REPORT No. 47.

POWER CHARACTERISTICS OF FUELS FOR AIRCRAFT ENGINES.

PART I.—POWER CHARACTERISTICS OF AVIATION GASOLINE.
PART II.—POWER CHARACTERISTICS OF SUMATRA AND BORNEO GASOLINES.
PART III.—POWER CHARACTERISTICS OF 20 PER CENT BENZOL MIXTURE.

PART I.

POWER CHARACTERISTICS OF AVIATION GASOLINES.

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RÉSUMÉ.

The importance of securing the best possible fuel for aircraft engines led to the testing of a number of fuels in the altitude laboratory of the Bureau of Standards. The tests were made with the carbureter adjusted by hand to give maximum power with minimum fuel consumption for this power, the engine operating with full throttle at various speeds and under conditions corresponding to various altitudes.

It has been customary to judge the "usability" of a gasoline by its volatility. The meaning of usability of a gasoline has often been, perhaps wrongly, expanded to include the power performance of the engine. Combining the ideas, the distillation curve of a gasoline has been accepted by many as a true criterion of the power to be obtained when using a fuel in an engine.

The results of the tests made at the Bureau of Standards indicate that the distillation curve of a gasoline gives no indication of the power that can be obtained from an engine using this fuel, when the carbureting conditions are suited to the fuel, and that it is not impracticable to attain these conditions.

These tests were made to determine the gasoline or gasolines giving maximum power. Analysis of the data was made in an endeavor to find the properties controlling the power-producing ability of a gasoline. The question of economy is not considered in this report, being deferred for a subsequent investigation. The tests proved that any of the gasolines used can be made, by proper "carbureting," to give the same power within a range of the order of 5 per cent. It is probable that the relative merits of fuels for commercial and perhaps some war uses will depend upon economy more than upon power ability.

Specification No. 3512 of the Bureau of Aircraft Production for aviation gasoline (export) gives a satisfactory fuel. More rigid specifications apparently do not give appreciably better power performance in an engine.

DESCRIPTION OF APPARATUS AND OBJECT OF TESTS AND STUDIES.

The following report is based on tests made in the altitude laboratory of the Bureau of Standards. The engine was a Type A Hispano-Suiza, made by the Wright-Martin Aircraft Corporation, New Brunswick, N. J., fitted with pistons giving a compression ratio of 5.3 and developing 180 h. p. at 1,800 r. p. m. The eight cylinders are 120 mm. by 130 mm. (4.725 by 5.118 inches) and are arranged in two blocks of four, set at an angle of 90°. The intake manifold was the regular design, with water-jacketed tee. The carbureter was a Claudel duplex, manufactured in France, with a valve between the float chamber and the jets to control the amount of fuel supplied. The altitude chamber has thermally insulated walls. The air may be partially exhausted from the chamber by means of a blower, reducing the barometric pressure to that corresponding to any altitude up to 30,000 feet. As the air enters the chamber it is passed over a series of refrigerating coils which serve to regulate the temperature during the tests. The engine is coupled to an electric dynamometer placed outside the chamber by means of which the power of the engine may be absorbed and measured. Complete description of this apparatus and the methods of observation may be found in Report No. 44.

The purpose of these engine tests was to determine the relative power-producing values of several different kinds of gasoline. Analyses of the data obtained have been made to correlate the results of these tests with some of the physical and chemical properties of the gasolines. The results of these studies show that the properties considered are not the ones which exert the major control of the power-producing qualities of a gasoline. The physical properties which were considered were the distillation curves, the heating values, the densities, the magneto-optical rotations, and the critical solution temperatures with aniline. The chemical properties were much less carefully studied, because of the considerable time required for chemical analyses.

SPECIFICATION FOR AVIATION GASOLINES.

Following is a brief summary of the specifications for the various gasolines as issued by the Bureau of Aircraft Production 1918, for several types of aviation gasolines:

Aviation gasoline (domestic), Specification No. 3511–B.
Aviation gasoline (export), Specification No. 3512.
Aviation gasoline (fighting), Specification No. 3513.

In these specifications certain requirements were given to insure freedom from acid and other impurities, these requirements being identical for each grade. In the requirements for volatility and distillation range, the specifications vary in the temperature limits for the various fractions. The following table gives the temperature requirements in degrees centigrade as the various percentages of the sample have been recovered in the graduated receiver:

Per cent recovered.	Domestic.	Export.	Fighting.
5	Not over 75° C.	Not over 65° C.	Not over 75° C.[1]
	Not under 50° C.	Not under 50° C.	Not under 60° C.
50	Not over 105° C.	Not over 95° C.	Not over 95° C.
90	Not over 155° C.	Not over 125° C.	Not over 113° C.
96	Not over 175° C.	Not over 150° C.	Not over 125° C.

[1] Specification of June 27, 1918. Changed in October, 1918, to 70° C.

It will be noted that the higher temperatire at the 5 per cent point in the specifications for export gasoline is lower than for fighting gasoline. With this exception a gasoline that will meet the specification for fighting gasoline will meet the specification for either of the others. It will also be noted that a gasoline distilling throughout the entire range at temperatures over 50° C. and under those specified would fill the specifications for domestic and export, and one in which all fractions distilled at any temperature over 60° C. and under those specified would comply with the specification for fighting gasoline. In other words, the specifications do not provide for a lower limit of temperature except for the first 5 per cent. Attention is called to these points to show the wide range of gasolines which may be provided and yet fulfill the requirements of these specifications.

DESCRIPTION OF GASOLINES USED.

Ten gasolines form the subject of this report, nine being compared in turn with a standard gasoline as a reference fuel. Before describing these fuels in detail, a brief description of their general characteristics will be given. Two of the fuels, one of them the reference standard, were representative American straight run gasolines from an eastern refinery and complying closely with the specifications for export gasoline. A third followed closely the specifications for fighting gasoline, while two others were slight variations of the fighting gasoline. These gasolines, representing the French aviation gasolines, were imported from France, and followed closely the requirements given above for export and fighting gasolines, respectively. Two gasolines representing the average motor car gasoline as sold at automobile filling stations were run as a matter of comparison. One of these was of eastern origin, and the other a California gasoline. Reference to the distillation curves (plot 1) will show that these fuels were quite outside the area covered by the distillation curves of the aviation gasolines. The numbers employed to designate the various fuels which were tested in the progress of this investigation are the sample numbers given them by the Bureau of Mines, Petroleum Division, which collaborated with the Bureau of Standards in selecting and securing samples for their tests and in making all the analyses of these samples. They have no other significance, except in the case of "X" which is the designation employed by the Bureau of Standards for the reference standard, it being the refinery abbreviation for "Export." A detailed description of the various fuels follows:

Standard X gasoline was manufactured by the Atlantic Refining Co. as one of their standard products. Two lots of this fuel were employed in these tests, because the supply of the first became exhausted before the series was completed. The first, designated as "Old X," complies with the specifications for domestic gasoline, and was employed as a reference fuel when testing gasolines 263, 264, 265, and 266. The second, designated as New X, complies with the specification for export gasoline and was employed as a reference fuel for the remainder of the gasolines, namely 185, 191, 261, 262, and commercial. The distillation curves of these two reference fuels are quite different, although their mean volatilities are practically the same and their power characteristics were similar. The unavoidable use of two standards necessitated an indirect method of comparison, which is more fully discussed later.

In May, 1918, the Bureau of Mines requested the Atlantic Refining Co., of Philadelphia, to furnish sundry grades of gasoline for examination and test. These were to be used for guidance in drawing specifications for the fighting grade. In compliance with this request. the Atlantic Refining Co. submitted four samples of 100 gallons each as follows:

Gasoline No. 264 was designed to represent as closely as possible a gasoline complying with the then existing specifications adopted by the Petroleum War Service Committee in accordance with the report on aviation gasoline. These specifications were: 5 per cent above 50° C., 8 per cent below 70° C., 50 per cent below 90° C. and not over 3 per cent of the residue to remain in the flask at 150° C. The actual distillation curve for 264 is given with the curves for all the others on plot 1.

Gasoline No. 265 was prepared to comply with the requirements of the then existing specifications for the fighting grade, which were the same as those of specifications No. 3513, excepting that the first 5 per cent must pass below 70° C. instead of 75° C.

Gasoline No. 263 has about the same average boiling point as No. 265, except that it is obtained from the still within a very narrow temperature range. It is what is termed a 70° C.–90° C. cut. It complies with the requirements of Specification No. 3513 of the Bureau of Aircraft Production, 1918.

Gasoline No. 266 is of the same general quality as the fighting grade, except that it contains a considerably larger proportion of material distilling at low temperatures. This fuel complies with the specifications for the fighting grade except that the distillation temperature when the first 5 per cent has been recovered is 54.5° C. instead of being above 60° C., as required. Quoting from a letter from the Atlantic Refining Co. under date of May 23, 1918, this gasoline was prepared "for the purpose of ascertaining by examination whether the specification, with respect to light ends, has been drawn too rigidly. It is our fear that, by making the specifications too rigid in this direction, it has resulted in decreasing rather than increasing the efficiency of the gasoline."

Gasolines Nos. 261 and 262 were imported from France and were received at the Bureau of Standards May 21, 1918. Gasoline No. 261 was marked "Essence Sumatra," denoting that it was derived from Sumatra crudes. This is a gasoline considerably used for aviation purposes in France. It is described quite fully in Part II of this report, "Power Characteristics of Sumatra and Borneo Gasolines."

Gasoline 262 was received in containers marked "Essence Legere de Borneo." It is a close-cut gasoline, approximately a 70° C.–90° cut, and in this feature similar to No. 263.

Gasoline No. 185 is a fuel with a very narrow distillation range, a 60° C.–70° C. cut, and close end points. The original distillation, from which the curve in plot 1 was drawn, shows that the distillation temperature lies between 60° C. and 70° C. for 80 per cent of the sample. A check distillation made from a sample taken from the barrel several months later shows over

90 per cent of the sample lying between these two temperatures, with the first 5 per cent going over at 61° C. and 95 per cent at 70° C. The check distillation brings the gasoline within the requirements of the specification for the fighting grade, but considerably below the required temperatures at 50, 90, and 96 per cent. Gasoline No. 185 is, therefore, close to the lower limit of distillation temperatures that will comply with the requirements of Specification No. 3513 for aviation gasoline (fighting). This is not an inference that a closer cut can not be made, but that No. 185 well represents the lower extreme of the specification just as No. 261 represents the higher limit.

Gasoline No. 191–A was shipped to the Bureau of Standards by the Associated Oil Co. from Avon, Calif. The sample used in the test corresponds very closely in its distillation curve with commercial gasoline.

Commercial gasoline is a fair sample of the fuel usually sold at gasoline filling stations and is of a lower grade (higher boiling point) than X. It was purchased under the United States General Supply Committee's specifications for 1918–19, as follows: Twenty per cent must not distill under 50° C.; 20 per cent must distill under 105° C.; 60 per cent must distill under 140° C.; 90 per cent must distill under 177° C.; "dry point" not above 210° C.

PROPERTIES OF THE FUELS.

DISTILLATION CURVES.

Plot I shows the distillation curves of the various gasolines. The distillations were made by the United States Bureau of Mines, Petroleum Division, and are in conformity with the method outlined and described in Bureau of Mines Technical Paper No. 214, entitled "Motor Gasoline, Laboratory Methods for Testing, and Practical Specifications." The temperatures are observed after equal fractions are recovered in a graduated receiver, and the curves are plotted with fractions of the sample as abscissae, and temperatures as ordinates. The temperatures are noted after each tenth of the sample is recovered in the receiver. For convenience of reference, the limiting temperatures denoted in the various specifications for aviation gasolines are indicated by reference letters.

Measurements of the properties of each gasoline are given in Table I. The first seven items are those regularly noted by the Bureau of Mines in connection with the determination of the distillation temperatures.

TABLE I.—*Physical and chemical properties of gasolines tested.*

[ABBREVIATIONS: Arom.=Aromatic, denoting the presence of benzenes in considerable quantity. W. w.=Water white. Lt. br.=Light brown.]

	Old X.	New X.	185	191A	261	262	263	264	265	266	Commercial.
Color	W. w.	W. w.	W. w.	W. w.	W. w.	W. w.	W. w.	W. w.	W. w.	W. w.	W. w.
Odor	O. K.	O. K.	O. K.	Normal.	Arom.	Arom.	Normal.	Normal.	Normal.	Normal.	O. K.
Specific gravity	0.735	0.713	0.681	0.740	0.723	0.725	0.703	0.710	0.701	0.692	0.747
Unsaturated[1], per cent	1.2	1.8	1.2	1.6	1.5	1.4	.60	.89	.60	1.0	1.4
Doctor test for sulphur	Minus.	Minus.	Minus.	Minus.	Minus.	Minus.	Minus.	Minus.	Minus.	Minus.	Minus.
Residue	....	Lt. br.	Lt. br.	....	....	....	....	....	....	....	....
Loss, per cent	1.0	1.5	0.8	1.5	1.8	2.0	0.8	1.4	1.8	2.0	0.5
Mean volatility[2], °C.	97	95	67	117.5	95	81	80	93	85.5	79.0	121
Heat value (total) b.t.u. per lb.	....	20,340	20,645	19,980	20,340	20,195	20,320	20,375	20,465	20,450	20,195
Critical solution, temp.[3], °C	....	....	61.0	....	52.1	45	....	57.3	58.4	....	....
Magnetic rotation[4] × 10^7	....	2,322	2,349	2,524	2,425	2,523	2,271	2,344	2,340	2,125	2,533

[1] Unsaturated compounds, ethylenes.
[2] Mean ordinate of distillation curve.
[3] Temperature of critical solution with aniline.
[4] Magnetic rotation of green mercury light, figure is Verdet's constant, i. e., the rotation in circular degrees for 1 centimeter length and 1 magnetic line per square centimeter.

MEAN VOLATILITY.

The mean volatility is determined by integration of the distillation curve and determination of the mean ordinate in terms of temperature.

HEAT OF COMBUSTION.

The heat of combustion was determined at the Bureau of Standards. The apparatus employed was a specially fitted Junkers calorimeter. The total or higher heat values are given in the table.

CRITICAL SOLUTION TEMPERATURE.

The critical temperatures of solution with aniline were determined at the Bureau of Standards. The upper critical solution temperature is the highest temperature at which two liquid layers can appear. A sudden clouding of the homogeneous liquid takes place upon cooling through this critical temperature. The subject is one treated in standard works on physical chemistry.[1] As applied to gasoline, in connection with close fractionation, it gives an approximation of the proportions of the various chemical compounds. Critical solution temperatures were determined for five typical gasolines among those being investigated.

MAGNETO-OPTIC ROTATORY POWER.

In determining the properties of various organic mixtures, it has been found that the presence of considerable proportions of compounds of the benzene group has a tendency to increase the rotation of the plane of polarization, when a beam of mono-chromatic light is passed through the substance, in a strong magnetic field. The presence of the benzene group has been thought, by some, to be associated with increased engine power. Thus it was a conceivable hypothesis that the magnetic rotation might prove a convenient indicator of the power-producing ability of the fuel. This hypothesis seemed worth testing, in view of the fact that the apparatus for measuring magnetic rotation was in operation at the Bureau of Standards and this property of the gasolines could be measured in a few moments. Also, the method has value as an aid to chemical analysis. As forecast of an analysis, wherever equipment is available, it may save much time by indicating what substances to look for and what not to expect. No definite connection between this physical property and the engine performance of a gasoline was proved.

The apparatus employed was a magnetic polarimeter having a maximum field intensity of 50,000 lines per square centimeter, and capable of being read to one thousandth of a degree of circular arc. The samples to be tested are placed in tubes 20 cm. long. Through them is projected a polarized ray of monochromatic light of great intensity selected from the spectrum of the light from a quartz mercury vacuum tube of special construction. By means of a narrow mirror the green ($546.1\mu\mu$) is selected from the spectrum of the tube, and projected through the polarimeter. From the rotation, the measured strength of the magnetic field, and the length of the sample, are obtained the values tabulated.

For the purpose of comparison, the various properties of the principal hydrocarbons commonly found in gasolines are given in Table II.

CHEMICAL COMPOSITION.

An effort was made to determine, approximately, the general chemical character of the gasolines tested. The chemical determination of the constituents of a gasoline is a long and tedious process, and the amount of work involved prevented such procedure at this time. However, an approximate idea of the nature of the fuel may be had from the characteristics that have been determined.

Gasoline No. 185 agrees quite generally in its general properties with hexane. The specific gravity is but 2 per cent higher, the mean volatility is just below the boiling point, the critical solution temperature with aniline slightly higher, the heat of combustion is practically the same, and the magnetic rotation slightly below that of hexane.

No. 191–A and commercial gasoline are not within the range of aviation gasolines.

Gasoline No. 262 has a low critical solution temperature, possibly indicating napthenes. The mean volatility is the same as the boiling point of natural cyclohexane. The magnetic rotation of this fuel is much higher than that of hexane, probably due to the benzenes and the higher members of the naphthene series.

[1] Findlay, A., Phase Rule; Rothmund, V., Solubility.

