REPORT No. 277

THE COMPARATIVE PERFORMANCE OF AN AVIATION ENGINE AT NORMAL AND HIGH INLET AIR TEMPERATURES

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SUMMARY

This report presents some results obtained at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics during an investigation to determine the effect of high inlet air temperature on the performance of a Liberty 12 aviation engine. The purpose of this investigation was to ascertain, for normal service carburetor adjustments and a fixed ignition advance, the relation between power and temperature for the range of carburetor air temperatures that may be encountered when supercharging to sea level pressure at altitudes of over 20,000 feet and without intercooling when using plain aviation gasoline and mixtures of benzol and gasoline.

Laboratory tests were made at full throttle over the speed range from 1,400 to 1,800 R. P. M., in which the pressure at the carburetor and exhaust was maintained sensibly constant and the inlet air temperature varied from 45° to 180° F. The range of mixtures was that normally used in flight. Plain aviation gasoline, a mixture consisting of 30 per cent (by volume) of commercial benzol and 70 per cent gasoline, and a mixture of 65 per cent benzol and 35 per cent gasoline were used. Additional tests were made with a Wright E-4 aviation engine.

The results show that for the conditions of test, both the brake and indicated power decrease with increase in air temperature at a faster rate than given by the theoretical assumption that power varies inversely as the square root of the absolute temperature. On a brake basis, the order of the difference in power for a temperature difference of 120° F. is 3 to 5 per cent. The observed relation between power and temperature when using the 30–70 blend was found to be linear. But, although these differences are noted, the above theoretical assumption may be considered as generally applicable except where greater precision over a wide range of temperatures is desired, in which case it appears necessary to test the particular engine under the given conditions.

INTRODUCTION

In conducting flight research with supercharged engines equipped with a gear-driven Roots type supercharger, no air intercooler has been employed, thus giving rise to a condition where, with full supercharging maintained to 20,000 feet, air temperatures before the carburetor as high as 160° F. have been observed. As a result of these high temperatures the power of the engine is obviously impaired, owing to a reduction in the weight of charge inducted and, possibly, to the existence of temperature conditions within the engine conducive to appreciable detonation with a consequent further loss in power. A blended fuel, consisting of 30 per cent benzol and 70 per cent gasoline, has been used to obviate this latter possibility.

In view of the above conditions it was desirable to determine the reduction in power at this high air temperature and thus obtain information of aid in ascertaining the advisability of providing an intercooler and to ascertain the gain, if any, that is obtained by using the special fuel.

It is generally conceded that, for a given compression ratio, the character of combustion obtained with a given fuel is dependent to some extent upon the particular engine in which it is used. Moreover, there is some disagreement among investigators regarding the magnitude of the influence of temperature on the tendency for detonation. For the condition of normal combustion, White (Reference 3) and Sparrow (Reference 4) favor the application of a general law for correcting horsepower measurements for changes in air temperature. Sparrow has considered in detail the various factors affecting the density of the induced charge and has arrived at the conclusion "that the assumption that the indicated horsepower of an engine varies inversely as the square root of the absolute temperature has sufficient justification to warrant its adoption as a basis for correcting horsepower measurements to a standard temperature." The tests on which this conclusion was based covered a temperature range from −20° to +40° C. and were made at a time when higher temperatures were of comparatively little practical importance. A review of available information indicated that the application of a general law for the variation of power with air temperature, especially for a wide range of temperature and air-fuel ratios, may not give the precision desired.

Investigations have shown that the air-fuel ratio employed has a marked effect on the power variation with temperature. Brown found (Reference 6) that the power was actually increased at high temperatures when using very lean mixtures; that the power remained practically constant from 80° to 250° F. when using a mixture ratio slightly richer than the chemical combining ratio, and that the power decreased with increase in temperature when using still richer mixtures, the decrease being greater the richer the mixture. Berry obtained (Reference 5) that an appreciable decrease in power resulted from an increase in temperature for mixture proportions equal to and richer than that for the chemical combining ratio. In both of these investigations, maximum power occurred with air-fuel ratios between 12 and 12.5 at all temperatures. Sparrow states (Reference 7) that the maximum power of aviation engines is usually obtained with air-fuel ratios between 12.5 and 14.3 for the range of pressures and temperatures encountered in flight and that the mixture ratio giving maximum power is sensibly constant for all entrance air temperatures. Gibson found (Reference 8) that the power of an engine, without water-jacketing on the manifolds, decreased most rapidly with increase in entrance air temperatures when using lean mixtures, and least rapidly when using over-rich mixtures.

Therefore the present investigation was undertaken at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics to determine, for normal service carburetor adjustments and a fixed ignition advance, the performance of a Liberty 12 aviation engine over a wide range of air temperatures, and to ascertain the comparative performance under these conditions when using plain gasoline and two fuel mixtures of benzol and gasoline. Some tests were also made with a Wright E–4 aviation engine.

DESCRIPTION OF APPARATUS AND METHODS

A standard Liberty 12 aviation engine, 5-inch bore by 7-inch stroke, having a compression ratio of 5.4 to 1, was used for the major part of the investigation. It was equipped with two Stromberg inverted carburetors, Model NA–L5A, of the duplex type, having fixed main metering jets, No. 44 drill. The manifolds used with these carburetors are water-jacketed, so that a portion of the internal surface is backed by water at approximately the temperature of the water discharged from the engine, in this case about 160° F.

A standard Wright E–4 aviation engine, 4.72-inch bore by 5.12-inch stroke, having a compression ratio of 5.3 to 1, was also used. It was equipped with a single Stromberg carburetor, Model NA–U5A, also of the duplex type, having fixed main metering jets, No. 47 drill. The intake manifolds on this engine are also water-jacketed.

In each case the engine was coupled to a 300/400 HP. electric cradle dynamometer, which was used to absorb the engine output and to motor the engine during friction tests.

Two methods were employed for heating the air supplied the engine. For all tests with the Wright engine and for some tests with the Liberty engine, a separately driven Roots supercharger was used, but for the major part of the tests with the latter engine, a lagged heating box, housing several large-size steam radiators, was used. When using the supercharger, the air was heated by throttling the intake. In making tests at low temperatures, air was piped from outside the building.

Plain domestic aviation gasoline, conforming to standard Army specifications, a mixture of 30 per cent benzol (commercial, 90 per cent) and 70 per cent gasoline (30–70 blend) and a mixture of 65 per cent benzol and 35 per cent gasoline (65–35 blend) were used during tests of the Liberty engine. The 30–70 blend was used in the Wright engine tests.

Inlet air temperatures were measured at a point directly before the carburetors. The temperature of the discharge water was maintained about 160° F. for both engines.

Friction power was measured by motoring the engine, with the throttle open and fuel and gnition off, immediately following a series of power runs; the air pressure, and the air, water, and oil temperatures were held practically the same as for the preceding power runs.

The test procedure consisted in determining the engine performance, with a given fuel and mixture condition and with a fixed spark advance of 30° for the Liberty and 27° for the Wright engine, over the interesting speed range at several nominally constant air temperatures from 45° to 180° F. After conditions were stabilized, a run was made extending over a one-minute interval, during which two complete sets of readings were taken, one at the beginning and another near the end of the interval; the average of the two readings was taken as the average for the run. Timing of the rate of fuel flow was started at the beginning of the run and extended somewhat over the one-minute interval, but conditions were stabilized sufficiently to obviate introducing appreciable error in the fuel measurements from this cause.

Two carburetor settings were used—i. e., with the mixture control maintained in the full-rich position (rich) and with the control adjusted to give the approximate condition of maximum power with best economy (best setting).

