NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
May 1945 as
Memorandum Report E5E18

EFFECT OF ENGINE-OPERATING VARIABLES AND INTERNAL COOLANTS

ON SPARK-ADVANCE REQUIREMENTS OF A LIQUID-COOLED CYLINDER

By John F. Pfender, Carl Dudugjian, and A. F. Lietzke

Aircraft Engine Research Laboratory
Cleveland, Ohio

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

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

By John F. Pfender, Carl Dudugjian, and A. F. Lietzke

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 unevenness 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 those 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; how-
ever, 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 de-
creases 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 con-
sumption 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. Conse-
quently 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 in-
fluence of mixture temperature on peak-power spark advance is
almost negligible. In these tests the effect of mixture tem-
perature 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 pre-
sented 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 tempera-
ture 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 mix-
ture with the internal coolants, any additional cooling of the mix-
ture must occur after the intake valves close, which makes it im-
possible 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 speci-
fic 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 opera-
tion 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 tempera-
tures; whereas the increase was considerably greater at high mix-
ture 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 distri-
bution, 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 con-
sumption 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 dis-
tribution 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 reduc-
tion 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 distri-
bution. It is estimated, however, that an increase of approximately
10 performance numbers in the lean rating of the fuel would be re-
quired 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.

REFERENCES

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.
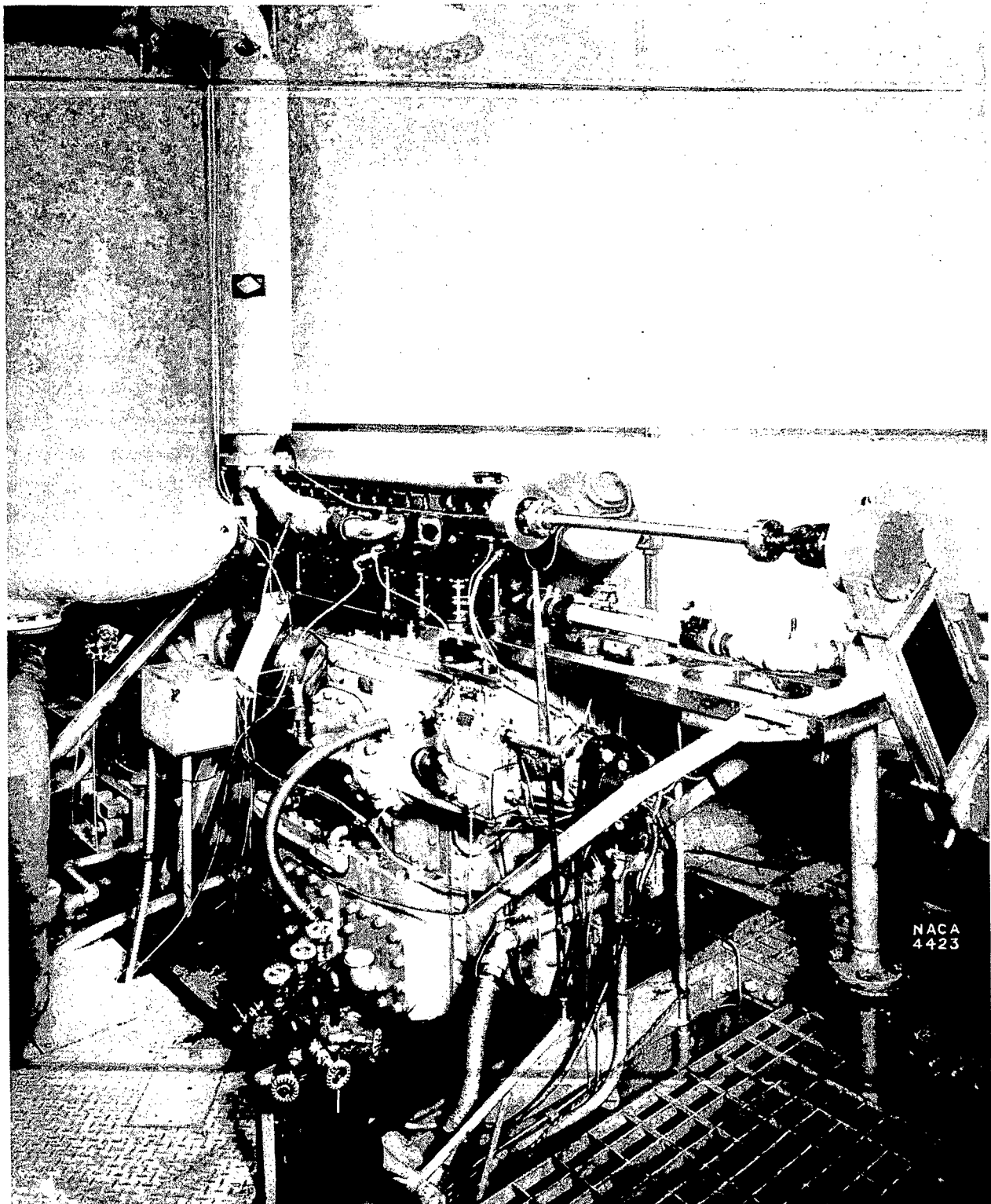
Figure 1. - Multicylinder block adapted to CUE crankcase.
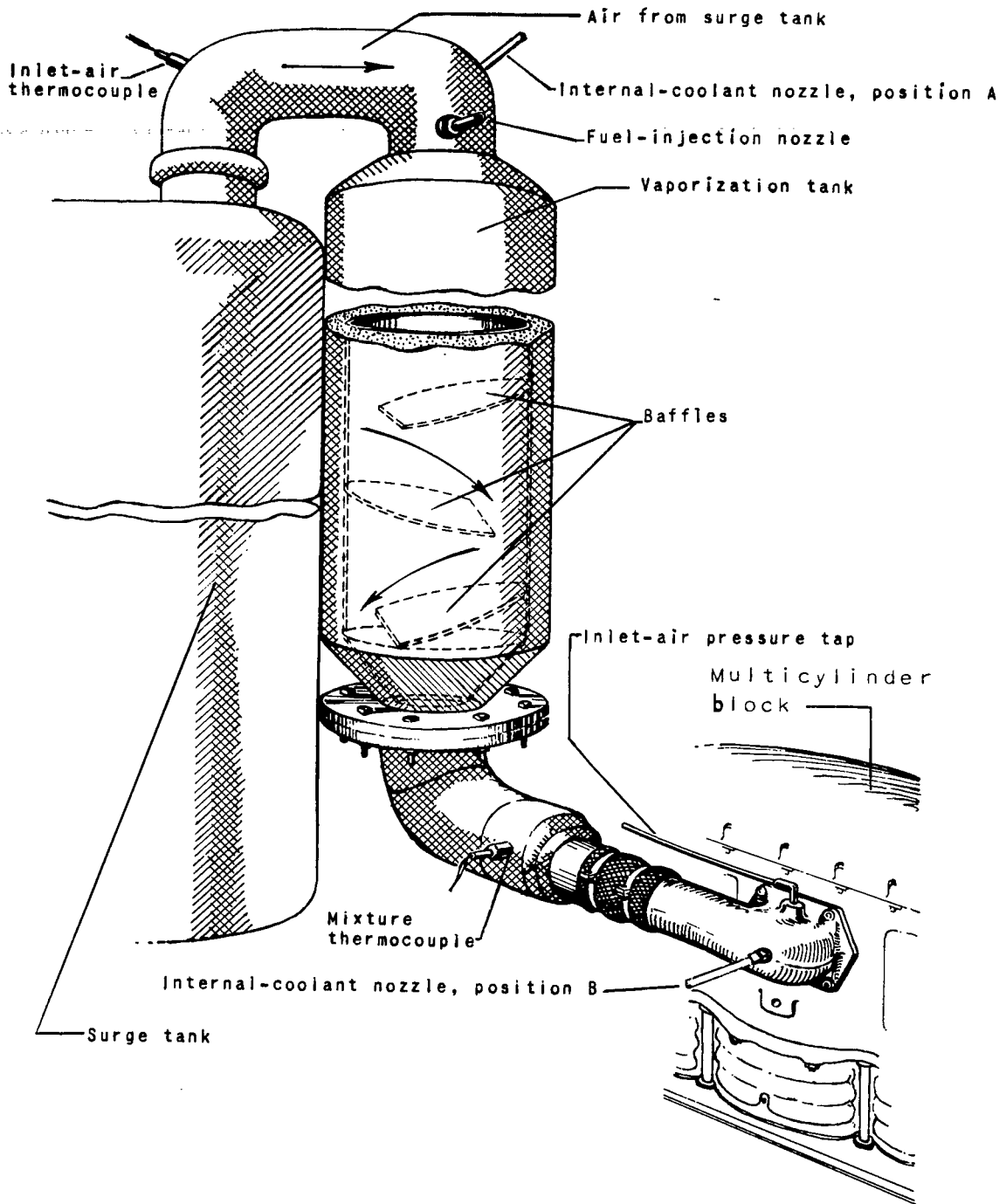
Figure 2. - Induction system used with multicylinder-block
adaptation to CUE crankcase showing two positions of
internal-coolant nozzle.

Intake side

Exhaust side

11°

2 3/8"

