NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

August 1945 as
Memorandum Report E5H12

EFFECT OF WATER-ALCOHOL INJECTION AND MAXIMUM-ECONOMY SPARK ADVANCE ON KNOCK-LIMITED PERFORMANCE AND FUEL ECONOMY OF A LARGE AIR-COOLED CYLINDER

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WASHINGTON

NACA MR No. E5H12

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MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces

EFFECT OF WATER-ALCOHOL INJECTION AND MAXIMUM-ECONOMY SPARK ADVANCE ON KNOCK-LIMITED PERFORMANCE AND FUEL ECONOMY OF A LARGE AIR-COOLED CYLINDER

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SUMMARY

An investigation was conducted to determine the effect of a coolant solution of 25 percent ethyl alcohol, 25 percent methyl alcohol, and 50 percent water by volume and maximum-economy spark advance on knock-limited performance and fuel economy of a large air-cooled cylinder. The knock-limited performance of the cylinder at engine speeds of 2100 and 2500 rpm was determined for coolant-fuel ratios of 0.0, 0.2, and 0.4. The effect of water-alcohol injection on fuel economy was determined in constant charge-air flow tests. The tests were conducted at a spark advance of 20° B.T.C. and maximum-economy spark advance.

The following results were obtained:

1. The knock-limited power at an engine speed of 2100 rpm was increased as much as 88 percent by operation at a fuel-air ratio of 0.060 and a coolant-fuel ratio of 0.4.

2. An increase in the coolant-fuel ratio from 0.2 to 0.4 was 2.5 times as effective in raising the knock-limited indicated mean effective pressure at a fuel-air ratio of 0.075 as an increase in the coolant-fuel ratio from 0.0 to 0.2.

3. The indicated specific liquid consumption was less with a coolant-fuel ratio of 0.4 than with fuel alone for power levels above a knock-limited indicated mean effective pressure of 225 pounds per square inch at an engine speed of 2500 rpm.

4. When the spark advance was increased from 20° B.T.C. to maximum-economy spark advance at a fuel-air ratio of 0.060, the indicated specific fuel consumption was decreased 4 percent in constant charge-air flow tests and the knock-limited indicated mean effective pressure was decreased 21 percent.

INTRODUCTION

The tests reported in references 1 and 2 have shown that improvements in knock-limited power and specific liquid consumption at high power may be obtained by water or water-alcohol injection. Therefore, as part of the general program requested by the Air Technical Service Command, Army Air Forces, to improve the cooling performance of a large air-cooled engine, knock-limited and fuel-economy tests were conducted at the NACA Cleveland laboratory to determine the effect of water-alcohol injection and maximum-economy spark advance on the knock-limited power and fuel economy. The water-alcohol mixture used was a solution of 25 percent ethyl alcohol, 25 percent methyl alcohol, and 50 percent water by volume, which has been considered by the Air Technical Service Command, Army Air Forces, as a suitable internal coolant. Both the knock-limited and fuel-economy tests were conducted at a spark advance of 20° B.T.C. and at maximum-economy spark advance. The fuel-economy tests were conducted at constant charge-air flow conditions to eliminate the effect of inlet-air pressure on specific fuel consumption.

APPARATUS AND PROCEDURE

A large air-cooled cylinder equipped with ducted baffles was mounted on a CUE crankcase. Knock was detected by a magnetostriction pickup unit mounted in the combustion chamber and by an oscilloscope.

The temperature of the exhaust-valve seat was held constant throughout each test. The valve seat has been shown to be in a critical temperature region of the cylinder. A thermocouple was embedded in the head metal 1/8-inch from the combustion-chamber wall and was located on a center line from the exhaust valve to the rear spark-plug bushing.

The internal coolant used in these tests was a mixture of 25 percent ethyl alcohol, 25 percent methyl alcohol, and 50 percent water by volume and the fuel used was 28-R. The alcohol contained in the internal coolant was not considered to be a part of the fuel supplied to the engine. The fuel and coolant were injected through separate systems into the upstream end of the vaporization tank. The coolant was injected through an impinging-jets nozzle in a continuous spray.