TABLE II.—*Physical properties of the chief constituents of gasoline.*

Fr.—French Physical Society Tables, 1910, 1911, 1912, and 1913.
H.—Hildebrand Jour. Amer. Chem. Soc., 39 (1917), p. 2126.
L.—Landolt Bornstein Physikalisch Chemische Tabellen, 1912 edition.
Ol.—Olsen, Van Nostrand Chemical Annual, 4th issue, 1918.
S.—Bureau of Standards.
T.—Timmermans Bull. Soc. Chem. Belg., 1911 and later years (several papers).

Name.	Formula.	Specific gravity at 20° C.	Freezing point, °C.	Boiling point, °C.	Heat of combustion, cal./gram.	Critical sol. temp., °C.	Rotatory power.
Aromatics	C_nH_{2n-6}						
Benzene	C_6H_6	0.8786 $Fr._{13}$	5.6 L.	80.2 L.	10030 S.	Miscible	0.000550 S.
Toluene	C_7H_8	0.8657 $Fr._{13}$	− 94.5 T.	110.7 T.	10150 L.	do	0.000485 S.
Xylene-O	C_8H_{10}	0.8633 L.	− 27.1 L.	141.0 L.	10229 L.	do	
Xylene-M	C_8H_{10}	0.8642 L.	− 54.8 L.	139.0 T.	10228 L.	do	
Xylene-P	C_8H_{10}	0.8612 L.	+ 15.0 L.	137.5 L.	10229 L.	do	0.000446 S.
Napthenes	C_nH_{2n}						
Cyclopentane	C_5H_{10}	0.751 L.	Below −80° L.	50.5 L.			
Methylcyclopentane	C_6H_{12}				11237 L.		
Dimethylcyclopentane.	C_7H_{14}				11219 L.		
Cyclohexane	C_6H_{12}	0.7764 L.	+ 6.40 L.	80.9 L.	11217 L.	31.3 T.	0.000226 S.
Methylcyclohexane	C_7H_{14}	0.7695 $Fr._{11}$		101.0 $Fr._{11}$	11151 L.	41.3 T.	
Cycloheptane	C_7H_{14}	(0.825 at 0° C.) L.		(117° at 743 mm.)	10187 L.		
Methylcycloheptane	C_8H_{16}		Very low L.				
Cyclooctane	C_8H_{16}						
Aliphatics (saturated)	C_nH_{2n+2}						
Pentane-normal	C_5H_{12}	(0.6454 at 0°) T.	−130.8 $Fr._{11}$	36.3 $Fr._{12}$	11650 S.		0.000211 S.
Isopentane	C_5H_{12}	0.6200 $Fr._{13}$	−158.0 $Fr._{13}$	27.9 $Fr._{13}$			
Hexane-normal	C_6H_{14}	0.6694 $Fr._{13}$	− 94.0 $Fr._{11}$	69.0 $Fr._{12}$	11501 L.	59.2 H.	0.000247 S.
Isohexane	C_6H_{14}	0.6599 $Fr._{13}$		62.0 $Fr._{13}$			
Heptane-normal	C_7H_{16}	0.733 $Fr._{10}$	− 97.1 $Fr._{11}$	98.4 $Fr._{12}$	11374 L.		
Isoheptane	C_7H_{16}	(0.707 at 0°) Ol.		90.3 Ol.			
Octane-normal	C_8H_{18}	(0.7185 at 0°) $Fr._{12}$	− 56.5 $Fr._{11}$	125.6 $Fr._{12}$	11497 L.		
Isooctane	C_8H_{18}						
Olefines	C_nH_{2n}						
Amylene-normal	C_5H_{10}	0.6597 $Fr._{12}$		38.0 $Fr._{12}$	11491 L.	21.8 T.	
Hexylene-normal	C_6H_{12}	0.6825 Ol.	− 98.5 Ol.	65.9 $Fr._{13}$	11413 L.		
Heptylene-normal	C_7H_{14}	0.703 Ol.		98.0 Ol.			
Octylene-normal	C_8H_{16}	0.7223 Ol.		124.0 Ol.			

Gasoline No. 263 can be judged chiefly by its low rotatory power, which is slightly greater than that of pentane. Being an American gasoline, a large proportion of napthenes would not be expected. Benzenes might raise the rotation. It would appear, perhaps, to be a mixture rich in pentane.

Gasoline No. 264 may be judged first from its magnetic rotation and second from its critical solution temperature, both of which approach those of hexane. Its mean volatility and specific gravity would indicate an admixture of a considerable proportion of heptane and a small amount of octane. If pentane is present, it perhaps forms an exceedingly small percentage of the whole.

Gasoline No. 265, if judged solely from its physical characteristics, would appear to be of much the same constitution as No. 264. It has a slightly lower rotation, and lower mean volatility than No. 264, but the critical solution temperature is higher. Examination of the distillation curve, however, shows that it has a much larger proportion of lower boiling point constituents, and approaches in this respect very closely to No. 266. On account of its low power characteristics, the physical characteristics of this fuel should be particularly noted.

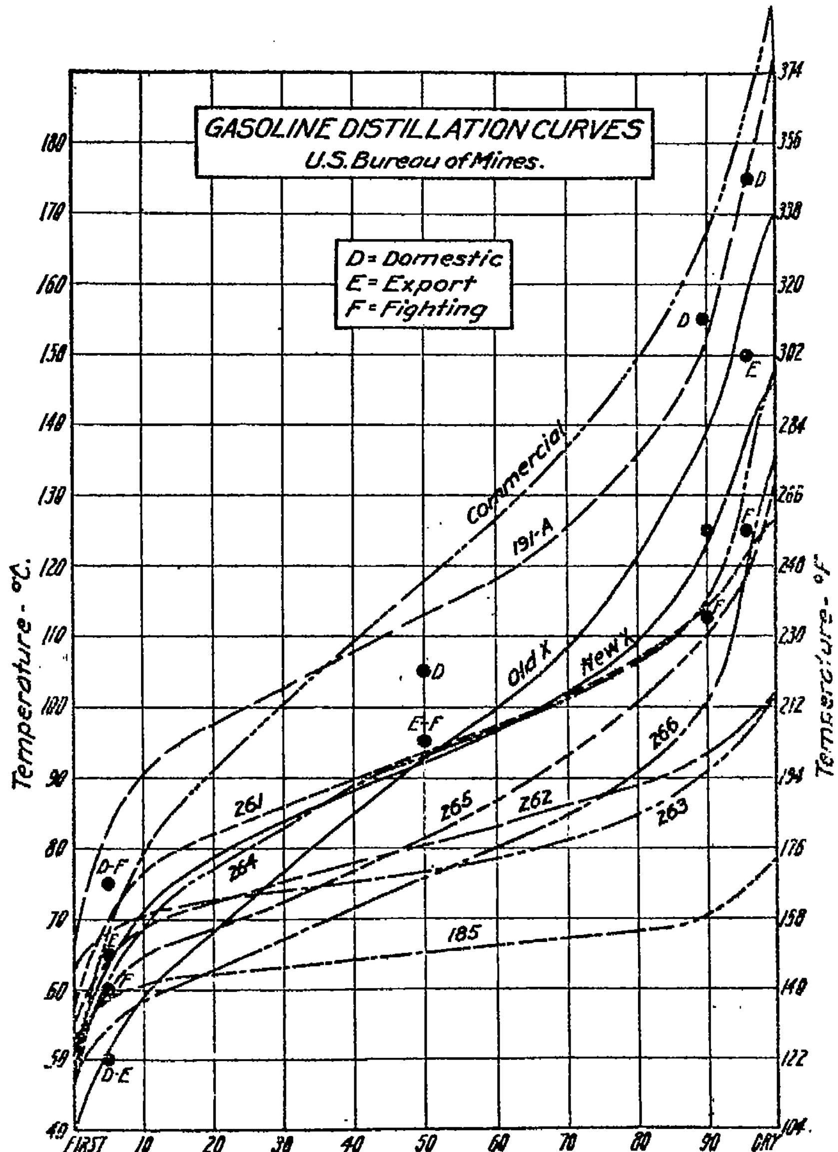
Gasoline No. 266 would appear from its low magnetic rotation to be particularly rich in pentane. This is confirmed in a measure by its comparatively low mean boiling and the general character of the distillation curve.

METHODS OF TESTING.

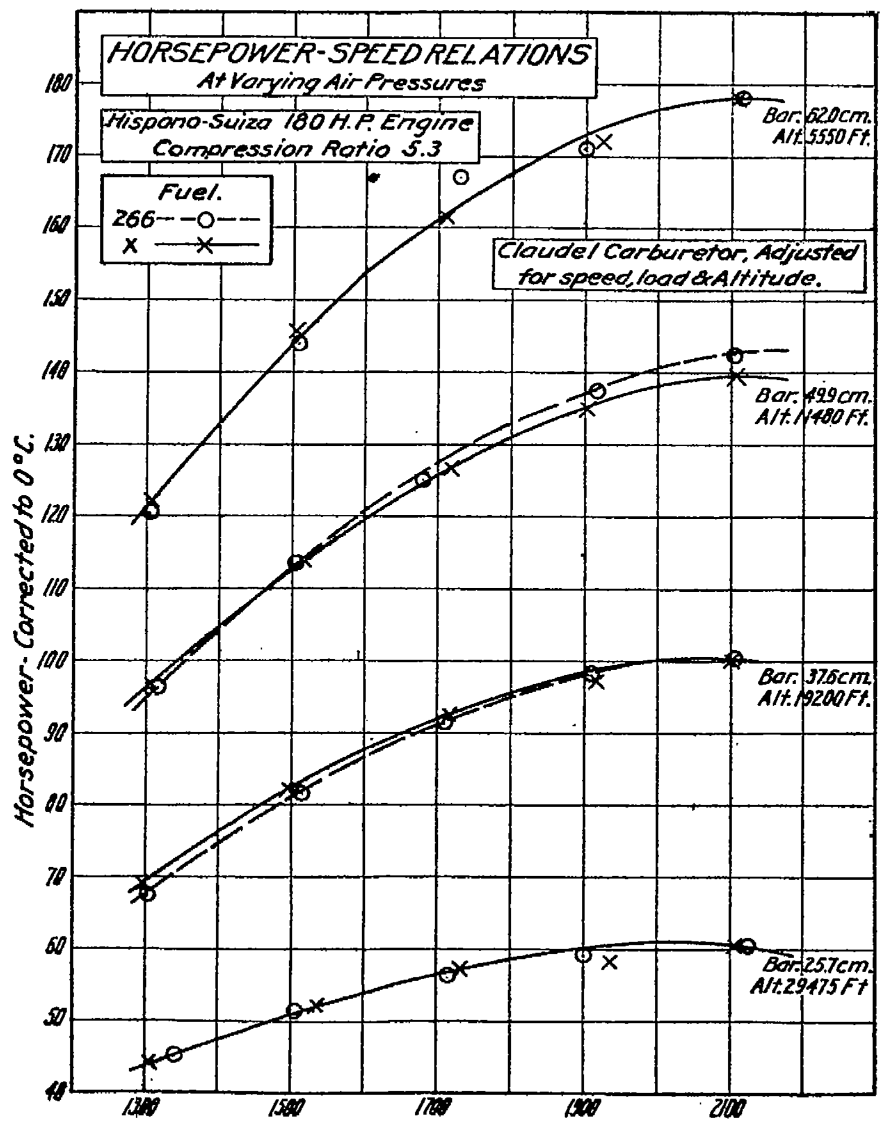
The engine was operated in reduced pressures, corresponding to four different altitudes varying slightly in the different tests but averaging approximately as follows:

5,350 feet (62.5 cm. Hg.)
11,000 feet (50.8 cm. Hg.)
19,000 feet (38.0 cm. Hg.)
25,500 feet (25.8 cm. Hg.)

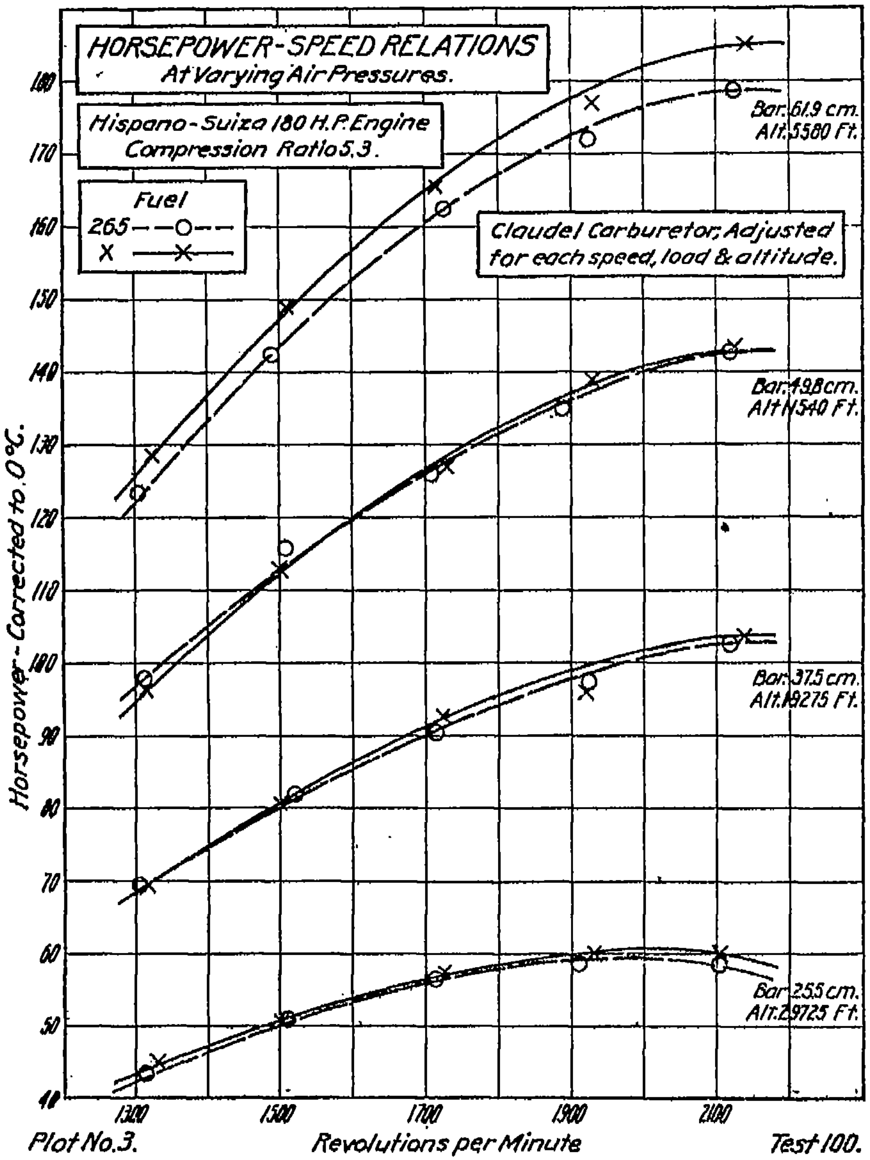
and at five different speeds at each altitude: 1,300, 1,500, 1,700, 1,900 and 2,100 r. p. m. The carbureter was adjusted by hand for each test to secure the maximum horsepower for that particular speed, altitude, and fuel, with the leanest possible mixture for maximum power. The method of adjustment employed was as follows: The carbureter was first set to secure the