Iron-constantan thermocouple

Exhaust spark-plug bushing
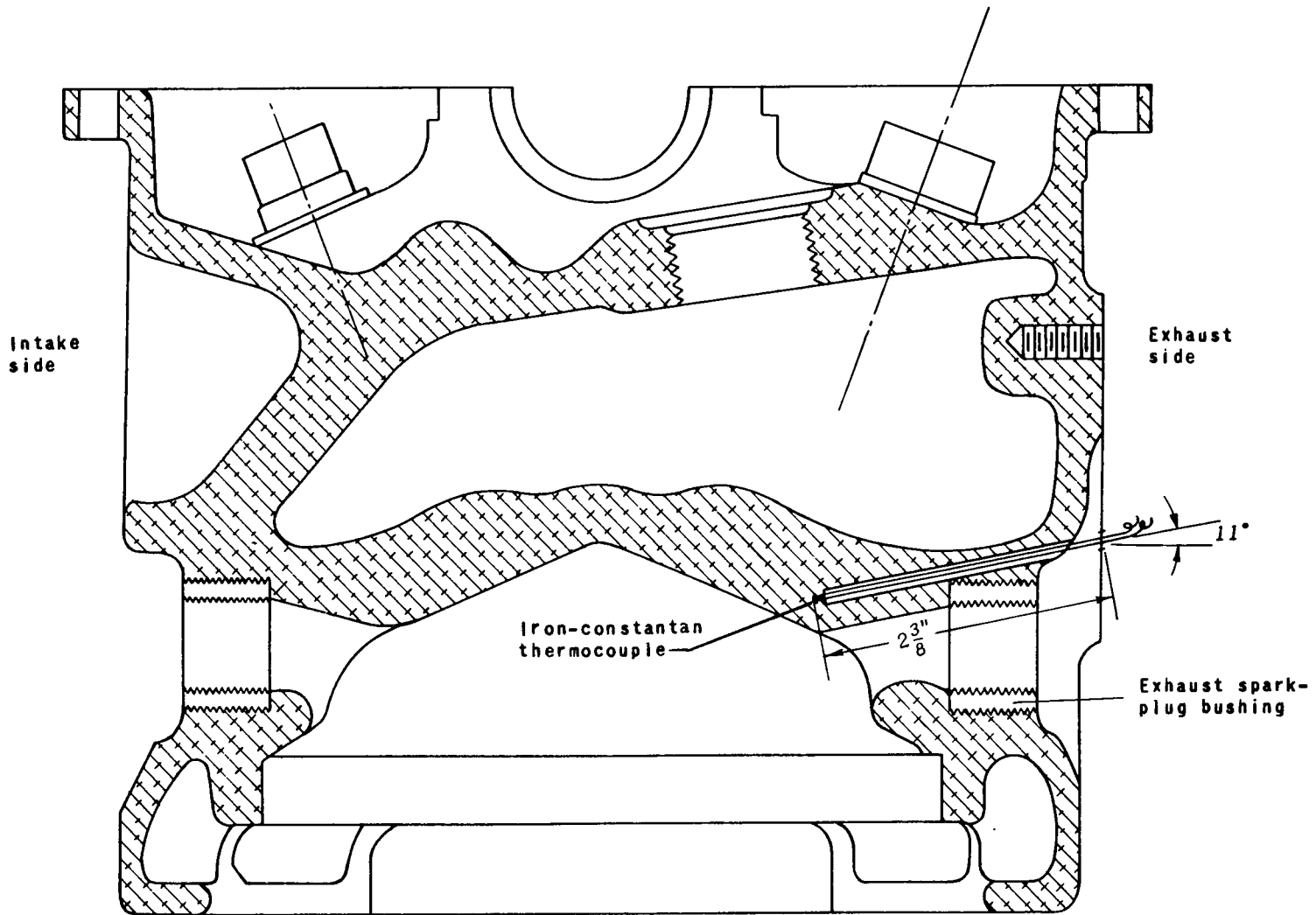
Figure 3. - Thermocouple installation in cylinder head.
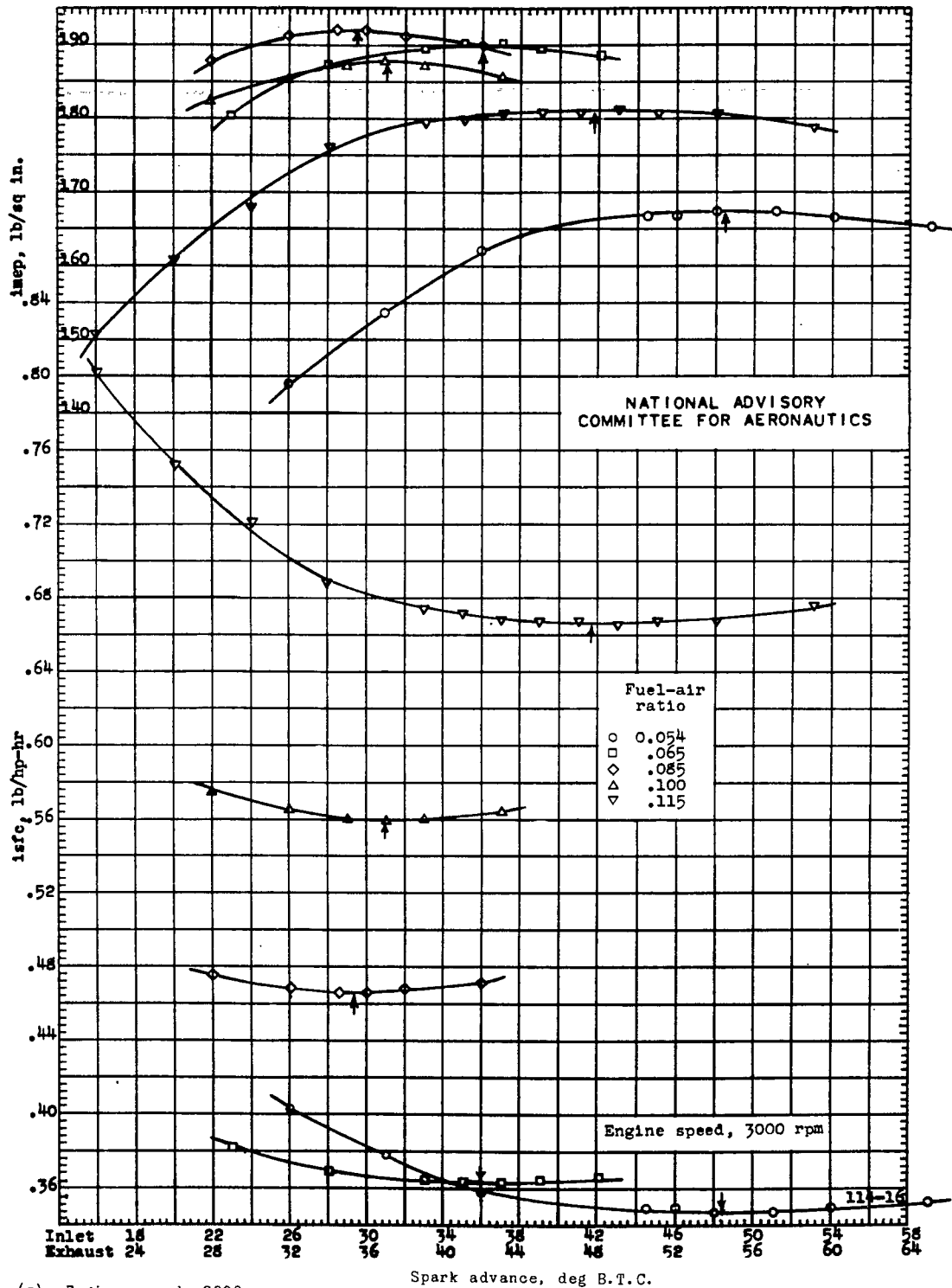
(a) Engine speed, 3000 rpm.
Figure 4. – Effect of spark advance on power and fuel consumption at various fuel-air ratios.
 Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio,
 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; mixture tempera-
 ture, 175° F; inlet-air pressure, 40 inches mercury absolute. (Arrows indicate spark
 advance for peak power.)
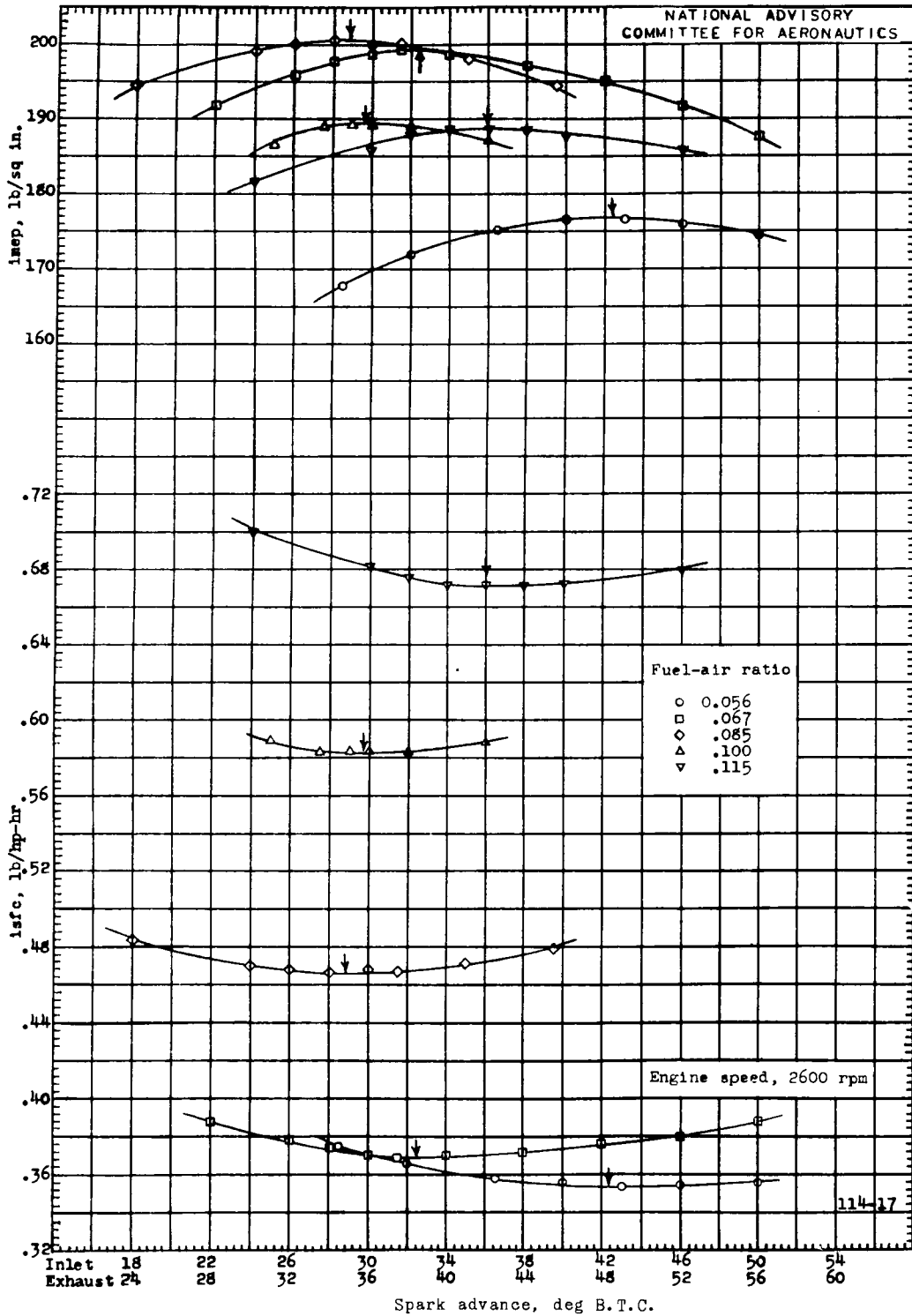
(b) Engine speed, 2600 rpm.
Figure 4. - Continued. Effect of spark advance on power and fuel consumption at various
   fuel-air ratios. Single-cylinder adaptation of multicylinder engine to CUE crankcase;
   compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250°
