.88	87	.073	.057	276	52	328	.72	.72	84	1,600	.68
1,800	415	69	484	.95	.97	86	.073	.048	216	51	267	.58	.58	81	1,600	.53
1,900	419	77	496	.98	.99	84	.073	.040	163	50	213	.46	.46	77	1,600	.40
2,000	410	90	500	1.00	1.00	82	.073	.033	96	49	145	.36	.32	66	1,600	.24

TABLE I.—*Metric units.*

Ground runs. Full power.

Run No.	Approximate altitude (meters).	Revolutions per minute.	Torque (kilogram meter).	Brake mean effective pressure kilograms per square centimeter.	Brake horsepower.	Kilograms of fuel per hour.	Kilogram of fuel per brake horsepower hours.	Temperature (°C.). Oil. Inlet.	Oil. Outlet.	Jacket water. Inlet.	Jacket water. Outlet.	Carburetor air.	Oil pressure (kilograms per square centimeter).	Manifold suction centimeter Hg. cyl. 4-5-6 R.	Barometric pressure centimeter Hg.
5 A....	305	1,220	179	8.3	306	73	0.24	27	61	64	75	15	2.5	1.4	72.6
6 A....	305	1,410	178	8.3	350	82	.24	29	69	58	68	15	2.5	2.0	72.7
7 A....	305	1,600	173	8.0	385	93	.24	31	73	65	74	12	2.8	2.4	71.9
8 A....	305	1,800	163	7.6	410	99	.24	31	73	57	66	15	2.9	3.2	71.3
9 A....	305	1,790	165	7.7	414	95	.23	31	72	56	66	15	2.9	2.7	72.1
10 A....	305	1,890	157	7.3	415	102	.25	38	90	59	67	16	2.9	3.4	72.0
1 B....	305	1,800	166	7.8	420	99	.23	27	71	62	72	15	3.0	2.7	72.4
2 B....	305	1,900	161	7.5	425	102	.24	33	80	63	73	15	2.8	3.3	72.3
3 B....	305	2,000	148	6.9	415	113	.27	37	90	64	74	15	2.9	3.5	72.0

TABLE II.—*Metric units.*

Ground runs. Full power.

Run No.	Heat distribution based on brake horsepower.				Heat distribution based on heat in fuel.				Air density (kilograms per cubic meter).	Kilogram of air per hour.	Volumetric efficiency (per cent).	Thermal efficiency (per cent).	Kilograms of air per kilogram of fuel ±0.2.
	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.).	Brake horsepower (per cent).	Jacket (per cent).	Exhaust (per cent).	Residual (per cent).					
5 A..	4.3	0.57	1.8	0.9	23	13	42	22	1.17	970	85	25	13.3
6 A..	4.2	.53	1.7	1.0	24	13	40	23	1.17	1,150	87	26	14.0
7 A..	4.3	.46	1.7	1.2	23	11	38	28	1.17	1,270	84	25	13.6
8 A..	4.3	.53	1.8	.9	23	12	43	22	1.15	1,380	83	25	13.9
9 A..	4.1	.56	1.9	.6	24	14	46	16	1.16	1,400	84	25	14.7
10 A..	4.4	.44	1.8	1.2	23	10	41	26	1.16	1,450	82	24	14.1
1 B..	4.2	.56	1.9	.8	24	13	44	19	1.17	1,400	83	25	14.1
2 B..	4.3	.55	1.9	.8	23	13	45	19	1.17	1,440	81	25	14.1
3 B..	4.8	.64	2.0	1.2	21	13	41	25	1.16	1,460	78	22	13.0

TABLE III.—*Metric units.*

Altitude runs. Full power.

