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SOME EFFECTS OF INTERNAL COOLANTS ON KNOCK-LIMITED AND

TEMPERATURE-LIMITED POWER AS DETERMINED IN A

SINGLE-CYLINDER AIRCRAFT TEST ENGINE

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TEMPERATURE-LIMITED POWER AS DETERMINED IN A

SINGLE-CYLINDER AIRCRAFT TEST ENGINE

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SUMMARY

Object. - To determine the permissible increase in engine power by using various internal coolants from the consideration of fuel knock and cylinder cooling.

Scope. - Tests were conducted on a Wright C9GC cylinder under the following conditions:

Compression ratio 7.0
Spark advance (except for variable spark-advance test),
    degrees B.T.C. 20
Cooling-air upstream temperature, °F 125
Engine speed, rpm 2500, 1830
Cooling-air pressure drop at engine speed of 2500 rpm,
    inches of water 20, 5
Cooling-air pressure drop at engine speed of 1830 rpm,
    inches of water 10
Inlet-air temperature (except for variable inlet-air-
    temperature tests), °F 250

Internal coolants tested were:

   1. Water
   2. 30-70 methyl alcohol-water volume percent mixture
   3. 70-30 methyl alcohol-water volume percent mixture
   4. Methyl alcohol
   5. 80-20 ethyl alcohol-water volume percent mixture

Coolant-fuel weight ratios of 0, 0.20, 0.35, 0.50, and 0.65 were tested with Army 100-octane aviation gasoline used as the fuel throughout these tests.

For each test the fuel-air ratio was varied and at each fuel-air ratio the inlet-air pressure was increased until either fuel knock was recorded or the temperature of the rear middle cylinder barrel exceeded a value of 325^0 F.

The relative effects of decreasing the spark advance and of decreasing the inlet-air temperature are compared with the effects of internal cooling.

Summary of results. - The following results were obtained from single-cylinder tests reported herein:

1. Based on these single-cylinder tests, it is estimated that temperature-limited take-off power may be increased 60 percent, knock-limited rated power increased 50 percent, and knock-limited cruising power increased 60 percent through the use of internal coolants.

2. Results with different percentages of methyl alcohol in a mixture of alcohol and water indicate that a 70-30 methyl alcohol-water volume percent mixture permitted the highest knock-limited or temperature-limited performance at high fuel-air ratios.

3. The mixture of ethyl alcohol and water raised the permissible temperature-limited power more than the mixture of methyl alcohol and water.

4. The mixture of methyl alcohol and water raised the permissible knock-limited power more than the mixture of ethyl alcohol and water.

5. At knock- or temperature-limited indicated mean effective pressures, the indicated specific liquid consumption with internal coolants was less than the indicated specific fuel consumption with fuel alone above 250 indicated mean effective pressure at 2500 rpm and a cooling-air pressure drop of 20 inches of water and above 230 indicated mean effective pressure at 1830 rpm and a cooling-air pressure drop of 10 inches of water.

6. Lowering the inlet-air temperature or retarding the ignition timing within practical limits did not permit as high knock-limited or temperature-limited power as the addition of suitable amounts of internal coolants.

INTRODUCTION

The NACA and other laboratories have been investigating the effectiveness of internal coolants as a means of improving the cooling and of suppressing the knock at high aircraft-engine powers. Kuhring (reference 1) determined the effect of water and water-alcohol mixtures as internal coolants on the temperatures of a super-charged Jaguar aircraft engine. Rothrock, Krsek, and Jones (reference 2) found that water injected into the intake manifold of a single-cylinder aircraft engine permitted a large increase in knock-limited power. Potential benefits of water as an internal coolant for aircraft engines at cruising power are shown by tests in reference 3. Koenig and Hieser (reference 4) show that it is possible to obtain greater cooling in an aircraft engine by using both water and fuel than with fuel alone.

The purpose of the investigation reported herein is (a) to compare the effectiveness of mixtures of ethyl or methyl alcohol and water as internal coolants on the basis of both knock-limited and temperature-limited power and (b) to compare internal cooling with decreased inlet-air temperature or retarded spark as a means of increasing the knock-limited or temperature-limited power in aircraft engines.

The tests were made at the Langley Memorial Aeronautical Laboratory, Langley Field, Va., during October and November 1942.

APPARATUS AND TEST PROCEDURE

The tests were conducted on a Wright C9GC cylinder mounted on a CUE crankcase. The cylinder cowling and the points for measuring cooling-air static pressure drop across the cowling are shown in figure 1.

A spray nozzle inserted into the intake manifold about 12 inches upstream from the intake-valve port was used to introduce the coolant into the intake air (fig. 2). Both this nozzle and the fuel nozzle were pointed downstream. The coolant was supplied at a pressure of approximately 100 pounds per square inch and the flow was controlled by a needle valve in the spray nozzle. This arrangement permitted a large change of flow rate with a small change in pressure drop across the spray nozzle. The coolant spray was continuous, whereas the fuel injection was timed to take place during

the intake stroke. Inlet-air temperature was measured at the outlet of the surge tank and before the introduction of fuel or coolant. The coolant-fuel ratios were set by calibrated rotameters and the air flow was measured by a flat-plate orifice installed according to A.S.M.E. practice (reference 5).

Engine conditions were as follows:

Compression ratio 7.0
Spark advance (except for variable spark-advance test),
    degrees B.T.C. 20
Cooling-air upstream temperature, ^{o}F 125
Engine speed, rpm 2500, 1830
Cooling-air pressure drop at engine speed of 2500 rpm,
    inches of water 20, 5
Cooling-air pressure drop at engine speed of 1830 rpm,
    inches of water 10
Inlet-air temperature (except for variable inlet-air-
    temperature tests), ^{o}F 250

The engine speeds and the cooling-air flow rates were arbitrarily selected to simulate conditions at take-off, level flight at rated power, and cruising.

Throughout the tests with internal coolants a constant spark advance of 20° B.T.C. was used and no attempt was made to get the optimum spark advance with the coolant.

All the internal coolants were tested with one lot of Army 100-octane aviation gasoline. The fuel was obtained from the Army supply at Langley Field.

Specific liquid consumption in this paper is the sum of the specific fuel and coolant consumptions in pounds per indicated horsepower-hour. Fuel-air ratios used include only the gasoline and the air and not the internal coolants.

The methyl alcohol was a 95 percent commercial grade with 5 percent alcohols of higher molecular weight. The ethyl alcohol was 95 percent commercial grade denatured with 0.1 percent benzene.

The maximum freezing point of the alcohol-water mixtures was arbitrarily selected as -70° F. In order to satisfy this limit, the following approximate compositions of the internal coolants were used: Methyl alcohol and water, a minimum of 60 percent alcohol by volume; ethyl alcohol and water, a minimum of 80 percent alcohol by volume.

The tests consisted in determining the maximum permissible
indicated mean effective pressure and the corresponding indicated
specific fuel consumption at various fuel-air ratios and several
coolant-fuel ratios as limited by either (1) incipient knock
determined by an oscillograph with a Stancal pickup unit in the
cylinder or (2) a middle rear cylinder-barrel temperature of
325° F. It was found that, by use of this value for a temperature
limit, the tests could be run without frequent overhauls caused
by rapid ring wear or ring sticking. Throughout this report
temperature-limited data points as distinguished from knock-
limited data points will be marked only on the curves of indicated
mean effective pressure against fuel-air ratio. Surface ignition,
when it occurred, was detected by momentarily cutting the ignition
switch.

TEST RESULTS AND DISCUSSION

Alcohol-Water Mixtures

Methyl alcohol. - Four volume-percentage mixtures of methyl
alcohol and water were used to find the mixture that would give
the best engine performance: 100 percent water; 30 percent alcohol
and 70 percent water; 70 percent alcohol and 30 percent water; and
100 percent alcohol. The coolant-fuel ratio was kept constant in
each case at 50 percent by weight.

Results shown in figures 3 and 4 indicate that a 70-30 methyl
alcohol-water volume percent mixture permitted the highest power
at fuel-air ratios higher than 0.05, whereas water alone was best
at the lower ratios. Temperatures of the rear spark-plug bushing
for any one fuel-air ratio and for any constant power appear to
increase with increasing alcohol content. (See points A, B, and
C in fig. 4.) Figure 5 shows that, with the 70-30 methyl alcohol-
water mixture, the indicated specific liquid consumption is con-
siderably the lowest for the indicated mean effective pressures
recorded above 280 pounds per square inch. Inasmuch as the curves
in figure 4 are based on only four data points, the data do not
accurately define the alcohol-water ratio for peak performance for
high fuel-air ratios. Based on the results in figure 4, a
70-30 methyl alcohol-water mixture was used in the subsequent
tests. This mixture also satisfies the arbitrarily selected
freezing-point limit of the internal coolant.

Ethyl alcohol. - An 80-20 ethyl alcohol-water volume percent
mixture was used in the tests with ethyl alcohol because this
mixture has the lowest ethyl-alcohol content that would satisfy
a freezing temperature of -70° F.

Effect of Different Coolants on Power Limitations and Fuel Consumption

as Determined by Engine Speed and Cooling-Air Pressure Drop

Engine speed, 2500 rpm; cooling-air pressure drop across cowling, 5 inches of water. - Figure 6 presents data at various coolant-fuel ratios with methyl alcohol and water as the coolant. At a cooling-air pressure drop of 5 inches of water, the engine performance was limited by temperature in every case.

At any fuel-air ratio lower than 0.06, the maximum permissible power did not increase as the coolant-fuel ratio increased. Any increase in power with coolant at constant fuel-air ratio was at the expense of increased indicated specific fuel consumption except at fuel-air ratios lower than 0.065, where the indicated specific fuel consumption decreased with increase of coolant-fuel ratio. The indicated specific fuel consumption is plotted against the fuel-air ratio instead of the total liquid-air ratio; therefore, in any case where the coolant burned, the indicated specific fuel consumption decreased in the lean regions with increased coolant-fuel ratio.

It may be seen in figure 7 that temperature rather than knock was again the limit with the mixture of ethyl alcohol and water as the coolant. The maximum permissible power with coolant shows little or no increase over the maximum with fuel alone at very high fuel-air ratios (points A and B). Although not shown, 80-20 ethyl alcohol-water mixture at an engine speed of 2500 rpm and a cooling-air pressure drop of 5 inches of water seems to give an abrupt peak in the power curve owing to extremely rough running of the engine when the fuel-air ratio is increased beyond a certain value at high coolant-fuel ratios.

Engine speed, 2500 rpm; cooling-air pressure drop across cowling, 20 inches of water. - At a cooling-air pressure drop of 20 inches of water the performance with fuel alone was knock-limited. Data with a mixture of methyl alcohol and water (fig. 8) indicate that a considerable increase in power is made possible at any one fuel-air ratio with increased coolant-fuel ratios. The performance was knock-limited with low coolant-fuel ratios and became temperature-limited at high coolant-fuel ratios.

Data with the mixture of ethyl alcohol and water as the internal coolant are shown in figure 9. One noticeable fact is that knock rather than temperature was the limiting factor even at high indicated mean effective pressures. It appears from the mixtures used at these engine conditions that the mixture of methyl alcohol and water is a better knock suppressor than is the mixture of ethyl alcohol and

water. At the lower fuel-air ratios with ethyl alcohol-water as
the coolant the lower coolant-fuel ratio gave no increase in per-
missible power.

Engine speed, 1830 rpm; cooling-air pressure drop across
cowling, 10 inches of water. - Figure 10 shows performance with
the mixture of methyl alcohol and water. At these engine condi-
tions, a large increase in permissible power was possible with high
coolant-fuel ratios with the power becoming temperature-limited at
the high ratios. Also, the indicated specific fuel consumption did
not increase at the high fuel-air ratios with internal coolants to
the extent observed in the previous figures.

Figure 11 presents data with the mixture of ethyl alcohol and
water as the coolant. All the data points are knock-limited and,
as in figure 9, no increase in power was evident with the low
coolant-fuel ratios until high fuel-air ratios were reached.

Effect of Different Coolants and Power on Representative

Cylinder Temperatures as Determined by Engine Speed

and Cooling-Air Pressure Drop

Engine speed, 2500 rpm; cooling-air pressure drop across
cowling, 5 inches of water. - Figure 12 presents cylinder tempera-
tures as affected by various coolant-fuel ratios of mixtures of
methyl alcohol and water and ethyl alcohol and water at the knock-
limited or temperature-limited power. The temperatures of the rear
spark-plug bushing, for any one fuel-air ratio, decreased at high
coolant-fuel ratios although the power increased. For any one
power level, however, the temperatures remained nearly constant as
the coolant-fuel ratio was increased and the fuel-air ratio was
decreased (points A, B, and C on fig. 12). The ethyl alcohol-
water mixture permitted higher permissible indicated mean effective
pressure at high fuel-air ratios and high coolant-fuel ratios than
did the methyl alcohol-water mixture.

The termination of the curves of indicated mean effective
pressure is, in most cases, not an indication of maximum performance
obtained but is the limitation of the cross plots.

Engine speed, 2500 rpm; cooling-air pressure drop across
cowling, 20 inches of water. - Figure 13 gives representative engine
temperatures as affected by various coolant-fuel weight ratios of
mixtures of methyl alcohol and water and ethyl alcohol and water.

At these engine conditions the methyl alcohol-water mixture permits higher permissible indicated mean effective pressure than does the ethyl alcohol-water mixture.

Engine speed, 1830 rpm; cooling-air pressure drop across cowling, 10 inches of water. - Engine-temperature data with mixtures of methyl alcohol and water and ethyl alcohol and water as the coolants are shown in figure 14. The general temperature level was lower at the lower engine speed.

Temperatures with the methyl alcohol and water coolant were the highest for constant power whether the data points with this coolant were knock-limited or temperature-limited. The fuel-air ratios for any power level were different for the various coolants.

Effect of Internal Coolants on Process of Combustion

Effect of internal coolants on weight of inducted air. - Figure 15 presents data which indicate that the injection of different ratios of various coolants into the intake manifold directly ahead of the cylinder of this engine setup did not increase the weight of inducted air to the engine.

Effect of internal coolants on thermal efficiency. - Values of heat liberated per pound of air at the stoichiometric mixture of the fuel and the combustibles in the coolants are as follows:

	Low heating value (Btu/lb)	Stoichiometric fuel-air ratio	Heat liberated (Btu/lb air)
Fuel, 100-octane aviation gasoline	18,800	0.0663	1245
Methyl alcohol	8,420	.155	1305
Ethyl alcohol	11,590	.111	1287

Data in figure 16 indicate that the thermal efficiency calculated from the indicated specific liquid consumption and from the foregoing table was decreased very little relative to fuel alone. Points A, B, and C on figure 10, concluded, show that at a constant power level the indicated specific air consumption decreased slightly as the coolant-fuel ratio of any one coolant was increased because the fuel-air ratio was decreasing.

Effect of coolant-fuel ratio on the limiting-rich fuel-air mixture. - In figure 17 knock-limited or temperature-limited data are presented which show engine performance with and without

coolants as limited by the richest fuel-air mixture that permitted
regular firing of the engine. This fuel-air mixture is designated
limiting-rich fuel-air mixture. These curves do not represent
exact values but give a good approximation with any of the coolants
used.

Engine Performance with Methyl Alcohol as a Fuel

Figures 18 and 19 show the comparison of engine performance
and temperatures obtained with methyl alcohol and Army 100-octane
aviation gasoline as fuels. In this case the alcohol was injected
continuously and not timed as the gasoline fuel was in the other
cases. In order to compare the two fuels, the ratio of the actual
fuel-air ratio to the stoichiometric fuel-air ratio was used as the
abscissa of the curves. For gasoline fuel, 0.0663 was used as the
stoichiometric fuel-air ratio and, for the methyl alcohol, 0.155
was used. The data with methyl alcohol were limited by the capacity
of the fuel system.

Effect of Inlet-Air Temperature on Performance with the

Mixture of Methyl Alcohol and Water as a Coolant

Data of engine performance with a mixture of methyl alcohol
and water as the internal coolant as affected by raising the inlet-
air temperature from 250° F to 325° F are presented in figures 20
and 21. At rich mixtures the internal cooling at an inlet-air
temperature of 325° F permitted increases in power over fuel alone
at 250° F even though the inlet-air temperature was increased 75° F
(fig. 20). The temperature of the rear spark-plug bushing, in the
rich regions, was lower with the low inlet-air temperature and
coolant than with the high inlet-air temperature and coolant even
though the power was greater. (See fig. 21.)