   mixture temperature, 175° F; inlet-air pressure, 40 inches mercury absolute. (Arrows
   indicate spark advance for peak power.)
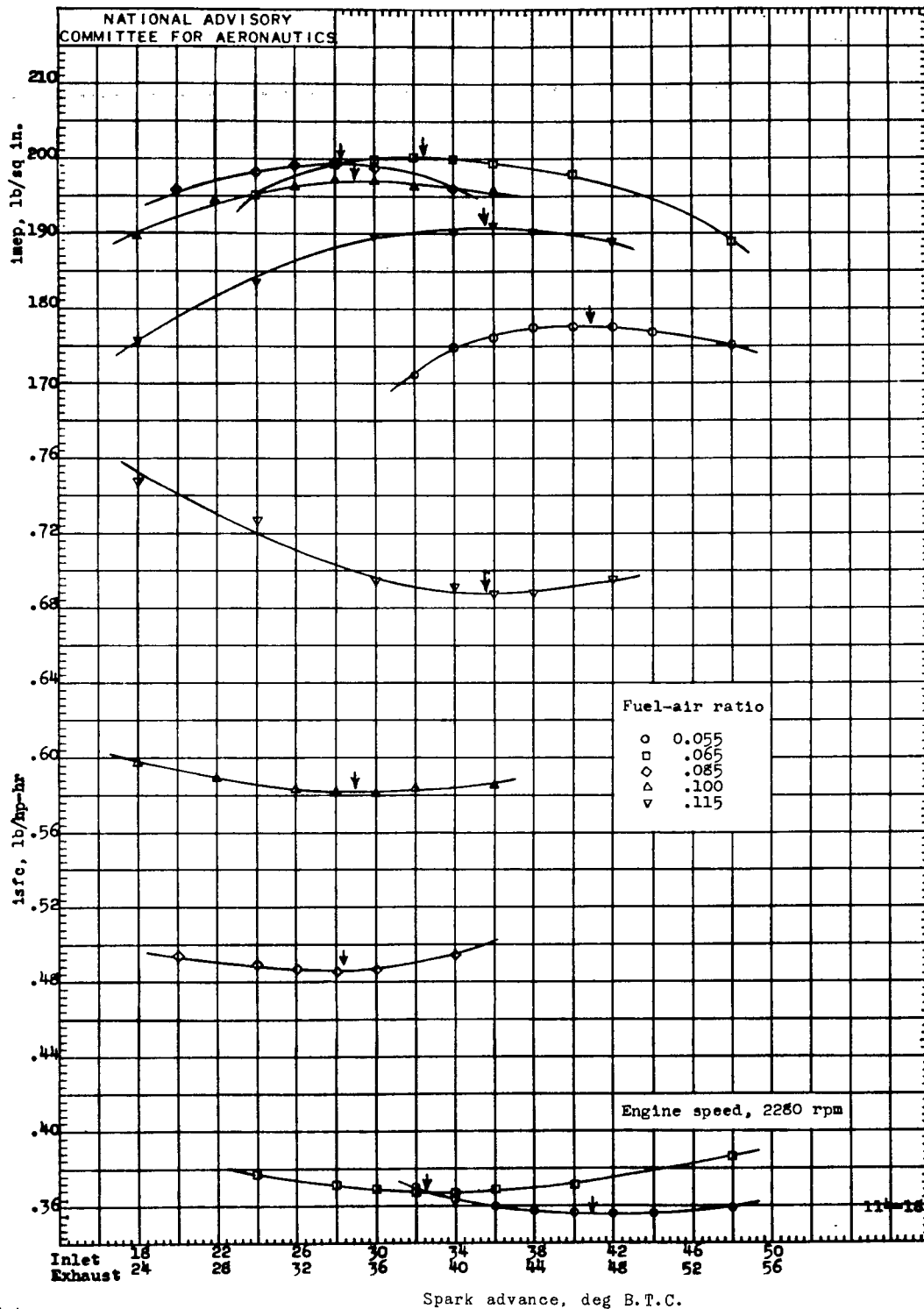
(c) Engine speed, 2280 rpm.
Figure 4. – Concluded. Effect of spark advance on power and fuel consumption at various
fuel-air ratios. Single-cylinder adaptation of multicylinder engine to CUE crankcase;
compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F;
mixture temperature, 175° F; inlet-air pressure, 40 inches mercury absolute. (Arrows
indicate spark advance for peak power.)
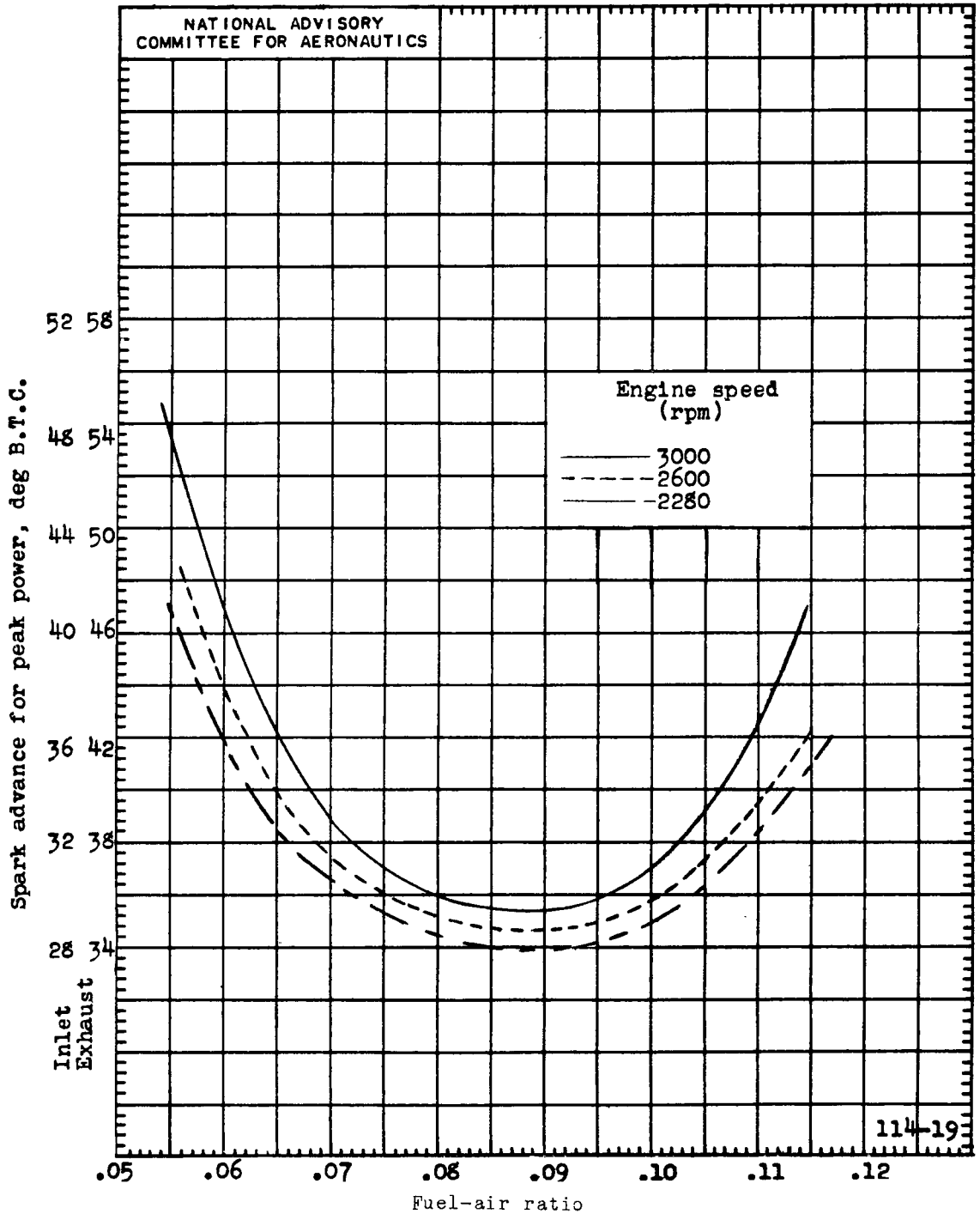
Figure 5. — Effect of fuel-air ratio on spark advance for peak power at various engine speeds. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; mixture temperature, 175° F; inlet-air pressure, 40 inches mercury absolute.
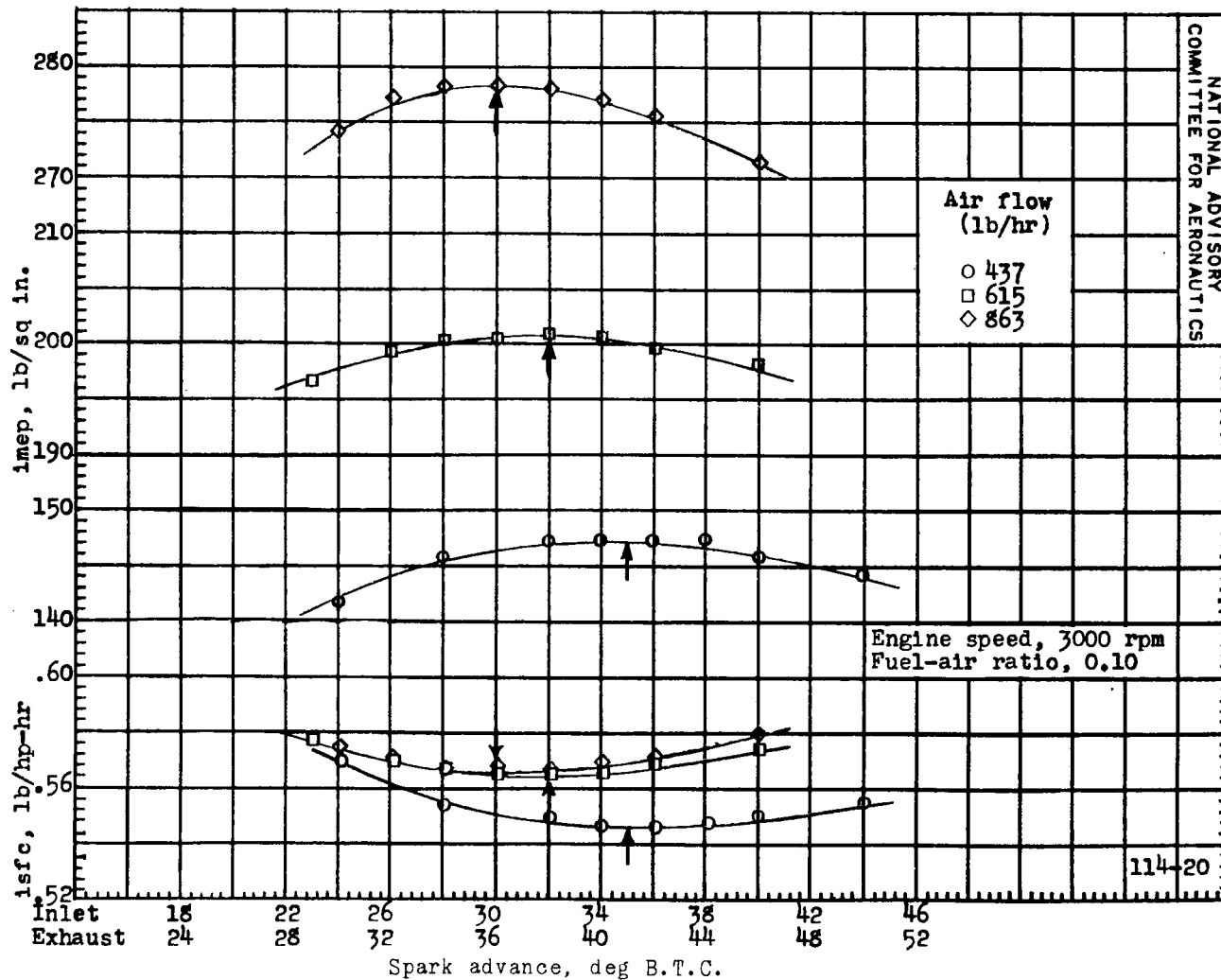
(a) Mixture temperature, 125° F.

