NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

February 1945 as
Advance Restricted Report E5B01b

FUEL CONSUMPTION CORRECTED FOR COOLING DRAG OF AN AIR-COOLED RADIAL AIRCRAFT ENGINE AT LOW FUEL-AIR RATIOS AND WITH VARIABLE SPARK ADVANCE

By J. Elmo Farmer and Maurice Munger

Aircraft Engine Research Laboratory
Cleveland, Ohio

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

FUEL CONSUMPTION CORRECTED FOR COOLING DRAG OF AN AIR-COOLED RADIAL AIRCRAFT ENGINE AT LOW FUEL-AIR RATIOS AND WITH VARIABLE SPARK ADVANCE

By J. Elmo Farmer and Maurice Munger

INTRODUCTION

Reliability and power capacity are the only factors in the operation of aircraft engines that are of greater importance than fuel economy. A reduction in engine specific fuel consumption will result in either increased range or increased useful load. If minimum fuel consumption at any power output is to be achieved, the most favorable conditions of engine operation must be selected.

Swan and Morley (reference 1) in 1931 conducted tests with a multicylinder engine, the results of which showed that at low powers the specific fuel consumption could be reduced by decreasing the mixture strength and advancing the ignition timing. Investigation of the fuel consumption of a Wright R-1820-G cylinder and of a Pratt & Whitney R-1340-H cylinder (reference 2) indicated that the optimum spark advance for lean mixtures varied from 50° to 60° B.T.C., depending upon the engine speed and manifold pressure. In single-cylinder tests of a Wright R-1820-G cylinder (reference 3) operation with lean mixtures and advanced spark timing resulted in a decrease in the specific fuel consumption at cruising conditions. Pierce (reference 4) found that the specific fuel consumption of a Wright G200 series engine can be decreased almost 10 percent by the proper choice of compression ratio and spark advance, provided that suitable fuel is used.

Results are presented herein of tests conducted during September 1944 at the NACA laboratory at Cleveland with an air-cooled, radial aircraft engine to determine the reduction in the brake specific fuel consumption that would result from operating with a very low fuel-air ratio and an increased spark advance. Computed values of the brake specific fuel consumption corrected for cooling-air drag are also given.

APPARATUS AND TEST PROCEDURE

Tests were conducted with a Wright R-1820-97 engine mounted on a test stand. The engine power was absorbed by a hydromatic flight propeller, and the engine speed was controlled by a hydromatic constant-speed governor. The brake mean effective pressure was determined by means of a hydraulic torquemeter. The fuel used was AN-F-28, Amendment-2, and the fuel flow was measured with a calibrated rotameter.

The combustion air was measured by observing the pressure differential across the air diaphragm in the regulator unit of the carburetor. The carburetor and its inlet elbow were calibrated prior to these tests in a carburetor air box. The standard exhaust-collector ring was replaced by stub stacks to allow observation of the exhaust flames from each cylinder. A test ring cowl was used on the engine, and additional cooling air was obtained by means of an axial-flow fan that drew air across the engine. Cooling-air quantities were determined by using the baffle pressure drops and a calibration curve furnished by the engine manufacturer.

The engine conditions for the tests were as follows:

Engine speed, rpm	1900
Brake horsepower	600
Spark advance, degrees B.T.C.	20, 30, 35, 40
Maximum rear-spark-plug-bushing temperature, °F	400

An engine speed of 1900 rpm was used because at lower speeds the available boost was insufficient to maintain the required power at low fuel-air ratios.

A series of test runs was made at each of the foregoing spark advances, in each of which the fuel-air ratio was varied from about 0.088 to 0.055. The rear-spark-plug-bushing temperature of the hottest cylinder was held constant at 400° F for all of the runs except the one at a spark advance of 40° B.T.C. by varying the quantity of cooling air. At this spark advance the capacity of the cooling-air fan was sufficient only at the low and the high fuel-air ratios.