The maximum-economy spark advance was determined by operating the engine with the time of maximum rate of pressure rise at 3° A.T.C. for each test condition. This procedure gives values of indicated specific fuel consumption within ±0.3 percent of the minimum (reference 3). Preliminary studies for the investigation showed that this method of determining maximum-economy spark advance was also correct with water-alcohol injection.

The engine operating conditions that were used in the single-cylinder tests to investigate knock-limited power and fuel economy at coolant-fuel ratios of 0.0, 0.2, and 0.4 and at a constant compression ratio of 6.88 are presented in the following table:

Test	Engine speed (rpm)	Inlet-air temperature (°F)	Exhaust-valve-seat temperature (°F)	Spark advance (deg B.T.C.)
Knock limited	2500	276	625	20
	2100	188	625	20
	2100	188	625	Maximum economy
Fuel economy	2100	188	550	20
	2100	188	550	Maximum economy

RESULTS AND DISCUSSION

Knock-limited tests with coolant injection. - Knock-limited performance with coolant-fuel ratios of 0.0, 0.2, and 0.4 are presented in figures 1 and 2 for engine speeds of 2500 and 2100 rpm. Only the minimum point of the curve of fuel-air-ratio response was determined at an engine speed of 2100 rpm, coolant-fuel ratio of 0.4, and spark advance of 20° B.T.C. (fig. 2) because of the high indicated mean effective pressures encountered at these conditions.

When the ratio of water-alcohol to fuel was increased from 0.0 to 0.4, the knock-limited indicated mean effective pressure was increased 50 and 88 percent over that with fuel alone at engine speeds of 2500 and 2100 rpm, respectively, at a fuel-air ratio of 0.060 and a spark advance of 20° B.T.C. The indicated specific liquid consumption was decreased by increasing the coolant-fuel ratio from 0.0 to 0.4 for power levels above an indicated mean effective pressure of 225 pounds per square inch at an engine speed of 2500 rpm. Figure 1 shows that increasing the coolant-fuel ratio from 0.0 to 0.4 decreased the indicated specific liquid consumption 19 percent at a constant knock-limited indicated mean effective pressure of 257 pounds per square inch. The knock-limited indicated mean effective pressure was increased 13 and 29 percent at an indicated specific liquid consumption of 0.5 pound per indicated horsepower-hour by operation at coolant-fuel ratios of 0.2 and 0.4, respectively, as presented in figure 2(a).

When the spark advance was increased from 20° B.T.C. to the maximum-economy spark advance (fig. 2(b)), the knock-limited indicated mean effective pressure was decreased 21 percent without water-alcohol injection and 29 and 30 percent at coolant-fuel ratios of 0.2 and 0.4, respectively, at a fuel-air ratio of 0.060. The gain in fuel economy with advanced spark timing is discussed for constant charge-air flow tests in a subsequent part of this report. The data for indicated specific fuel consumption at knock-limited conditions and at constant charge-air flow are in close agreement. The increased efficiency of the combustion cycle at maximum-economy spark advance permitted smooth engine operation at a fuel-air ratio of 0.042.

A comparison of the effects of water and water-alcohol injection on knock-limited performance at a fuel-air ratio of 0.075 is presented in figure 3. These data are presented herein to define more accurately than is done in figures 1 and 2 the nonlinear effect of water-alcohol to fuel ratio on knock-limited power. An increase from 0.2 to 0.4 in the water-alcohol to fuel ratio was 2.5 times as effective in raising the knock-limited indicated mean effective pressure at a fuel-air ratio of 0.075 as was an increase from 0.0 to 0.2. These data were obtained from preliminary tests of a cylinder having worn rings and a burnt exhaust-valve seat; therefore, they agree with the data shown in figure 1 only in general trend. The effect of water injection on knock-limited indicated mean effective pressure was approximately a linear function of coolant-fuel ratio at the lower values of this ratio. The nonlinear response obtained with the water-alcohol mixture must be attributable to the alcohol.