Effect of Spark Advance and Inlet-Air Temperature on Knock-Limited

or Temperature-Limited Performance

The effect of retarding the spark below 20° B.T.C. at the high
engine speed of 2500 rpm is shown in figure 22. The data show that,
under the test conditions, retarding the spark permitted little or
no increase in the permissible power because of temperature limita-
tions with the retarded spark. The permissible power in the lean
regions was somewhat increased with retarded spark but was hardly
affected at high fuel-air ratios. This engine, with a spark advance

of 15° B.T.C. and a fuel-air ratio of 0.07, permitted an indicated
mean effective pressure of 186 pounds per square inch with an indi-
cated specific fuel consumption of 0.40 pound per horsepower-hour.
The same permissible power level, with a spark advance of 20° B.T.C.,
required an indicated specific fuel consumption of 0.42 pound per
horsepower-hour. The decrease in spark advance allowed a lower
fuel-air ratio for the same power level. The temperature of the
exhaust-valve guide (fig. 23) increased as the spark was retarded
for any one fuel-air ratio, whereas the temperature of the rear
spark-plug bushing increased in the lean regions but was only
slightly affected at high fuel-air ratios.

Data presented in figures 24 and 25 compare the effect of
retarded spark or decreased inlet-air temperature with the effect
of internal cooling on permissible engine performance and cylinder
temperatures. From figures 22 and 24 the indicated specific fuel
consumptions were very close together for a spark advance of
20° B.T.C. at the two inlet-air temperatures, whereas at a spark
advance of 5° B.T.C. the specific fuel consumption was higher with
the lower inlet-air temperature.

The addition of suitable amounts of internal coolant was more
effective for raising the permissible knock-limited or temperature-
limited power than the retarding of the ignition timing or the
lowering of the inlet-air temperature. In the lean-mixture regions
retarding the ignition timing raised the knock-limited performance
but lowered the temperature-limited performance. Lowering the
inlet-air temperature raised the knock-limited performance and
slightly raised the temperature-limited performance. Addition of
internal coolants tested raised both the knock and the temperature
limits in the rich-mixture regions.

SUMMARY OF RESULTS

The following results apply to tests of internal coolants to
increase the permissible engine power as determined in a single-
cylinder aircraft test engine:

1. Based on these single-cylinder tests, it is estimated that
temperature-limited take-off power may be increased 60 percent,
knock-limited rated power increased 50 percent, and knock-limited
cruising power increased 60 percent through the use of internal
coolants.

2. Results with different percentages of methyl alcohol in a
mixture of alcohol and water indicate that a 70-30 methyl alcohol-
water volume percent mixture permitted the highest knock-limited
or temperature-limited performance at high fuel-air ratios.

3. The mixture of ethyl alcohol and water raised the permissible temperature-limited power more than the mixture of methyl alcohol and water.

4. The mixture of methyl alcohol and water raised the permissible knock-limited power more than the mixture of ethyl alcohol and water.

5. At knock- or temperature-limited indicated mean effective pressures, the indicated specific liquid consumption with internal coolants was less than the indicated specific fuel consumption with fuel alone above 250 indicated mean effective pressure at 2500 rpm and a cooling-air pressure drop of 20 inches of water and above 230 indicated mean effective pressure at 1850 rpm and a cooling-air pressure drop of 10 inches of water.

6. Lowering the inlet-air temperature or retarding the ignition timing within practical limits did not permit as high knock-limited or temperature-limited power as the addition of suitable amounts of internal coolants.

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        National Advisory Committee for Aeronautics,
            Cleveland, Ohio.

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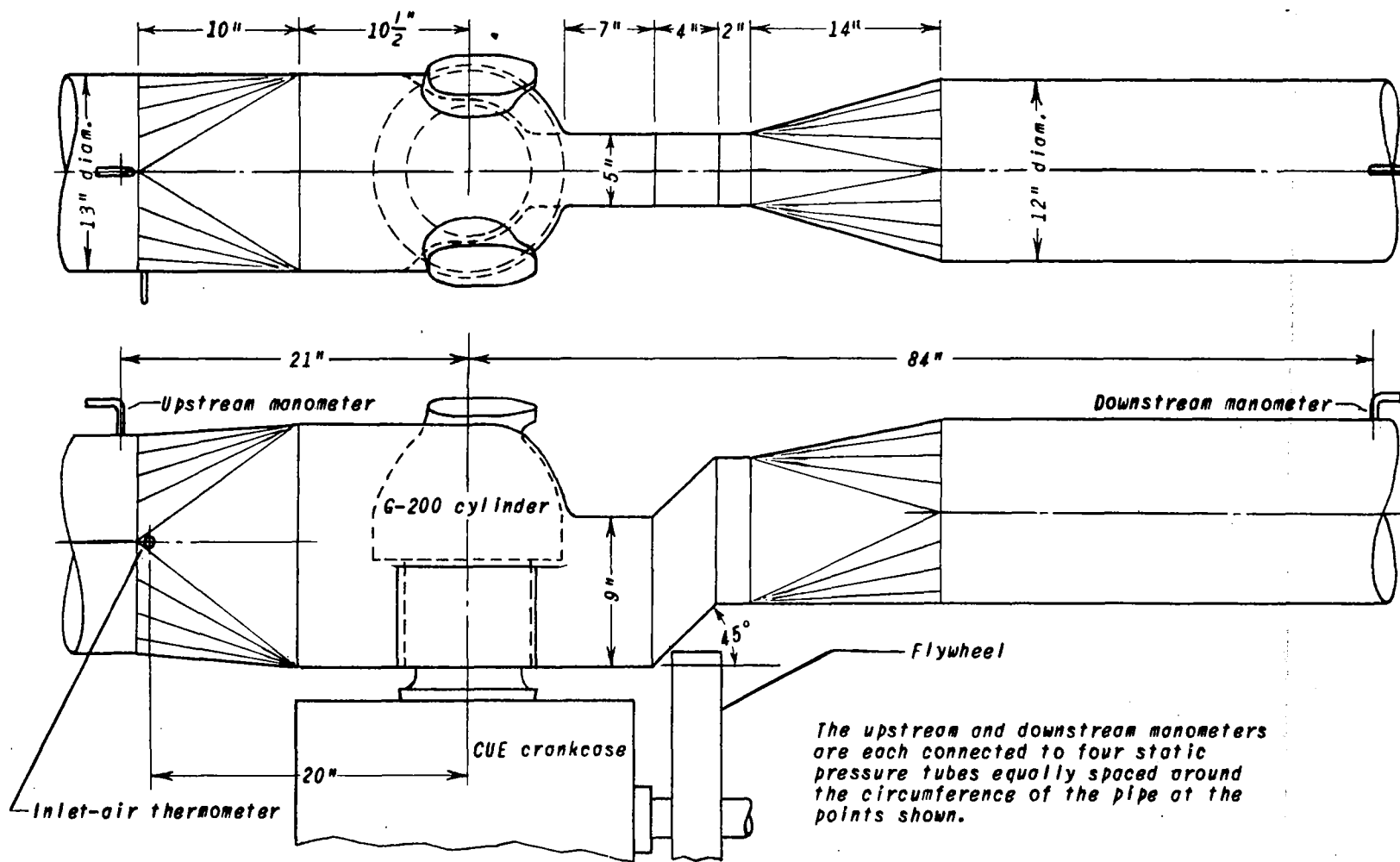
Figure 1. - Diagram of air duct and cowling.