RESULTS AND DISCUSSION

Brake Specific Fuel Consumption without Consideration of Cooling-Air Drag

The variation of brake specific fuel consumption with fuel-air ratio at spark advances of 20°, 30°, 35°, and 40° B.T.C. is shown in figure 1. At the spark advance that is standard for the engine, 20° B.T.C., a minimum brake specific fuel consumption slightly greater than 0.44 pound per brake horsepower-hour was obtained at a fuel-air ratio of 0.063. With a spark advance of 40° B.T.C. and at a fuel-air ratio of 0.056, the brake specific fuel consumption was somewhat greater than 0.41, which is about 7 percent less than the minimum obtained with a spark advance of 20° B.T.C. Attempts to operate the engine at a fuel-air ratio lower than about 0.055 were unsuccessful. Reducing the fuel-air ratio below this value caused the engine to misfire and operation became unstable. Although the values of brake specific fuel consumption given herein may not be the same as those obtained in flight, the relative decrease resulting from a reduction in fuel-air ratio and an advance in spark timing should be approximately the same for an engine in flight.

Brake Specific Fuel Consumption Corrected for Cooling-Air Drag

The quantity of cooling air required to maintain a maximum rear-spark-plug-bushing temperature of 400° F increased with an advance in spark timing. Figure 2 shows the variation of average required baffle pressure drop, corrected for inlet-air temperature, with fuel-air ratio for the four spark advances.

The data taken with a spark advance of 40° B.T.C. and fuel-air ratios of 0.068 and 0.076 were also corrected to show the baffle pressure drop that would have been required to maintain the rear-spark-plug-bushing temperature at 400° F. The method used in applying this correction was adapted from reference 5. The constants used in making the correction were obtained from reference 6.

The additional horsepower required because of the cooling-air drag to maintain a maximum rear-spark-plug-bushing temperature of 400° F was calculated using the equation

$$hp_D = \frac{Q\sigma\Delta p}{550}$$

hp_D cooling-air drag horsepower

Q volume rate of air flow, cubic feet per second

Δp measured baffle pressure drop, pounds per square foot

σ ratio of inlet cooling-air density to density of air at 29.92 inches of mercury absolute and 59° F

Figure 3 shows that the cooling-air drag horsepower required to maintain a maximum rear-spark-plug-bushing temperature of 400° F increased when the spark timing was earlier than 20° B.T.C. The values of $\sigma\Delta p$ used in calculating the cooling-air drag horsepower were taken from the faired curves in figure 2.

The brake specific fuel consumption corrected for cooling-air drag was calculated from the following equation, obtained from reference 7, by using the cooling-power requirements given in figure 3:

$$bsfc_{corr} = \frac{W}{bhp - \left(\frac{hp_D}{\eta}\right)}$$

where

W weight rate of fuel flow, pounds per hour

bhp brake horsepower

η propeller efficiency (assumed to be 0.8 for these calculations)

The variation of brake specific fuel consumption, corrected for cooling-air drag, with fuel-air ratio at the four spark advances is shown in figure 4. With a spark advance of 20° B.T.C., the minimum corrected brake specific fuel consumption was about 0.45 pound per brake horsepower-hour at a fuel-air ratio of 0.062. The minimum corrected brake specific fuel consumption with a spark advance of 40° B.T.C. and at a fuel-air ratio of 0.055 was somewhat over 0.42 pound per brake horsepower-hour. The reduction in the corrected brake specific fuel consumption represents a fuel saving from 5 to 6 percent. An additional fuel saving might be possible if stable engine operation could be maintained at fuel-air ratios lower than those found possible under the test conditions and at a spark advance of 40° B.T.C. or earlier. This possibility is indicated by the curves in figure 4.

SUMMARY OF RESULTS

Tests with a Wright R-1820-97 engine at 600 brake horsepower, at an engine speed of 1900 rpm, and with variable spark advance and fuel-air ratio gave the following results:

1. Advancing the spark from 20° B.T.C. to 40° B.T.C. and reducing the fuel-air ratio from 0.063 to 0.056 resulted in a reduction in brake specific fuel consumption of about 7 percent.

2. Advances in spark timing greater than 20° B.T.C. resulted in a considerable increase in cooling-air requirements.

3. When the cooling-air drag was considered in computing the net power output, the reduction in brake specific fuel consumption was between 5 and 6 percent.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCES

1. Swan, J., and Morley, A. W.: Tests of a Nine Cylinder Radial Engine at Reduced Mixture Strength and with Variable Ignition Timing. R. & M. No. 1485, British A.R.C., 1931.

2. Schey, Oscar W., and Clark, J. Denny: Fuel Consumption of a Carburetor Engine at Various Speeds and Torques. NACA TN No. 654, 1938.

3. Gerrish, Harold C., and Voss, Fred: Analysis of Cylinder-Pressure-Indicator Diagrams Showing Effects of Mixture Strength and Spark Timing. NACA TN No. 772, 1940.