Fuel-economy tests. - The effect of maximum-economy spark advance and water-alcohol injection on fuel and liquid economy at constant charge-air flow is presented in figure 4. These tests were run at constant charge-air flow to eliminate the effect of inlet-air pressure on indicated specific fuel consumption. The indicated specific fuel consumption at maximum-economy spark advance was 4 percent lower than that at a spark advance of 20° B.T.C. for a fuel-air ratio of 0.060 without coolant injection. For a spark advance of 20° B.T.C. the indicated specific fuel consumption was lowest at a fuel-air ratio of 0.060, whereas it continued to decrease as the fuel-air ratio was reduced at maximum-economy spark advance. The minimum indicated specific fuel consumption observed for maximum-economy spark advance at a coolant-fuel ratio of 0.0 was 12 percent lower than that for a spark advance of 20° B.T.C. Thus the greatest reduction in indicated specific fuel consumption was obtained by increasing the spark advance to the maximum-economy spark advance and decreasing the fuel-air ratio.

When the coolant-fuel ratio was increased from 0.0 to 0.4, the indicated specific fuel consumption decreased approximately 9 percent at a fuel-air ratio of 0.055 and a spark advance of 20° B.T.C. (fig. 4(a)). This decrease is slightly misleading because the alcohol in the coolant may burn and contribute additional energy that would not be evident in the calculations based on only 28-R as the fuel. The data in figure 4(a) are repeated in figure 5 to show the effect of the ratio of fuel plus alcohol to air on indicated specific fuel plus alcohol consumption. From figure 5, it can be seen that the total indicated specific fuel consumption increases in the lean region with water-alcohol injection.

SUMMARY OF RESULTS

From the tests made on a large air-cooled cylinder to determine the effect of water-alcohol injection and maximum-economy spark advance on knock-limited performance and fuel economy, the following results were obtained:

1. The knock-limited power at an engine speed of 2100 rpm was increased as much as 88 percent by operation at a fuel-air ratio of 0.060 and a coolant-fuel ratio of 0.4.

2. An increase in the coolant-fuel ratio from 0.2 to 0.4 was 2.5 times as effective in raising the knock-limited indicated mean effective pressure at a fuel-air ratio of 0.075 as an increase in the coolant-fuel ratio from 0.0 to 0.2.

3. The indicated specific liquid consumption was less with a coolant-fuel ratio of 0.4 than with fuel alone for power levels above a knock-limited indicated mean effective pressure of 225 pounds per square inch at an engine speed of 2500 rpm.

4. When the spark advance was increased from 20° B.T.C. to maximum-economy spark advance at a fuel-air ratio of 0.060, the indicated specific fuel consumption was decreased 4 percent in constant charge-air flow tests and the knock-limited indicated mean effective pressure was decreased 21 percent.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, August 12, 1945.