Fig. 1

A   Surge tank

B   Intake-air heaters

C   Intake-air-pressure connection

D   Thermostat

E   Wire screen

F   Front of cylinder

G   Knock pickup

H   Intake manifold

I   Fuel nozzle

J   Rubber-hose connection

K   Thermometer

L   Internal-coolant nozzle

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Fig. 2
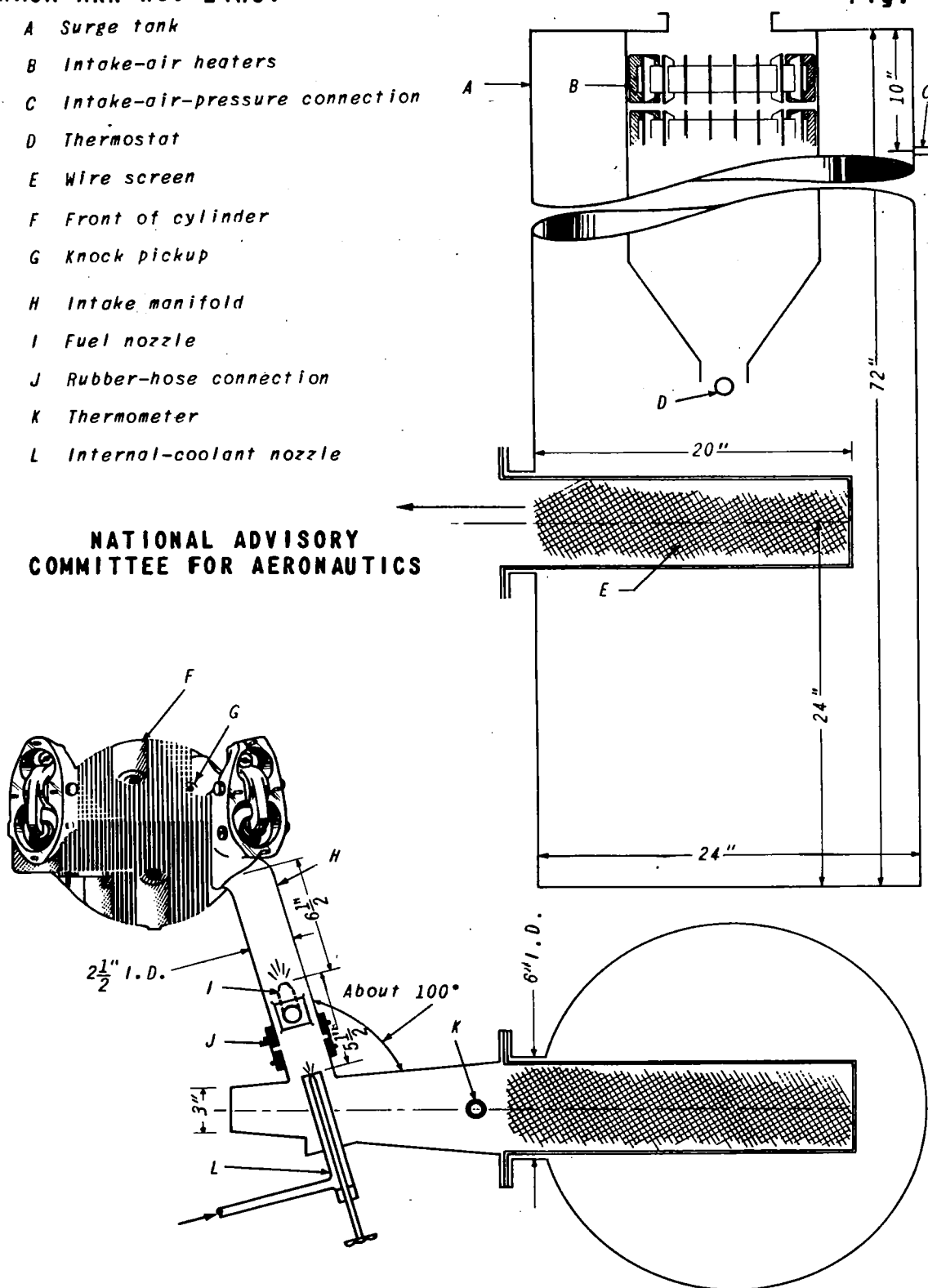
Figure 2. - Induction system for internal coolant tests.
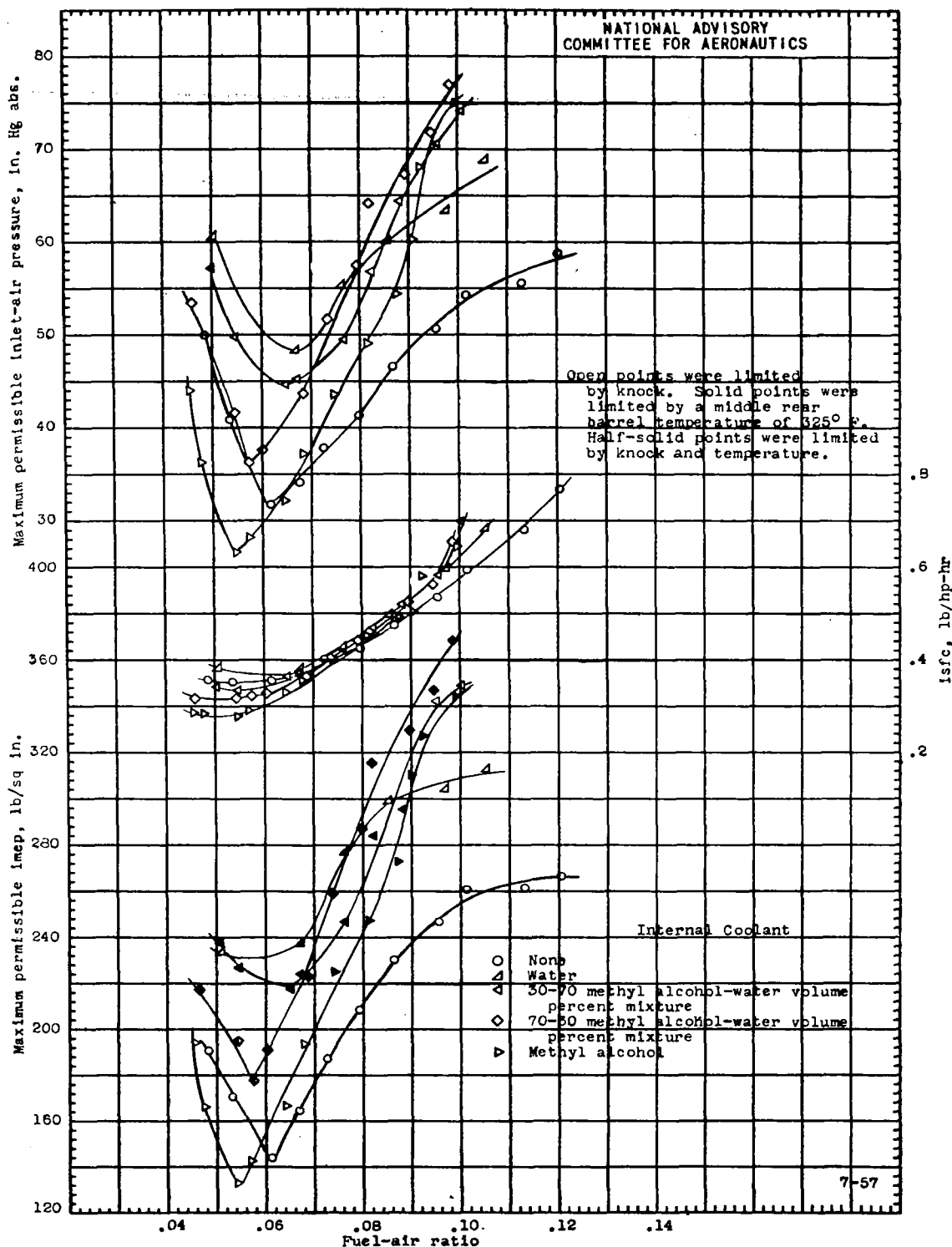
Figure 3. — Engine performance as permitted by various internal coolants. Internal coolant relative to fuel, constant at 50 percent by weight; Wright C9GC cylinder; engine speed, 2500 rpm; cooling-air pressure drop across cowling, 20 inches of water; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 250° F; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.
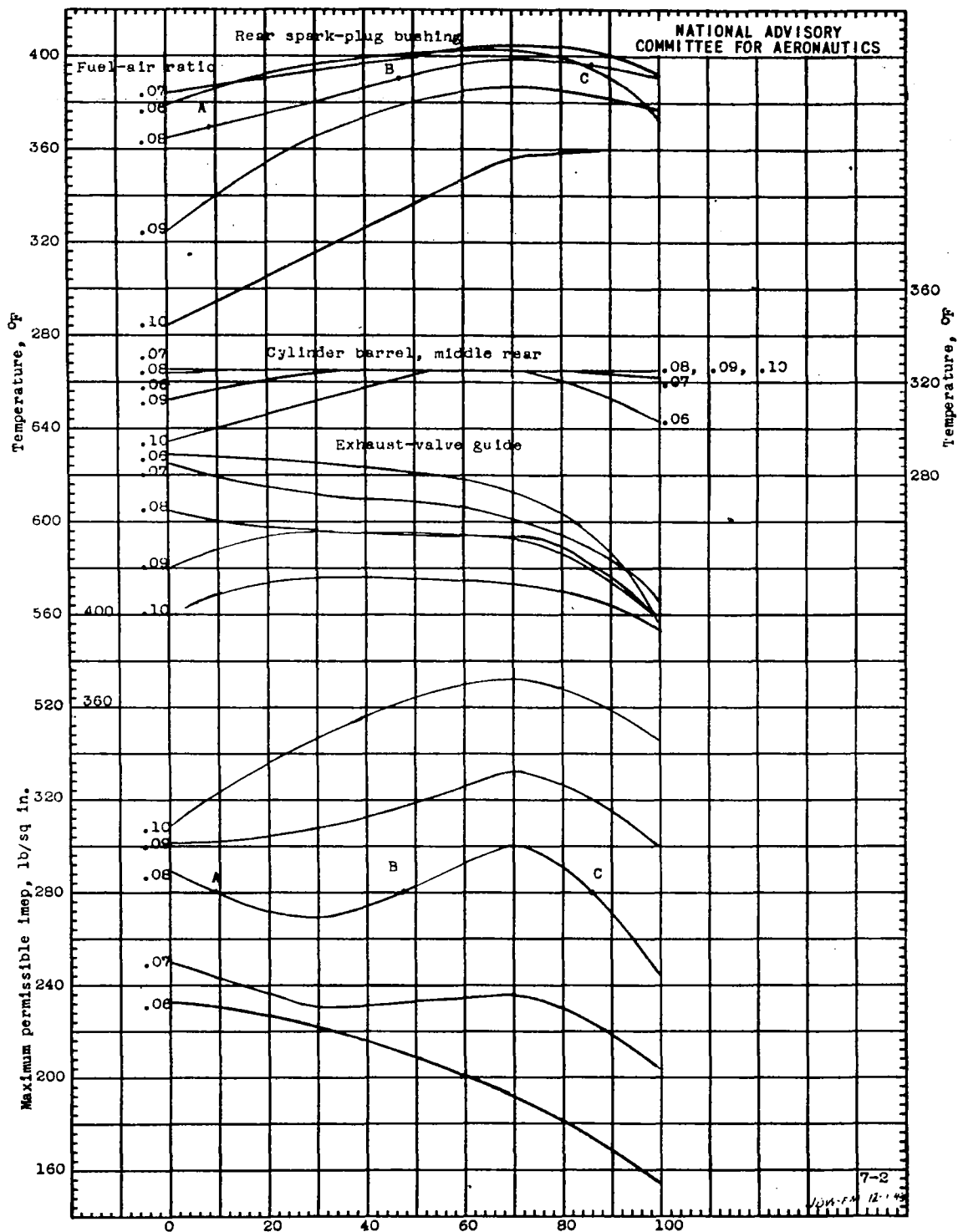
Figure 4. - Representative engine temperatures and maximum permissible indicated mean effective pressure as determined by percentage methyl alcohol in the internal coolant and fuel-air ratio. Internal coolant relative to fuel, constant at 50 percent by weight; Wright C9GC cylinder; engine speed, 2500 rpm; cooling-air pressure drop across cowling, 20 inches of water; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 250° F; cooling-air upstream temperature. 125° F; fuel. Army 100-octane aviation gasoline.
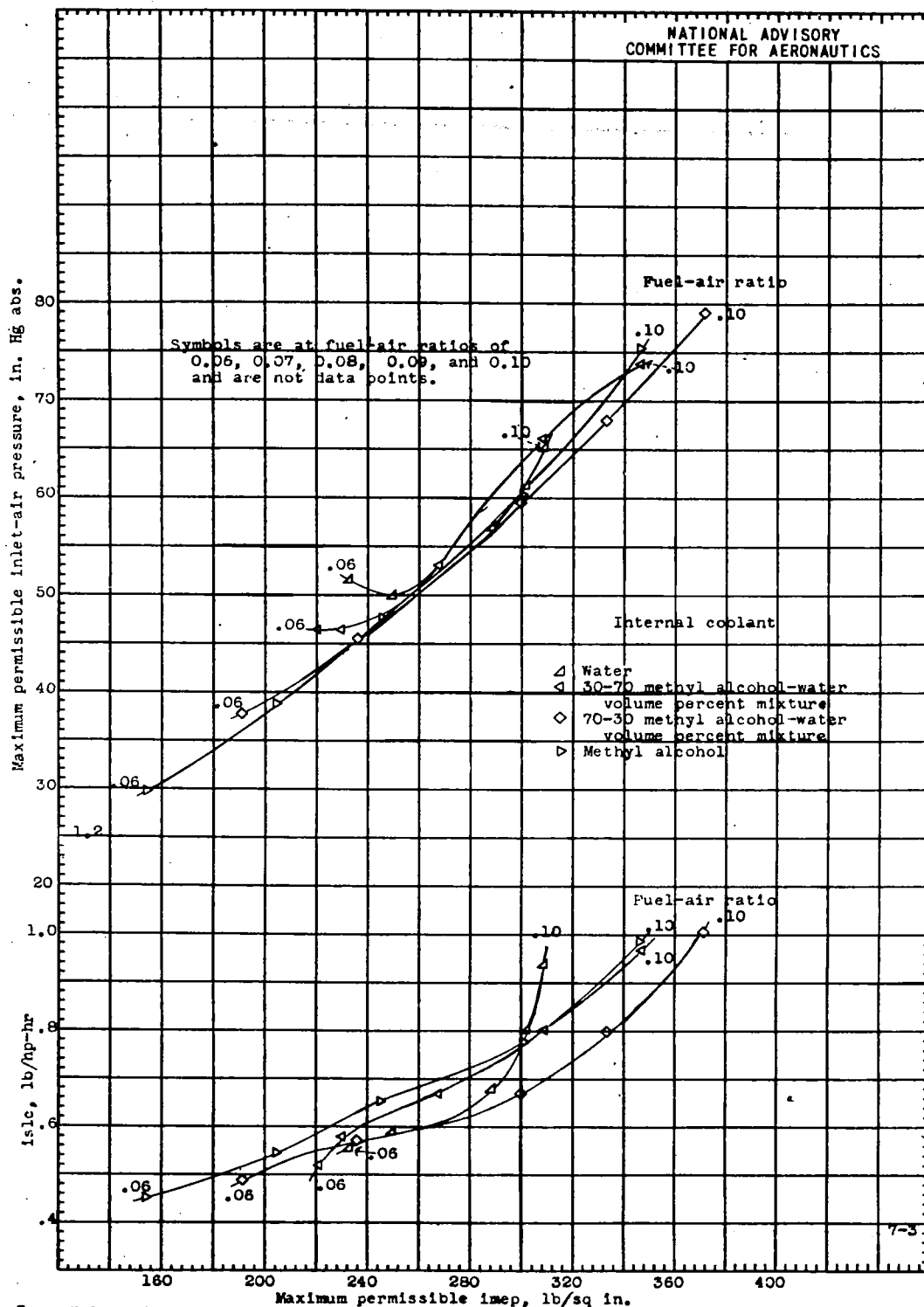
Figure 5. – Inlet-air pressure and indicated specific liquid consumption required at various power levels with various volume percentage of methyl alcohol in alcohol-water internal coolant as parameters. Internal coolant relative to fuel, constant at 50 percent by weight; Wright C9GC cylinder; engine speed, 2500 rpm; cooling-air pressure drop across cowling, 20 inches of water; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 250° F; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.
