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EFFECT OF ENGINE-OPERATING VARIABLES AND INTERNAL COOLANTS ON SPARK-ADVANCE REQUIREMENTS OF A LIQUID-COOLED CYLINDER

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NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

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SUMMARY

Tests were conducted to determine the effect of engine-operating variables and internal coolants on spark-advance requirements of a single cylinder from a 12-cylinder liquid-cooled engine for maximum take-off power and maximum cruise economy. The effects of fuel-air ratio, engine speed, air flow (charge density), mixture temperature, and internal coolants on peak-power (optimum) spark advance were investigated. In addition, tests were conducted to determine the effect of spark advance on the knock-limited engine performance at several mixture temperatures for conditions simulating take-off, high-power cruise, and low-power cruise.

In the liquid-cooled cylinder operated with 28-R fuel, the following results were obtained:

1. Among the variables tested only fuel-air ratio and internal coolant-fuel ratio have large effects on the peak-power spark timing.

2. When the spark timing is advanced from normal (inlet, 28° B.T.C.; exhaust, 34° B.T.C.) at a fuel-air ratio of 0.060 to peak power at a fuel-air ratio of 0.057, which sacrifices no engine power for a given inlet-air pressure, a 4-percent reduction in indicated specific fuel consumption is realized. Any uneveness in mixture distribution of a multicylinder engine would result in a decrease in brake specific fuel consumption greater than that for a single-cylinder engine; the more uneven the mixture distribution, the greater is the decrease to be expected.

3. An increase of approximately 10 performance numbers in the lean rating of the fuel would be required to maintain the same knock-limited power at a fuel-air ratio of 0.060 if the spark timing was advanced to peak power.

4. Knock-limited indicated mean effective pressure at take-off conditions was increased about 6 percent when the spark timing was retarded from the normal value (inlet, 28° B.T.C.; exhaust, 34° B.T.C.) to the point where rough operation was reached (inlet, 16° B.T.C.; exhaust, 22° B.T.C.). When the additional supercharger power necessary to supply the higher manifold pressure is considered, the gain in the knock-limited brake horsepower for a multicylinder engine with a single-stage supercharger is approximately 4 percent.

INTRODUCTION

Most current models of the in-line liquid-cooled engine have fixed spark timing. It was desirable, however, to investigate the advantages of variable spark timing in these engines because a higher knock-free take-off power can be obtained when the spark timing is retarded and a lower fuel consumption can be obtained for lean-mixture cruising when the spark timing is advanced than results when fixed spark timing is used.

In order to evaluate these advantages, engine tests were conducted at the NACA Cleveland laboratory during the latter part of 1944 to determine the effects of fuel-air ratio, engine speed, air flow (charge density), and mixture temperature on the peak-power (optimum) spark advance and to determine the effect of spark advance on knock-limited power. An investigation was also made of the spark-advance requirements with the use of water and a mixture of water and ethyl alcohol as internal coolants. The results of these tests, which constitute part of the general program for improving the power output of the multicylinder liquid-cooled engine as requested by the Army Air Forces, Air Technical Service Command, are reported herein.

APPARATUS

The tests were conducted with a multicylinder block adapted to a CUE crankcase (reference 1). Figure 1 shows cylinder 2 in position for firing; cylinder 3, however, was used in these tests.

The internal-coolant injection system comprised a pressurized supply tank, a rotameter, and an injection nozzle.

The injection nozzle was a copper tube sealed at the end and drilled with four small holes spaced in a row along the length of the tube. Figure 2 illustrates the two positions used for the injection of internal coolants: position A before the vaporization tank and position B at the intake elbow. In both positions the nozzle was installed to inject the internal coolant downstream.

Cylinder-head temperatures were measured by a thermocouple located between the exhaust-valve seats (fig. 3), which is the region of highest cylinder-head temperature. Knock was detected by means of a magnetic vibration-type pickup, an amplifier, and an oscilloscope.

TEST PROCEDURE

The following engine conditions were maintained:

Compression ratio	6.65
Engine speed, rpm	2280, 2600, 3000
Inlet-oil temperature, °F	185
Outlet-coolant temperature, °F	250
Coolant flow at 2280 rpm, gallons per minute	90
Coolant flow at 2600 rpm, gallons per minute	105
Coolant flow at 3000 rpm, gallons per minute	120

The normal spark advance for the engine is 28° B.T.C. for the inlet side and 34° B.T.C. for the exhaust side. The timing of the inlet spark was retarded 6° from that of the exhaust spark for all tests. The engine coolant was 30-percent ethylene glycol, Army-Navy specification AN-E-2, and 70-percent water. Cold spark plugs were used to prevent preignition and the fuel was 28-R.

Tests were conducted to determine the effect of fuel-air ratio, engine speed, air flow, mixture temperature, and internal coolants on peak-power spark advance. The spark timing was varied over a range sufficiently wide to determine accurately the point of maximum power. Two internal coolants were used: water and a mixture by volume of 50-percent water and 50-percent ethyl alcohol. Several ratios by weight of the internal coolant to fuel were investigated with injection into the vaporization tank and with injection into the intake elbow.

Knock-limited engine performance was also determined for a range of spark advance from approximately 15° retarded from normal to 15° advanced from normal at engine conditions simulating take-off, high-power cruise, and low-power cruise.

RESULTS AND DISCUSSION

Effect of Engine Variables and Internal Coolants on Spark Advance for Peak Power

Fuel-air ratio.- The effect of spark advance on power and fuel consumption at three engine speeds and for several fuel-air ratios is presented in figure 4. The values of peak-power (optimum) spark advance are indicated by arrows on these curves. These values were chosen to correspond with minimum fuel consumption as well as with peak power. Inasmuch as spark advance does not appreciably affect the amount of charge entering the cylinder, the spark advance giving the best cycle efficiency will give minimum fuel consumption as well as maximum power. Hereinafter, the optimum value of spark advance will be designated the spark advance for peak power; however, it is also the spark advance at which minimum fuel consumption is obtained at the same operating conditions. The values of spark advance indicated by the arrows on figure 4 have been plotted in figure 5 to show the influence of fuel-air ratio on spark advance for peak power. The decided effect of fuel-air ratio on spark advance for peak power is caused by the pronounced influence of fuel-air mixture on flame speed. Inasmuch as the flame speed decreases for fuel-air ratios leaner or richer than about 0.085 to 0.095 (reference 2), the ignition timing for peak power must be advanced when operating at fuel-air mixtures leaner or richer than 0.085 to 0.095.

Engine speed.- Flame speed increases rapidly with engine speed because of increased turbulence. In the liquid-cooled cylinder, the flame speed increased at a slightly slower rate than engine speed over the range tested. It was therefore necessary to advance the spark a small amount to maintain peak power for a given fuel-air ratio as the speed was increased (fig. 5).

Air flow.- The effect of spark advance on power and fuel consumption with various air flows and two mixture temperatures (125° and 225° F) is shown in figure 6. The inlet-air pressure and the exhaust back pressure are equal at 30 inches of mercury absolute (approximate air flow, 437 lb/hr); therefore, the valve-overlap losses are smaller than at higher inlet-air pressures where there is a greater differential pressure to blow the unburned charge through the exhaust valves during the scavenging period. Consequently for inlet-air pressures near atmospheric, the indicated specific fuel consumption is lower. Data from figure 6 have been plotted in figure 7 to illustrate the effect of air flow on spark advance for peak power. This plot indicates that in the liquid-cooled cylinder flame speed varies only slightly with air flow.

Mixture temperature. - Figure 8 shows the effect of spark advance on power and fuel consumption for mixture temperatures of 175° and 295° F at constant air flow. Data from figures 6 and 8 have been replotted in figure 9 and indicate that the influence of mixture temperature on peak-power spark advance is almost negligible. In these tests the effect of mixture temperature on flame speed was isolated by maintaining constant air flow.

Internal coolants. - The influence of spark advance on fuel consumption, power, and cylinder-head temperature for the two internal coolants and for the two positions of injection are presented in figure 10. Peak-power values of spark advance from figure 10 have been plotted in figure 11 to illustrate the effect of internal coolant-fuel ratio on spark advance for peak power. Water, when injected before the vaporization tank and allowed to mix thoroughly with the fuel-air mixture, slowed the flame speed more than when injected into the intake elbow. On the other hand, the flame speed was slowed to about the same degree regardless of injection position when injecting the 50-50 water-ethyl alcohol mixture. For the same internal coolant-fuel ratios and the same position of injection, the water-ethyl alcohol mixture retarded burning less than water injection. This difference in burning rate might be expected because alcohol is a fuel and therefore takes part in the combustion process.

For vaporization-tank injection, the mixture temperature decreased as more internal coolant was injected until the fuel-air mixture became saturated (fig. 12) and then the mixture temperature remained relatively constant. In a corresponding manner, the power at peak-power spark advance increased because of the increased charge weight inducted into the cylinder until the internal coolant-fuel ratio for saturation was reached (fig. 13), at which point the power leveled off. After complete saturation of the incoming mixture with the internal coolants, any additional cooling of the mixture must occur after the intake valves close, which makes it impossible to increase engine power through an effect on air flow. From this point, the power obtainable at peak-power spark advance dropped slightly as the internal coolant-fuel ratio was increased because some heat of vaporization was extracted from the air during the compression stroke, resulting in a decrease in cycle efficiency. When the internal coolant was injected at the manifold elbow, the power increase at peak-power spark advance was relatively small (fig. 13) because there was insufficient time for charge cooling before the intake valves closed.

The percentage loss in power at various values of spark advance over that which could be obtained by using peak-power spark advance for each internal coolant-fuel ratio investigated is presented in figure 14. When the engine is operated with normal spark timing at a given internal coolant-fuel ratio and position of injection, this loss is approximately twice as much when injecting water as an internal coolant as when injecting a mixture of 50-50 water-ethyl alcohol. In all cases, however, the engine power at normal spark advance with a given inlet-air pressure is increased by the use of internal coolants.

Increase in Cruise Economy Using Variable Spark Timing

A comparison of performance with normal spark advance and performance with peak-power spark advance (fig. 15) indicates no appreciable difference in power and in specific fuel consumption for fuel-air ratios greater than 0.065. For mixtures leaner than 0.065, however, some improvement in fuel economy and power is realized by using peak-power spark advance. If the spark timing is advanced from normal at a fuel-air ratio of 0.060 to peak power at a fuel-air ratio of 0.057, which sacrifices no power for a given inlet-air pressure, a 4-percent reduction in indicated specific fuel consumption is attained.

Effect of Spark Advance on Knock-Limited Engine Performance

The effect of spark timing on knock-limited engine performance for conditions simulating take-off, high-power cruise, and low-power cruise is shown in figure 16. In all cases the knock-limited engine power increased as the spark was retarded until rough operation was encountered (inlet, 16° B.T.C.; exhaust, 22° B.T.C.). A power increase of approximately 6 percent was realized by retarding the spark 12° from normal at low and intermediate mixture temperatures; whereas the increase was considerably greater at high mixture temperatures. When the additional supercharger work necessary to supply the higher manifold pressure is taken into account, this power increase of 6 percent on an indicated basis results in a power increase of approximately 4 percent on a brake basis for a multicylinder engine with a single-stage supercharger.

PROBABLE EFFECT OF SPARK ADVANCE ON THE ECONOMY OF A MULTICYLINDER ENGINE HAVING IMPERFECT MIXTURE DISTRIBUTION

The discussion thus far has been based on the single-cylinder engine. The data shown for lean-mixture fuel consumption would apply to a multicylinder engine only if the mixture distribution was perfect.

The multicylinder engine, which has imperfect mixture distribution, stands to gain somewhat more in fuel economy than the single-cylinder results presented indicate. For example, it if is assumed that the multicylinder engine is operating at an average fuel-air ratio of 0.060 with normal spark timing, any cylinders that have richer or leaner fuel-air mixtures than this value will have higher fuel consumption than a cylinder operating at a fuel-air ratio of 0.060 because the minimum point on the fuel-consumption curve (fig. 15) is at this fuel-air ratio. The over-all fuel consumption of the multicylinder engine would then be higher than that of a single cylinder operating at a fuel-air ratio of 0.060. If the spark timing is now advanced to peak power, the minimum point on the fuel-consumption curve shifts to a considerably leaner mixture. The fuel-air ratio of 0.060 is no longer at the minimum point, so any cylinders that now operate at a richer fuel-air ratio have a higher fuel consumption than one operating at 0.060; whereas, any cylinders that operate at a leaner fuel-air ratio have a lower fuel consumption than those operating at 0.060. The over-all fuel consumption for the multicylinder engine would then approach that of a single-cylinder engine operating with peak-power spark advance at a fuel-air ratio of 0.060. The reduction in over-all fuel consumption obtained by advancing the spark of the multicylinder engine with imperfect distribution is therefore greater than that obtained from single-cylinder tests. The more imperfect the mixture distribution, the greater would be the gain by advancing the spark to the peak-power condition.

The single-cylinder data presented have shown a possible reduction in lean-mixture fuel consumption of approximately 4 percent by advancing the spark. The multicylinder engine would be expected to show a somewhat greater reduction depending on the mixture distribution. It is estimated, however, that an increase of approximately 10 performance numbers in the lean rating of the fuel would be required to maintain the same knock-limited power at a fuel-air ratio of 0.060 if the spark timing was advanced to peak power.

SUMMARY OF RESULTS

From an investigation to determine the effect of engine-operating variables and internal coolants on spark-advance requirements of liquid-cooled single cylinder for maximum take-off power and maximum cruise economy, the following results were obtained:

1. Among the variables tested only fuel-air ratio and internal coolant-fuel ratio have large effects on the peak-power spark timing.

2. When the spark timing is advanced from normal (inlet, 28° B.T.C.; exhaust, 34° B.T.C.) at a fuel-air ratio of 0.060 to peak power at a fuel-air ratio of 0.057, which sacrifices no engine power for a given inlet-air pressure, a 4-percent reduction in indicated specific fuel consumption is realized. Any uneveness in mixture distribution of a multicylinder engine would result in a decrease in brake specific fuel consumption greater than that for a single-cylinder engine; the more uneven the mixture distribution, the greater is the decrease to be expected.

3. An increase of approximately 10 performance numbers in the lean rating of the fuel would be required to maintain the same knock-limited power at a fuel-air ratio of 0.060 if the spark timing was advanced to peak power.

4. Knock-limited indicated mean effective pressure at take-off conditions was increased about 6 percent when the spark timing was retarded from the normal value (inlet, 28° B.T.C.; exhaust, 34° B.T.C.) to the point where rough operation was reached (inlet, 16° B.T.C.; exhaust, 22° B.T.C.). When the additional supercharger power necessary to supply the higher manifold pressure is considered, the gain in the knock-limited brake horsepower for a multicylinder engine with a single-stage supercharger is approximately 4 percent.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, May 18, 1945.

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1. Waldron, C. D., and Biermann, A. E.: Method of Mounting Cylinder Blocks of In-Line Engines on CUE Crankcases. NACA RB No. E4G27, 1944.