4. Pierce, Erold F.: Altitude and the Aircraft Engine. SAE Jour. (Trans.), vol. 47, no. 4, Oct. 1940, pp. 421-431.

5. Pinkel, Benjamin: Heat-Transfer Processes in Air-Cooled Engine Cylinders. NACA Rep. No. 612, 1938.

6. Sanders, J. C., Wilsted, H. D., and Mulcahy, B. A.: Cooling Tests of an Air-Cooled Engine Cylinder with Copper Fins on The Barrel. NACA ACR, July 1942.

7. Rubert, K. F., Corson, Blake W., Jr., and Nielsen, Jack: The Advantages of Uniform Fuel Distribution for Air-Cooled Economy. NACA CB No. 3L07, 1943.

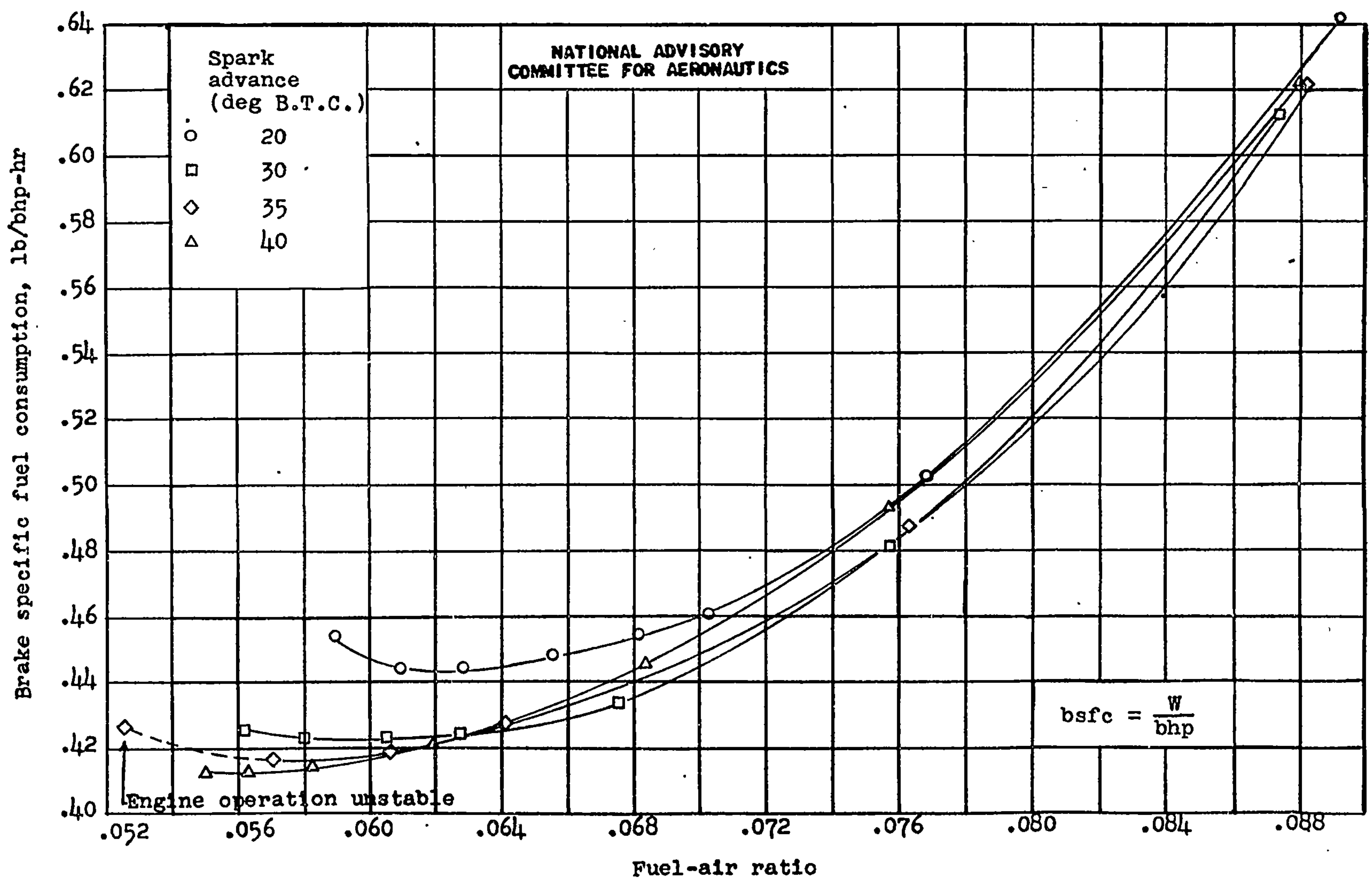

Figure 1. - Variation of brake specific fuel consumption with fuel-air ratio at four spark advances. Wright R-1820-97 engine; brake horsepower, 600; engine speed, 1900 rpm; maximum rear-spark-plug bushing temperature, 400° F.