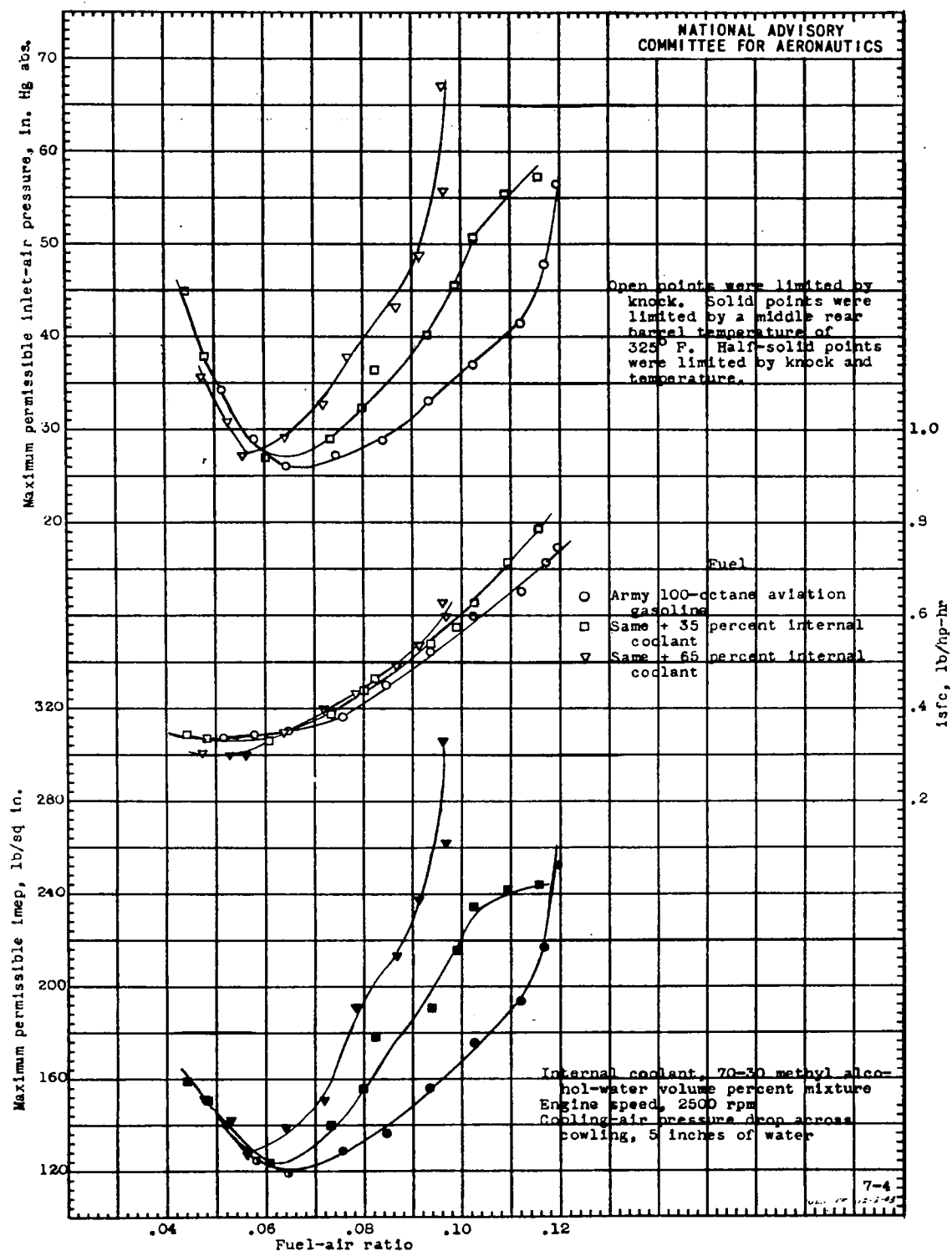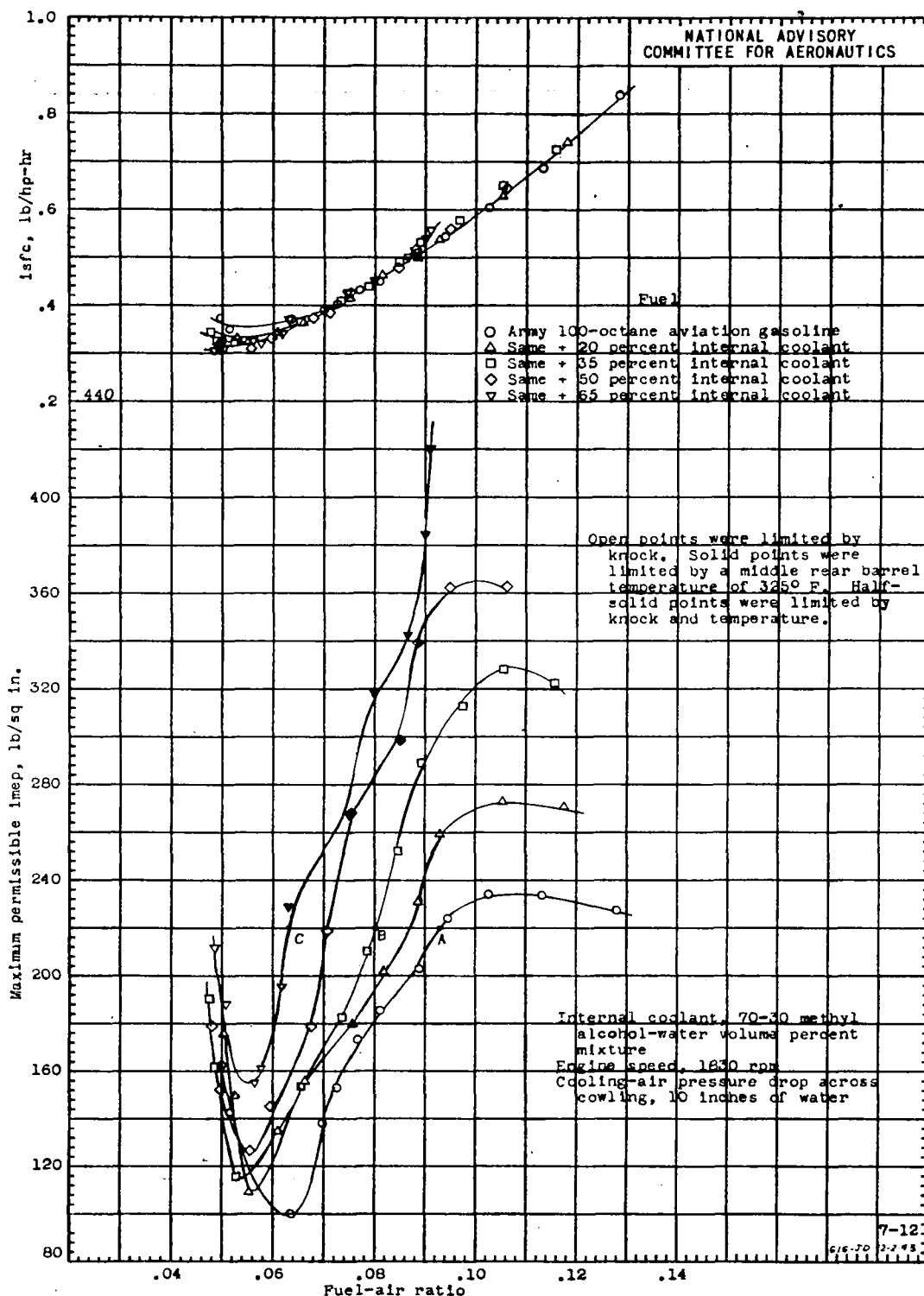
Figure 6. – Engine performance permitted with a mixture of methyl alcohol and water as an internal coolant at an engine speed of 2500 rpm and a cooling-air pressure drop across cowling of 5 inches of water. Wright C9GC cylinder; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 250° F; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.
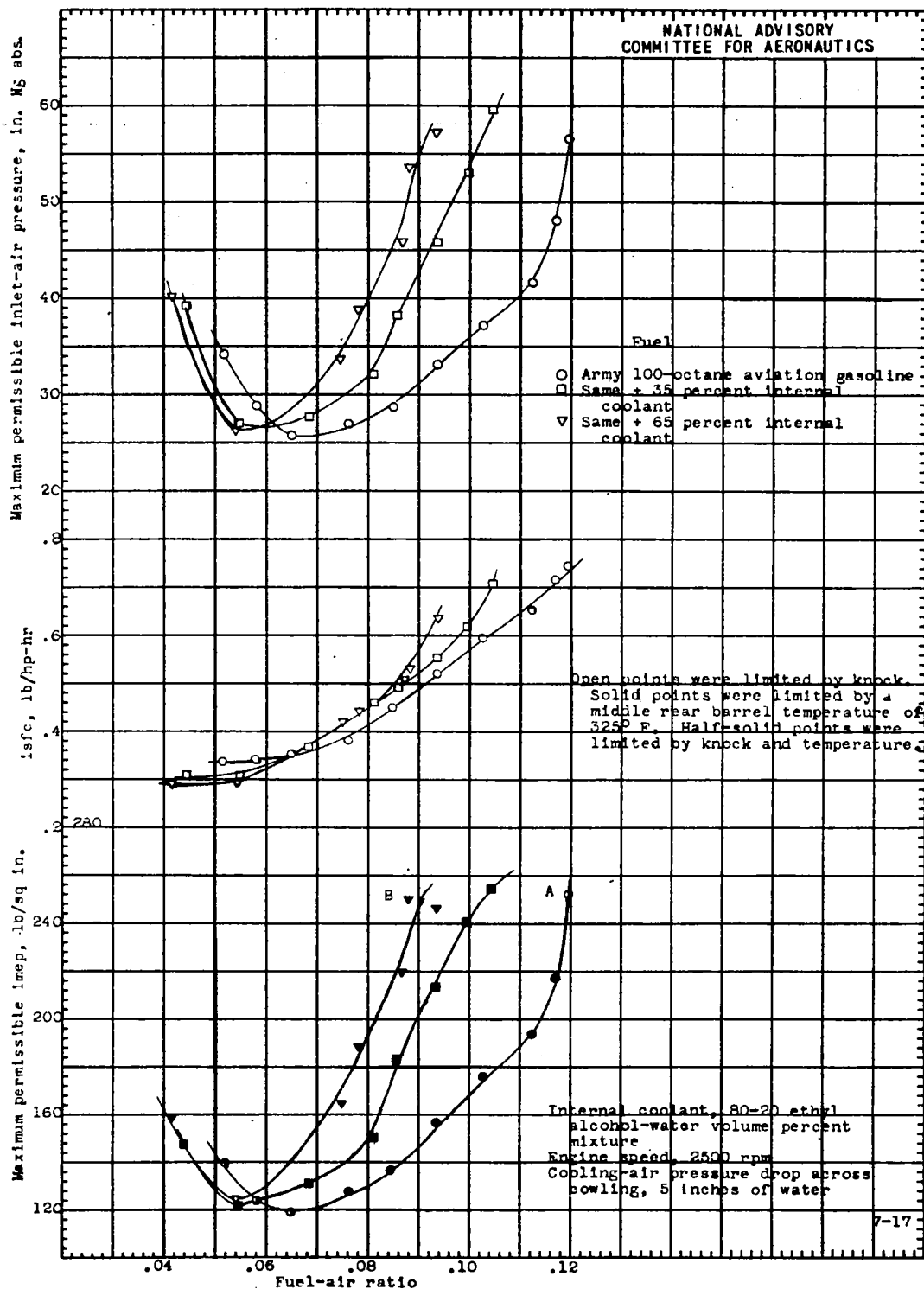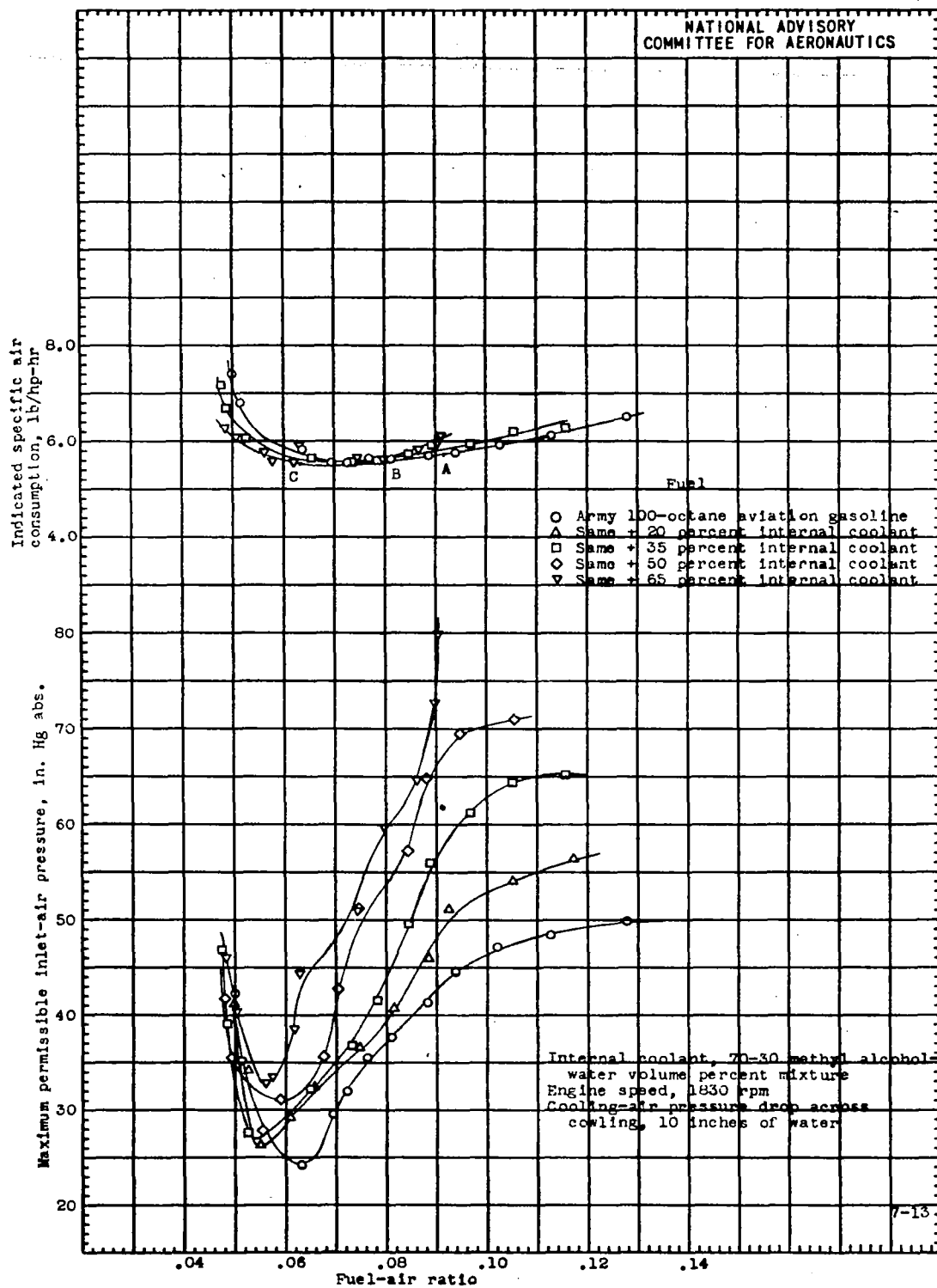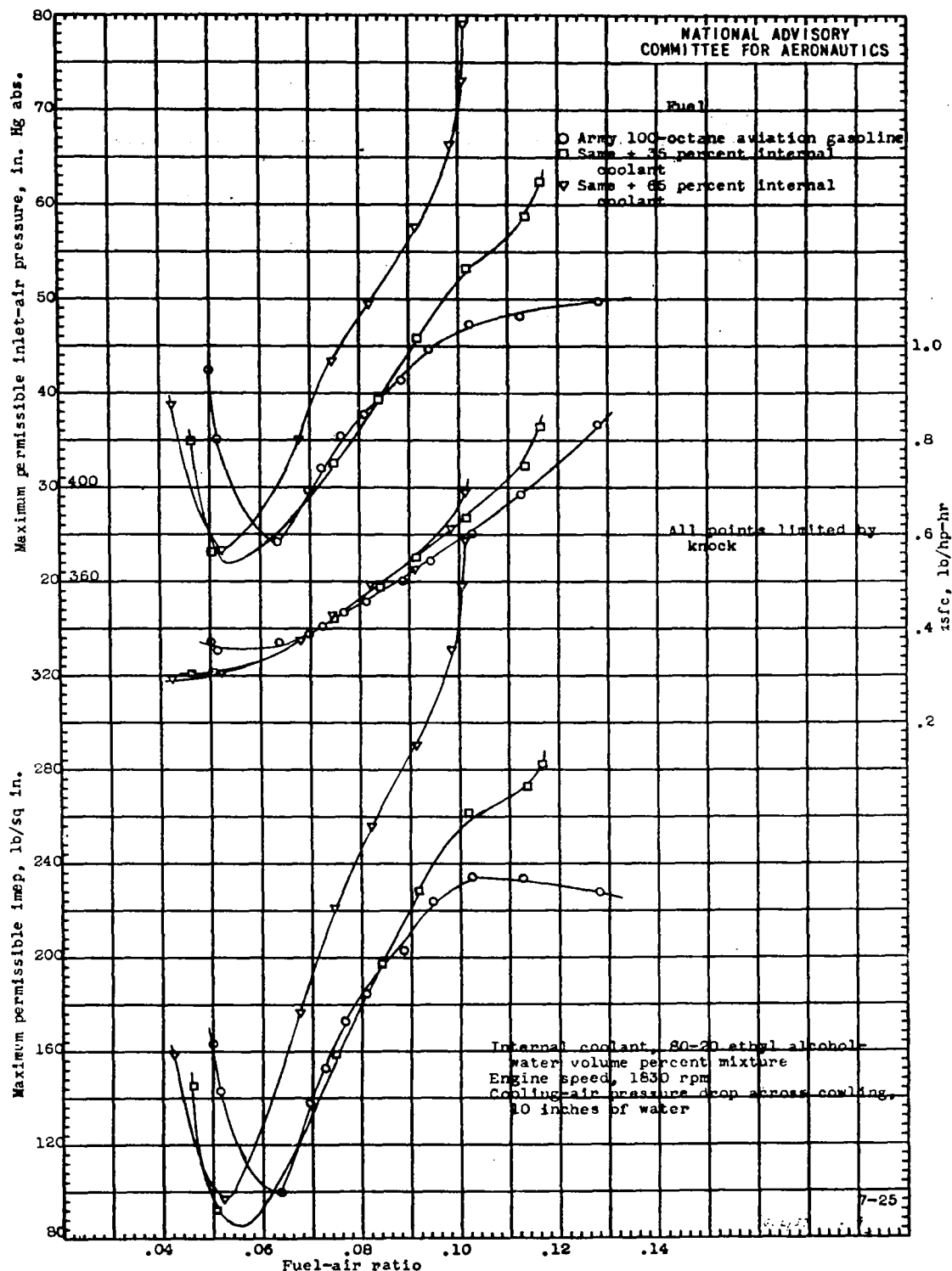
Figure 7. – Engine performance permitted with a mixture of ethyl alcohol and water as an internal coolant at an engine speed of 2500 rpm and a cooling-air pressure drop across cowling of 5 inches of water. Wright C9GC cylinder; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 250° F; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.
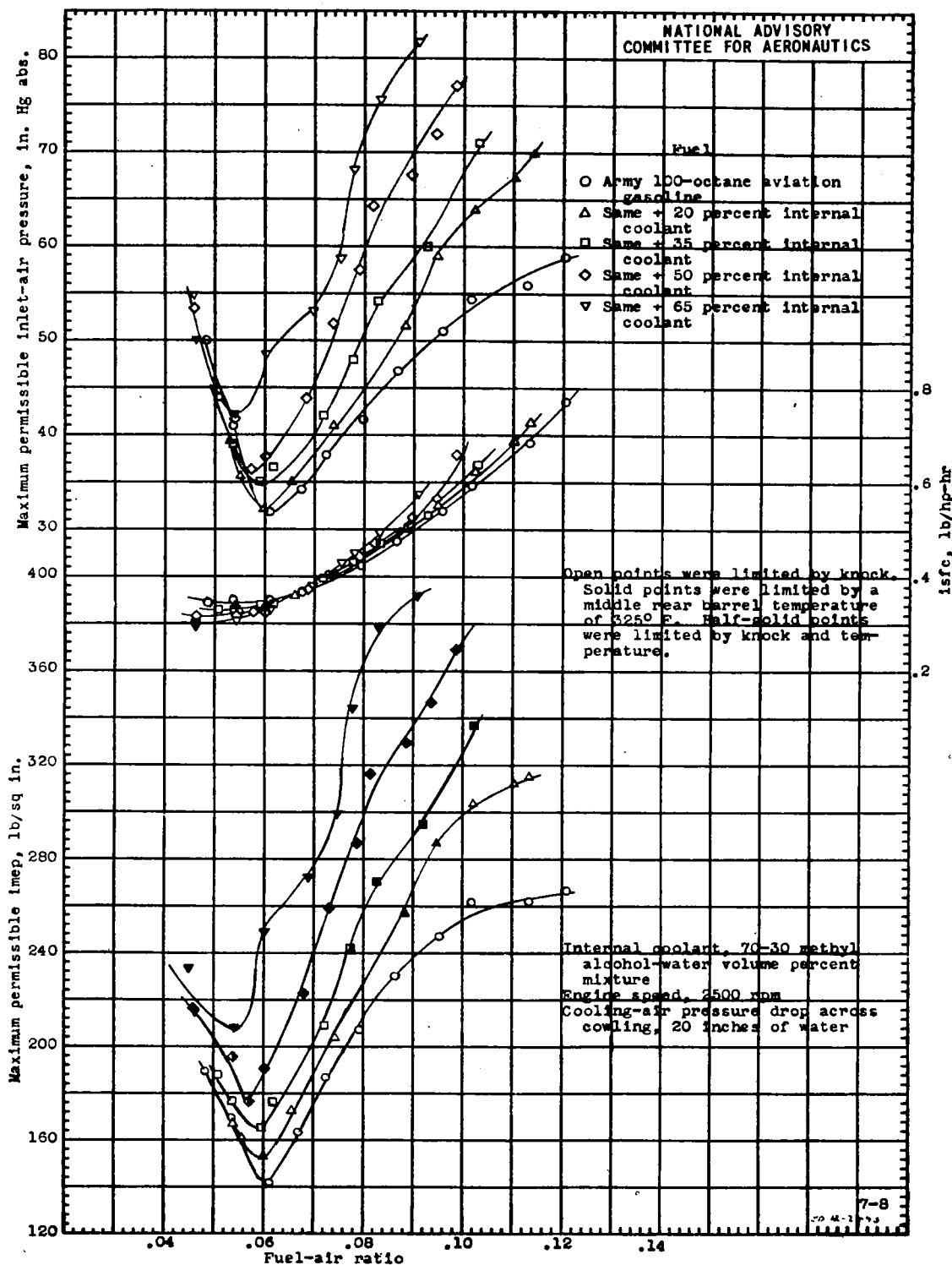
Figure 8. - Engine performance permitted with a mixture of methyl alcohol and water as an internal coolant at an engine speed of 2500 rpm and a cooling-air pressure drop across cowling of 20 inches of water. Wright C9GC cylinder; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 250° F; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.
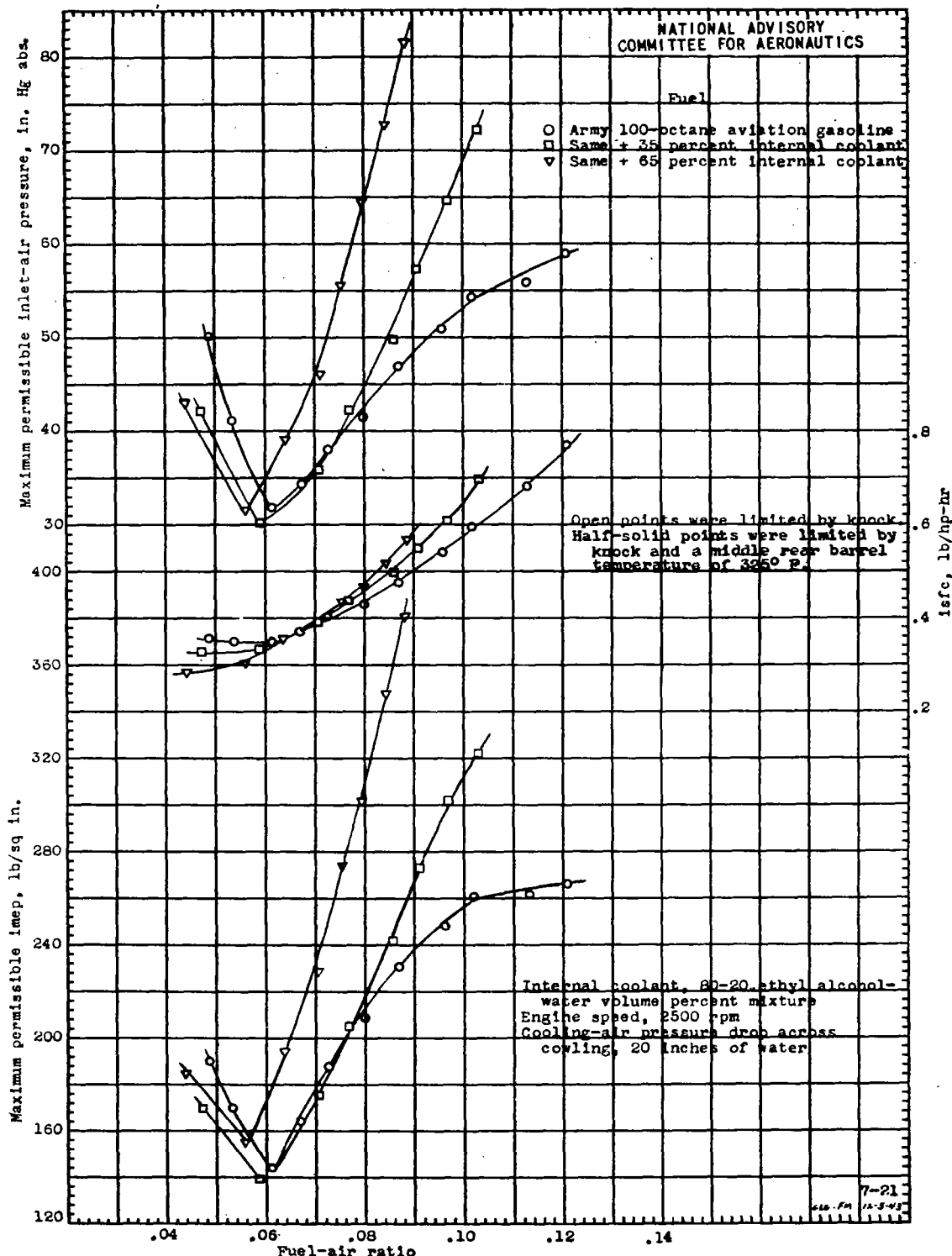
Figure 9. - Engine performance permitted with a mixture of ethyl alcohol and water as an internal coolant at an engine speed of 2500 rpm and a cooling-air pressure drop across cowling of 20 inches of water. Wright C9GC cylinder; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 250° F; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.

