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**REPORT No. 90**

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**COMPARISON OF HECTER FUEL WITH EXPORT  
AVIATION GASOLINE**

By H. C. DICKINSON, V. R. GAGE, AND S. W. SPARROW  
Bureau of Standards



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#### RÉSUMÉ.

This report was prepared for the National Advisory Committee for Aeronautics and describes an investigation conducted at the altitude laboratory at the Bureau of Standards.

Aviation engine developments for attaining higher power at altitude are following two principal lines, supercharging and increase in compression ratio. For the latter, fuels have been demanded which are capable of operating under compressions too high for gasoline. Among the fuels which will operate at compression ratios up to at least 8.0 without preignition or "pinking" is Hecter fuel, whence a careful determination of its performance is of importance.

A comprehensive investigation by the United States Bureau of Mines of fuels for internal-combustion engines included the development of cyclohexane mixtures to ascertain definitely whether they possessed the marked advantages attributed to them in rumors from abroad. The Bureau of Mines, cooperating with others, developed hydrogenation of benzol to cyclohexane, testing mixtures of the two in various types of engines at compression ratios ranging from 5.3 to 8.2. The cyclohexane benzol mixtures, the former constituent predominating, were designated "Hecter" fuels. They gave very promising results at high compression in the experimental engines at ground level, and their usability at altitude was tested by actual flight tests. Accordingly, data were desired regarding power development and economy at altitude, data not readily obtainable under the varying conditions of actual flight. The fuel was submitted to the Bureau of Standards for test in the altitude laboratory.

The Hecter fuel supplied by the Bureau of Mines for use in these tests was a mixture of 30 per cent benzol ( $C_6H_6$ ) and 70 per cent cyclohexane ( $C_6H_{12}$ ), having a low freezing point, and distilling from first drop to 90 per cent at nearly a constant temperature, about  $20^\circ C.$  below the average distillation temperature ("mean volatility") of the X gasoline.

This comparison of the performance of the two fuels in an aviation engine was made in the altitude chamber at the Bureau of Standards, duplicating altitude conditions up to about 25,000 feet, except that the temperature of the air entering the carburetor was maintained nearly constant at about  $10^\circ C.$  A Liberty 12-cylinder aviation engine was used, supplied with special pistons giving a compression ratio of 7.2 (the compression pressure measured by check valve gage was 170 pounds per square inch). Stromberg carburetors were used and were adjusted for each change of fuel, speed, load, and altitude so as to give the maximum possible power with the least fuel for this power. The tests covered a speed range of 1,400 to 1,800 r. p. m.

The results of these experiments show that the power developed by Hecter fuel is the same as that developed by Export aviation gasoline, at about 1,800 r. p. m. at all altitudes. At lower speeds differences in the power developed by the fuels become evident. At 1,400 r. p. m. and 25,000 feet Hecter gives a little less power than X gasoline, at 15,000 feet about the same, and at 6,000 feet perhaps 6 per cent more. Comparisons at ground level were omitted to avoid any possibility of damaging the engine by operating with open throttle on gasoline at so high a compression. The fuel consumption per unit power based on weight, not volume, averaged more than 10 per cent greater with Hecter than with X gasoline, considering all conditions. The thermal efficiency of the engine when using Hecter is less than when using gasoline, particularly at the higher speeds, a generalization of the difference for all altitudes and speeds being

8 per cent. The general deduction from these facts is that more Hecter is exhausted unburnt. Undoubtedly Hecter can withstand high compression pressures and temperatures without preignition. This characteristic was proved by operating the engine (compression ratio 7.2) with full throttle at 1,500 r. p. m. on the ground, carburetor air temperature 42° C. (107.6° F.) and jacket-water temperature, leaving engine, at 90° C. (194° F.). No signs of preignition or "pinking" were noted.

The engine was not operated for a sufficient period to compare the compression ratios or the fuels as regards effects upon engine deterioration.