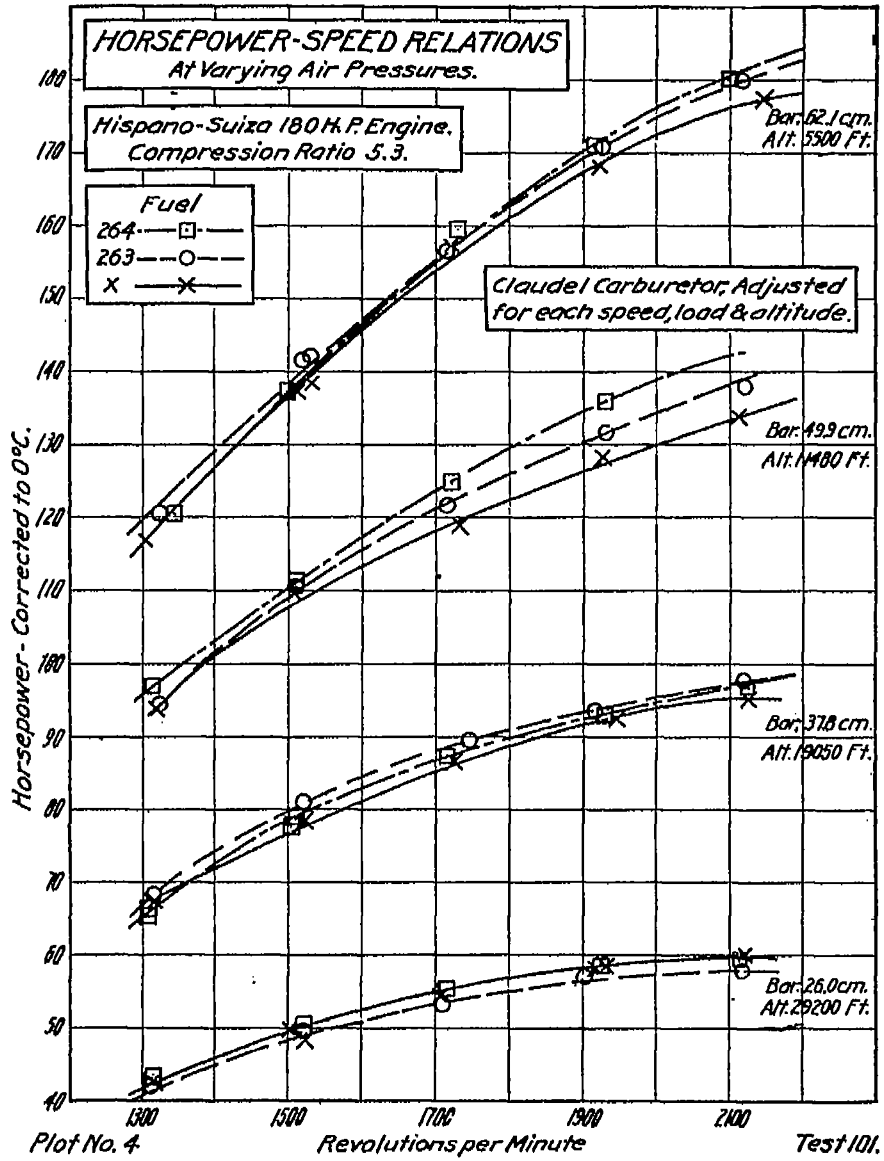


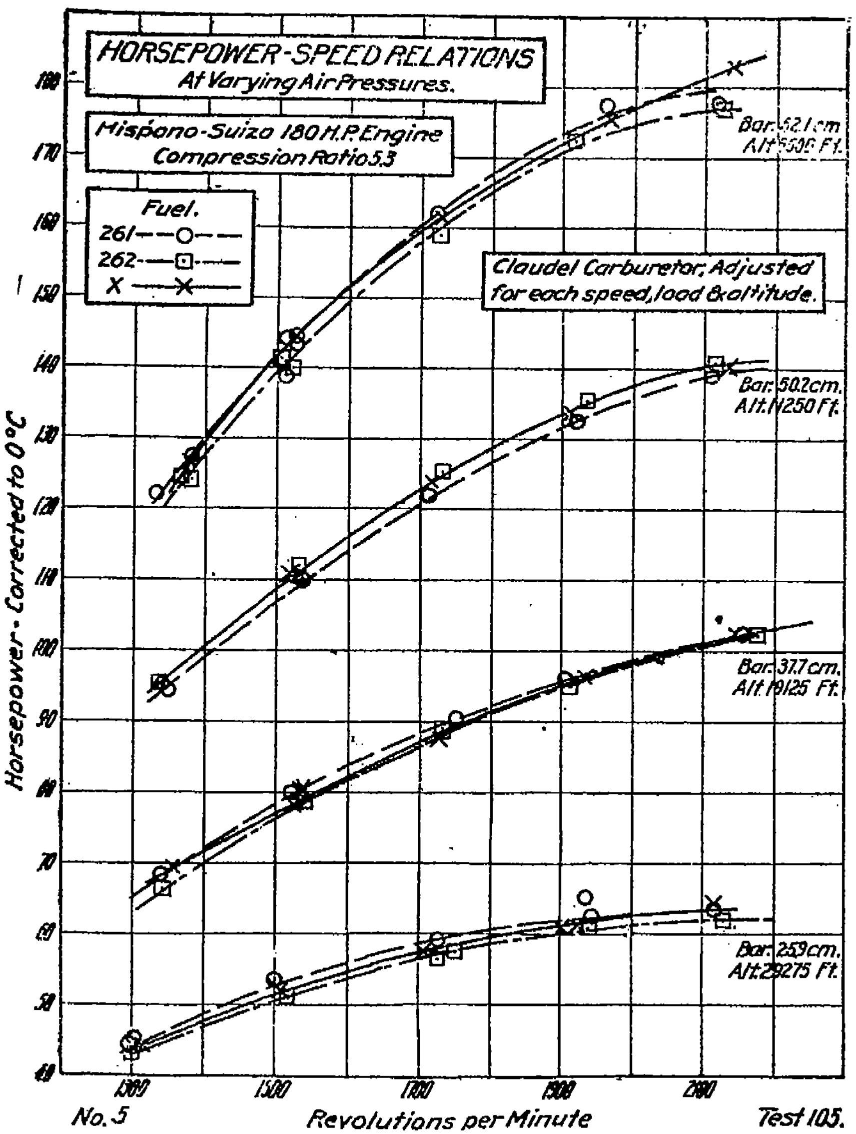
Plot No. 1.



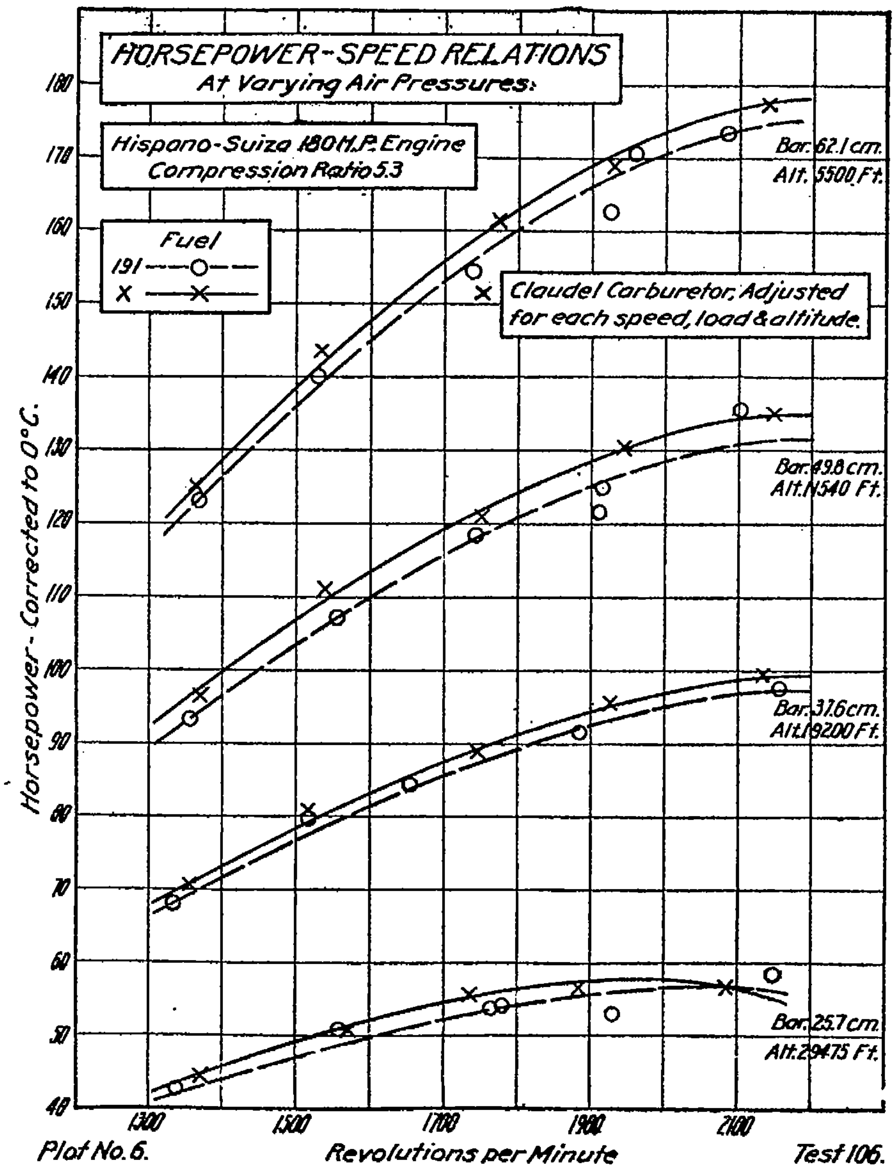
Plot No. 2


HORSEPOWER-SPEED RELATIONS
At Varying Air Pressures.
Hispano-Suiza 180 H.P. Engine
Compression Ratio 5.3.
Fuel
265
X
Claudel Carburetor; Adjusted for each speed, load & altitude.
Bar. 61.9 cm. Alt. 5580 Ft.
Bar. 49.8 cm. Alt. 11540 Ft.
Bar. 37.5 cm. Alt. 19275 Ft.
Bar. 25.5 cm. Alt. 29725 Ft.
Horsepower - Corrected to 0°C.
Revolutions per Minute
Plot No. 3.
Test 100.

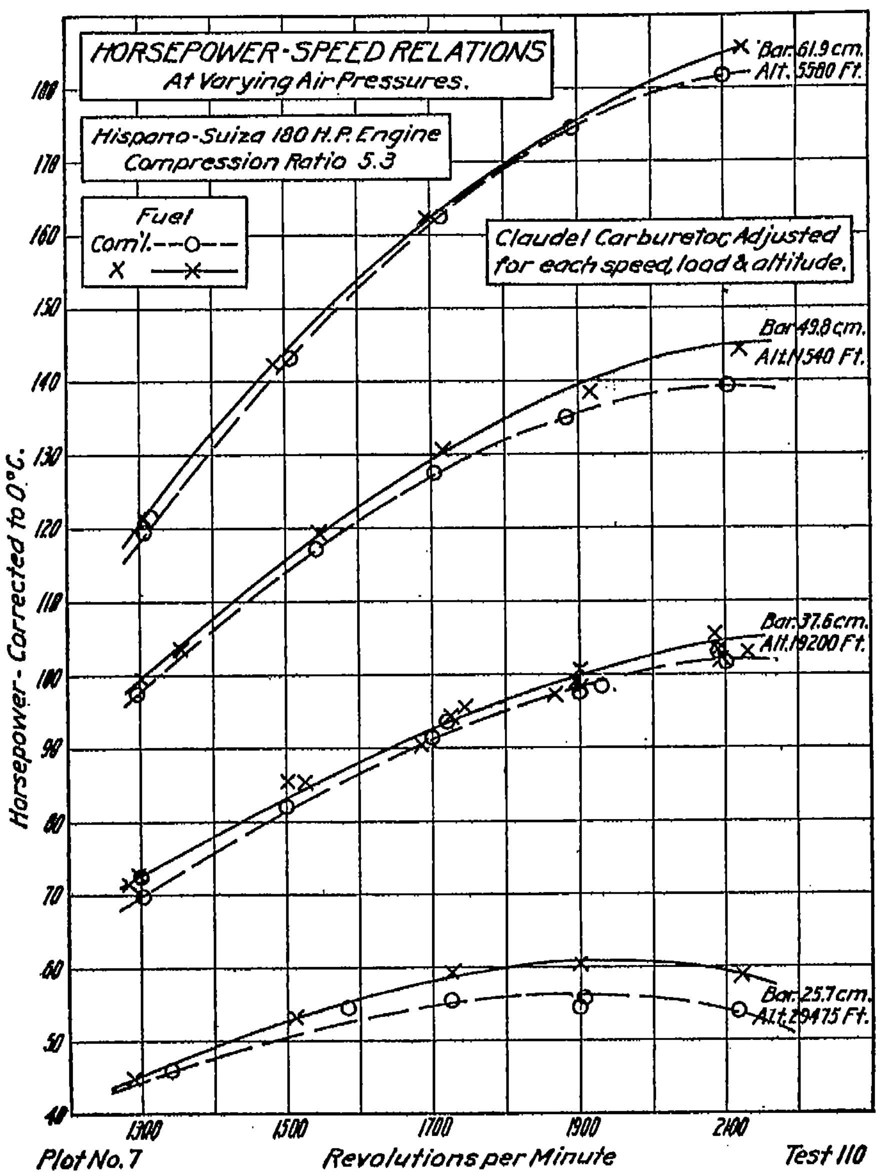

HORSEPOWER-SPEED RELATIONS
At Varying Air Pressures.
Hispano-Suiza 180 H.P. Engine.
Compression Ratio 5.3.
Fuel
264
263
X
Claudel Carburetor; Adjusted for each speed, load & altitude.
Bar. 62.1 cm. Alt. 5500 Ft.
Bar. 49.9 cm. Alt. 11480 Ft.
Bar. 37.8 cm. Alt. 19050 Ft.
Bar. 26.0 cm. Alt. 29200 Ft.
Horsepower - Corrected to 0°C.
Revolutions per Minute
Plot No. 4.
Test 101.



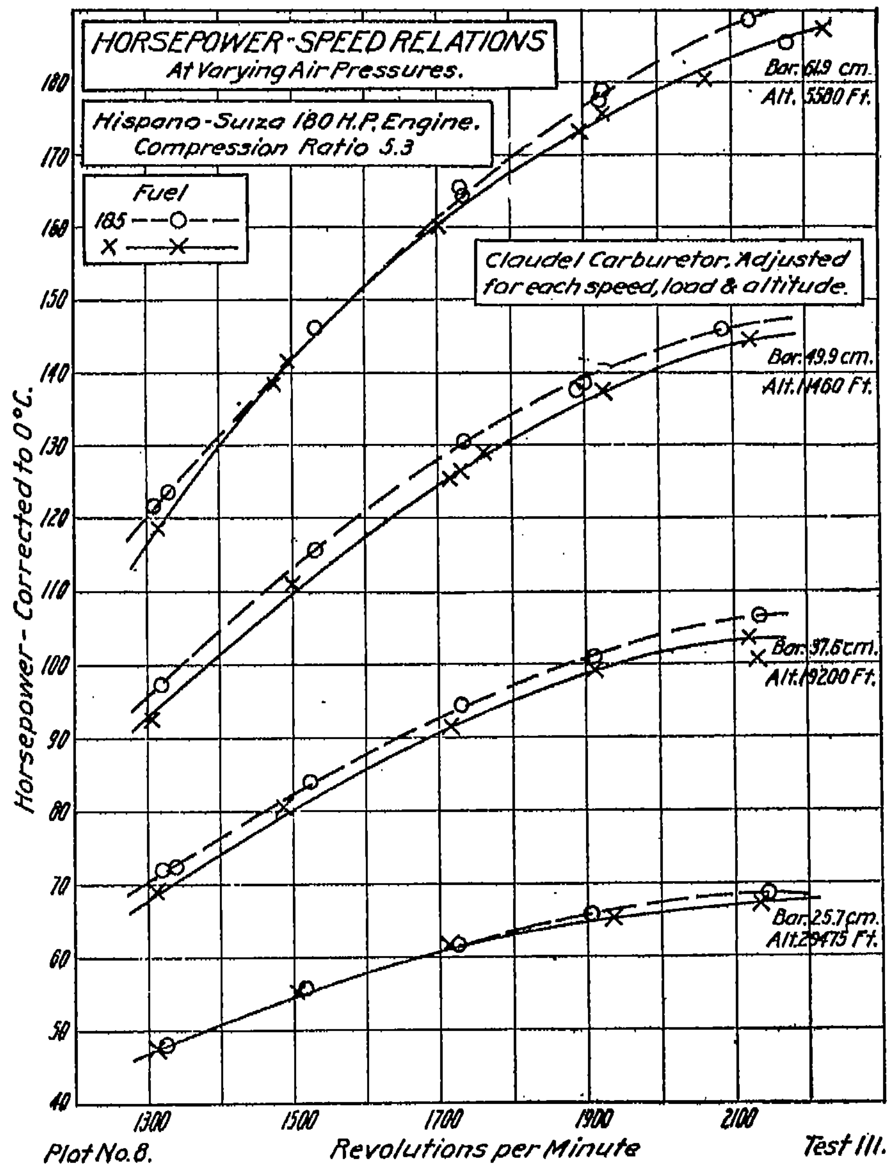
HORSEPOWER-SPEED RELATIONS
At Varying Air Pressures.
Hispano-Suiza 180 H.P. Engine
Compression Ratio 5.3
Fuel.
261
262
X
Claudel Carburetor; Adjusted for each speed, load & altitude.
Bar. 50.2 cm.
Alt. 11250 Ft.
Bar. 37.7 cm.
Alt. 19125 Ft.
Bar. 25.9 cm.
Alt. 29275 Ft.
Horsepower - Corrected to 0°C
Revolutions per Minute
No. 5
Test 105.



HORSEPOWER-SPEED RELATIONS
At Varying Air Pressures.
Hispano-Suiza 180 H.P. Engine
Compression Ratio 5.3
Fuel
191
X
Claudel Carburetor; Adjusted for each speed, load & altitude.
Bar. 62.1 cm.
Alt. 5500 Ft.
Bar. 49.8 cm.
Alt. 11540 Ft.
Bar. 37.6 cm.
Alt. 19200 Ft.
Bar. 25.7 cm.
Alt. 29475 Ft.
Horsepower - Corrected to 0°C.
Revolutions per Minute
Plot No. 6.
Test 106.