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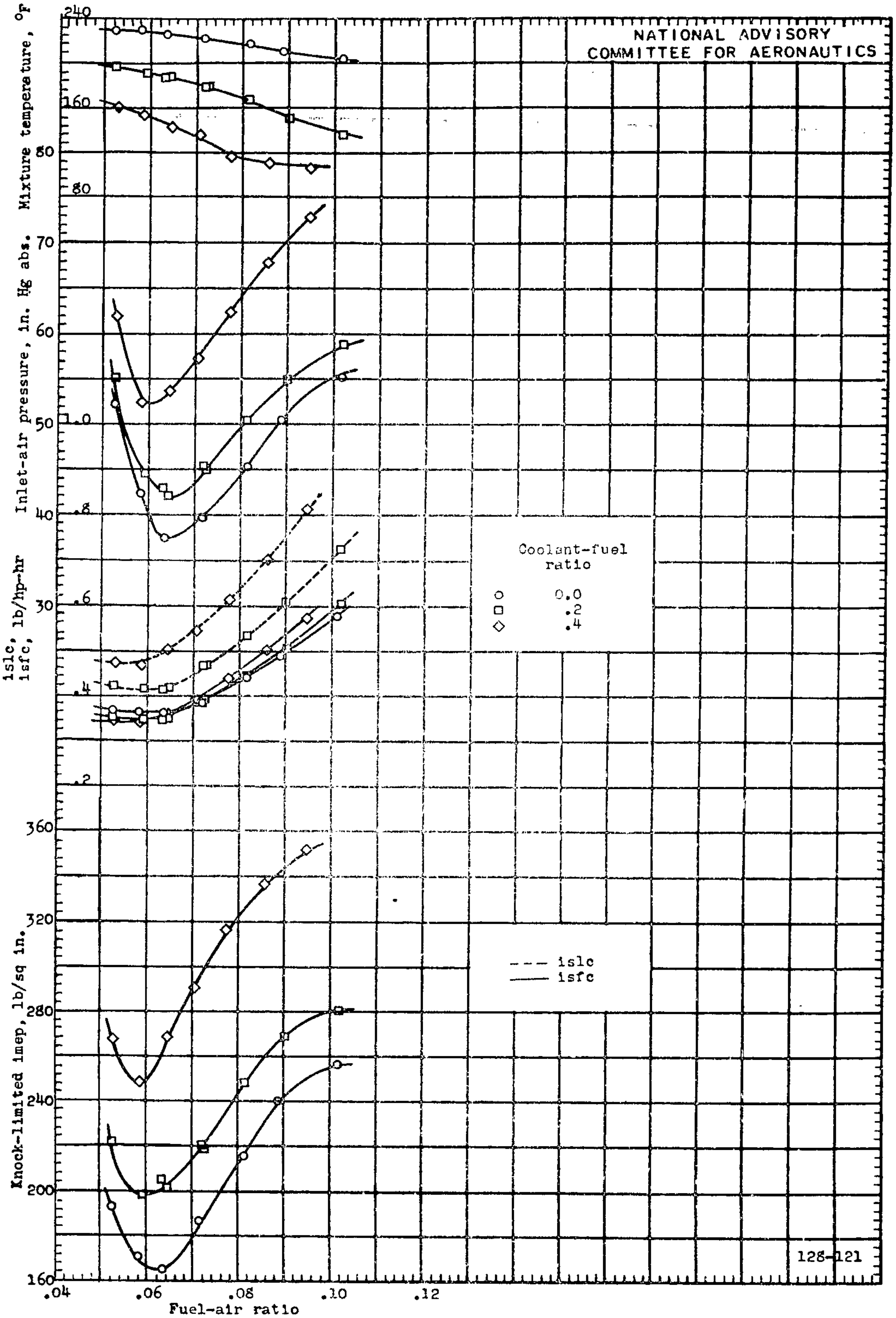

Figure 1. - Knock-limited performance with water-alcohol at a spark advance of 20° B.T.C. Large air-cooled cylinder; engine speed, 2500 rpm; inlet-air temperature, 276° F; exhaust-valve-seat temperature, 625° F; fuel, 28-R; compression ratio, 6.88.