It is of interest to compare the engine performance using X gasoline in a 5.6 compression engine and Hecter in a 7.2 compression engine of the same type. Previous tests with a similar engine, using one fuel, show that a change of compression ratio from 5.6 to 7.2 results in about 10 per cent increase in power. This indicates that Hecter in a 7.2 compression would produce 10 per cent more power for the same weight fuel consumption per unit power than would X gasoline in a 5.6 compression.

#### OBJECT OF TESTS.

The object of the tests and the subject of this report is the comparison of Hecter fuel with X gasoline, with regard to the relative power-producing qualities and fuel consumptions of the two fuels when used in an extremely high compression aviation engine (7.2 compression ratio).

#### DESCRIPTION OF THE FUELS.

The gasoline used in these tests was the standard reference fuel of this laboratory (known as "X" gasoline), prepared for the Bureau of Standards by the Atlantic Refining Co. from Pennsylvania crude oil. It complies with the specification No. 3512 of the Bureau of Aircraft Production, for export aviation gasoline for the use of the A. E. F., 1918. The heating value (higher) is 11,300 calories per gram (20,340 B. t. u. per pound). The Hecter fuel supplied through the Bureau of Mines for these tests was a mixture of approximately 30 per cent benzol, 70 per cent cyclohexane by volume. The freezing point was about -32° C. (-25° F.) and the heat of combustion (higher) was 10,800 calories per gram (19,440 B. t. u. per pound), about 4.5 per cent less than that of X gasoline.

The distillation curves and other properties of the two fuels are given on figure 1. The values for the distillation curves are also given in Table I.

TABLE I.—Distillation.

	Hecter fuel.	X gasoline.
	° C.	° C.
Initial boiling point.....	76	59
10 per cent.....	77	72
20 per cent.....	77	77
30 per cent.....	77	82
40 per cent.....	78	87
50 per cent.....	78	92
60 per cent.....	78	97
70 per cent.....	78	103
80 per cent.....	78	111
90 per cent.....	78	127
95 per cent.....	79	150
Dry point.....	132	2 153

<sup>1</sup> 98 per cent.

<sup>2</sup> 96 per cent.

#### DESCRIPTION OF APPARATUS.

A Liberty 12-cylinder airplane engine was used for these tests, manufacturer's No. 586, Aircraft Production No. 30641. Mobile "B" oil was used for lubrication. The equipment was standard except for the high-compression pistons and the Stromberg carbureters. The clearance volumes were measured by filling them with oil, and were found to give a compression ratio of 7.2. The compression pressure as measured by gage and check valve was 170 pounds per square inch. The carbureters were equipped with a manual adjustment of float-chamber pressure so that the mixture ratio could be changed as desired. This adjustment was ample at all altitudes and speeds, so that it was always possible to make the mixture too lean.

The engine was mounted in the altitude chamber of the Bureau of Standards automotive power plants laboratory. The air from the chamber can be exhausted so that the pressure will correspond to that at any altitude up to 30,000 feet. By means of refrigerating coils and heaters, the temperature of the air in the chamber and of that supplied to the carbureter can be changed through a very wide range. All controls, adjustments, and measuring instruments (including dynamometer) are outside the chamber. A complete description of this equipment can be found in Report No. 44 of the National Advisory Committee for Aeronautics.

#### TEST PROCEDURE.

A complete description of the standard method of test procedure for this laboratory is in preparation. Accordingly a brief treatment of the subject will suffice here. In examining curves and the tables of data attached to this report the reader should bear in mind that many of the measurements made in connection with these tests are for use in further analyses not connected with the fuel comparison, which is the subject of this report. Only the features which have direct bearing on the fuel comparison need be considered here.

