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USE OF WATER INJECTION TO DECREASE GASOLINE CONSUMPTION IN AN AIRCRAFT ENGINE CRUISING AT HIGH POWER

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RESTRICTED BULLETIN

USE OF WATER INJECTION TO DECREASE GASOLINE CONSUMPTION IN AN AIRCRAFT ENGINE CRUISING AT HIGH POWER

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INTRODUCTION

When an aircraft is cruising at relatively high power outputs, fuel-mixture enrichment may be required in order that the temperature limitations of the engine will not be exceeded. This enrichment results in higher fuel consumptions than would be the case if the fuel-air ratio could be maintained at approximately 0.06, the value for maximum economy. As a possible means of maintaining this fuel-air ratio, water can be injected into the inlet charge to provide the internal engine cooling normally supplied by the excess fuel. From a useful-load consideration, with such a system, the weight of the gasoline plus water must be compared with the weight of the gasoline alone under conventional operation with fuel-mixture enrichment.

This report describes tests on a multicylinder aircraft engine in which such a procedure and the resultant fuel savings were investigated. All tests were conducted at ground-level conditions at the Aircraft Engine Research Laboratory of the NACA at Cleveland, Ohio, during the summer and fall of 1943. Additional information on the use of water as an internal coolant can be found in references 1, 2, and 3.

APPARATUS

These tests were run on a Wright R-2600-8 engine with the following conditions held constant:

Carburetor-air temperature, °F	90±2
Spark advance, degrees B.T.C.	
Exhaust	20
Intake	20
Spark plugs	AC LS85
Fuel	AN-F-28, Amendment-1

The engine was equipped with a Bendix Stromberg PT-13E2 injection carburetor that was provided with a special air bypass and bleed valve across the metering diaphragm. This device permitted leaning the mixture from full rich to values below automatic lean.

PROCEDURE AND RESULTS

The water was injected to individual cylinders through brass nozzles fitted into the primer-plug holes. The orifice diameter of the nozzles was 0.035 inch. The flow to each cylinder was separately controlled and was measured by orifices and manometers. The engine was equipped with a torque nose for the measurement of engine power.

The runs using internal cooling through water injection were made as follows: At an engine speed of 2000 rpm, a manifold pressure of 27.1 inches of mercury absolute, and a fuel-air ratio of 0.066, the external cooling air was adjusted until the maximum rear middle-barrel temperature reached a value of approximately 340° F. For these conditions, the engine brake horsepower was 700. The water was then injected into the inlet manifolds and the engine throttle was sufficiently opened that, at each value of water-fuel ratio, the maximum rear middle-barrel temperature would again reach its original value. The data for these water-injection runs are represented in figures 1 and 2 by the solid lines. The temperature-limited horsepower of the engine was increased from 700, at a water-fuel ratio (W/F) of 0, to 1180, at a water-fuel ratio of 0.55 (fig. 2). The brake specific fuel consumption remained essentially constant.

Similar data in which increased temperature-limited powers for a constant maximum rear middle-barrel temperature of 343° F were obtained by enriching the fuel-air mixture. These data are represented in figures 1 and 2 by the dashed lines.

DISCUSSION OF RESULTS

Up to 900 brake horsepower, the curves for fuel cooling (cooling through enriching the mixture strength) and for water internal cooling lie close together (figs. 1 and 2). Above this value, fuel cooling requires a greater brake specific liquid consumption (bslc) than does cooling through the addition of water (fig. 2). At a value of 1040 brake horsepower, the curve for fuel cooling was limited by knock.

The points designated by squares on figure 2 at a brake specific fuel consumption of 0.61 and at approximately 980 brake horsepower were from tests conducted at ground level according to the operating instructions provided by the engine manufacturer for 75 percent cruise (reference 4); namely, engine speed, 2100 rpm; manifold pressure, 31.0 inches of mercury absolute; and mixture setting, automatic rich. The values given in reference 4 for these conditions at an altitude of 6700 feet are 1125 brake horsepower and a brake specific fuel consumption of 0.613 pound per horsepower-hour. (See boxed values, fig. 2.) Comparable altitude conditions could not be provided on the test engine.