Figure 10. – Engine performance permitted with a mixture of methyl alcohol and water as an internal coolant at an engine speed of 1830 rpm and a cooling-air pressure drop across cowling of 10 inches of water. Wright C9OC cylinder; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 250° F; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.

Figure 10. – Concluded.

Figure 11. - Engine performance permitted with a mixture of ethyl alcohol and water as an internal
coolant at an engine speed of 1830 rpm and a cooling-air pressure drop across cowling of 10
inches of water. Wright C9GC cylinder; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-
air temperature, 250° F; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation
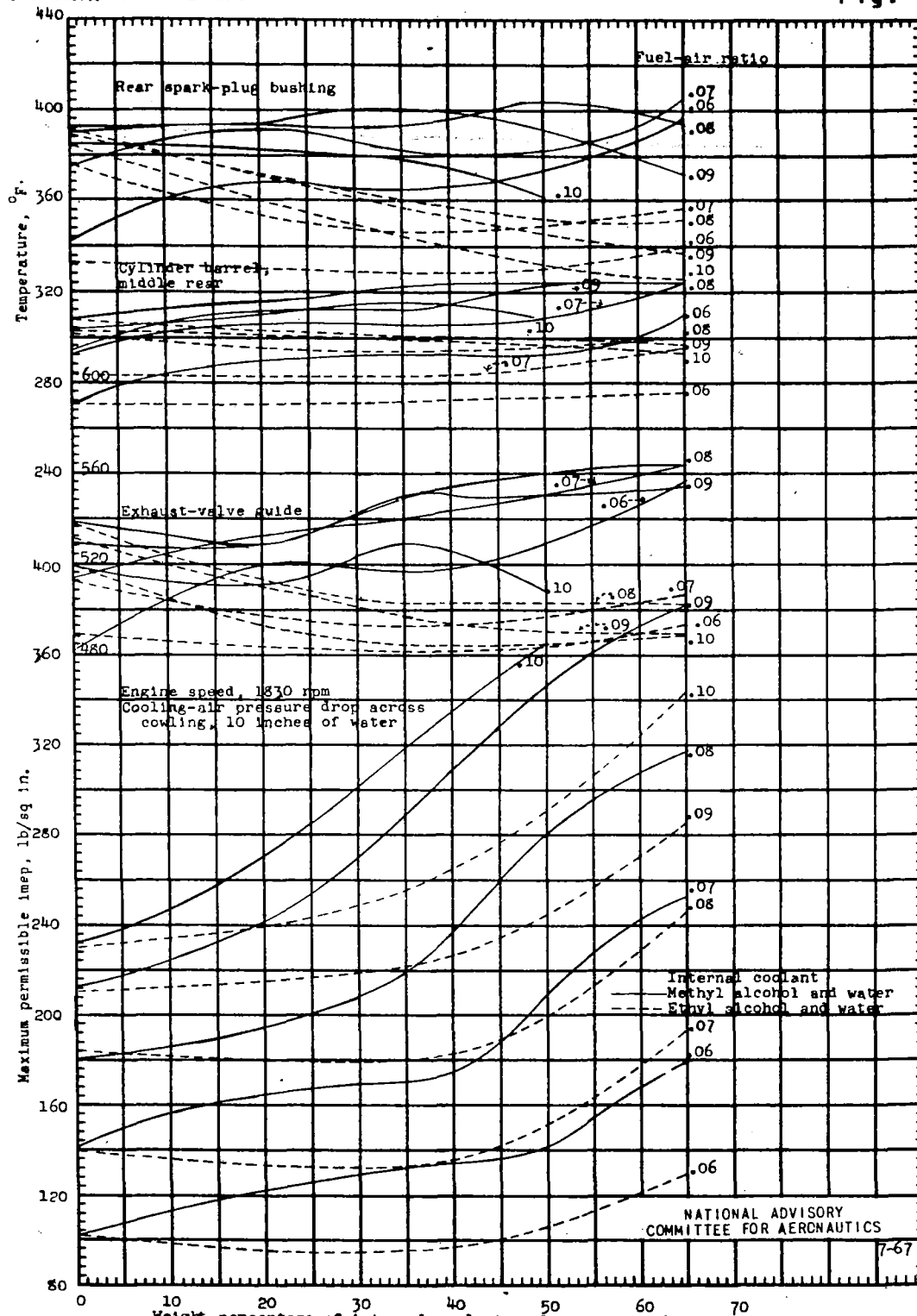gasoline.
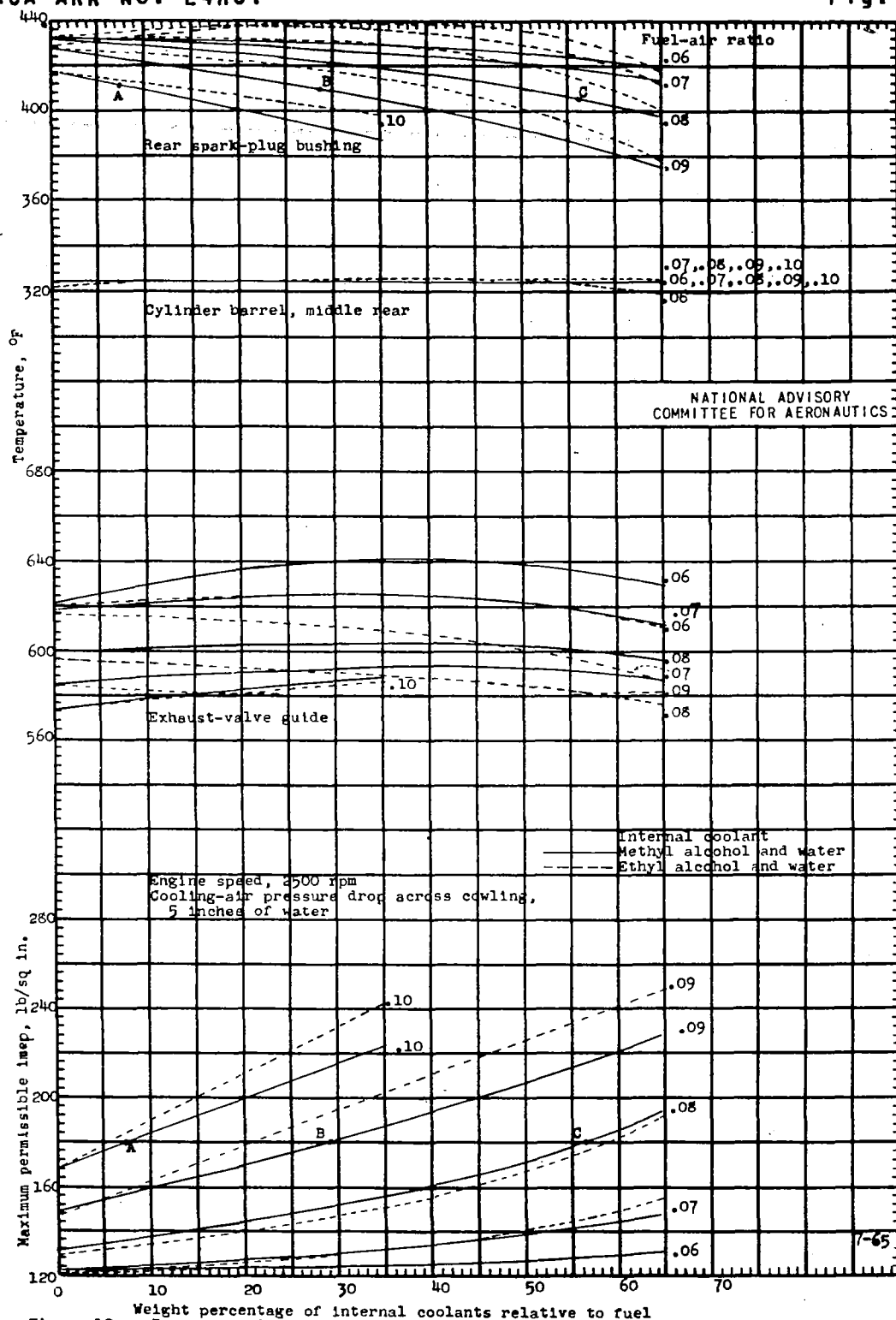
Figure 12. – Representative engine temperatures and maximum permissible indicated mean effective pressure as determined by percentage of internal coolants at various fuel-air ratios at an engine speed of 2500 rpm and a cooling-air pressure drop across cowling of 5 inches of water. Wright C9GC cylinder; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 250° F; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.
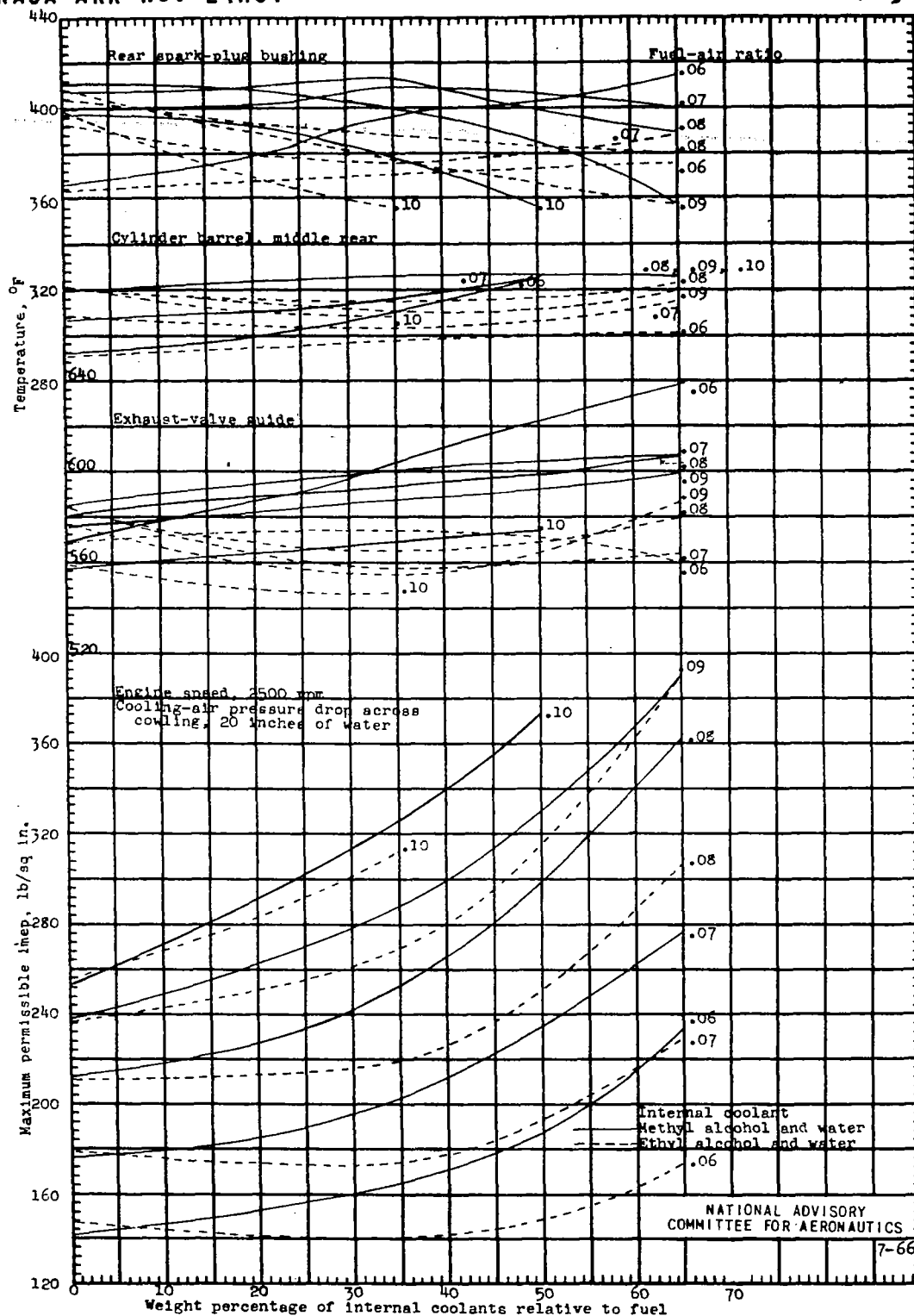
Figure 13. - Representative engine temperatures and maximum permissible indicated mean effective pressure as determined by percentage of internal coolants at various fuel-air ratios at an engine speed of 2500 rpm and a cooling-air pressure drop across cowling of 20 inches of water. Wright C9GC cylinder; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 250° F; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.
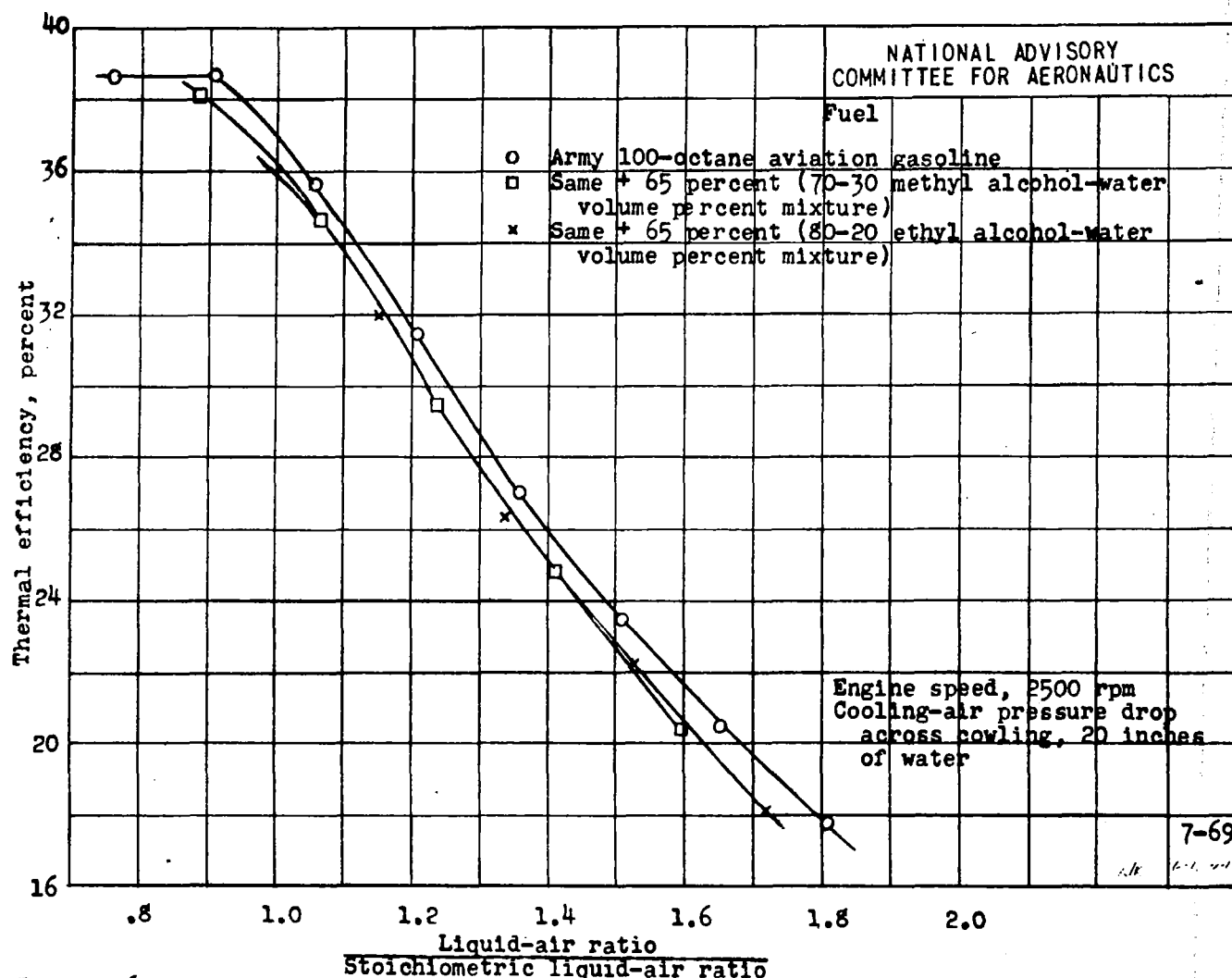
Figure 14. – Representative engine temperatures and maximum permissible indicated mean effective pressure as determined by percentage of internal coolants at various fuel-air ratios at an engine speed of 1830 rpm and a cooling-air pressure drop across cowling of 10 inches of water. Wright C9GC cylinder; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 250° F; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.
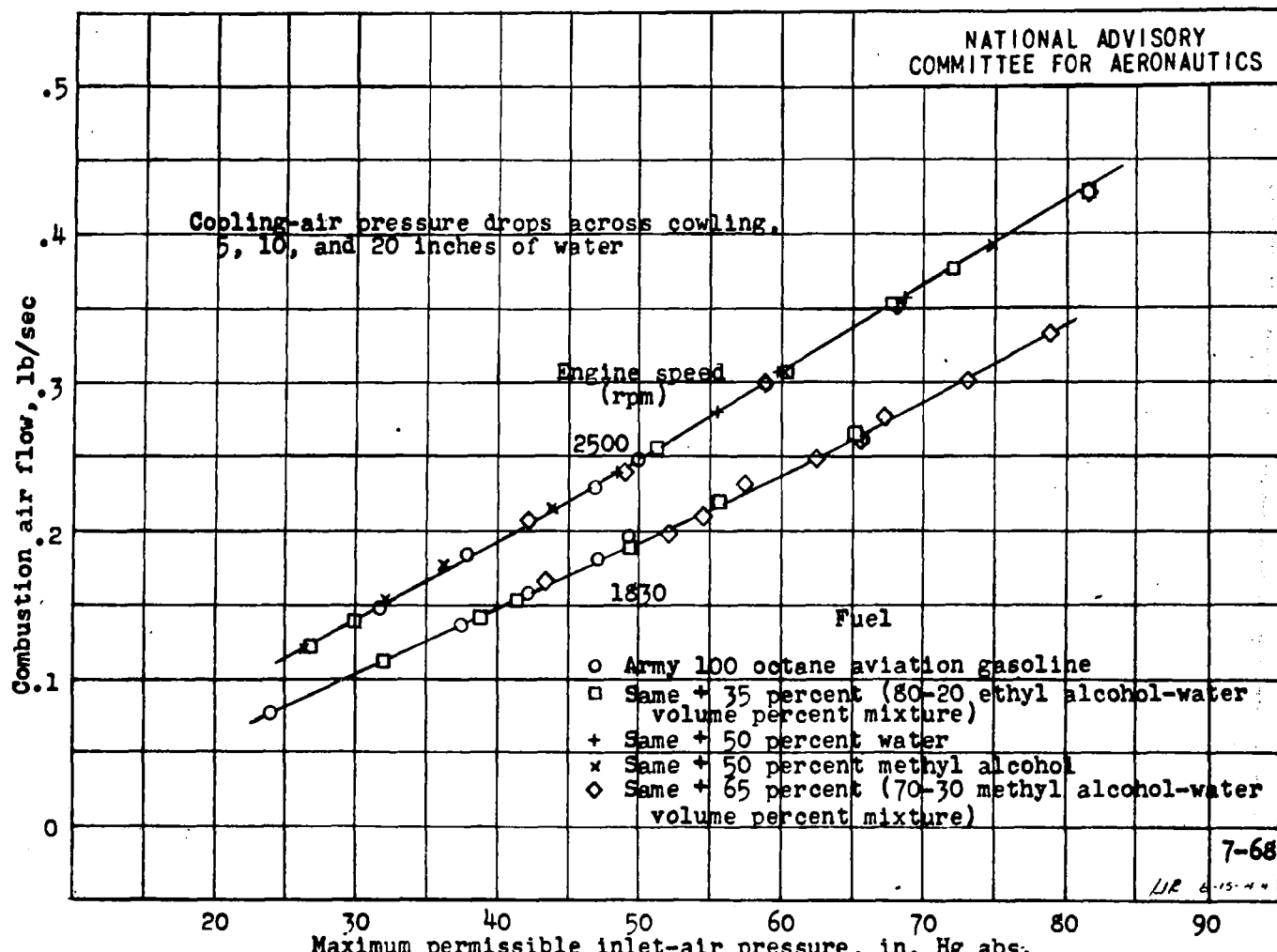
Figure 15. – Weight of induced air as affected by internal coolants injected into the intake manifold at cooling-air pressure drops across cowling of 5, 10, and 20 inches of water. Wright C9GC cylinder; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 250° F; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.