2. Bouchard, C. L., Taylor, C. Fayette, and Taylor, E. S.: Variables Affecting Flame Speed in the Otto-Cycle Engine. SAE Jour., vol. 41, no. 5, Nov. 1937, pp. 514-520.

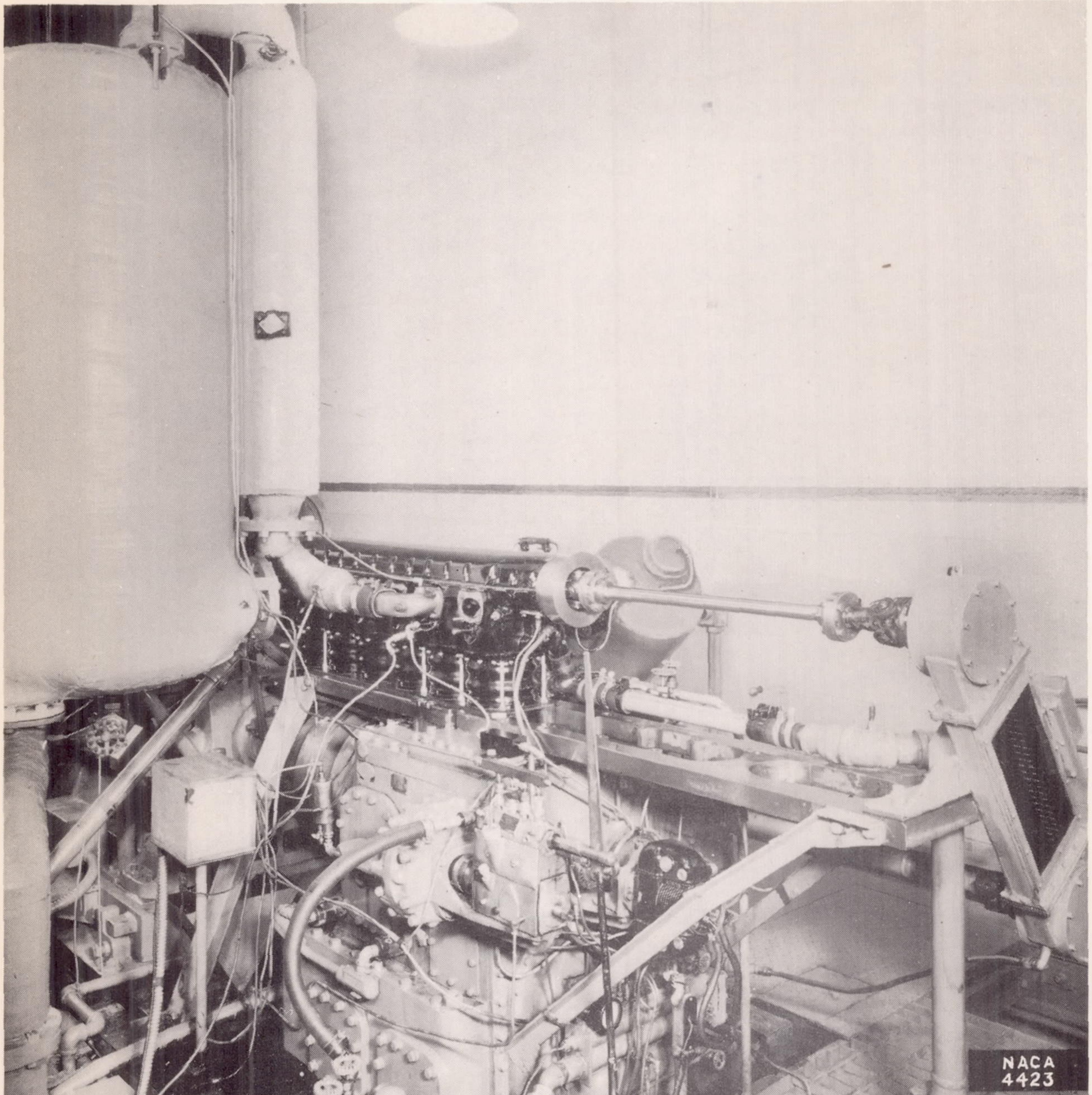

Figure 1. - Multicylinder block adapted to CUE crankcase.

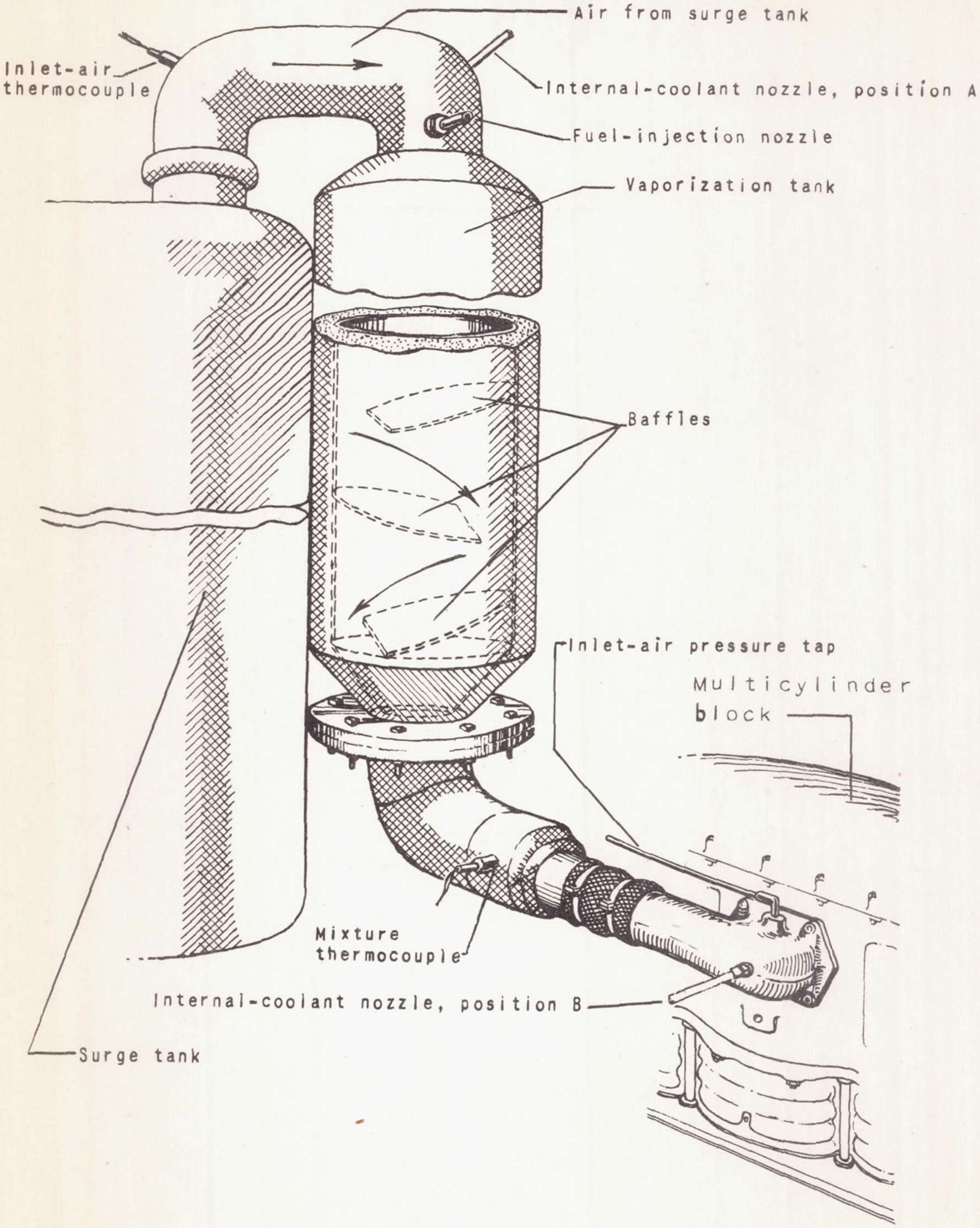

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Figure 2. - Induction system used with multicylinder-block adaptation to CUE crankcase showing two positions of internal-coolant nozzle.

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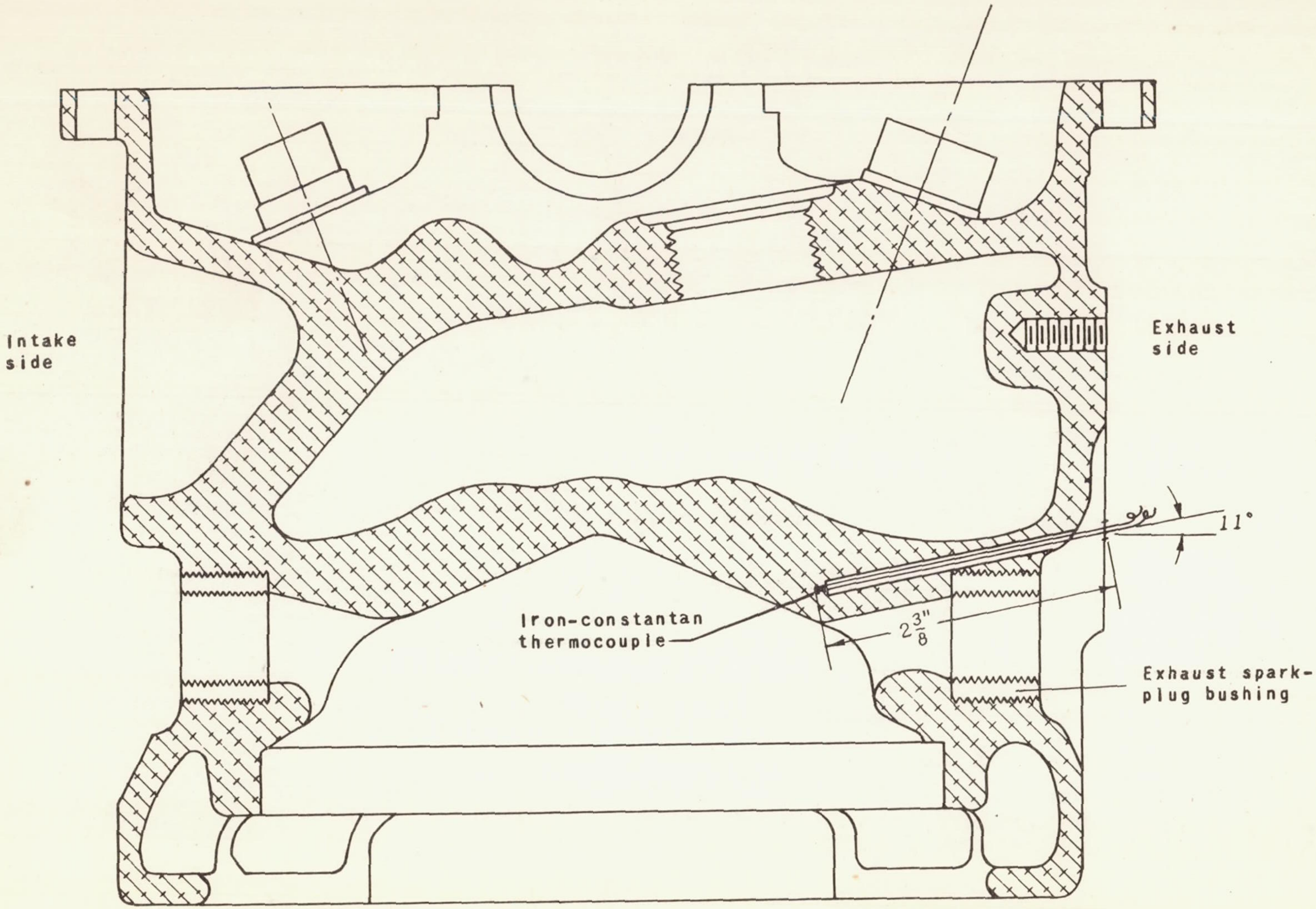
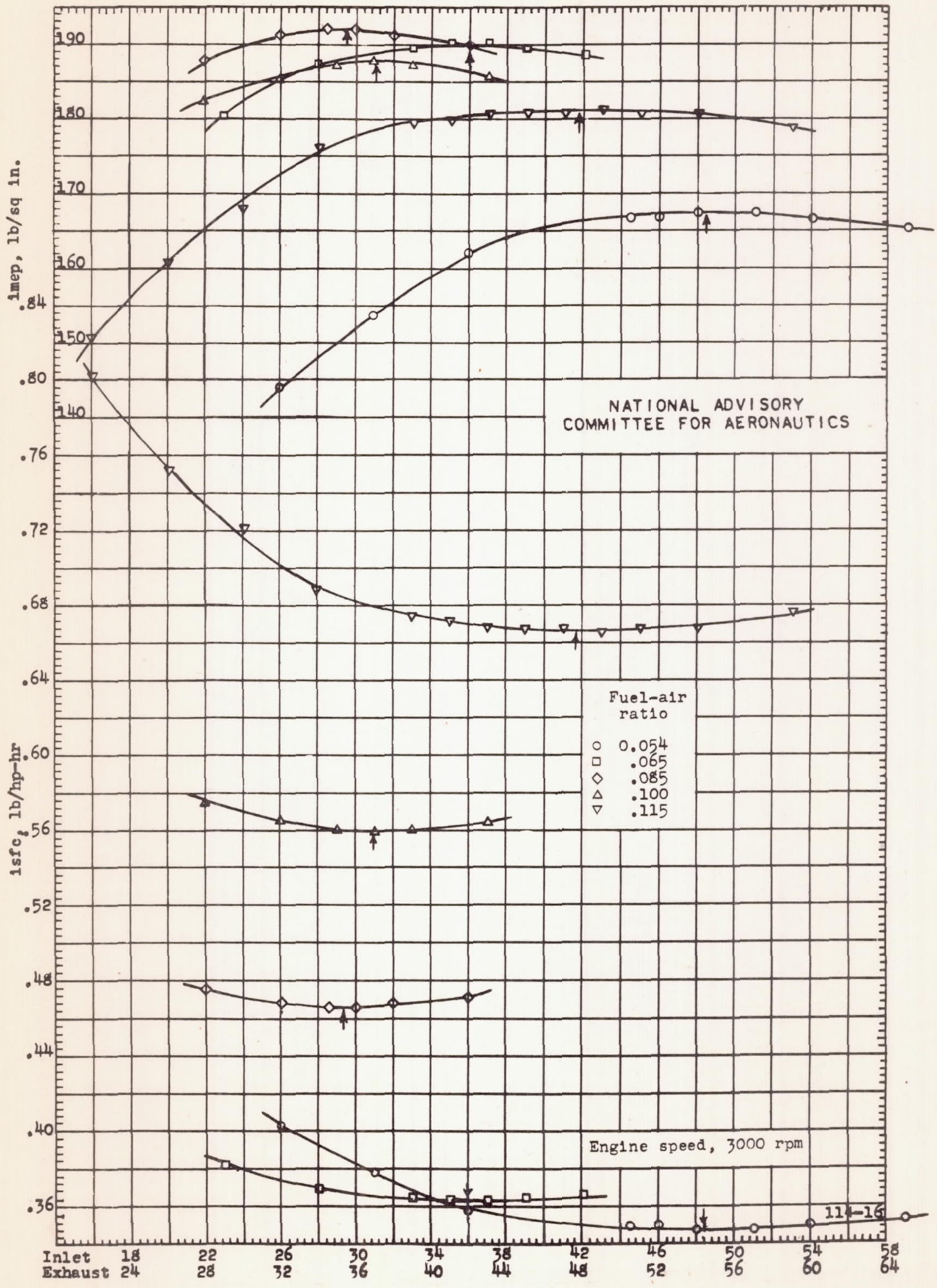
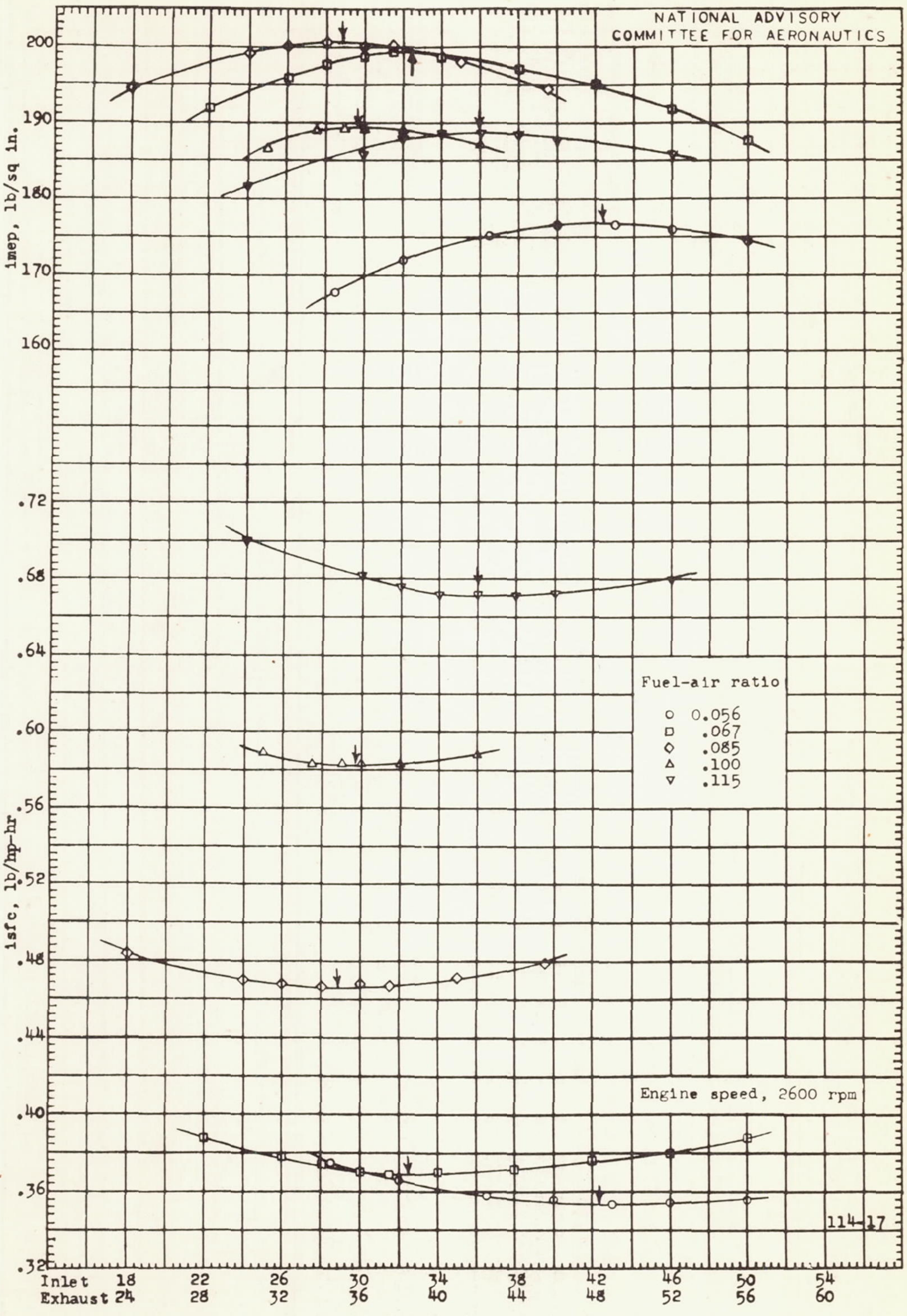


