

**NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS**

# **WARTIME REPORT**

ORIGINALLY ISSUED

August 1945 as  
Memorandum Report E5H08

FLIGHT AND TEST-STAND INVESTIGATION OF HIGH-PERFORMANCE  
FUELS IN MODIFIED DOUBLE-ROW RADIAL AIR-COOLED ENGINES  
III - KNOCK-LIMITED PERFORMANCE OF 33-R AS COMPARED  
WITH A TRIPTANE BLEND AND 28-R IN FLIGHT

By Calvin C. Blackman and H. Jack White

Aircraft Engine Research Laboratory  
Cleveland, Ohio

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NACA MR No. E5H08

## NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces

FLIGHT AND TEST-STAND INVESTIGATION OF HIGH-PERFORMANCE

FUELS IN MODIFIED DOUBLE-ROW RADIAL AIR-COOLED ENGINES

III - KNOCK-LIMITED PERFORMANCE OF 33-R AS COMPARED

WITH A TRIPTANE BLEND AND 28-R IN FLIGHT

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## SUMMARY

A comparison has been made in flight of the antiknock characteristics of 33-R fuel with that of 28-R and a triptane blend. The knock-limited performance of the three fuels - 33-R, a blend of 80 percent 28-R plus 20 percent triptane (leaded to 4.5 ml TEL/gal), and 28-R - was investigated in two modified 14-cylinder double-row radial air-cooled engines. Tests were conducted on the engines as installed in the left inboard nacelle of an airplane. A carburetor-air temperature of approximately 85° F was maintained. The conditions covered at an engine speed of 2250 rpm were high and low blower ratios and spark advances of 25° and 32° B.T.C. For an engine speed of 1800 rpm only the high-blower condition was investigated for both 25° and 32° spark advances.

For the conditions investigated the difference between 33-R and the triptane blend was found to be slight; the performance of 33-R fuel, however, was slightly higher than that of the triptane blend in the lean region. The knock-limited power obtained with the 33-R fuel was from 14 to 28 percent higher than that of the 28-R fuel for the entire range of test conditions; the greatest improvement was shown in the lean region.

The knock-limited power for any one fuel at a given set of conditions was essentially the same for the two modified engines used in these tests.

### INTRODUCTION

At the request of the Air Technical Service Command, Army Air Forces, an investigation has been made to evaluate 33-R fuel (115/145) for its antiknock characteristics and to compare the performance of this fuel with 28-R and a fuel blend of 80 percent 28-R plus 20 percent triptane (leaded to 4.5 ml TEL/gal). This work is part of the general triptane and high-performance fuel program being conducted at the NACA Cleveland laboratory. The knock-limited performance with 28-R and the triptane blend has been determined and compared with the cooling-limited performance of a modified double-row radial air-cooled engine. (See reference 1.) The entire cooling correlation for the engine and a complete description of the instrumentation for the airplane is given in reference 2.

Included herein are data on 33-R, a triptane blend, and 28-R fuels. The data were obtained with two modified engines installed successively in the left inboard nacelle of a four-engine airplane. The data from the first modified engine with the triptane blend and 28-R were checked by the second modified engine. The 33-R data were obtained with the second test engine prior to a failure of the rear main roller bearing and crankshaft. Flight tests with the second engine were terminated by this failure after a total of 43 hours of which 17 hours were at knock-limited power.

### TEST EQUIPMENT AND PROCEDURE

Equipment and installation. - The two R-1830-94 (modified) engines were altered to operate in conjunction with a turbosupercharger. The equipment and the instrumentation are the same as described in the appendix of reference 2.

All instrumentation was set up to record data within a very short period of time. Figure 1 shows the installation of thermocouples, cooling-air pressure tubes, and knock pickup on the cylinders.

A few of the measurements of particular interest in determining the knock-limited performance of the fuels are as follows:

1. Carburetor-air temperature - knock curves run at 85° F as indicated by the standard B-24 thermometer unit. A carburetor-screen thermocouple was used for air-flow calculations.

2. Air flow - computed from calibration of PD-12F2-16 carburetor involving air temperature and metering pressures of the carburetor.

3. Fuel flow - indicated by a deflecting-vane-type flowmeter and checked by a rotameter.

4. Knock detection - by magnetostriction-type knock pickups inserted into the combustion chamber of all cylinders. Three oscilloscopes were used to view the combustion traces of three cylinders simultaneously.

5. Mixture temperatures - by a bare thermocouple inserted into the center of each intake pipe at a distance of  $8\frac{1}{2}$  inches from the supercharger outer case.

6. Embedded rear-spark-plug-boss thermocouple ( $T_{38}$ ) - thermocouple junction inserted one-third of head metal thickness in rear-spark-plug boss.

7. Rear-spark-plug-gasket thermocouple ( $T_{12}$ ).

8. Rear middle-barrel thermocouple ( $T_6$ ) - thermocouple junctions peened 1/16 inch into the outer barrel wall between fins 8 and 9 from top.

9. Cooling-air pressure drop - average total pressure at the baffle inlet to the front-row cylinders minus the average static pressure behind the rear-row cylinders, for heads and barrels.

Test fuels. - The F-3 and F-4 knock ratings of the test fuels as obtained at the Cleveland laboratory are as follows:

Fuel	Army-Navy performance numbers	
	F-3 rating (lean)	F-4 rating (rich)
28-R	100	130
33-R	115	145
Triptane blend	109	147

Test conditions and procedure. - The test conditions are tabulated as follows:

Engine speed (rpm)	Carburetor-air temperature (°F)	Blower ratio	Spark advance (deg B.T.C.)	Figure
1800	85	High	25	2
1800	85	High	32	3
2250	85	High	25	4
2250	85	High	32	5
2250	85	Low	25	6
2250	85	Low	32	7

The procedure for conducting the knock tests is given in the appendix of reference 2. Briefly, carburetor-air temperature was maintained constant while test runs were made by boosting to the knock-limited manifold pressure for a series of successive mixture strengths. Knock data were taken while operating the airplane at an indicated airspeed of approximately 200 miles per hour with full-open cowl flaps on the test engine at a pressure altitude of 7000 feet. Consequently, the cooling-air pressure drop remained approximately constant at 14 and 16 inches of water for engine speeds of 1800 and 2250 rpm, respectively.

## RESULTS AND DISCUSSION

Presentation of data. - The knock data are presented in figures 2 to 7. Each figure is subdivided into two parts: (a) presents the knock-limited performance data of manifold pressure, brake horsepower, fuel flow, brake specific fuel consumption, and average mixture temperature; and (b) presents cylinder temperatures measured at the rear middle barrel, the rear-spark-plug gasket, and the rear-spark-plug boss (embedded thermocouple). Each figure presents data on all three fuels for a specific set of engine conditions. (See table under Test Equipment and Procedure.)

The data as presented consist of knock points taken with two modified engines. The tailed points indicate check data taken on subsequent flights. All data after flight 46 were taken with the second test engine; the data for 33-R were obtained with this engine. In flights 38 and 56 (fig. 6) the embedded rear spark-plug-boss temperatures are omitted owing to instrument failures.

Discussion of results. - The reproducibility of knock data for the two engines was fairly good, as is seen in figures 2, 3, 6, and 7. Usually the knock-limited power differed by less than 40 brake horsepower; the exception was the check points with 28-R fuel in flight 56 (fig. 6).

In figures 2 and 3 for an engine speed of 1800 rpm, high blower ratio, and spark advances of 25° and 32° B.T.C., respectively, 33-R fuel permits approximately 8 percent higher knock-limited power at a fuel-air ratio of 0.065 than the triptane blend and about the same performance as the triptane blend fuel in the rich region. This trend is in agreement with Army-Navy performance rating. The knock-limited power with 33-R fuel was from 15 to 28 percent higher than with 28-R fuel for the range of test conditions in these figures.

Figures 4 and 5 for an engine speed of 2250 rpm, high blower ratio, and spark advances of 25° and 32° B.T.C., respectively, show the knock-limited power with 33-R fuel for these conditions to be generally about the same as with the triptane blend and from 14 to 21 percent higher than with 28-R fuel.