Observed power and mean effective pressures were corrected to the standard pressure of 29.92 inches of mercury; the average correction was considerably less than 1 per cent. Specific fuel consumption was based on the observed power and rate of consumption.

RESULTS

The results of the tests are presented in the form of curves (figs. 1 to 14, inclusive).

Due to the test procedure employed, it was difficult to duplicate the air temperatures in the various series of tests, so that cross plots are relied upon to give comparative information at any given temperature and also to determine the variations with temperature. Values for mean effective pressure, friction power, hourly fuel consumption, and manifold depressions taken from the faired curves of the original plots are shown on the cross plots to indicate the precision with which the latter are determined. The most probable values at the arbitrary base temperatures, 59° F. for the Liberty tests and 70° F. for the Wright tests, have been used in establishing the percentage ratios for the performance at other temperatures; these base values are given on the several curves.

Fuel consumption data were not obtained for the Wright engine. Also, only a few friction power tests were made with this engine, and as these did not indicate any consistent variation between friction power and air temperature, one curve has been drawn averaging all data. (Fig. 3.)

As the power with a given fuel was practically the same for both mixture adjustments, the cross-plot curves of mean effective pressure against air temperature for several engine speeds have been drawn averaging all data for each fuel irrespective of mixture adjustment. (Figs. 6 and 7.) Likewise, on the cross plots showing the percentage variation in mean effective pressure with change in temperature (figs. 8 and 9), the plotted point at a given temperature represents the average of the individual percentages for the several speeds.

Data on fuel consumption were, in some cases, erratic, due to the short time intervals during which the rate of fuel flow was measured and the probability of errors in timing, but the information obtained is sufficiently precise to indicate the order of the variation with air temperature.

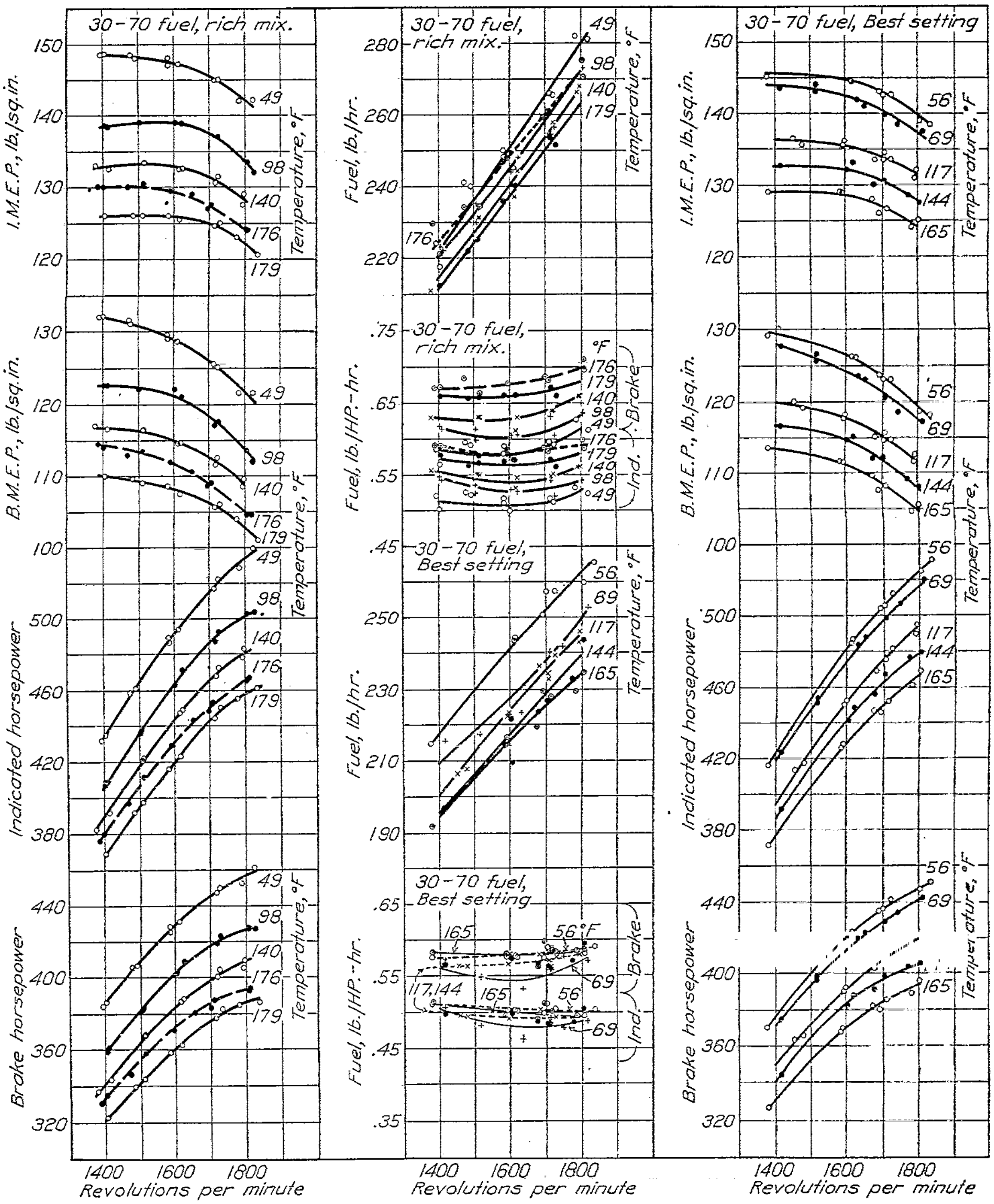


FIG. 1.—Liberty 12 engine. Full throttle power and fuel consumption at various air temperatures using a fuel mixture containing 30 per cent benzol and 70 per cent aviation gasoline. Full rich mixture and best setting. Stromberg inverted carburetors, Model NA-L5A with 1⅝ in. Venturi and No. 44 drill main metering jets. Fixed ignition advance 30°. Dash curves for fuel mixture containing 65 per cent benzol and 35 per cent gasoline with full rich mixture. Figures on curves denote average air temperatures for individual series of tests