Figure 3. - Thermocouple installation in cylinder head.



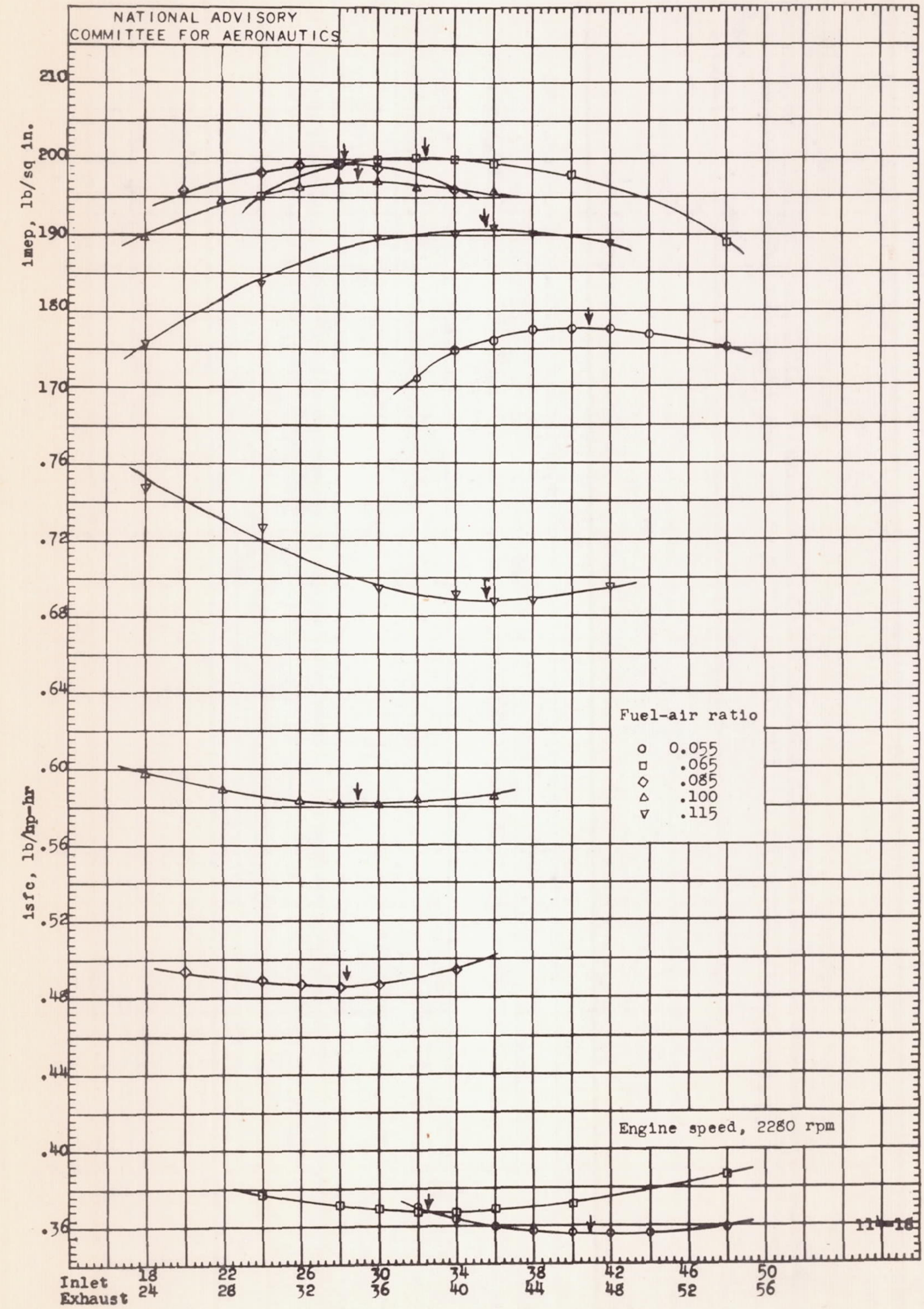
(a) Engine speed, 3000 rpm.

Figure 4. - Effect of spark advance on power and fuel consumption at various fuel-air ratios. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; mixture temperature, 175° F; inlet-air pressure, 40 inches mercury absolute. (Arrows indicate spark advance for peak power.)



(b) Engine speed, 2600 rpm.

Figure 4. - Continued. Effect of spark advance on power and fuel consumption at various fuel-air ratios. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° mixture temperature, 175° F; inlet-air pressure, 40 inches mercury absolute. (Arrows indicate spark advance for peak power.)



(c) Engine speed, 2280 rpm.
Figure 4. - Concluded. Effect of spark advance on power and fuel consumption at various fuel-air ratios. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; mixture temperature, 175° F; inlet-air pressure, 40 inches mercury absolute. (Arrows indicate spark advance for peak power.)

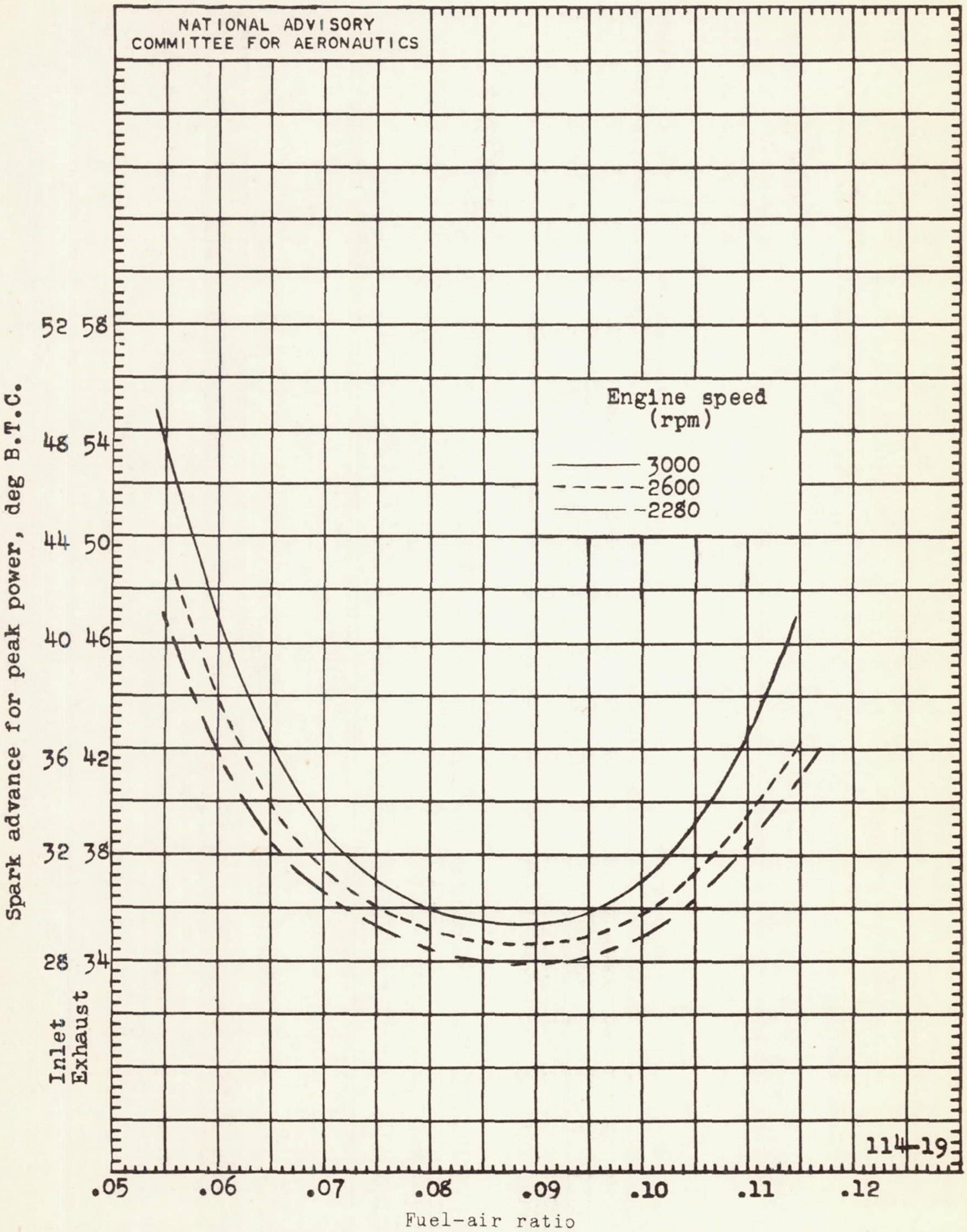
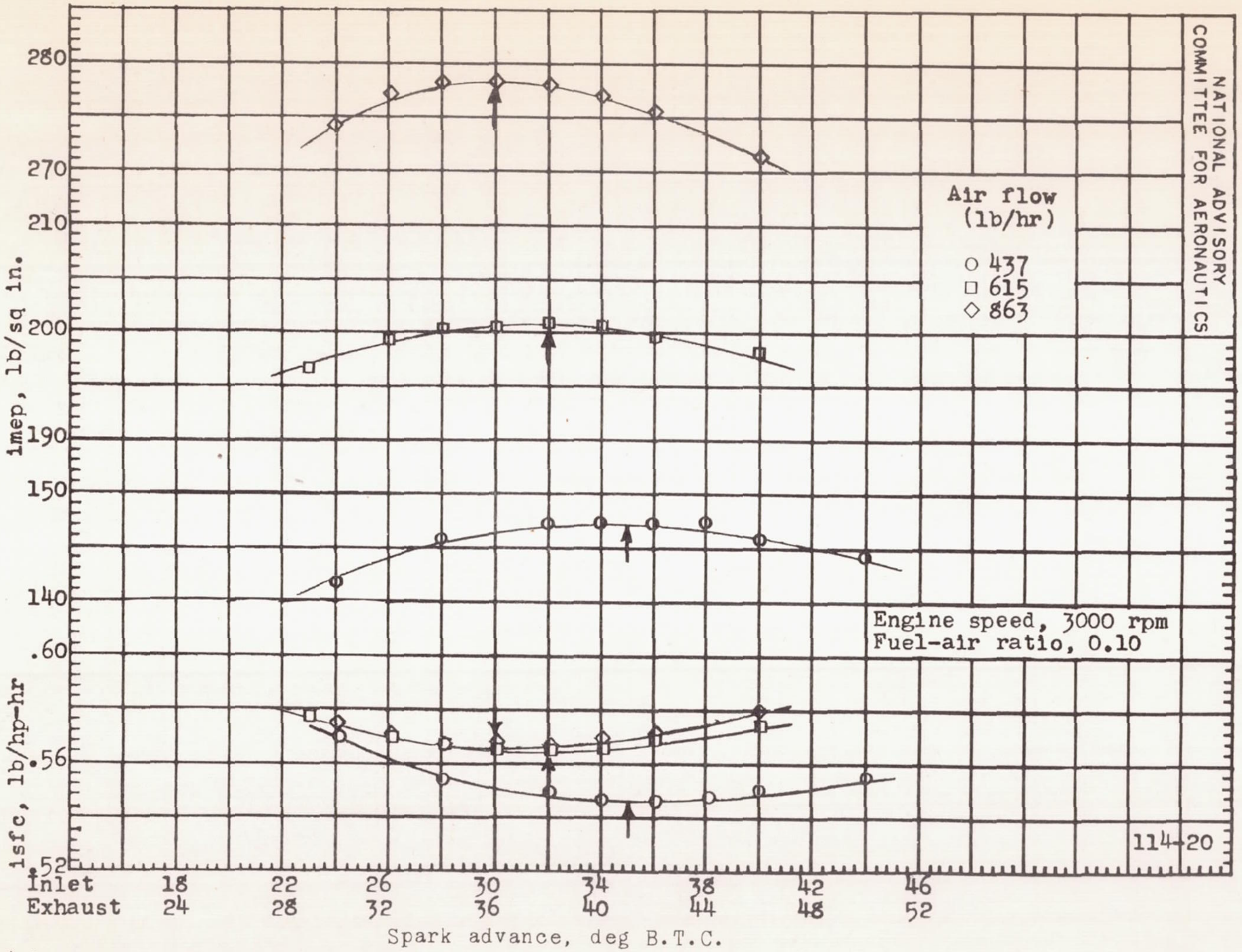
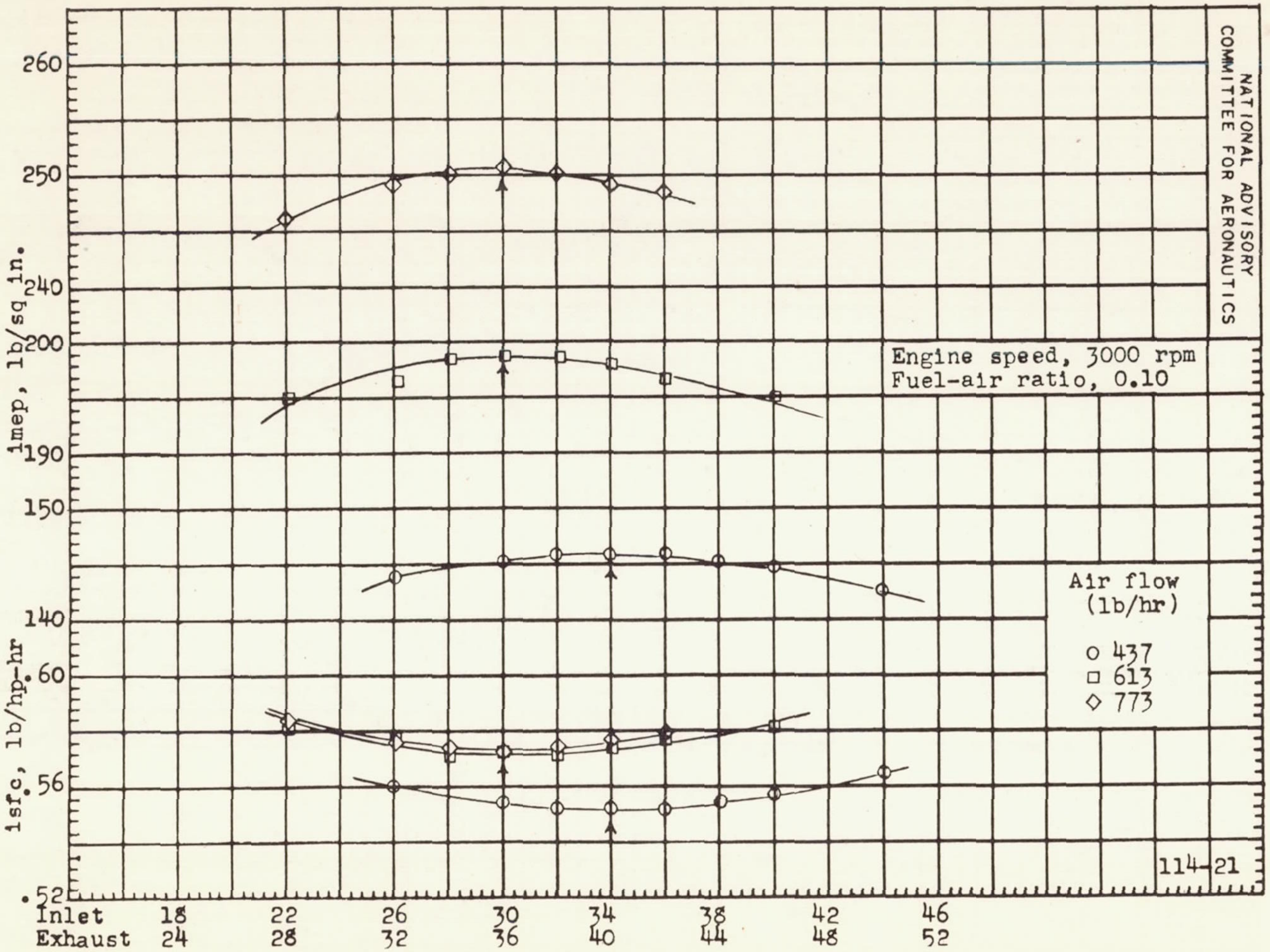