Two fuel tanks were used, each mounted on a balance; one containing the X gasoline, the other Hecter. The engine was started on X gasoline and the desired conditions of speed and altitude reached with a comparatively rich mixture. The maximum dynamometer (engine) torque having been attained, observations of torque were continued while the rate of gasoline supply was gradually reduced. The leaning of the mixture was continued until the torque fell off considerably, then the mixture was very gradually enriched again, but only enough to secure a torque equal to the maximum which had previously been noted. Readings were then taken of the various temperatures, pressures, torque, rates of flow, speed, etc. The fuel supply from the X tank was cut off, and Hecter was supplied to the carbureter. The carbureter adjustment was again made for maximum torque at the least possible expenditure of fuel, as described for X, and readings of test data again were made. By changing from one fuel to another in this manner, it is possible to eliminate, to a great extent, the relative effect upon the comparison of the fuels of any changes in the condition of the engine. By adjusting the carbureter for each fuel at each change of load, speed, or altitude, it is possible to obtain the engine characteristics, independent of the carbureter characteristics, and also to obtain information as to what the desired carbureter action should be. This knowledge of how the carbureter should perform is highly essential as generally the engine is hampered by poor carbureter characteristics.

#### DISCUSSION OF CURVES.

##### METHODS OF COMPUTATION, CURVE DRAWING, AND OF REDUCING TO STANDARD CONDITIONS.

The dynamometer torque as observed was reduced to brake mean effective pressure by means of a multiplication constant. These values were plotted versus r. p. m., figure 2. On the ground run it will be noted that brake power and mean effective pressure have both been corrected for exhaust pressure. The corrected points are those marked by triangles. Normally the exhaust pressure is kept near enough to carbureter air pressure so that no correction is required. Many considerations aid in determining the relative value of the actual points from the data. These are to be found in the notes on the original data sheets regarding steadiness of conditions during the run, difficulties in determining correct settings, apparent ignition troubles, etc. Also the various measurements of pressure and temperatures throughout the induction system, not bearing directly upon the fuel comparison, are of great value in determining the probable location of the curves. The curve for 1,250 feet on figure 6 may be cited as an illustration. The points which have been neglected in locating the curve were those where the manifold suction was found to be abnormal.

The curves of brake horsepower versus speed (fig. 3) are drawn through values computed from the faired curves of figure 2, because on the curves as drawn the mean effective pressure (torque) values give more nearly a straight line relation than does the brake horsepower. However, the points shown on figure 3 are computed directly from the test data. A detailed exposition of the analyses of the test data and notes would be required to make more clear the reasons

for locating the curves of figures 2 and 3 as drawn instead of passing them more nearly through the apparent average of the points. As a check on the faired curves of figures 2 and 3 horsepower values were read from the curves for constant speeds, and then were plotted against the third variable air pressure (figs. 4 and 5.) This relation should be nearly linear. It appears that the slope of the H. P. barometer curves is greater with increased speed. This tendency may be attributed to the effect of increased friction H. P. at higher speeds, but there are so many factors entering into the friction losses that it is well to defer discussion until analysis may be made of many tests.

#### FUEL CONSUMPTION.

The test results of weight of fuel consumed per hour are plotted versus r. p. m. on figure 6, a curve for each barometric pressure. These are used to assist in judging the results of the tests. On figure 7 are plotted pounds of fuel per brake horsepower per hour, versus r. p. m. On figure 8, the pounds fuel per brake horsepower per hour versus barometric pressure are obtained from the faired curves of figure 7. Even under the most favorable conditions, considerable change in mixture is possible for a slight change in power, so that very high accuracy is impossible in duplicating the condition of maximum power with minimum fuel consumption. This is the reason for the scattering of the points on figures 6 and 7, rather than lack of precision in fuel measurements. Had the carbureter setting been left unchanged for the two fuels, the results would have been more consistent, but of no value as a measure of their power-producing ability. It is probable that different fuels require different air to fuel ratios and it is by no means certain that the same carbureter setting will give the same air to fuel ratio with two different fuels. Likewise, it would have been possible to secure more consistent results if a definite and fixed carbureter setting had been used for each fuel. But, by doing this, the carbureter characteristics would have been superposed upon the engine characteristics. In these tests it was desired to know what was the best the engine could do, independent of the kind of carbureter used, and also to find what carbureter characteristics gave the best performance with each fuel.