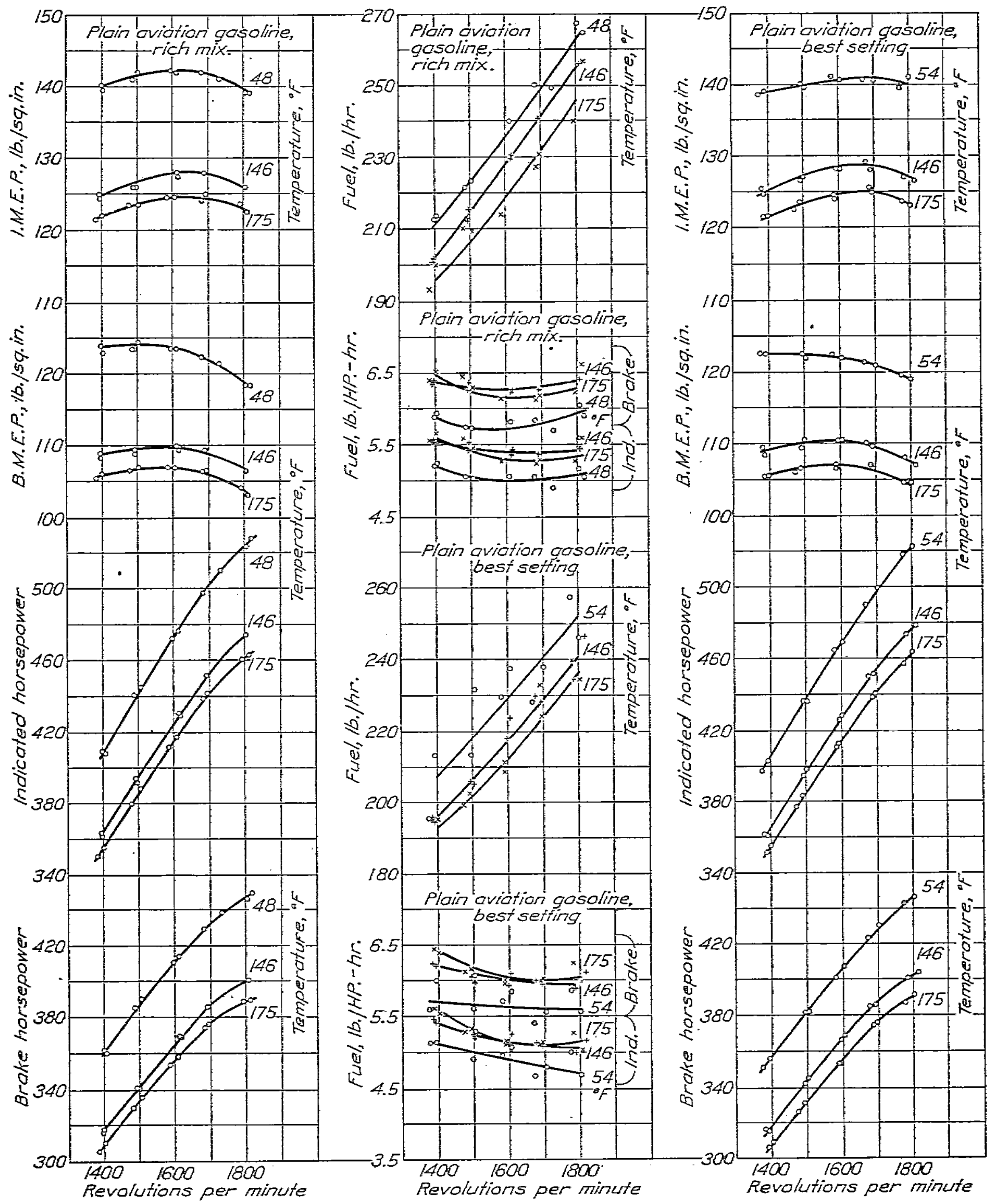


FIG. 2.—Liberty 12 engine. Full throttle power and fuel consumption at various air temperatures using plain domestic aviation gasoline. Full rich mixture and best setting. Same carburetor, carburetor settings, and ignition advance as given under Figure 1. Figures on curves denote average air temperatures for individual series

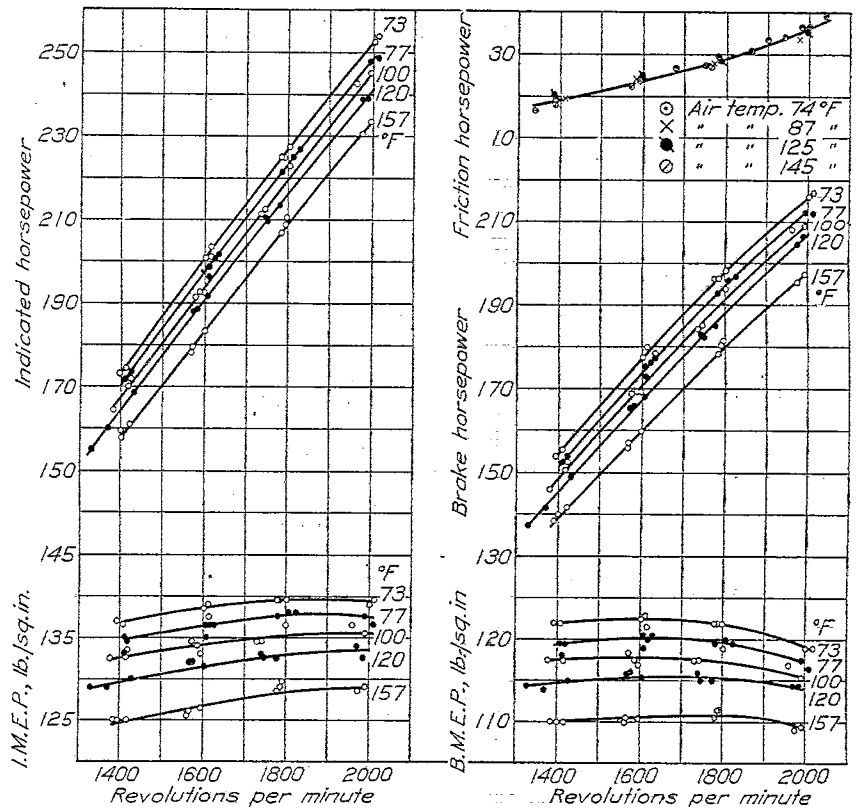


FIG. 3.—Wright E-4 engine. Full throttle power at various air temperatures using a fuel mixture containing 30 per cent benzol and 70 per cent aviation gasoline. Full rich mixture. Stromberg carburetor Model NA-U5A, No. 47 main metering jets. Fixed ignition advance 27°. Friction power curve at upper right. Figures on curves denote average air temperatures for individual series