Run No.	Approximate altitude (meters).	Revolutions per minute.	Torque (kilogram meters).	Brake mean effective pressure (kilograms per square centimeter).	Brake horsepower.	Kilograms of fuel per hour.	Kilogram of fuel per brake horsepower. hour.	Temperature (°C.)					Oil pressure (kilograms per square centimeter).	Manifold suction centimeter Hg.		Barometric pressure (centimeter Hg).
								Oil.		Jacket water.		Carburetor air.		Cylinder 4-5-6 R.	Cylinder 1-2-3 L.	
								Inlet.	Outlet.	Inlet.	Outlet.					
5 C..	Ground.	1,620	176	8.2	399	94	0.24	28	63	63	74	15	3.0	3.5	2.9	74.5
6 C..	Ground.	1,700	177	8.2	420	96	.23	29	73	61	73	15	2.9	3.1	3.1	74.3
7 C..	1,520	1,690	151	7.0	357	85	.24	33	74	57	67	4	2.7	2.6	2.5	63.8
8 C..	1,520	1,610	153	7.1	344	90	.26	35	75	57	67	5	2.8	2.8	1.5	63.6
9 C..	3,050	1,600	124	5.8	277	72	.26	35	74	54	63	− 3	2.7	1.1	1.2	52.9
10 C..	3,050	1,690	113	5.2	266	82	.31	29	69	56	65	− 2	2.9	1.9	0.8	52.8
1 D..	3,050	1,710	120	5.6	286	69	.24	23	61	58	65	− 3	3.2	2.7	2.3	52.8
2 D..	4,570	1,690	90	4.2	212	63	.30	31	88	69	78	−10	2.5	2.2	2.6	43.6
3 D..	4,570	1,590	99	4.6	219	56	.26	34	92	59	68	−11	2.4	0.5	1.0	43.5
4 D..	6,040	1,570	77	3.6	168	51	.30	34	74	62	67	13	2.1	1.9	2.1	36.1
5 D..	6,040	1,700	67	3.1	159	58	.36	28	68	69	76	0	2.4	1.5	1.4	36.0
6 D..	7,620	1,700	37	1.7	89	56	.63	31	70	66	70	− 7	2.0	1.5	1.6	29.7
7 D..	7,620	1,590	46	2.1	102	51	.50	33	73	65	69	−12	2.0	1.5	1.4	30.1

TABLE IV.—*Metric units.*

Altitude runs. Full power.

Run No.	Heat distribution based on brake horsepower.				Heat distribution based on heat in fuel.				Air density (kilograms per square centimeter).	Kilograms of air per hour.	Volumetric efficiency (per cent).	Thermal efficiency (per cent).	Kilograms of air per kilogram of fuel ±0.2.
	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.).	Brake horsepower (per cent).	Jacket (per cent).	Exhaust (per cent).	Residual (per cent).					
5 C....	4.2	0.62	2.0	0.6	24	15	47	14	1.20	1,350	86	25	14.3
6 C....	4.1	.58	1.9	.6	24	14	46	16	1.20	1,390	85	26	14.5
7 C....	4.3	.61	1.9	.7	23	14	45	18	1.06	1,220	83	25	14.3
8 C....	4.6	.60	1.8	.7	21	13	39	27	1.06	1,160	85	23	13.0
9 C....	4.6	.66	1.9	1.0	22	14	42	22	.91	970	83	23	13.5
10 C....	5.5	.71	1.9	1.9	18	13	34	35	.90	990	81	20	12.2
1 D....	4.3	.51	1.8	1.0	23	12	42	23	.91	1,010	81	25	14.5
2 D....	5.3	.63	1.9	1.5	19	17	35	29	.77	790	76	20	12.5
3 D....	4.6	.85	2.1	1.1	22	19	45	14	.77	790	81	23	14.3
4 D....	5.3	.65	1.8	1.9	19	12	33	36	.64	620	76	20	12 2
5 D....	6.5	.64	1.9	2.5	15	16	29	40	.61	640	77	16	11.1
6 D....	11.2	.95	2.6	6.7	9	8	23	60	.52	510	73	9	9.1
7 D....	8.9	.80	2.3	4.8	11	9	25	55	.53	510	74	12	10.0

TABLE V.—*Metric units.*

Propeller load runs.