The relative "pulverization" of fuels is dependent partly on surface tension, or cohesion, partly on the form of carbureting device, and partly on the temperatures, pressures and time available for vaporization. These factors and others are to be considered in studying figure 8. Here the fuel consumption (per unit power) of X gasoline seems to reach a minimum at about 50 centimeters barometer (13,000 feet). This tendency has been noted at other times with other set-ups, and it remains to be studied.

The heat distribution is presented in the form of curves in figures 9, 10, and 11, percentage of heat supplied versus r. p. m. The points shown are the original test results of per cent heat appearing in brake horsepower, exhaust, and jacket. The curves of "residual" heat are the differences between 100 per cent and the sum of the above three. The residual heat as computed here, therefore, includes the unburnt fuel in the exhaust and the so-called radiation losses, less the heat supplied by combustion of lubricating oil. The heat supplied is computed from the total or higher heating value of the fuel, and the exhaust heat is measured by "exhaust calorimeter" methods. The residual heat when using Hecter is always more than when using X gasoline, the exhaust and jacket losses, and the brake thermal efficiency are always less. The interpretation is that less of the heat energy of Hecter is liberated in the cylinder and more of the fuel is exhausted unburnt. These curves should not be construed as showing the exact quantitative effect of speed changes alone upon heat distribution, being considerably influenced by the carburetor adjustment.

The computed values of heat distribution for two normal speeds (1,600 and 1,700 r. p. m.), are the points plotted on figure 12, as per cent of heat supplied by the fuel versus barometric pressure. Curves were drawn through these points, and the per cent residual heat was derived from the other curves. Again, this plot should be interpreted more as heat distribution at various altitudes than as the exact quantitative effect of altitude on the distribution. The reverse curvature of the exhaust and residual lines, indicating a more complete burning of

X gasoline at 12,000 feet, is a tendency noted on other tests, and which will require further study.

Figure 13 is derived from the preceding curves, and presents the net results of the first comparison in graphical form.

For the sake of clearness the scale of per cent is made open, so that differences of little magnitude (2 per cent) may give an impression of a gain or loss which is in reality a probable equality.

#### CONCLUSIONS.

(1) For flight at low altitudes Hecter fuel showed slight advantages in comparison with gasoline by affording a small increase of power over and above that necessary to offset the disadvantage of increased fuel consumption. The usual ratio of fuel weight to plane weight is of the order of 1 to 7 so that for full throttle flying an increased fuel consumption of 7 per cent balances an increase of 1 per cent in power developed. The test at 6,500 feet altitude showed that Hecter fuel developed slightly more power than X gasoline, the maximum advantage being 7 per cent and the average for all speeds 4 per cent, whereas the increase in fuel consumption averaged 5 per cent or 6 per cent. Since at 14,000 feet and 25,000 feet no appreciable difference in power was obtained, whereas the fuel consumption of Hecter was greater to the extent of 15 per cent by weight, the advantage lies with X gasoline.