HORSEPOWER-SPEED RELATIONS
At Varying Air Pressures.
Hispano-Suiza 180 H.P. Engine
Compression Ratio 5.3
Fuel
Com'l. ---O---
X ——X——
Claudel Carburetor, Adjusted for each speed, load & altitude.
Bar. 61.9 cm. Alt. 5580 Ft.
Bar. 49.8 cm. Alt. 11540 Ft.
Bar. 37.6 cm. Alt. 19200 Ft.
Bar. 25.7 cm. Alt. 29475 Ft.
Horsepower - Corrected to 0°C.
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
1300
1500
1700
1900
2100
Plot No. 7
Revolutions per Minute
Test 110



HORSEPOWER-SPEED RELATIONS
At Varying Air Pressures.
Hispano-Suiza 180 H.P. Engine.
Compression Ratio 5.3
Fuel
185 ---O---
X ——X——
Claudel Carburetor, Adjusted for each speed, load & altitude.
Bar. 61.9 cm. Alt. 5580 Ft.
Bar. 49.9 cm. Alt. 11460 Ft.
Bar. 37.6 cm. Alt. 19200 Ft.
Bar. 25.7 cm. Alt. 29475 Ft.
Horsepower - Corrected to 0°C.
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
1300
1500
1700
1900
2100
Plot No. 8.
Revolutions per Minute
Test 111.

maximum possible brake pull regardless of fuel consumption. The fuel supply was then diminished until the brake pull was reduced. Then the gasoline flow was increased gradually until the brake pull reached the maximum obtained in the preliminary trial.

In these tests the engine was run at the various speeds at one barometric pressure and, immediately before or after, corresponding runs were made with the comparison fuel, the Standard X. This insures that the engine is in practically the same condition when run with the fuel under observation as when run on the comparison fuel. This method permits the comparison of one fuel with another, by comparing the ratio of the performance of each with the performance of the standard.

METHODS OF HANDLING THE TEST DATA.

These tests were all made at nearly the same air temperatures. In order to correct for slight differences in the performance of the engine with the various fuels, the horsepowers were reduced to a standard or to a mean temperature. The standard temperature used in these tests is 0° C. (plots 2 to 8, inclusive). The formula used for the temperature correction to 0° C. is that given in Report No. 45, Part III, Variation of Horsepower with Temperature.

After the horsepowers were corrected for temperature, they were plotted against speed, plots 2 to 8, inclusive.

There are three major variables entering into these tests, namely, speed, power, and air density. The relations between these three must form a smooth surface, when plotted in three dimensions. When a two dimensional section is employed, such as the relation between power and speed for a constant altitude, such a curve must not be faired without some regard to the relations between another two of the variables. In this way each observation in the entire set, regardless of the speed or density at which taken, becomes a check on all the other observations.

From the scattering of the points on plots 2 to 8, it is apparent that different investigators would necessarily disagree slightly as to the location of the faired curves. By selecting the horsepowers corresponding to different altitudes for a given speed, other series of graphs were prepared, in which the relation of power to barometric pressure is found to be nearly a straight line. One investigator favored faired curves which were strictly linear. The values resulting from this latter assumption lead to the percentage power differences shown in Table III, and on plots 9 to 12. The percentage differences are computed from the performance of "X" gasoline as a reference standard.

TABLE III.—*Power differences.*

The percentage difference in power developed by the engine when using the several fuels, compared with the power when using "X" gasoline as a standard.

Rev. per minute.	Barometer cm. (appr).	Gasoline Number.								
		266 (loss).	265 (loss).	263 (gain).	264 (gain).	261 (gain).	262 (loss).	191 (loss)	Commercial (loss).	185 (gain).
2,100	62	0.0	2.9	1.1	1.4	1.2	1.3	1.5	1.8	2.9
	50	.0	2.1	1.2	1.6	1.4	1.2	1.6	1.9	3.0
	38	.0	3.2	1.3	1.6	1.4	1.3	1.8	2.3	4.2
	26	.0	3.6	1.5	1.7	1.6	1.6	1.8	2.3	3.6
1,900	62	0.3	2.0	0.8	1.4	1.1	1.0	1.4	2.2	2.4
	50	.3	1.7	.8	1.4	1.0	1.1	1.5	2.2	2.5
	38	.3	2.0	.8	1.5	1.1	1.1	1.5	2.3	2.6
	26	.3	2.3	.9	1.7	1.2	1.2	1.7	2.6	2.8
1,700	62	0.6	1.2	0.7	1.3	1.4	0.8	1.5	1.8	2.1
	50	.6	1.2	.6	1.3	1.4	.8	1.6	1.8	2.2
	38	.7	1.0	.6	1.4	1.2	.8	1.7	1.9	2.3
	26	.7	1.2	.7	1.6	1.6	.9	1.8	2.0	2.5
1,500	62	0.7	0.3	0.4	1.3	2.0	0.7	1.4	1.3	1.7
	50	.7	.8	.4	1.3	1.7	.7	1.4	1.4	1.8
	38	.7	.4	.5	1.3	1.8	.5	1.5	1.4	2.0
	26	.8	.4	.7	1.5	2.3	.7	1.6	1.5	2.2
1,300	62	0.8	0.0	0.4	1.3	3.1	0.0	1.6	0.8	1.6
	50	.8	.0	.4	1.3	3.2	.2	1.7	.8	1.8
	38	.8	.0	.4	1.3	3.2	.0	1.7	.8	1.9
	26	.8	.0	.4	1.4	3.4	.3	1.8	.9	1.9

Since the horsepower observations for both the Old and New "X" vary somewhat with the condition of the engine, it was necessary to select a representative X curve. For this purpose two curves were chosen, one from the test comparing 265 to Old X, and one from the comparison of commercial to New X. The reason for choosing these particular tests as the best tie between the old and new standard fuels is that each was conducted after a thorough cleaning and overhaul of the engine, when the conditions were most favorable to identity of engine performance in the two cases. The power curves for the two X gasolines were practically identical. It is unfortunate that conditions rendered impossible a direct comparison of the two fuels, eliminating all assumptions as to constancy of engine performance.

CONCLUSION.

The magnitude of the change in power developed by the engine when using these different gasolines must be considered very carefully. The data from the tests have been worked up in many different ways by several individuals. When the data have been digested as in securing Tables III, IV, and plots 9 to 12, the maximum increase of engine power, referred to X gasoline as a standard, is 2.5 per cent at a normal speed of 1,700 r. p. m., and the greatest loss at this speed is 2 per cent. At the excessive speed of 2,100 r. p. m., where the effects of uncertain engine performance are greater, the greatest changes of power shown are 3.6 per cent above and below the X values. The power values from the various fuels agree, therefore, within about 3 per cent plus or minus. In ordinary engineering work this is a permissible variation. Every known precaution was taken in the testing to insure accuracy, so it may be that the data are subject to a less error than 3 per cent. If the test data and subsequent methods of handling give results of an accuracy better than 3 per cent, then the results may be of a positive nature. If greater errors are inherent, then the results are of a negative nature, failing to prove any appreciable difference in these gasolines when carbureting conditions are adapted to the fuel used.

By using the data in the manner which led to Table III (plots 9 to 12), exact numerical values may be assigned to the power differences. Omitting considerations as to whether the accuracy of these numbers warrants any such ranking of the fuels, it may be of interest to tabulate them in the order of power producing ability as indicated by these numbers. The result is Table IV, which is reproduced to demonstrate that there is very little or no definite connection between the power ability and the properties considered.

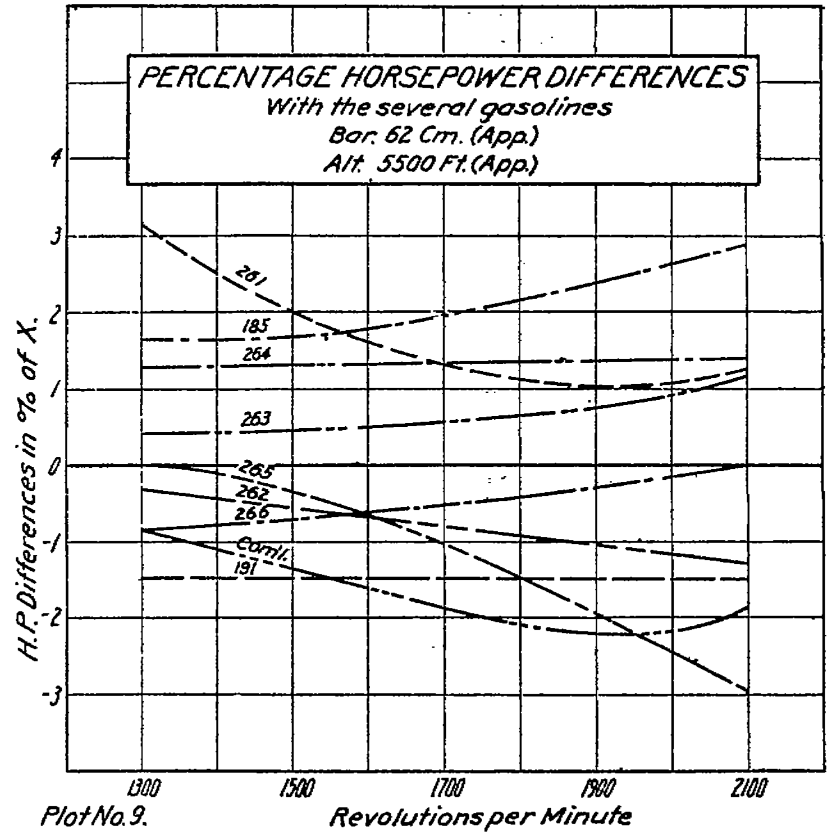
TABLE IV.—*The gasolines as arranged in order of variation of properties.*

Order of magnitude.	1	2	3	4	5	6	7	8	9	10	11
Power-producing qualities decrease	185	264	261	263	New X	Old X	266	262	265	192	Com'l
Mean volatility temperature increases	185	266	263	262	265	264	261	New X	Old X	191	Com'l
First drop temperature decreases	263	191	261	262	185	New X	265	264	Com'l	266	Old X
50 per cent point temperature increases	185	266	263	262	265	New X	Old X	264	261	191	Com'l
90 per cent point temperature increases	185	263	262	266	265	261	264	New X	Old X	191	Com'l
Specific gravity increases	185	266	265	263	264	New X	261	262	Old X	191	Com'l
Unsaturated per cent increases	263	265	264	266	Old X	155	262	Com'l	261	191	New X
Rotatory power decreases	Com'l	191	262	261	185	264	265	New X	263	266	....
Heating value decreases	185	265	266	264	261	New X	263	262	Com'l	191	....
Critical solution temperature decreases	185	265	264	261	262	....	....	....	....	....	....

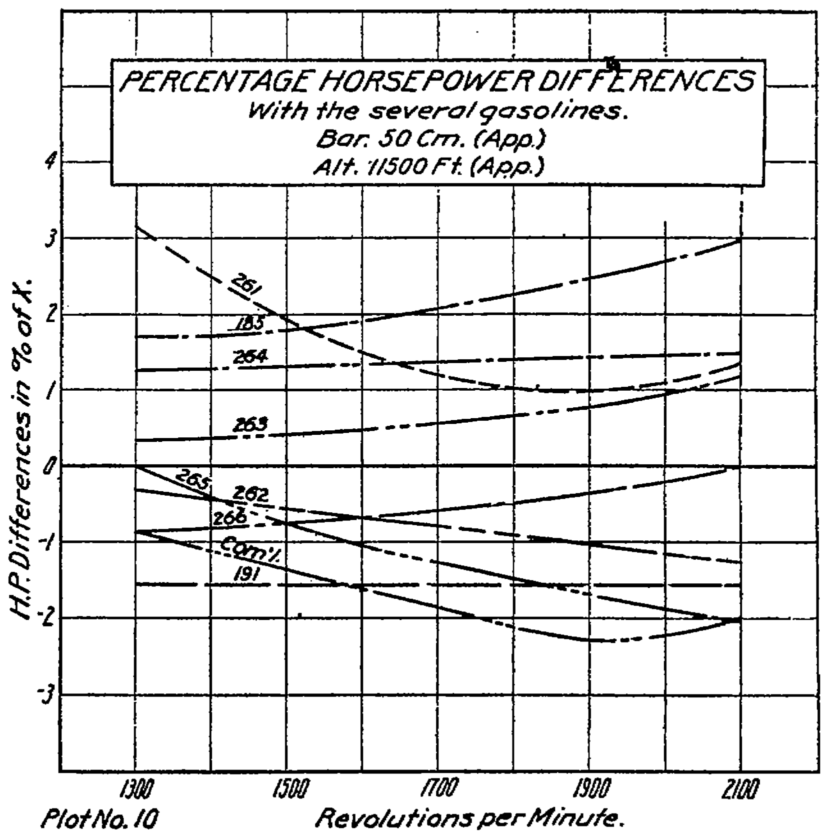
The order for the last three properties applies only to the fuels shown, and would probably be altered by data of remaining fuels.

It is evident that the best and some of the average gasolines had similar properties, and some of the average fuels had properties similar to the poorest. No way was found of predicting the power performance from any one, or from any group of properties. Admitting appropriate probable errors in Table III, the only unqualified general deduction warranted is equally evident fron the original laboratory curves of power vs. speed, plots 2 to 8.

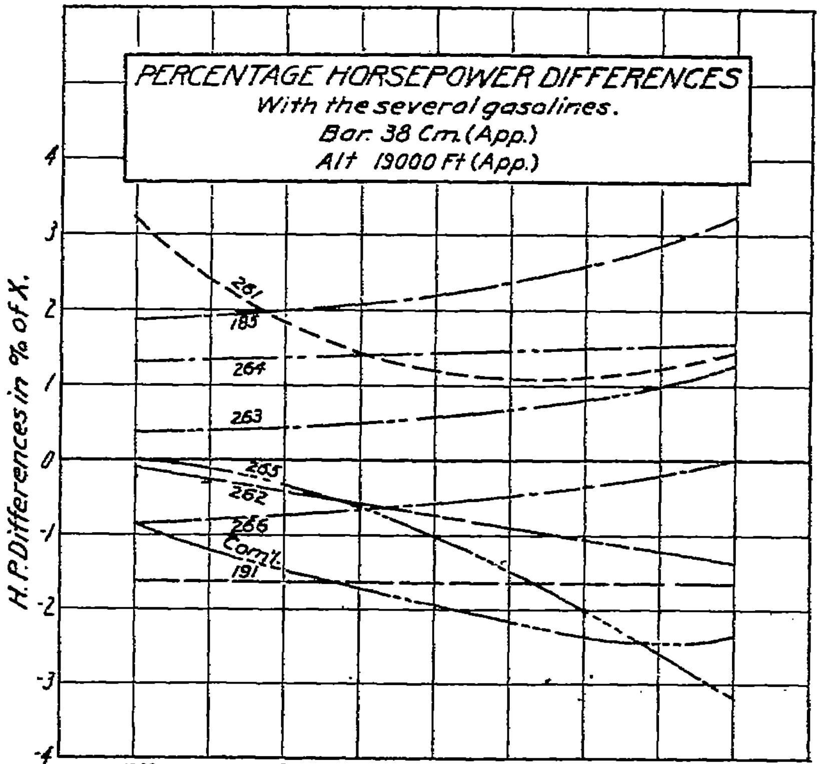
The definite general conclusion from this work is that when the necessary carburetion changes have been made so that each fuel was prepared as well as possible for combustion in the engine, then one particular gasoline was slightly superior in power producing qualities, a large number of others were nearly as good, and two were slightly but distinctly inferior to the others, the extreme differences being of the order of magnitude of 5 per cent.



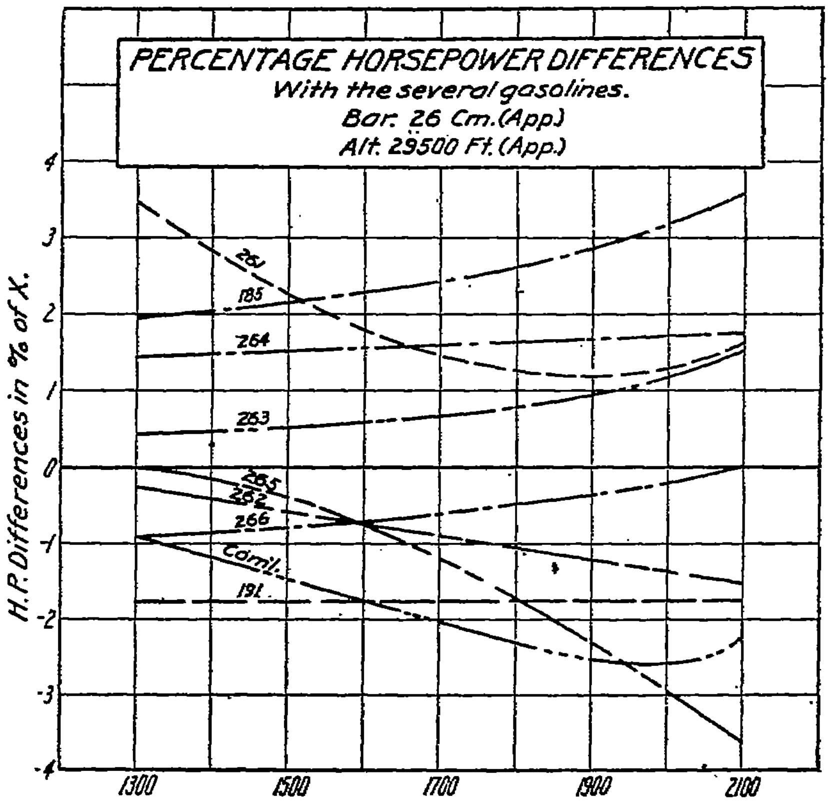
Plot No. 9.