Included in figure 4 are knock points for 28-R fuel taken during a series of runs of flight 34 by operating the engine at a constant maximum rear-spark-plug-boss temperature of approximately 465° F. These data indicate that the knock-limited performance differs only slightly when the knock curve is determined at constant head temperature rather than at constant cooling-air pressure drop. All the other knock curves were obtained at constant cooling-air pressure drop and engine temperatures varied as shown in figures 2(b) to 7(b).

Knock data at an engine speed of 2250 rpm with low blower ratio are presented in figures 6 and 7 for spark advances of 25° and 32° B.T.C., respectively. For these conditions the knock-limited power of 33-R is approximately 7 percent higher than that of the triptane blend at a fuel-air ratio of 0.065. For the conditions tested the difference between the 33-R and the triptane blend fuels is slight; however, the performance of 33-R is slightly higher in the lean region. The knock-limited power with 33-R fuel is from 14 to 28 percent higher than that with the 28-R fuel for the test conditions. The greatest improvement on percentage basis is shown in the lean region.

The following table presents a comparison of the knock-limited performance of 33-R and the triptane blend relative to 28-R:

RATIOS OF KNOCK-LIMITED BRAKE HORSEPOWER OF TEST FUELS RELATIVE  
TO 28-R AT A CARBURETOR-AIR TEMPERATURE OF 85° F

Fuel →	33-R			Triptane blend		
Fuel-air ratio →	0.065	0.03	0.09	0.065	0.08	0.09
Engine speed, 1800 rpm; high blower; spark advance, 25° B.T.C.	1.21	1.21	1.19	1.11	1.21	1.20
Engine speed, 1800 rpm; high blower; spark advance, 32° B.T.C.	1.28	1.23	1.22	1.20	1.19	1.20
Engine speed, 2250 rpm; high blower; spark advance, 25° B.T.C.	1.19	1.20	1.14	1.24	1.19	1.21
Engine speed, 2250 rpm; high blower; spark advance, 32° B.T.C.	1.16	1.21	1.20	1.15	1.28	1.27
Engine speed, 2250 rpm; low blower; spark advance, 25° B.T.C.	1.28	1.24	----	1.20	1.21	1.24
Engine speed, 2250 rpm; low blower; spark advance, 32° B.T.C.	1.23	1.17	----	1.15	1.17	----

SUMMARY OF RESULTS

The following results apply to the modified double-row radial air-cooled engine in a four-engine airplane for tests conducted at engine speeds of 1800 and 2250 rpm, at spark settings of 25° and 32° B.T.C., and for high and low blower ratios:

1. The knock-limited performance of 33-R fuel was approximately the same as that of the triptane blend. It was somewhat higher in the lean region and had a tendency to be slightly lower in the rich region.

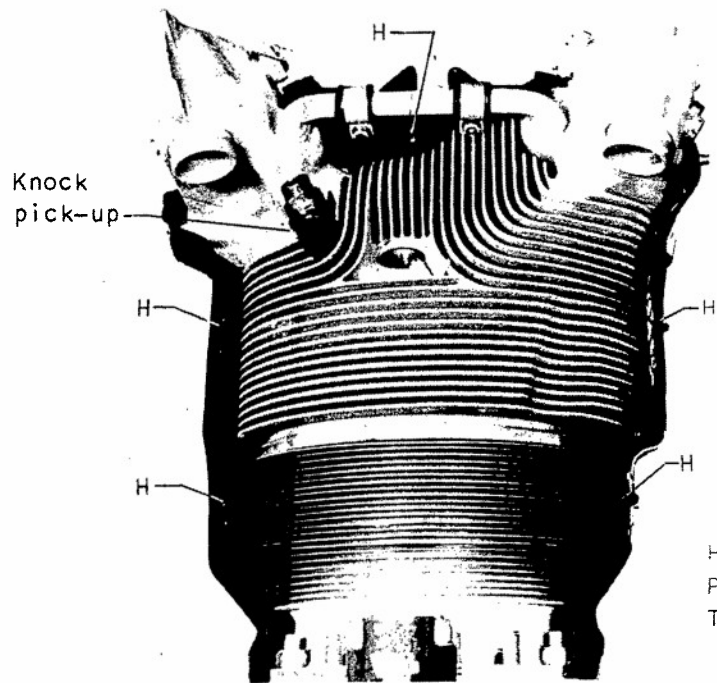
2. The knock-limited power obtained with 33-R fuel was from 14 to 28 percent higher than 28-R fuel. The improvement on a percentage basis was greatest in the lean region.

3. The knock-limited performance of the two modified engines was essentially the same for the conditions investigated.

Aircraft Engine Research Laboratory,  
National Advisory Committee for Aeronautics,  
Cleveland, Ohio, August 8, 1945.

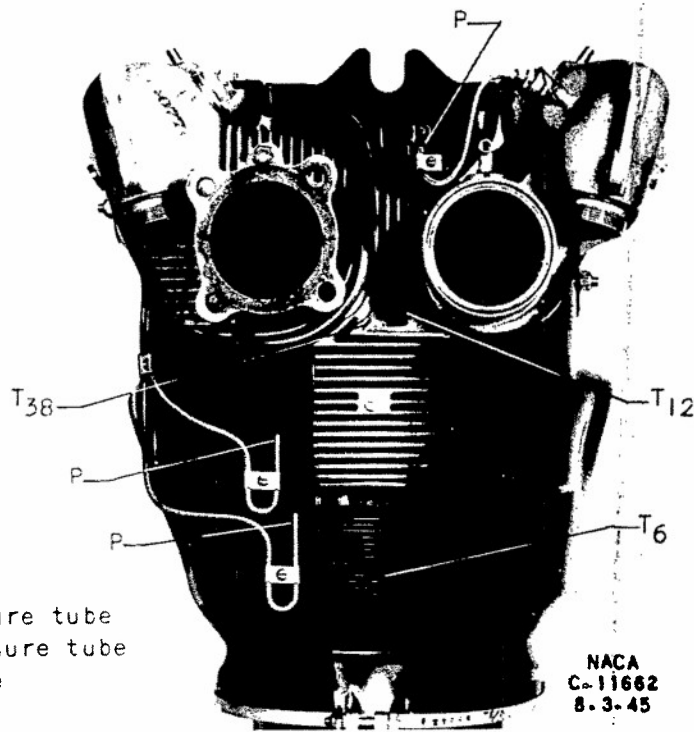
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1. White, H. Jack, Pragliola, Philip C., and Blackman, Calvin, C.: Flight and Test-Stand Investigation of High-Performance Fuels in Modified Double-Row Radial Air-Cooled Engines. II - Flight Knock Data and Comparison of Fuel Knock Limits with Engine Cooling Limits in Flight. NACA MR No. E5H04, 1945.
2. Werner, Milton, Blackman, Calvin C., and White, H. Jack: Flight and Test-Stand Investigation of High-Performance Fuels in Modified Double-Row Radial Air-Cooled Engines. I - Determination of the Cooling Characteristics of the Flight Engine. NACA MR No. E5G09, 1945.



