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KNOCK-LIMITED BLENDING CHARACTERISTICS OF BENZENE, TOLUENE, MIXED XYLENES, AND CUMENE IN AN AIR-COOLED CYLINDER

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MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

KNOCK-LIMITED BLENDING CHARACTERISTICS OF BENZENE, TOLUENE, MIXED XYLENES, AND CUMENE IN AN AIR-COOLED CYLINDER

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SUMMARY

An investigation was conducted to determine the knock-limited blending characteristics of leaded fuels containing selected aromatic fuel components (benzene, toluene, mixed xylenes, and cumene). Each of the aromatics was blended with an alkylate blending agent and with a virgin base stock. The blending characteristics of the resulting fuels were determined in a full-scale aircraft-engine cylinder.

The knock-limited indicated mean effective pressures of blends of the two base fuels, each containing equal concentrations of an aromatic, varied according to the reciprocal blending equation. Good correlation was obtained between knock-limited data at spark advances of 20° and 30° B.T.C. and between rich and lean fuel-air mixtures at the same spark advance.

INTRODUCTION

Engine tests to evaluate the knocking characteristics of a selected group of aviation-fuel components are being conducted at the NACA Cleveland laboratory at the request of the Army Air Forces, Air Technical Service Command.

The tests reported herein were conducted during the autumn of 1944 to determine the blending characteristics of benzene, toluene, mixed xylenes, and cumene with alkylate blending agent and virgin base stock when tested in a full-scale air-cooled cylinder.

APPARATUS AND PROCEDURE

The base fuels used in this investigation were an alkylate blending agent and a virgin base stock. The blending agents were:

- Benzene
- Toluene (methylbenzene)
- Mixed xylenes
  - o-xylene, 14.9 percent
  - m-xylene, 47.4 percent
  - p-xylene, 23.5 percent
  - ethylbenzene, 11.5 percent
  - unidentified impurities, 2.7 percent
- Cumene (isopropylbenzene)

All fuels contained 4 ml TEL per gallon. Unless stated otherwise, all subsequent references to any fuel or fuel blend will refer to the fuel or blend leaded to this concentration of tetraethyl lead.

Inspection data for the fuels used in this program are given in reference 1.

Blends containing 25 percent of the aromatic blending components and 75 percent of each of the two base fuels were prepared, and the two fuels containing the same aromatic were then blended as described in reference 2. The rest of the test procedure was identical with the procedure described in reference 2. All blend compositions are given on a weight basis.

Tests were conducted with an R-2800 cylinder mounted on a CUE crankcase. The apparatus is described in detail in reference 2.

The engine operating conditions were as follows:

Compression ratio	7.7
Spark advance, deg B.T.C.	20 and 30
Engine speed, rpm	2000
Condition of fuel-air mixture	Prevaporized
Inlet-mixture temperature, °F	240
Cooling-air temperature, °F	80 to 100
Cylinder-head temperature at exhaust end zone, °F	350

The temperature of the rear spark-plug bushing was approximately 400° F.

RESULTS AND DISCUSSION

Reference fuels. - The knock-limited performances of leaded S-4 reference fuel and leaded blends of S-4 reference fuel with M-4 reference fuel are given in figures 1 and 2. Figure 1 presents the data obtained for a spark advance of 20° B.T.C. and figure 2 presents similar data for a spark advance of 30° B.T.C.

The knock-limited indicated mean effective pressures and the indicated specific fuel consumptions for the mixture-response curves of leaded S-4 reference fuel and of a leaded blend containing 50 percent S-4 plus 50 percent M-4 reference fuels for a range of fuel-air ratios from approximately 0.05 to 0.115 are shown in figure 1(a).

Figure 1(b) is a rating chart constructed from the data of figure 1(a) for the purpose of rating fuels at fuel-air ratios of 0.067 and 0.10 in terms of the percentage S-4 plus 4 ml TEL per gallon in M-4 plus 4 ml TEL per gallon. The ordinate is an inverted reciprocal scale. Inasmuch as the data at a spark advance of 20° B.T.C. for blends of these two fuels were found to be in agreement with the reciprocal blending relation in reference 2, it was considered unnecessary to repeat the tests of blends of these two fuels at constant fuel-air ratios. Ratings of fuels having knock-limited indicated mean effective pressures greater than that of S-4 plus 4 ml TEL per gallon can be estimated in terms of the abscissa scale from the straight-line extrapolation beyond a concentration of 100 percent S-4.

An estimated reference-fuel framework for intervals of 5-percent concentrations of S-4 is given in figure 1(c). The ordinate is a reciprocal scale and, because of the assumed agreement of the data with the reciprocal blending relation, the curves for equal increments of composition are equally spaced. For comparison, the knock-limited mixture-response curve for unleaded S-4 reference fuel is also shown.

The data for a spark advance of 30° B.T.C., presented in figure 2, are similar to the data presented in figure 1 except that blends of the two reference fuels were tested at fuel-air ratios of 0.067 and 0.10 (fig. 2(a)). Figure 2(b) shows that these data are in agreement with the reciprocal blending relation.

Aromatic fuels at a spark advance of 20° B.T.C. - Mixture-response curves for blends of 25 percent benzene with alkylate blending agent and with virgin base stock are shown in figure 3(a), together with knock-limited data points for blends of these two fuels at fuel-air ratios of approximately 0.067 and 0.10. Additional knock-limited data points for virgin base stock and for alkylate blending agent at fuel-air ratios of approximately 0.067 and 0.10 are included in order to show the increase in knock-limited performance obtained by the addition of the benzene to the base stocks. The data for the base stocks were obtained either immediately before or immediately after the data for the blends in order to minimize the effect of any change in engine operating conditions with time.

The data for varying blend composition at constant fuel-air ratios result in straight lines when plotted with the reciprocal of the knock-limited indicated mean effective pressure as the ordinate and the percentage of the 75 percent alkylate plus 25 percent benzene component in the blend as the abscissa. (See fig. 3(b).)

Data for toluene, mixed xylenes, and cumene are presented in figures 4, 5, and 6, respectively, in the same manner as the benzene data and are generally similar to the data for benzene. The data for cumene were not taken at the same time as those for the other aromatics and, consequently, may not be strictly comparable with them.

Figure 7(a) presents the data obtained by blending 25 percent mixed xylenes plus 75 percent alkylate with 25 percent toluene plus 75 percent virgin base stock at a fuel-air ratio of approximately 0.067. Figure 7(b) shows that the knock-limited performance of a blend of these two fuels can be predicted by the reciprocal blending relation.

<u>Aromatic fuels at a 30° B.T.C. spark advance.</u> - Data for toluene, mixed xylenes, and cumene obtained at a spark advance of 30° B.T.C. are shown in figures 8, 9, and 10, respectively. Data points for the virgin base stock and the alkylate were not taken at the same time as the data for each of the aromatic blends as was done for the 20° B.T.C. spark-advance data. Instead, the values for the base stocks were taken from complete mixture-response curves, which were obtained before the aromatic blends were tested. These mixture-response curves are shown in figure 11 and are not plotted on the graphs with the aromatic-blend data. The data at a spark advance of 30° B.T.C. are presented in the same manner as those at 20° B.T.C. and are, in general, similar to them. With all fuel blends tested, the reciprocal blending relation was verified.

<u>Correlation between rich and lean data.</u> - The correlation between knock-limited indicated mean effective pressures at fuel-air ratios

of 0.067 and 0.10 for a spark advance of 20° B.T.C. is shown in figure 12(a). Reciprocal scales were used for the coordinates because, with these scales, the points representing blends of two components will lie on a straight line that connects the points representing the components, provided the knock limits of the blends follow the reciprocal blending equation. Data for the blends containing 25 percent of an aromatic and data for the paraffinic reference fuels and base fuels are shown. Two points are shown for each aromatic; the point giving the higher indicated mean effective pressure represents the blend of the aromatic and the alkylate, whereas the lower point represents the blend of the aromatic and the virgin base stock. The data points determine two straight lines, one for the paraffinic fuels and another for the aromatic fuel blends.

Figure 12(b) is a similar correlation for the results obtained at a spark advance of 30° B.T.C. A comparison of figures 12(a) and 12(b) shows that advancing the spark timing increases the slope of the correlation curve for the aromatic blends more rapidly than the slope of the curve for the paraffinic fuels. This fact is a consequence of the greater sensitivity of the aromatic blends, as compared with the paraffinic fuels, to changes in the severity of the test conditions, as is exemplified by the greater steepness of the mixture-response curves for the aromatic blends at the advanced spark timing.

Correlation between 20° and 30° B.T.C. spark-advance data. - The correlation between data for spark advances of 20° and 30° B.T.C. at a fuel-air ratio of 0.067 is shown in figure 13(a). As in the previous correlations, separate correlation lines are established by the paraffinic fuels and the aromatic blends.

Figure 13(b) presents a correlation of the 20° and 30° B.T.C. spark-advance data at a fuel-air ratio of 0.10. At this fuel-air ratio the change in spark advance makes very little difference in the knock-limited performance of any of the fuels, as is evidenced by the fact that all the data points, for both paraffinic fuels and aromatic blends, lie close to the match line.

Caution should be exercised in using the data shown in figure 13(a) for estimating the effect of spark advance upon the antiknock effectiveness of the aromatics. The knock curve of pure xylenes is extremely steep at lean mixtures as can be seen in figure 14. Any slight variation in engine conditions will result in an extremely large difference in the observed knock limit. The knock-limited inlet-air pressures of blends with virgin base were below atmospheric pressure at lean mixtures and, consequently, the test conditions were more severe (see reference 3) than in the cases where the base fuel was alkylate and the knock-limited inlet-air pressures were above the exhaust back pressure.

Subsequent tests under slightly different engine conditions showed that 25-percent additions of an aromatic to both virgin base stock and alkylate blending agent resulted in small and approximately equal depreciations in the knock-limited performance at a fuel-air ratio of 0.067. These tests also verified the data presented insofar as the blending characteristics discussed herein are concerned.

SUMMARY OF RESULTS

From a series of knock tests in a full-scale air-cooled cylinder of blends containing 25 percent of an aromatic, 75 percent of a paraffinic base stock, and leaded to a concentration of 4 ml TEL per gallon, the following results were obtained:

1. The knock-limited indicated mean effective pressures of blends of fuels containing the same aromatic concentration followed the reciprocal blending equation.

2. Based on knock-limited indicated mean effective pressures, good correlation was obtained between data at spark advances of 20° and 30° B.T.C. and between data at rich and lean fuel-air mixtures with the same spark advance.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, February 3, 1945.