Figure 5. - Effect of fuel-air ratio on spark advance for peak power at various engine speeds. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; mixture temperature, 175° F; inlet-air pressure, 40 inches mercury absolute.



(a) Mixture temperature, 125° F.

Figure 6. - Effect of spark advance on power and fuel consumption at various values of air flow. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; engine speed, 3000 rpm; fuel-air ratio, 0.10. (Arrows indicate spark advance for peak power.)



(b) Mixture temperature, 225° F.

Figure 6. - Concluded. Effect of spark advance on power and fuel consumption at various values of air flow. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; engine speed, 3000 rpm; fuel-air ratio, 0.10. (Arrows indicate spark advance for peak power.)

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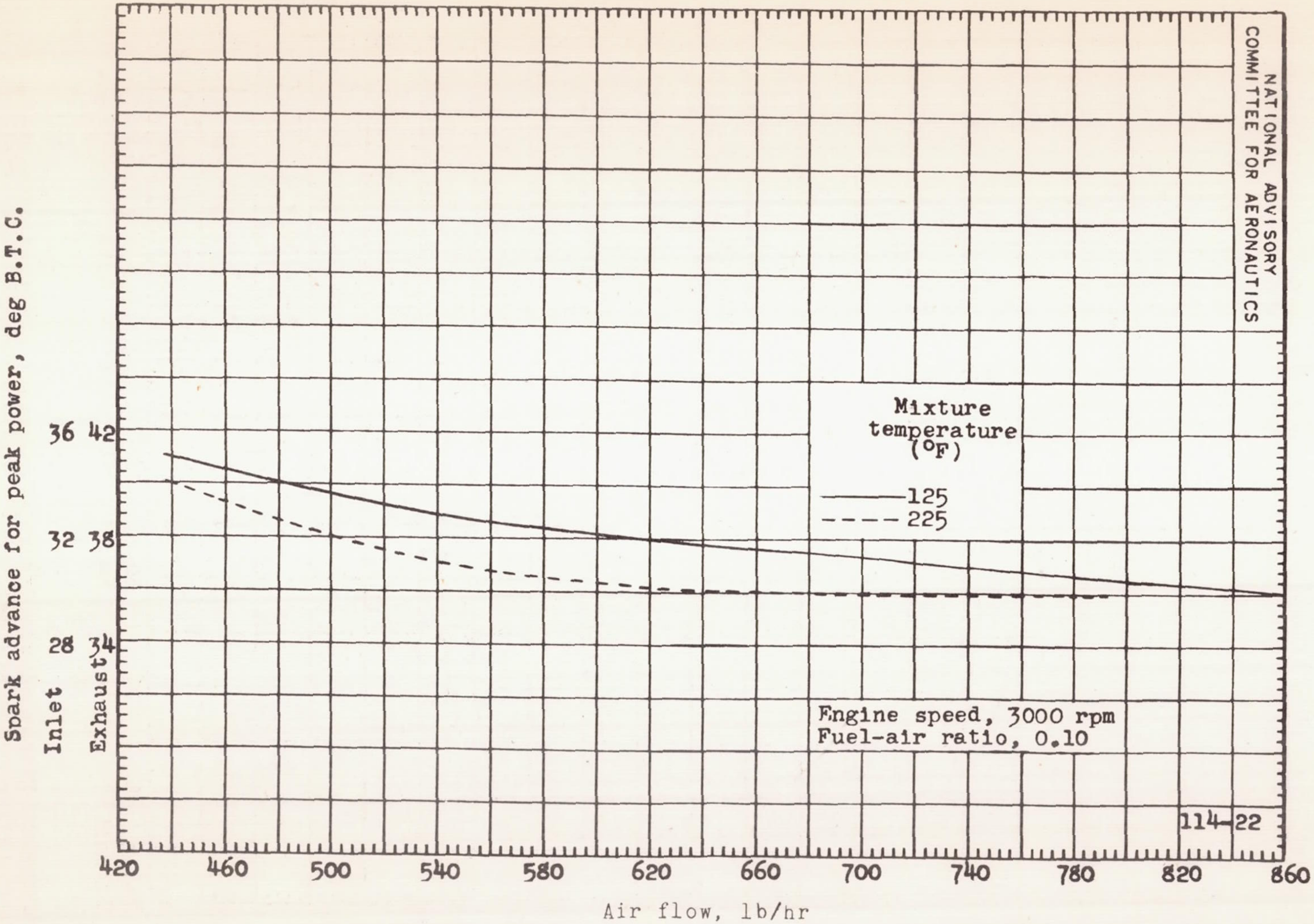


Figure 7. - Effect of air flow on spark advance for peak power at two mixture temperatures. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; engine speed, 3000 rpm; fuel-air ratio, 0.10.

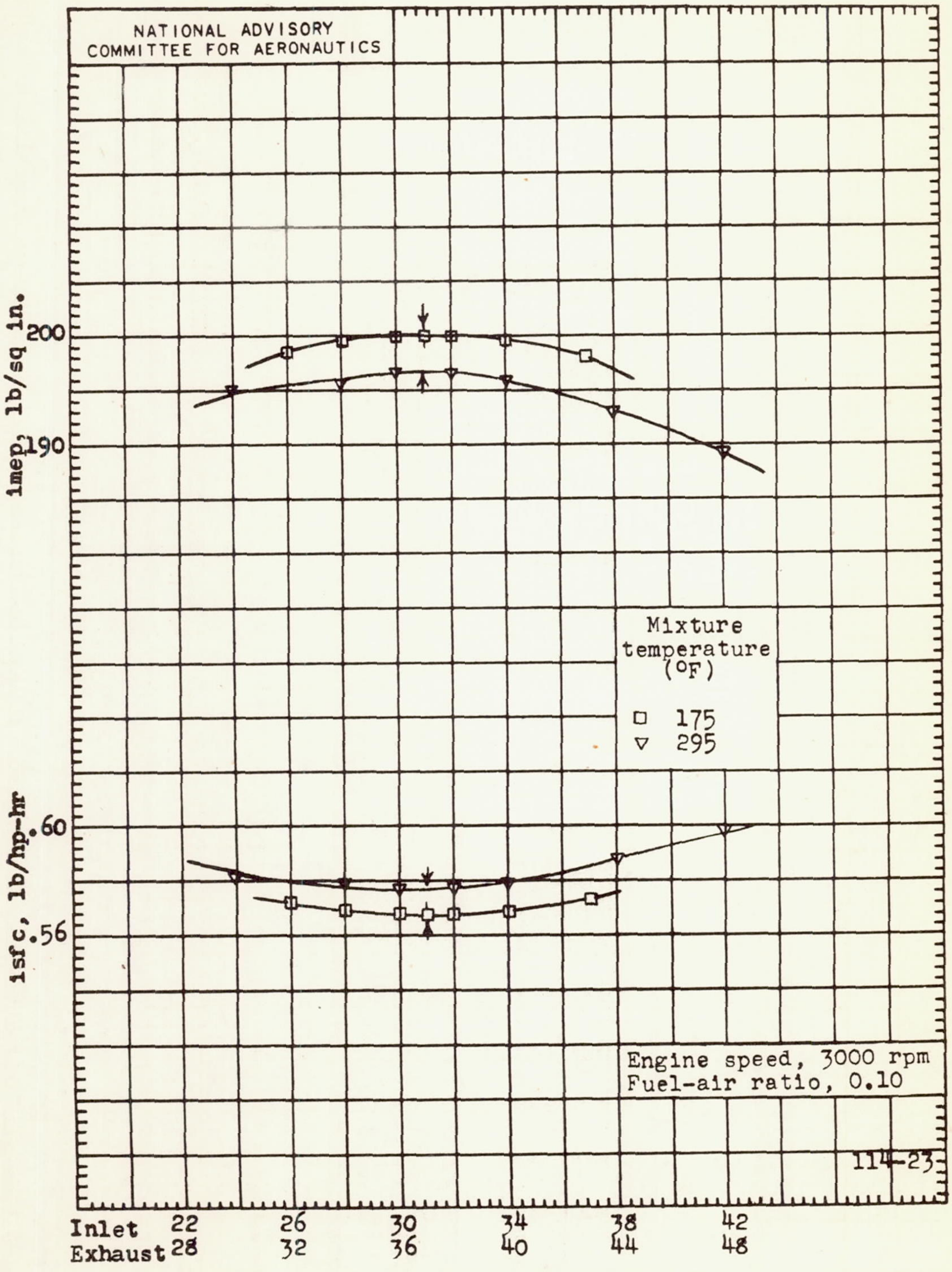


Figure 8. - Effect of spark advance on power and fuel consumption at two mixture temperatures. Single-cylinder adaptation of multi-cylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; engine speed, 3000 rpm; fuel-air ratio, 0.10; air flow, 614 pounds per hour. (Arrows indicate spark advance for peak power.)