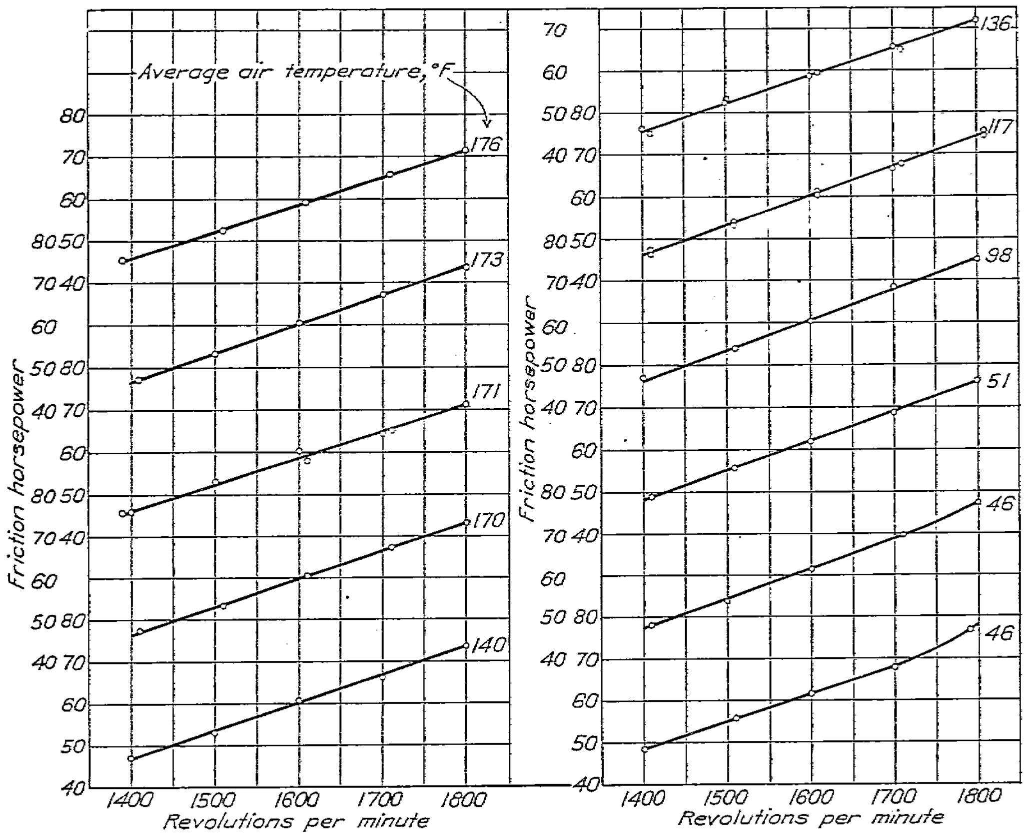


FIG. 4.—Friction power of Liberty 12 engine at various air temperatures

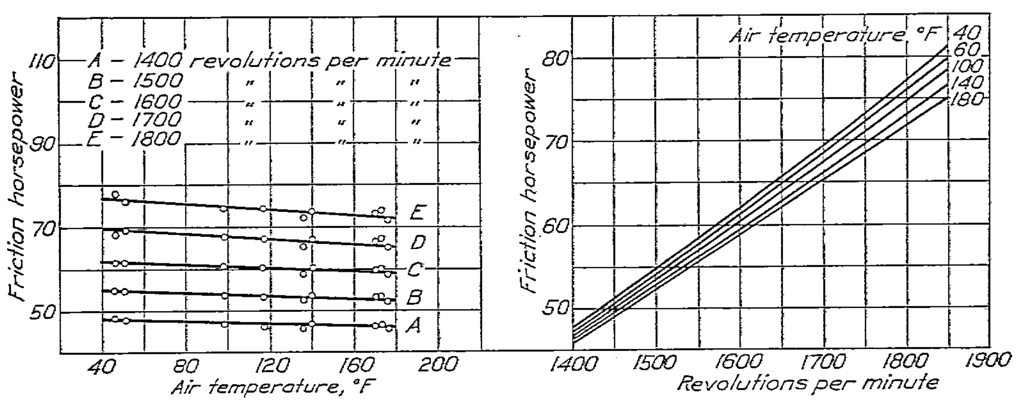


FIG. 5.—Variation infriction power of Liberty engine with temperature (cross plot of curves, fig. 5) and composite curves of friction vs. R P. M. at various temperatures (cross plot of upper group, this figure)

The power obtained with the Liberty engine at normal temperatures when using the 30–70 blend was appreciably greater than that obtained with average service engines. The power obtained with gasoline was about normal for this engine, but detonation was encountered at all temperatures, as evidenced by free carbon in the exhaust and the fact that leaks developed in practically all of the cylinder jackets during the period of testing with this fuel.

Fuel consumption for the Liberty engine was above the average.

The power developed by the Wright engine at normal temperature when using the 30–70 blend was about normal.

DISCUSSION

TEST CONDITIONS

In this investigation the flight conditions of the supercharged engine were simulated, especially with regard to the fuel flow conditions existing at the carburetors. Air pressure at the entrance to the carburetors and in the float chambers was maintained sensibly constant, as for the condition in flight with sea-level pressure maintained at the carburetors and the float chambers balanced by the supercharging pressure. Tests were not made to simulate flight conditions above the critical altitude of the supercharger-engine unit, where the pressure at the carburetors is reduced below the sea-level standard. Air-fuel ratios were on the rich side of the chemically correct mixture, and probably slightly on the rich side of maximum power mixtures.

In these tests the engine exhausted into air at approximately sea-level pressure. Therefore the effect of the differential pressure existing in flight, between intake and exhaust, on the scavenging of the cylinders, the amount of residual gases left in the cylinders and the combined effect of more complete scavenging coupled with high temperatures on the character of the combustion was not ascertained. The present data are only applicable in showing the independent effect of air temperature.

EFFECT OF FUEL USED ON THE PERFORMANCE OF THE LIBERTY ENGINE AT NORMAL AND HIGH TEMPERATURES

Comparison of the performance of the Liberty engine obtained with the various fuels and mixture conditions at 59° and 176° F. are given below. These temperatures have been chosen because they lie within the extremes of the range of temperatures for most of the tests; the higher temperature is the average of the single series of tests made with the 65–35 blend.

For the tests with the 30–70 blend at 59° F., it appears that, in leaning the mixture to obtain the best setting, there resulted a slight decrease in power at all speeds (figs. 6 and 7), probably caused by leaning too far. However, the power obtained with both mixture conditions for this fuel did not vary appreciably at the higher temperatures, and for this reason the cross-plot curves for mean effective pressure have been drawn averaging all data for this fuel irrespective of mixture condition. Although no air measurements were made during the present investigation, by assuming the volumetric efficiencies for the Liberty engine given in Reference 9 as an approximation, it is found that the probable air-fuel ratios obtaining with the 30–70 blend, rich mixture, range from 11.8 to 12.2, or but slightly richer than mixtures giving maximum power. (References 7 and 11.) Values for volumetric efficiencies given in this reference are for the Liberty engine equipped with Zenith carburetors having a common air intake, and as the power obtained with the inverted Stromberg carburetors and separate intake stacks for each carburetor is somewhat greater (Reference 10) than that obtained with the standard Zenith carburetors, the volumetric efficiency with the Stromberg carburetors is probably higher; and the above values for air-fuel ratios should be increased. Assuming the same efficiencies, corresponding values for the 30–70 blend, lean mixture, lie between 12.9 and 13.2, or well within the range of mixtures normally giving maximum power. From the standpoint of fuel mixtures, then, values of mean effective pressure at 59° F. taken from the curves on the above figures should represent fairly closely the maximum power obtainable with this fuel, and as it has been found (References 12 and 13) that a 30–70 blend may be used at normal air temperature in a single cylinder Liberty test engine for compression ratio up to 6 to 1 without encountering detonation, it may be further reasonably assumed that these values represent the maxima for the engine at this temperature.

The power obtained with plain domestic aviation gasoline at 59° F. departs but little from that obtained with the best Stromberg carburetor adjustments determined in Reference 10. In leaning the mixture to obtain best power and economy with this fuel, the power remained unchanged. Based on the assumed volumetric efficiencies, the air-fuel ratios for the rich mixture lie between 12.5 and 13 and for the best setting, between 13 and 13.3. Even at this low temperature there was considerable detonation, especially at the lower speeds. The brake power obtained with this fuel at this temperature at 1,800 R. P. M. is 1.5 per cent lower than the assumed maximum power for the engine obtained with the 30–70 blend, but there is a marked reduction, about 6 per cent, in the relative power at 1,400 R. P. M. This indicates the loss in power resulting from the use of plain aviation gasoline in this engine under conditions of full throttle at ground level at the lower range of the usual operating speeds, where the volumetric efficiency is a maximum and the higher density of the fuel charge induces considerable detonation. The decrease in detonation at the higher speeds is in accordance with common experience, the primary cause in the case of the Liberty engine being attributable to the marked decrease in volumetric efficiency and the greater proportion of residuals at the higher speeds. That there is a certain amount of detonation in this particular engine at ground level when using gasoline is generally known, but it is not believed that the order of the loss in power at normal temperatures resulting from detonation is generally appreciated.

It is known that gasolines obtained from different sources have varying influences on detonation even though they comply with the same specifications, and it may be that the loss in power caused by detonation was greater in these tests than would occur with a different lot of gasoline.