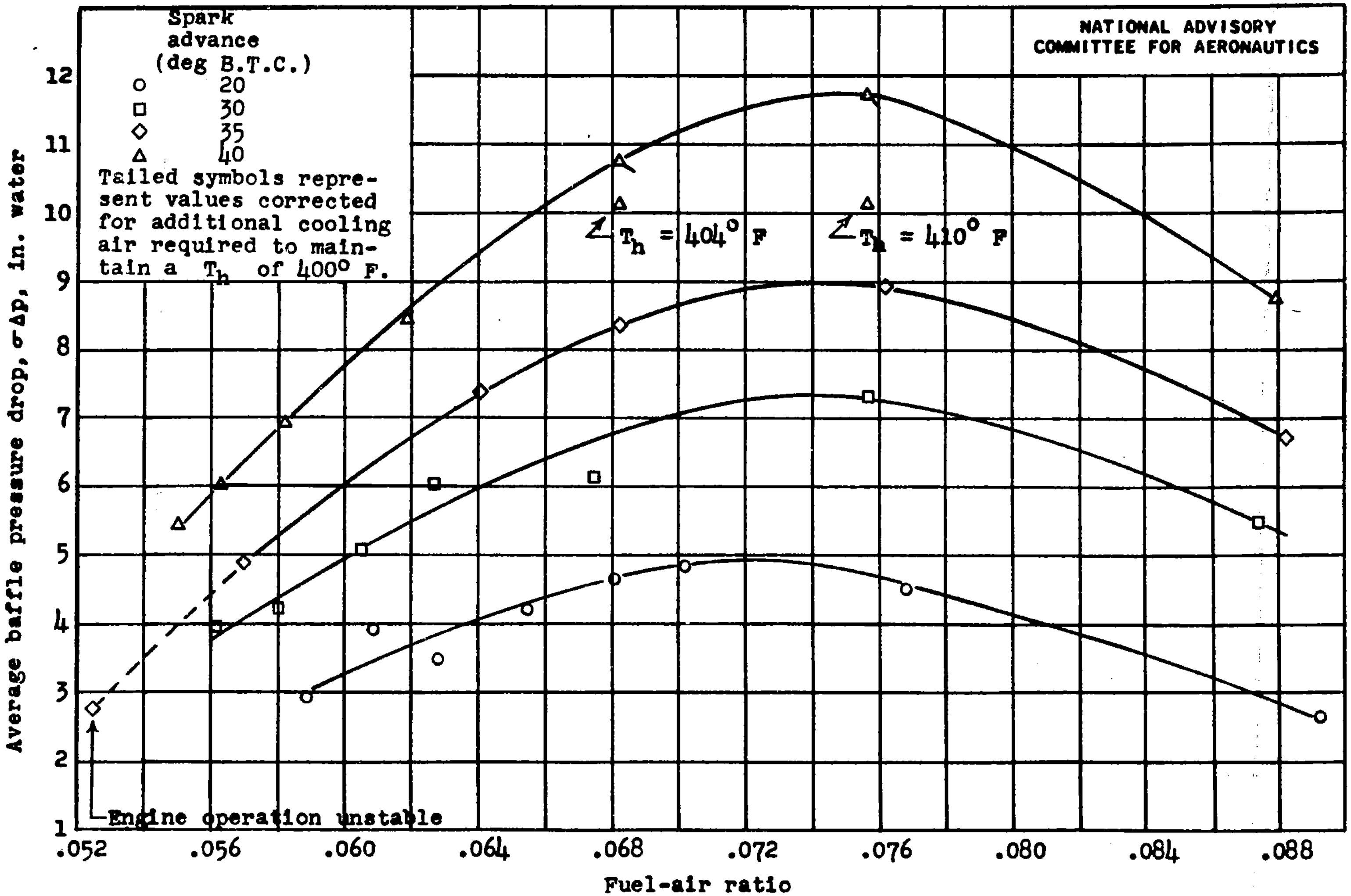

Figure 2. - Variation of cooling-air baffle pressure drop required to maintain a maximum rear-spark-plug-bushing temperature T_h of 400° F at four spark advances. Wright R-1820-97 engine; brake horsepower, 600; engine speed, 1900 rpm.