Run No.	Approximate altitude (meters).	Revolutions per minute.	Torque (kilogram meter).	Brake mean effective pressure (kilograms per square centimeter.	Brake horsepower.	Kilograms of fuel per hour.	Kilograms of fuel per brake horsepower hour.	Barometric pressure (centimeters Hg.).
8 D	4,570	1,710	74	4.2	215	64	0.30	43.7
1 E	4,570	1,640	83	3.8	189	48	.26	44.1
2 E	4,570	1,530	71	3.3	152	35	.23	43.7
3 E	4,570	1,400	62	2.9	121	31	.26	43.8
4 E	4,570	1,300	54	2.5	98	28	.28	43.0
5 E	4,570	1,210	46	2.1	78	25	.32	44.1
6 E	3,050	1,690	120	5.6	284	74	.26	52.5
7 E	3,050	1,610	106	4.9	239	55	.23	52.7
8 E	3,050	1,460	92	4.3	187	42	.22	52.1
9 E	3,050	1,390	80	3.7	155	32	.21	52.2
10 E	3,050	1,300	70	3.2	128	28	.22	52.7
11 E	3,050	1,190	59	2.8	99	24	.24	52.7
12 E	1,520	1,690	145	6.7	343	76	.22	63.5
13 E	1,520	1,620	135	6.3	304	66	.22	63.7
14 E	1,520	1,510	120	5.6	253	55	.22	63.2
15 E	1,520	1,410	102	4.7	202	44	.22	63.6
16 E	1,520	1,320	91	4.2	167	37	.22	63.3
17 E	1,520	1,200	75	3.5	126	29	.23	63.4

TABLE VI.—*Metric units.*

Propeller load runs.

Run No.	Temperature (° C.).					Manifold suction (centimeters Hg.).		Air density (kilograms per cubic meter).	Kilograms of air per hour.	Kilograms of air per kilograms fuel, ±0.2.
	Oil.		Jacket water.		Carburetor air.	Cylinder 4-5-6 R.	Cylinder 1-2-3 L.			
	Inlet.	Outlet.	Inlet.	Outlet.						
8 D	31	70	62	70	−1	1.7	1.9	0.75	790	12.4
1 E	24	60	62	70	−4	2.8	5.2	.76	730	15.0
2 E	31	68	61	68	−10	5.0	8.3	.77	650	18.6
3 E	31	69	64	71	−10	5.5	16.4	.77	510	16.1
4 E	27	63	65	73	−4	13.5	12.4	.74	400	14.5
5 E	28	64	60	66	−9	15.3	17.9	.78	350	14.1
6 E	31	72	64	73	−3	2.1	2.1	.90	990	13.3
7 E	34	74	58	67	−2	3.7	5.3	.90	870	16.0
8 E	34	74	62	70	−2	8.3	12.2	.89	690	16.5
9 E	33	74	67	76	−3	12.5	11.5	.90	590	18.3
10 E	24	52	54	62	−3	15.7	13.4	.91	490	17.6
11 E	25	59	69	74	−4	16.3	20.5	.91	430	17.7
12 E	30	71	63	72	5	2.4	2.5	1.06	1,190	15.7
13 E	32	73	60	69	5	5.2	4.7	1.06	1,060	16.0
14 E	33	72	58	67	6	7.6	6.7	1.07	890	16.3
15 E	33	71	59	67	5	11.1	10.0	1.06	780	17.7
16 E	32	69	59	67	5	15.1	13.5	1.06	670	18.2
17 E	31	67	62	70	5	21.4	18.0	1.06	540	19.0

TABLE VII.—*Metric units.*

Friction horsepower.