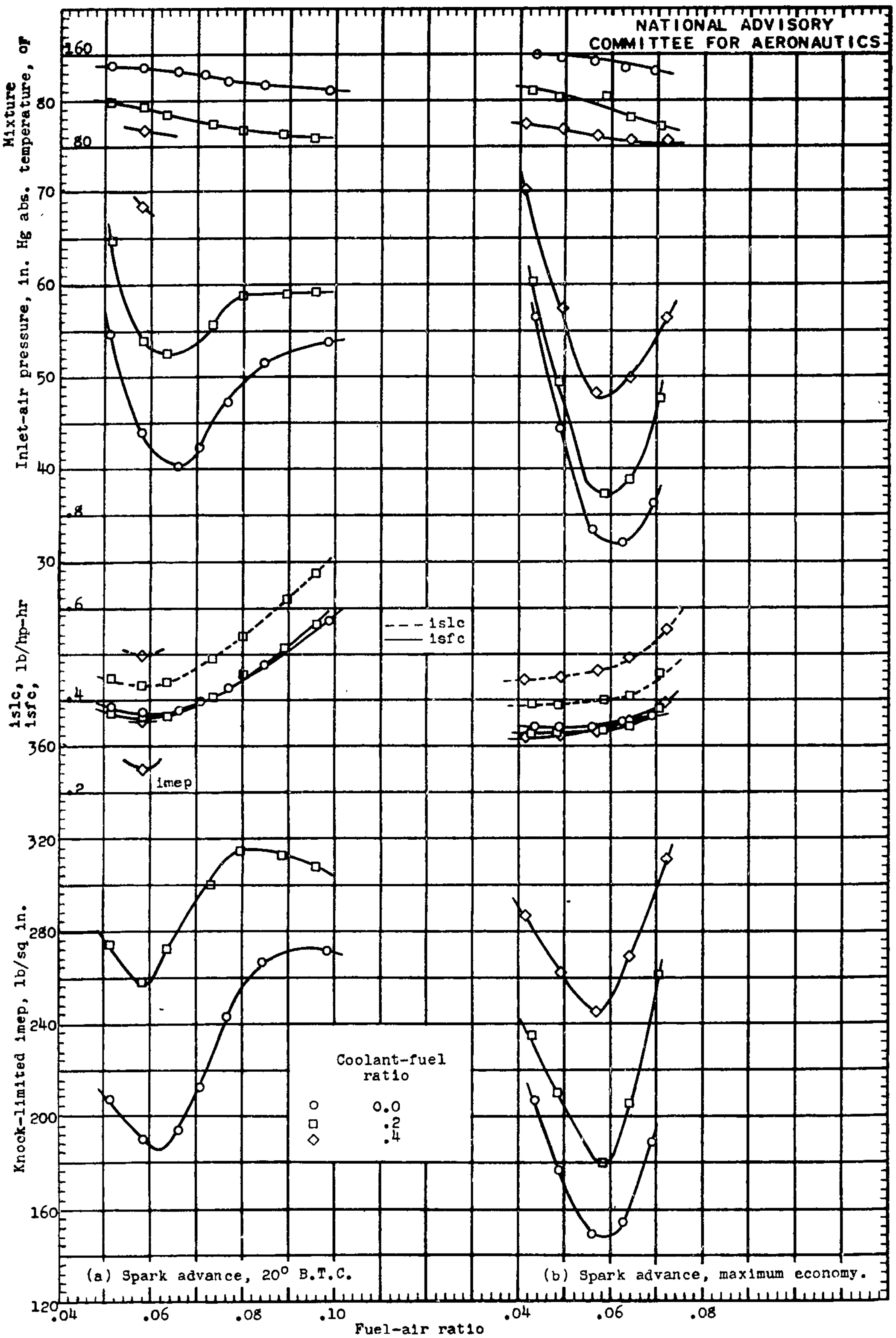

Figure 2. - Knock-limited performance with water-alcohol injection. Large air-cooled cylinder; engine speed, 2100 rpm; inlet-air temperature, 188° F; exhaust-valve-seat temperature, 625° F; fuel,28-R; compression ratio, 6.88.