Plot No. 10



Plot No. 11 Revolutions per Minute.



Plot No. 12 Revolutions per Minute.

REPORT No. 47.

PART II.

POWER CHARACTERISTICS OF SUMATRA AND BORNEO GASOLINES.[1]

By E. W. ROBERTS.

RÉSUMÉ.

The importance of securing the best possible airplane engine fuels has led to a series of experiments on a number of fuels in the altitude laboratory of the Bureau of Standards and at various flying fields. Two gasolines extensively used for aeronautical work by the French and therefore of particular interest are those distilled from crudes found in the Islands of Sumatra and Borneo. Experiments on gasolines from these crudes are of additional interest because of the very exhaustive research that has been made by L. J. Simon to determine their chemical constituents. These investigations by Simon were carried on in Paris, and are the subject of an extensive confidential report.

From the results of the experiments conducted at the Bureau of Standards with a sample of each of these fuels, having volatility ranges of from 50° C. to 130° C. for Sumatra, and from 50° C. to 100° C. for Borneo, the following conclusions have been drawn:

(1) The sample of Sumatra gasoline tested develops slightly more horsepower (maximum 1.4 per cent) than the United States standard (export) aviation gasoline (Aircraft Production Specification No. 3512) at the altitudes and the engine speeds covered by the experiments.

(2) The sample of Borneo gasoline tested develops slightly less horsepower (maximum 0.6 per cent) than United States standard (export) aviation gasoline, throughout the range of speeds and altitudes covered by the experiments.

(3) Both samples of Sumatra and of Borneo gasolines develop higher horsepowers than commercial gasoline. The maximum increase for Sumatra gasoline is 4.2 per cent and that for Borneo gasoline is 2.2 per cent.

(4) An investigation of the heats of combustion of Borneo and Sumatra gasolines shows these values to be practically identical.

(5) Fractional distillation shows a lower volatility (temperature of distillation) for the sample of Borneo gasoline than for the sample of Sumatra, although the latter shows a higher horsepower.

(6) The fuel economy when using the sample of Sumatra gasoline was much higher than when using the United States standard (export) aviation gasoline, except at the highest altitudes at which observations were made.

(7) The fuel economy of the sample of Borneo gasoline may be said to have averaged about the same as the United States standard (export) aviation gasoline.

INTRODUCTION.

The following report is based upon experiments made in the altitude laboratory of the Bureau of Standards. In this laboratory, the engine used in the tests is installed in a concrete chamber having insulated walls, from which the air may be partially exhausted by means of a blower. This blower also handles the exhaust from the engine, thus reducing the barometric pressure on the exhaust, the intake, and the surrounding space, to that corresponding to any desired altitude, up to about 40,000 feet. Before the air enters the chamber it is passed over a series of refrigerating coils, and by this means its temperature may be reduced during the ex-

[1] This report was confidentially circulated during the war as Bureau of Standards Aeronautic Power Plants Report No. 33.

periment. The engine is coupled to an electric dynamometer placed outside the chamber, by means of which the power of the engine may be measured. A complete description of the vacuum chamber and auxiliary apparatus may be found in Technical Report No. 44.

GENERAL DESCRIPTION OF FUELS.

The fuels, the characteristics of which are the subject of this report, are of special interest because of their representative character. The gasoline distilled from the crudes found in the Islands of Sumatra (Bureau of Mines No. 261) is very probably similar in proportions of its various hydrocarbons to the average German airplane fuel. That derived from Borneo crudes (Bureau of Mines No. 262) is particularly high in naphthenes (cyclics, hydroaromatics). The standard fuel with which both gasolines were compared during the experiments in the altitude laboratory, and referred to hereafter as X, fulfills the specifications of the United States Bureau of Aircraft Production for aviation gasoline (export), specification No. 3512. This is a typical American gasoline, a product of crudes from the Atlantic or Eastern oil fields.

Further interest is attached to the Sumatra and Borneo gasolines as they have been the subjects of a most exhaustive investigation in France, to determine the proportions of the various hydrocarbons of which they are comprised. These investigations were made at École Normale Superieur in Paris, under the auspices of L. J. Simon.

Some ten or more homologous series of hydrocarbons have been found in petroleums. Gasolines are generally comprised of varying proportions of the following four:

$C_nH_{2n}+2$ = Methanes, also called paraffins, acyclics, aliphatics.

$C_nH_{2n}-6+H_6$ = Naphthenes, also called hydro aromatics, cyclics, polymethelenes.

$C_nH_{2n}-6$ = Benzenes or aromatics.

C_nH_{2n} = Olefines, also called ethylenes, ethylenics.

The sequence in which the compounds are noted above is the order of predominance, and the first of the names given are those most commonly used. The olefines are also known as unsaturated compounds, and contain less hydrogen than the methane group. Benzenes and naphthenes are of a more stable nature than the olefines. The naphthenes are frequently given the same group formula as the olefines, of which they are isomers, although different both in their physical and chemical characteristics. The proportions of these several groups in the principal aviation gasolines are given by Simon as follows:

TABLE I.

Gasoline.	American.	Sumatra.	Borneo.	German.	
				Nanteuil.	Sixth Army.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Methanes	81.2	71.3	26.0	73.0	68.55
Naphthenes	16.5	22.2	70.8	20.0	24.10
Benzenes	2.3	6.5	2.9	7.0	7.25
Olefines (United States Bureau of Mines.)	1.8	1.5	1.4	....	....

It should be noted that Simon does not give the proportion of unsaturated compounds, but includes them in the methanes. The percentage of methanes is determined by difference after determining benzenes and naphthenes. It is interesting to note that the composition of Sumatra gasoline is an approximate average of the two German gasolines. It may be considered as probable that the performance of Sumatra is an indication of what might be expected of German airplane fuels. The proportions given by Simon for American gasoline are not obtained from standard X, but the figures may be considered as approximately the proportions of X.

The following information on Sumatra and Borneo fuels was furnished by Henry P. Wescott, the author of several books on petroleum. Sumatra crudes contain about 12 per cent of natural gasoline, while Borneo crudes contain about 8 per cent. The gasoline output is further increased in each case by cracking the residua, and in the Borneo gasoline by adding casing head gasoline. The cracking system in use is that known as the Trumbull process. The casing head gasoline is obtained by the absorption process. The final percentage of gasoline obtained is approximately as follows: Sumatra, 42 per cent; Borneo, 30 to 32 per cent.

METHOD OF CONDUCTING TESTS.

The engine employed in these experiments at the Bureau of Standards was a 150-horsepower type A, Hispano-Suiza, built by the Wright-Martin Aircraft Corporation, New Brunswick, N. J., and fitted with special high-compression pistons. The engine has eight cylinders in blocks of four, set at 90°, with the following general dimensions:

Bore	120 mm. (4.725 inches).
Stroke	130 mm. (5.118 inches).

Compression ratio $\left(\frac{\text{Total volume}}{\text{Clearance}}\right)=5.3$.

The engine was operated under pressures corresponding to four different altitudes, as follows:

5,200 feet	62.7 cm. Hg.
11,200 feet	50.5 cm. Hg.
19,000 feet	38.0 cm. Hg.
29,100 feet	26.1 cm. Hg.

and at five different speeds at each altitude, 1,300, 1,500, 1,700, 1,900, and 2,100 revolutions per minute.

The carburetor was carefully adjusted by hand for each test to secure the maximum horsepower at that particular speed and altitude with the leanest mixture. The method of adjustment employed was as follows: The carburetor was first adjusted so that the engine developed the maximum power possible regardless of fuel consumption. The fuel was then cut down until the power decreased. Then the gasoline flow was gradually increased till the maximum power was developed as before. There was no adjustment of carburetor air temperatures, which varied between −10 and −20° C.

In these experiments the engine was operated at the various speeds and at one barometric pressure, while on the fuel being tested, and then immediately before and after, corresponding runs were made on the standard X comparison fuel. This method of observation gives assurance that the engine is in practically the same condition during runs on both kinds of fuel. It also permits of comparison between one fuel and another by means of the ratios of performance of each fuel to the standard fuel.

The samples of Sumatra and Borneo gasolines which are the subject of this report show the same range of distillation temperatures as given by Simon for the French aviation gasolines from the same sources.

The standard fuel referred to as X is manufactured by the Atlantic Refining Co., as one of their regular products, and as already noted, accords with specification No. 3512 of the Bureau of Aircraft Production.

As a matter of interest, the performance of "commercial gasoline" has been tabulated and plotted with the results obtained from the samples of Sumatra and Borneo and from X gasoline. The values for commercial gasoline have been tabulated by percentage differences between the values obtained for this fuel and X in another test.

"Commercial gasoline" is a fair sample of the fuel usually sold at gasoline filling stations, and distills at higher temperature than X. It was purchased under the United States General Supply Committee's Specification for 1918.

In order that a fair comparison of the performance of the engine, while using the various fuels, could be made, the horsepowers in each case were reduced to 0° C. The method of making this correction is described in Technical Report No. 45, Part I.

METHOD OF WORKING UP DATA.

In working up the data secured from these tests it was found that the horsepower differences were so small as to make the usual method of fairing curves too uncertain. A study of plot 1 will show that at all altitudes except 11,000 feet the sample of Sumatra gasoline showed a greater horsepower than X, while at the latter altitude it was lower than X. This is so unusual and has been so seldom found in tests with other fuels that the results were open to suspicion. Therefore the data were carefully analyzed for the purpose of determining the probable cause of the discrepancy.

By plotting the horsepowers against barometric pressure, plot 2, it is apparent that the results were obtained at a higher altitude than that recorded. Shifting all these points the same distance to the right, or to the ordinate corresponding to 49 cm. Hg., they will be found to lie very nearly on straight lines drawn through observed horsepowers at the highest and lowest altitude of the test. The new positions are indicated by dots. It will be noted that in the majority of cases all horsepowers observed at one speed lie on a straight line, or very nearly so. The points shown on plot 2 are obtained from plot 1 by drawing curves as closely as possible through the horsepowers plotted from the observations. The intersections of the straight lines of plot 2 with the ordinates representing the four altitudes at which observations were taken were plotted in plot 1, and any error in selecting the proper line was at once apparent. It was in this way that the curves of plot 1 were obtained.

One feature of the lines of horsepower plotted against barometric pressure was particularly helpful in this method of analysis. It was found that the intercepts of these lines on the axis of zero pressure were quite evenly spaced. For example, in the equation of the line

$$y = ax - b$$

wherein $y =$ horsepower, and
$x =$ barometric pressure in cm. Hg.,

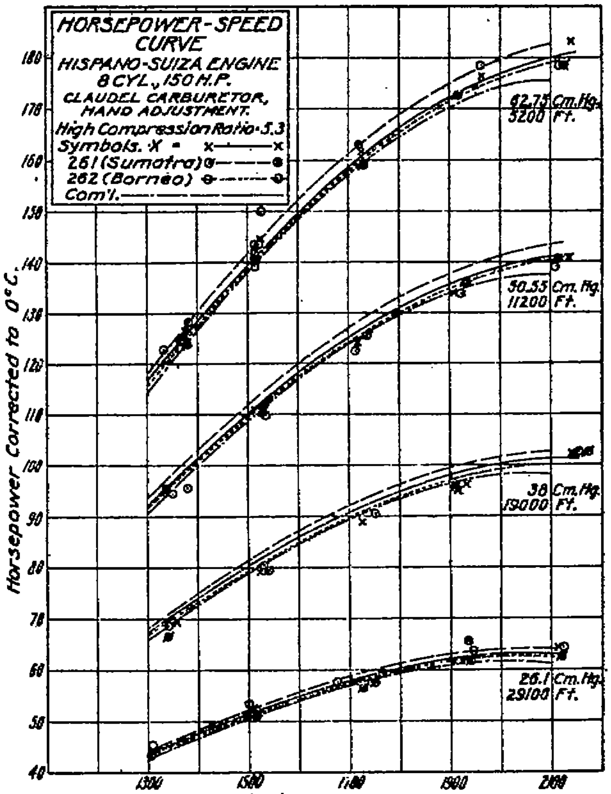
the values of b increased by even increments for even increments of speed. The value of b is a function of the friction horsepower at that particular speed. Since the friction horsepower is entirely independent of the fuel employed, the values of b should be the same for each speed regardless of the fuel. Roughly estimating the equations of the various lines from the highest and the lowest horsepowers in each case showed that the values of b were approximately the same for all fuels. Plotting these values of b against speed and drawing an average line through these points gave the final values of b, which were employed for the lines of plot 2. It is from these equations, and not from the intersections in plot 2, that the horsepower values in Table III were obtained.

In the case of commercial gasoline the values are those taken from another test by first fairing the curves of both X and commercial by the method just described, and then transferring to the present test sheets by the ratio commercial bears to X.

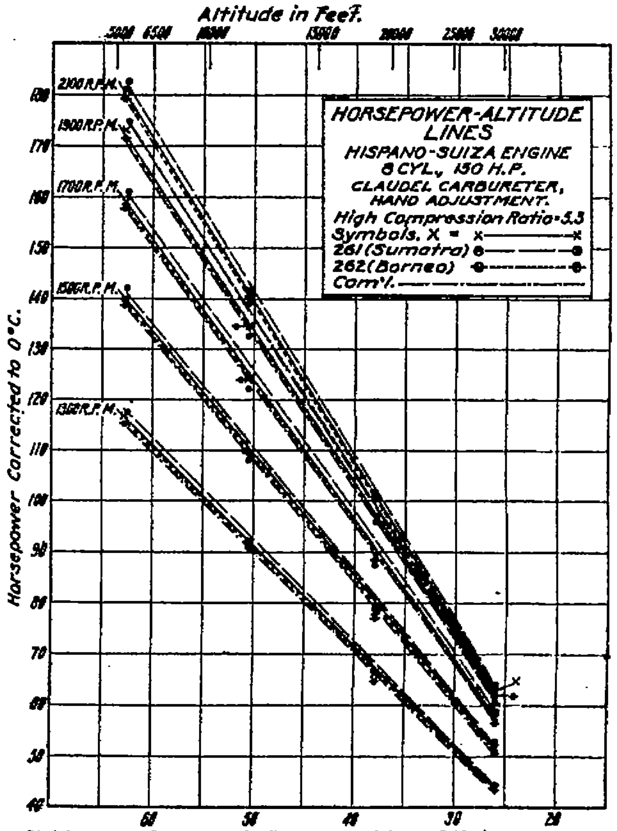
In plot 3 are plotted the horsepower differences between X and the two fuels under observation. In this figure it will be seen that the horsepowers given by the sample of Sumatra show a practically constant gain over X for each speed throughout the entire range of altitude. The horsepowers given by the sample of Borneo are less than the X horsepowers by a fixed amount for each speed throughout the range of the observations.

In plot 4 are plotted the percentage horsepower differences between X and the two fuels as compared to X. These curves show practically the same percentage differences for all altitudes at one speed. In the case of Sumatra the maximum appears at 1,900 revolutions per minute, while the percentage of Borneo below X is practically constant at 0.7 per cent for all speeds and all altitudes.

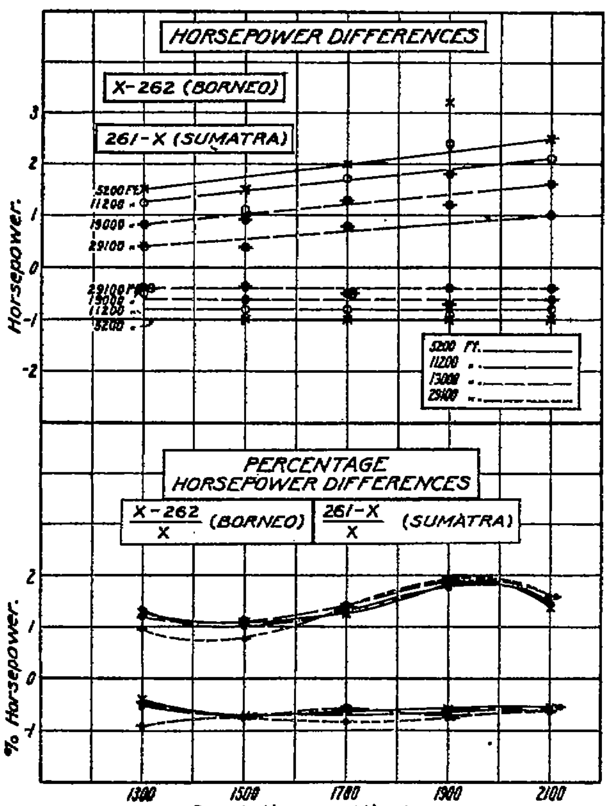
Plot 5 shows the horsepower differences between the sample of Sumatra and that of Borneo as compared to commercial. Sumatra gasoline shows an advantage which increases as the speed increases, but decreases as the altitude increases. Borneo gasoline shows the same general relation, but to a much smaller degree. At 1,700 and 1,900 revolutions per minute the horsepower difference is less than 0.5 per cent. The only point at which there is a marked difference between Borneo and commercial is at 2,100 revolutions per minute.