Run No.	Approximate altitude (meters).	Revolutions per minute.	Friction horsepower.	Barometric pressure (centimeters Hg.).	Air density (kilograms per cubic meter).	Temperature (° C.).				
						Oil.		Jacket water.		Carburetor air.
						Inlet.	Outlet.	Inlet.	Outlet.	
26 E	4,570	1,210	30	43.7	0.75	33	76	68	68	0
27 E	4,570	1,410	41	43.9	.75	33	69	70	70	−2
28 E	4,570	1,610	52	43.5	.75	34	69	72	73	−2
29 E	4,570	1,790	61	43.4	.75	38	72	74	74	−3
30 E	4,570	1,980	70	43.5	.75	42	78	66	76	−2
31 E	(1)	1,200	33	....	1.14	37	66	74	75	32
32 E	(1)	1,400	43	....	1.13	35	68	75	76	34
33 E	(1)	1,600	55	....	1.12	35	69	75	76	36
34 E	(1)	1,800	69	....	1.11	36	71	77	78	38

[1] Ground.

TABLE VIII.—*Metric units.*

Ground and altitude runs.

Revolutions per minute.	Brake horsepower.	Friction horsepower.	Indicated horsepower.	Kg. air per hour ÷ (kg. air per hour at 2,000 r. p. m.).	I. h. p. ÷ (i. h. p. at 2,000 r. p. m.).	Mechanical efficiency (per cent).	Approximate air density (kilograms per cubic meter).
1,200	299	33	333	0.64	0.66	90	1.17
1,400	349	44	393	.78	.77	89	1.17
1,600	391	56	447	.87	.88	87	1.17
1,800	421	70	491	.95	.97	86	1.17
1,900	425	78	503	.98	.99	84	1.17
2,000	416	91	507	1.00	1.00	82	1.17

Air density (kilograms per cubic meter).	Brake horsepower.	Friction horsepower.	Indicated horsepower.	Kg. air per hour ÷ (kg. air per hour at 1.22 density).	I. h. p. ÷ (i. h. p. at 1.22 density).	Mechanical efficiency (per cent).	Revolutions per minute.	B. h. p. ÷ (b. h. p. at 1.22 density).
1.22	409	56	465	1.00	1.00	88	1,600	1.00
1.06	341	54	395	.85	.86	86	1,600	.83
.91	280	53	333	.72	.72	84	1,600	.68
.77	219	52	271	.58	.58	81	1,600	.53
.64	165	51	216	.46	.46	77	1,600	.40
.53	97	50	147	.36	.32	66	1,600	.24

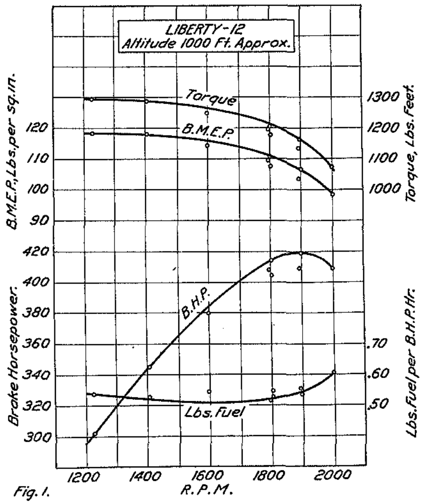


Fig. 1.