Front-row cylinder  
Front view

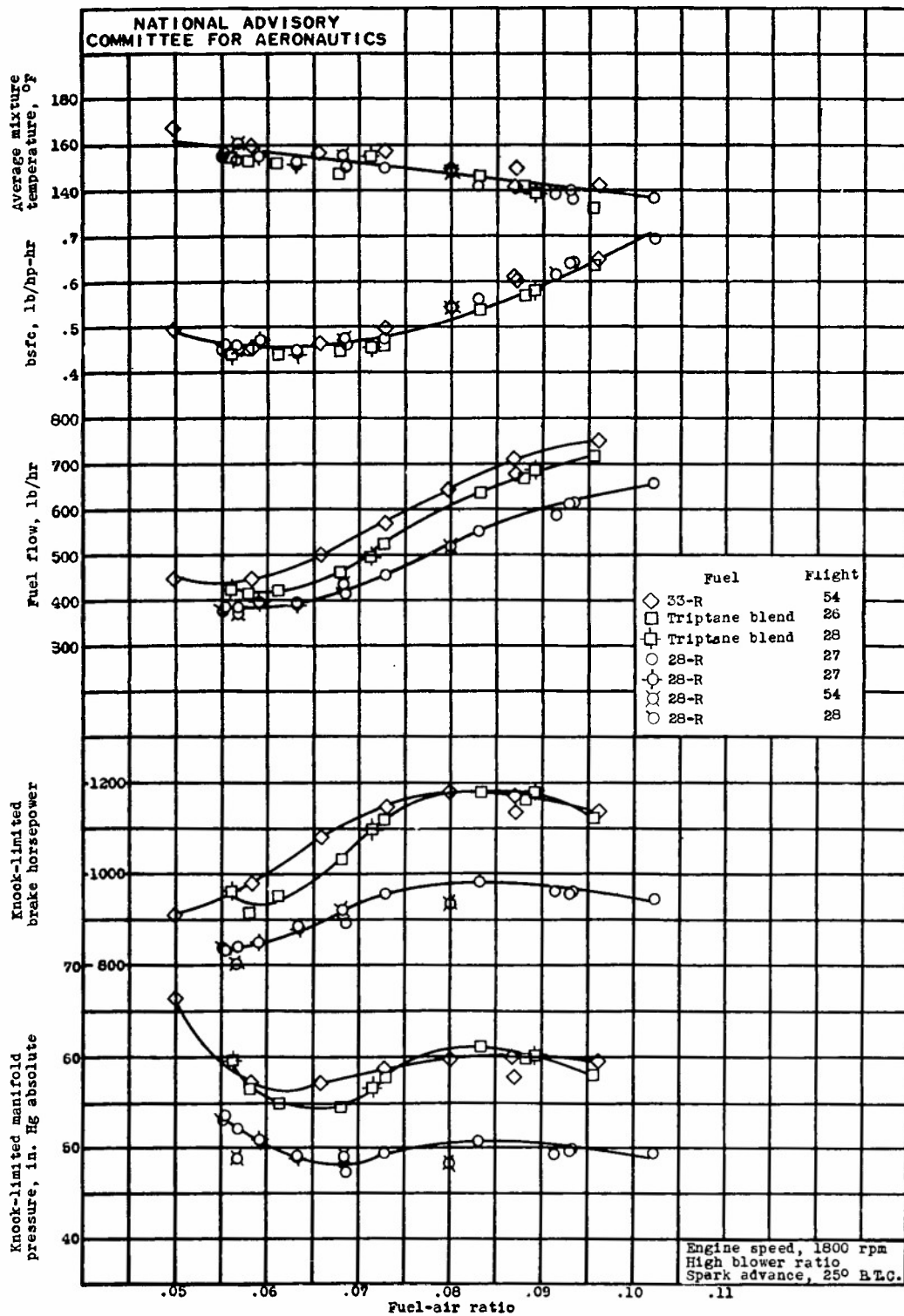
H Total-Pressure tube  
P Static-pressure tube  
T Thermocouple



Rear-row cylinder  
Rear view

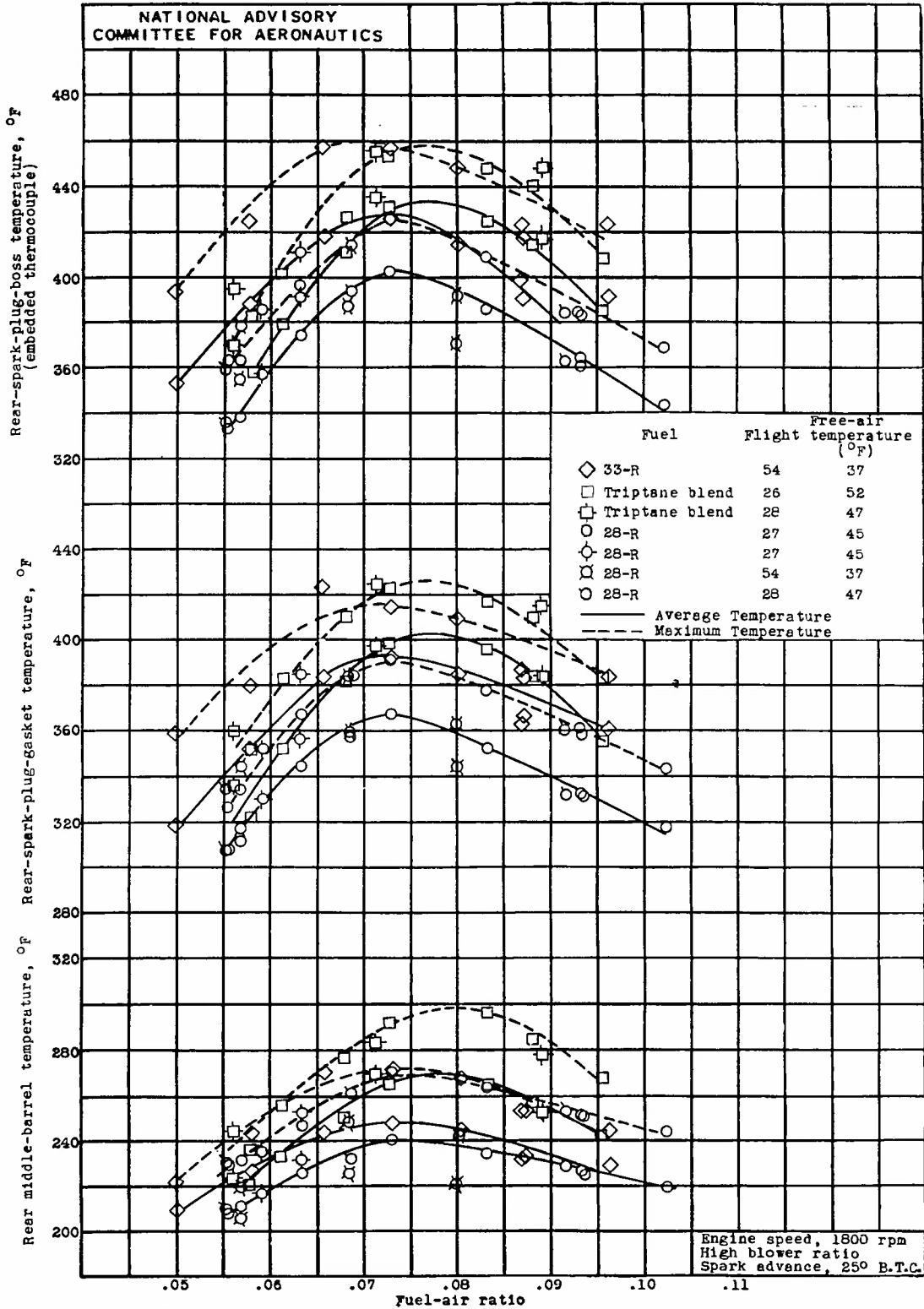
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Figure 1. - Thermocouple, cooling-air pressure-tube, and knock pickup installation on air-cooled cylinders.