Fig. 15

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Fuel

o   Army 100-octane aviation gasoline
□   Same + 65 percent (70-30 methyl alcohol-water volume percent mixture)
x   Same + 65 percent (80-20 ethyl alcohol-water volume percent mixture)

Engine speed, 2500 rpm
Cooling-air pressure drop across cowling, 20 inches of water

Thermal efficiency, percent

$\dfrac{\text{Liquid-air ratio}}{\text{Stoichiometric liquid-air ratio}}$

7-69

Figure 16. - Thermal efficiency as affected by the addition of various internal coolants at an engine speed of 2500 rpm and a cooling-air pressure drop across cowling of 20 inches of water. Wright C9GC cylinder; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 250° F; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.

Fig. 16
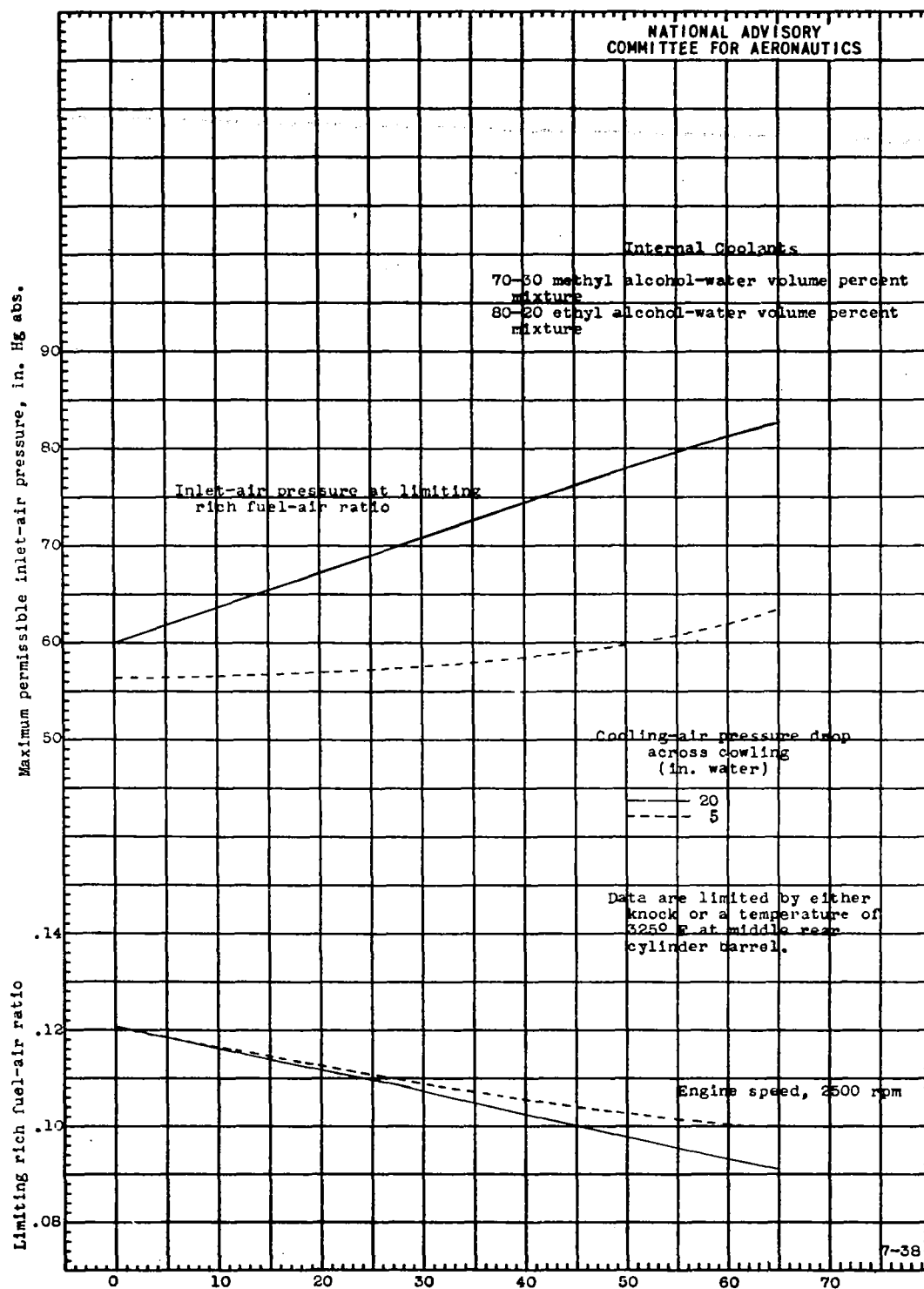
Figure 17. - Effect of percentage internal coolants on limiting rich fuel-air ratio and maximum permissible inlet-air pressure at an engine speed of 2500 rpm. Wright C9GC cylinder; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 250° F; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.
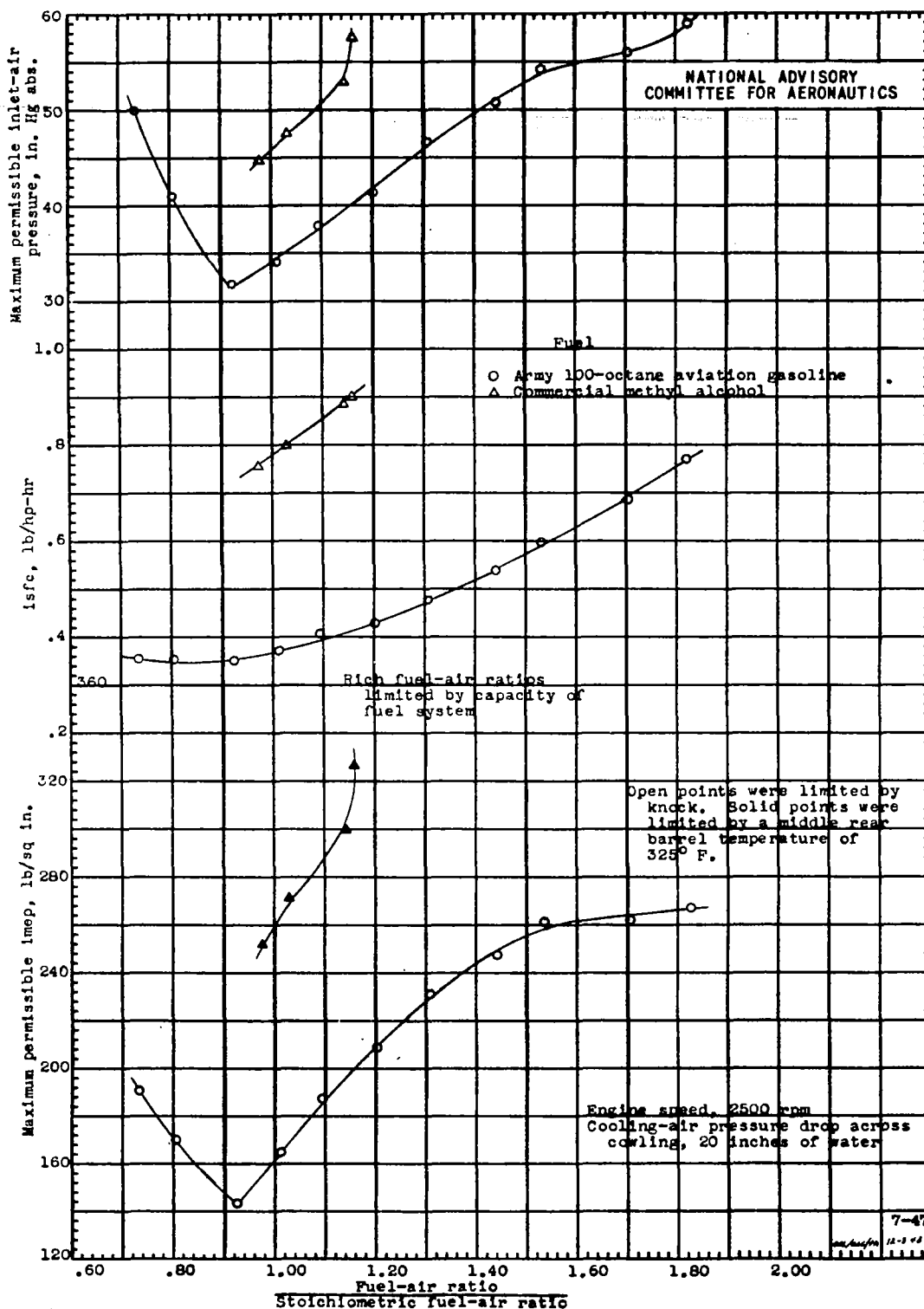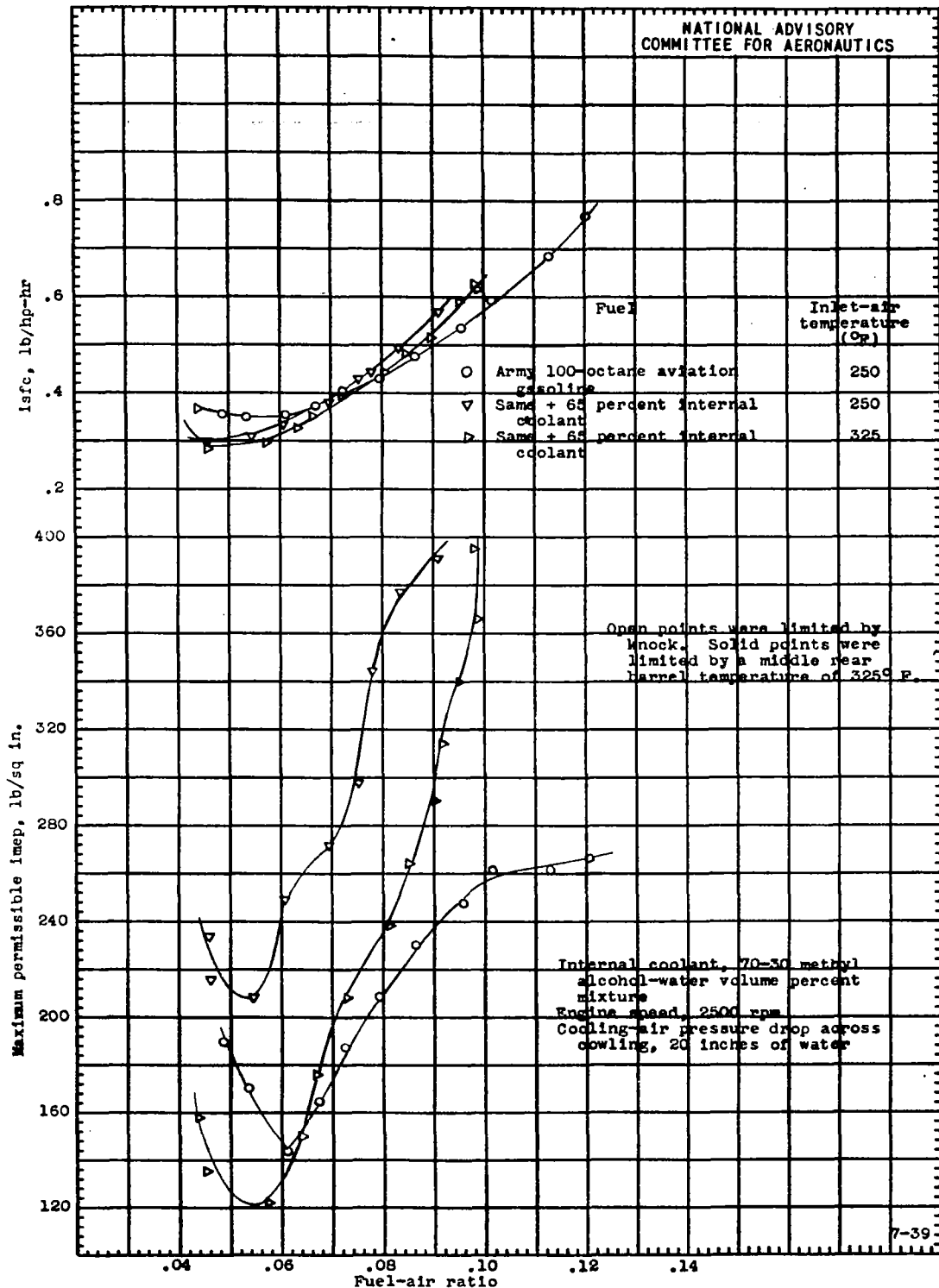
Figure 18. — Maximum permissible engine performance with methyl alcohol as a fuel at an engine
speed of 2500 rpm and a cooling-air pressure drop across cowling of 20 inches of water. Wright
C9GC cylinder; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 250° F;
cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.
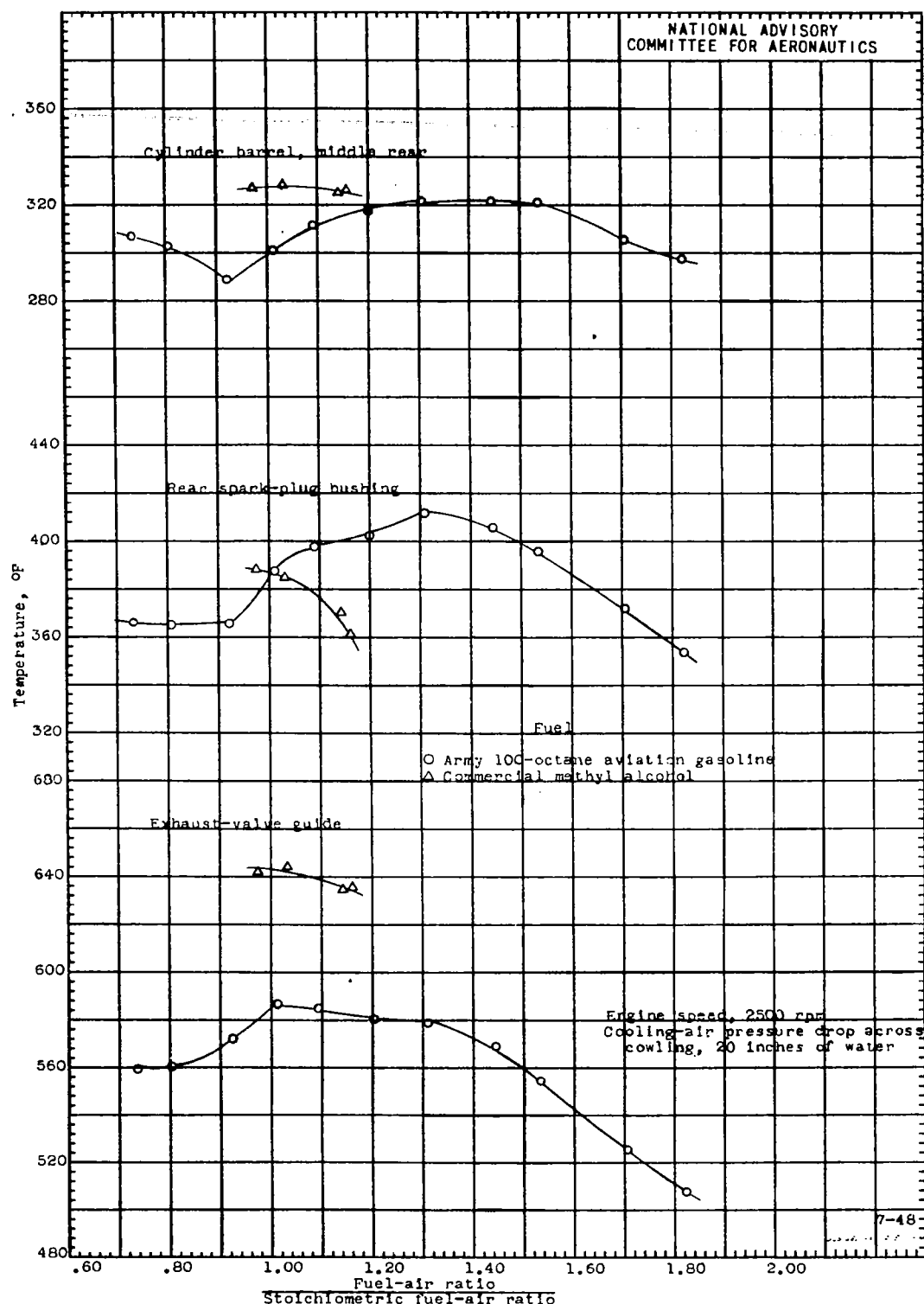
Figure 29. – Effect of methyl alcohol as a fuel on representative engine temperatures at maximum permissible inlet-air pressure at an engine speed of 2500 rpm and a cooling-air pressure drop across cowling of 20 inches of water. Wright C9CC cylinder; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 250° F; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.