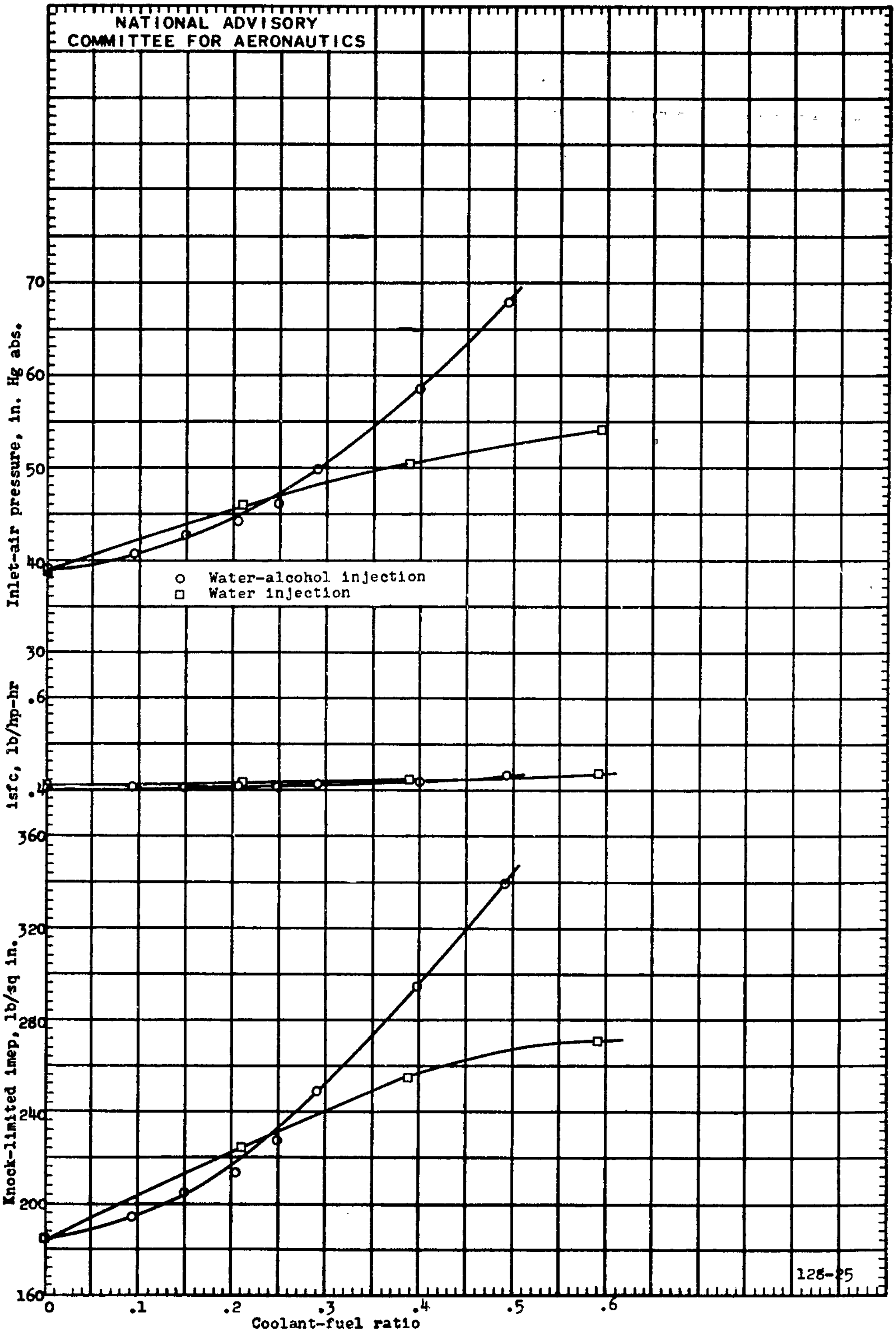

Figure 3. - Effect of coolant-fuel ratio on knock-limited performance. Large air-cooled cylinder; fuel-air ratio, 0.075; engine speed, 2500 rpm; spark advance, 20° B.T.C.; inlet-air temperature, 276° F; exhaust-valve-seat temperature, 625° F; fuel, 28-R; compression ratio, 6.88.