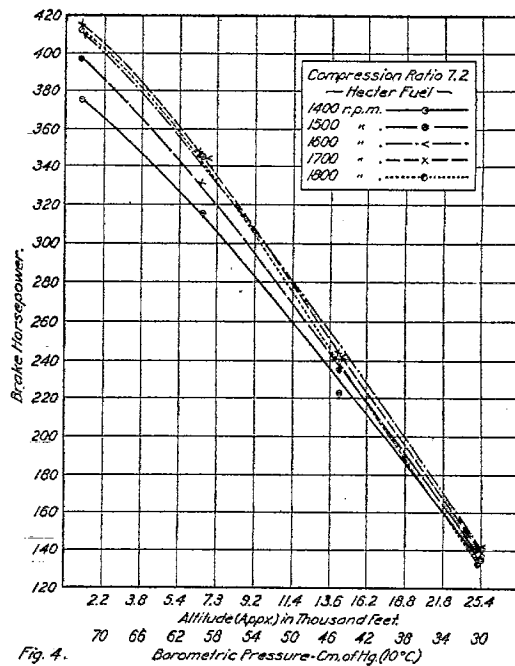
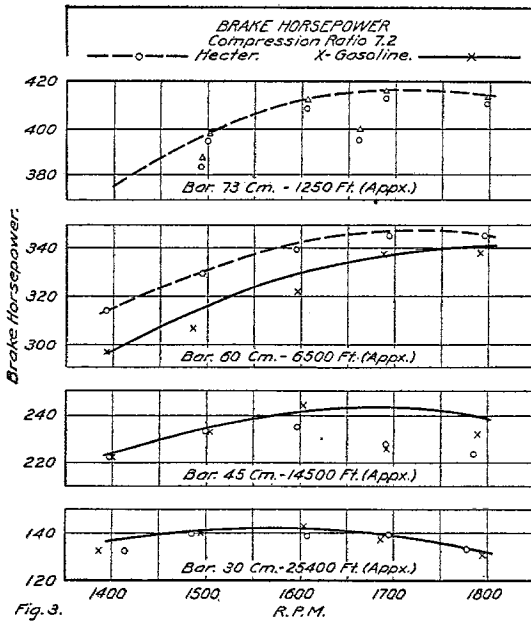
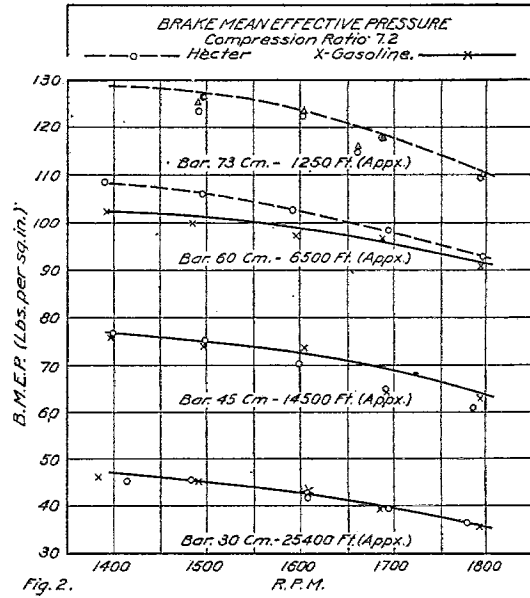
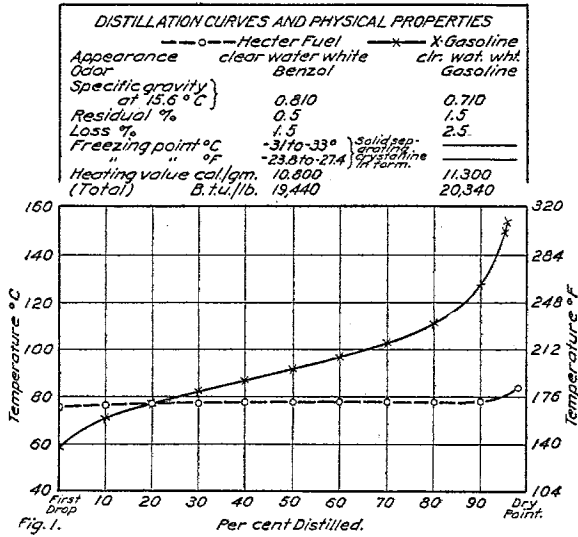
(2) The large difference in densities of Hecter fuel and X gasoline makes the fuel comparisons by weight and by volume read quite differently, and care must be exercised to distinguish them. Upon reducing pounds per brake horsepower hour to pints per brake horsepower hour it is found that Hecter consumption is the less by volume at ground, and about equal to that of X gasoline at 25,000 feet.