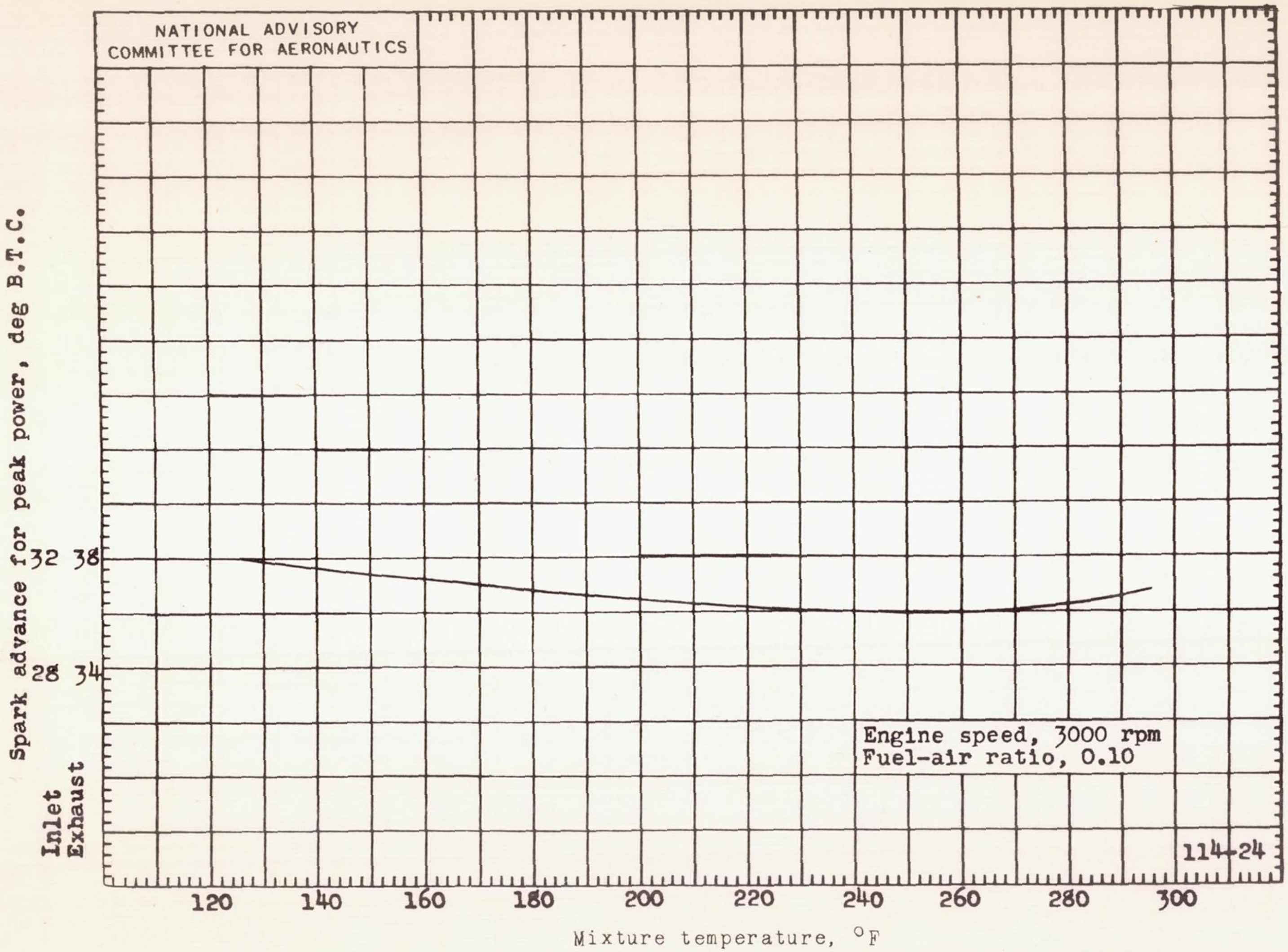
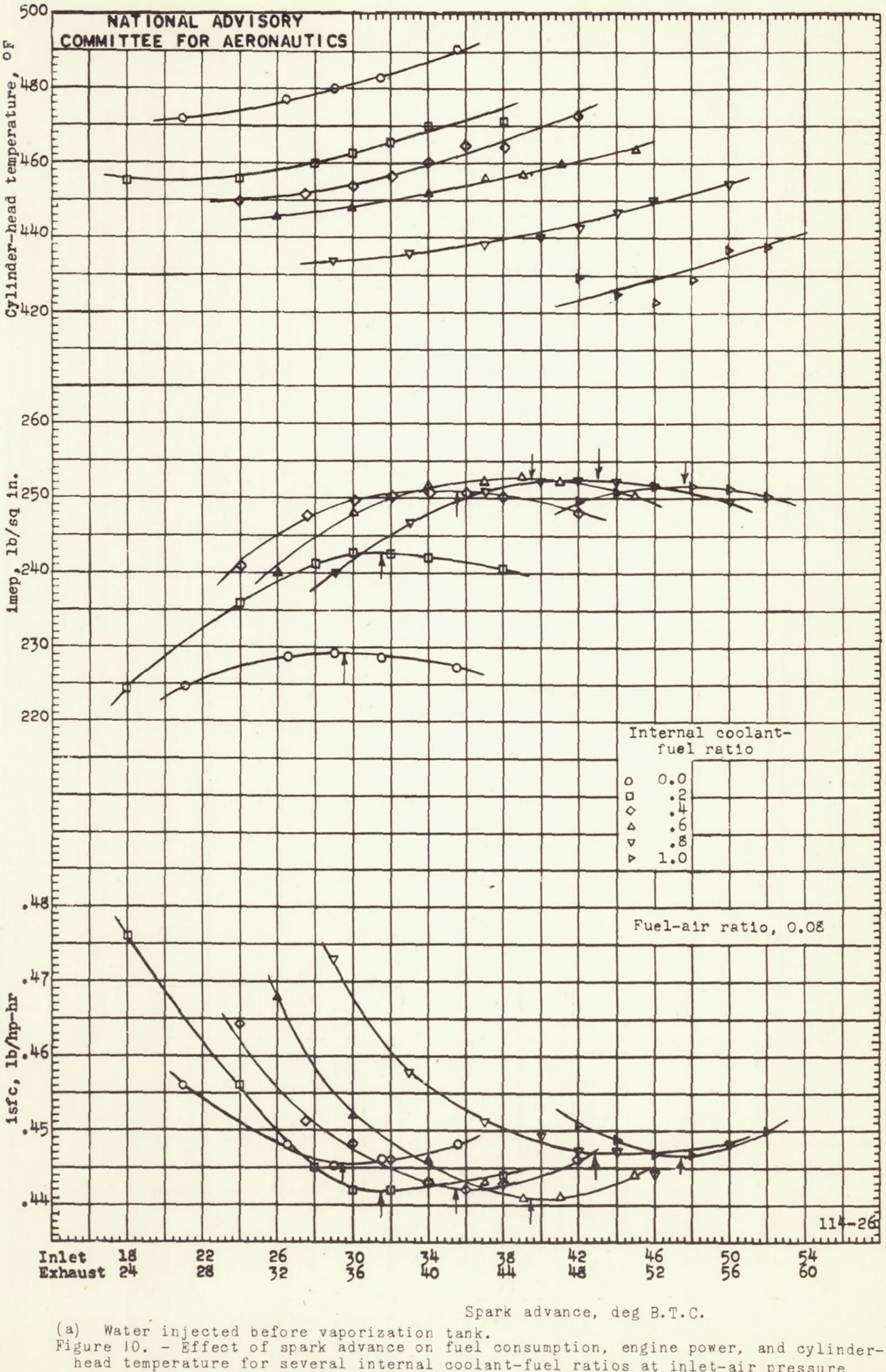
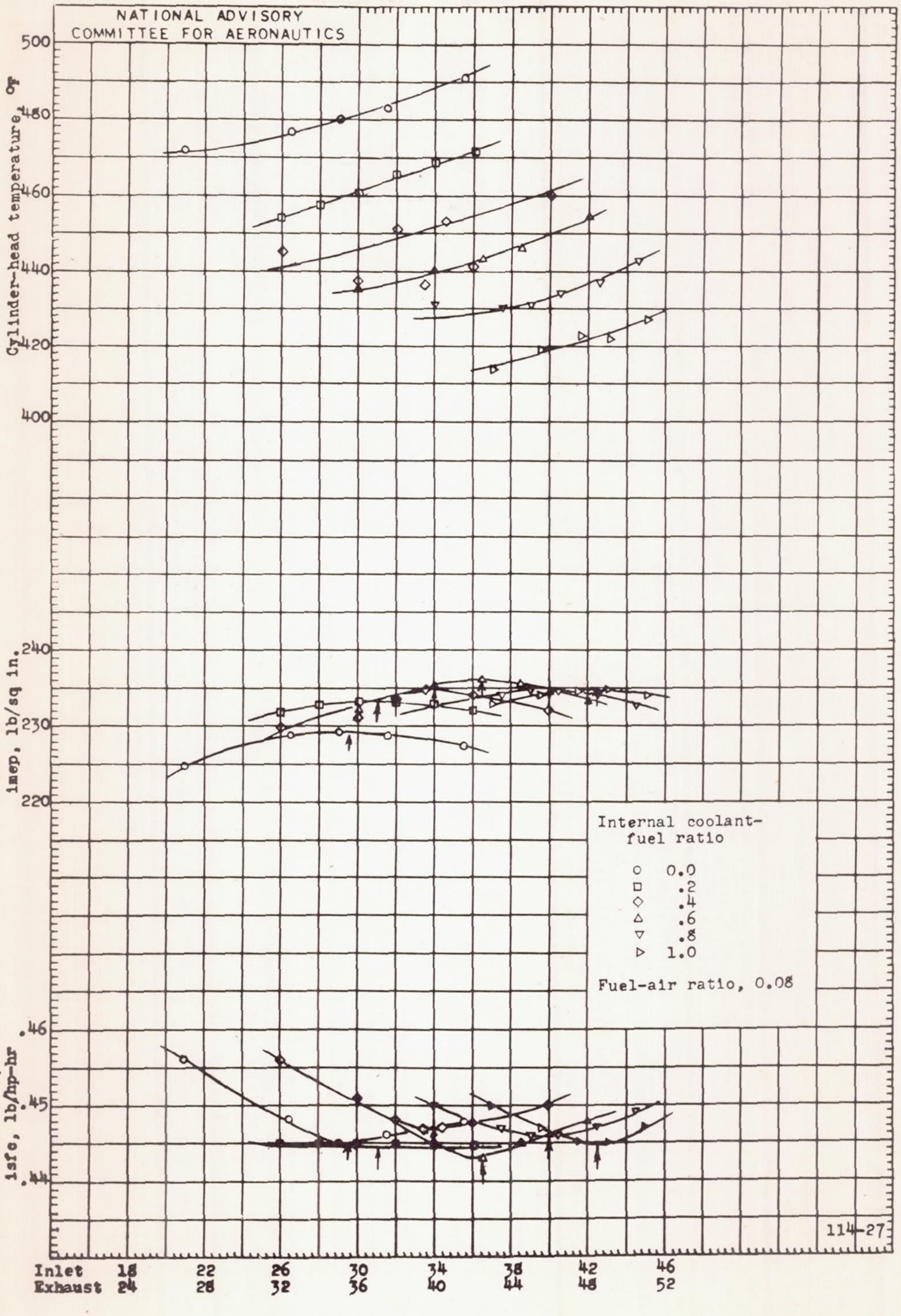


Figure 9. - Effect of mixture temperature on spark advance for peak power at constant air flow. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; engine speed, 3000 rpm; fuel-air ratio, 0.10; air flow, 614 pounds per hour.



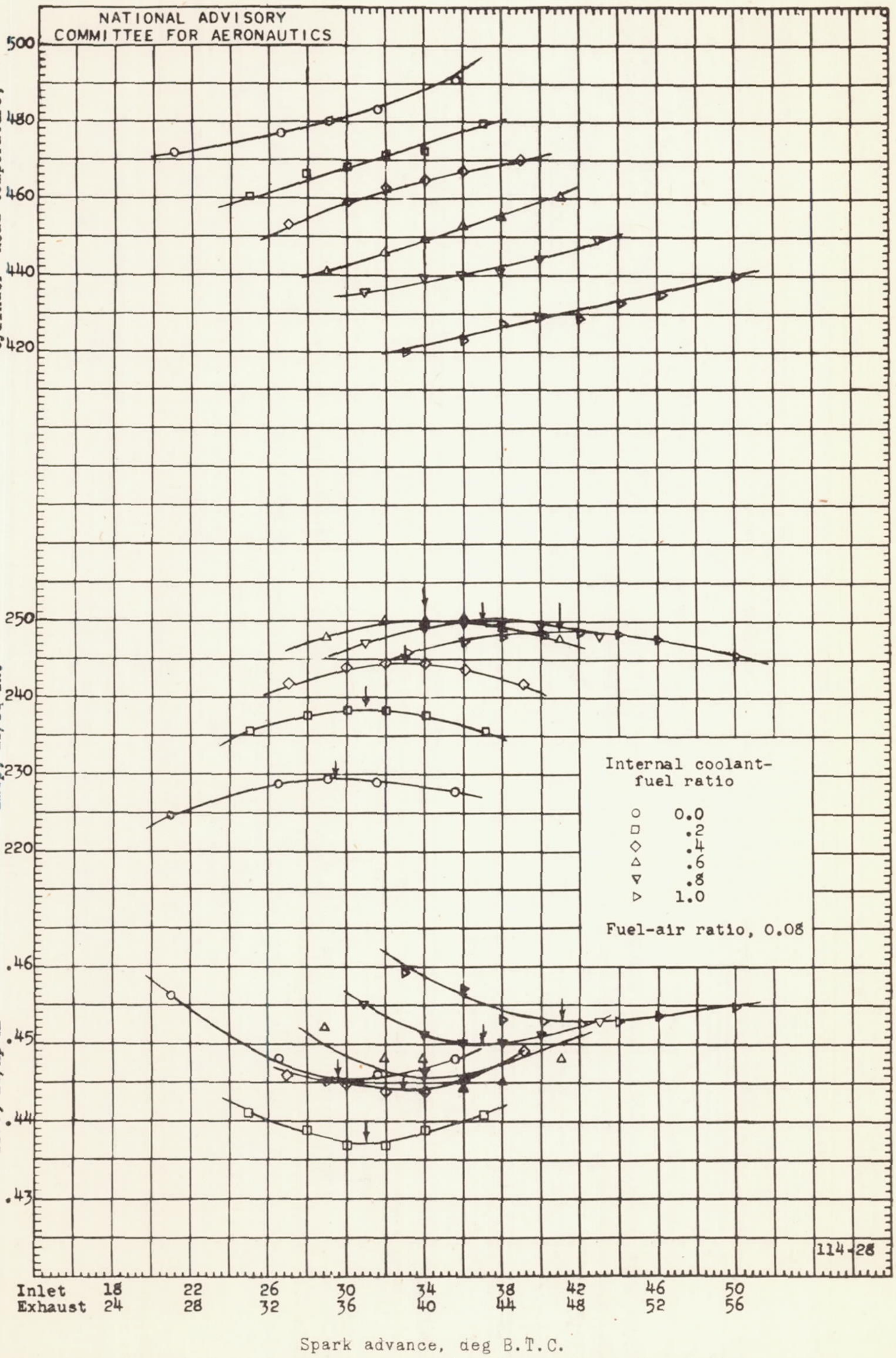
(a) Water injected before vaporization tank.

Figure 10. - Effect of spark advance on fuel consumption, engine power, and cylinder-head temperature for several internal coolant-fuel ratios at inlet-air pressure of 50 inches mercury absolute. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; inlet-air temperature, 250° F; engine speed, 3000 rpm.