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.)
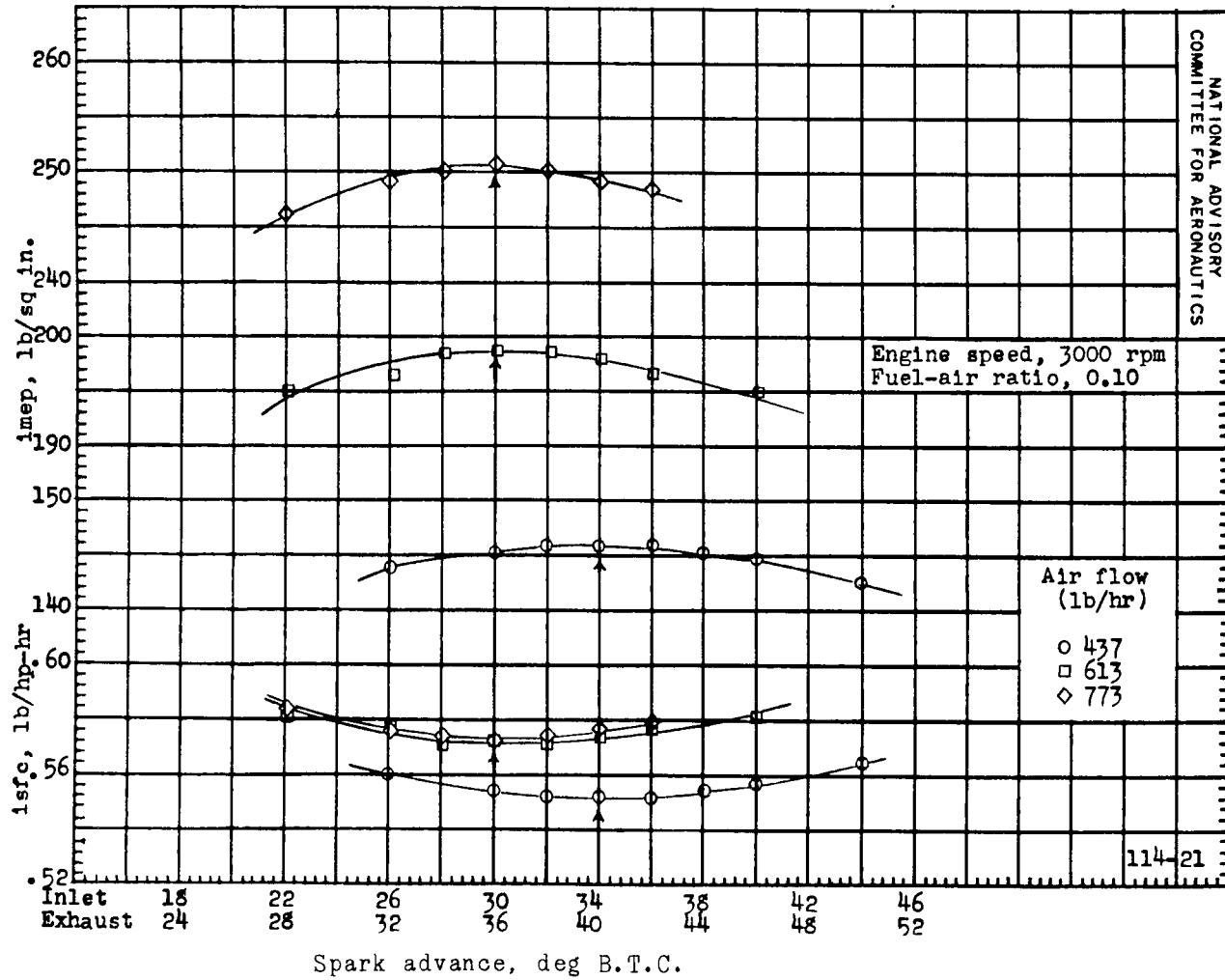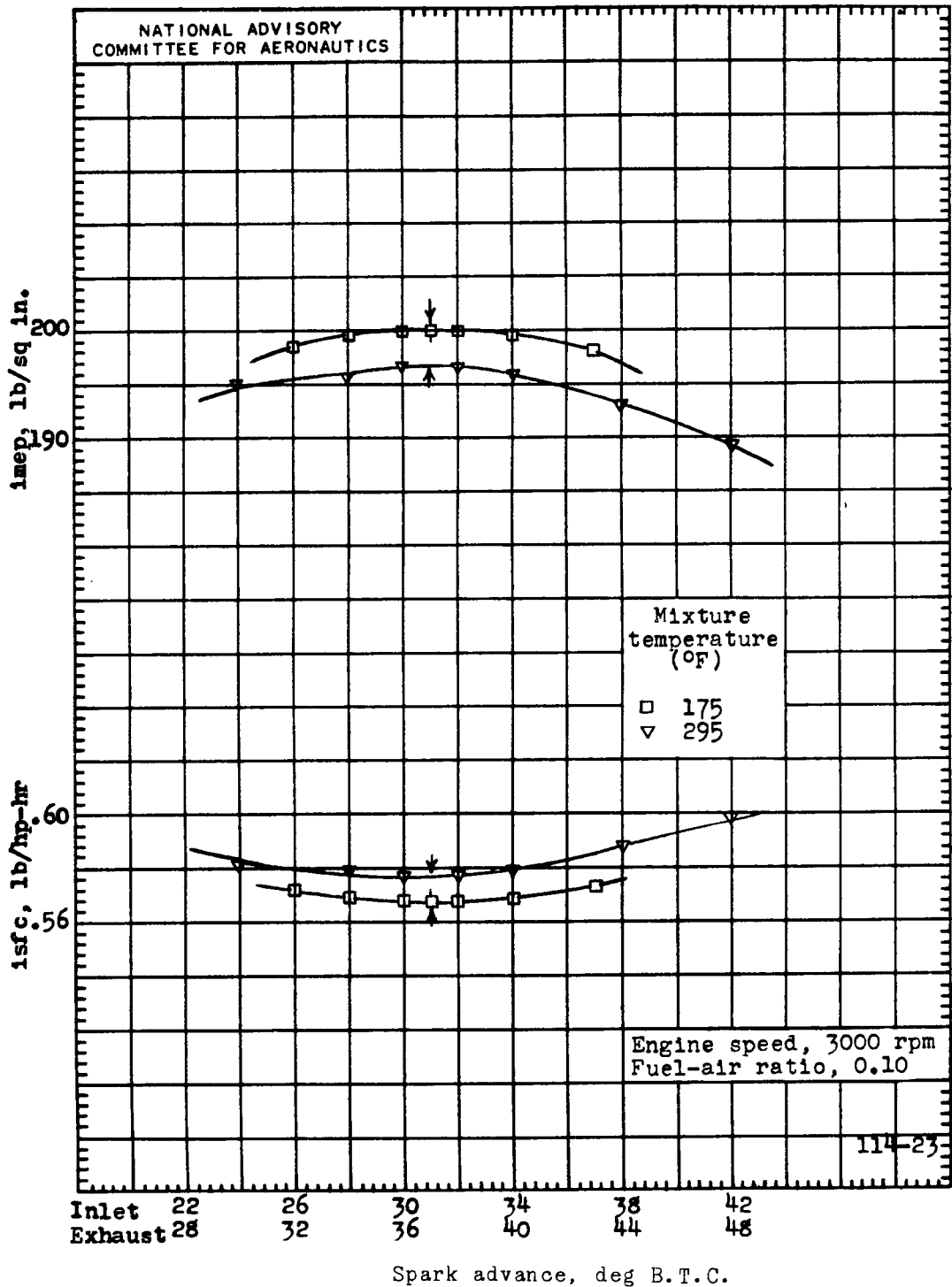
(b) Mixture temperature, 225° F.
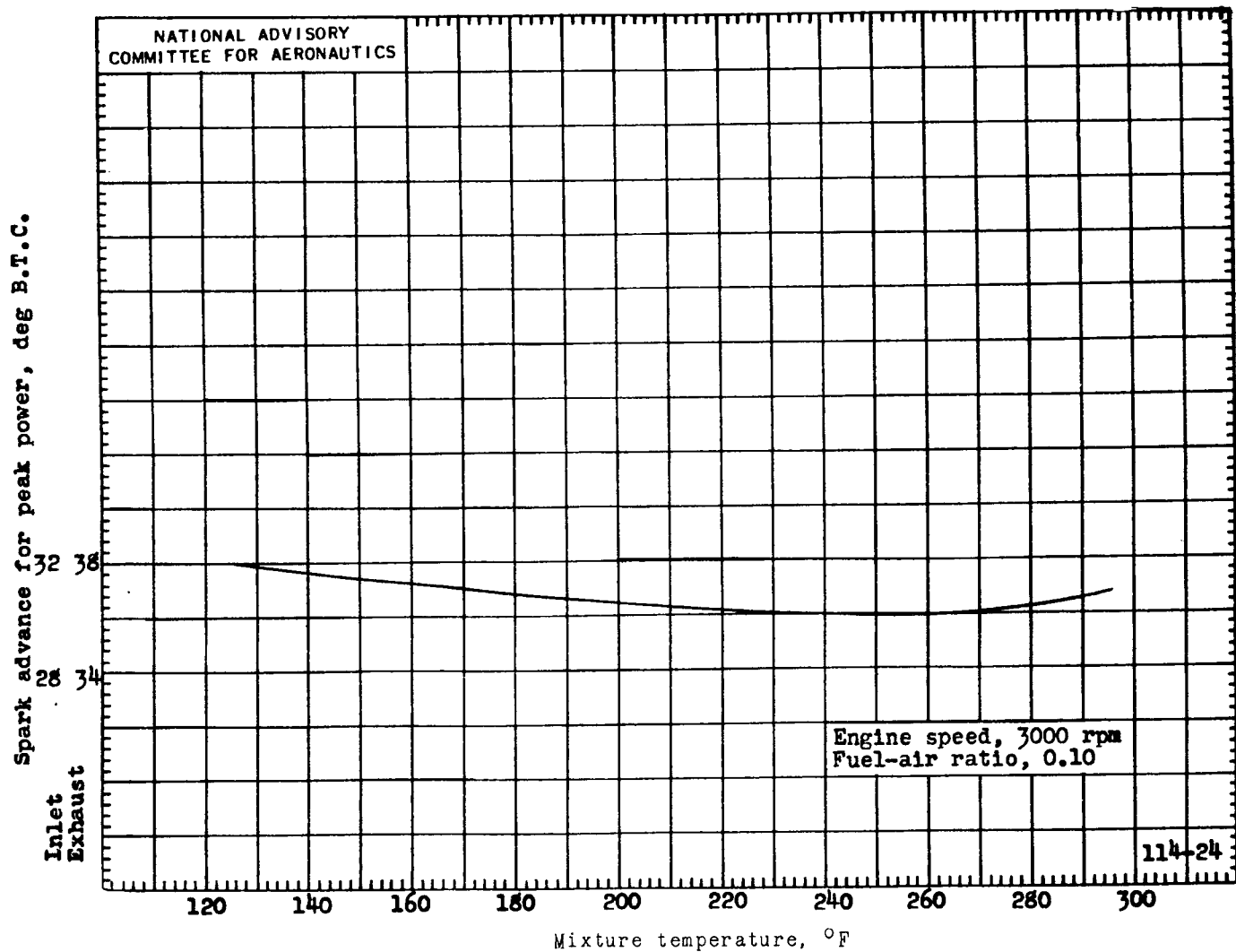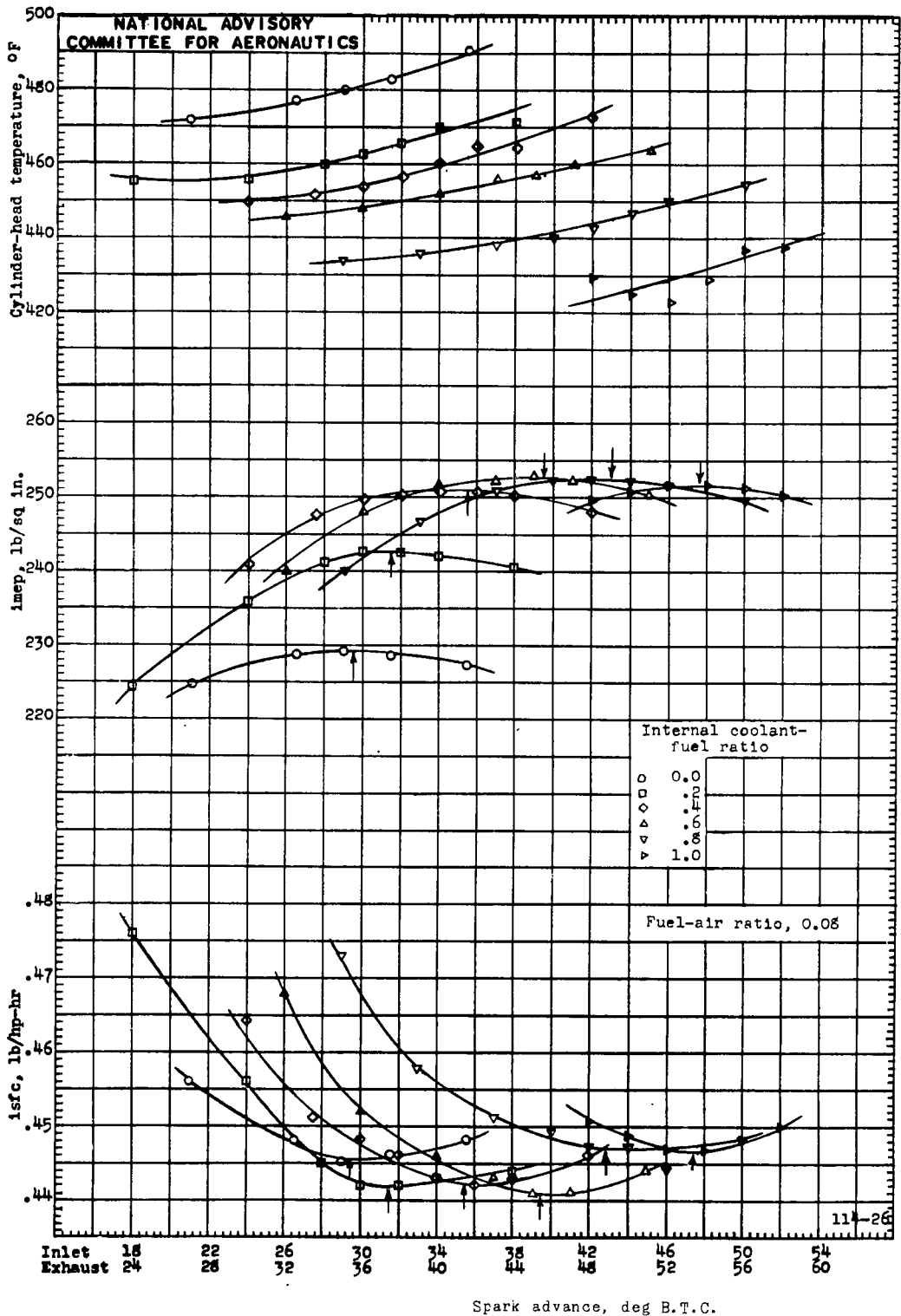
Figure 6. – Concluded. Effect of spark advance on power and fuel consumption at various values of air flow. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; engine speed, 3000 rpm; fuel-air ratio, 0.10. (Arrows indicate spark advance for peak power.)
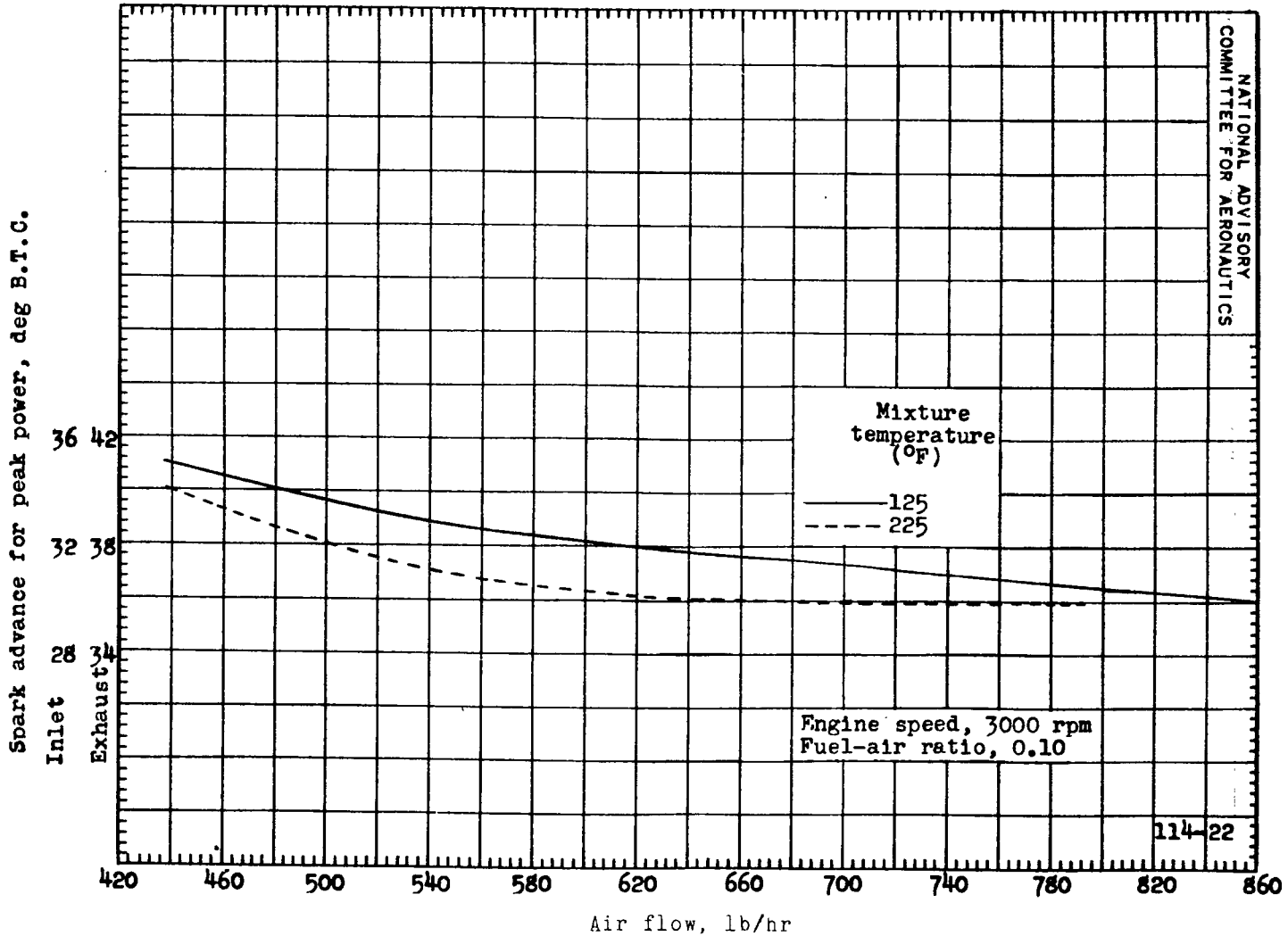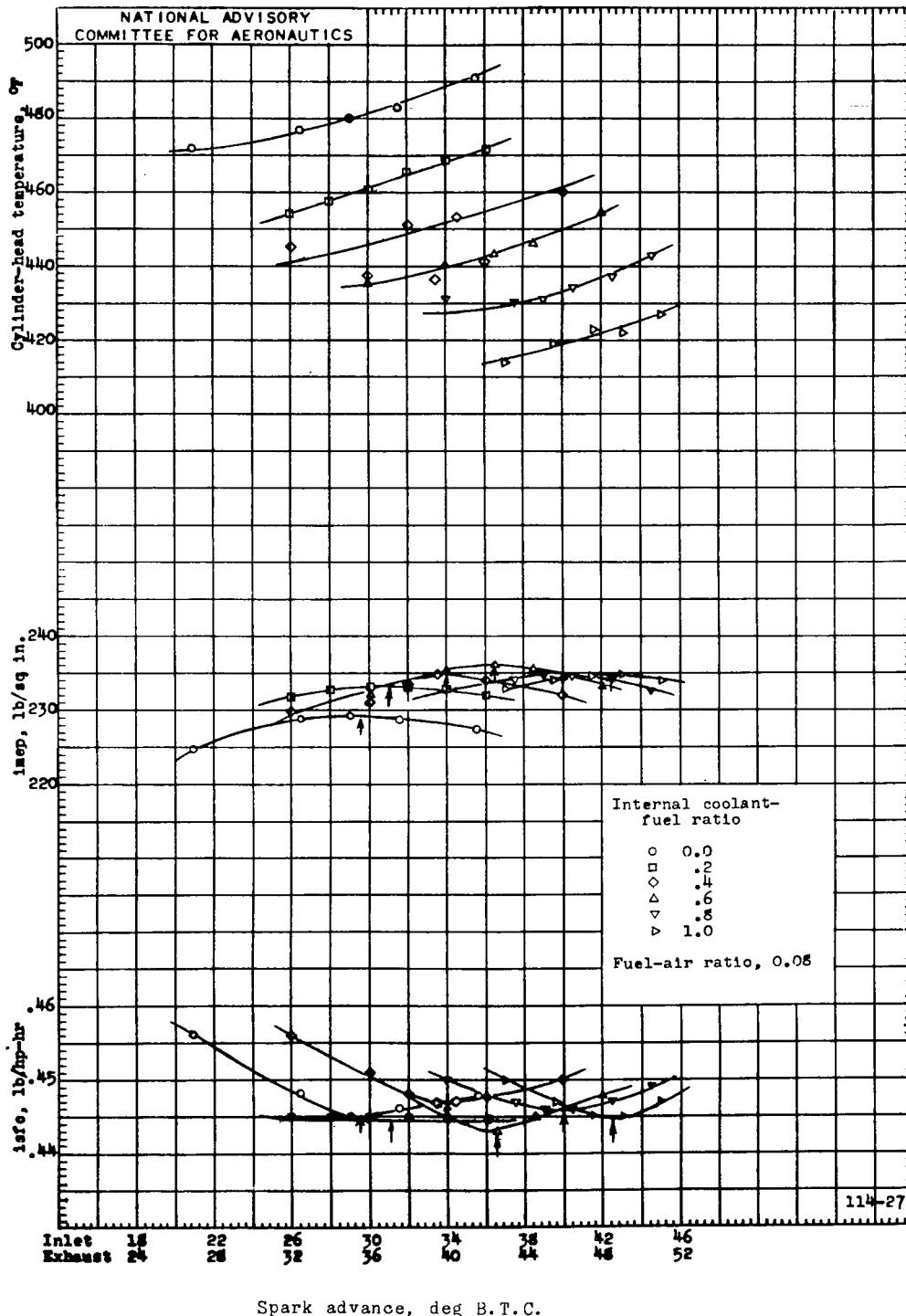
Figure 7. – Effect of air flow on spark advance for peak power at two mixture temperatures. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; engine speed, 3000 rpm; fuel-air ratio, 0.10.