(3) One gallon of Hecter contains nearly 9 per cent more heat units than a gallon of X gasoline, and the brake thermal efficiency of this engine using Hecter is about the same per cent less than when using X gasoline. Thus the same tank full of either fuel would supply a plane with about the same available energy. Any part of a flight at very low altitude might be accomplished at slightly higher plane speed with the Hecter than with gasoline, as a consequence of the power characteristics described above.

(4) It has been claimed that a high-compression engine has a greater factor of safety when operated with Hecter fuel than with gasoline. The engine was not operated for a sufficient period of time to ascertain whether engine deterioration was more rapid with the 7.2 compression ratio than would be expected from experience with the 5.6 compression ratio. Consequently no comparison can be made of the effect of compression or fuels upon engine deterioration.

(5) However, since it is not generally considered advisable to operate an engine of this type with gasoline at a higher compression ratio than 5.6, it is of interest to compare the performance of a Liberty 12-cylinder aviation engine of 5.6 compression ratio using gasoline with the performance of the same type of engine with 7.2 compression ratio using Hecter. Previous tests with this type of engine have shown that this change in compression produces about 10 per cent increase in power with about the same percentage decrease in weight of fuel consumed per unit power. This change would be expected from a comparison of the "air standard" efficiencies. From these data it is concluded that Hecter in a 7.2 compression ratio engine would produce about 10 per cent more power than would X gasoline in a 5.6 compression ratio, while using the same weight of fuel per unit power as for X gasoline in the lower compression.

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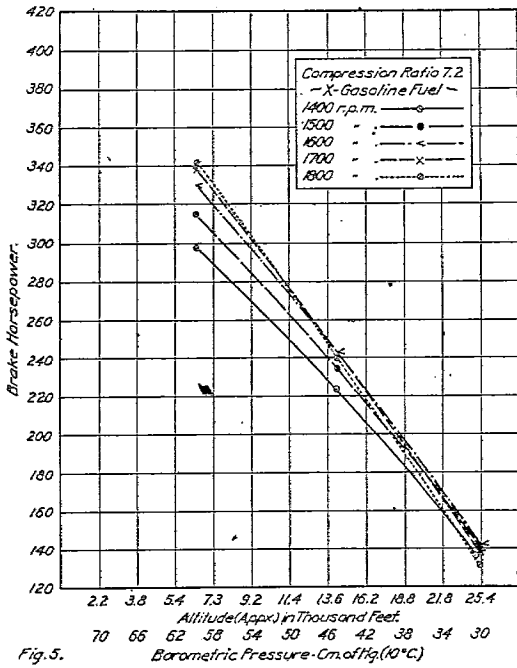


Fig. 5.

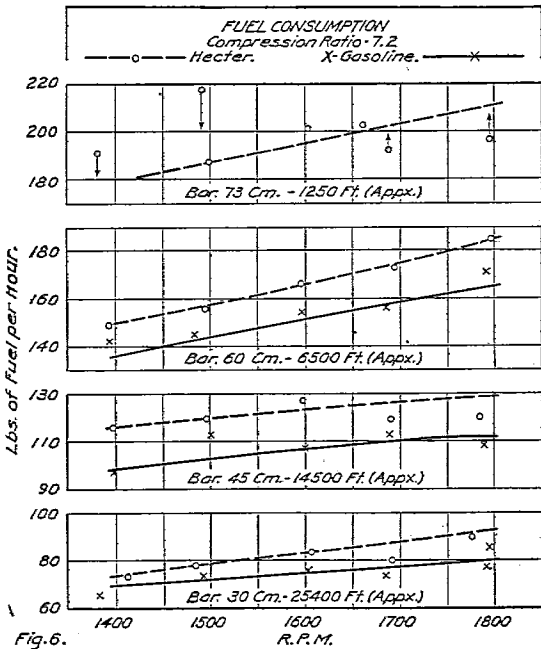


Fig. 6.