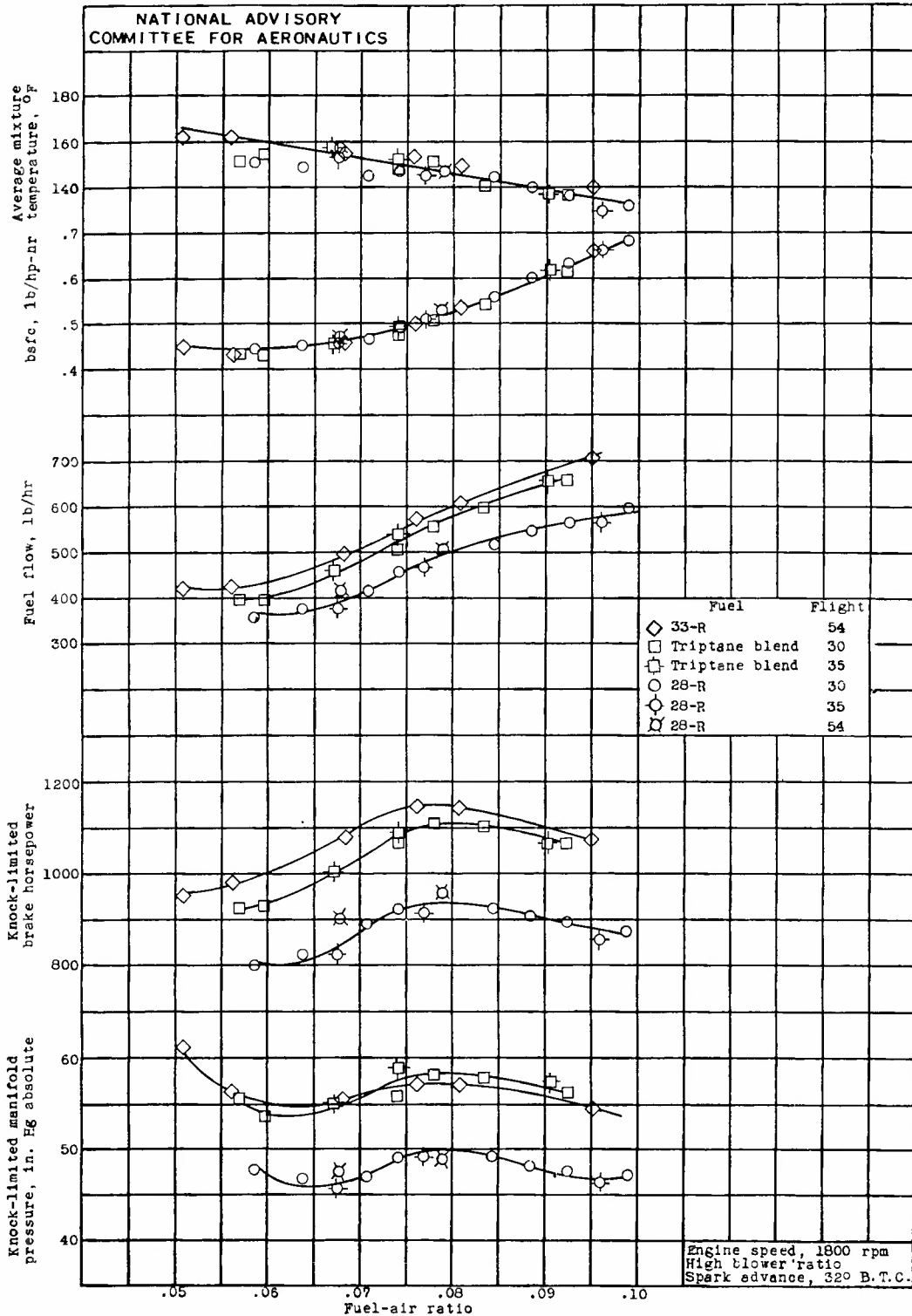
(a) Engine-performance variables.

Figure 2. - Performance of modified engines as limited by the knock characteristics of three fuels; engine speed, 1800 rpm; high blower ratio (8.47:1); spark advance, 25° B.T.C.; carburetor-air temperature (bulb), approximately 85° F; four-engine airplane.



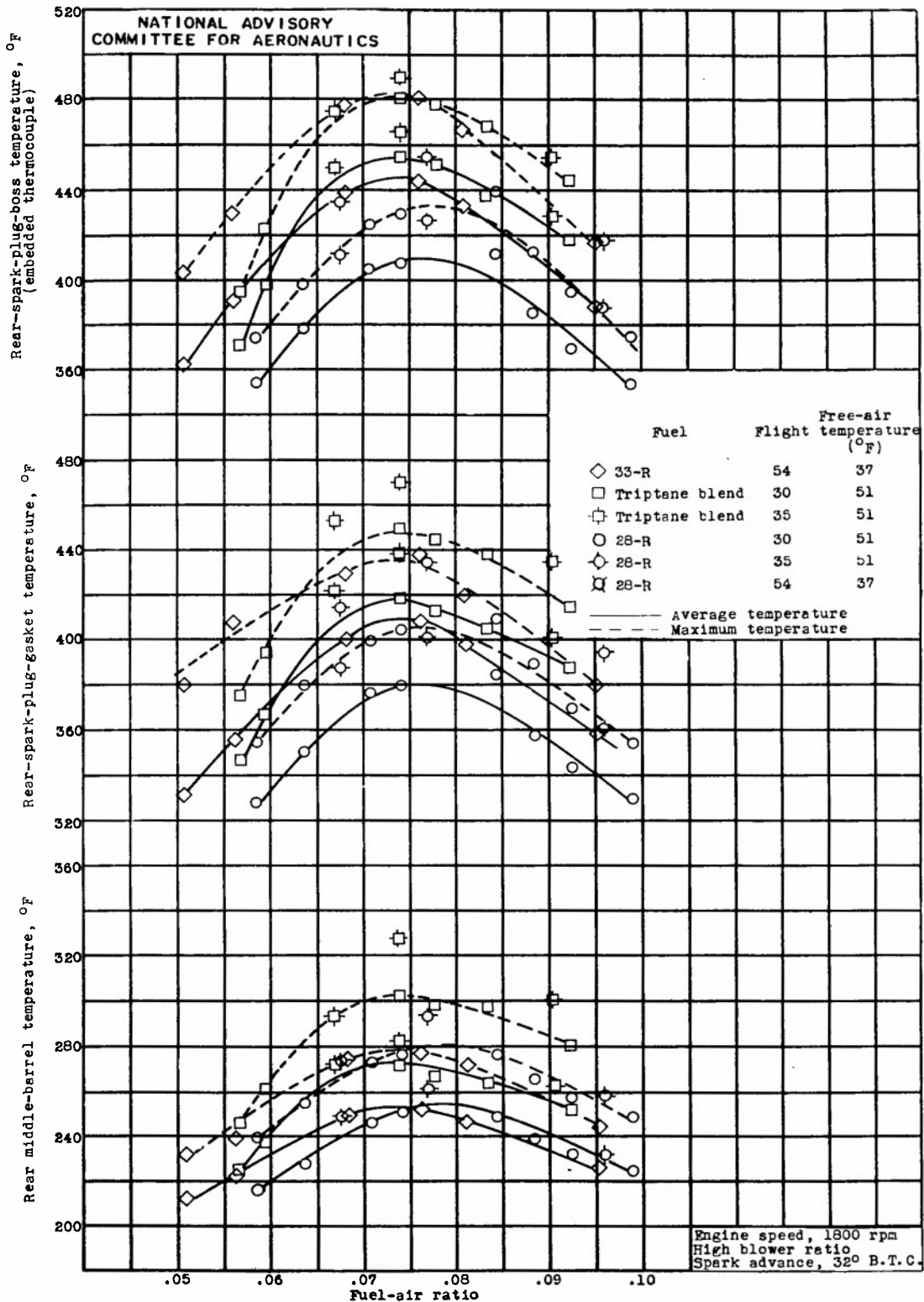
(b) Temperatures.

Figure 2. - Concluded.