Comparisons of the performance at a temperature of 176° F. when using the 30–70 blend, the 65–35 blend, and plain gasoline are given below. For the 30–70 blend, reducing the hourly fuel rate 10 to 11 per cent by leaning resulted in no change in power. Maximum power at this temperature was obtained with the 65–35 blend (fig. 8); only the rich mixture was used with this fuel. The brake power with the 30–70 blend was about 2.3 per cent lower than this maximum, ranging from 1.7 per cent lower at 1,800 R. P. M. to 2.5 per cent lower at 1,400 R. P. M. This difference is, apparently, not accounted for on the basis of differences in air-fuel mixtures. Optimum ignition advance was not determined for each fuel; the ignition advance remained fixed at 30°—a service condition. This may have influenced the results to give erroneous general comparisons. However, the indication is that a certain amount of detonation attended the use of the 30–70 blend at this temperature. An estimation of the probable air-fuel ratios at this temperature may be made by assuming that the weight of air charge inducted varies proportionally with the ratio of the indicated mean effective pressure obtained with the 65–35 blend at 176° F. to the indicated mean effective pressure obtained with the 30–70 blend at 59° F., and using the previous air weights determined for the low temperature. If this be permitted for the sake of making a rough approximation, it is found that the air-fuel ratios for the 30–70 blend lie between 11.2 and 11.4 for the rich condition and between 12.4 and 12.6 for the best setting; between 10.7 and 10.9 for the 65–35 blend, rich condition; between 11.7 and 12.2 for gasoline, rich mixture; and between 12.2 and 12.7 for gasoline, best setting. These values are at least comparative among themselves. It may be seen that the mixture for the 65–35 blend is apparently somewhat overrich to give maximum power, but the gain to be realized with an optimum mixture would probably not be very great, and it has been found (Reference 6) that power is less sensitive to mixture adjustment at the higher temperatures. For this reason, and for the additional reason that the high benzol content gives reasonable assurance of freedom from detonation, the power obtained with this fuel may be assumed to be the approximate maximum for the engine at this temperature.

The air-fuel ratios for gasoline given above are approximately those giving maximum power. Compared with the 30–70 blend, the relative power is slightly greater than observed at 59° F.;

in fact, at 1,800 R. P. M. (fig. 8), the power obtained with gasoline is actually greater. From the trend of the cross-plot curves, it may be seen that the power with gasoline tends to approach that for the 30–70 blend at all speeds. As the range of air-fuel ratios for the two fuels overlap this can not be readily explained on the basis of mixture differences. The fixed ignition advance and differences in the amount of vaporization taking place in the manifold may be cited as factors having a possible influence on the comparative results. The power with gasoline is from 1 per cent at 1,800 R. P. M. to 7 per cent at 1,400 R. P. M. less than that obtained with the 65–35 blend.

Thus the conclusion may be made that, as aviation gasoline does not give the maximum M. E. P. for the normal engine at speeds giving maximum volumetric efficiency, and as the volumetric efficiency under supercharged conditions is greater than for any condition of the normal engine, the loss in power resulting from the use of this fuel in the supercharged engine would probably be greater than evidenced by the present results. Also, unlike the normal engine, the conditions inducing detonation in the supercharged engine are encountered at all altitudes. For these reasons, the use of the 30–70 blend instead of plain aviation gasoline in the supercharged engine gives an appreciable gain in power.

THE EFFECT OF AIR TEMPERATURE ON POWER

Owing to the variation in the character of the combustion as influenced by varying degrees of detonation, no laws of general applicability can be promulgated from these tests for the variation in engine power with air temperature. Also, in the matter of air-fuel mixtures and ignition advance, the data are incomplete, and do not show definitely that the power obtained at each temperature was the maximum possible for the particular fuel used. The lack of complete data at several air temperatures in the case of the 65–35 blend, which might be considered suitable from the standpoint of detonation suppression, precludes the possibility of comparing the observed performance obtained with the other two fuels with the optimum performance of the engine. However, the power obtained with each fuel was probably within 1 per cent of the maximum obtainable with the given fuel, and the data are valuable as showing the variation in power with temperature of two representative engines for normal carburetor adjustments encountered in service, where overrich mixtures are usually employed to secure safe operation under all flight conditions and where the mixture is adjusted neither to give the absolute maximum power nor the best fuel economy. With this in mind, the following empirical relations determined from the present tests are submitted.

The ratios of the mean effective pressure at high temperatures to the mean effective pressure at a low base temperature, with comparative curves showing the ratios that would exist were the power to vary directly with air density or inversely as the square root of the inlet temperature, are plotted in Figures 8 and 9. As the magnitude of the differences in the values for relative power at high and low speeds was, in the present tests, small, average percentage values have been used instead of the individual values for each speed. The average values for brake power represent the observed values for all speeds within less than 1 per cent, and, in most cases, within less than 0.5 per cent.

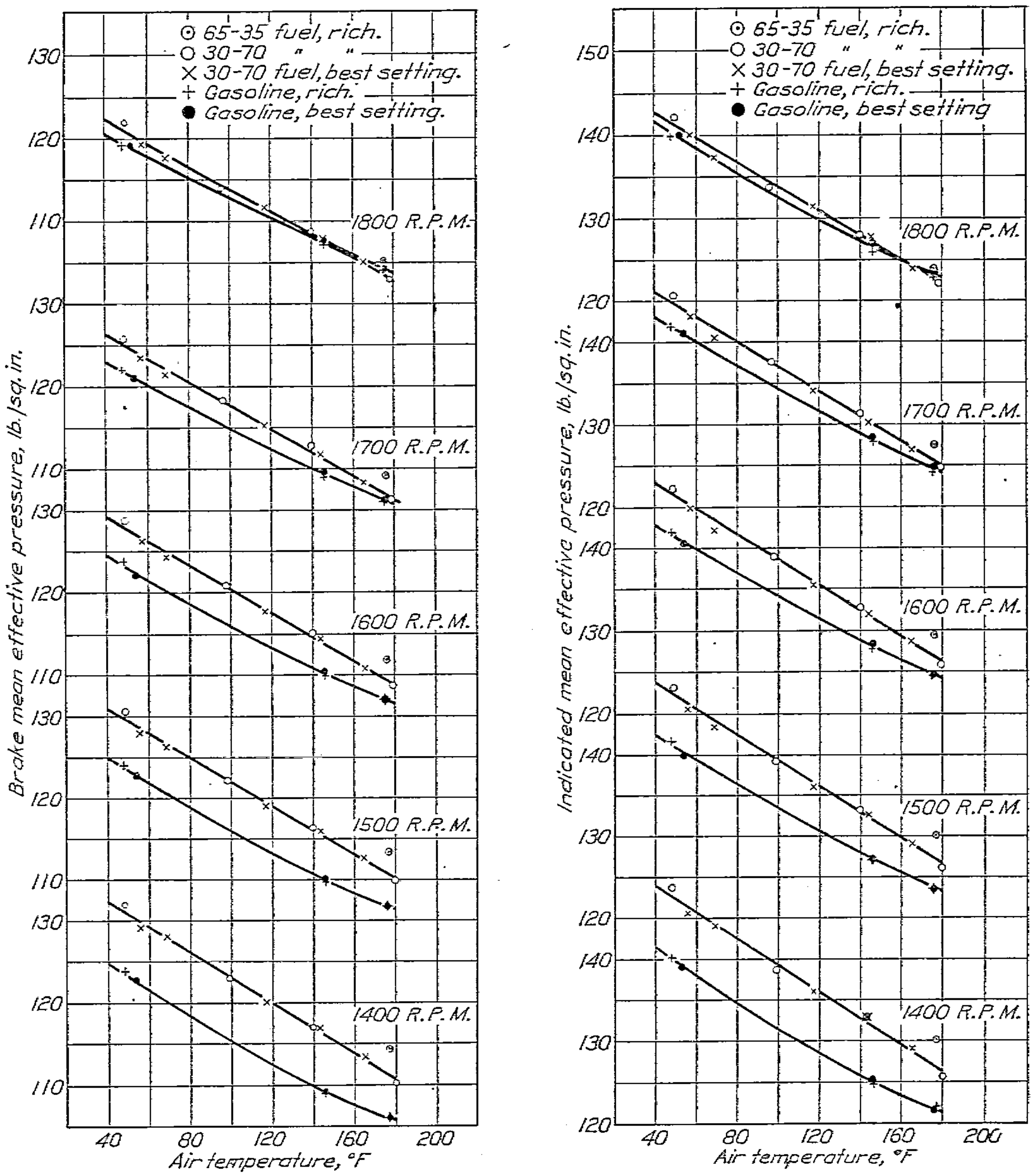
Considering first the performance of the Liberty engine when using the 30–70 blend, it is found that the cross plots at several engine speeds show the variation in mean effective pressure with air temperature to be linear. The relation between power ratio and air temperature may be thus given by general equation,