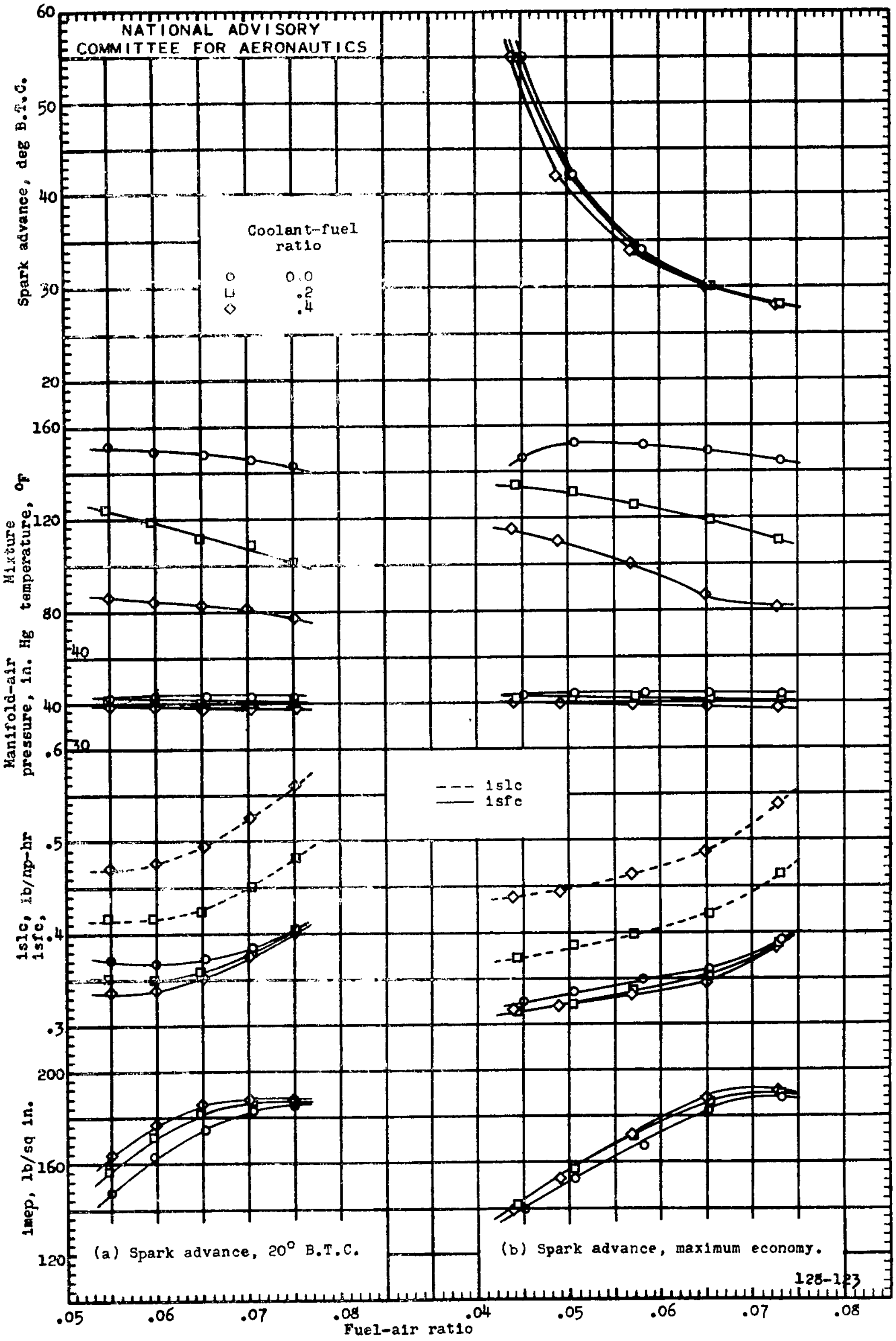

Figure 4. - Effect of water-alcohol injection on fuel and liquid economy at a constant charge-air flow of 495 pounds per hour. Large air-cooled cylinder; engine speed, 2100 rpm; inlet-air temperature, 188° F; exhaust-valve-seat temperature, 550° F; fuel, 28-R; compression ratio, 6.88.