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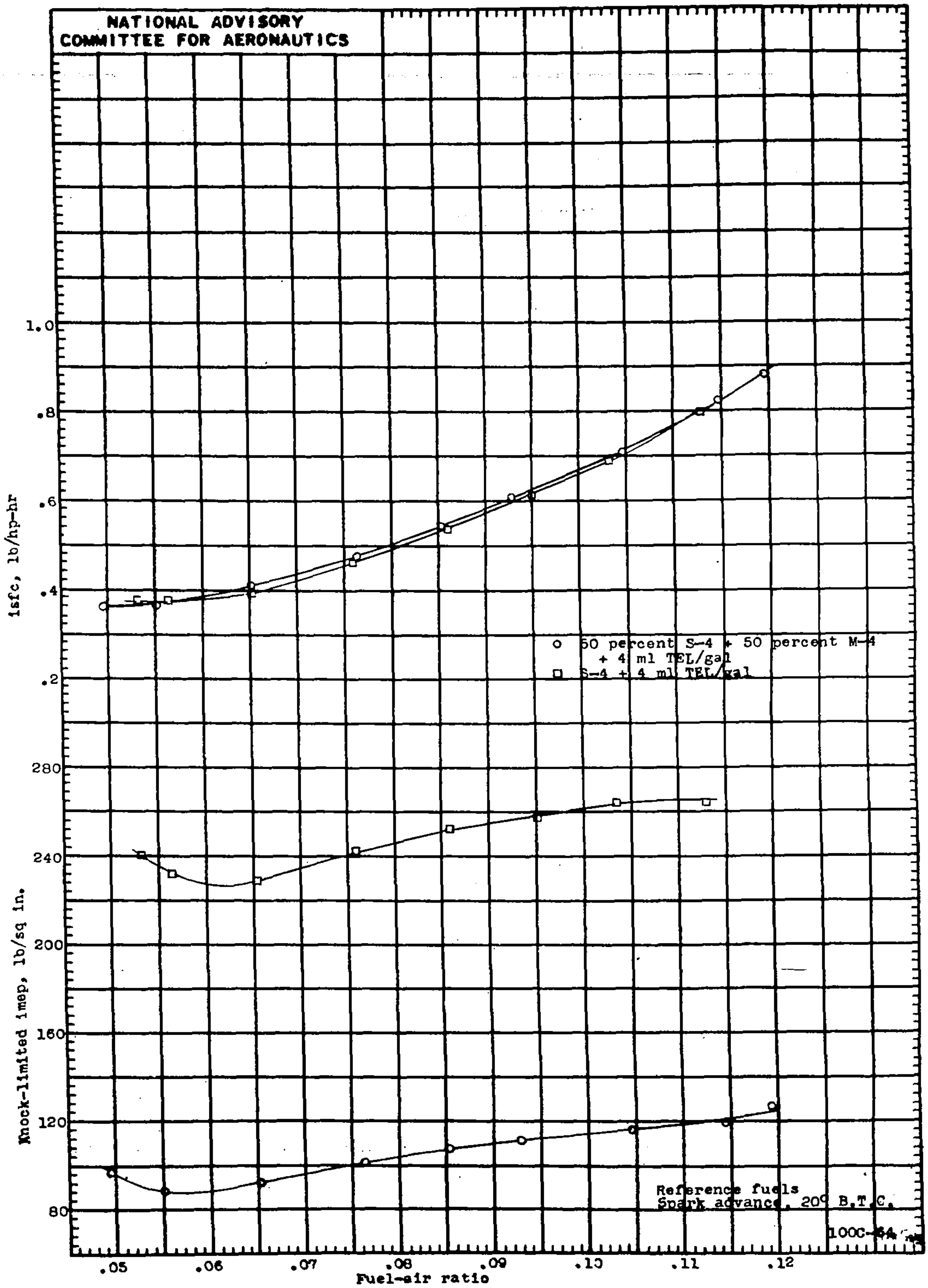
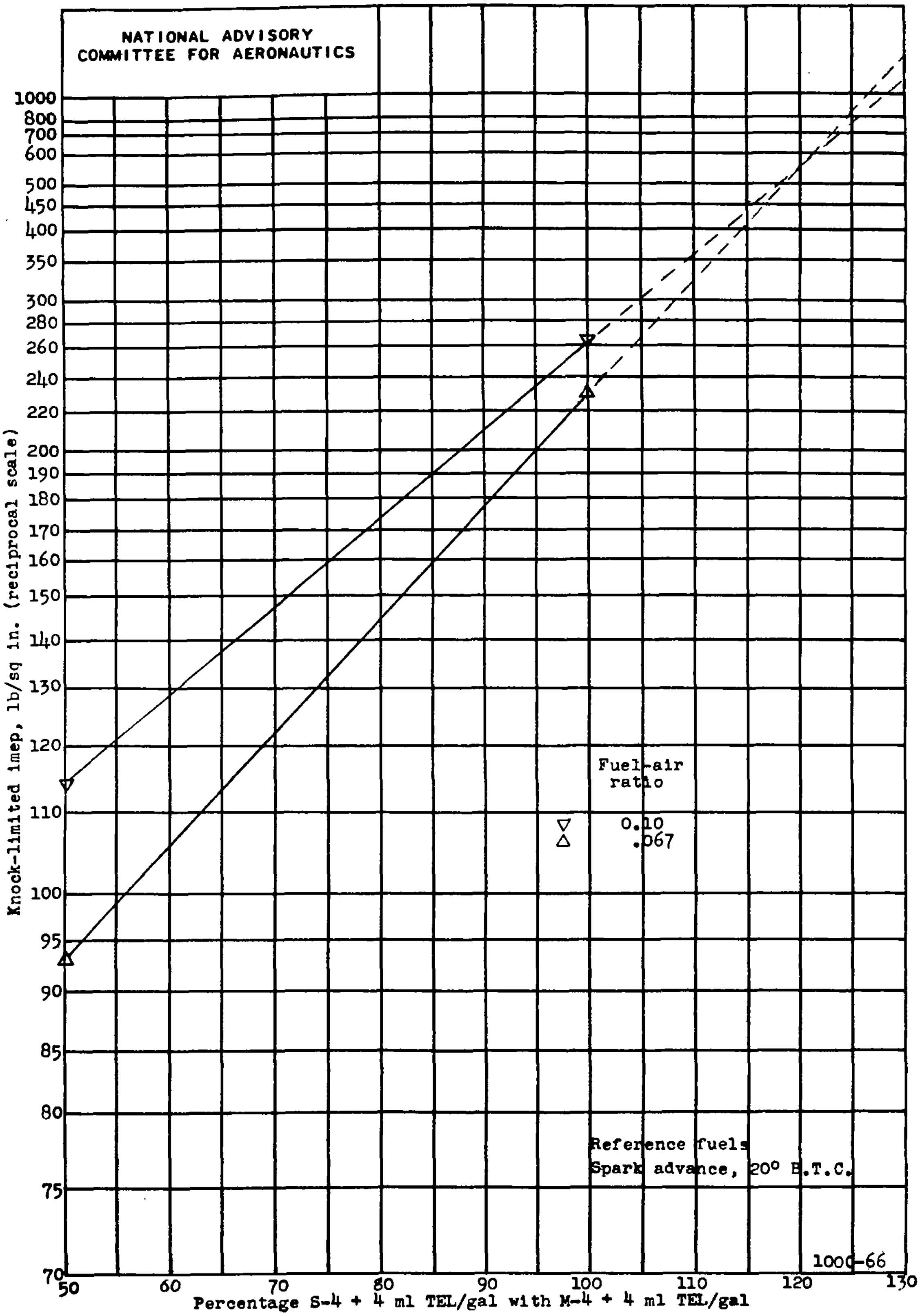
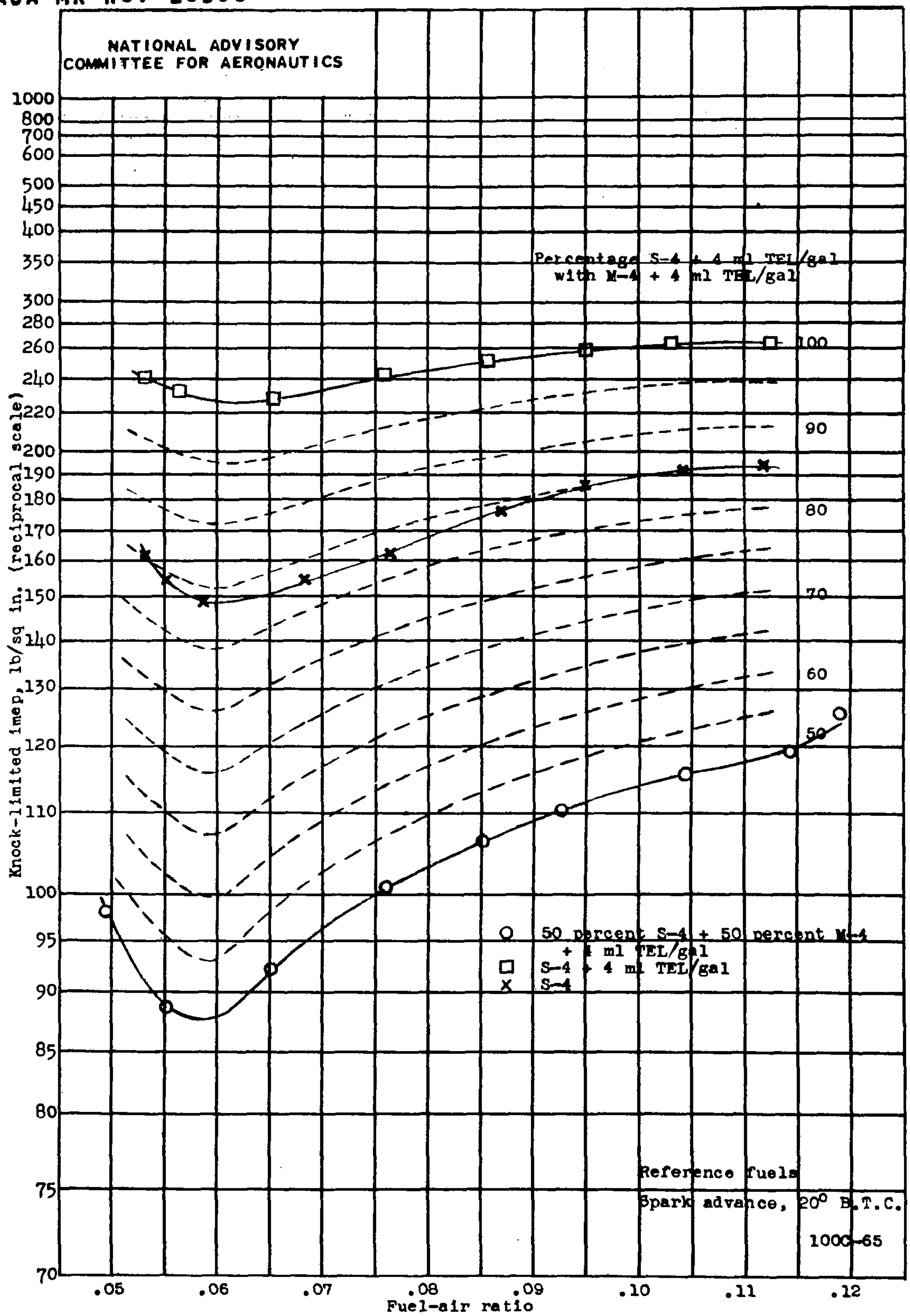


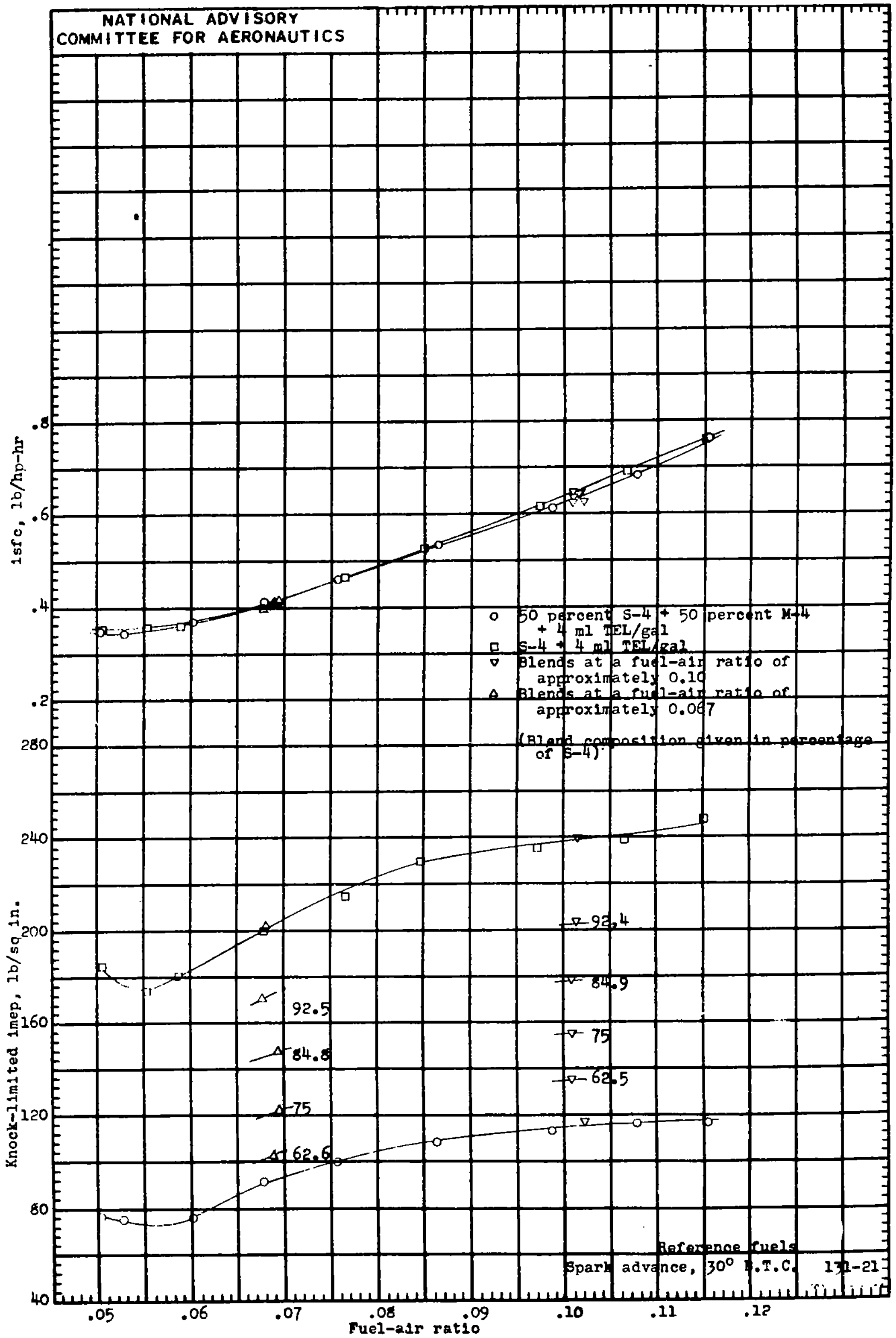
(a) Mixture-response curves.
Figure 1. - Knock-limited performance of S-4 reference fuel and 50 percent S-4 plus 50 percent M-4 reference fuels at spark advance of 20° B.T.C. Both fuels contain 4 ml TEL per gallon. Cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.



(b) Relation of knock limit to blend composition.
Figure 1. - Continued.

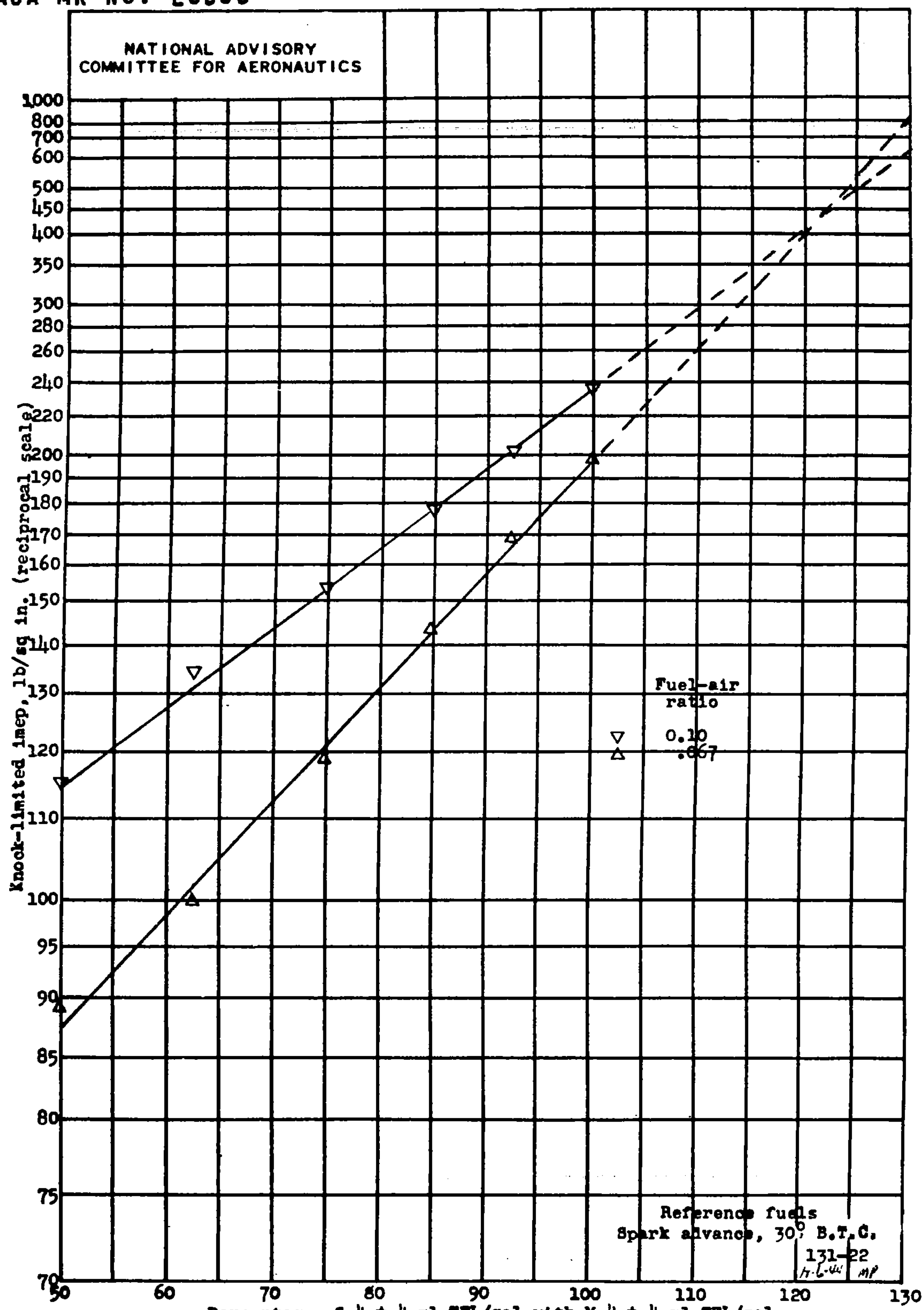


(c) Reference-fuel framework.
Figure 1. - Concluded.