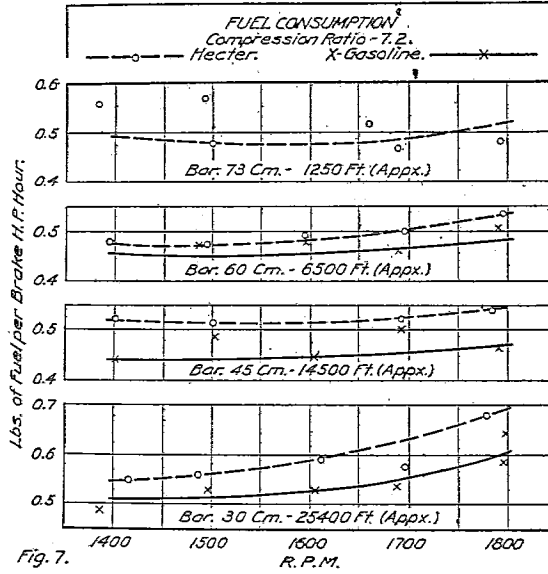


Fig. 7.

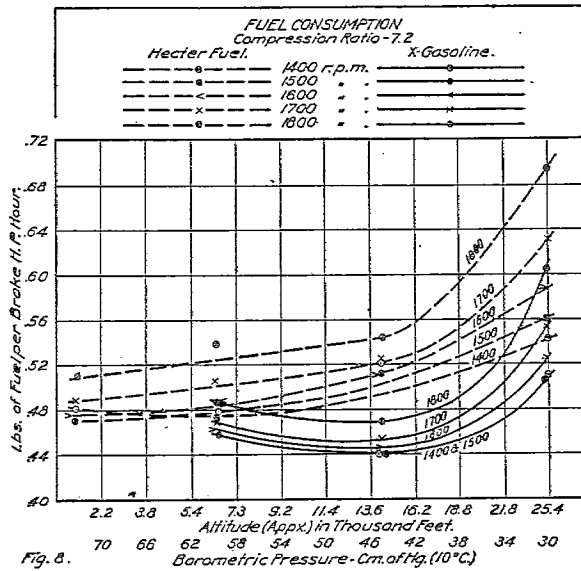


Fig. 8.

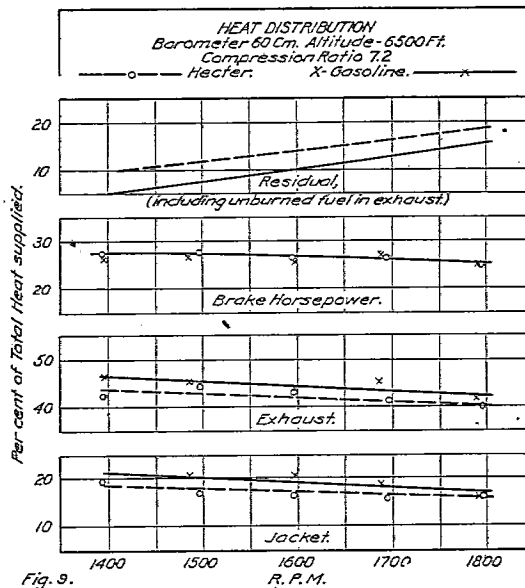


Fig. 9.

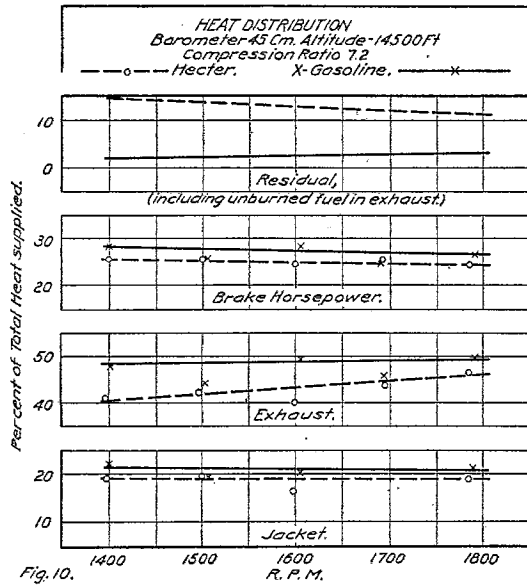


Fig. 10.