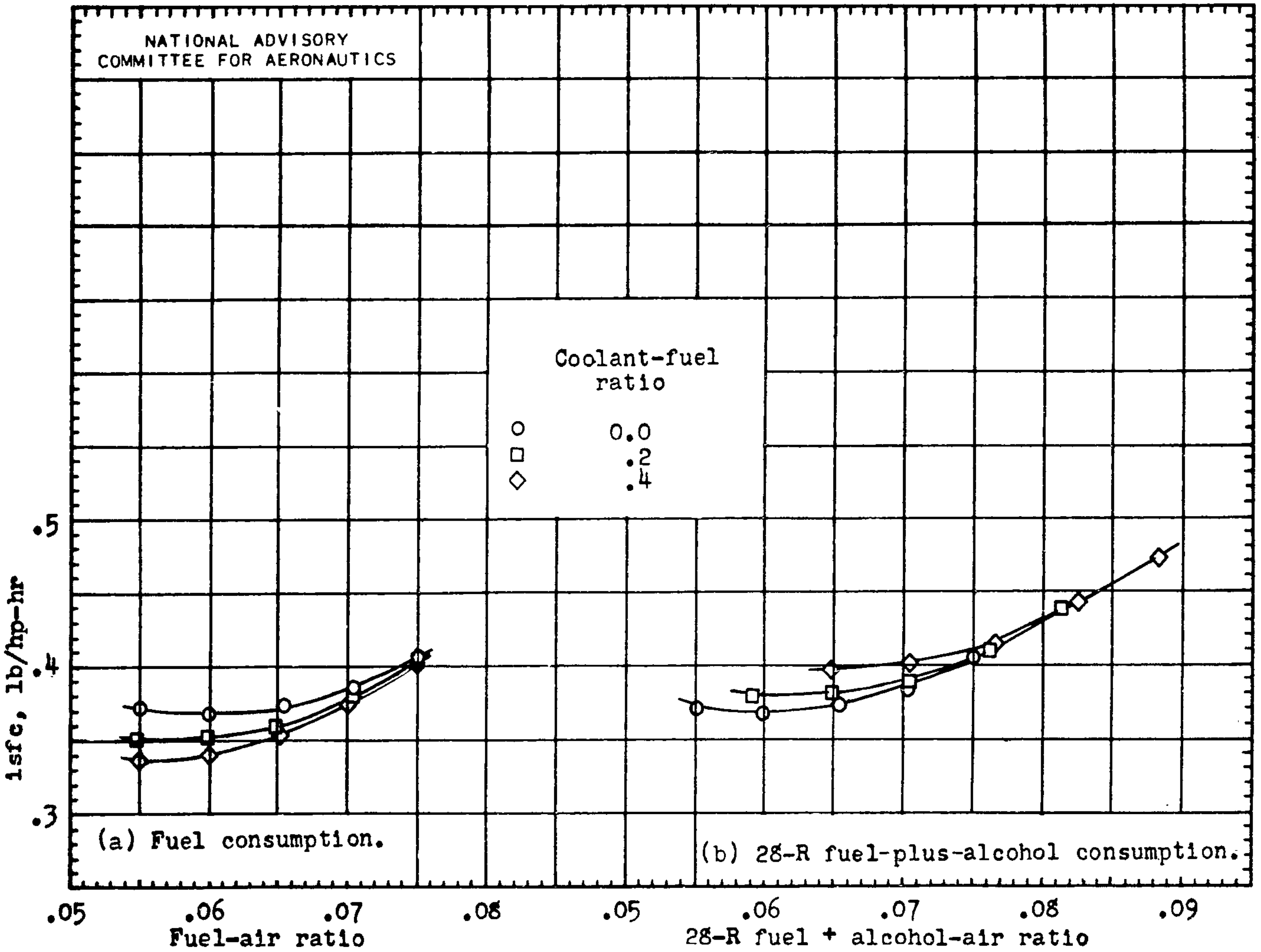

Figure 5. - Effect of water-alcohol injection on fuel economy at a spark advance of 20° B.T.C. Large air-cooled cylinder; engine speed, 2100 rpm; combustion-air flow, 495 pounds per hour; inlet-air temperature, 188° F; exhaust-valve-seat temperature, 550° F; fuel, 28-R; compression ratio, 6.88.