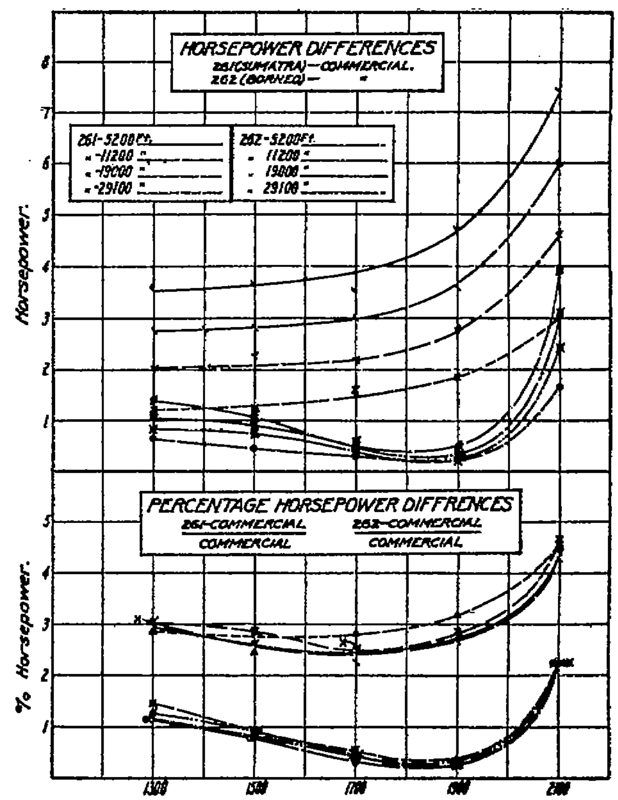
Plot 1.



Plot 2.



Plots 3&4.

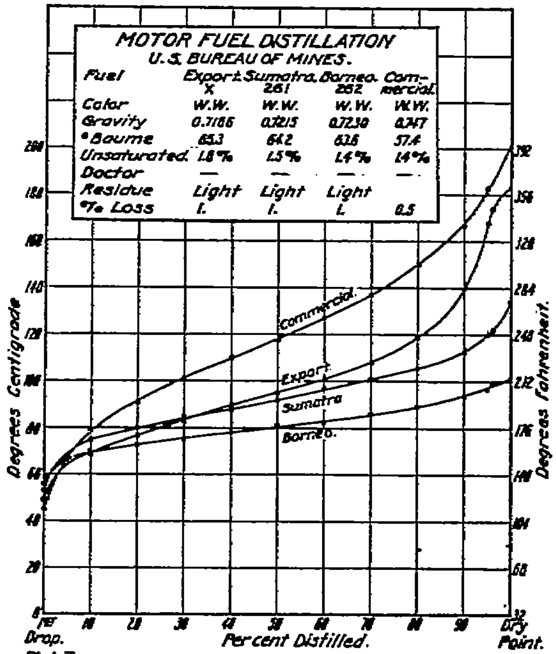


Plots 5&6

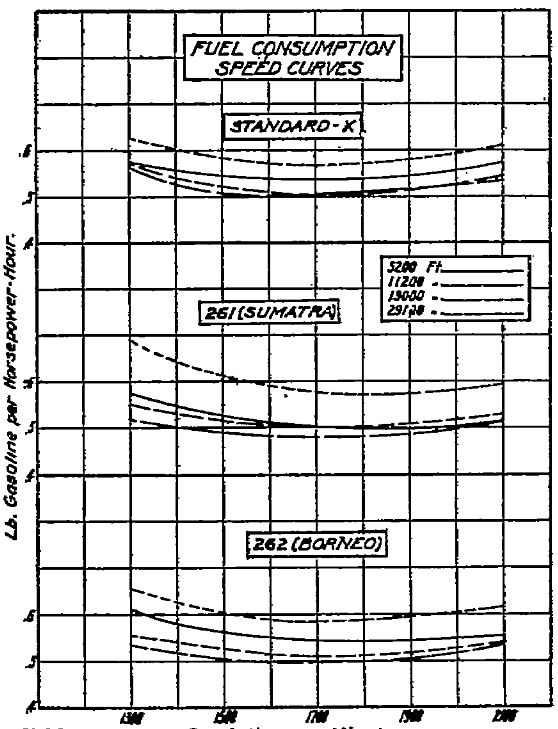
Plot 7 shows the distillation curves of Sumatra, Borneo, X, and commercial. These determinations were made by the United States Bureau of Mines. The method employed is described in this bureau's Technical Paper No. 166.

The fuel consumption results obtained in the engine tests at the Bureau of Standards should be interpreted in the light of the fact that a wide variation of fuel consumption is possible without affecting the horsepower output. The gasoline consumptions per hour were first plotted against revolutions per minute and then against barometric pressure. From the consumptions per hour derived from these curves were computed the consumptions per horsepower hour given in Table IV.

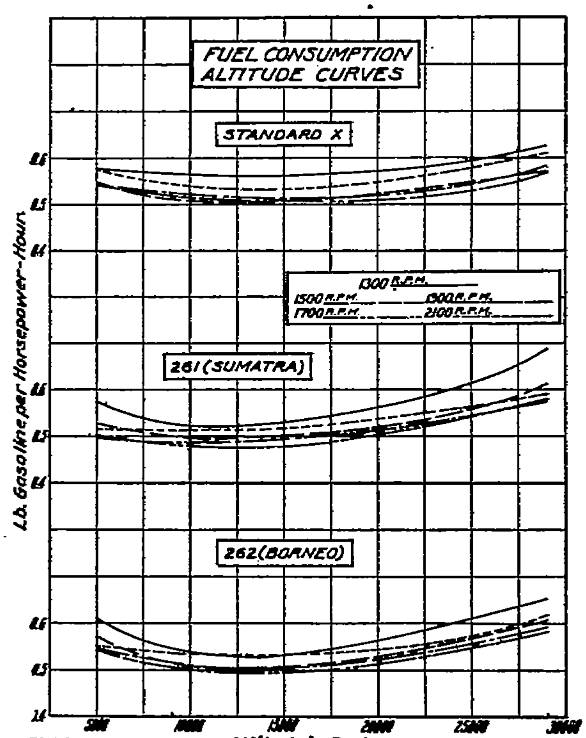
The data in Table IV are shown in plots 8 to 13. Plot 8 shows the gasoline consumption per horsepower hour for X and the samples of Sumatra and Borneo gasolines plotted against speed. Plot 9 shows the same data plotted against altitude.



Plot 7.



Plot 8. Revolutions per Minute.



Plot 9. Altitude in Feet.

The percentage differences between commercial and the fuels under observation are plotted in plot 6. As in plot 4, the percentages are practically the same at each speed regardless of altitude. The greatest difference occurs at 2,100 revolutions per minute.

Relative fuel economies determined by computing the differences between fuel consumptions per horsepower hour of the Sumatra and X and Borneo and X samples are plotted as percentages of the fuel consumption of X in plots 10 to 13. When the fuel consumption is lower than that of X, the percentage is shown as positive, while when it is higher than X the percentage is shown as negative. Hence points above the zero line show a higher fuel economy than X and points below the line indicate lower economy.

The calorific value of Borneo gasoline is estimated by Simon to be 1,099 kilogram calories per 100 grams, and that of Sumatra is estimated as 1,130 kilogram calories per 100 grams Careful determinations at the Bureau of Standards of the heats of combustion of samples of the fuels tested in the engine were made in a Junkers calorimeter, and every precaution taken to guard against possible errors. In the case of Borneo gasoline a large number of runs were made to determine the probable error of observation. The variation from the mean of 12 observations (6 pairs) was less than 0.4 per cent. These determinations gave the following results:

TABLE II.

[Heats of combustion in kilogram calories per kilogram and British thermal units per pound.]

Fuel.	High value.		Low value.	
	Calories.	British thermal units.	Calories.	British thermal units.
Sumatra	11,210	20,180	10,400	18,720
Borneo	11,220	20,200	10,460	18,830
Standard X	11,300	20,340	10,520	18,940
Commercial	11,220	20,200	10,450	18,810

The "low" values are those that determine the utility of the fuel in an internal combustion engine, and the greatest difference in heating values of all four fuels is but 120 calories in an average of 10,456 or 1.15 per cent.

CONCLUSIONS.

(1) The sample of Sumatra gasoline tested develops slightly more horsepower (maximum 1.4 per cent) than the United States standard (export) aviation gasoline (Aircraft Production Specification No. 3512) at the altitudes and engine speeds covered by the experiments.

(2) The sample of Borneo gasoline tested develops slightly less horsepower (maximum 0.6 per cent) than the United States standard (export) aviation gasoline throughout the range of speeds and altitudes covered.

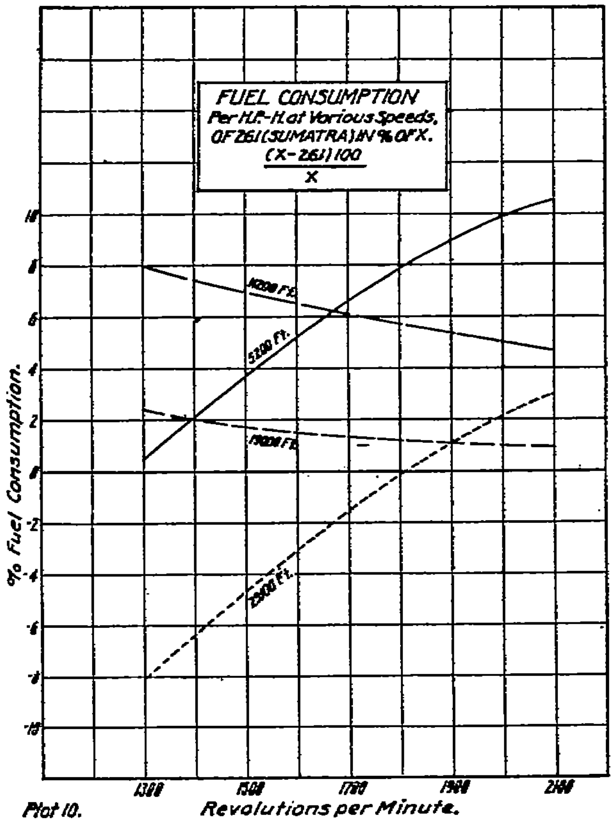
(3) Both samples of Sumatra and Borneo gasolines develop higher horsepower than the commercial gasoline. The maximum increase for Sumatra gasoline is 4.2 per cent and that for Borneo gasoline is 2.2 per cent.

(4) An investigation of the heats of combustion shows these values to be practically identical for both gasolines.

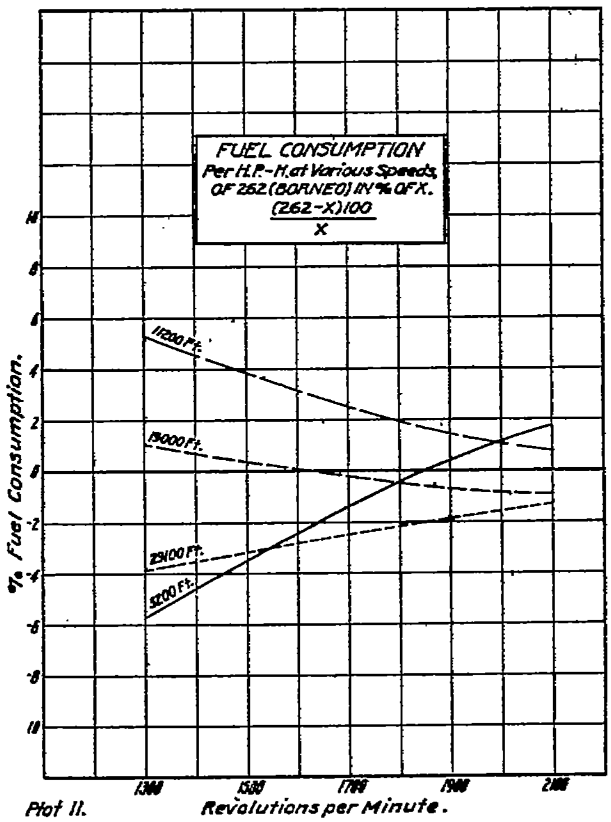
(5) Fractional distillation shows a lower volatility (temperatures of distillation) for the sample of Borneo gasoline than for the sample of Sumatra, although the latter shows a higher horsepower.

(6) Bearing in mind the facts in regard to fuel consumption mentioned above, the following conclusions can, nevertheless, be drawn: The fuel economy when using the sample of Sumatra is much higher than when using the United States standard (export) aviation gasoline, except at the highest altitudes at which observations were made.

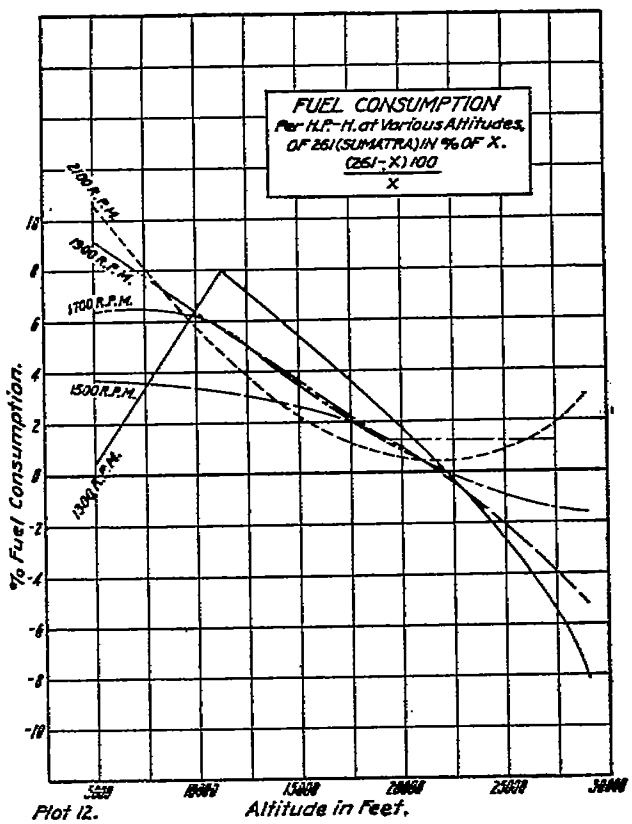
(7) The fuel economy of the sample of Borneo gasoline may be said to average about the same as the United States standard (export) aviation gasoline.



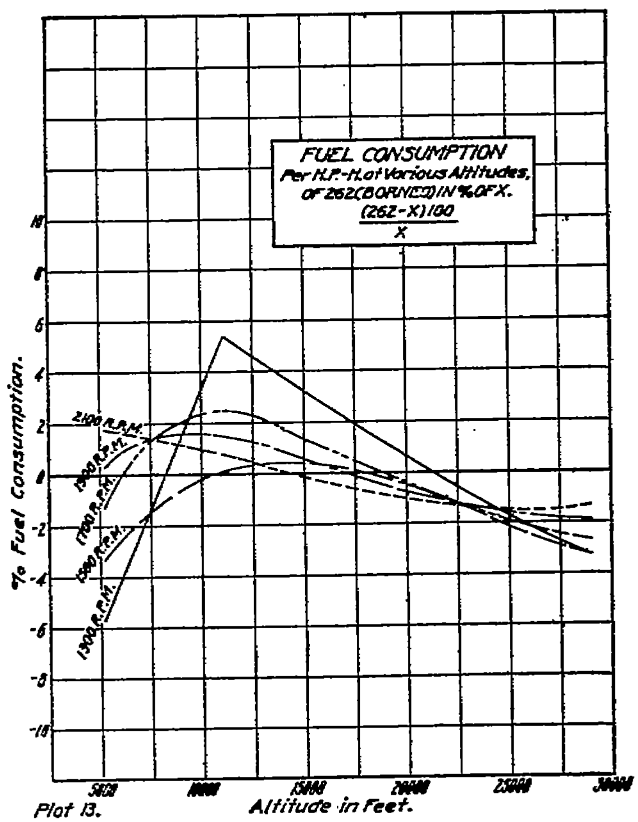
Plot 10.



Plot 11.



Plot 12.



Plot 13.