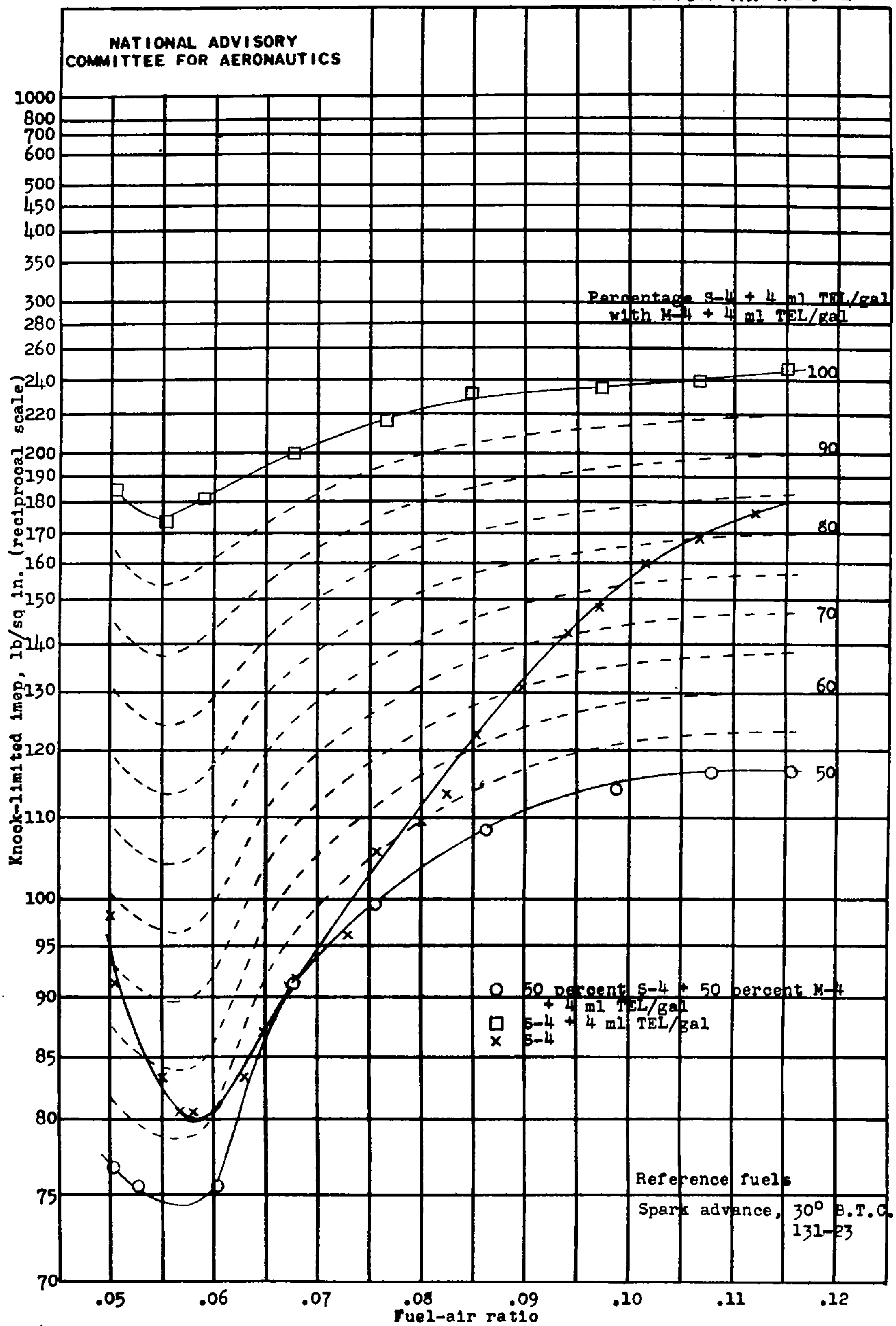


(a) Mixture-response curves.

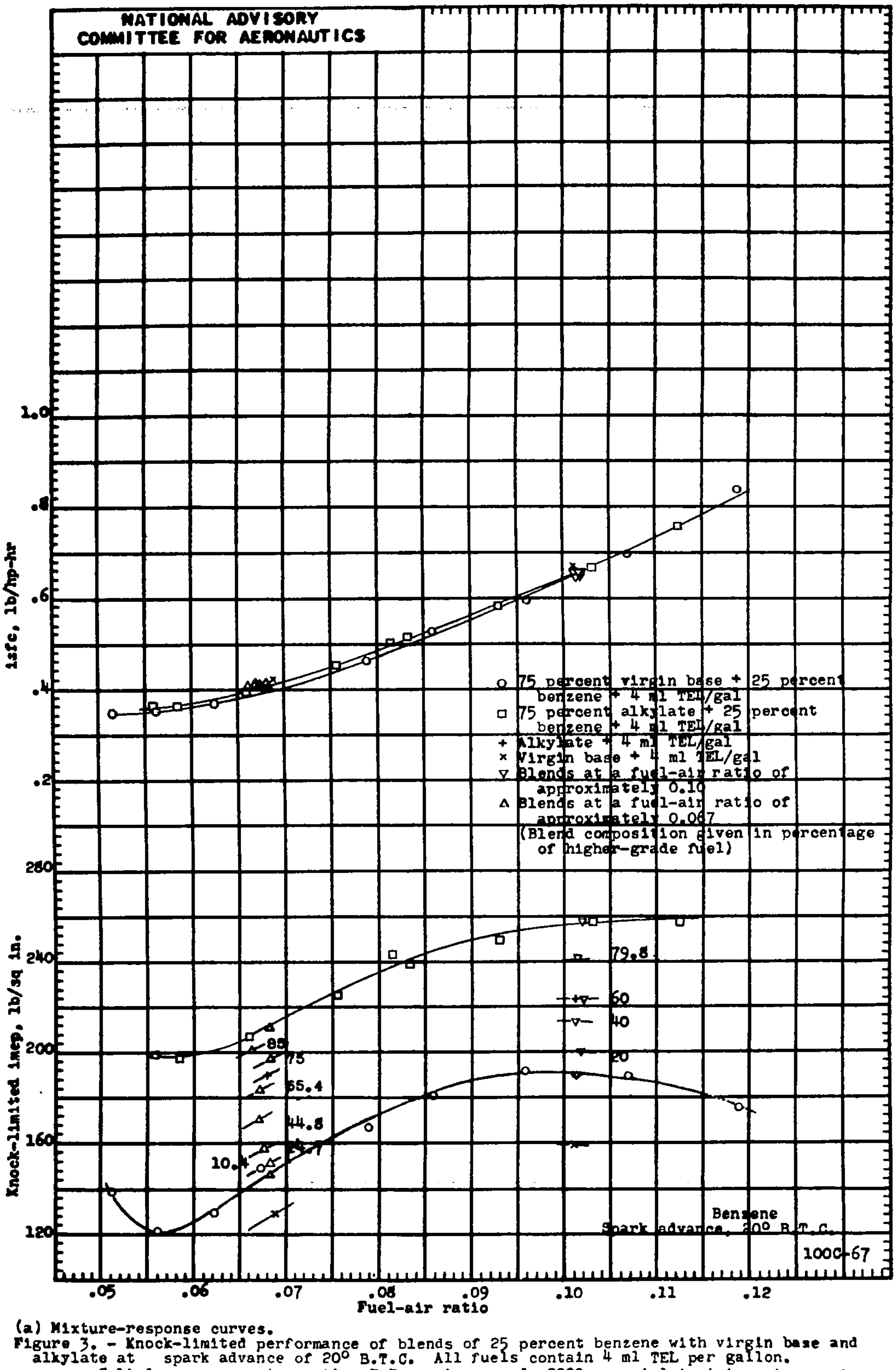
Figure 2. - Knock-limited performance of blends of S-4 reference fuel and M-4 reference fuel at spark advance of 30° B.T.C. All fuels contain 4 ml TEL per gallon. Cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.



(b) Relation of knock limit to blend composition.
Figure 2. - Continued.

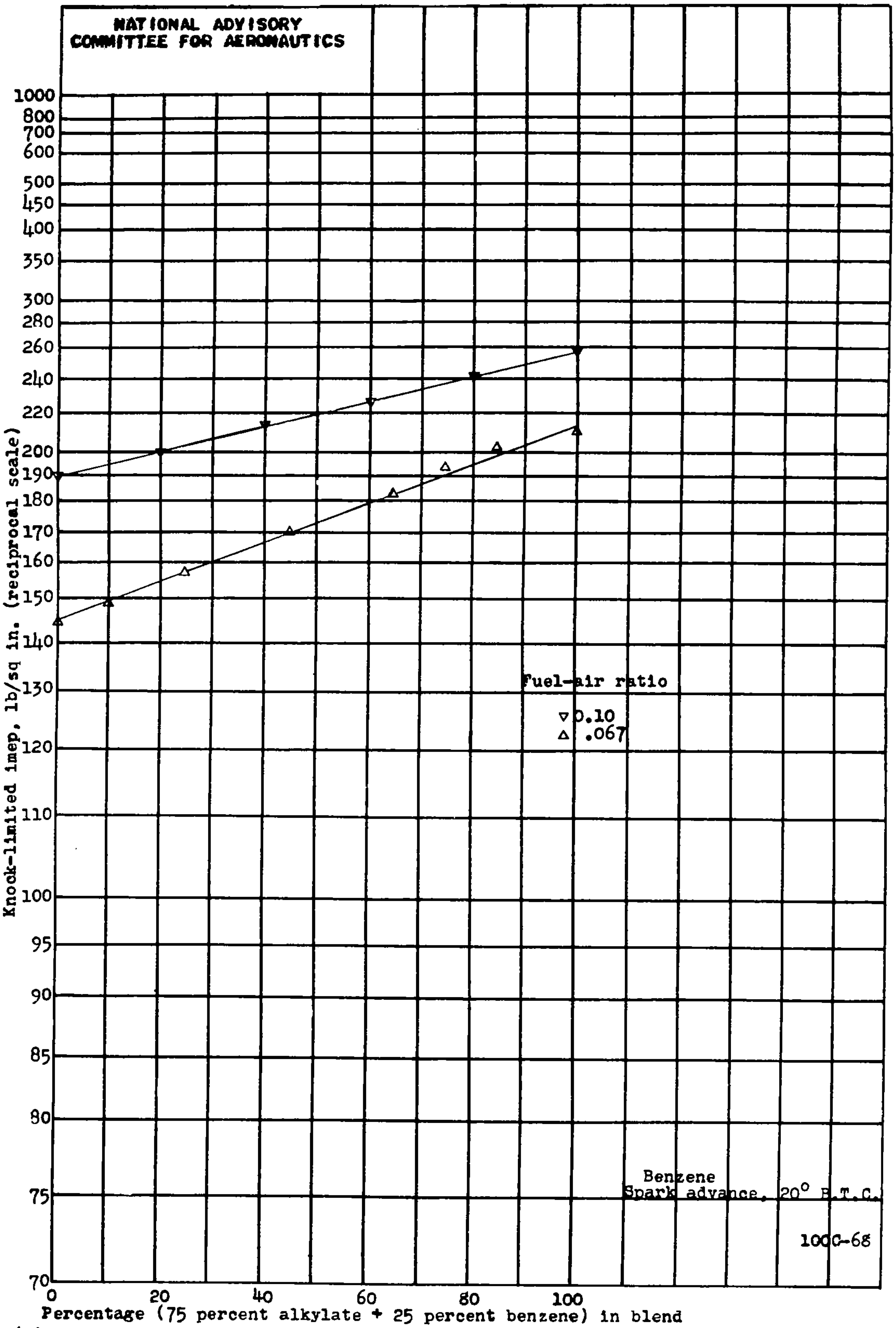


(c) Reference-fuel framework.
Figure 2. - Concluded.

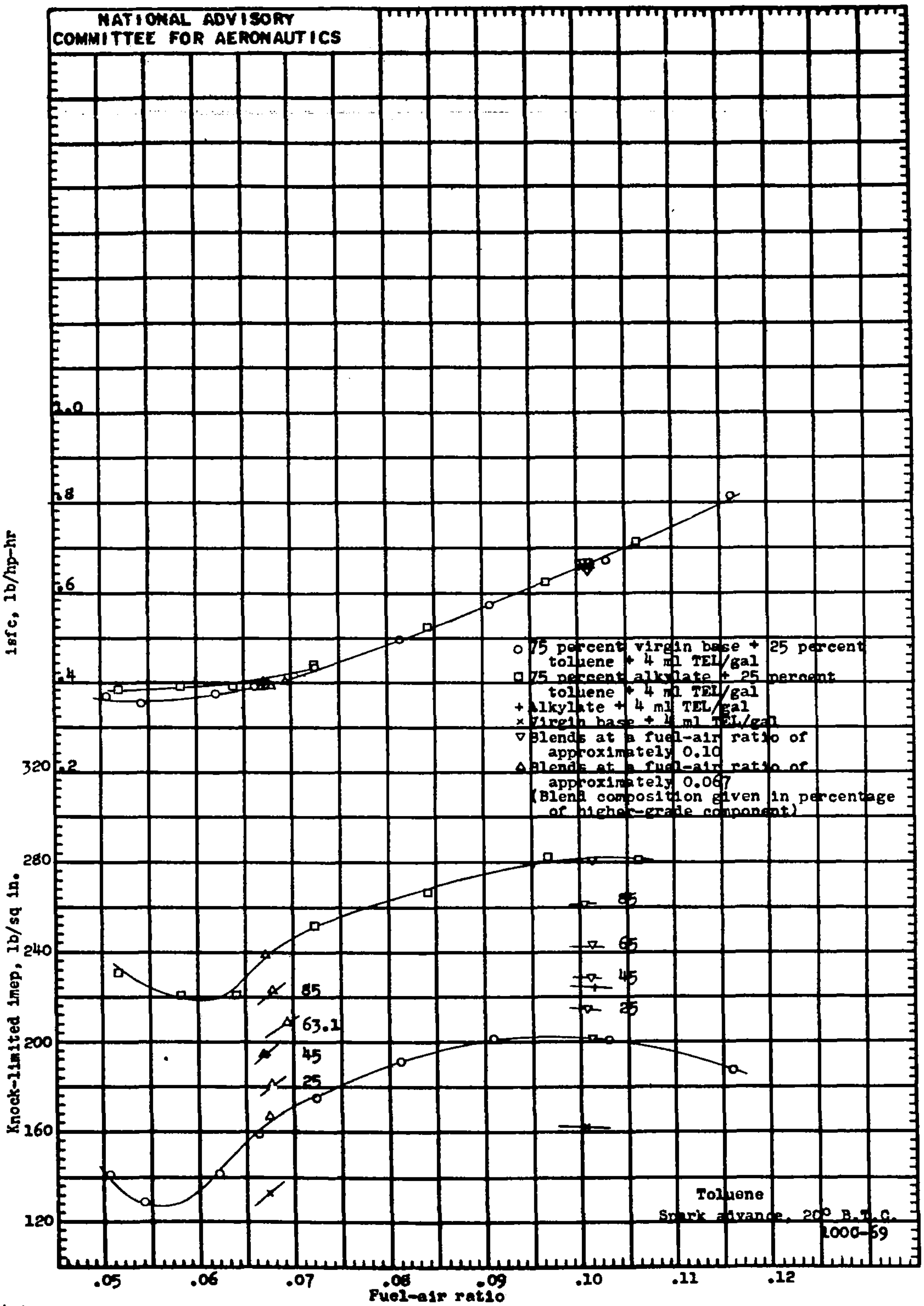


(a) Mixture-response curves.