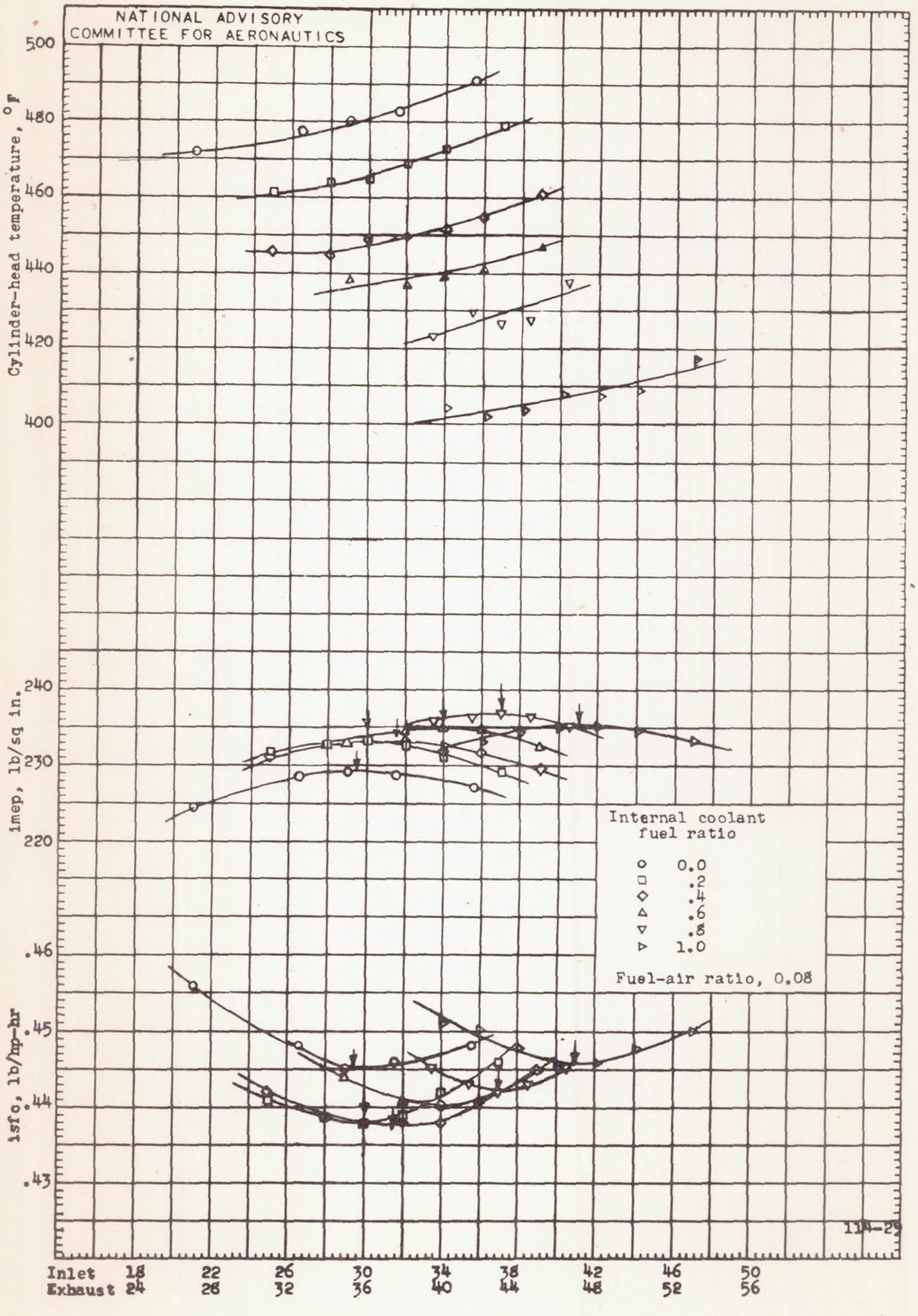
(b) Water injected in intake elbow.

Figure 10. - Continued. Effect of spark advance on fuel consumption, engine power, and cylinder-head temperature for several internal coolant-fuel ratios at inlet-air pressure of 50 inches mercury absolute. Single-cylinder adaptation of multi-cylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; inlet-air temperature, 250° F; engine speed, 3000 rpm.



(c) 50-50 water-ethyl alcohol mixture injected before vaporization tank.

Figure 10. - Continued. Effect of spark advance on fuel consumption, engine power, and cylinder-head temperature for several internal coolant-fuel ratios at inlet-air pressure of 50 inches mercury absolute. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; inlet-air temperature, 250° F; engine speed, 3000 rpm.



(d) 50-50 water-ethyl alcohol mixture injected in intake elbow.

Figure 10. - Concluded. Effect of spark advance on fuel consumption, engine power, and cylinder-head temperature for several internal coolant-fuel ratios at inlet-air pressure of 50 inches mercury absolute. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; inlet-air temperature, 250° F; engine speed, 3000 rpm.

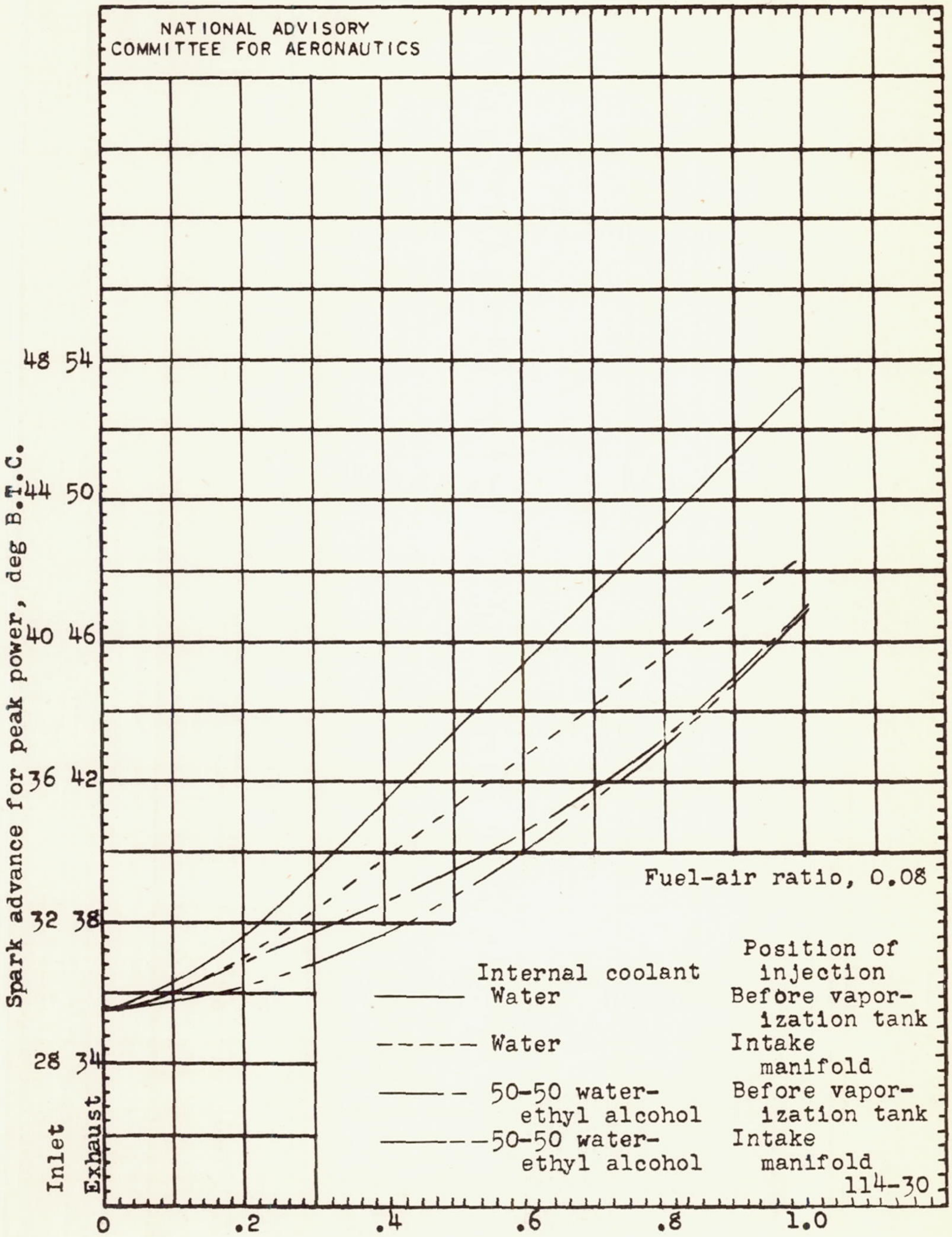


Figure 11. - Effect of internal coolant-fuel ratio on spark advance for peak power for two internal coolants and two positions of injection. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; inlet-air temperature, 250° F; inlet-air pressure, 50 inches mercury absolute; engine speed, 3000 rpm.

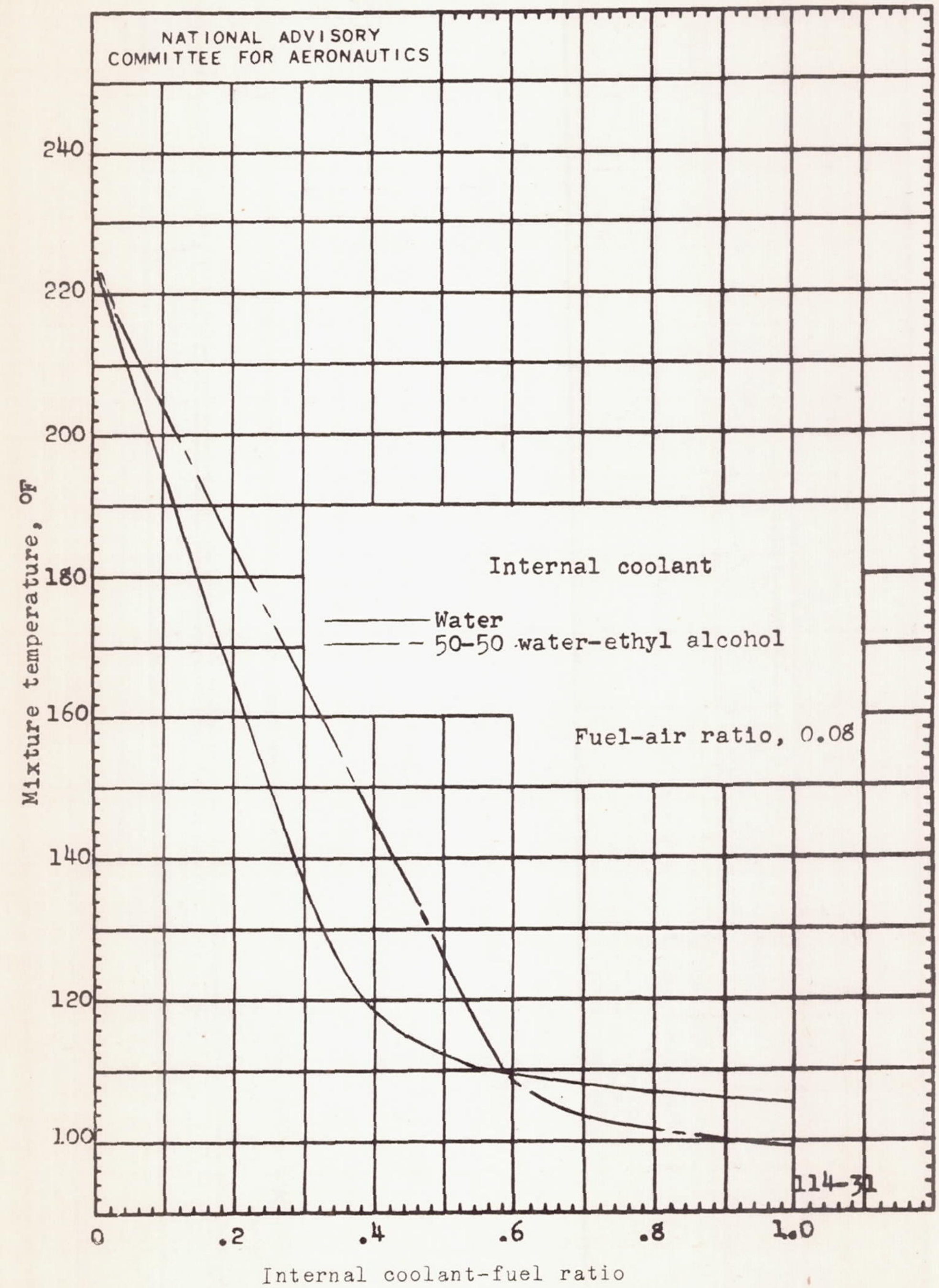


Figure 12. - Effect of internal coolant-fuel ratio on mixture temperature for two internal coolants injected before the vaporization tank. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; inlet-air temperature, 250° F; inlet-air pressure, 50 inches mercury absolute; engine speed, 3000 rpm.

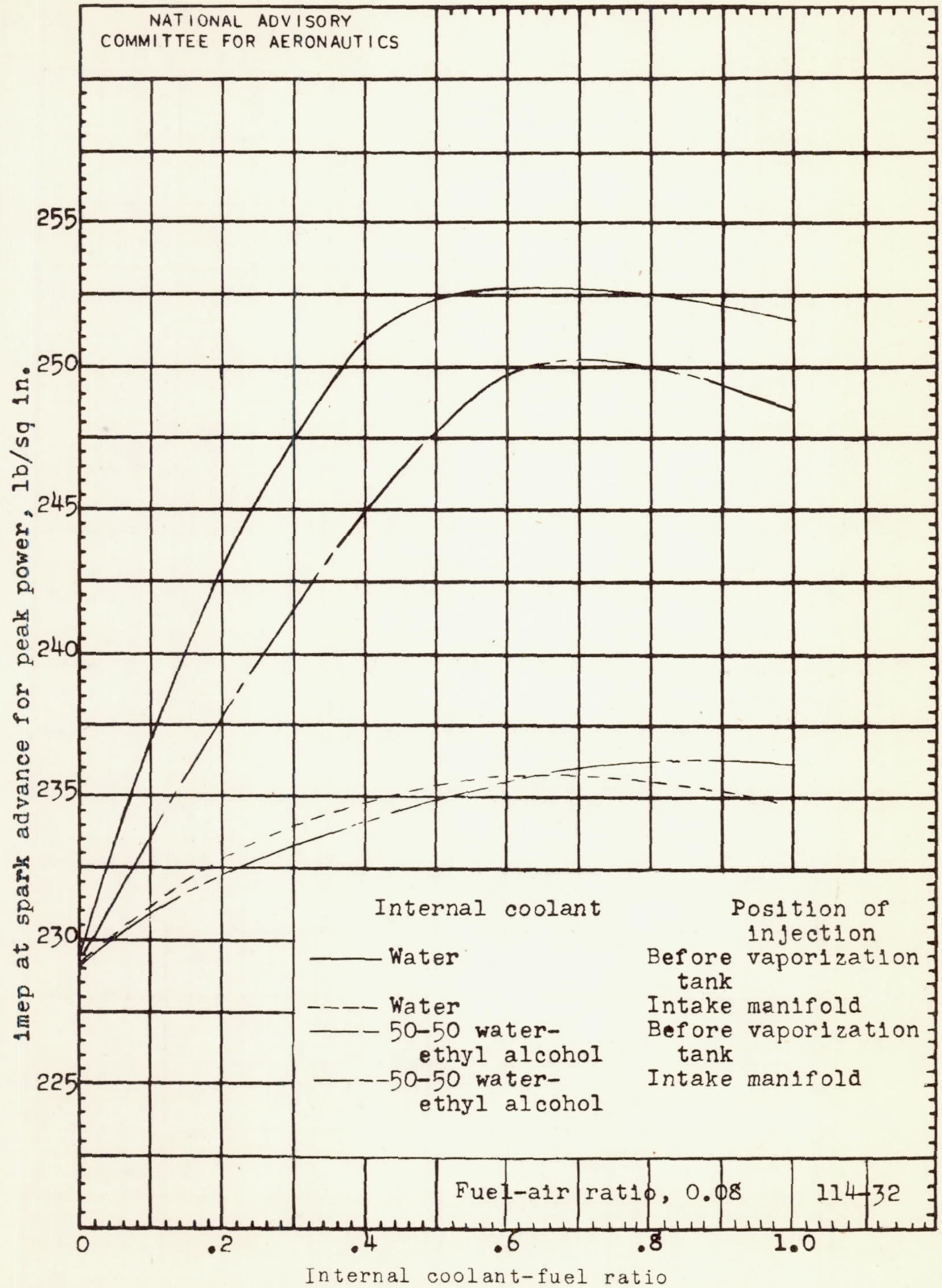


Figure 13. - Effect of internal coolant-fuel ratio on engine power at spark advance for peak power for two internal coolants and two positions of injection. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; inlet-air temperature, 250° F; inlet-air pressure, 50 inches mercury absolute; engine speed, 3000 rpm.