TABLE III.—*Horsepowers of Sumatra, Borneo, X, and commercial gasolines at various altitudes and speeds, together with horsepower differences and percentage differences.*

Alt. ft., cm. Hg.	R. p. m.	Sumatra.	X.	Sumatra—X.	(Sumatra—X.)/X	Borneo.	Borneo—X.
5,200—62.74	2,100	182.5	180.0	2.5	1.39	179.0	1.0
	1,900	175.2	172.0	3.2	1.86	171.0	1.0
	1,700	161.0	159.0	2.0	1.26	158.0	1.0
	1,500	141.5	140.0	1.5	1.07	139.0	1.0
	1,300	118.0	116.5	1.5	1.29	116.0	.5
11,200—50.55	2,100	143.3	141.2	2.1	1.45	140.4	.8
	1,900	137.8	135.4	2.4	1.77	134.5	.9
	1,700	127.1	125.4	1.7	1.36	124.6	.8
	1,500	111.8	110.7	1.1	1.00	109.9	.8
	1,300	93.5	92.3	1.2	1.30	91.8	.5
19,000—37.97	2,100	102.6	101.0	1.6	1.58	100.4	.6
	1,900	99.2	97.4	1.8	1.85	96.7	.7
	1,700	92.0	90.7	1.3	1.43	90.2	.5
	1,500	81.3	80.4	.9	1.12	79.8	.6
	1,300	68.2	67.4	.8	1.14	67.0	.4
29,100—26.09	2,100	64.2	63.2	1.0	1.58	62.8	.4
	1,900	62.8	61.6	1.2	1.95	61.2	.4
	1,700	58.8	58.0	.8	1.38	57.5	.5
	1,500	52.2	51.8	.4	.77	51.4	.4
	1,300	44.2	43.8	.4	.91	43.6	.4

Alt. ft., cm. Hg.	R. p. m.	(Borneo—X.)/X	Commercial.	Sumatra—C.	(Sumatra—C.)/C.	Borneo—C.	(Borneo—C.)/C.
5,200—62.74	2,100	0.56	175.1	7.4	4.23	3.9	2.23
	1,900	.58	170.5	4.7	2.76	.5	.29
	1,700	.63	157.5	3.5	2.22	.5	.32
	1,500	.72	137.9	3.6	2.61	1.1	.80
	1,300	.43	114.6	3.4	2.97	1.4	1.22
11,200—50.55	2,100	.57	137.3	6.0	4.37	3.1	2.26
	1,900	.67	134.2	3.6	2.68	.3	.22
	1,700	.64	124.1	3.0	2.42	.5	.40
	1,500	.72	109.0	2.8	2.57	.9	.83
	1,300	.54	90.76	2.74	3.02	1.04	1.15
19,000—37.97	2,100	.59	98.0	4.6	4.69	2.4	2.46
	1,900	.72	96.47	2.73	2.83	.23	.238
	1,700	.55	89.82	2.18	2.43	.38	.423
	1,500	.74	79.06	2.24	2.83	.74	.936
	1,300	.50	66.20	2.00	3.02	.8	1.21
29,100—26.09	2,100	.63	61.16	3.04	4.60	1.64	2.48
	1,900	.65	60.96	1.84	3.02	.24	.394
	1,700	.86	57.20	1.6	2.80	.3	.53
	1,500	.77	50.94	1.26	2.47	.46	.90
	1,300	.91	42.98	1.22	7.84	.62	1.44

TABLE IV.—*Fuel consumption.*

Cm. Hg., Alt. ft.	R. p. m.	Standard X fuel h. p. hr.	Sumatra (261) fuel h. p. hr.			Borneo (262) fuel h. p. hr.		
			Sumatra.	X—Sumatra.	(X—Sumatra.)/X	Borneo.	X—Borneo.	(X—Borneo.)/X
62.8—5,200	2,100	0.572	0.512	0.06	10.5	0.562	0.01	1.75
	1,900	.546	.496	.05	91.6	.544	.002	.37
	1,700	.534	.500	.034	6.37	.541	—.007	—1.31
	1,500	.543	.523	.02	3.63	.561	—.018	—3.31
	1,300	.575	.572	.003	.522	.608	—.033	—5.74
50.6—11,200	2,100	.538	.513	.025	4.65	.534	.004	.743
	1,900	.517	.488	.029	5.61	.509	.008	1.55
	1,700	.510	.480	.03	5.88	.497	.013	2.55
	1,500	.506	.490	.016	3.16	.505	.001	.198
	1,300	.564	.519	.045	7.98	.534	.03	5.33
38—19,000	2,100	.535	.531	.004	.75	.54	—.005	— .935
	1,900	.514	.507	.007	1.36	.517	—.003	— .57
	1,700	.507	.500	.007	1.38	.508	—.001	— .197
	1,500	.522	.514	.008	1.53	.523	—.001	— .192
	1,300	.564	.55	.014	2.48	.558	+.006	+1.06
26.1—29,100	2,100	.610	.592	.018	2.95	.618	—.008	—1.31
	1,900	.581	.574	.007	1.2	.592	—.011	—1.9
	1,700	.569	.578	—.009	—1.58	.584	—.015	—2.64
	1,500	.584	.614	—.03	—5.14	.603	—.019	—3.25
	1,300	.628	.679	—.051	—8.12	.652	—.024	—3.82

REPORT No. 47.

PART III.

POWER CHARACTERISTICS OF 20 PER CENT BENZOL MIXTURE.[1]

By E. W. Roberts.

RÉSUMÉ.

The importance of securing the best possible airplane engine fuel led to tests of a number of fuels in the altitude laboratory at the Bureau of Standards and at various flying fields. Among the promising fuels was a mixture of benzol and gasoline, 1,500 gallons of which were therefore prepared by the Government for distribution to the various laboratories for further tests. The results of the experiments in the altitude laboratory of the Bureau of Standards are given in this report.

From the results of these tests the following conclusions have been drawn: This mixture shows very little gain in power as compared with aviation gasoline (export) at the lower altitudes and the lower speeds. There is very little gain in horsepower below 10,000 feet. Above this altitude, and at high engine speeds, the engine shows considerable gain in power, which at 29,300 feet and 2,100 revolutions per minute is 5.8 per cent.

While the methods of measuring fuel consumption were not entirely satisfactory, the fuel consumption of 20 per cent benzol mixture appears to be about 4 per cent greater than X, at speeds and powers where it gives its best performance.

POWER CHARACTERISTICS OF 20 PER CENT BENZOL MIXTURE.

The following report is based upon tests made in the altitude laboratory of the Bureau of Standards. In this laboratory the engine under test is installed in a concrete chamber having insulated walls from which the air may be partially exhausted by means of a blower, thus reducing the barometric pressure within the chamber to that corresponding with any desired altitude, up to about 40,000 feet. As it enters the chamber the air is passed over a series of refrigerating coils, and by this means the temperature may be regulated during the tests. The engine is coupled directly to an electric dynamometer placed outside the chamber, and by which the power of the engine may be absorbed and and measured. A complete description of this apparatus and the methods of observation may be found in Technical Report No. 44.

The fuel herein called "Signal Corps Mixture" (hereafter referred to as S.C.M.) is a special blend of gasoline and benzol made, up in accordance to specifications prepared by W. E. Perdew, assistant chemical engineer of the Bureau of Mines, and presented to the Science and Research Division of the Signal Corps, United States Army, as follows:

Description.—The blend shall consist of 20 per cent by volume of commercial "90 per cent benzol" and 80 per cent by volume of a special straight run gasoline. The blending or mixing shall be thorough, so that all the individual containers will contain fuel of exactly the same composition.

Specifications for benzol to be used in making this fuel.

"COMMERCIAL 90 PER CENT BENZOL."

Color, water white.
Initial boiling point, not lower than 74° C.
90 per cent off at 86° C. or below.
95 per cent off at 95° C. or below.
End point, not above 150° C.
Bureau of Mines distillation method. (Tech. Paper No. 166.)

[1] This report was confidentially circulated during the war as Bureau of Standards Aeronautic Power Plants Report No. 23.

Specifications for special gasoline.

Color, water white.
Odor, not specified.
Unsaturated, no products of any cracking process (straight run gasoline).
Doctor, no requirements.
Distillation loss, not more than 2 per cent.
Recovery, not less than 97 per cent.
Distillation, first drop, not below 50° C. nor above 65° C.
20 per cent not above 80° C.
50 per cent not above 100° C.
70 per cent not above 115° C.
90 per cent not above 135° C.
Dry point not above 177° C.
Bureau of Mines distillation. (Tech. Paper No. 166).

The engine employed in these tests was a 180-horsepower, type E, Hispano-Suiza, built by the Wright-Martin Aircraft Corporation, New Brunswick, N. J. This engine has eight cylinders in blocks of four, set at 90°, and with the following dimensions:

Bore	120 mm. (4.725 inches).
Stroke	130 mm. (5.118 inches).
Compression ratio	$\frac{\text{Total volume}}{\text{Clearance}}=5.3$

The engine was operated under pressures corresponding to four different altitudes, as follows:

5,235 feet	62.5 cm. Hg.
11,235 feet	50.3 cm. Hg.
18,850 feet	38.0 cm. Hg.
29,300 feet	26.0 cm. Hg.

and at four different speeds at each altitude: 1,500, 1,700, 1,900, and 2,100 revolutions, per minute.

The carburetor was carefully adjusted by hand for each test, to secure the maximum horsepower at that particular speed and altitude with the leanest mixture. The method of adjustment employed was as follows: The carburetor was first set to secure the maximum possible brake pull regardless of fuel consumption. The fuel supply was then cut down until the power fell off. Then the gasoline flow was gradually increased until the maximum brake pull was again secured.

In these tests two sets of runs are made at the various speeds at each barometric pressure, one on the fuel being tested, the other immediately before or after, with a comparison fuel, known to the laboratory as standard *X*. This method of observation ensures that the engine is in practically the same condition during the runs on each fuel.

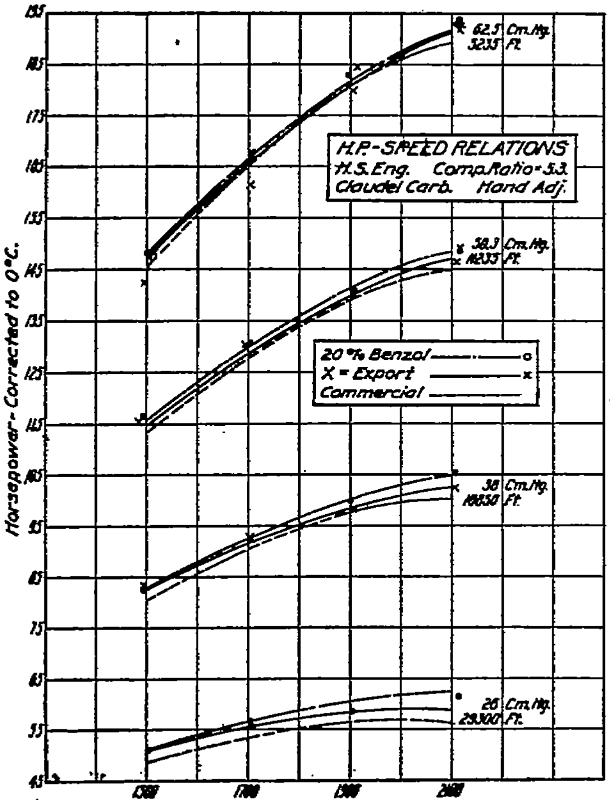
The fuel designated herewith as standard *X*, and manufactured by the Atlantic Refining Co. as one of their standard products, fulfills the specifications of the Bureau of Aircraft Production for aviation gasoline (export) Specification No. 3512.

As a matter of interest the performance of commercial gasoline has been tabulated and plotted with the results obtained from the S. C. M. and *X*. The values for commercial have been tabulated by percentage differences between this fuel and *X* secured in another test.

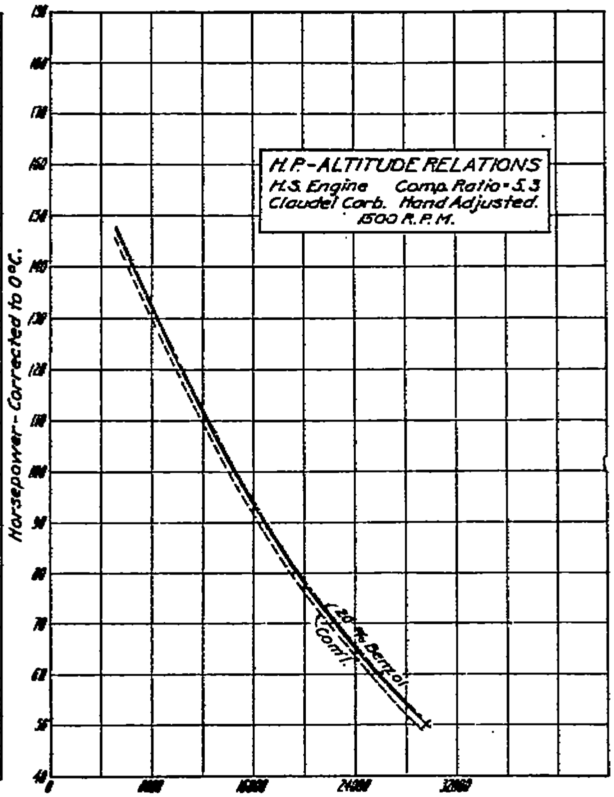
Commercial gasoline is a fair sample of the fuel usually sold at automobile filling stations and is of a lower grade than *X*. It was purchased under the United States General Supply Committee Specification for 1918.

In order that a fair comparison of the performance of the engine with the various fuels could be made, the horsepowers in each case were corrected to 0° C. The method of making this correction is described in Part I of Report No. 45.

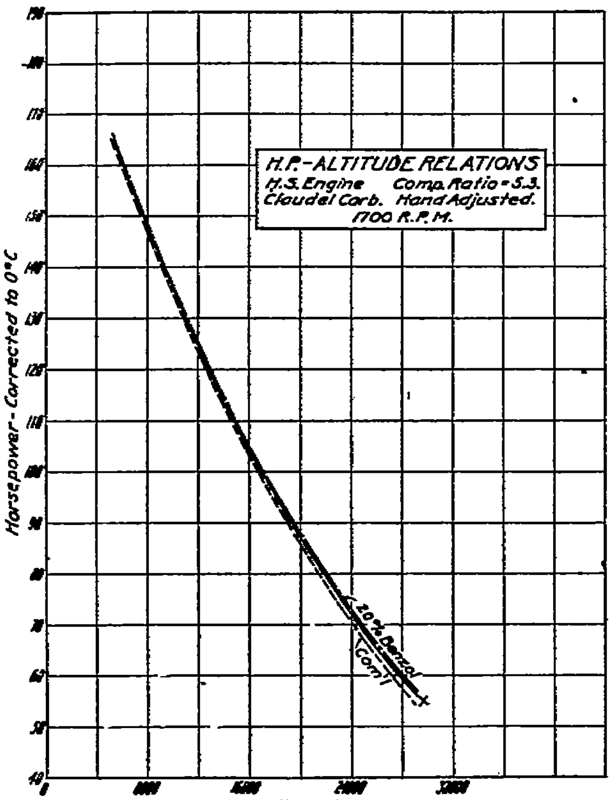
In working up the data secured from these tests, it was found that the horsepower differences, particularly at the lower altitudes, were so small as to make the usual method of fairing curves too uncertain. This can easily be understood by reference to plot 1. It will be readily seen that several curves could be drawn through the points obtained from the tests at 5,235 feet, any one of which might be considered as an average of the results. One set of curves



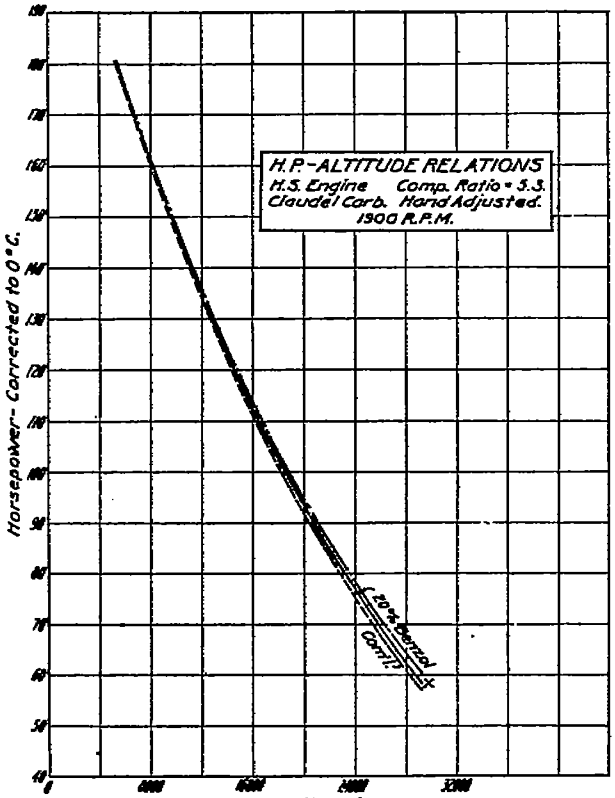
Plot No. 1



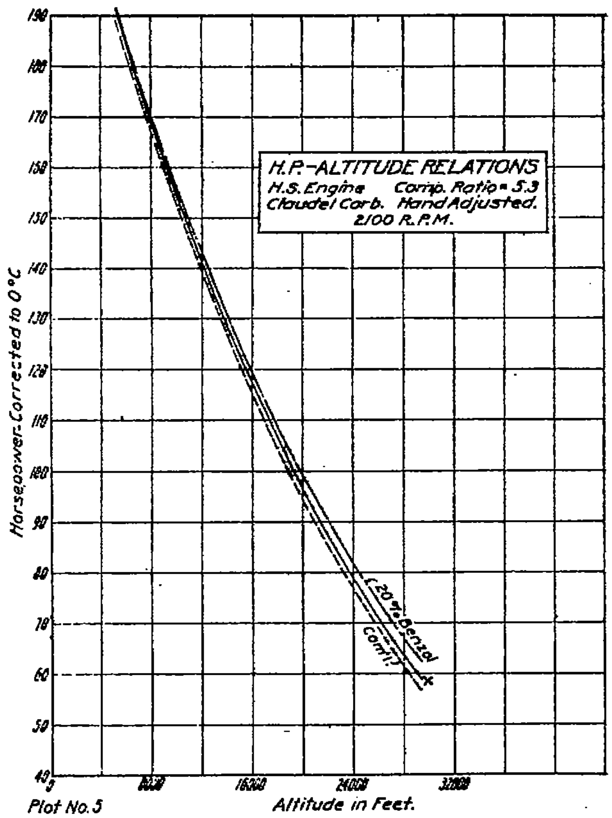
Plot No. 2.