Figure 3. - Knock-limited performance of blends of 25 percent benzene with virgin base and alkylate at spark advance of 20° B.T.C. All fuels contain 4 ml TEL per gallon. Cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.

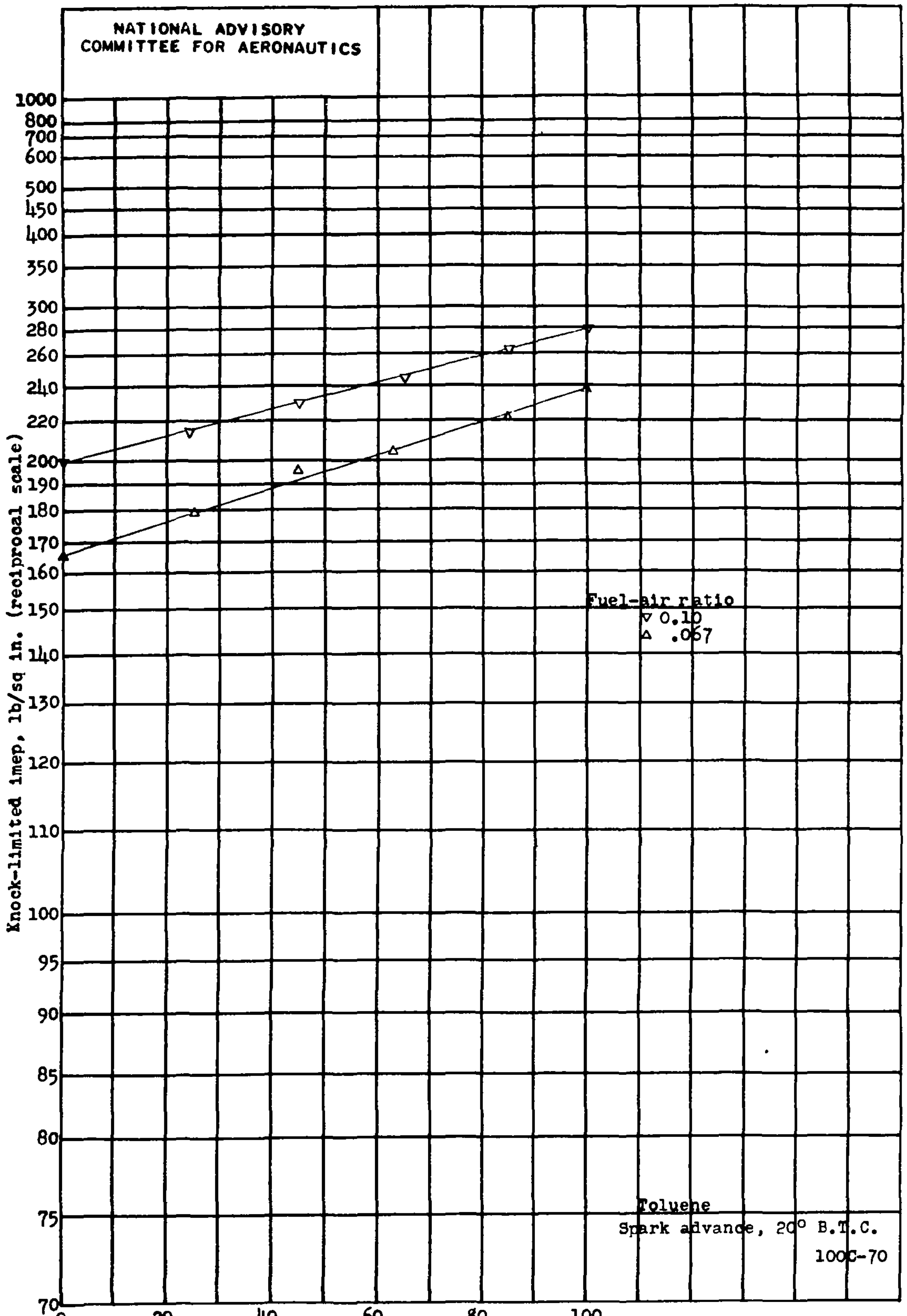


(b) Relation of knock limit to blend composition.
Figure 3. - Concluded.



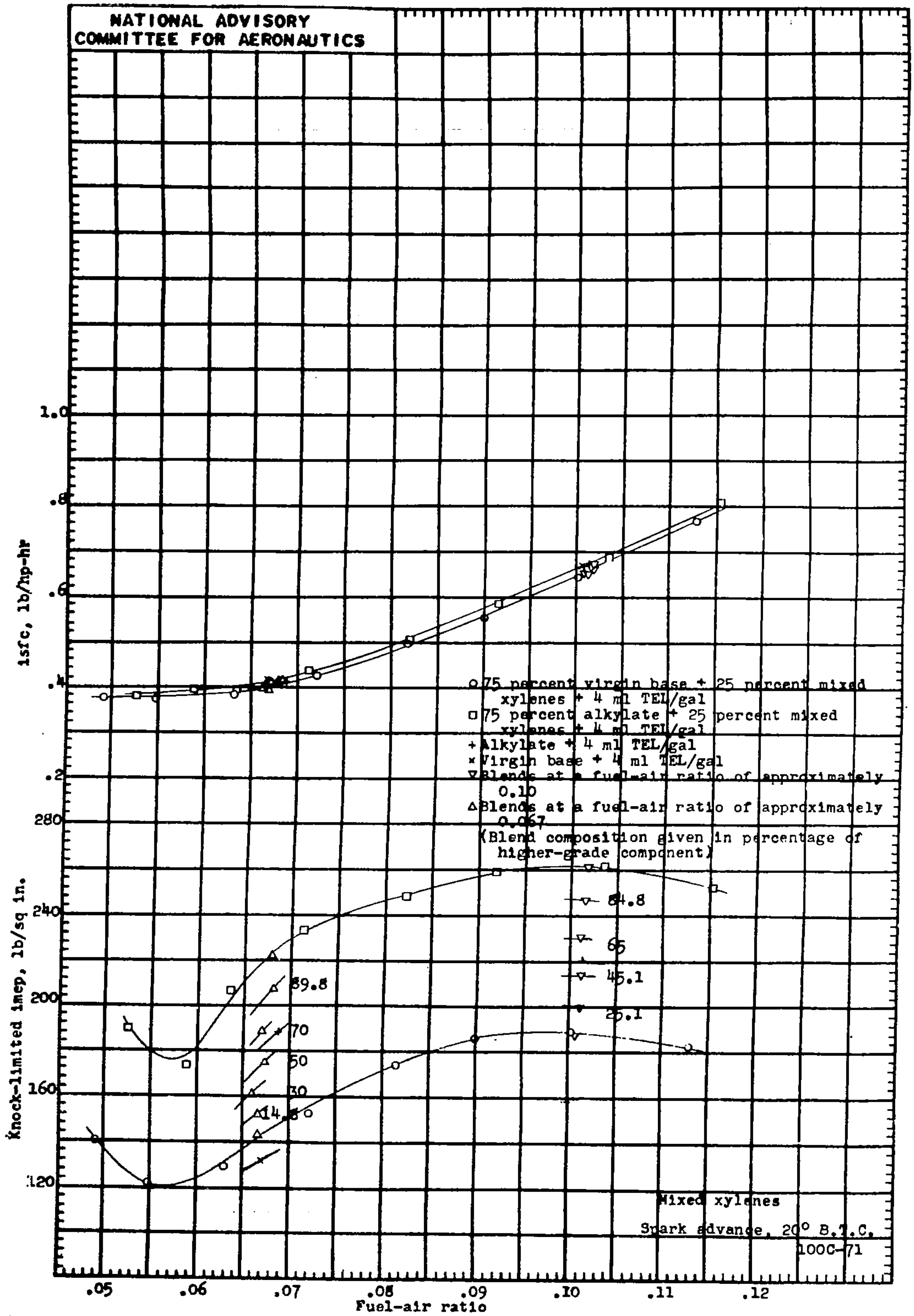
(a) Mixture-response curves.

Figure 4. - Knock-limited performance of blends of 25 percent toluene with virgin base and alkylate at spark advance of 20° B.T.C. All fuels contain 4 ml TEL per gallon. Cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.



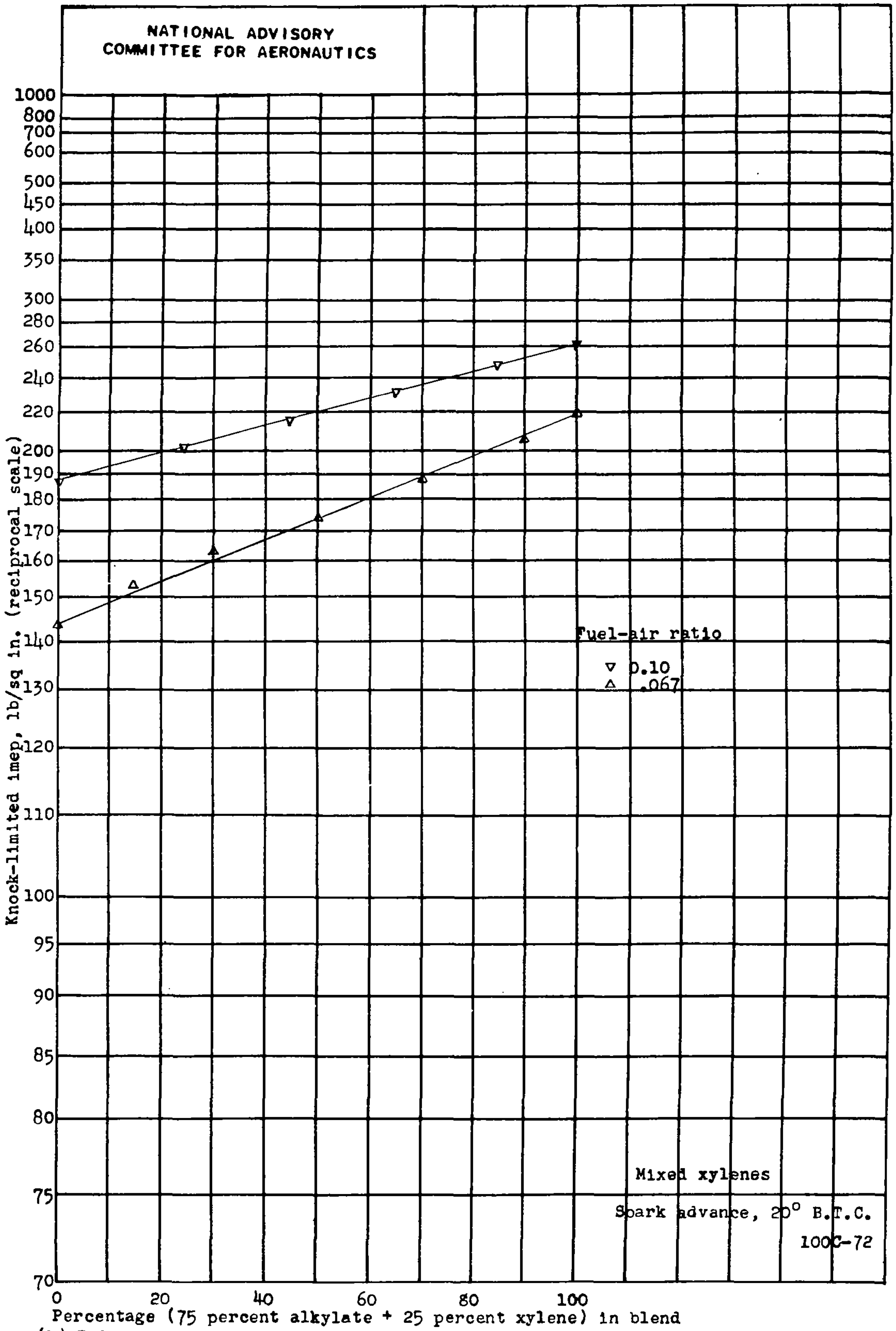
Percentage (75 percent alkylate + 25 percent toluene) in blend

(b) Relation of knock limit to blend composition.
Figure 4. - Concluded.