$$\text{Power ratio} = 1 \pm mt,$$

where m is the slope of the line and t the difference in temperature in degrees Fahrenheit. The straight lines determined by the average ratios for all speeds (fig. 8) have a slope, m, of 0.00115 for brake power and 0.00108 for indicated power. At the highest temperature, 180° F., temperature difference of 121° F., the brake power is about 5 per cent higher than given by straight density proportion, and about 4 per cent lower than given by the square root relation; corresponding values for indicated power are 6 per cent and 3 per cent, respectively.

As mentioned previously, there is a greater tendency for detonation with this fuel under flight conditions, but the above relation, and the given values of m, may be considered as more nearly representing the power variation with temperature for the supercharged Liberty engine, for the range of mixtures used with the 30–70 blend in flight, than would be given by the square root relation.

For a constant speed, data for both the rich and lean mixtures for plain gasoline lie on a single curve. Sufficient data were not taken to determine the exact trend of the mean effective pressure-temperature curves for this fuel, and no equation for the observed relation is submitted, but the indication is that the relation is not quite linear as was the case for the 30–70 blend (fig. 8). Also, the decrease in power with increase in temperature is not as great as observed for the 30–70 blend. The brake power at 180° F. is seen to be 2.5 per cent lower, and the indicated power 1.5 per cent lower than that given by the square root relation; the trend of the curve against air temperature approximates that given by the theoretical relation.



FIGS. 6 and 7.—Liberty 12 engine. Variation in mean effective pressure with air temperature for various speeds from 1,400 to 1,800 R. P. M. for all fuel conditions (cross plot of faired curves, figs. 1 and 2)

The ratios of the mean effective pressure obtained with the 65–35 blend at 176° F., the assumed maximum at this temperature, to the assumed maximum mean effective pressure obtained with the 30–70 blend at 59° F. are also shown on Figure 8, from which it is seen that the single points for this fuel closely approximate the percentage variation in power observed for plain gasoline.

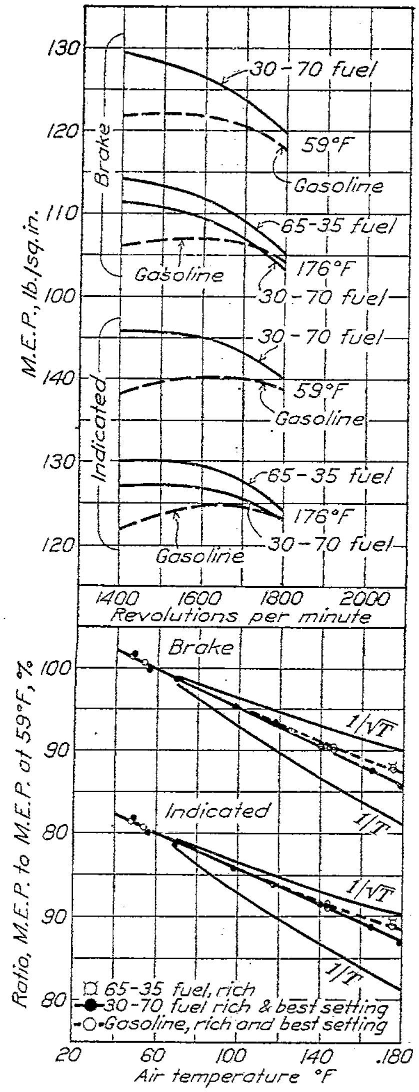


FIG. 8.—Liberty 12 engine. Mean effective pressure at 59° F. and 176° F. with various fuels (from faired curves of figs. 6 and 7) and percentage variation in mean effective pressure with air temperature. (Points on percentage plots are average of percentage decrease for five speeds)

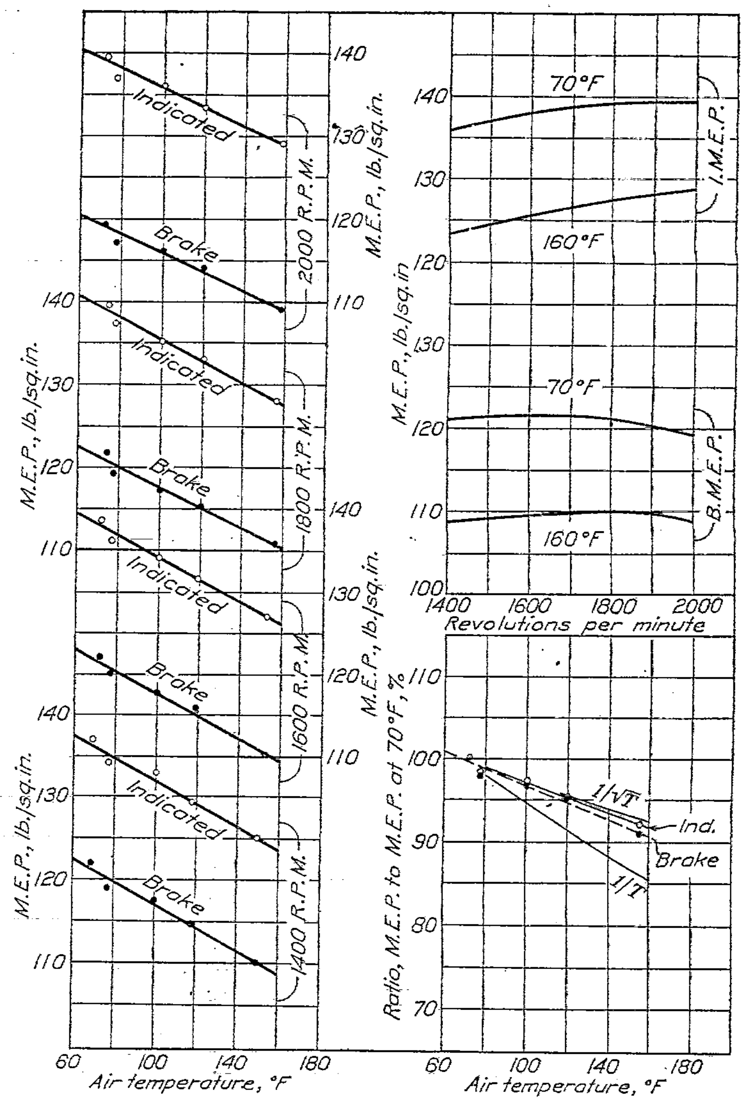


FIG. 9.—Wright E-4 engine. Variation in mean effective pressure with air temperature for various speeds (cross plot of curves, fig. 4), mean effective pressure at 70° and 160° F. and percentage variation in mean effective pressure with air temperature. (Points on percentage plots are average of four speeds)

The variation in power with temperature for the Wright engine using the 30–70 blend, rich mixture, is shown on Figure 9. The average ratios of mean effective pressure for all speeds determine a linear relation, as for the case of the same fuel in the Liberty engine, but in this case, the decrease in power is not as rapid, and approaches more nearly the variation given by the square-root relation. For a temperature difference of 90° F., the brake power is only 1.8 per cent, and the indicated power is only 0.8 per cent, below that given by the theoretical square-root relation, as compared to 2.8 per cent and 2 per cent for the same fuel and the same temperature difference for the Liberty engine. This comparison serves to indicate the differences that may exist in the variation in power with temperature between two different types of engines using the same fuel and approximately the same air-fuel mixtures. Again, it is noted that power decreased more rapidly with temperature at speeds giving the maximum volumetric efficiency. Using the average percentage for all speeds, values of m in the general relation,

$$\text{Power ratio} = 1 \pm mt,$$

are 0.00104 for brake and 0.00093 for indicated power.