Figure 1 presents data on manifold pressures and on average (of 14) rear spark-plug-gasket temperatures. The data in this figure are for the same runs as are plotted in figure 2. The positions of curves of temperature-limited brake horsepower in figure 1 corroborate the evidence in figure 2 by showing that, in the high-power range, water is the better coolant on a weight basis. Brake specific liquid consumption appears nearly the same for water cooling and for fuel cooling at constant liquid-air ratio (fig. 2).

An interesting observation in figure 1 is that the average temperatures of the rear spark-plug gasket decrease for an increase in temperature-limited brake horsepower where a maximum rear middle-barrel temperature was maintained constant. This decrease was greater for fuel cooling than for water cooling.

For military (or commercial) aircraft operation in theaters of activity where critical fuel or fuel transportation shortages exist, the use of water injection for engine cooling under cruising flight conditions would be of high strategic advantage. Table 1 shows the potential benefits of the use of water cooling. All calculations for this table are for a first approximation inasmuch as neither changes in power required as fuel and water are consumed nor weight penalties attendant upon the additional water-injection equipment are considered.

TABLE 1. - COMPARISON BETWEEN WATER COOLING AND FUEL COOLING FOR GROUND-LEVEL CRUISING POWER

The calculations are based on the following data from figure 2 at 980 brake horsepower:

brake specific fuel consumption (fuel cooling). 0.61
brake specific fuel consumption (water cooling) 45
brake specific liquid consumption (water cooling) 63

Performance criteria	Weight for 12-hour flight, two engines (lb)	Percentage of normal fuel load
Continuous flight:		
Normal fuel load (no water)	14,300	100
Fuel saving with water injection	3,800	26
Weight of water	4,200	30
One stop for water (all of fuel, one-half of water for entire flight carried):		
Liquid-weight reduction (over necessity of carrying fuel for entire flight with fuel cooling)	1,650	11.5

These results were obtained from calculations of which the following are examples: In figure 2, for 980 brake horsepower, the brake specific fuel consumption for the conditions given in reference 4 was found to be approximately 0.61, whereas the brake specific fuel consumption with water cooling at 2000 rpm was 0.45. The immediate gain in fuel economy is thus $\frac{0.61 - 0.45}{0.61}$, or about 26 percent. Brake specific liquid consumption, however, for water cooling at this power was 0.63. This value represents an increase in total liquid (water plus fuel) load of $\frac{0.63 - 0.61}{0.61}$, or about 3 percent. Calculations show that, for conditions where a midflight stop may be made for water, an over-all reduction in weight of liquid cargo of about 11 percent can be realized as compared with a situation under conventional operation where fuel must be carried for the entire flight.

If it is desired to obtain a high cruising power with fuel cooling at 2000 rpm instead of at 2100 rpm and if the rear middle-barrel temperatures are assumed to constitute the operational limit, then temperature-limited power (and consequent bsfc) are found from the dashed curve in figure 2. It is evident from the position of this curve with respect to the water-cooling curve (also for 2000 rpm) that with fuel cooling, as compared with water cooling, some liquid-weight penalty and a considerable brake-specific-fuel-consumption penalty would be involved for powers higher than approximately 900 brake horsepower.

SUMMARY OF RESULTS

A summarization of the results obtained from water-injection tests on a Wright R-2600-8 engine at ground-level conditions, is as follows:

The use of water instead of excess fuel to maintain engine temperature limits at powers normally requiring a fuel-air ratio of about 0.09 resulted in a decrease of approximately 26 percent in brake specific fuel consumption with a brake-specific-liquid-consumption increase of about 3 percent.

CONCLUSION

Water injection in aircraft engines would permit temperature-limited cruising powers to be reached at reduced engine speeds and increased brake mean effective pressures with fuel-air mixtures very near that for maximum economy. Such operation would yield significant improvements in fuel consumption, whereas the engine over-all liquid consumption would not be markedly increased.