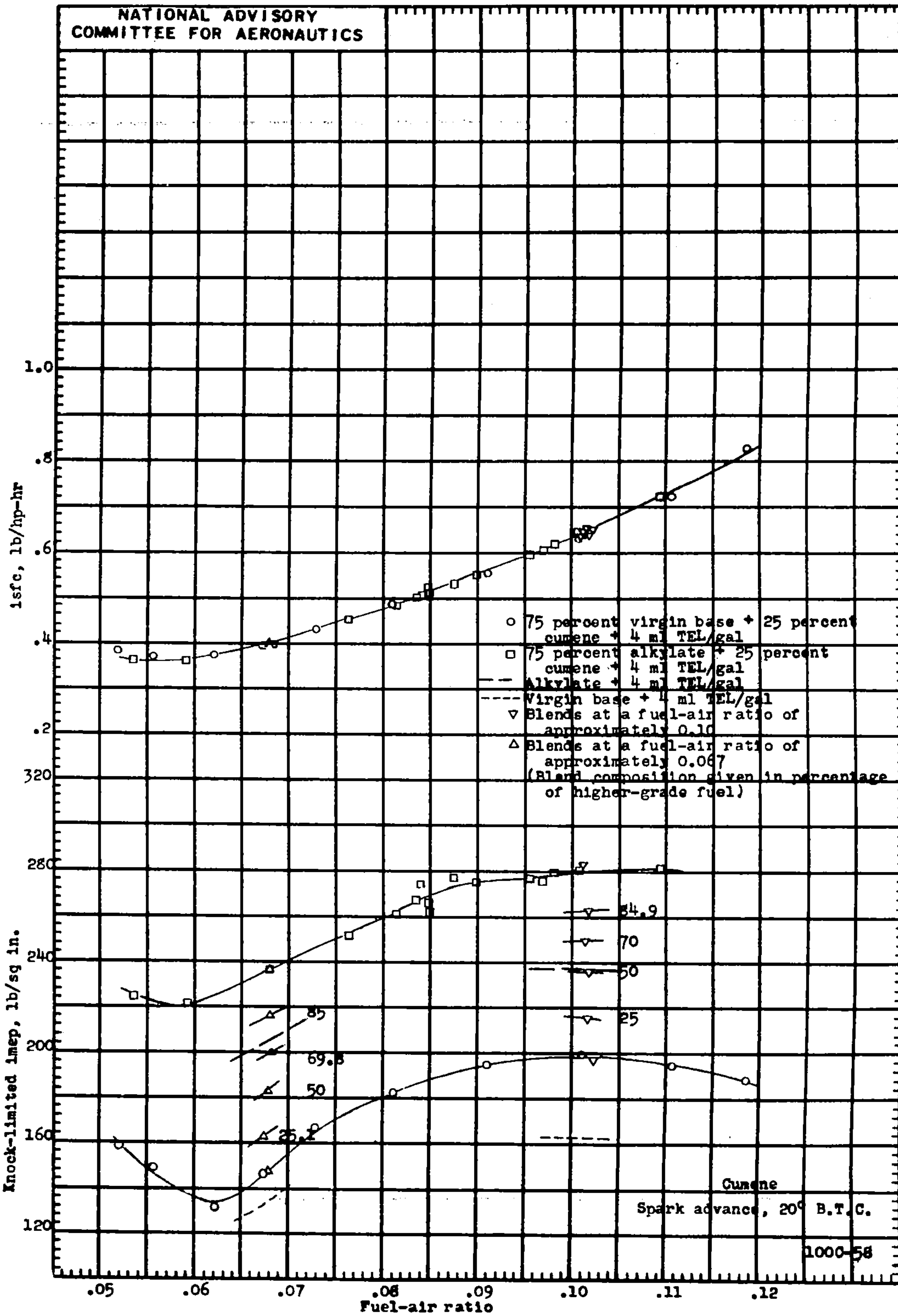


(a) Mixture-response curves.

Figure 5. - Knock-limited performance of blends of 25 percent mixed xylenes with virgin base and alkylate at spark advance of 20° B.T.C. All fuels contain 4 ml TEL per gallon. Cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.

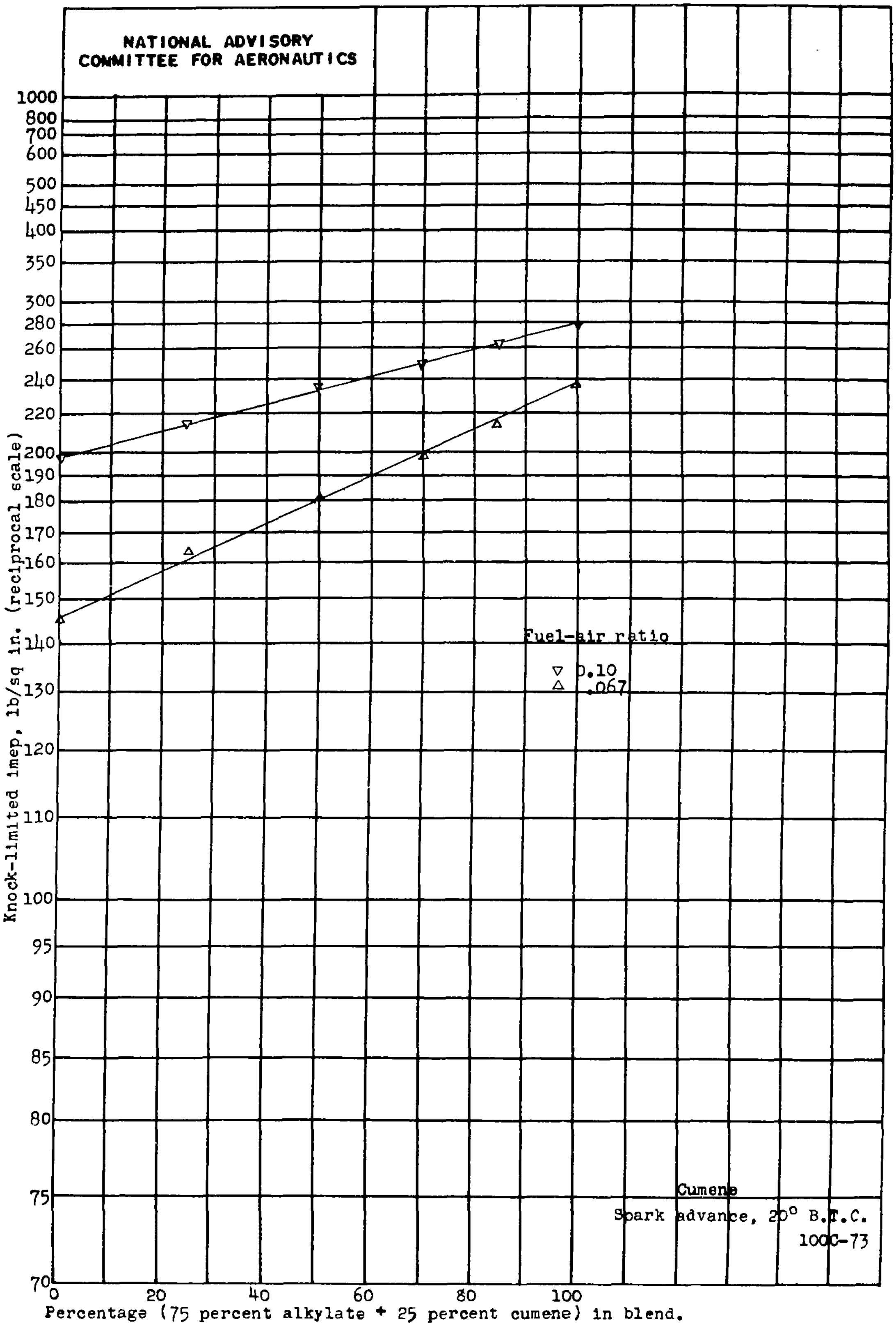


(b) Relation of knock limit to blend composition.
Figure 5. - Concluded.

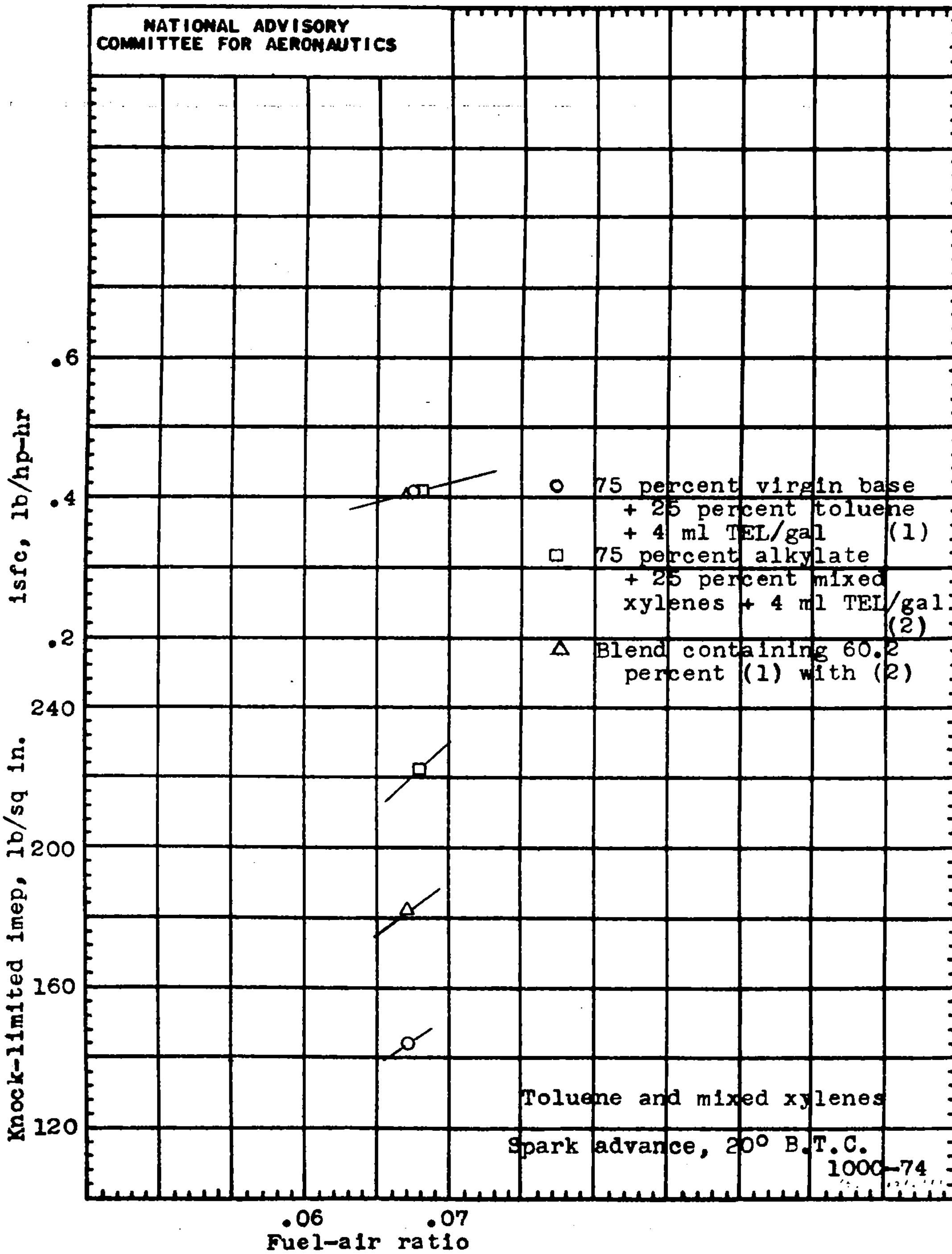


(a) Mixture-response curves.

Figure 6. - Knock-limited performance of blends of 25 percent cumene with virgin base and alkylate at spark advance of 20° B.T.C. All fuels contain 4 ml TEL per gallon. Cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet-mixture temperature 240° F; cylinder-head temperature at exhaust end zone, 350° F.

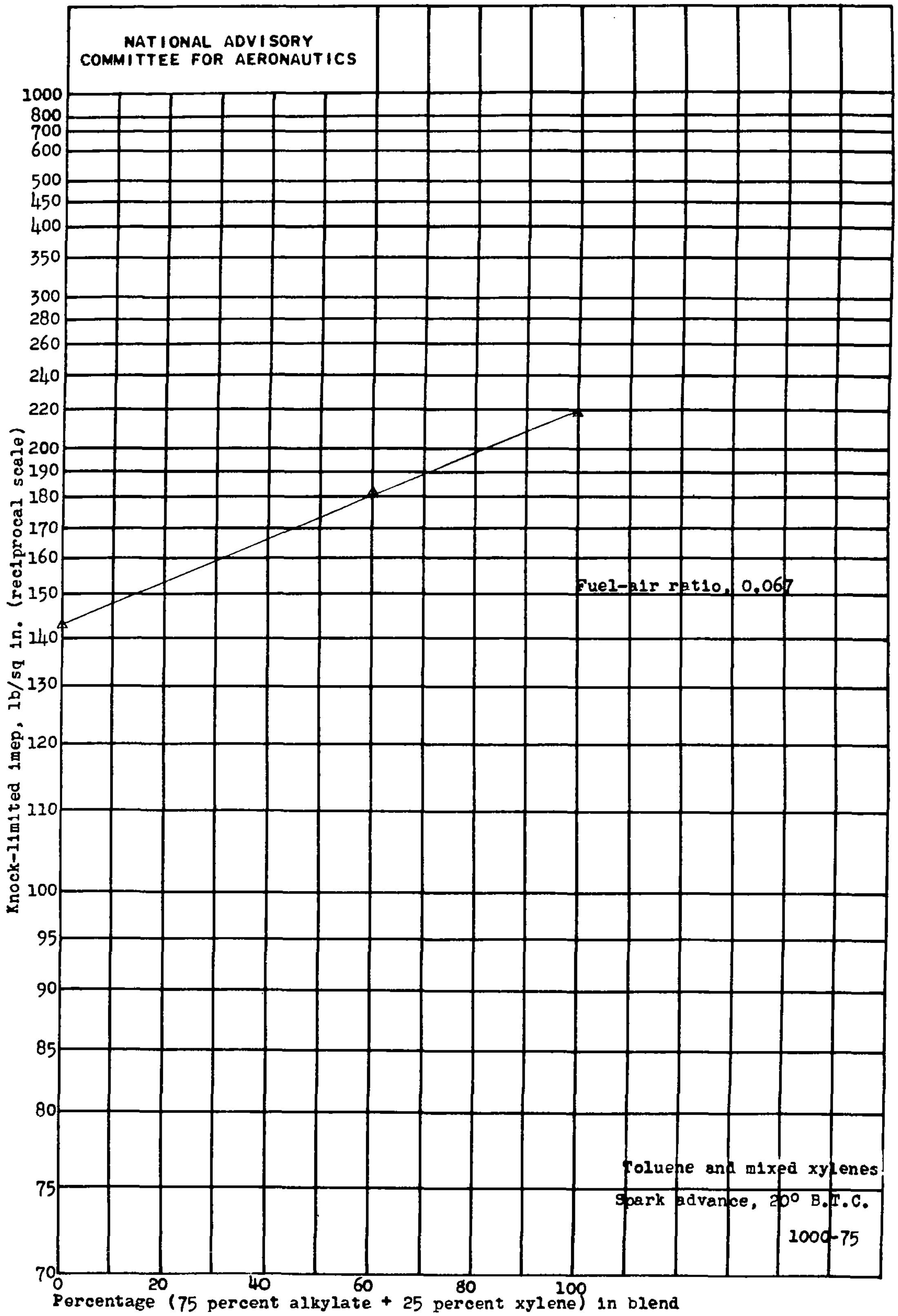


(b) Relation of knock limit to blend composition.
Figure 6. - Concluded.