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.)
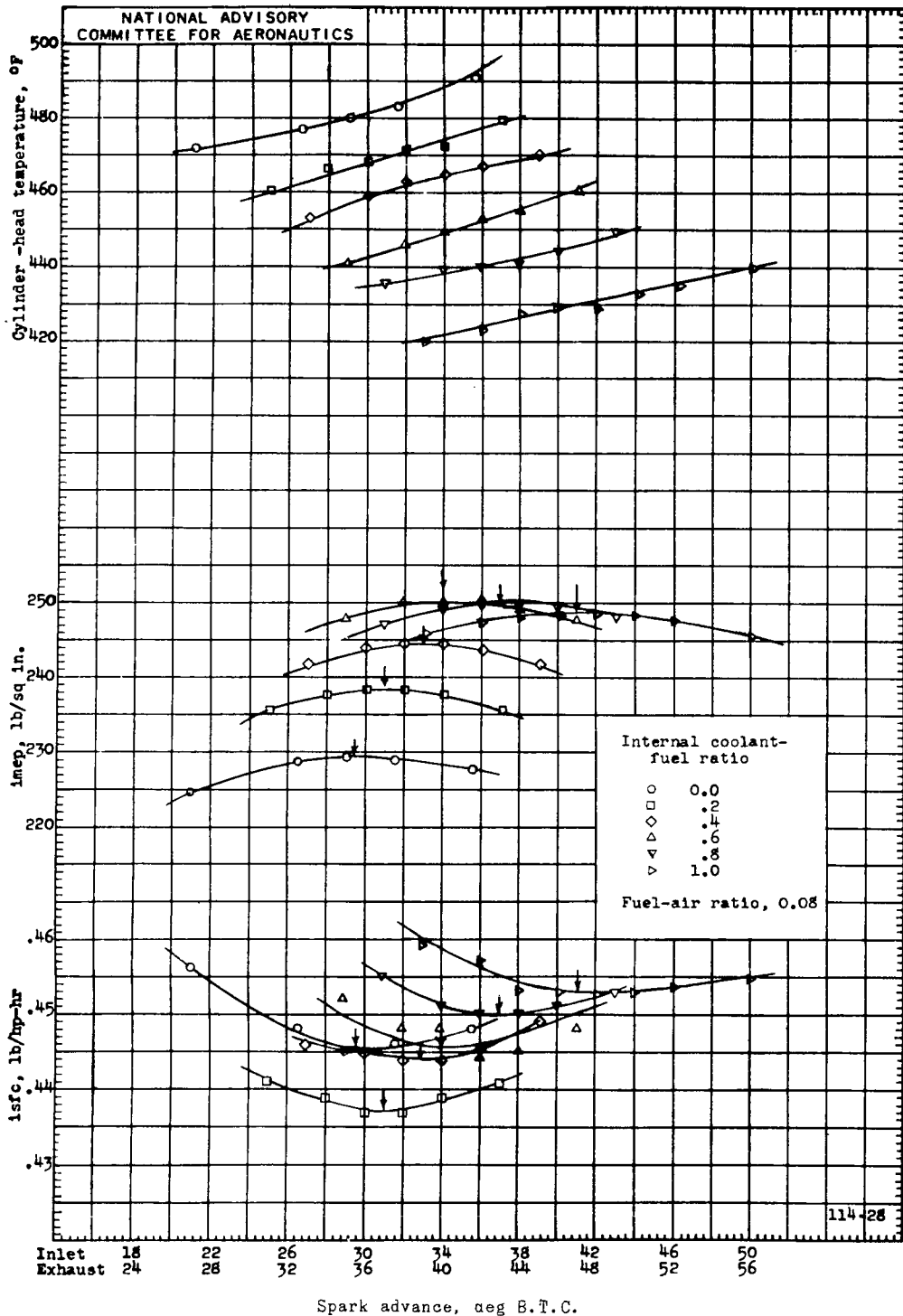
Figure 9. – Effect of mixture temperature on spark advance for peak power at constant air flow. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; engine speed, 3000 rpm; fuel-air ratio, 0.10; air flow, 614 pounds per hour.
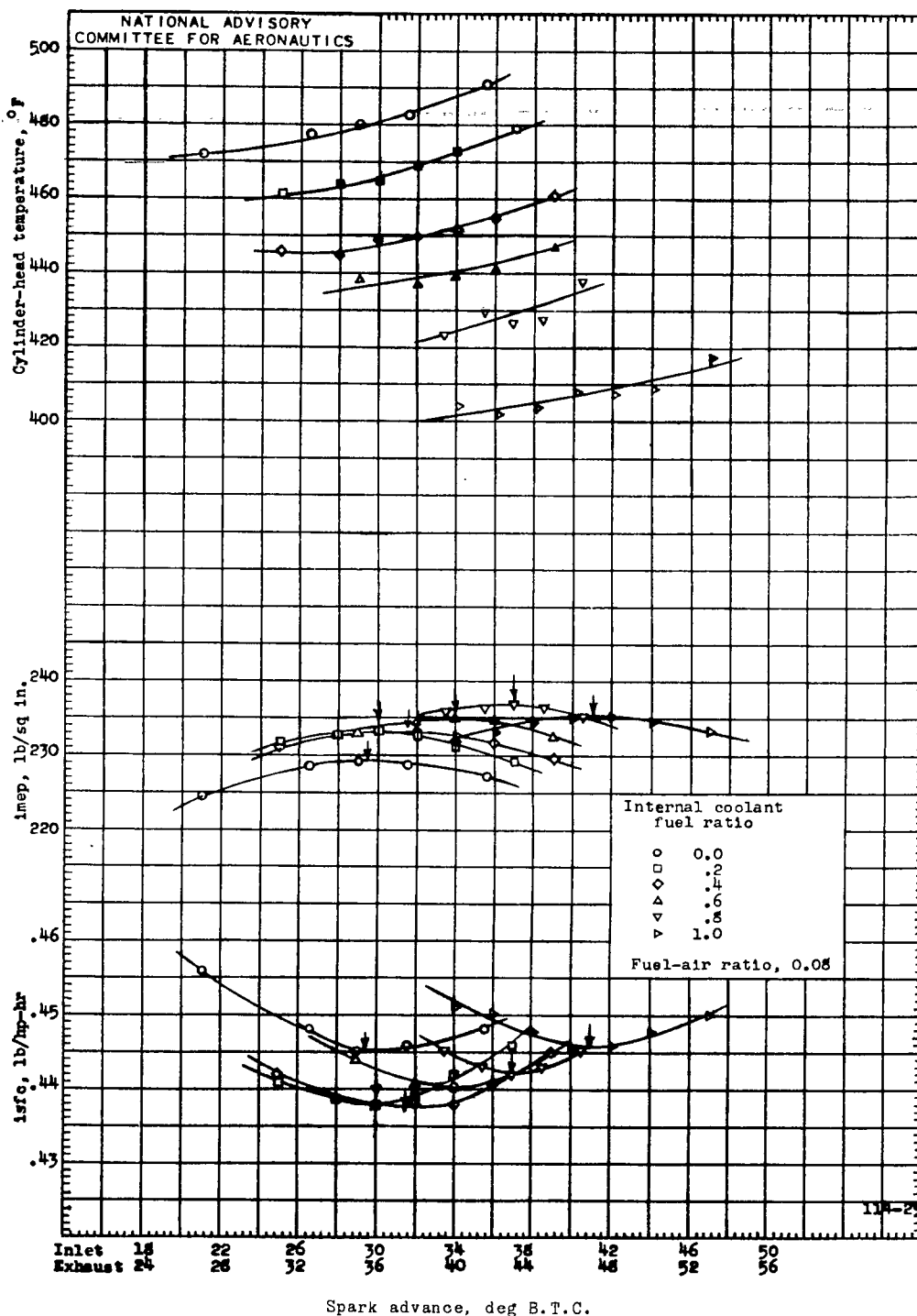
(a)   Water injected before vaporization tank.
Figure 10. – Effect of spark advance on fuel consumption, engine power, and cylinder-
head temperature for several internal coolant-fuel ratios at inlet-air pressure
of 50 inches mercury absolute. Single-cylinder adaptation of multicylinder engine
to CUE 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 I0. – 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.