Figure 20. – Engine performance with a mixture of methyl alcohol and water as an internal coolant as affected by inlet-air temperature at an engine speed of 2500 rpm and a cooling-air pressure drop across cowling of 20 inches of water. Wright C9GC cylinder; compression ratio, 7.0; spark advance, 20° B.T.C.; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.
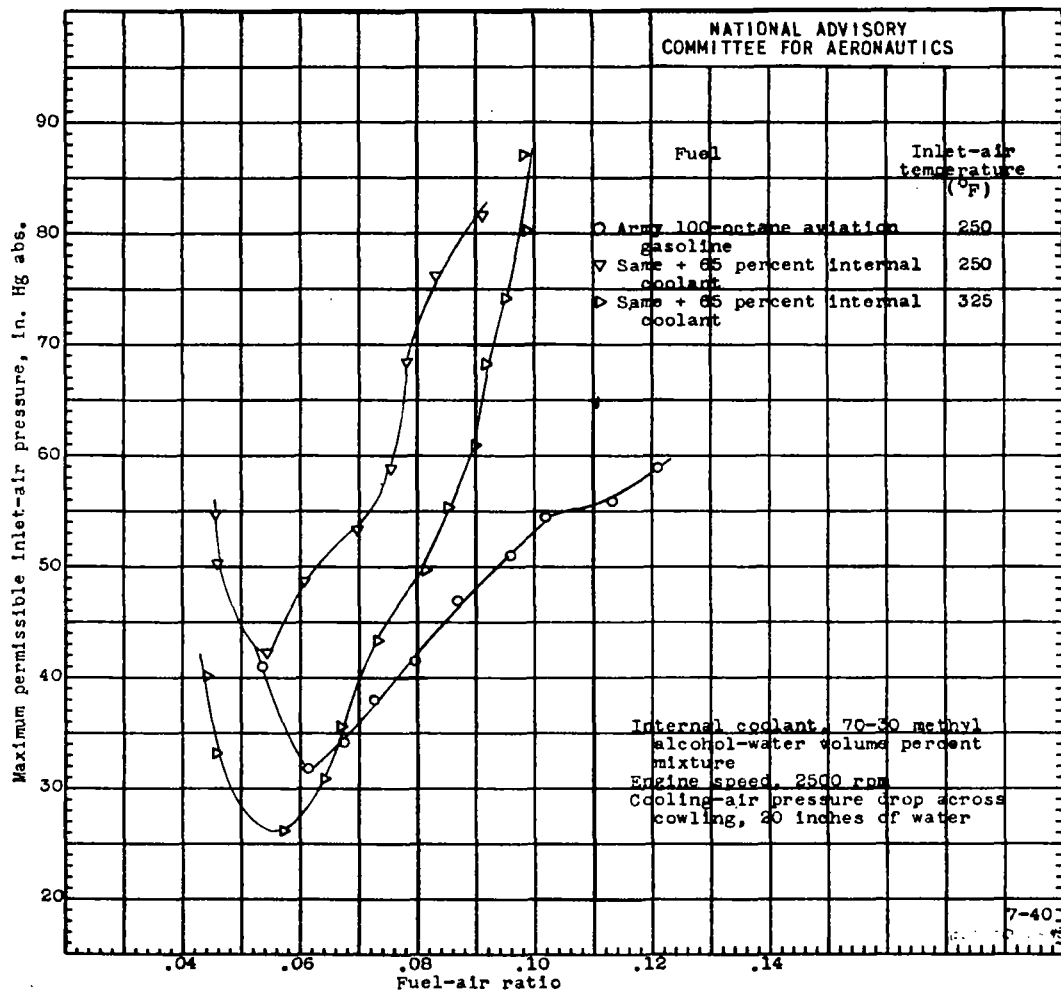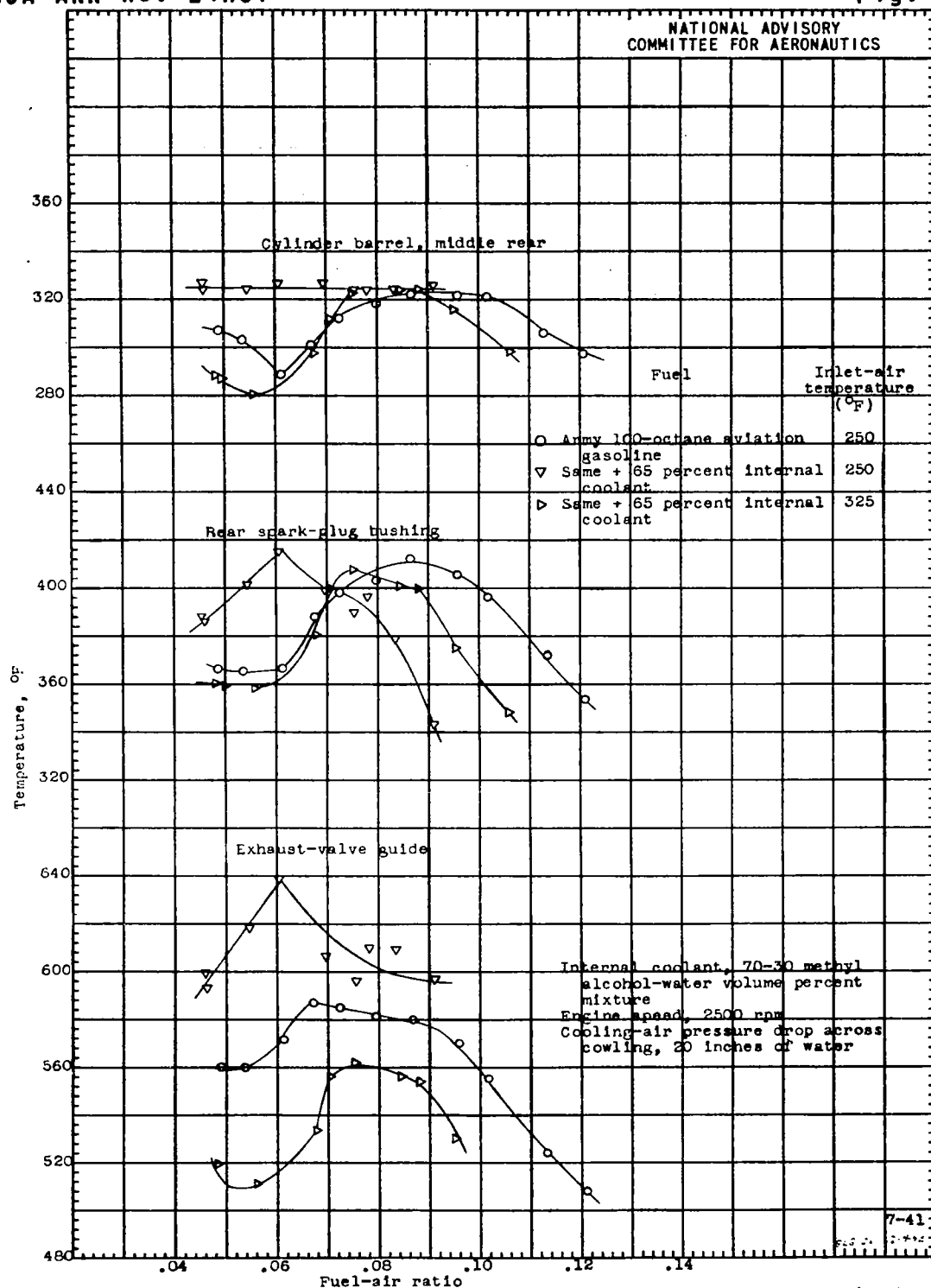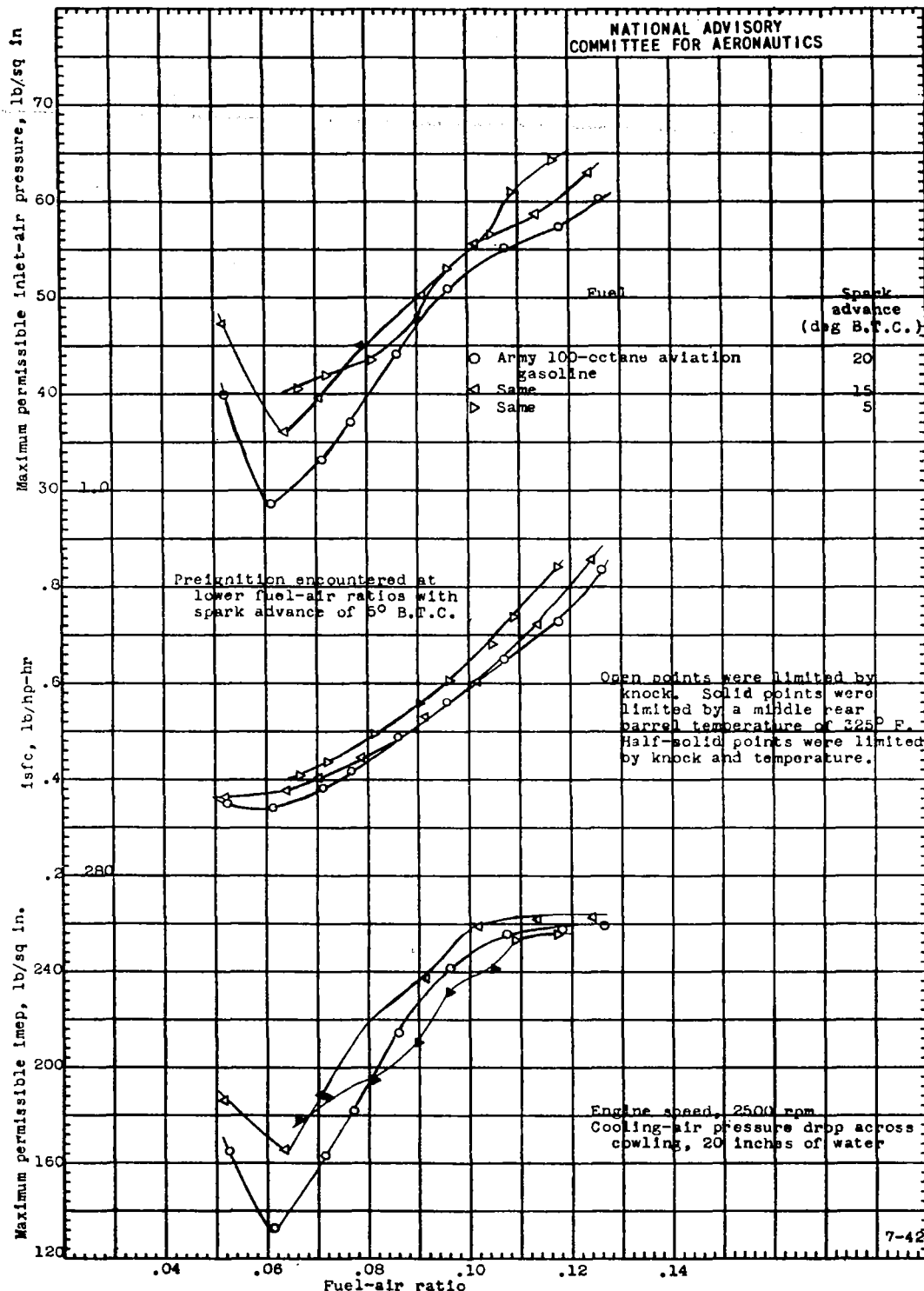
Figure 20. - Concluded.