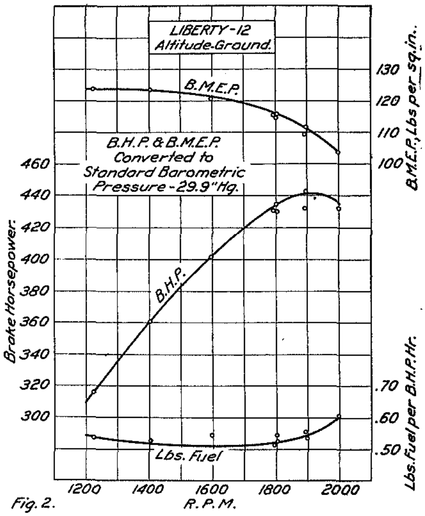
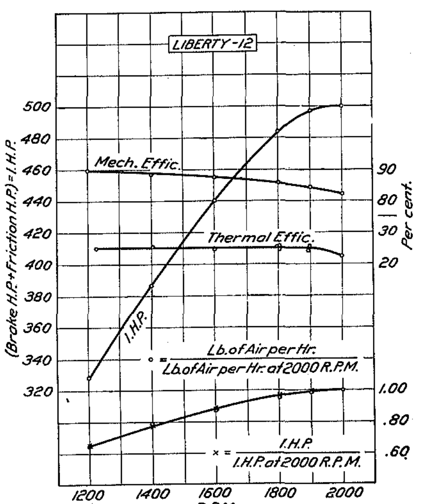


Fig. 2.



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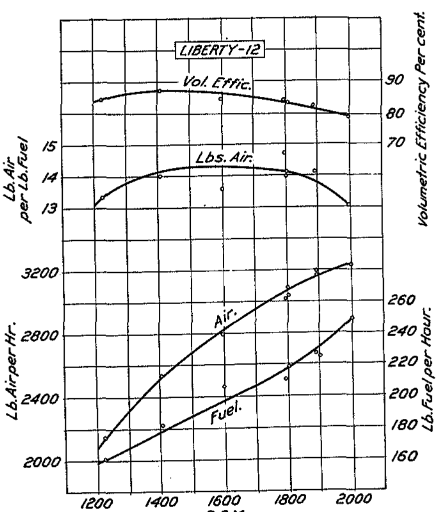

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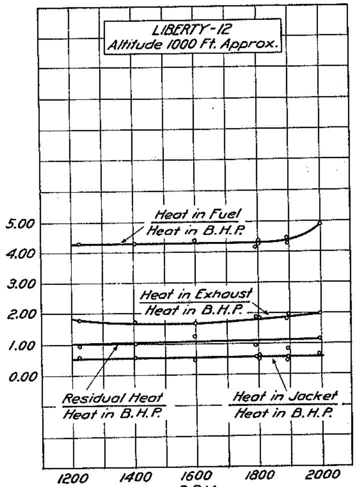

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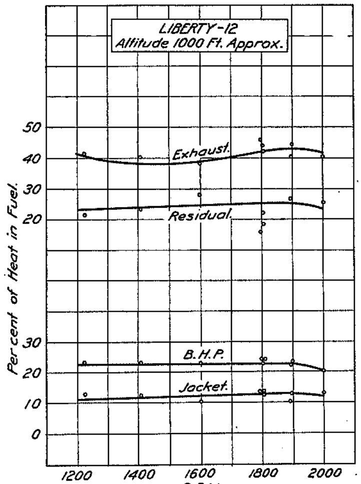
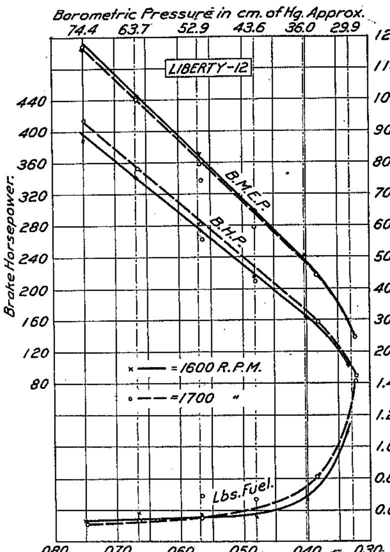


Fig. 5a.