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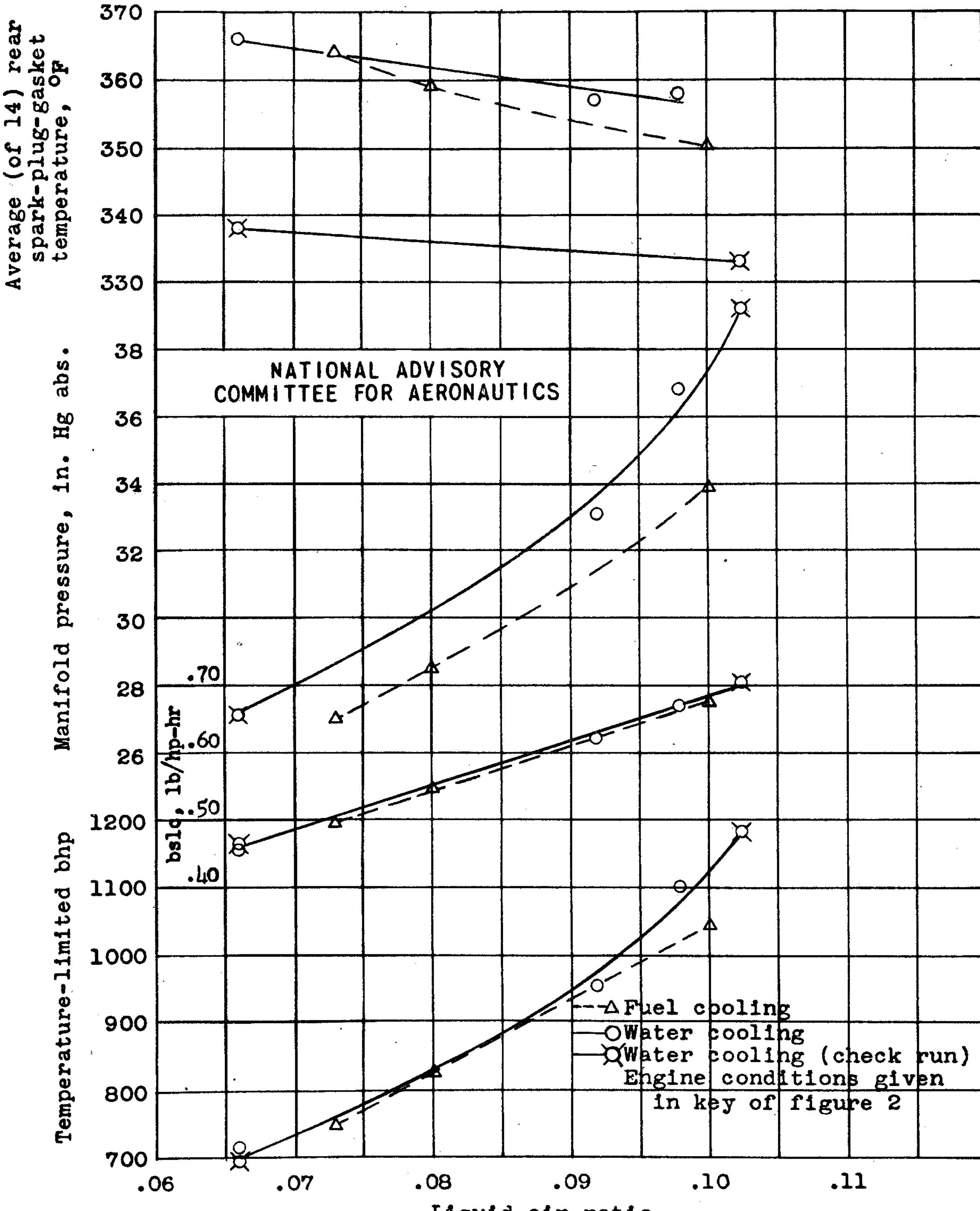

Figure 1. - Temperature-limited performance of a Wright Cyclone R-2600-8 engine for fuel cooling and for water cooling.