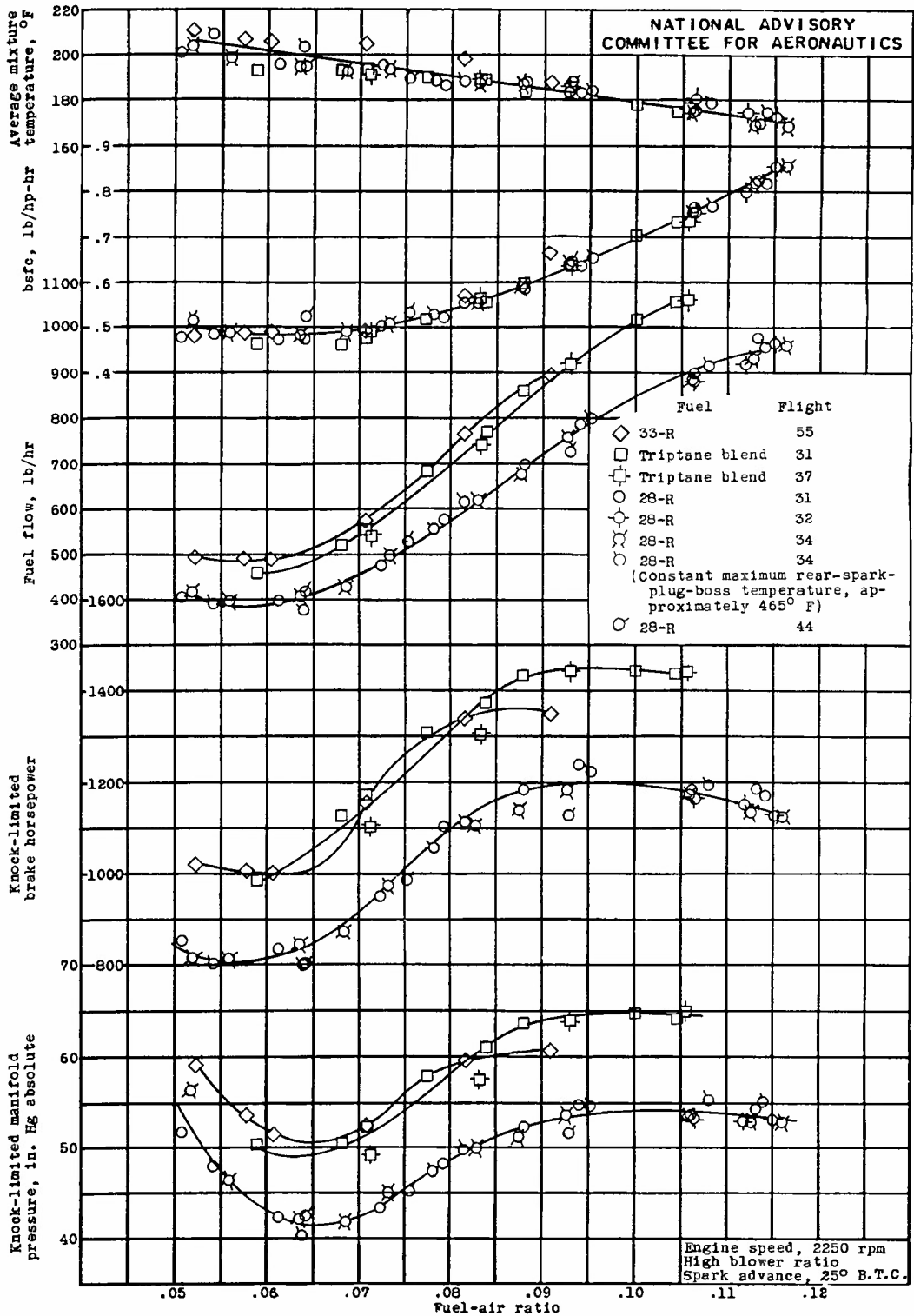
(a) Engine-performance variables.

Figure 3. - Performance of modified engines as limited by the knock characteristics of three fuels; engine speed, 1800 rpm; high blower ratio (8.47:1); spark advance, 32° B.T.C.; carburetor-air temperature (bulb), approximately 85° F; four-engine airplane.



(b) Temperatures.

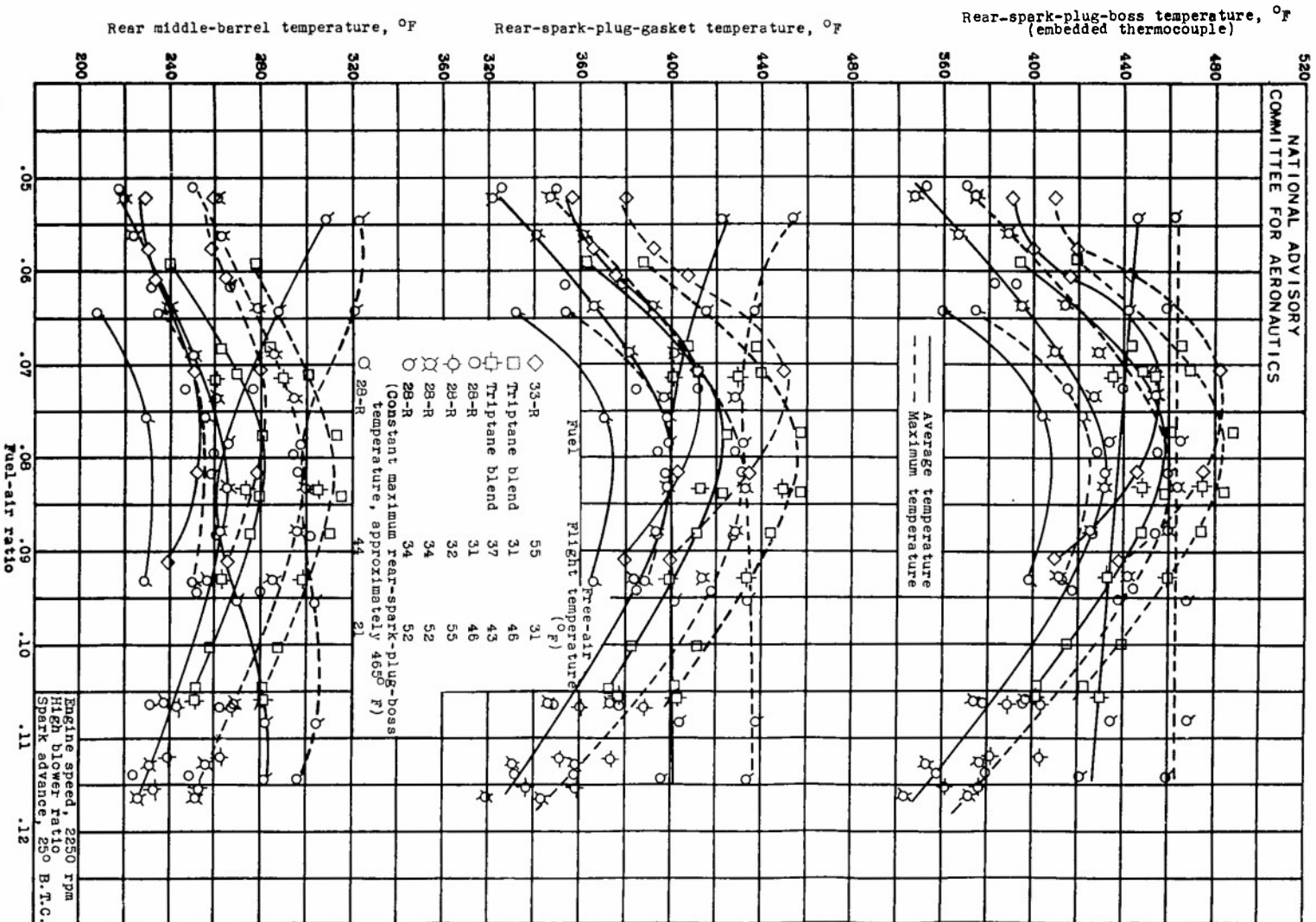
Figure 3. - Concluded.



(a) Engine-performance variables.