The results given in References 1, 5, 6, 8, 11, and 13 do not agree in all respects, but, in the main, the brake power obtained at high temperatures when using rich fuel mixtures is less than that given by the theoretical square-root relation. On a basis of indicated power, the results probably would have been in closer agreement with this relation, but the indications are that for overrich mixtures the indicated power would still be less, as found in the present tests.

From the present results, it may be concluded that, for normal service carburetor adjustments, both the brake and indicated power at high temperatures is less than given by the square-root relation, but that the square-root relation may be considered as generally applicable except when greater precision over wide range of temperatures is desired, in which case it appears that the particular engine should be tested under the given conditions.

EFFECT OF AIR TEMPERATURE ON FRICTION POWER

From theoretical considerations it is indicated that an increase in air temperature results in an increase in the absolute pressure during the suction stroke. (Reference 4.) As a result the pumping loss, and consequently the friction power, would decrease with an increase in temperature. Such an effect was noted in the present investigation.

Although the friction power was obtained by motoring the engine with the dynamometer, which method, it has been shown (Reference 15), may give values for friction power that may be in serious error compared to the friction actually existing with the engine under power, and although the volumetric efficiency with and without the engine firing would probably be different, the results obtained are comparative. Friction power curves for the Liberty engine are shown on Figure 5. Cross plots for constant engine speeds (fig. 6) show a measurable decrease in friction power with increase in temperature, the decrease over the temperature range from 40° to 180° F., being about 7 per cent at 1,800 R. P. M. and 3.5 per cent at 1,400 R. P. M.

Only a few friction power determinations were made with the Wright engine, and these data did not show a consistent variation with air temperature. (Fig. 3.)

EFFECT OF TEMPERATURE ON FUEL CONSUMPTION

The hourly fuel rates for the Liberty engine have been cross-plotted against temperature on Figure 10. Figure 11 presents curves showing the percentage change in the hourly rate with temperature; the points shown on this figure are the average of the percentages for the several speeds.

It is noted that for the condition with the mixture control in the full-rich position, the hourly rate for both the 30–70 blend and plain gasoline decreases about 5 per cent for the temperature change from 59° to 180° F., but as the decrease in air weight for this range of tempera-

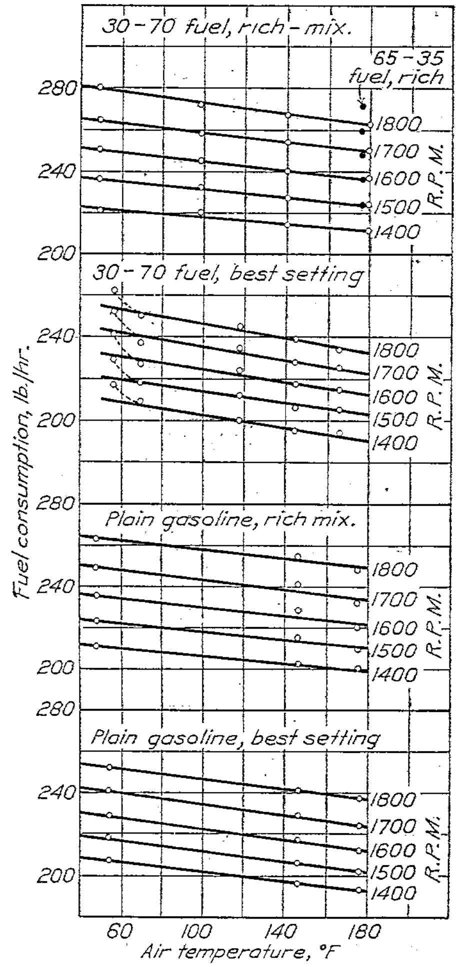


FIG. 10.—Liberty 12 engine. Variation in hourly fuel rate with air temperature for all fuels and mixture conditions (cross plot of faired curves, figs. 1 and 2)

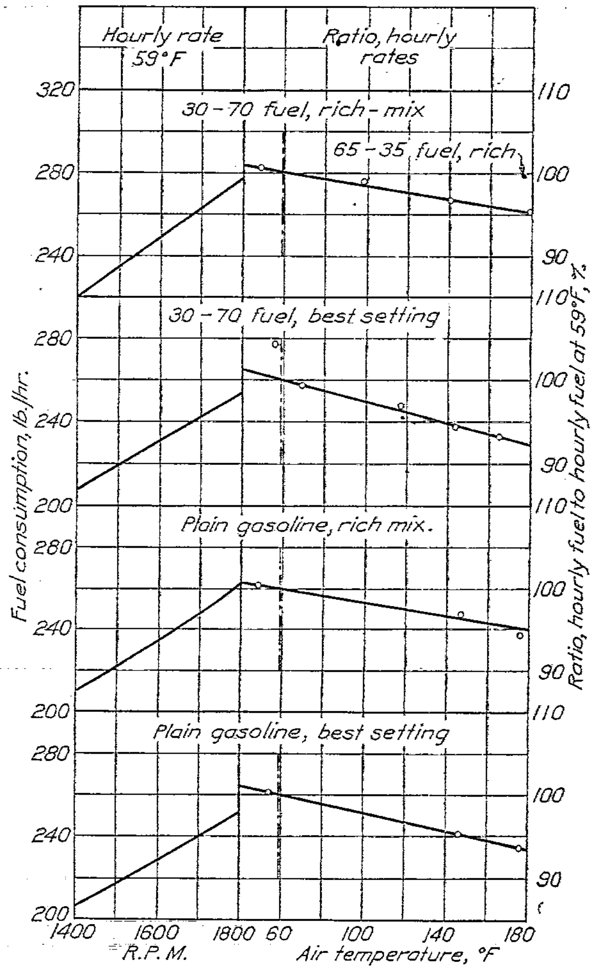


FIG. 11.—Liberty 12 engine. Hourly fuel rate at 59° F. (from faired curves, fig. 10) and percentage variation in fuel rate with air temperature. (Points are average of percentages for five speeds)

ture is considerably greater, the mixture is enriched at the higher temperature. Likewise, as the power decreases at a faster rate than the hourly consumption, the specific consumption is increased. For the leaned condition, the data are not very consistent, but the indication is that the indicated specific consumption is increased at the higher temperatures, either because the leaning was not carried far enough or because the loss in power due to detonation at the higher temperatures served to increase the specific consumption. These results point to the advisability of leaning as the temperature is increased, in order to effect a saving in fuel.