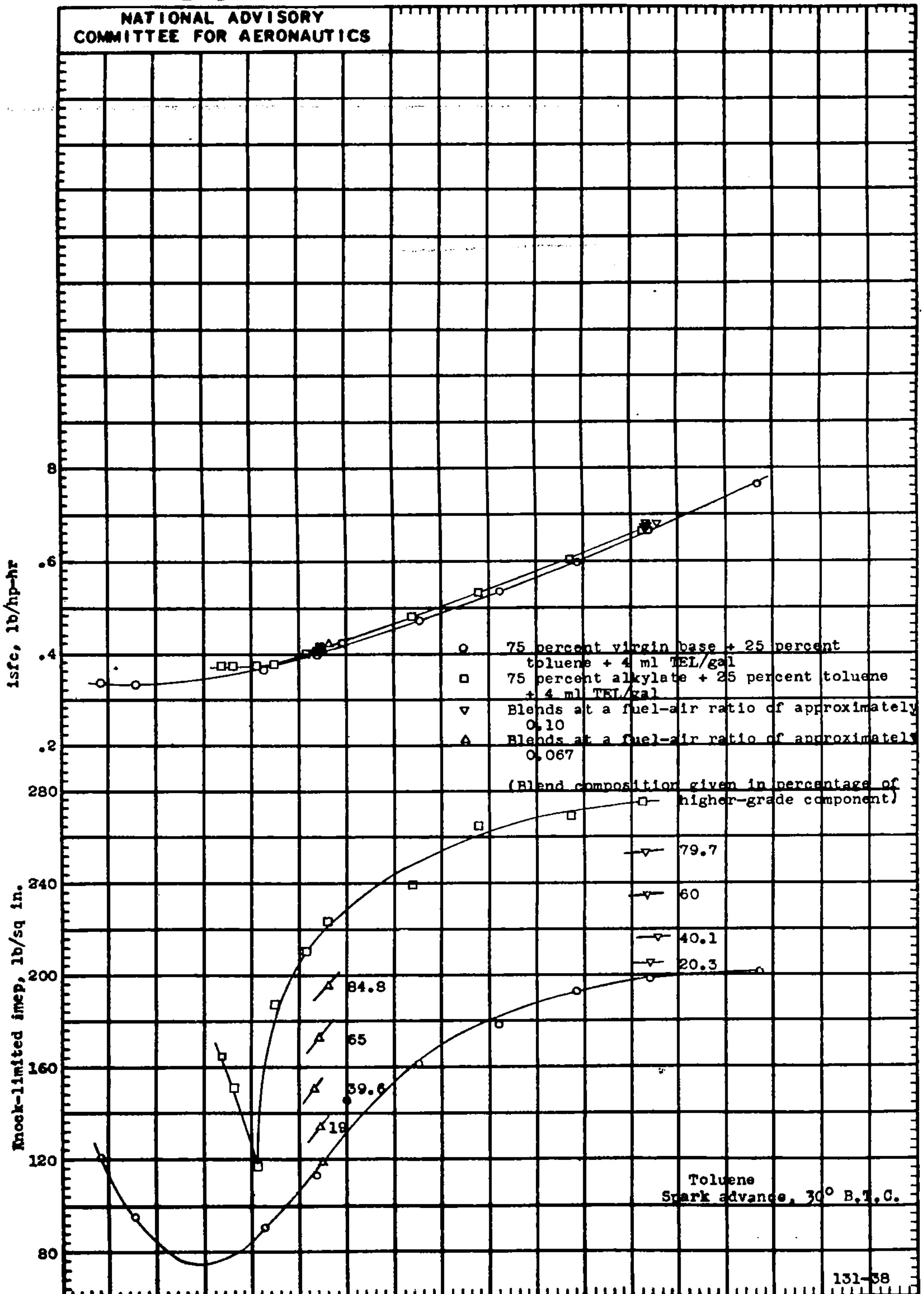


(a) Mixture-response data.

Figure 7. - Knock-limited performance of 75 percent virgin base plus 25 percent toluene and 75 percent alkylate plus 25 percent mixed xylenes at spark advance of 20° B.T.C. All fuels contain 4 ml TEL per gallon. Cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.

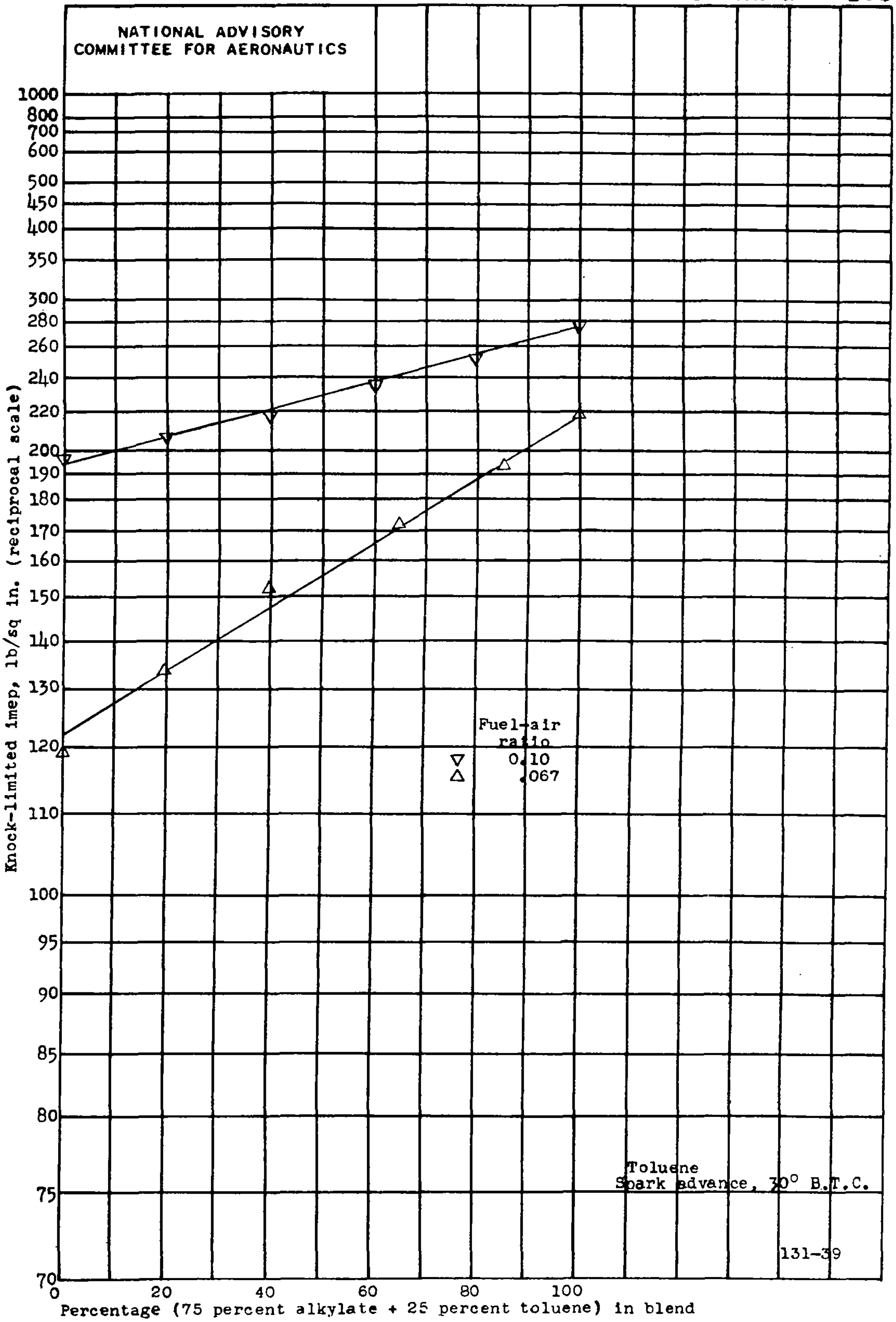


(b) Relation of knock limit to blend composition.
Figure 7. - Concluded.

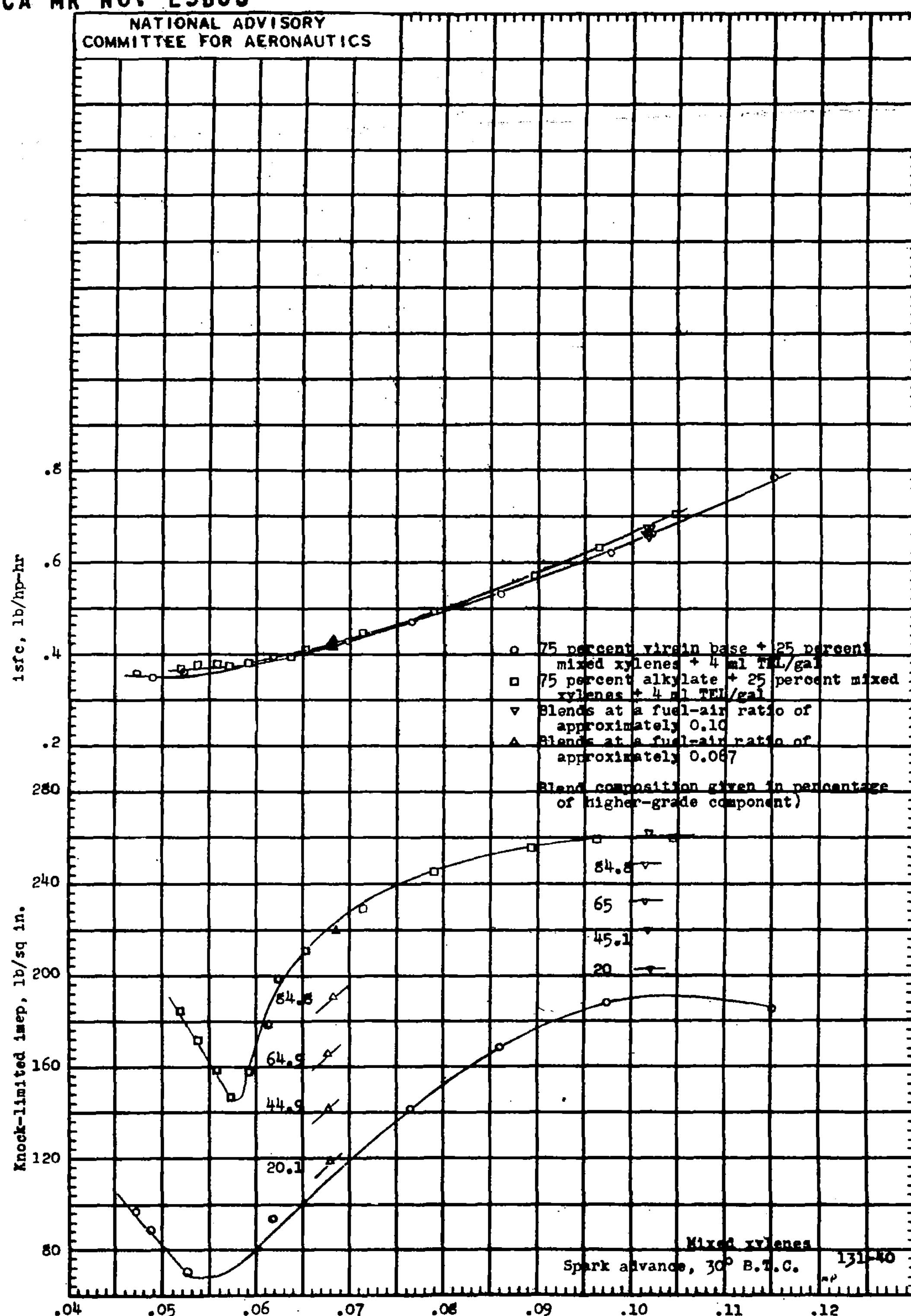


(a) Mixture-response curves.

Figure 8. - Knock-limited performance of blends of 25 percent toluene in virgin base and alkylate at spark advance of 30° B.T.C. All fuels contain 4 ml TEL per gallon. Cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.

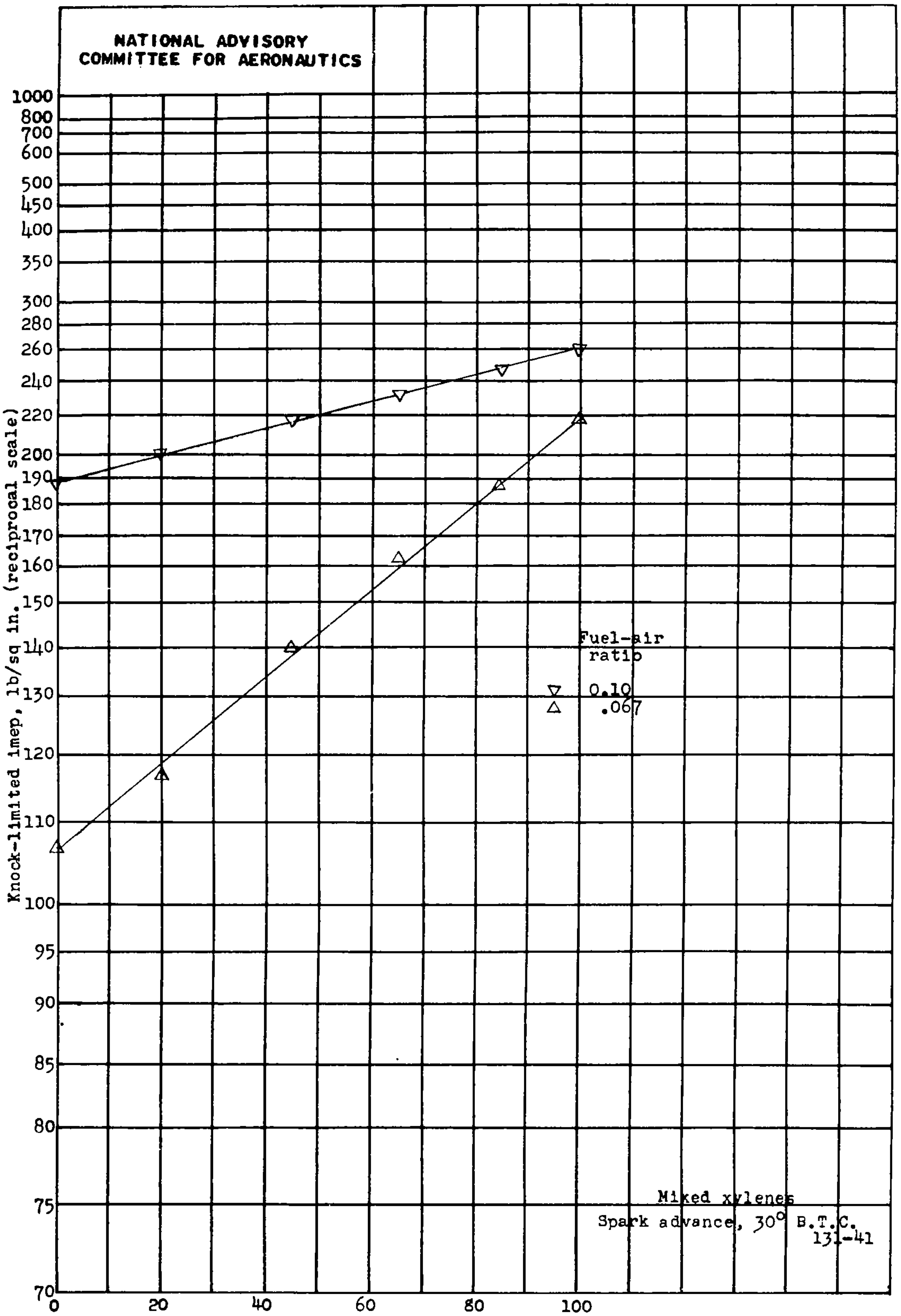


(b) Relation of knock limit to blend composition.
Figure 8. - Concluded.