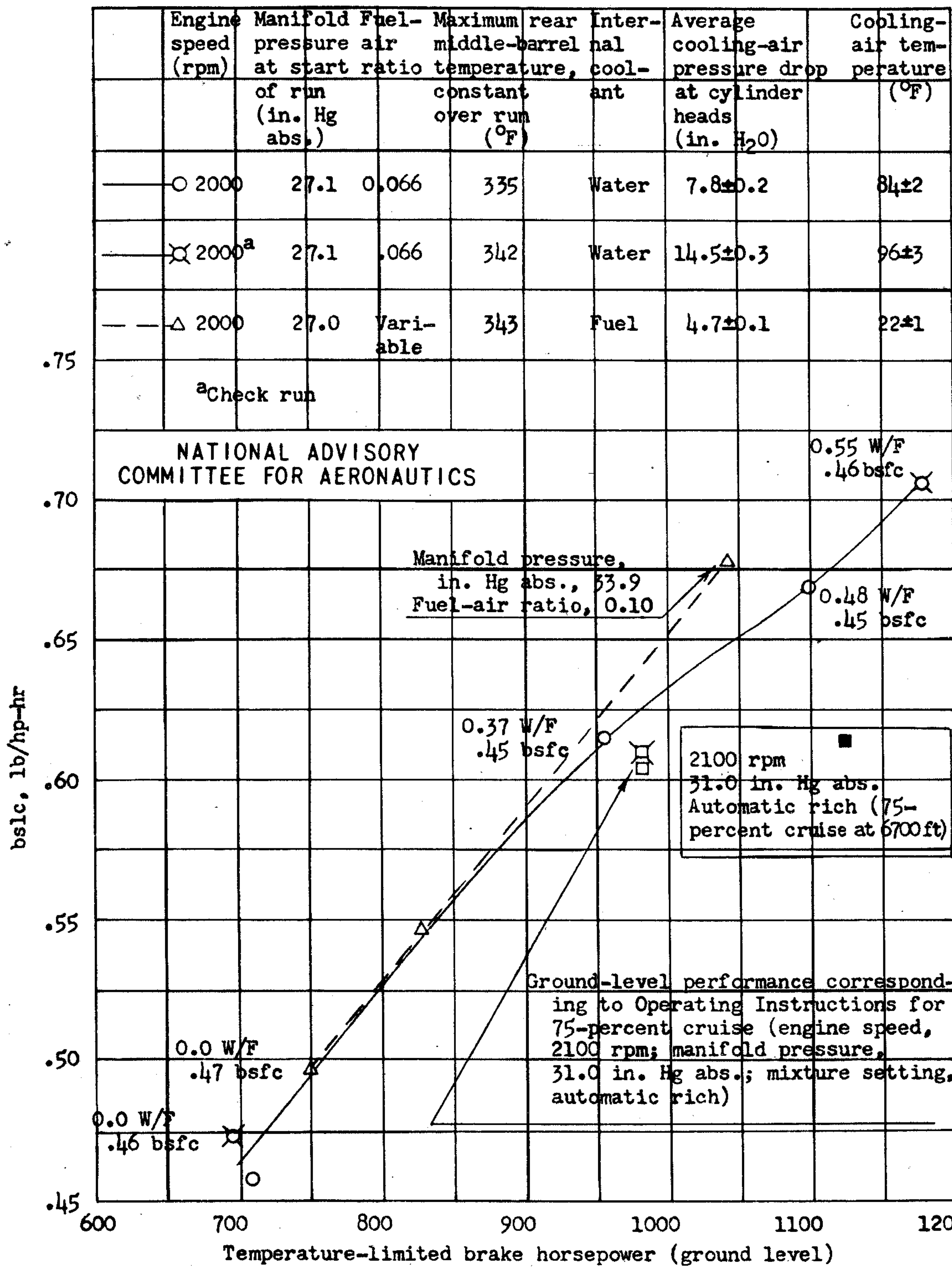

Figure 2. - Variation of brake specific liquid consumption with temperature-limited brake horsepower for water cooling and for fuel cooling for Wright Cyclone R-2600-8 engine.