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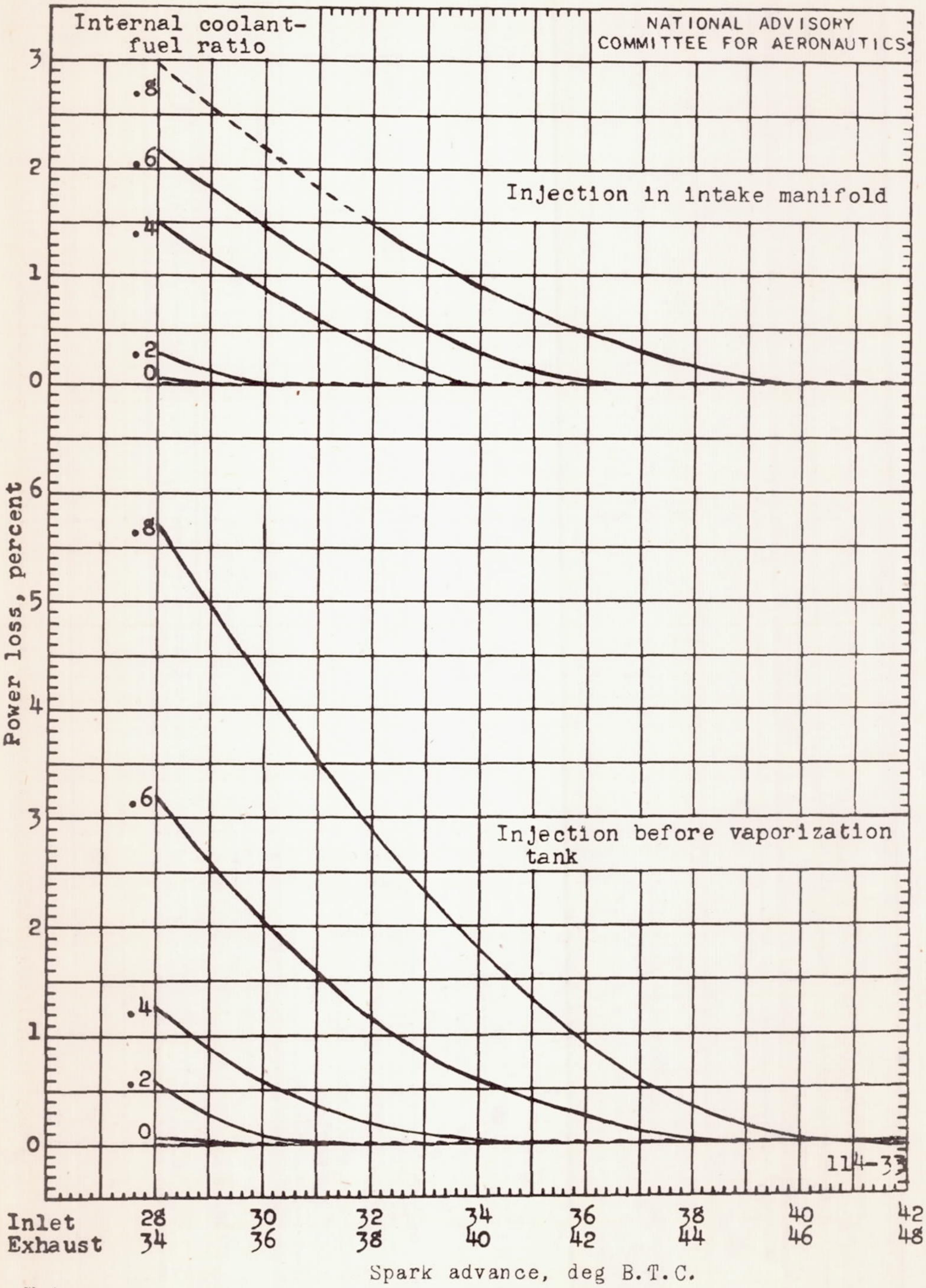
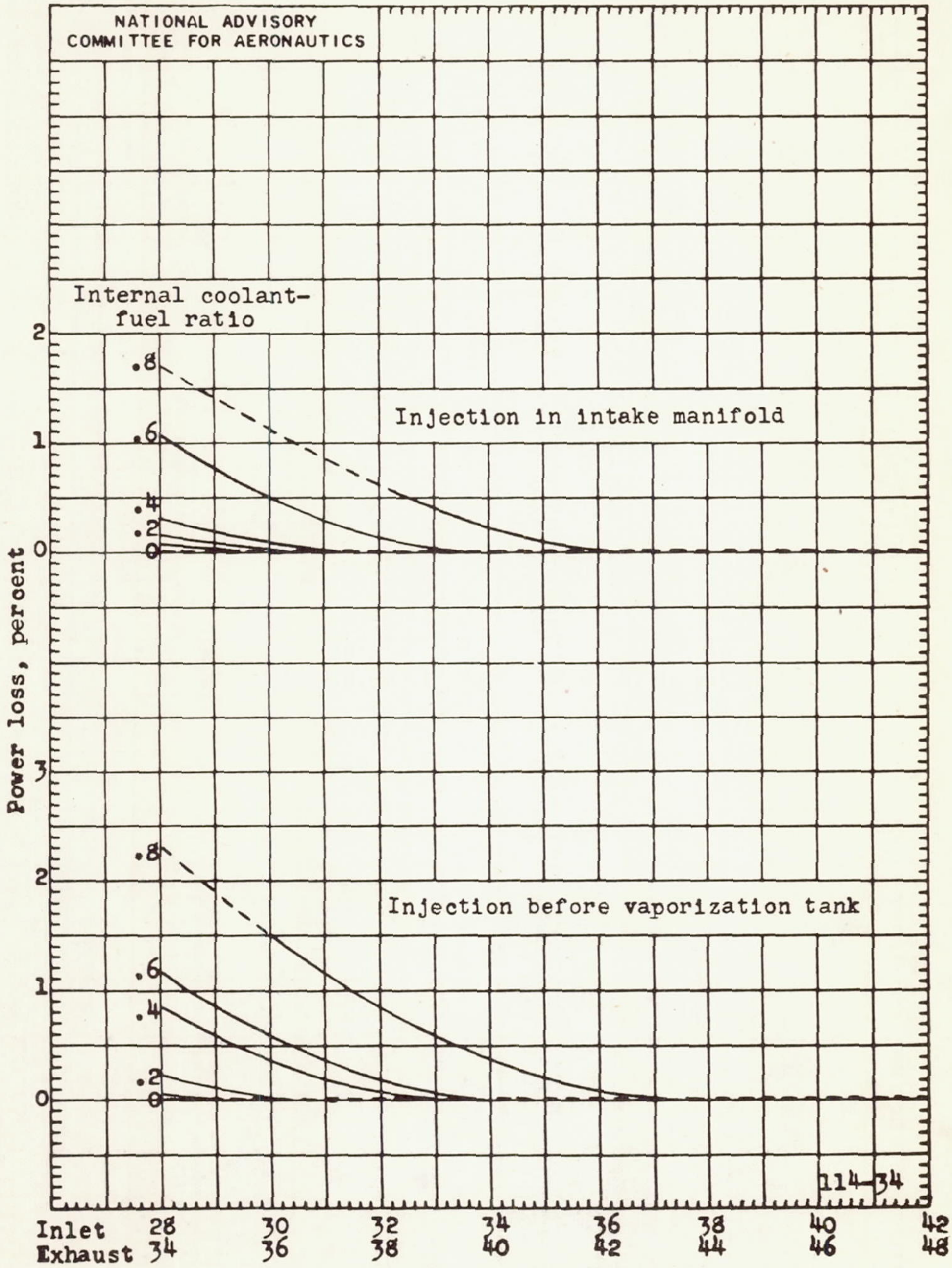


(a) Water.

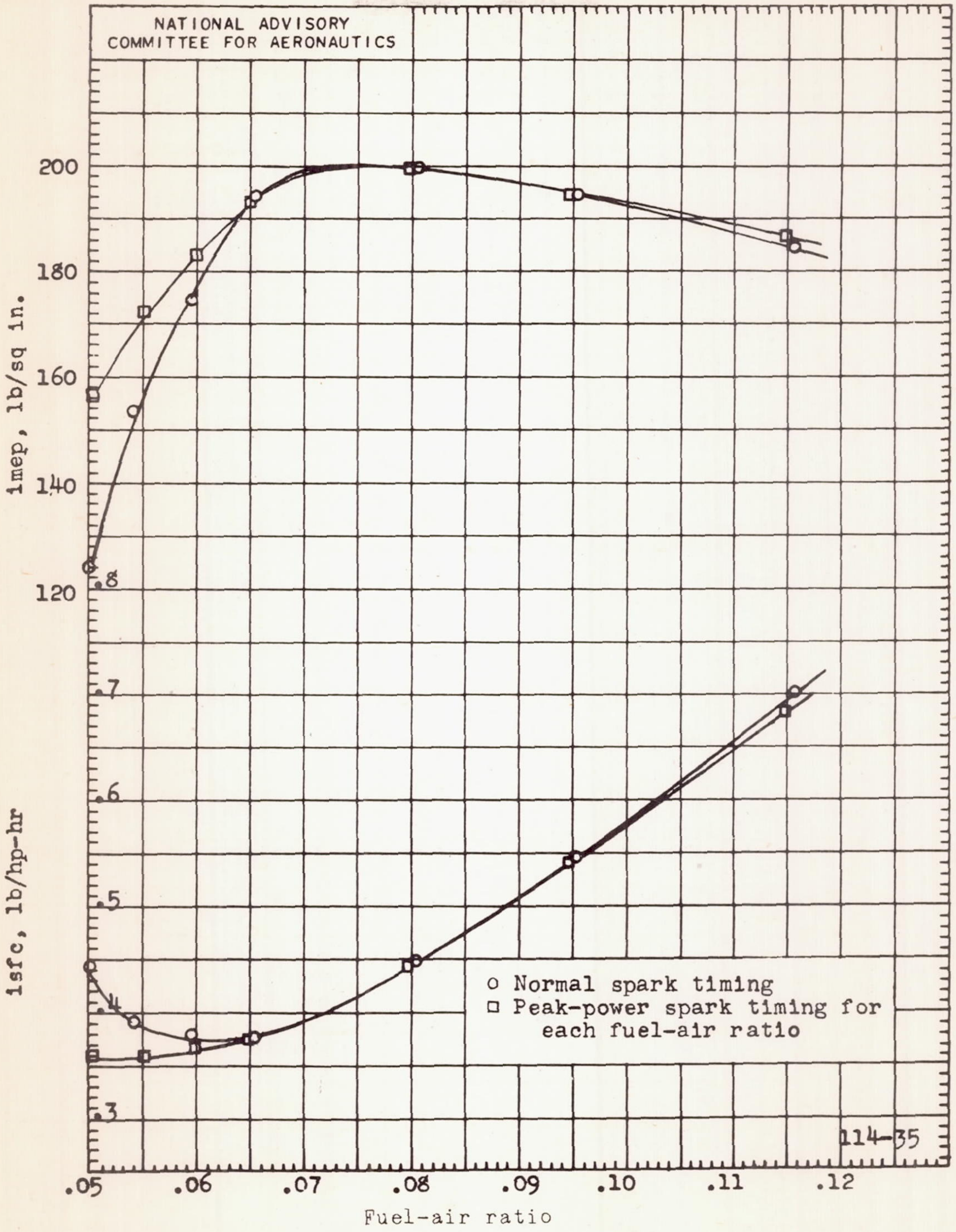
Figure 14. - Loss in power incurred by operating without peak-power spark advance for several internal coolant-fuel ratios and for two positions of injection. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; inlet-air temperature, 250° F; inlet-air pressure, 50 inches mercury absolute; engine speed, 3000 rpm; fuel-air ratio, 0.08.



Spark advance, deg B.T.C.