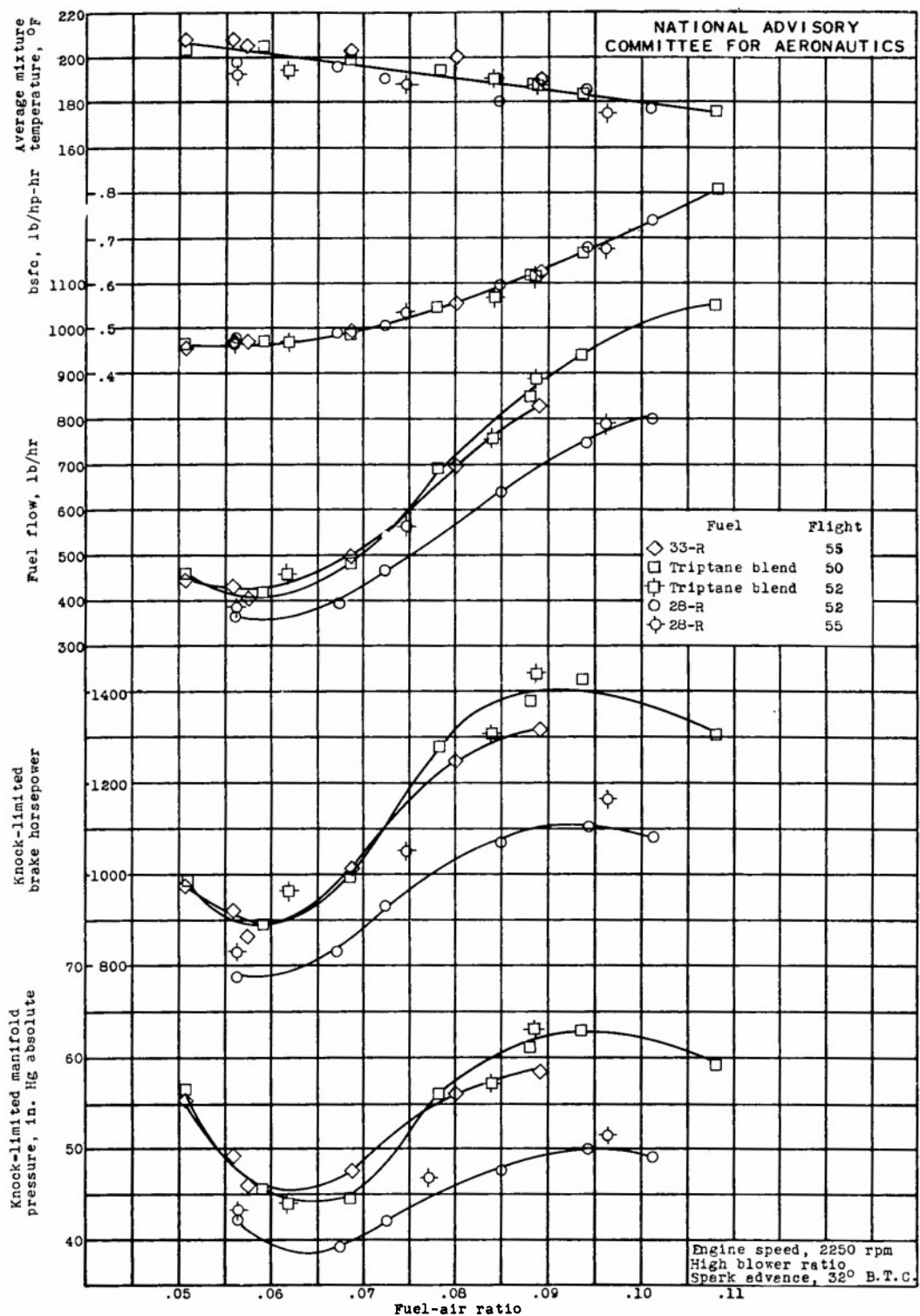
Figure 4. - Performance of modified engines as limited by the knock characteristics of three fuels; engine speed, 2250 rpm; high blower ratio (8.47:1); spark advance, 25° B.T.C.; carburetor-air temperature (bulb), approximately 85° F; four-engine airplane.

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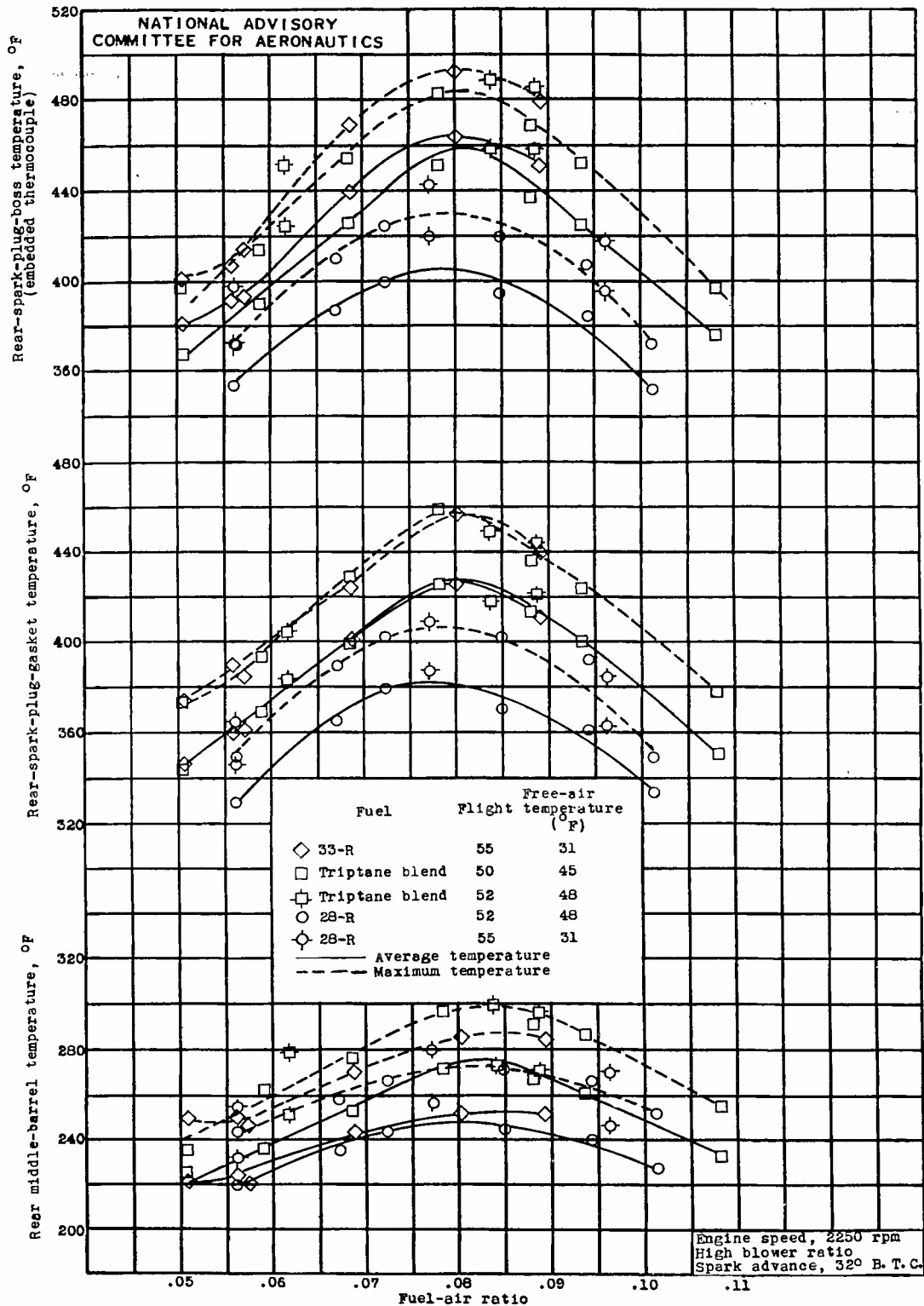
(b) Temperatures.  
Figure 4. - Concluded.

Engine speed, 2250 rpm  
High blower ratio  
Spark advance, 25° B.T.C.



(a) Engine-performance variables.