Spark advance, deg B.T.C.

(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.
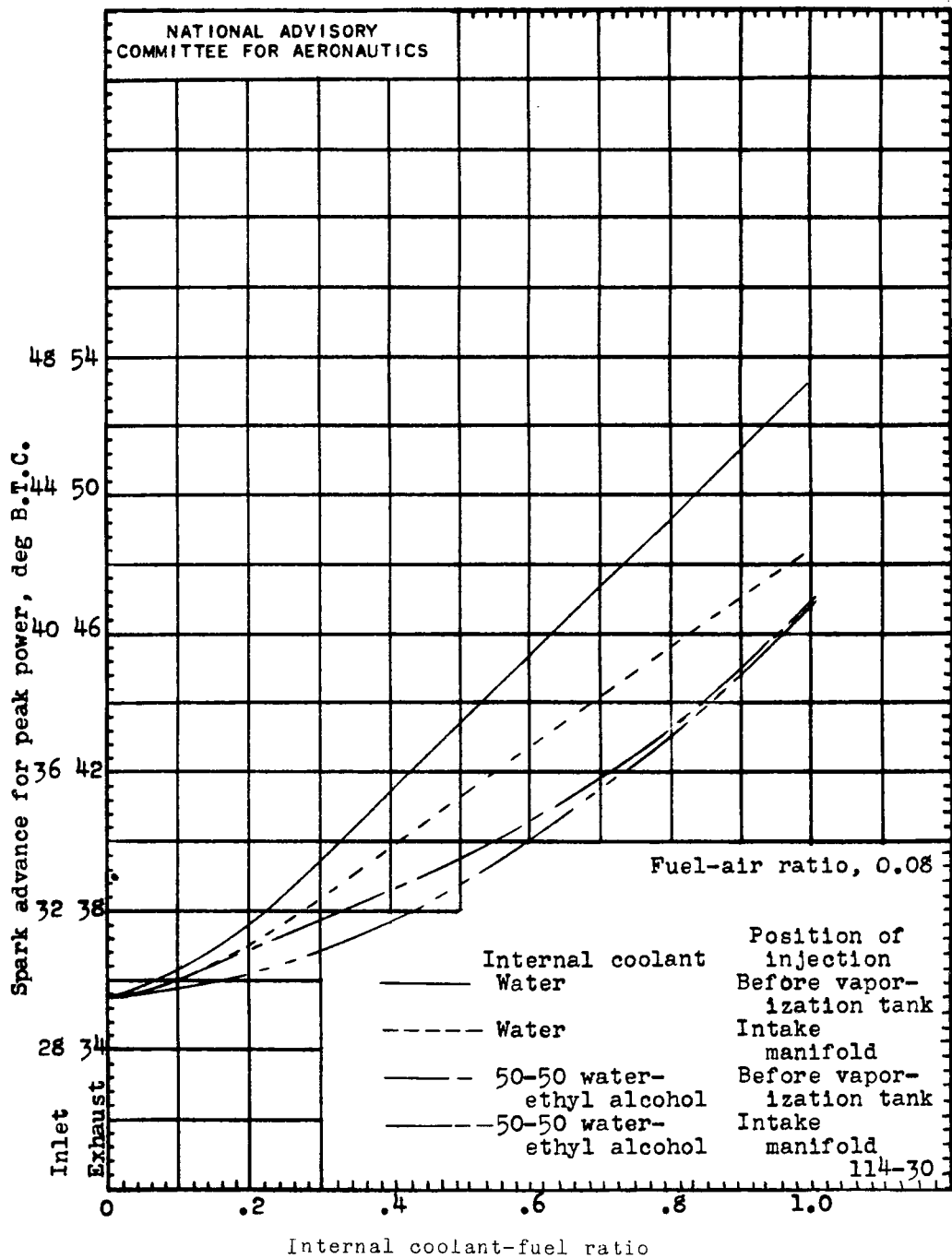
Spark advance, deg B.T.C.
(d)   50-50 water-ethyl alcohol mixture injected in intake elbow.
Figure 10. - Concluded. Effect of spark advance on fuel consumption, engine power, and
  cylinder-head temperature for several internal coolant-fuel ratios at inlet-air pressure
  of 50 inches mercury absolute. 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.
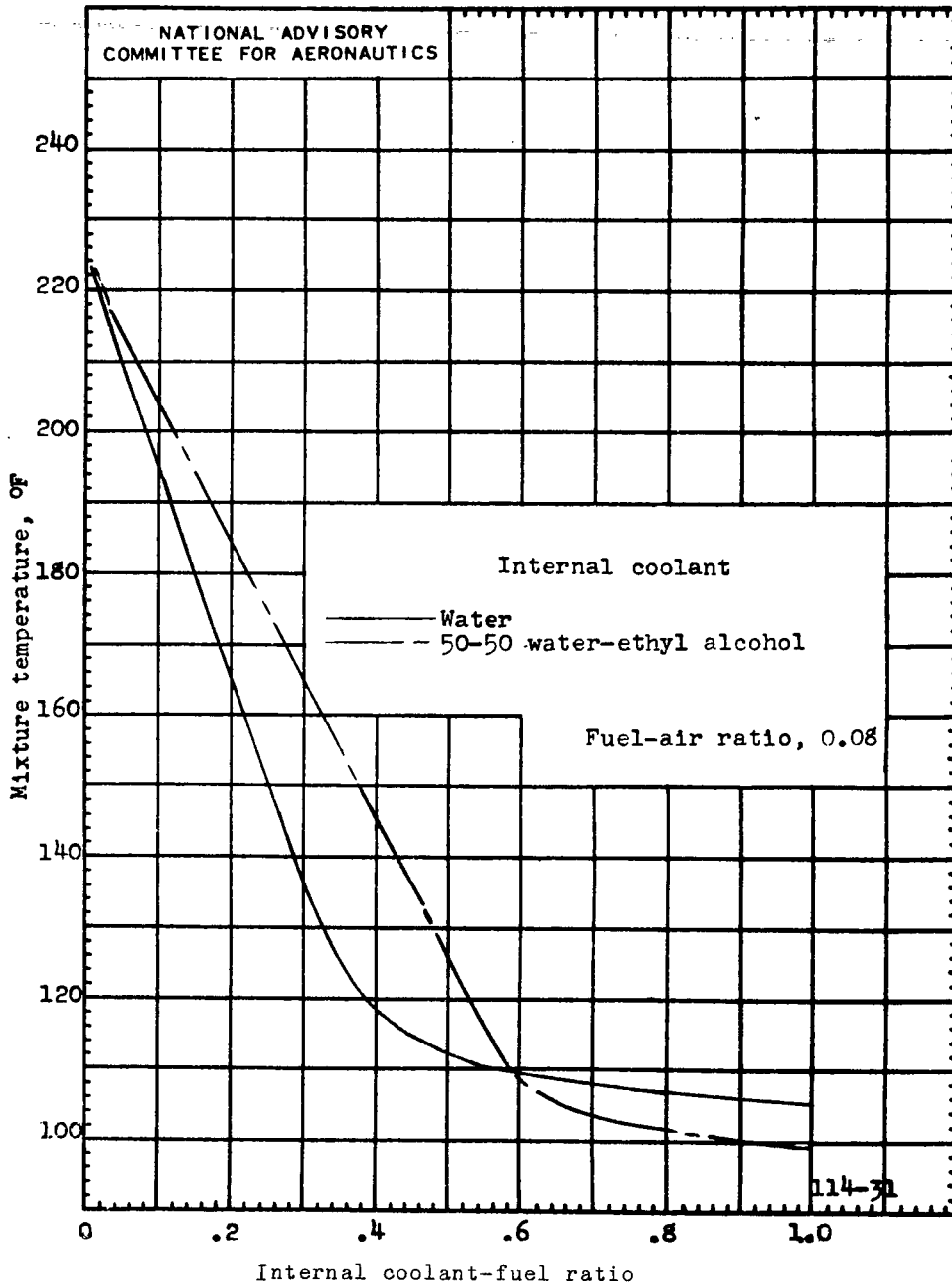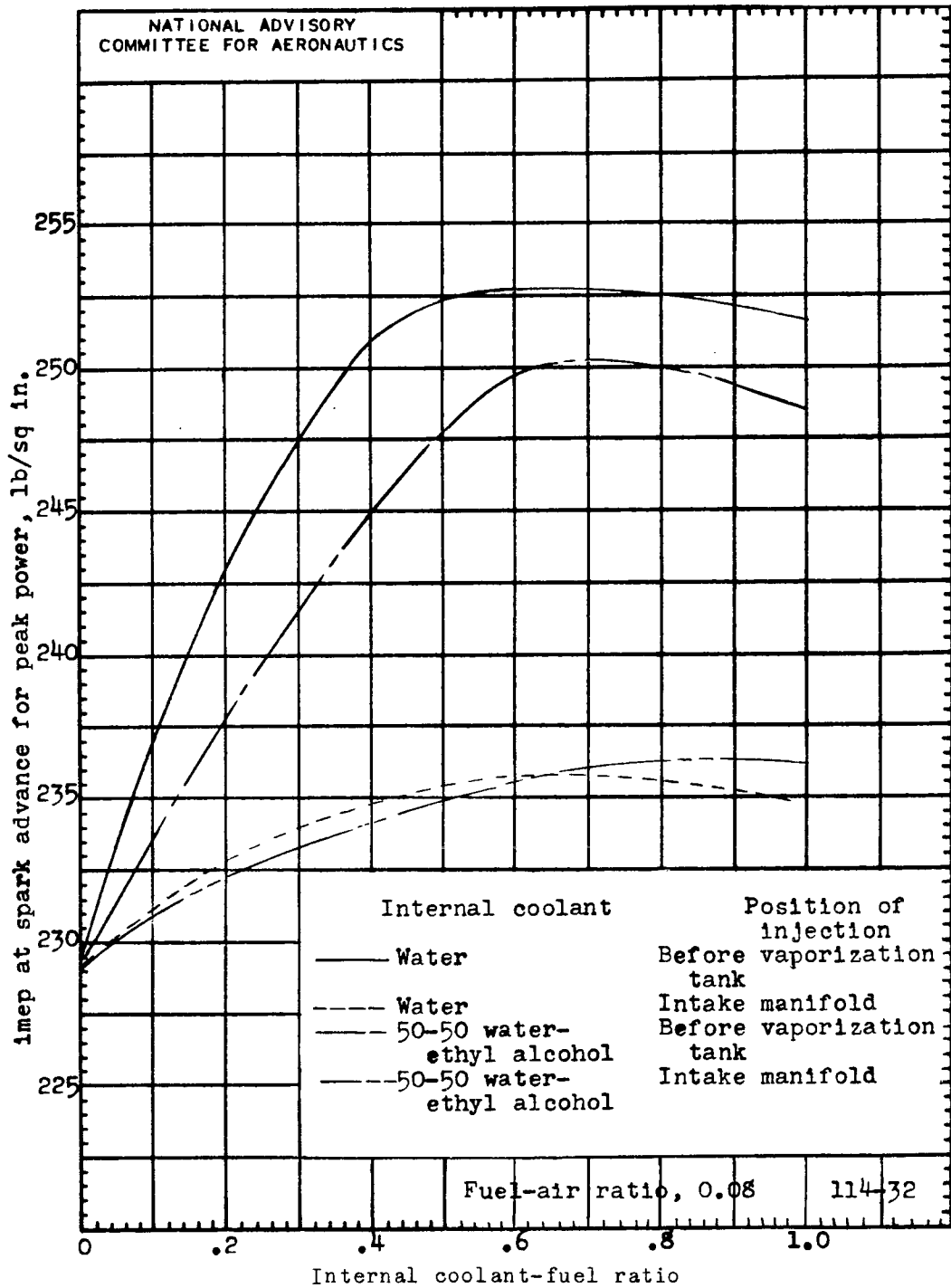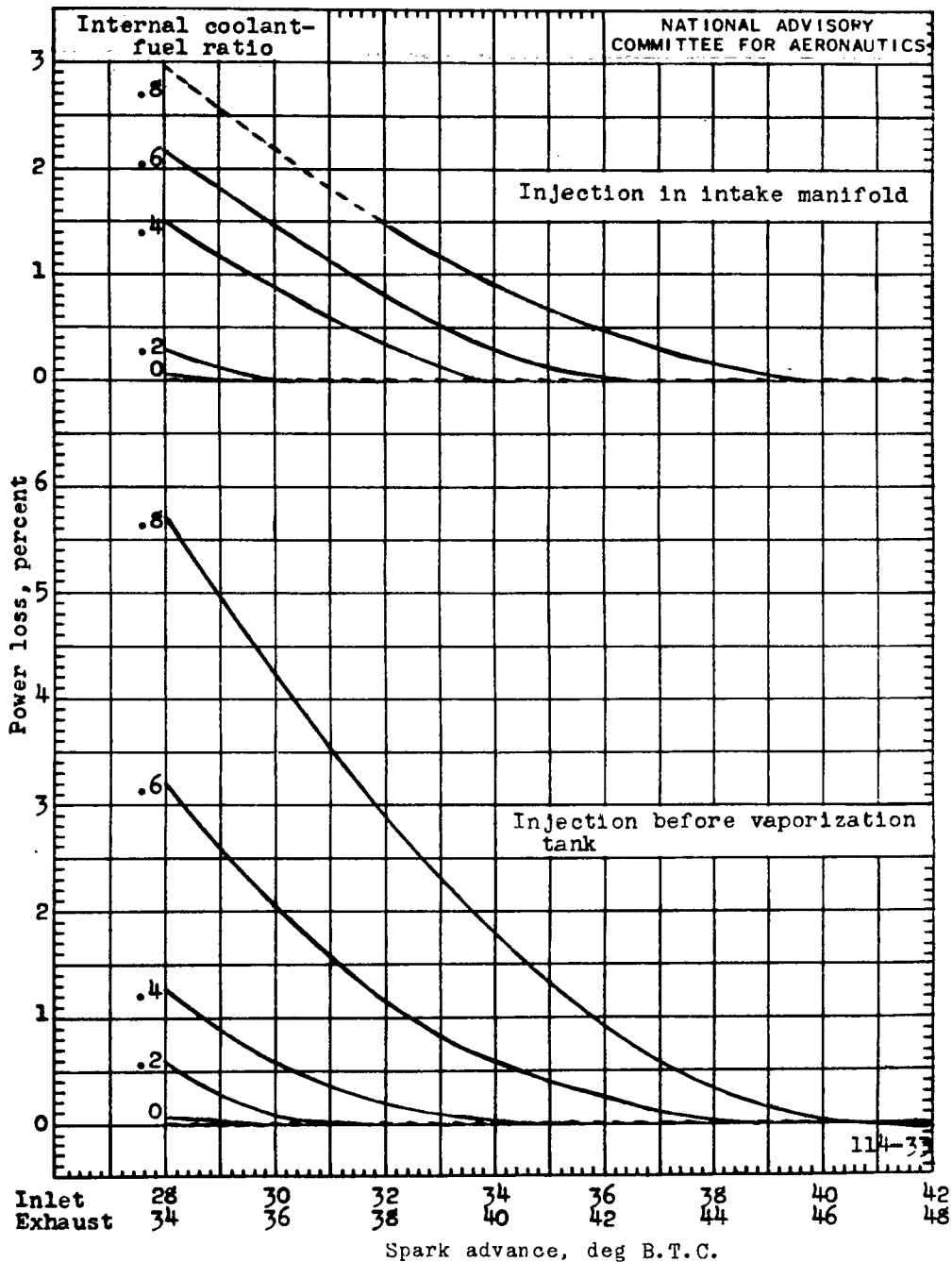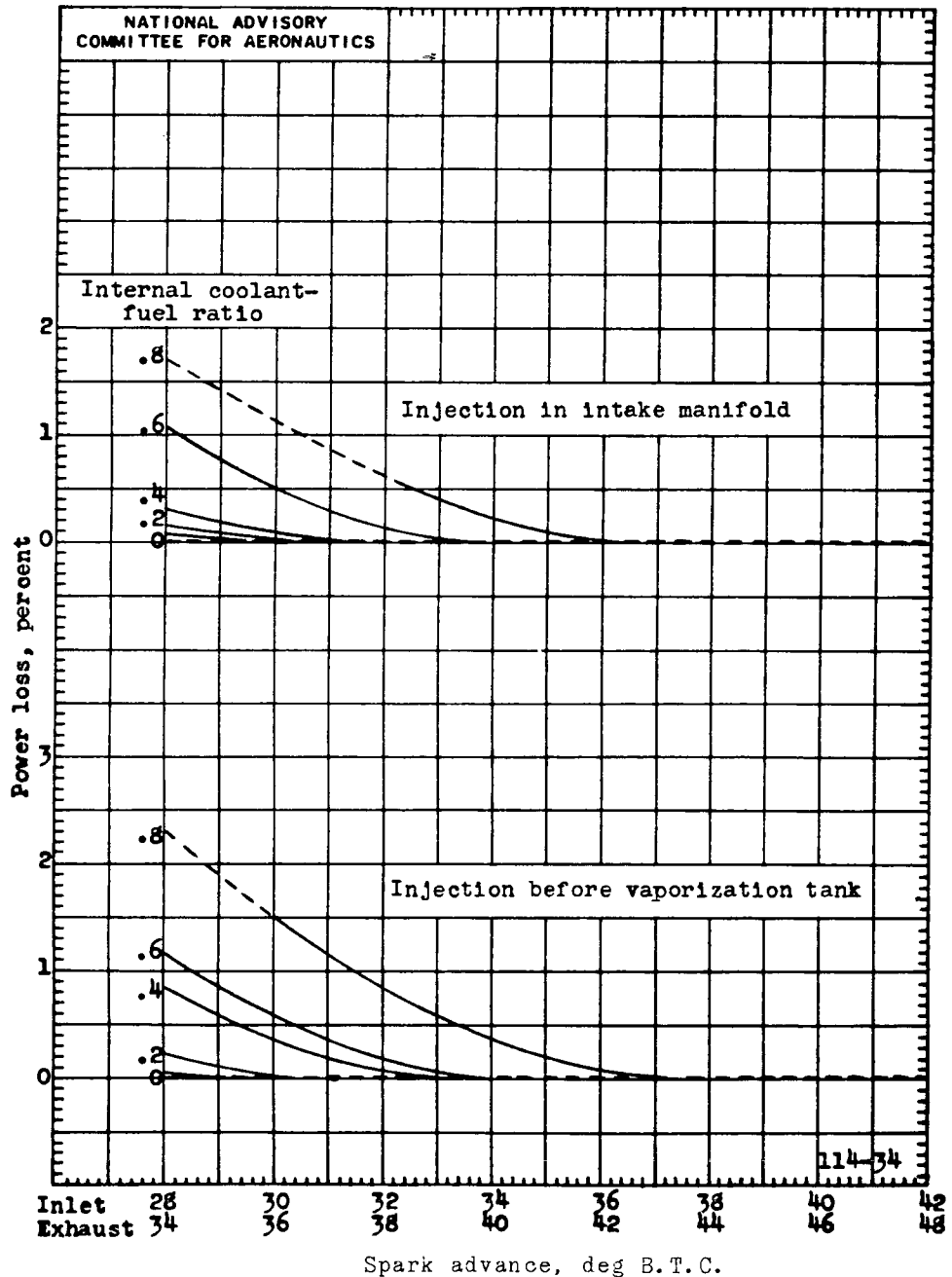
Figure 12. – Effect of internal coolant-fuel ratio on mixture temperature for two internal coolants injected before the vaporization tank. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F; inlet-air 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.