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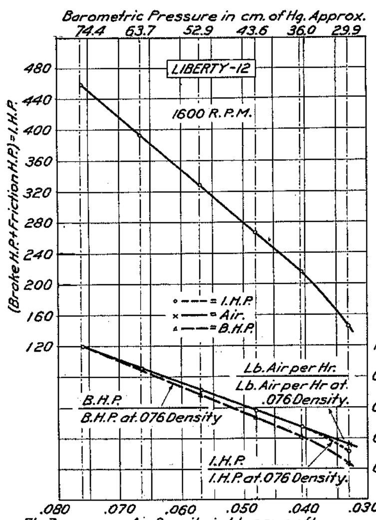

Fig. 7.

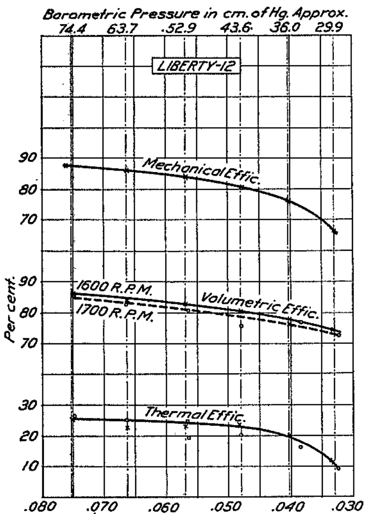

Fig. 8. Air Density in Lbs per cu. ft.

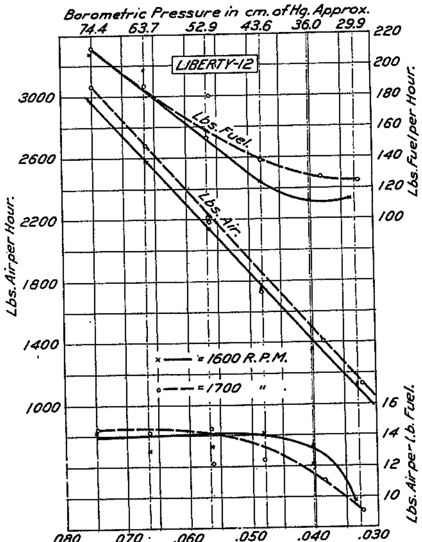

Fig. 9. Air Density in Lbs. per cu. ft.

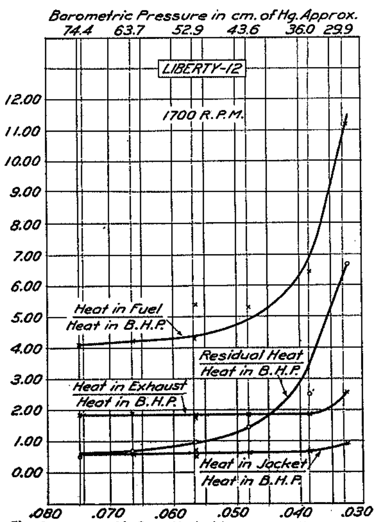

Fig. 10. Air Density in Lbs. per cu. ft.

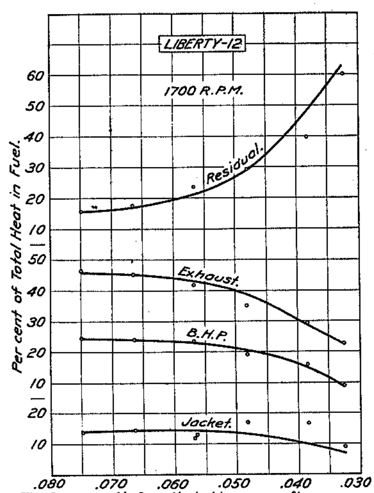

Fig. 10a. Air Density in Lbs per cu. ft.

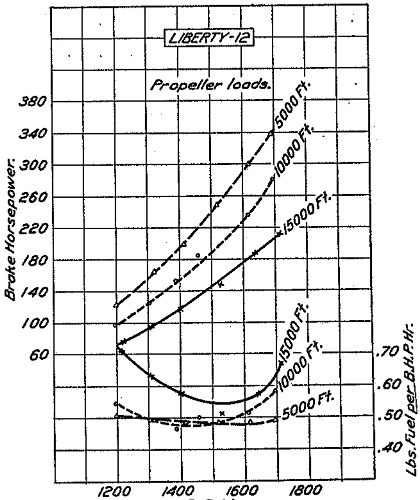

Fig. 11.