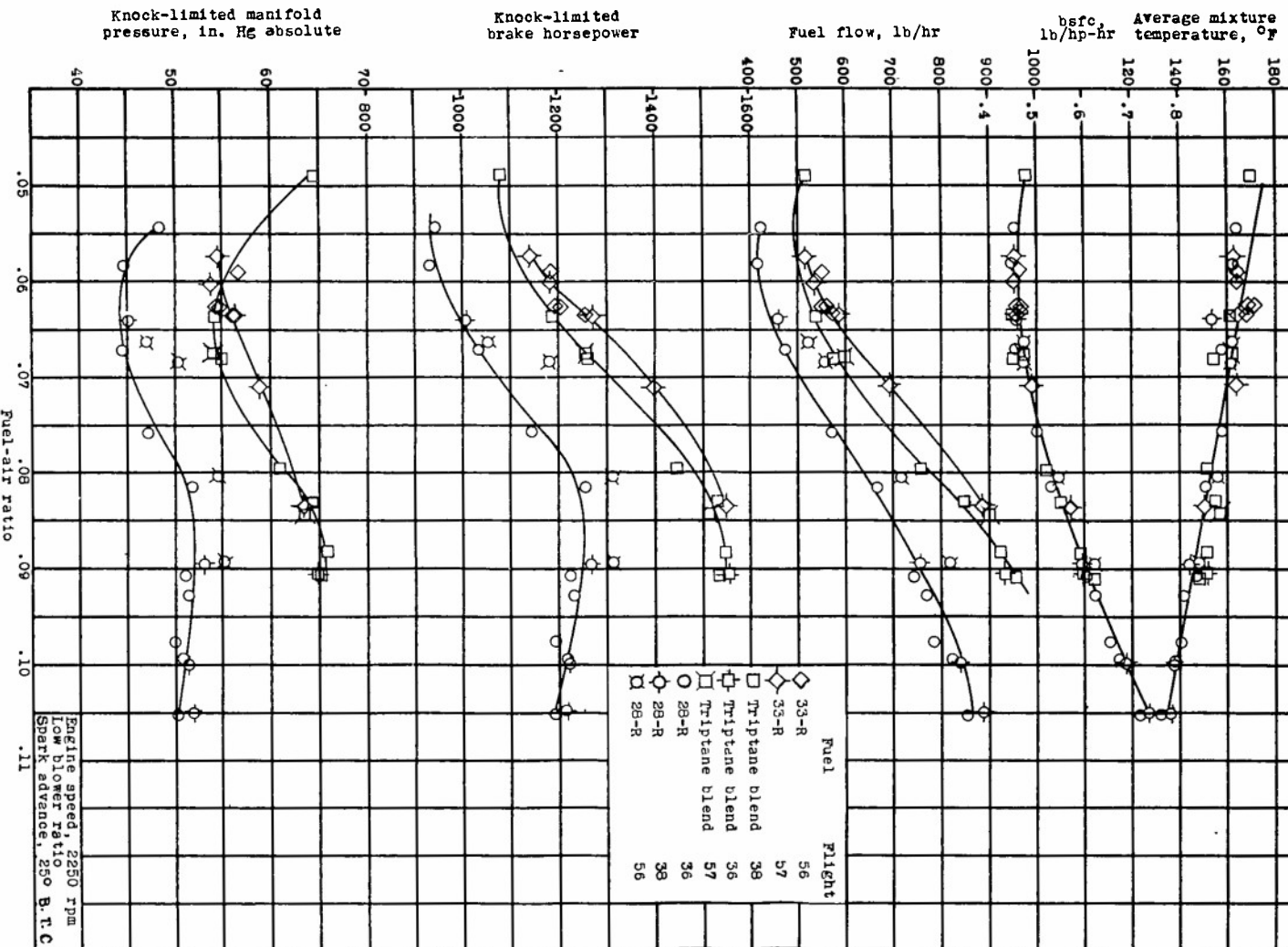
Figure 5. - Performance of modified engines as limited by the knock characteristics of three fuels; engine speed, 2250 rpm; high blower ratio (8.47:1); spark advance, 32° B.T.C.; carburetor-air temperature (bulb), approximately 85° F; four-engine airplane.



(b) Temperatures.

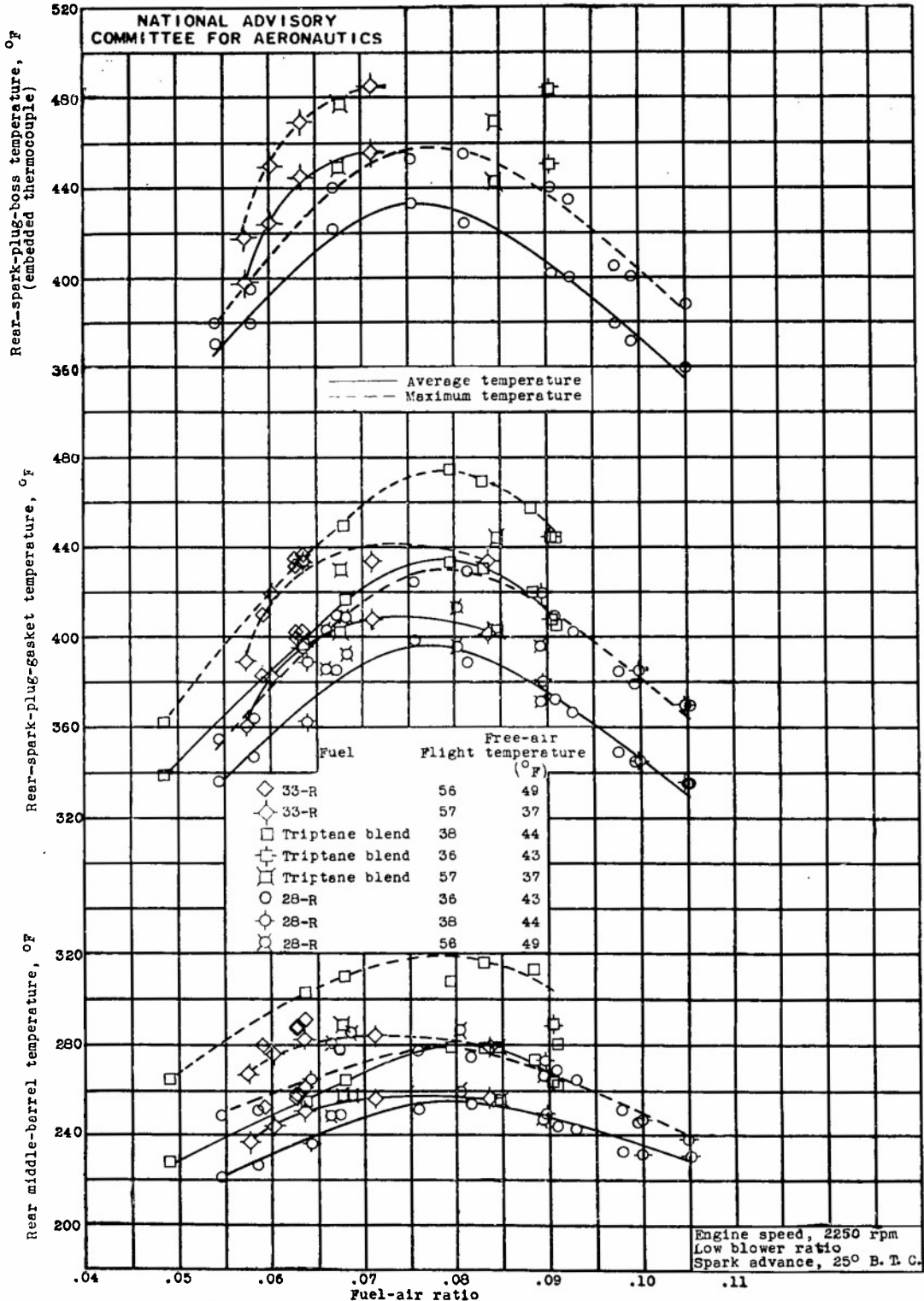
Figure 5. - Concluded.