(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;
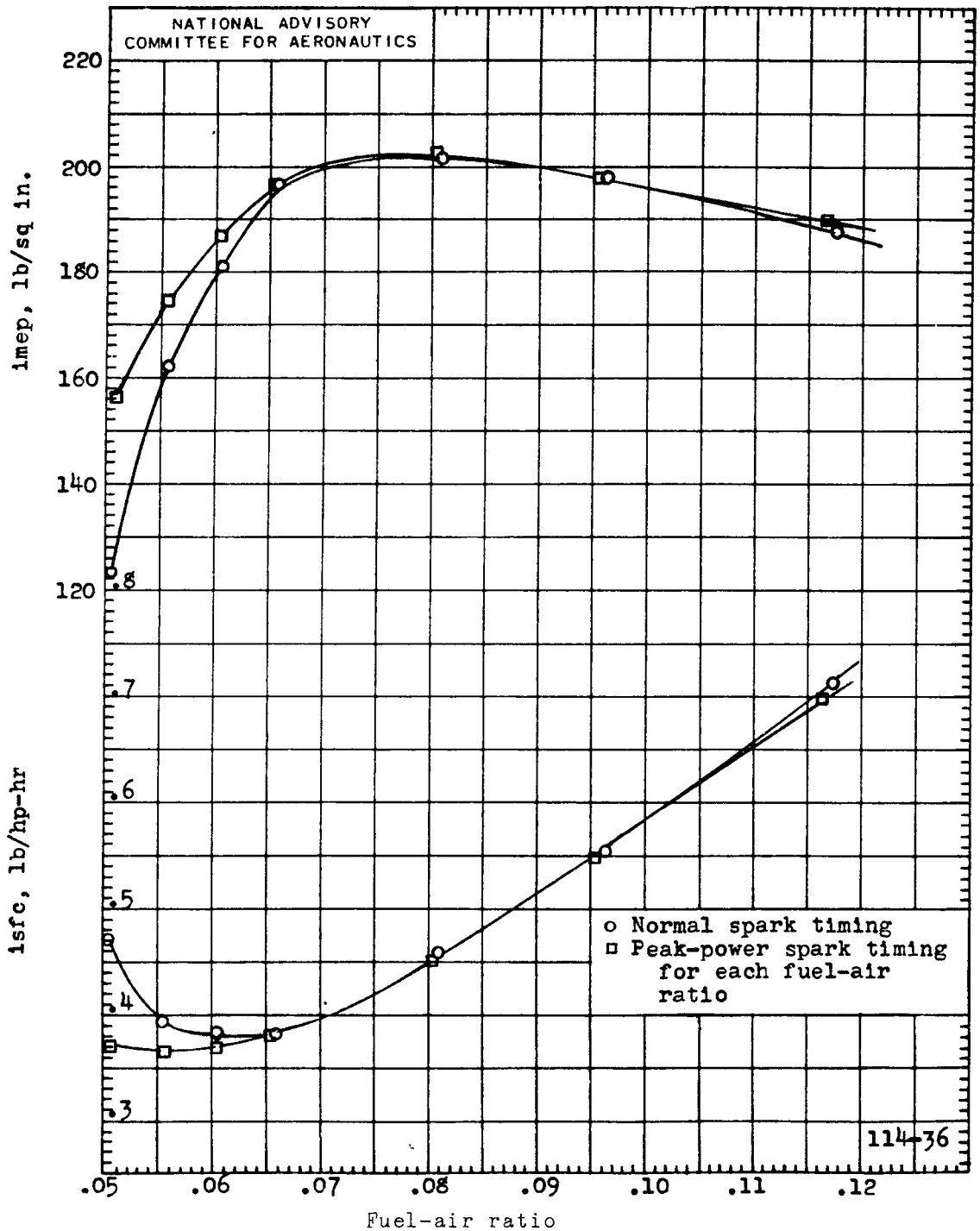 fuel-air ratio, 0.08.