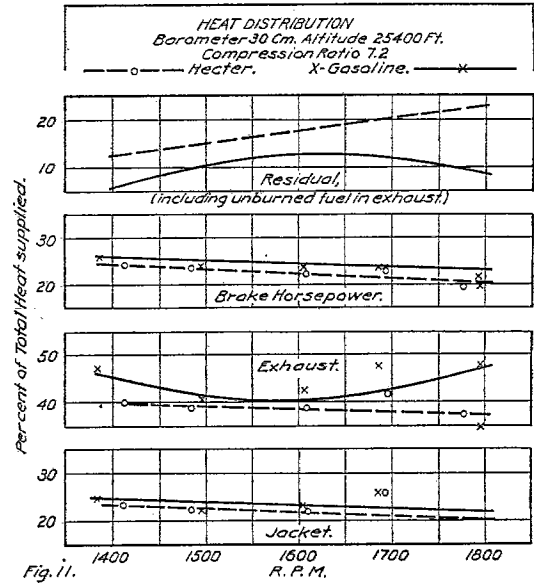


Fig. 11.

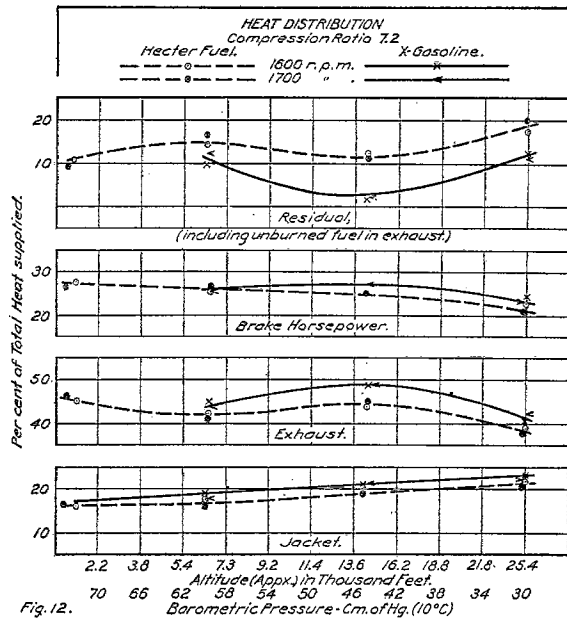


Fig. 12.

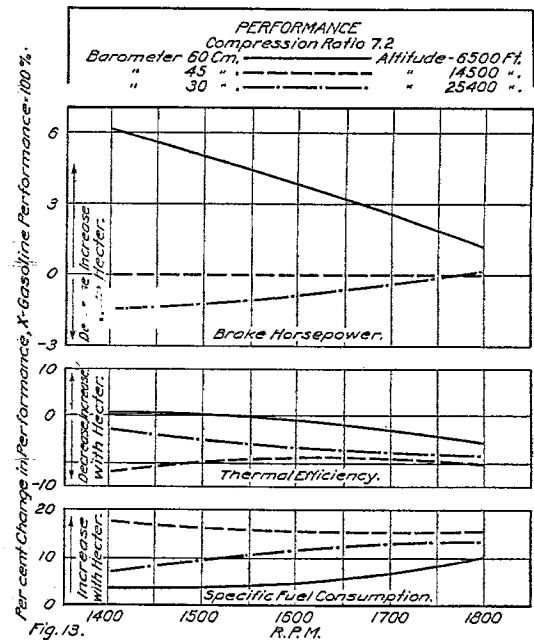


Fig. 13.