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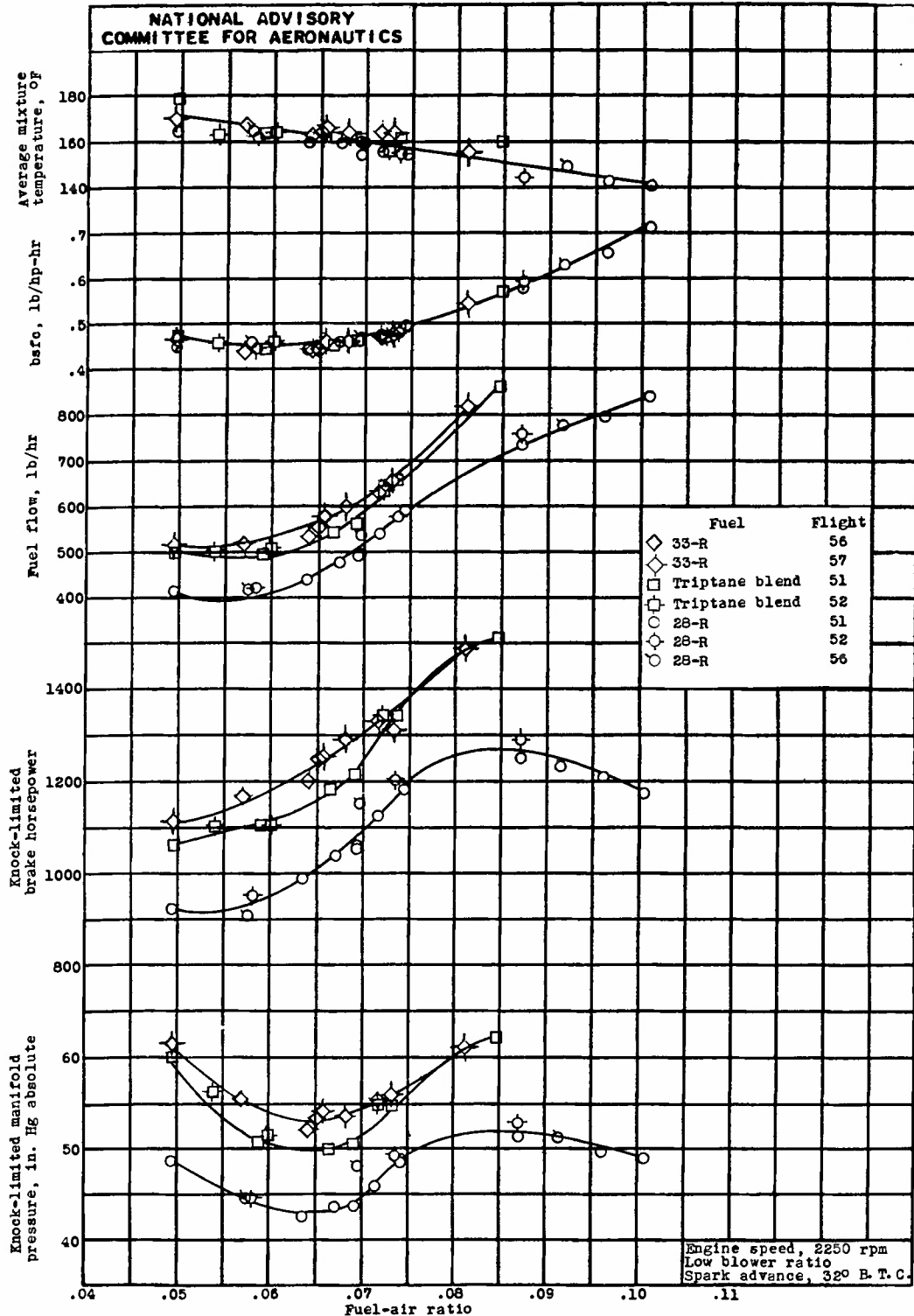
(a) Engine-performance variables.

Figure 6. - Performance of modified engine as limited by the knock characteristics of three fuels; engine speed, 2250 rpm; low blower ratio (7.15:1); spark advance, 25° B.T.C.; carburetor-air temperature (bulb), approximately 85° F; four-engine airplane.



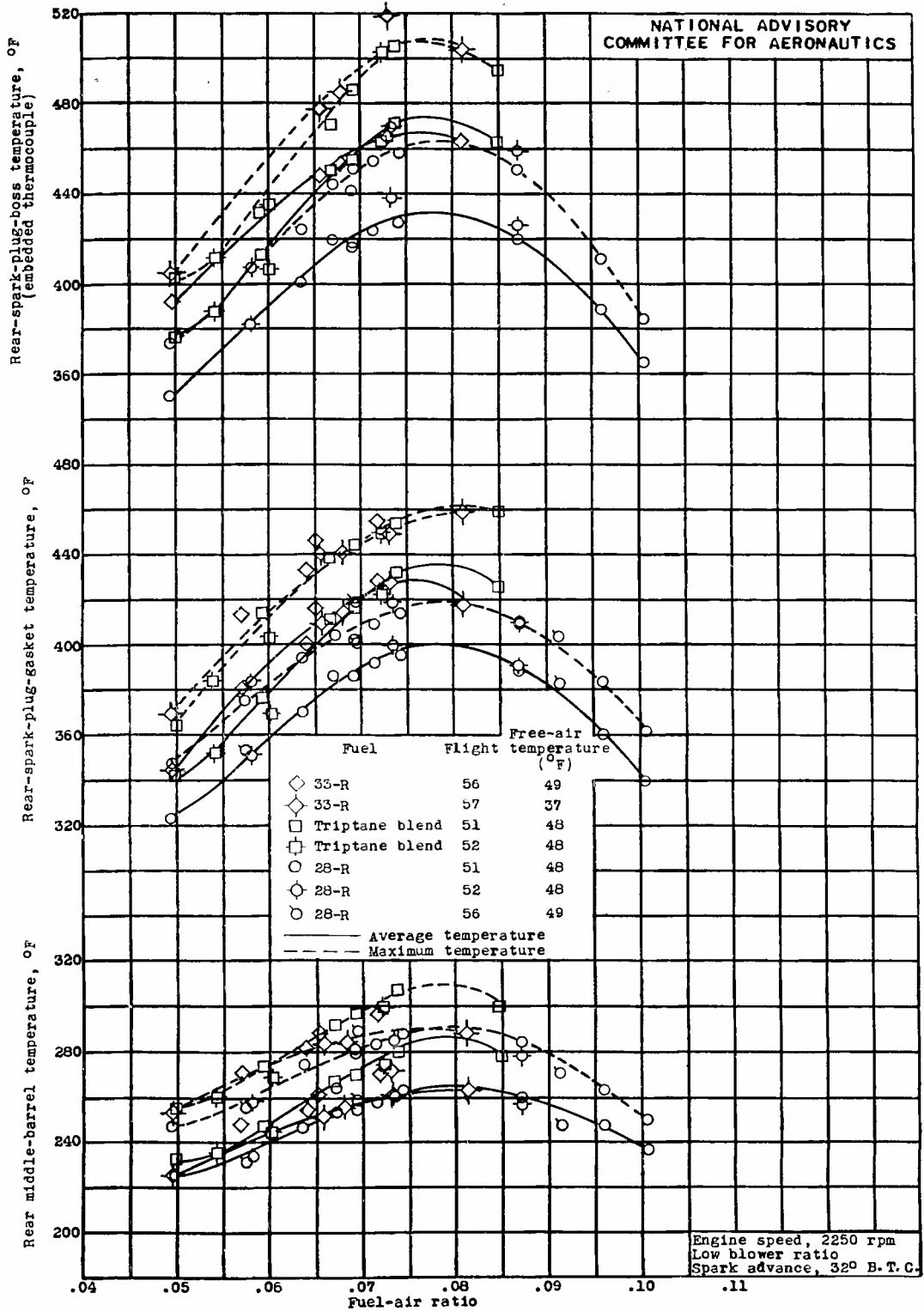
(b) Temperatures.

Figure 6. - Concluded.



(a) Engine-performance variables.

Figure 7. - Performance of modified engines as limited by the knock characteristics of three fuels; engine speed, 2250 rpm; low blower ratio (7.15:1); spark advance, 32° B.T.C.; carburetor-air temperature (bulb), approximately 85° F; four-engine airplane.



(b) Temperatures.

Figure 7. - Concluded.

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**ORIGINATING AGENCY:** National Advisory Committee for Aeronautics, Washington, D. C.

ATI- 22798

REVISION  
none

ORIG. AGENCY NO.  
MR E5H08

DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
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**SECTION:** Liquid Fuels (2)

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Air Materiel Command  
U. S. Air Force

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Dayton, Ohio

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