(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.
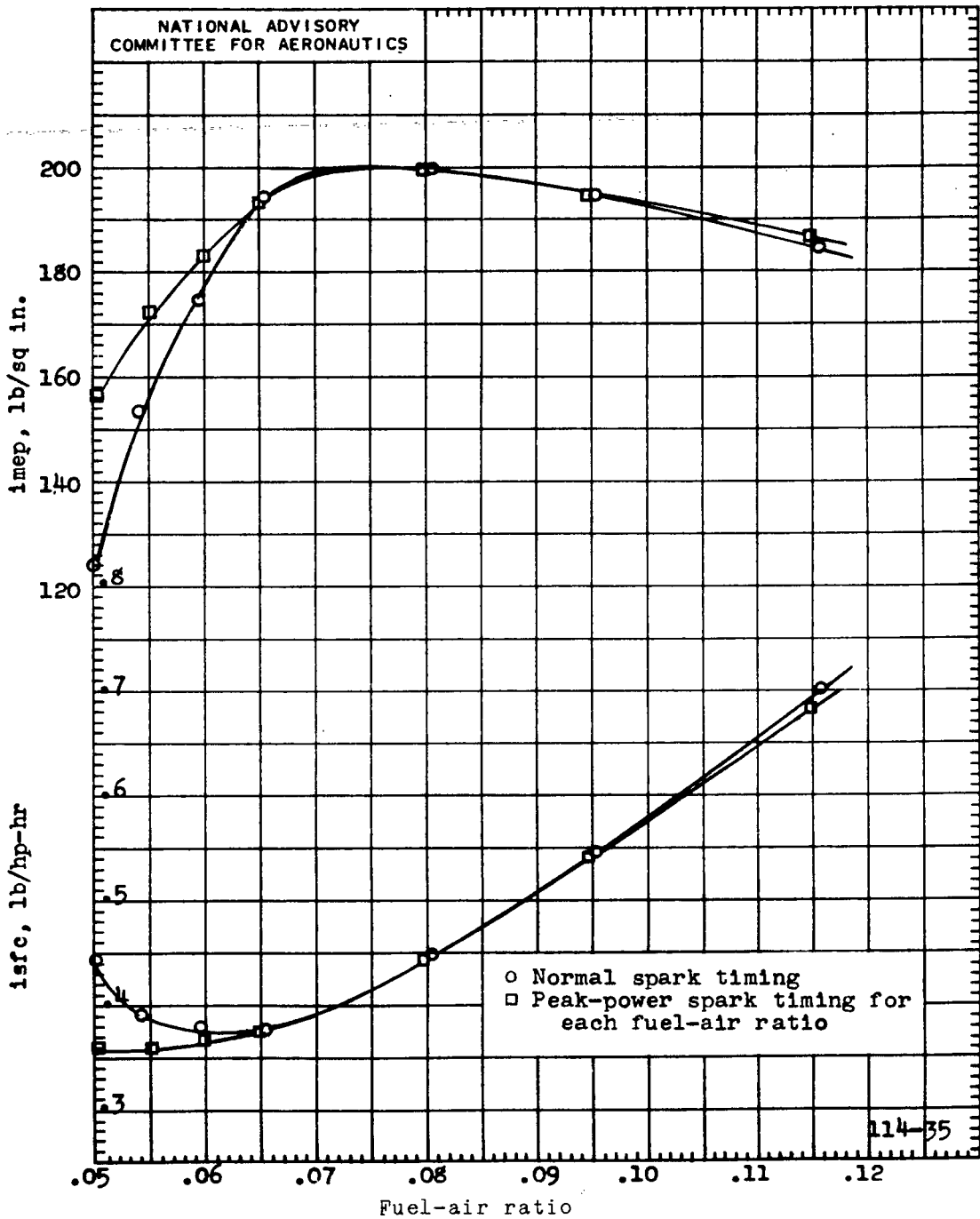
(a) Engine speed, 2600 rpm.
Figure 15. – Effect of fuel-air ratio on power and fuel con-
sumption when operating at either normal or peak-power spark
timing. Single-cylinder adaptation of multicylinder engine
to CUE crankcase; compression ratio, 6.65; inlet-oil tempera-
ture, 185° F; outlet-coolant temperature, 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; mix-
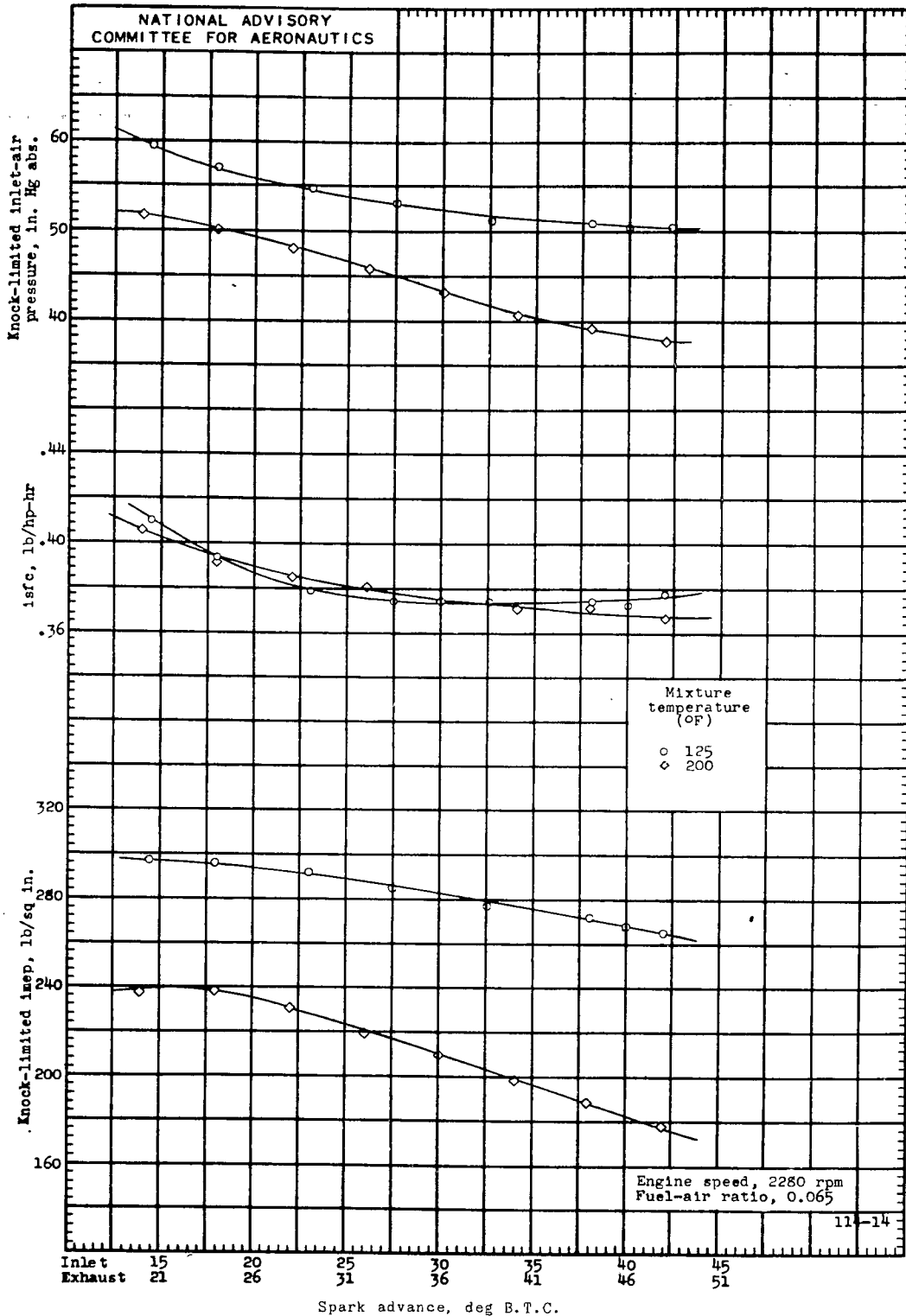   ture temperature, 175° F; inlet-air pressure, 40 inches
    mercury absolute.
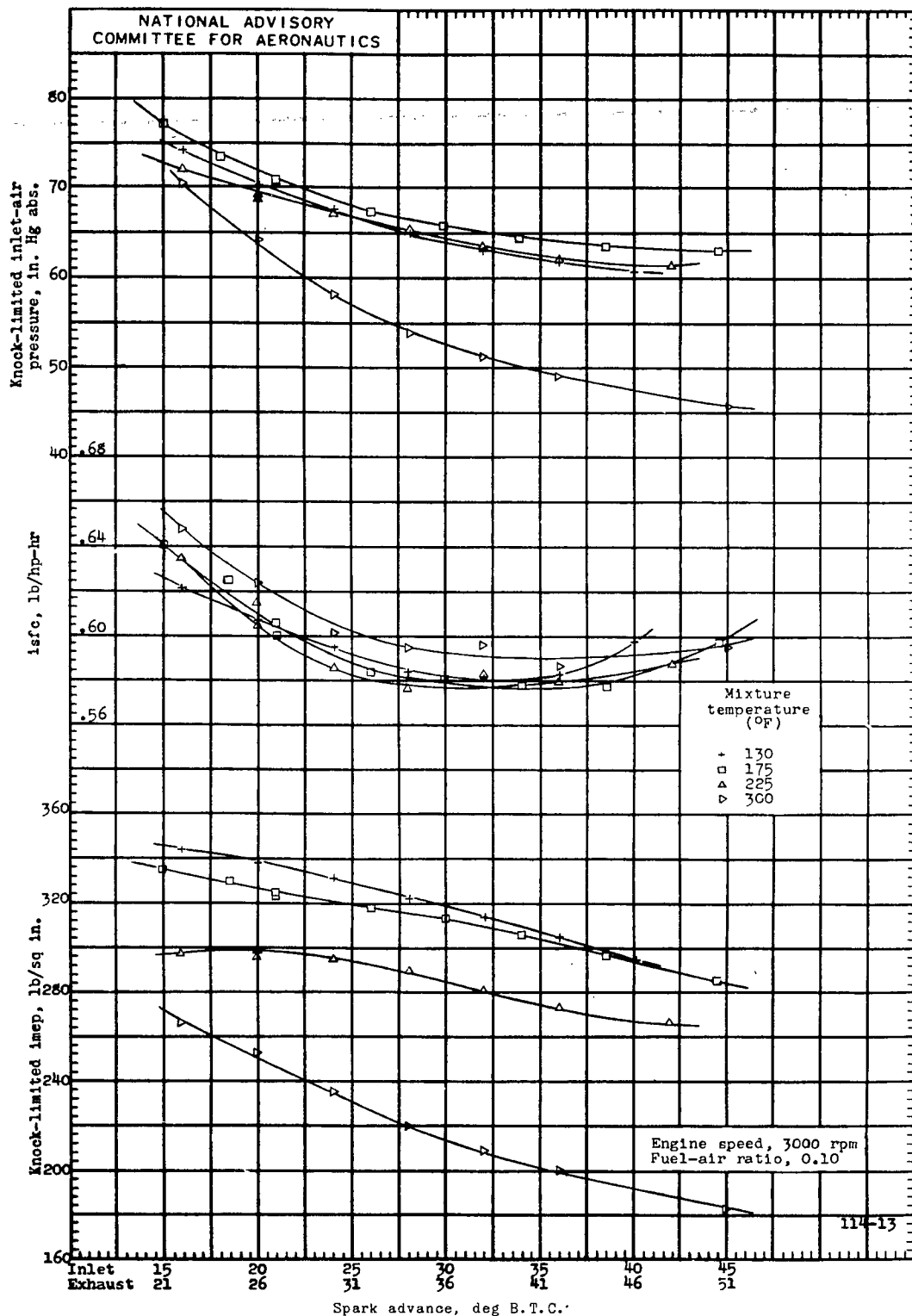
(a) Take-off conditions.
Figure 16. – Effect of spark advance on knock-limited performance at various mixture temperatures. Single-cylinder adaptation of multicylinder engine to CUE crankcase; compression ratio, 6.65; inlet-oil temperature, 185° F; outlet-coolant temperature, 250° F.
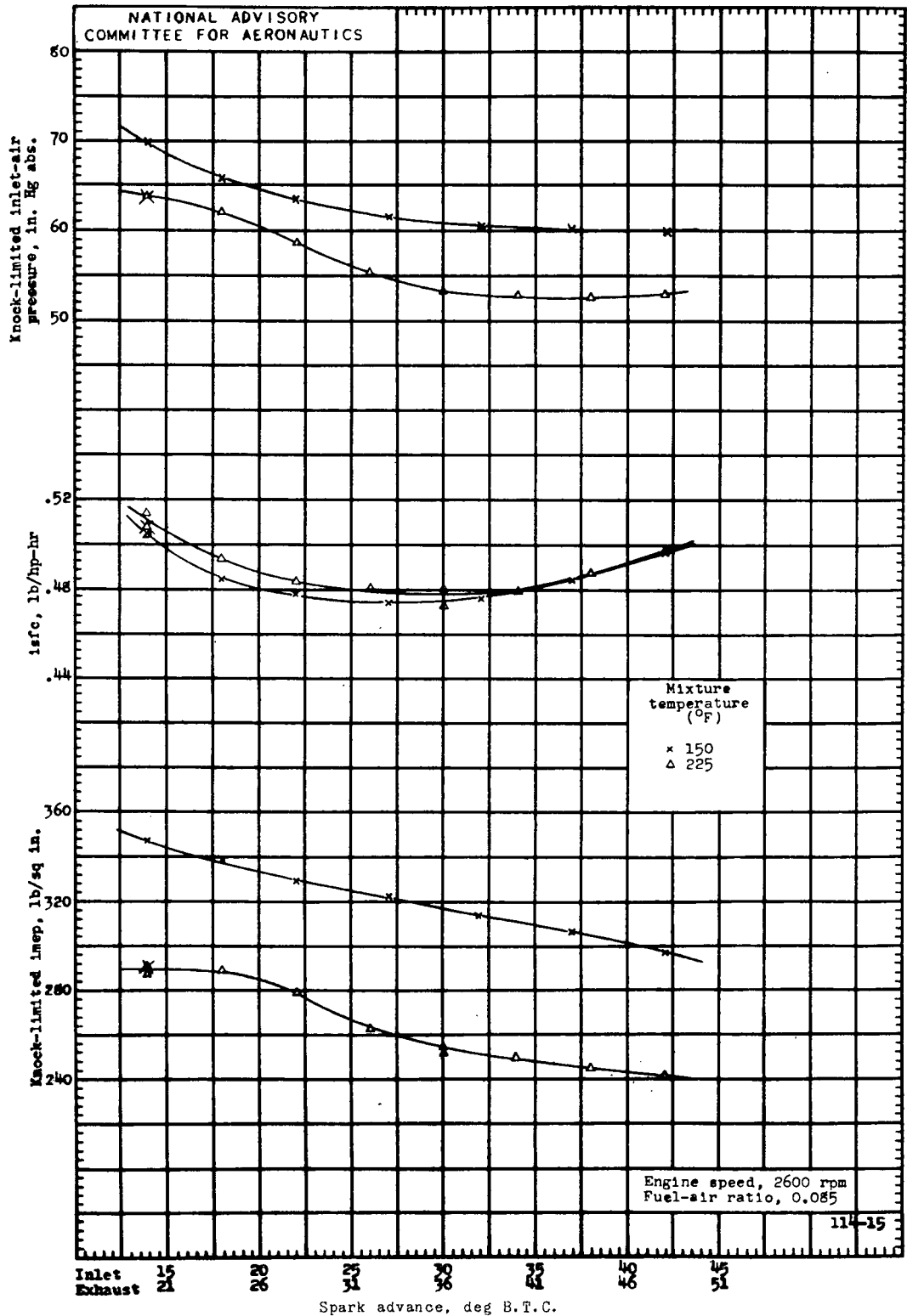
(b) High-power cruise conditions.

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.