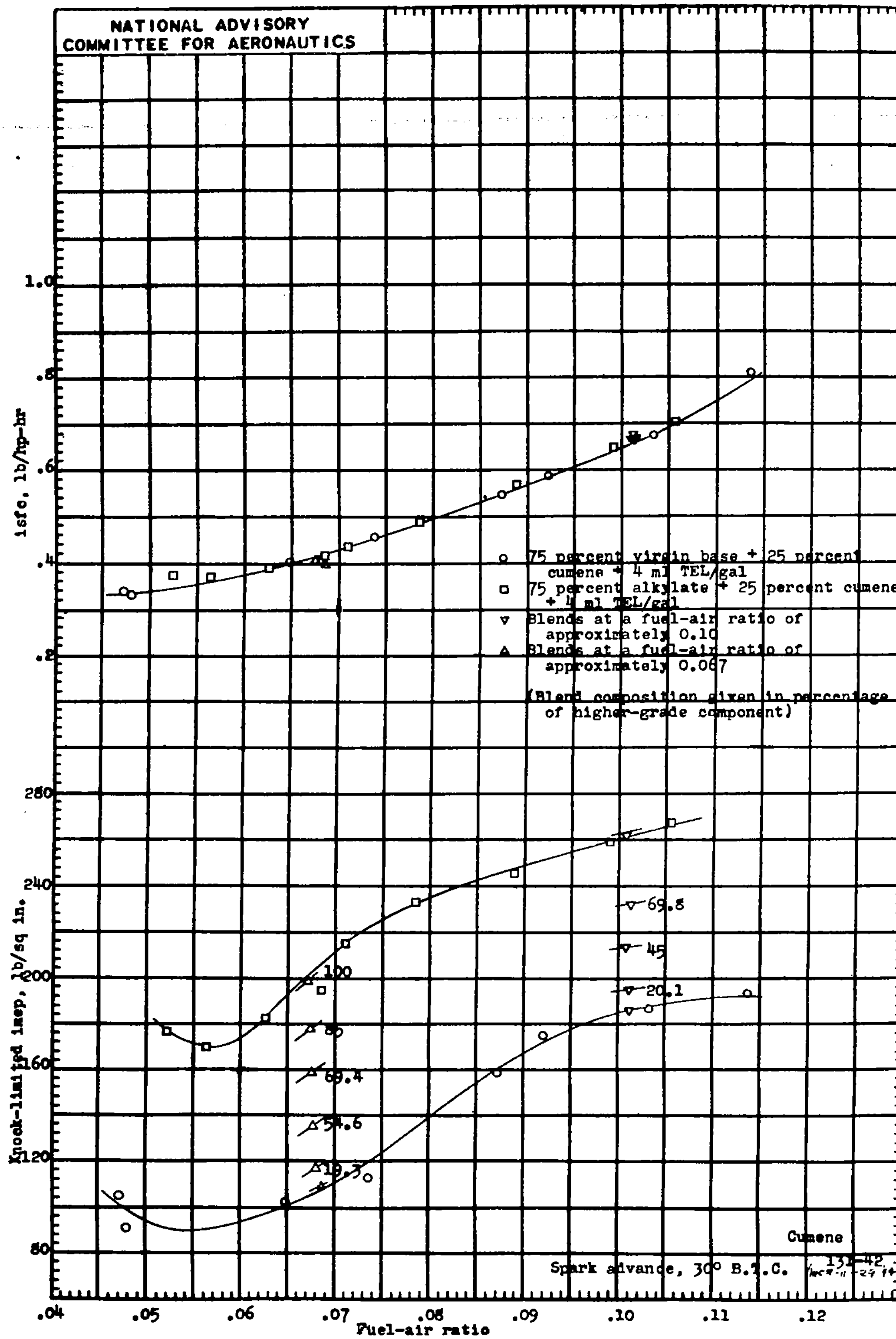
(a) Mixture-response curves.

Figure 9. - Knock-limited performance of blends of 25 percent mixed xylenes in virgin base and alkylate at spark advance of 30° B.T.C. All fuels contain 4 ml TEL per gallon.
Cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.



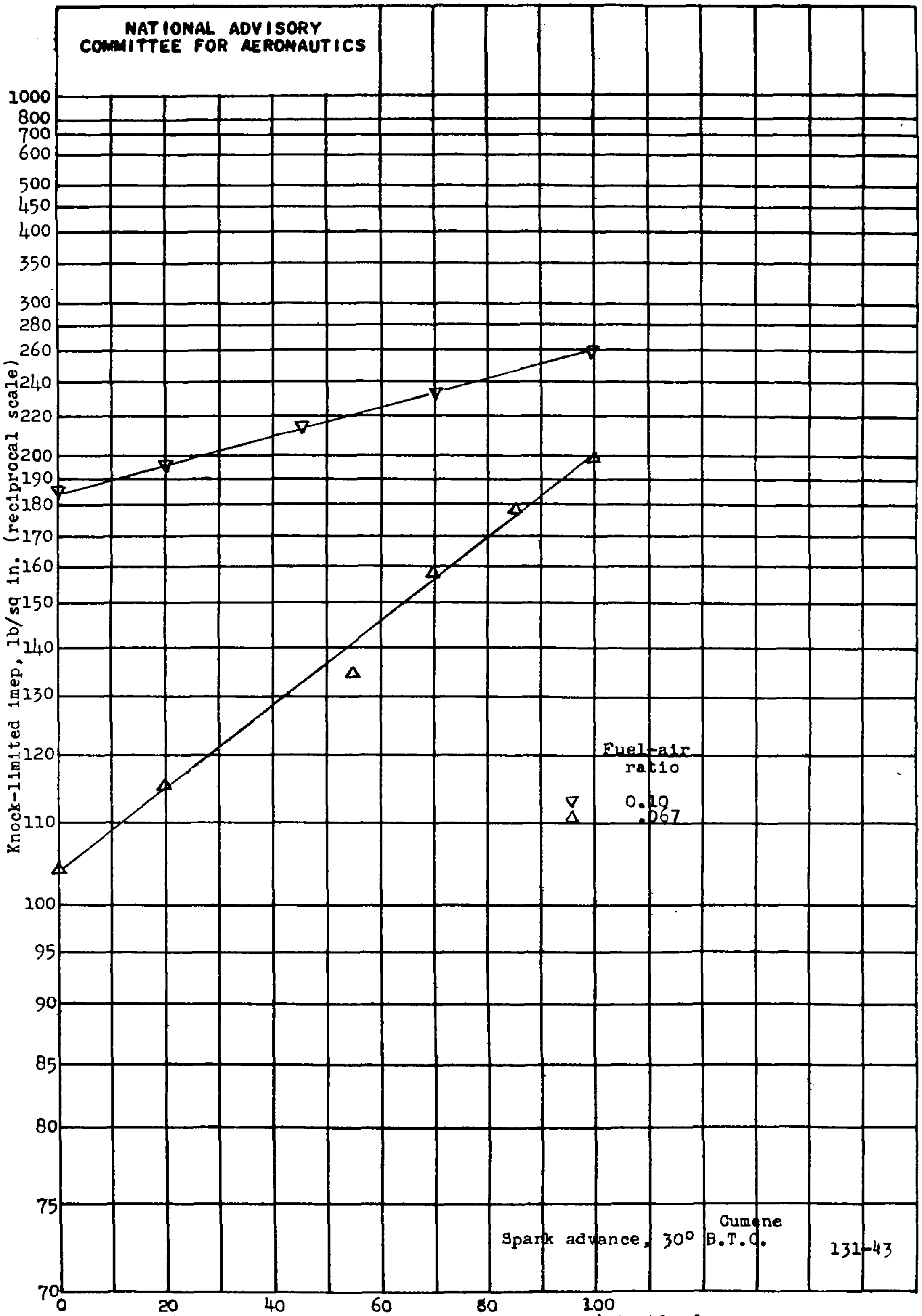
Percentage (75 percent alkylate + 25 percent xylene) in blend

(b) Relation of knock limit to blend composition.
Figure 9. - Concluded.



(a) Mixture-response curves.

Figure 10. - Knock-limited performance of blends of 25 percent cumene in virgin base and alkylate at spark advance of 30° B.T.C. All fuels contain 4 ml TEL per gallon. Cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.



Percentage (75 percent alkylate + 25 percent cumene) in blend.

(b) Relation of knock limit to blend composition.
Figure 10. - Concluded.