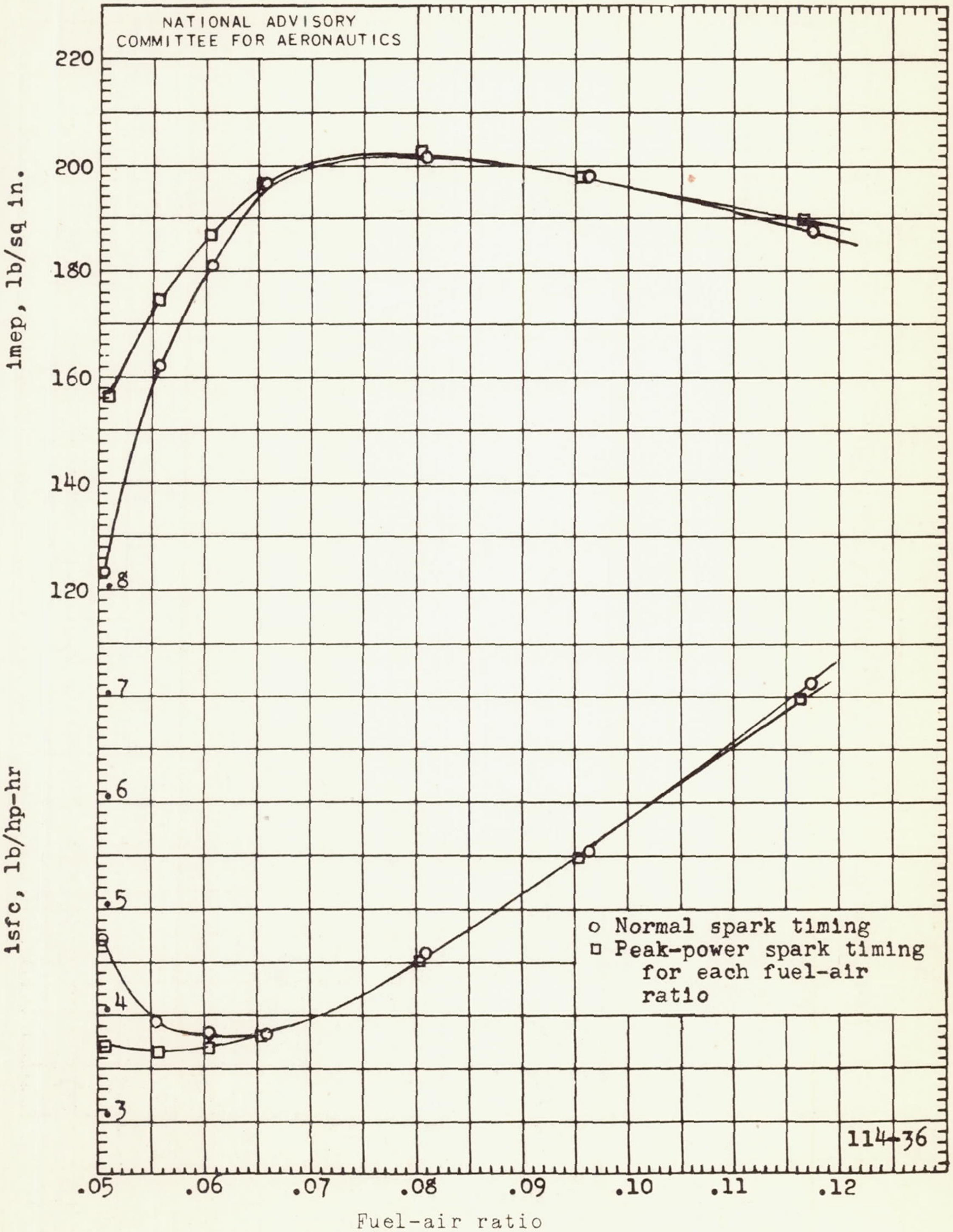
(b) 50-50 water-ethyl alcohol.

Figure 14. - Concluded. Loss in power incurred by operating without peak-power spark advance for several internal coolant-fuel ratios and for two positions of injection. Single-cylinder adaptation of multi-cylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; inlet-air temperature, 250° F; inlet-air pressure, 50 inches mercury absolute; engine speed, 3000 rpm; fuel-air ratio, 0.08.



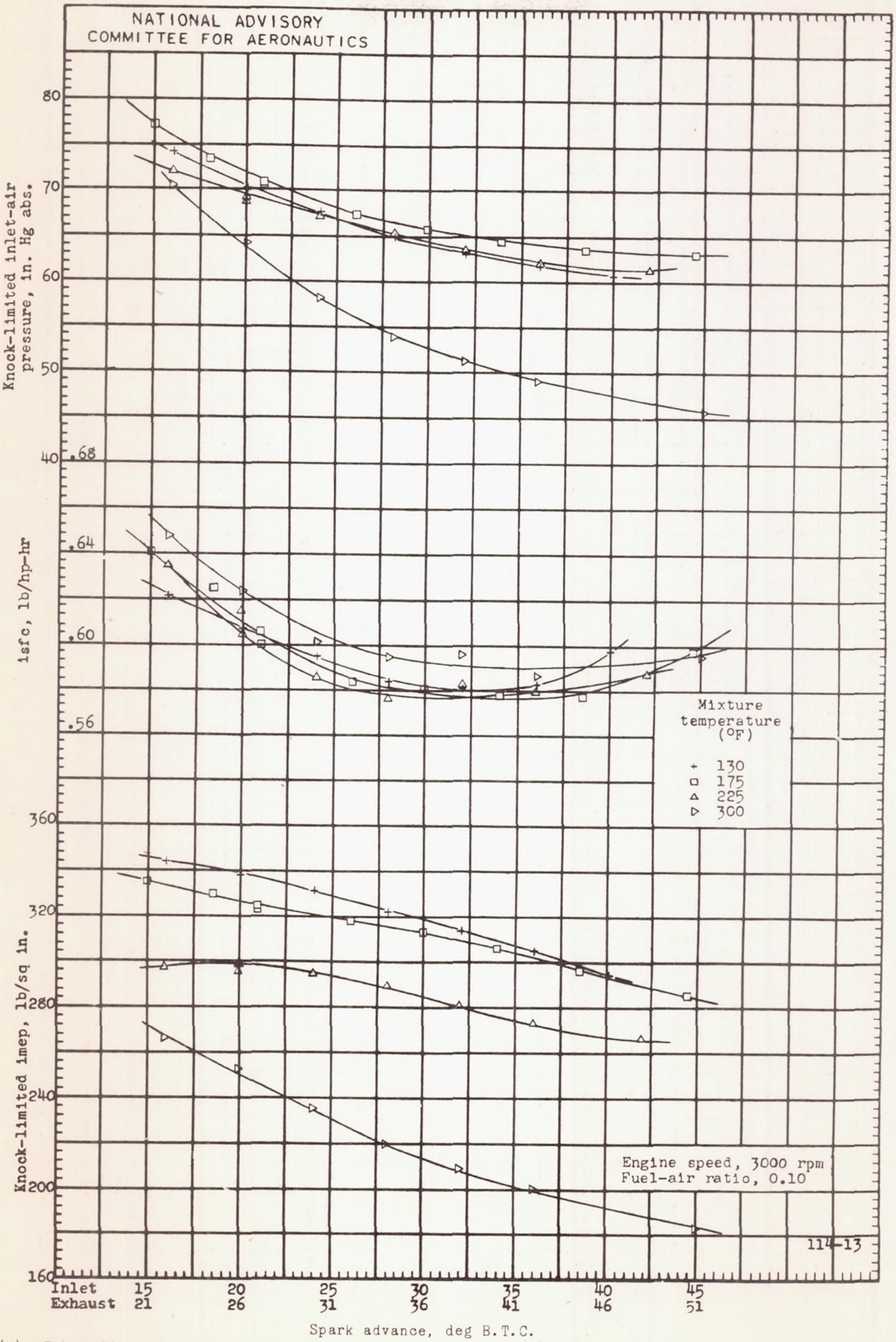
(a) Engine speed, 2600 rpm.

Figure 15. - Effect of fuel-air ratio on power and fuel consumption when operating at either normal or peak-power spark timing. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; mixture temperature, 175° F; inlet-air pressure, 40 inches mercury absolute.



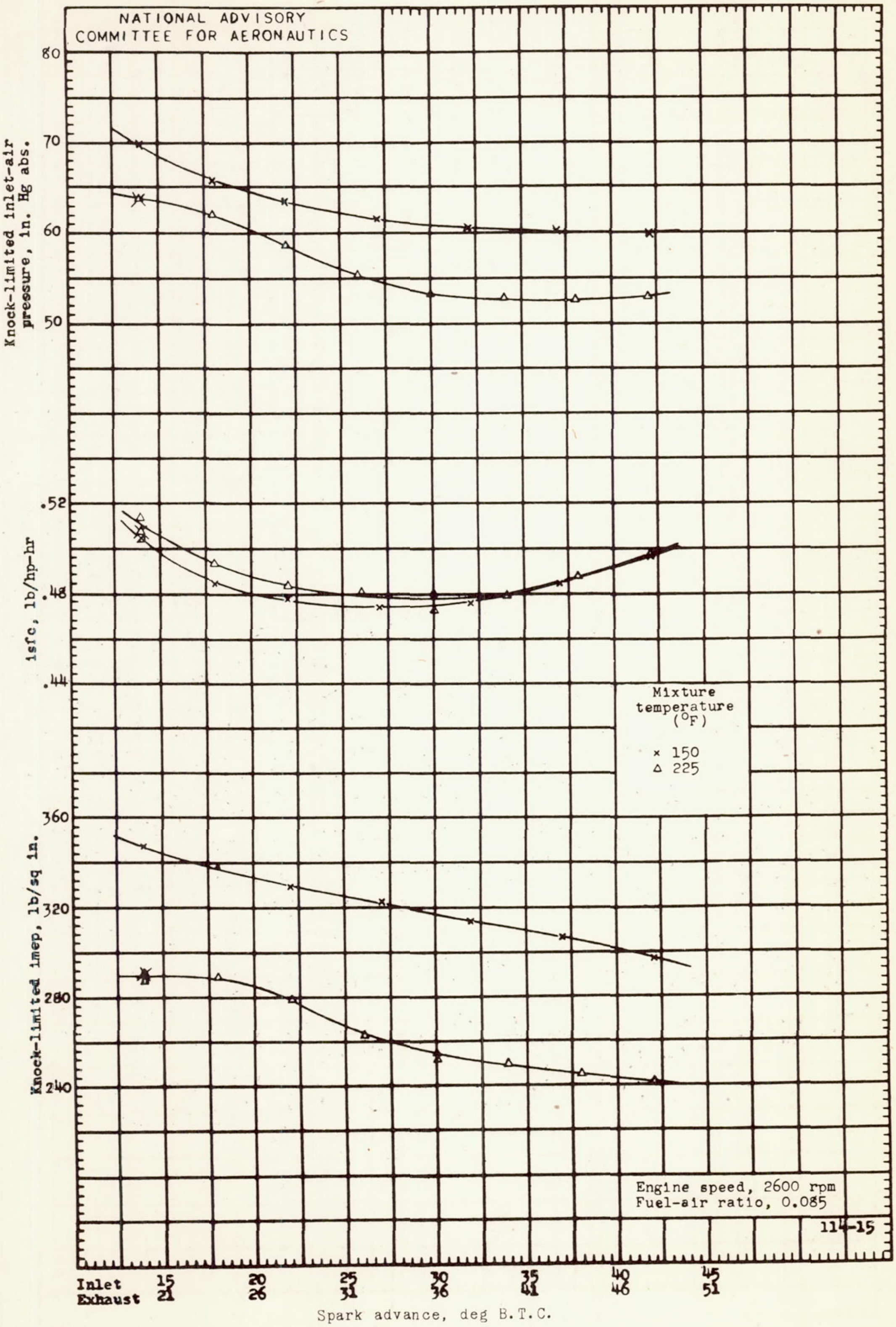
(b) Engine speed, 2280 rpm.

Figure 15. - Concluded. Effect of fuel-air ratio on power and fuel consumption when operating at either normal or peak-power spark timing. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; mixture temperature, 175° F; inlet-air pressure, 40 inches mercury absolute.

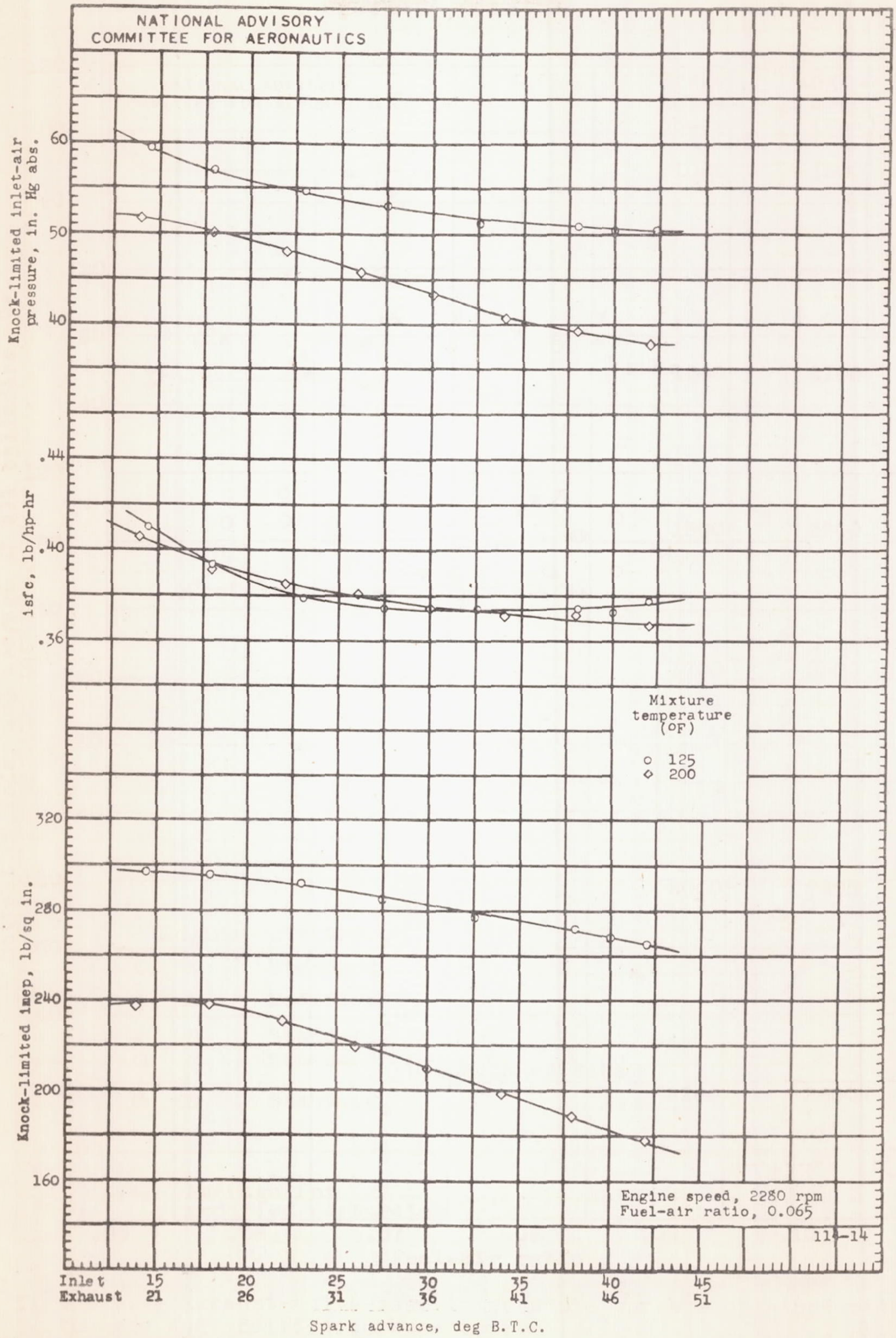


(a) Take-off conditions.

Figure 16. - Effect of spark advance on knock-limited performance at various mixture temperatures. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F.



(b) High-power cruise conditions.
Figure 16. - Continued. Effect of spark advance on knock-limited performance at various mixture temperatures. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F.



(c) Low-power cruise conditions.

Figure 16. - Concluded. Effect of spark advance on knock-limited performance at various mixture temperatures. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F.