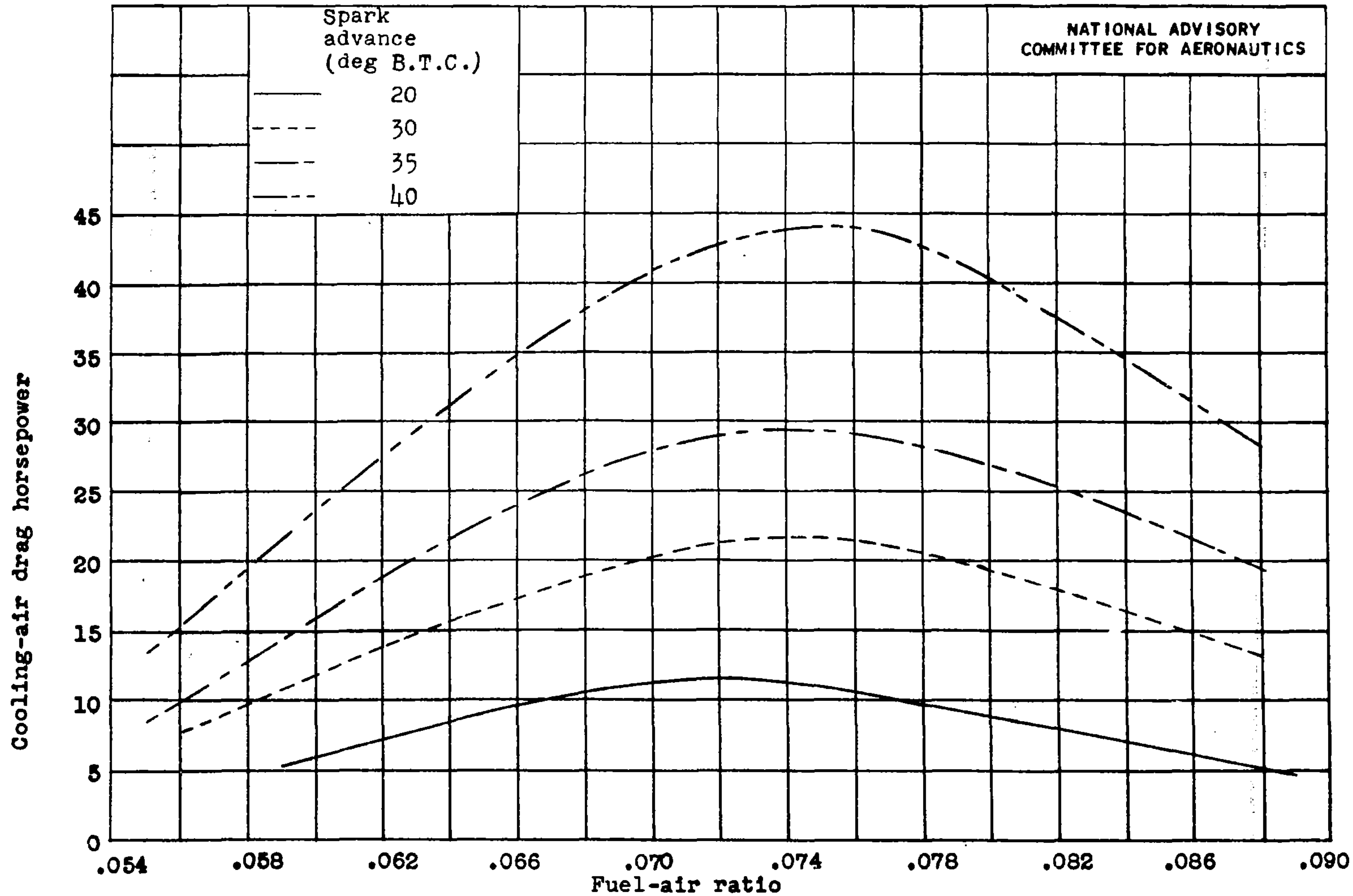

Figure 3.- Variation of required cooling-air drag horsepower with fuel-air ratio at four spark advances. Wright R-1820-97 engine; brake horsepower, 600; engine speed, 1900 rpm; maximum rear-spark-plug-bushing temperature, 400° F.