EFFECT OF TEMPERATURE ON MANIFOLD PRESSURES

With a constant pressure maintained at the entrance to the carburetor, it would be expected that some change in the friction loss through the carburetor would result from the change in air density caused by a change in temperature, and that this effect coupled with a variation in the amount and kind of fuel carried in the air stream, with consequent changes in the amount of vaporization taking place in the manifolds, would have some effect on the manifold pressures. Such an indication of the influence of air density was found during these tests.

Data for the Liberty engine, giving the average depressions in two manifolds below the existing carburetor pressure, are shown on Figures 12 and 13, and for the Wright engine, on Figure 14. From the average of the many observations taken, it was found that a measurable decrease in the depression in the manifold occurred with increase in air temperature. The order of the increase in the absolute manifold pressure, about 0.5 per cent for 140° F. temperature

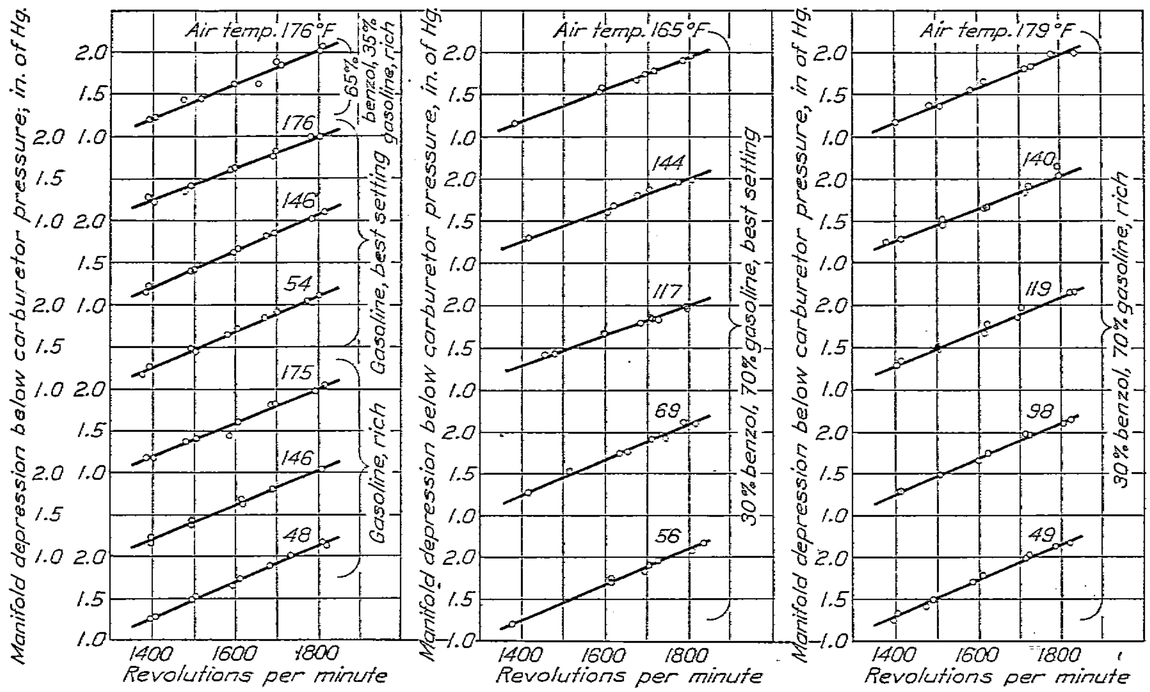


FIG. 12.—Liberty 12 engine. Depressions in manifold below existing pressure at entrance to carburetor for various air temperatures (average of front right and rear left manifolds)

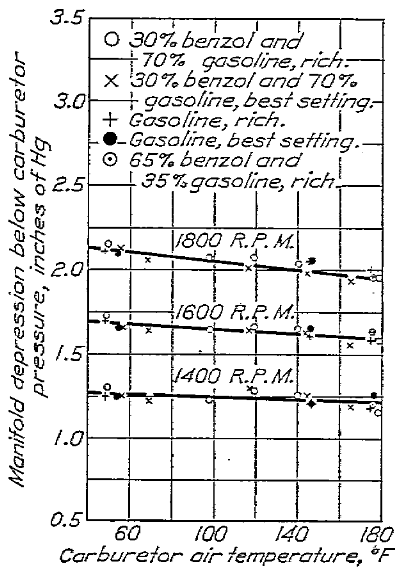


FIG. 13.—Liberty 12 engine. Variation in manifold depression with air temperature (cross plot of fig. 12)

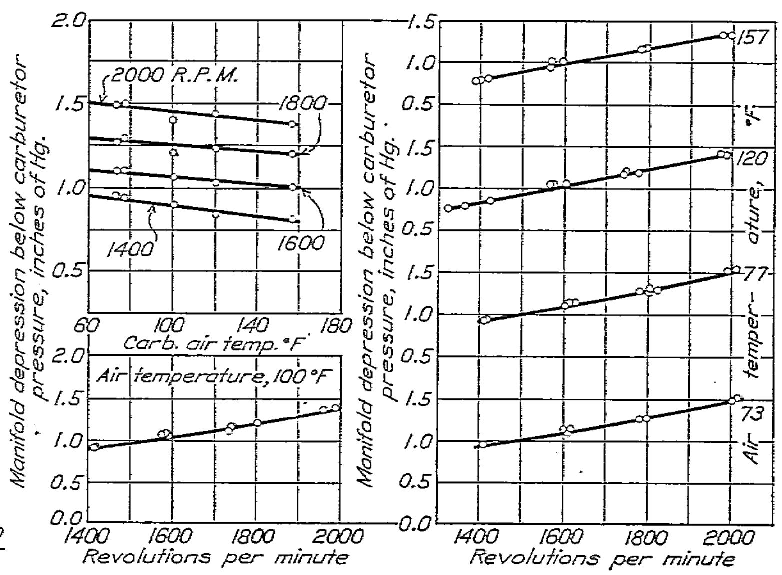


FIG. 14.—Wright E-4 engine. Depressions in manifold below existing pressure at entrance to carburetor for various air temperatures (average of right and left manifolds) and variation in manifold depression with air temperature (cross plot of above curves)

increase, has a relatively negligible effect on power; but the information is pertinent as showing the direction of the change, and the constancy of the pressure head on the intake valves at high temperatures.

CONCLUSIONS

The present results show that a gain of 5 to 6 per cent in the full-throttle power of the Liberty 12 aviation engine (5.4 to 1 compression ratio) at speeds giving the maximum volumetric efficiency is obtained by using a fuel mixture consisting of 30 per cent of commercial benzol and 70 per cent aviation gasoline instead of plain aviation gasoline. This gain is practically the same for all air temperatures investigated. As the volumetric efficiency of the supercharged engine with free exhaust is greater than for any condition of the normal engine, and as, unlike the normal engine, the conditions inducing detonation when using plain gasoline are encountered at all altitudes, the gain from the use of this special benzol blend in the supercharged Liberty engine would be appreciable.

The relative increase in power obtained at high air temperatures by increasing the benzol content in the fuel mixture to 65 per cent is only 2 per cent.

For the conditions of test, both the brake and indicated power of the normal Liberty and Wright engines decrease at a faster rate with increase in air temperature than given by the generally accepted square root relation. With regard to brake power, the order of the difference is from 3 to 5 per cent for a temperature difference of 120° F. When using the 30–70 benzol blend, the relation between power and air temperature is found to be linear for both engines. Although these differences are noted, the theoretical square root relation may be considered as being generally applicable except where greater precision over a wide range of temperatures is desired, in which case it appears that the particular engine should be tested under the given conditions.

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Langley Field, Va., *February 11, 1927.*

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