Figure 21. - Effect of internal coolant and inlet-air temperature on representative engine temperatures at maximum permissible inlet-air pressure at an engine speed of 2500 rpm and a cooling-air pressure drop across cowling of 20 inches of water. Wright C9GC cylinder; compression ratio, 7.0; spark advance, 20° B.T.C.; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.

Figure 22. — Engine performance as determined by spark advance at an engine speed of 2500 rpm and a cooling-air pressure drop across cowling of 20 inches of water. Wright C9GC cylinder; compression ratio, 7.0; inlet-air temperature, 250° F; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.
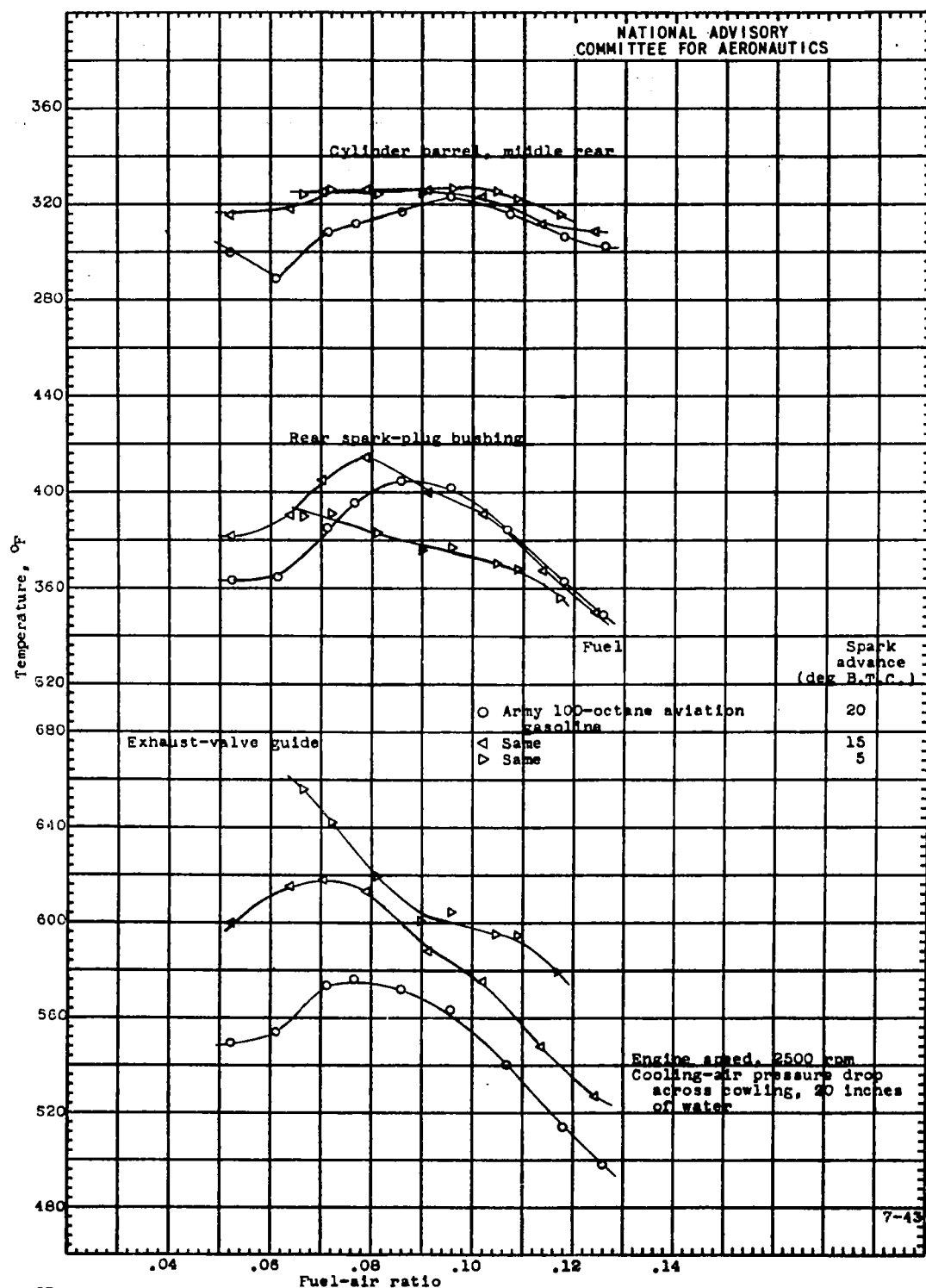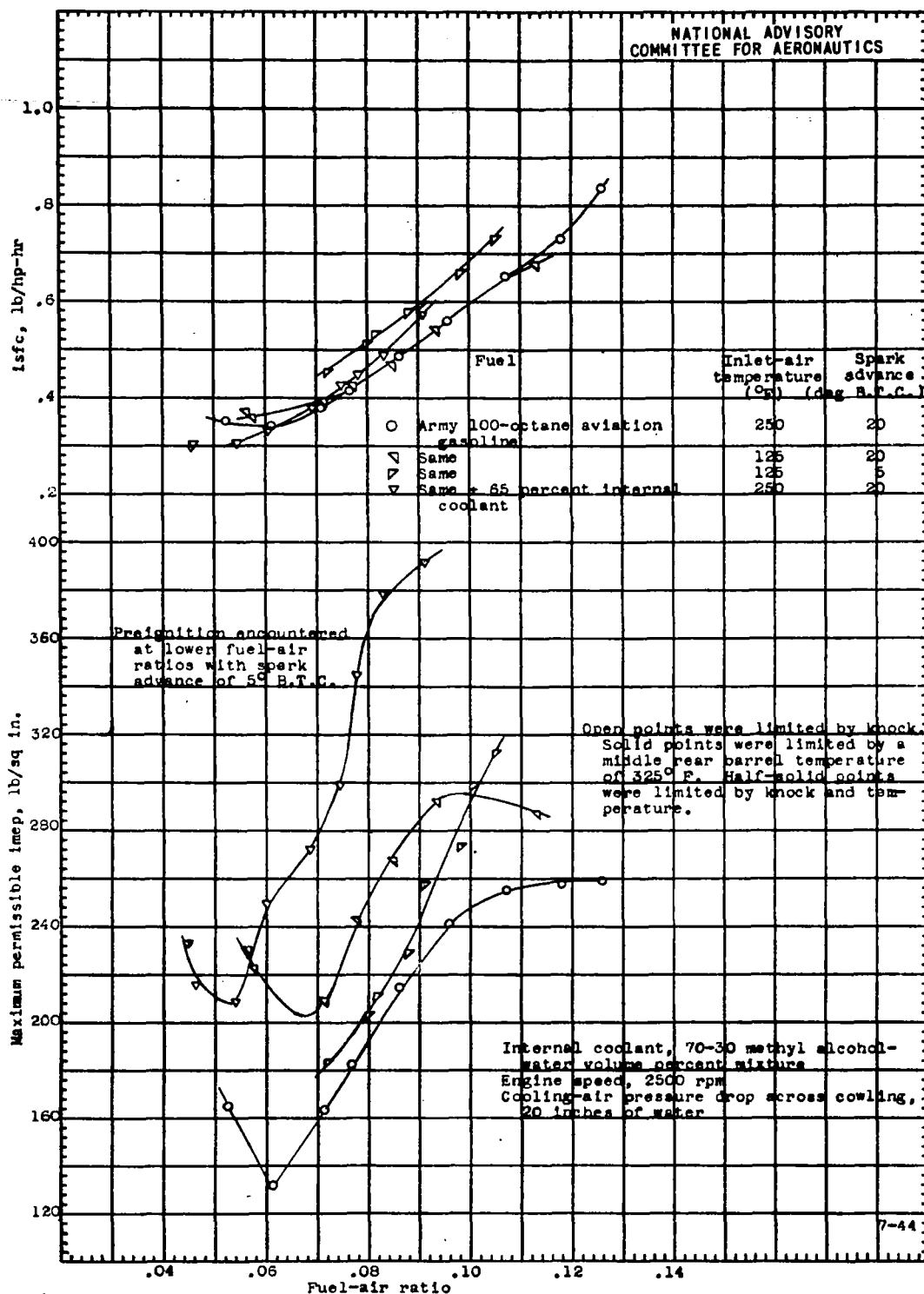
Figure 23. - Effect of spark advance on representative engine temperatures at maximum permissible inlet-air pressure at an engine speed of 2500 rpm and a cooling-air pressure drop across cowling of 20 inches of water. Wright C9GC cylinder; compression ratio, 7.0; inlet-air temperature, 250° F; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.

Figure 24. — Engine performance as determined by spark advance and inlet-air temperature with a mixture of methyl alcohol and water as an internal coolant at an engine speed of 2500 rpm and a cooling-air pressure drop across cowling of 20 inches of water. Wright C9GC cylinder; compression ratio, 7.0; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.
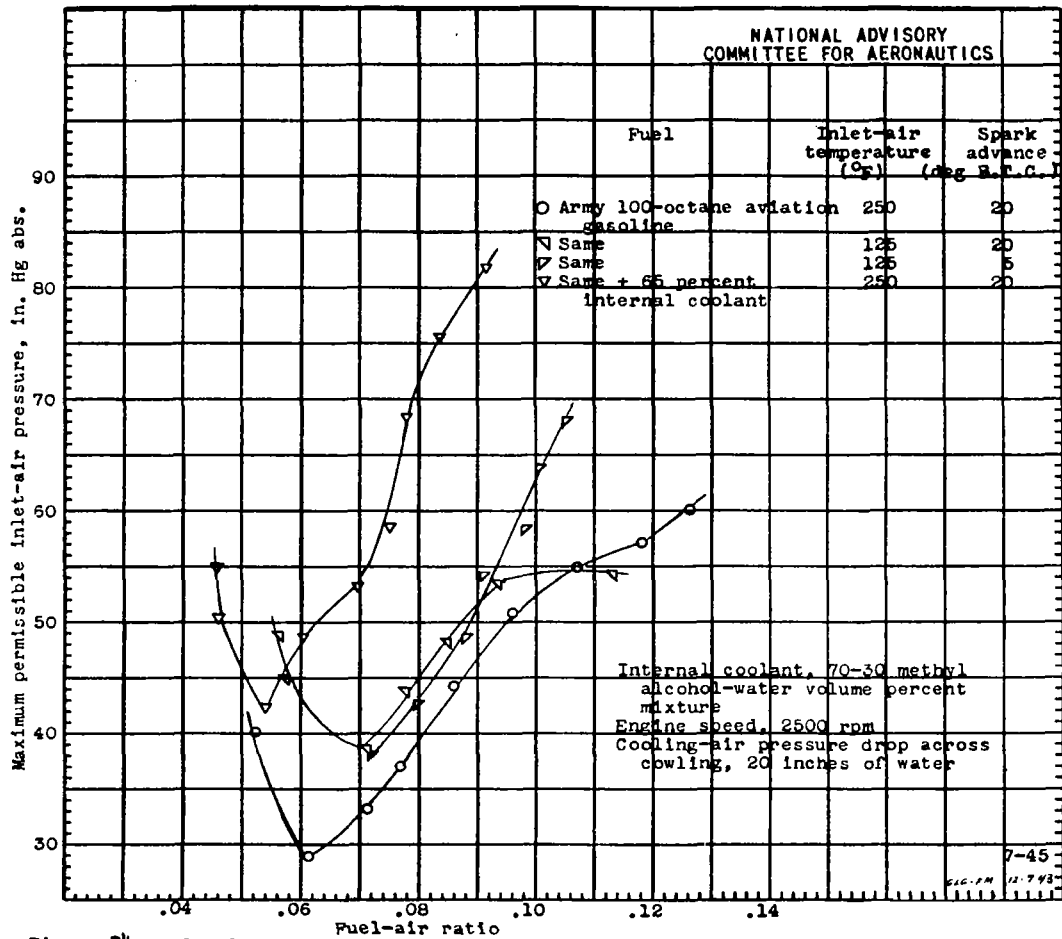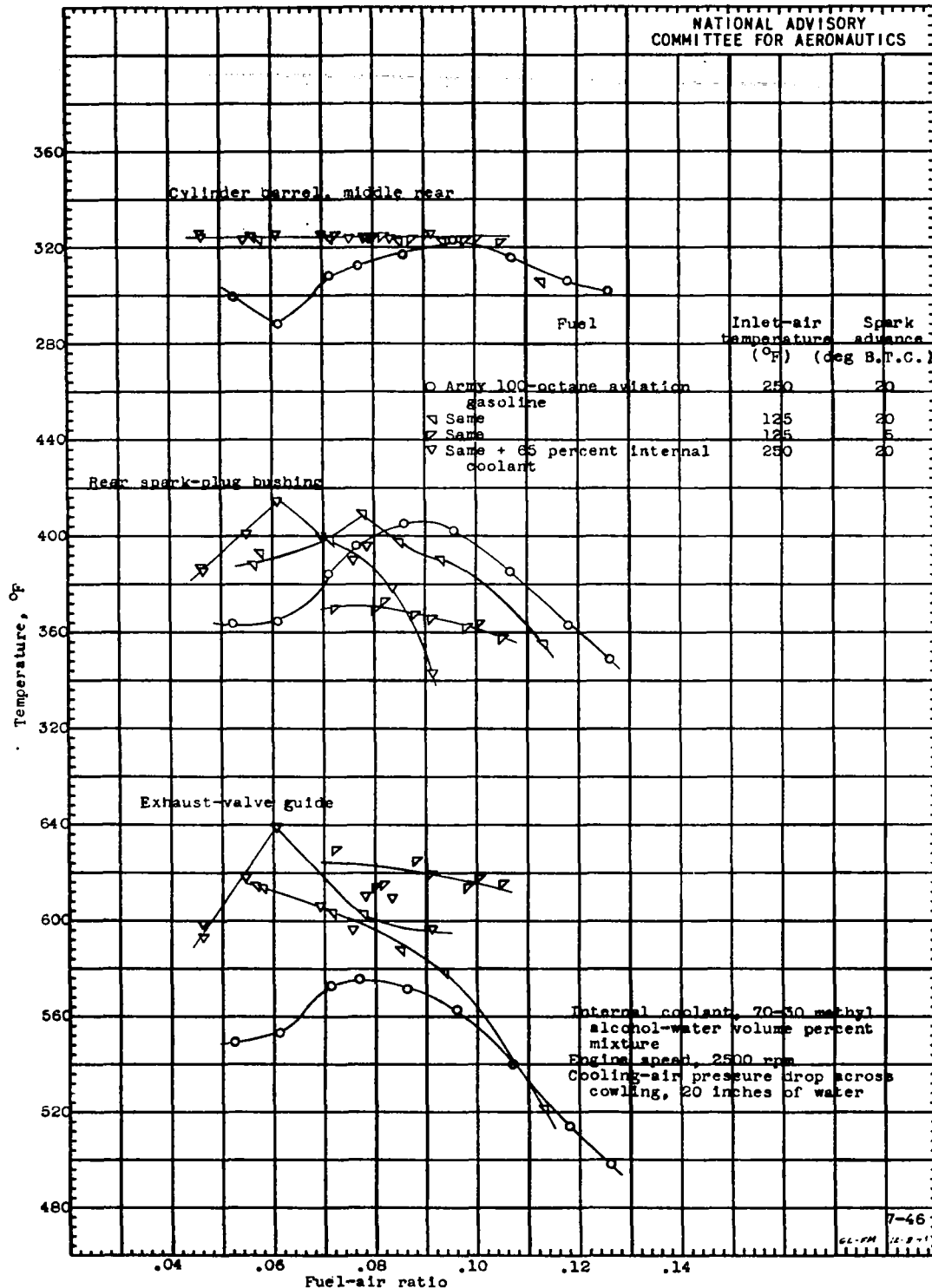
Figure 24. - Concluded.

Figure 25. – Effect of spark advance, inlet-air temperature, and internal coolant on representative engine temperatures at maximum permissible inlet-air pressure at an engine speed of 2500 rpm and a cooling-air pressure drop across cowling of 20 inches of water. Wright C9GC cylinder; compression ratio, 7.0; cooling-air upstream temperature, 125° F; fuel, Army 100-octane aviation gasoline.