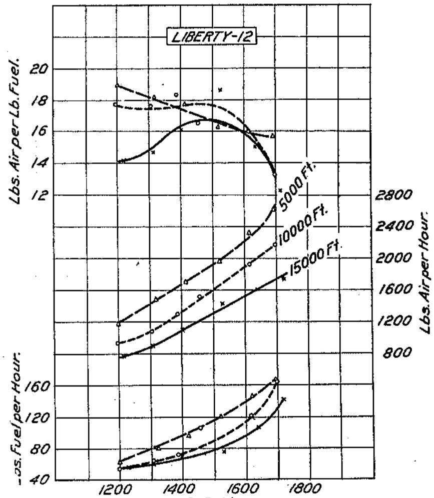

Fig. 12.

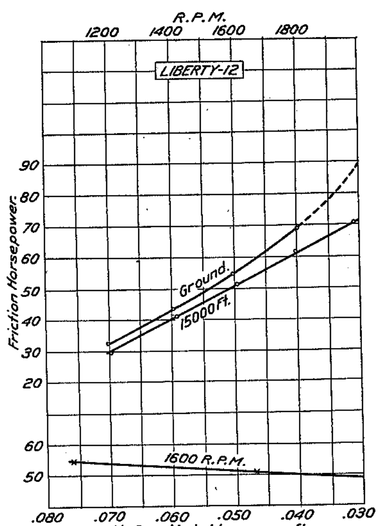

Fig. 13.

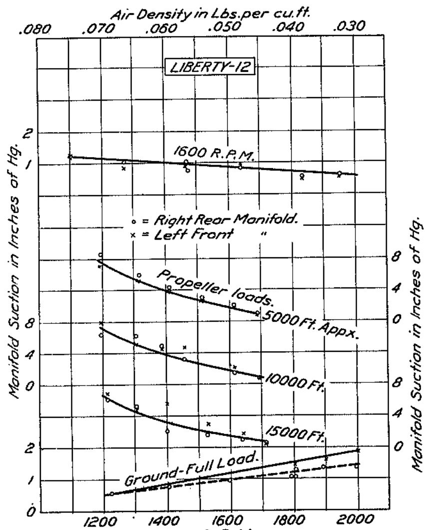

Fig. 14.

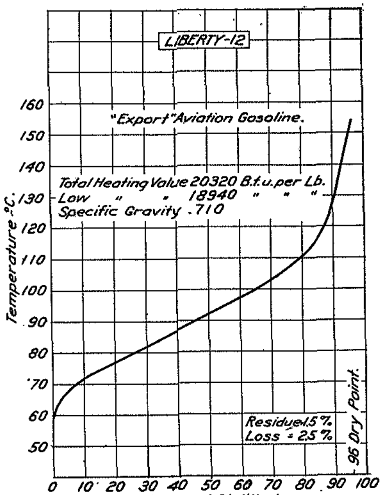

Fig. 15.

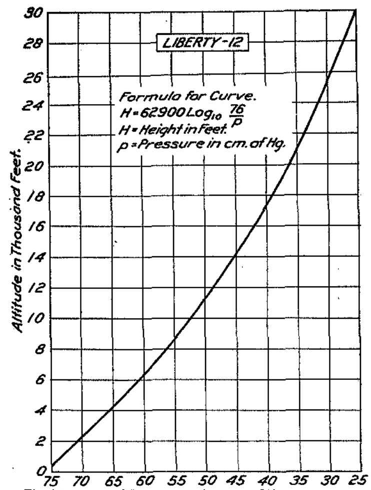

Fig. 16.

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