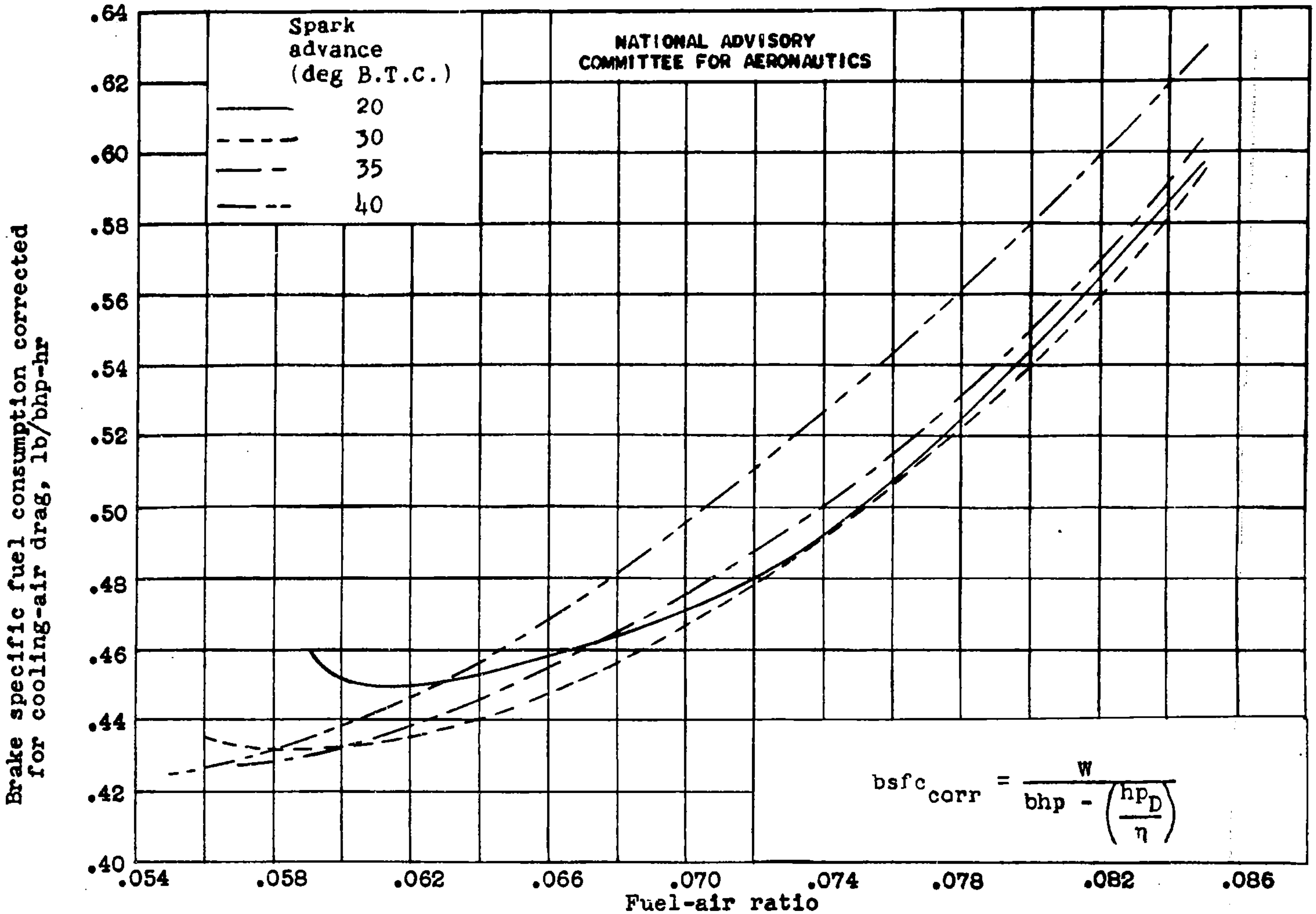

Figure 4.- Variation of brake specific fuel consumption corrected for cooling-air drag with fuel-air ratio at four spark advances. Wright R-1820-97 engine; brake horsepower, 600; engine speed, 1900 rpm; maximum rear-spark-plug-bushing temperature, 400° F.