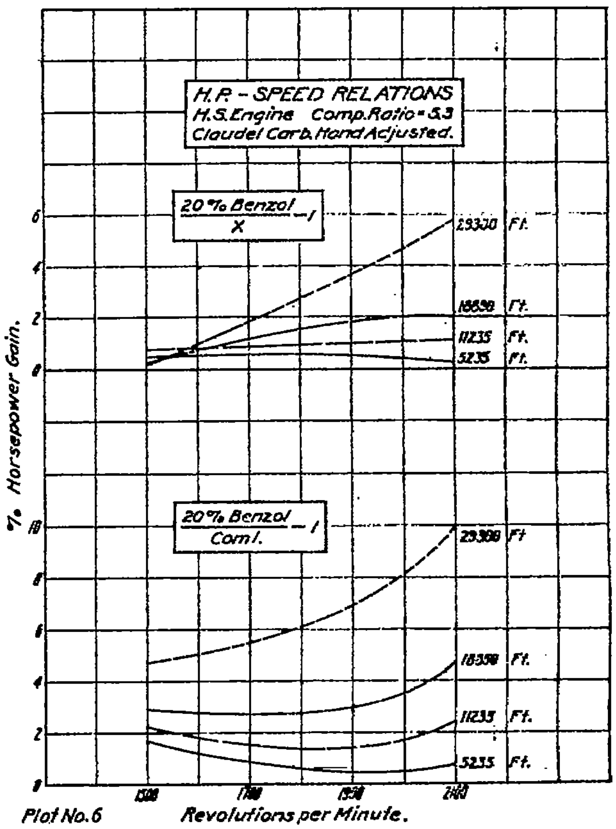
Plot No. 3



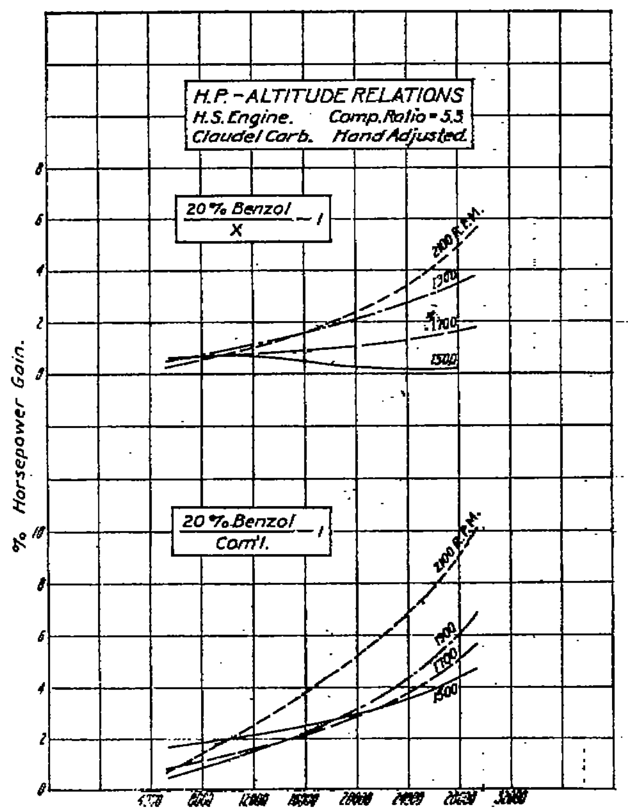
Plot No. 4



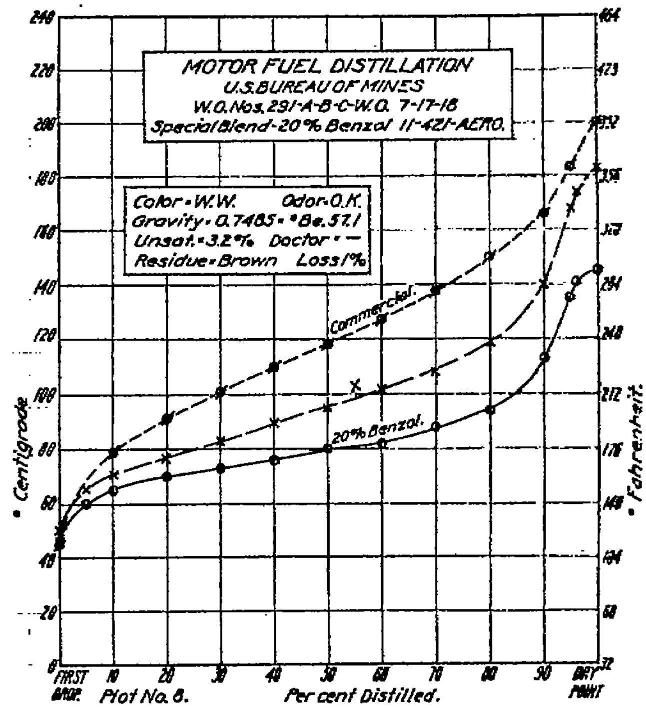
Plot No. 5



Plot No. 6



Plot No. 7



Plot No. 8.

might show S. C. M. higher than X, and another, equally fair, might show S. C. M. lower than X. It was obvious, therefore, that some better method should be employed.

By drawing fair curves through the observed points the approximate horsepower at each speed and pressure was obtained. These, in turn, were plotted against atmospheric pressure. In this plot, the points lie very nearly on a straight line. It was found that three out of the four points did actually lie upon a straight line and the other very close to it. Replotting the horsepowers obtained from the straight lines against speed a second time showed the probable error in plotting, and by carefully repeated trials, the curves of plot 1 were obtained. In this way, the results obtained at one altitude were used to check the results obtained at the other altitudes.

One feature of the lines of horsepower plotted against barometric pressure was particularly helpful in this method of analysis. It was found that the intercepts of these lines on the axis of zero pressure were quite evenly spaced. For example, in the equation for the line

$$y = ax - b$$

wherein y = horsepower

x = barometric pressure in cm. Hg

the values of b increased by even increments, for even differences of speed.

This method was employed for all three fuels involved, and the remainder of the data for plots 1 to 7, inclusive, was derived from these average curves. These results are also given in tabular form, at the end of this report.

Plot 1 shows the horsepowers of S. C. M., X, and commercial at various barometric pressures, plotted against revolutions per minute. These curves show a considerable gain in horsepower of S. C. M. over both X and commercial at the higher altitudes.

Plots 2 to 5 show the horsepowers plotted against altitude at different speeds. Plot 2 shows that S. C. M. and X are practically the same for 1,500 revolutions per minute for the entire range of altitudes. Plot 2 exhibits a slight divergence of the S. C. M. curve from that of X with increase of altitude, while in plot 3 the two curves practically coincide at the lower altitude, but diverge more than in plot 2 at the higher altitudes. Plot 4 shows a still wider divergence at 29,300 feet.

In plot 6 the percentage gain in power is plotted against speed for S. C. M. as compared with X and with commercial. Plot 7 shows the same results plotted against altitude at various speeds. Both sets of curves simply accentuate the characteristics indicated by the curves in the previous figures.

Plot 8 is the distillation curve of the fuel obtained by the United States Bureau of Mines and according to the method described in Bureau of Mines Technical Paper No. 166. For the purpose of comparison, the distillation curves of X and commercial are plotted on the same plate.

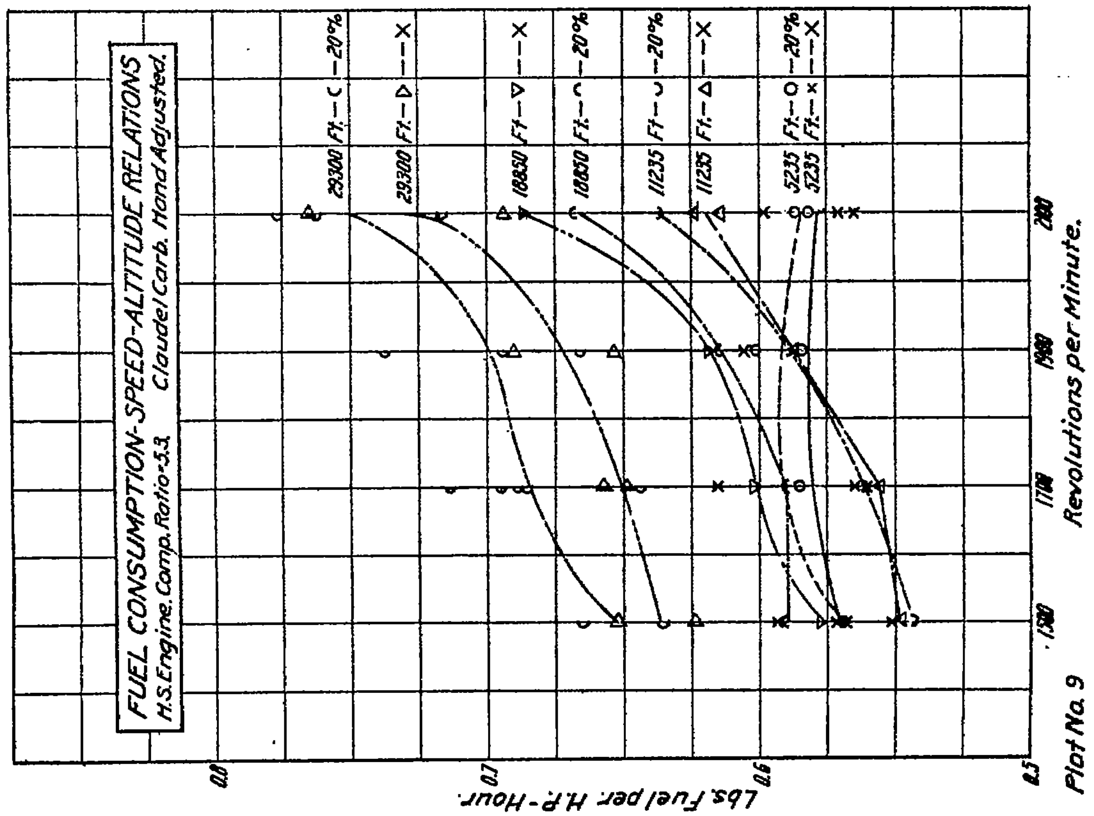
Plots 9 to 11 are from the fuel-consumption determinations made during the tests. Owing to the unsatisfactory operation of the fuel-weighing device, these results should be considered as comparative only.

Plot 9 shows the actual fuel consumption in pounds per horsepower hour plotted against revolutions per minute. The curves are drawn through the arithmetic means of the various points determined.

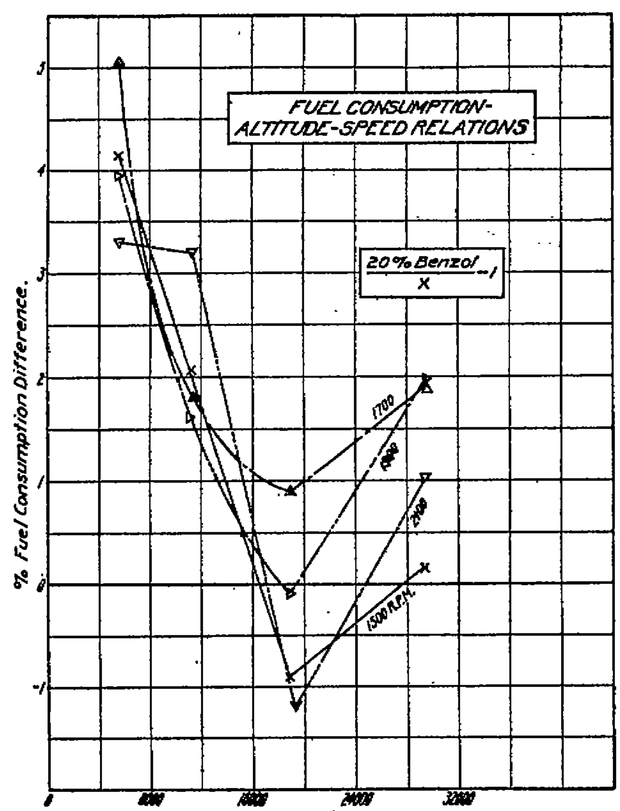
In plots 10 and 11 the differences in fuel consumption are plotted as percentages of the fuel consumption when using X fuel. The lines are simply to assist in following through the various results. These figures should not be considered as final.

CONCLUSIONS.

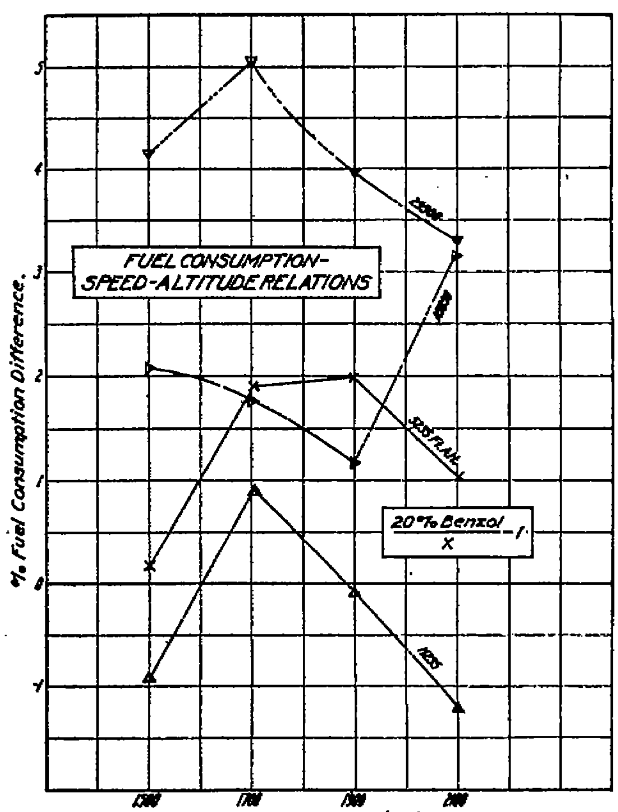
Signal Corps mixture shows very little gain in power as compared to X below 10,000 feet altitude. Above that altitude there is no gain of consequence at the lower speeds, but a marked gain at the higher speeds. It is, therefore, to be considered a high-altitude fuel. The fuel consumption would be about 4 per cent greater than X at the altitude where the fuel gives its best performance.



Plot No. 9



Plot No. 10



Plot No. 11

Table showing horsepower and horsepower ratios for S. C. M., X, and commercial at various speeds and altitudes.

Cms. Hg; altitude, feet.	Revolutions per minute.	Horsepower, S. C. M.	Horsepower, X.	Horsepower, S. C. M.–X.	Per cent horsepower $\frac{\text{S. C. M.–X}}{\text{X}}$,	Horsepower, commercial.	Horsepower, S. C. M.–commercial.	Per cent horsepower, $\frac{\text{S. C. M.–C.}}{\text{C.}}$
62.5—5,235	2,100	192.0	191.5	0.5	0.261	189.5	2.5	1.30
	1,900	182.0	181.0	1.0	0.55	181.1	0.9	0.50
	1,700	166.7	165.7	1.0	0.604	165.2	1.5	0.91
	1,500	148.2	147.5	0.7	0.475	145.6	2.6	1.78
50.3—11,235	2,100	148.6	147.0	1.6	1.088	145.0	3.6	2.40
	1,900	141.5	140.0	1.5	1.071	139.5	2.0	1.43
	1,700	129.8	128.8	1.0	0.776	127.9	1.9	1.49
	1,500	115.7	114.8	0.9	0.785	113.3	2.4	2.12
38.0—18,850	2,100	105.0	102.5	2.5	2.0	100.2	4.8	4.80
	1,900	100.5	98.6	1.9	1.89	97.6	2.9	2.97
	1,700	92.7	91.7	1.0	1.09	90.2	2.5	2.77
	1,500	83.0	82.8	0.2	0.24	80.7	2.3	2.85
26.0—24,300	2,100	62.3	58.9	3.4	5.78	56.6	5.7	10.07
	1,900	60.6	58.4	2.2	3.77	56.7	3.9	6.88
	1,700	56.6	55.6	1.0	1.80	53.6	3.0	5.60
	1,500	51.2	51.1	0.1	0.196	48.9	2.3	4.69

NOTE.—All horsepowers corrected to 0° C.