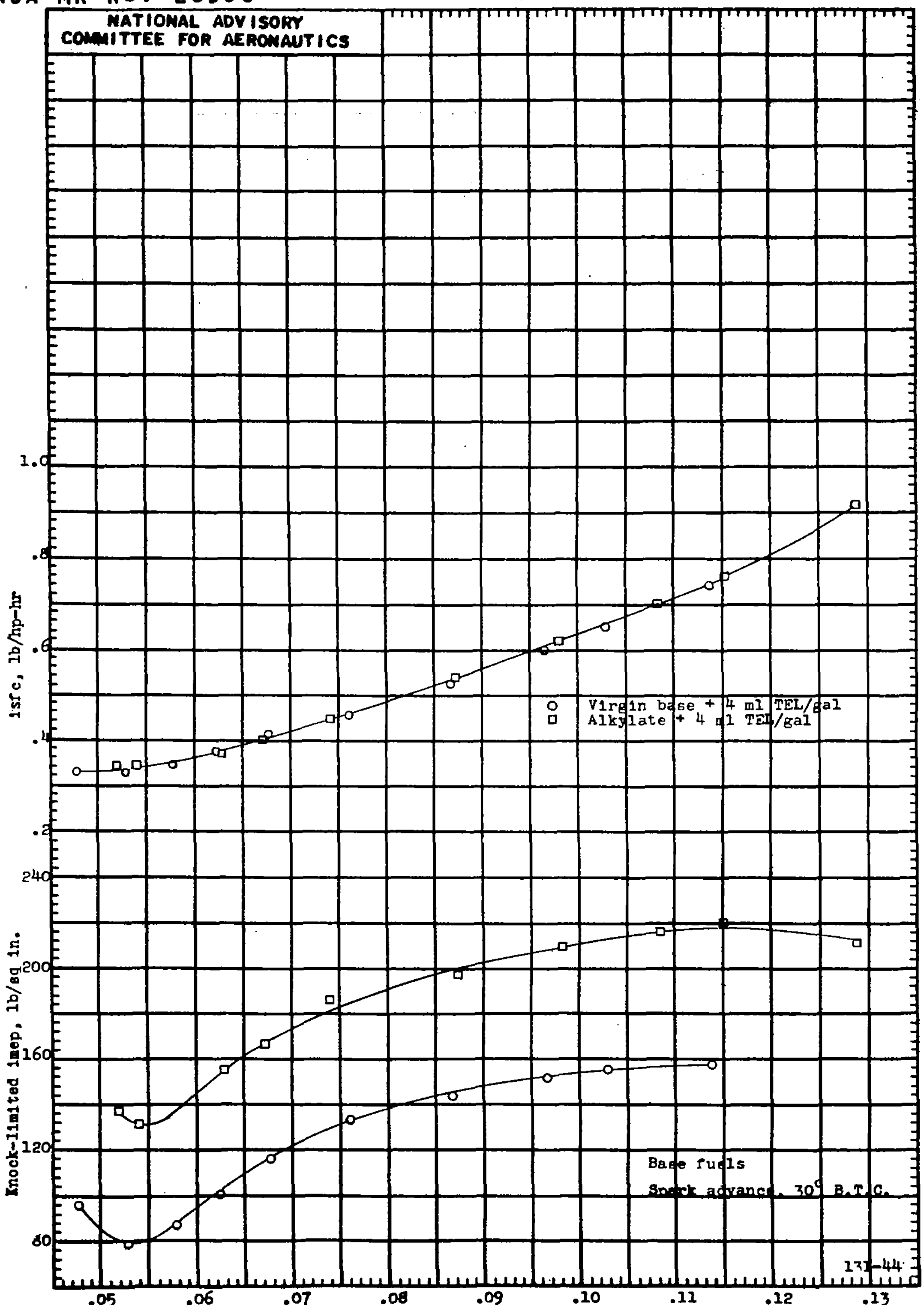
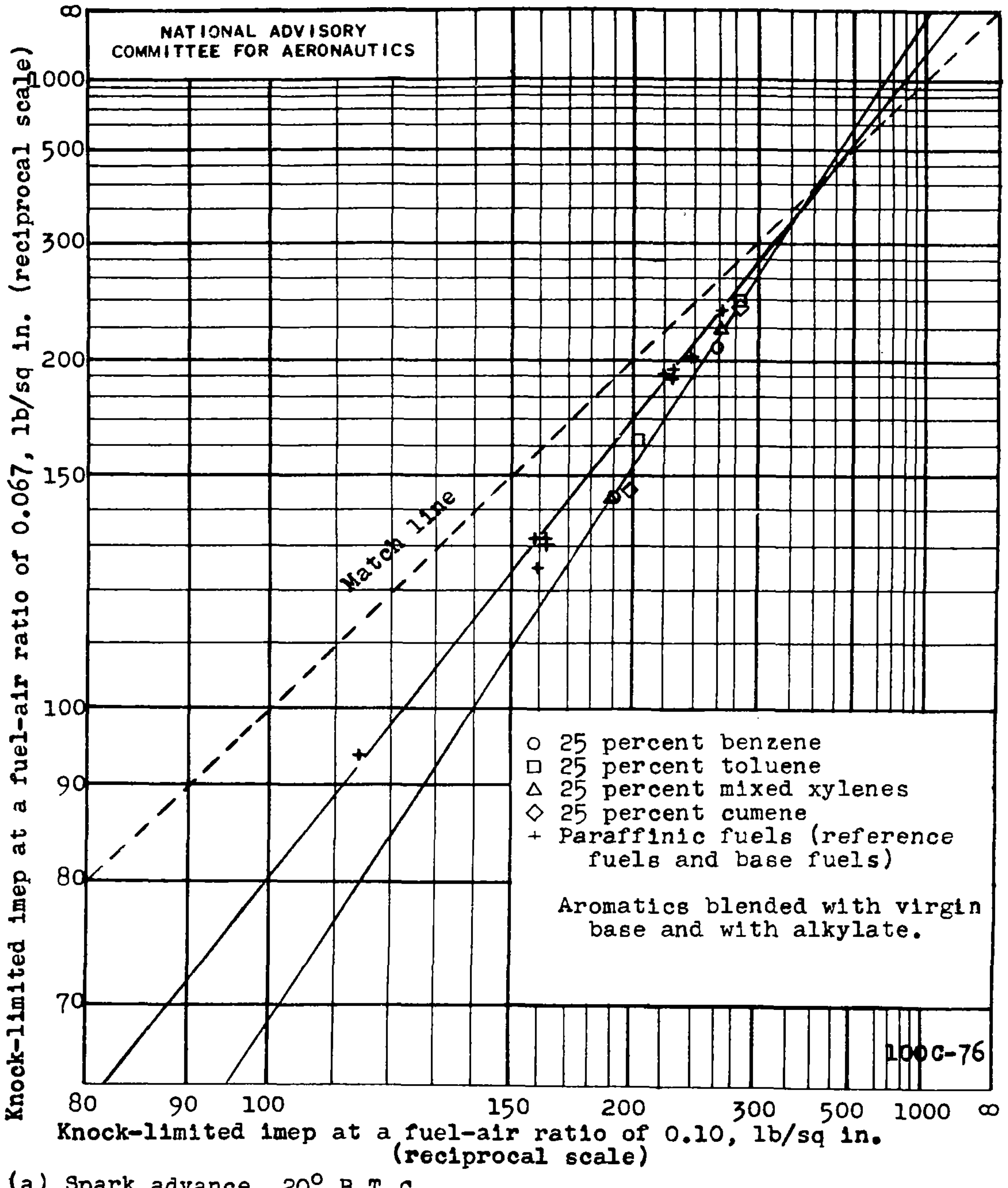
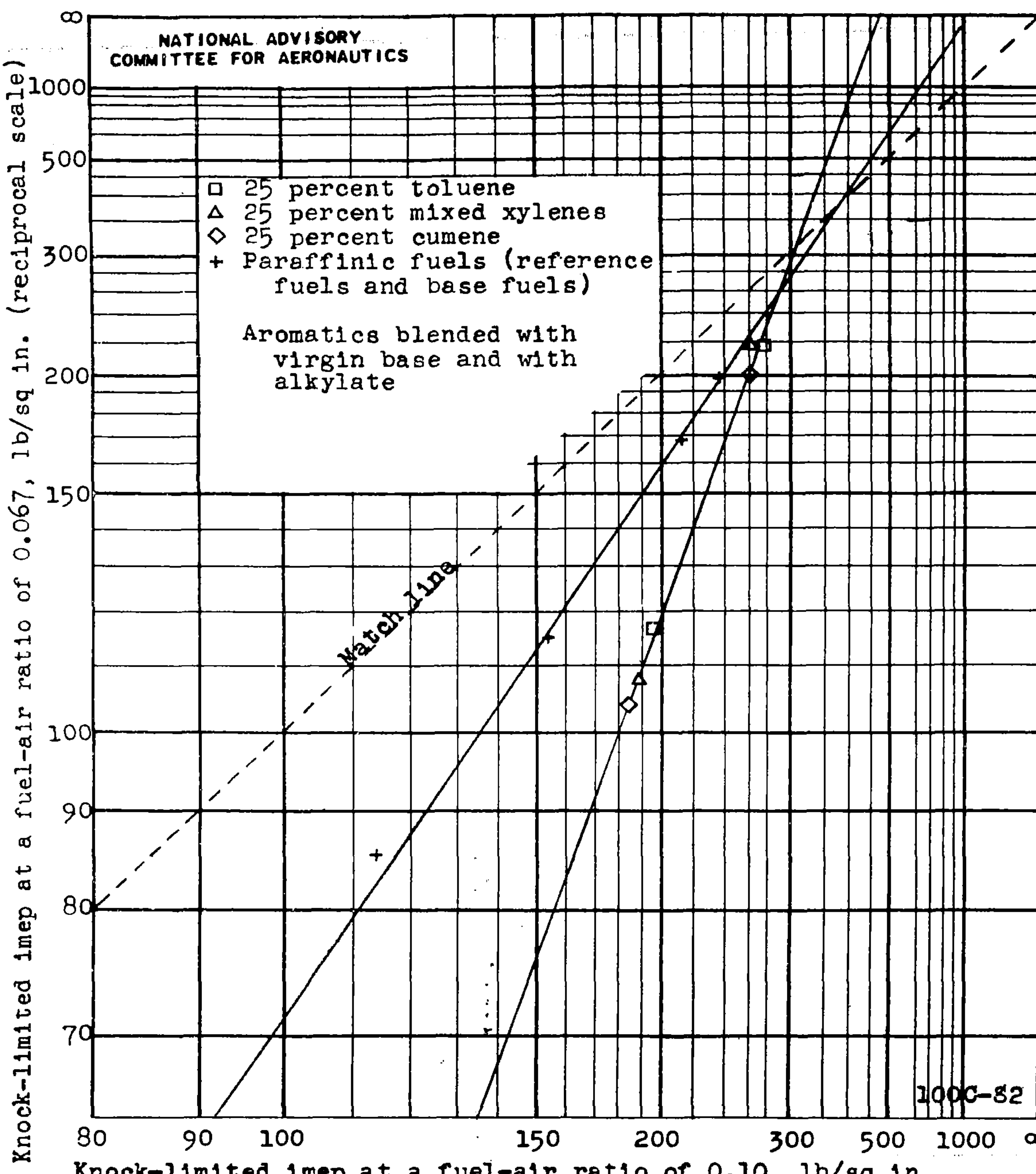


Figure 11. - Knock-limited performance of virgin base and alkylate at spark advance of 30° B.T.C. Both fuels contain 4 ml TEL per gallon. Cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.

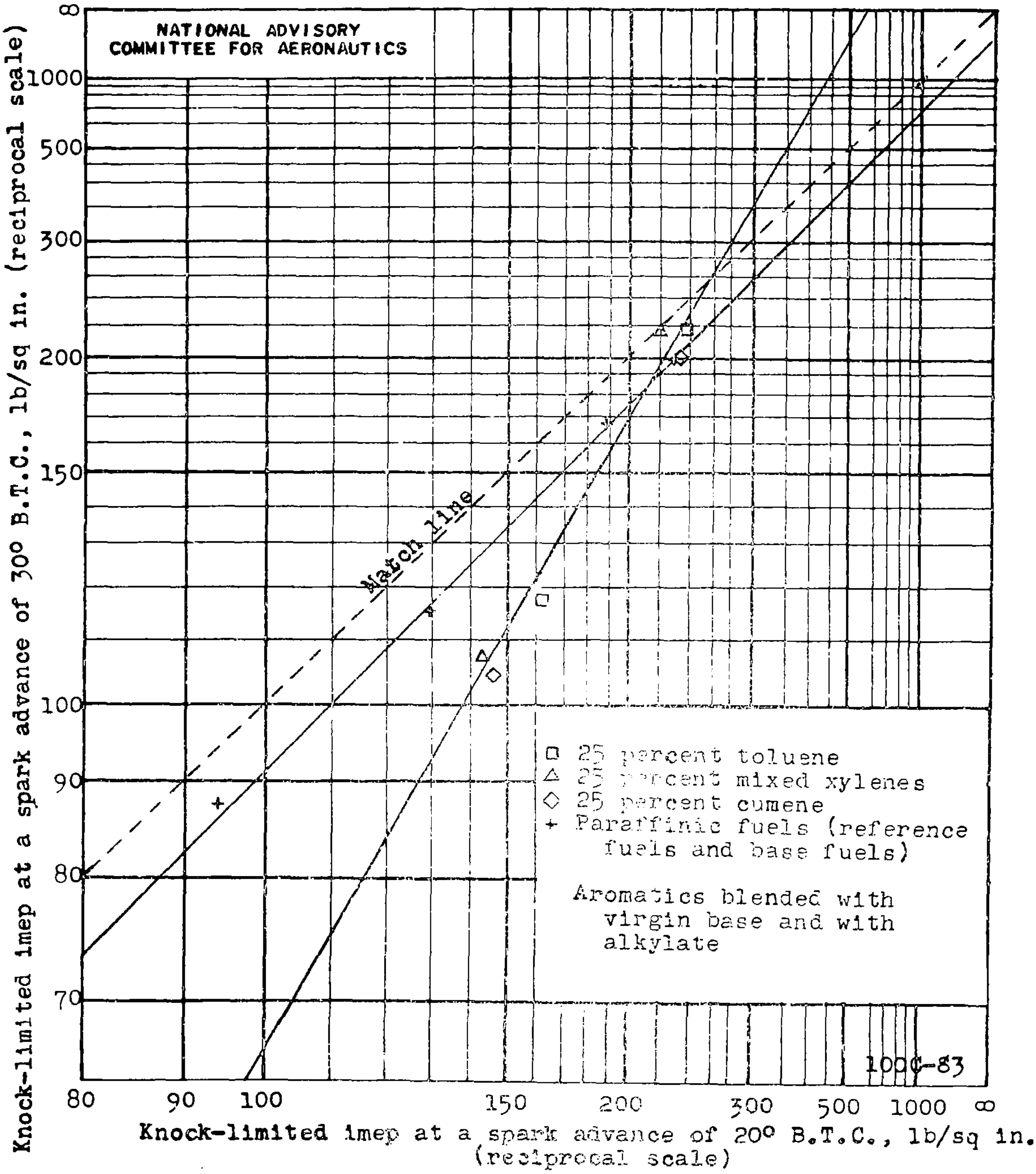


(a) Spark advance, 20° B.T.C.

Figure 12. - Correlation between knock limits at rich and lean mixtures. All fuels contain 4 ml TEL per gallon. Cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.

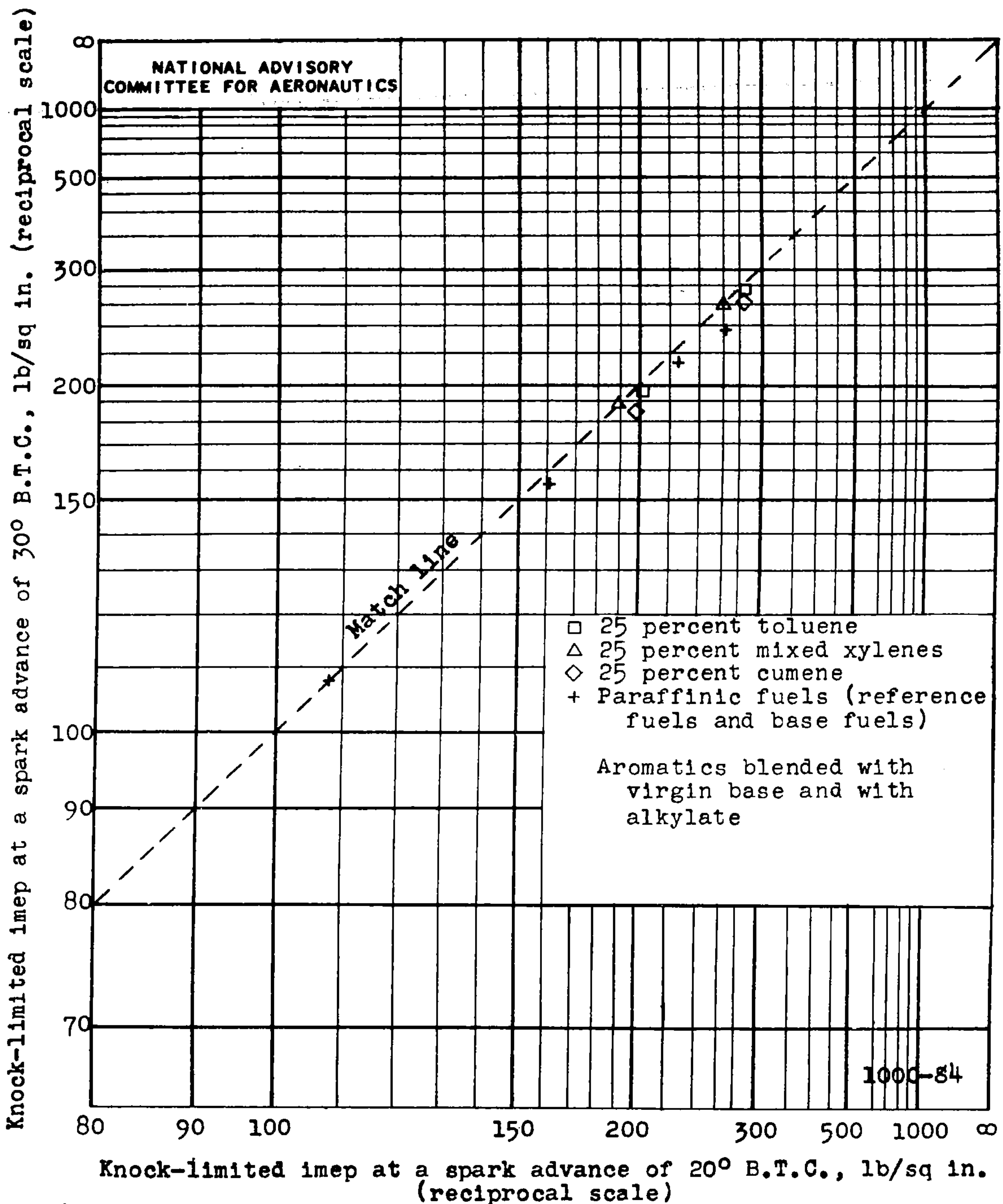


(b) Spark advance, 30° B.T.C.
Figure 12. - Concluded.



(a) Fuel-air ratio, 0.067.

Figure 13. - Correlation between knock limits at spark advances of 20° and 30° B.T.C. All fuels contain 4 ml TEL per gallon. Cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature + exhaust end zone, 350° F.



(b) Fuel-air ratio, 0.10.
Figure 13. - Concluded.

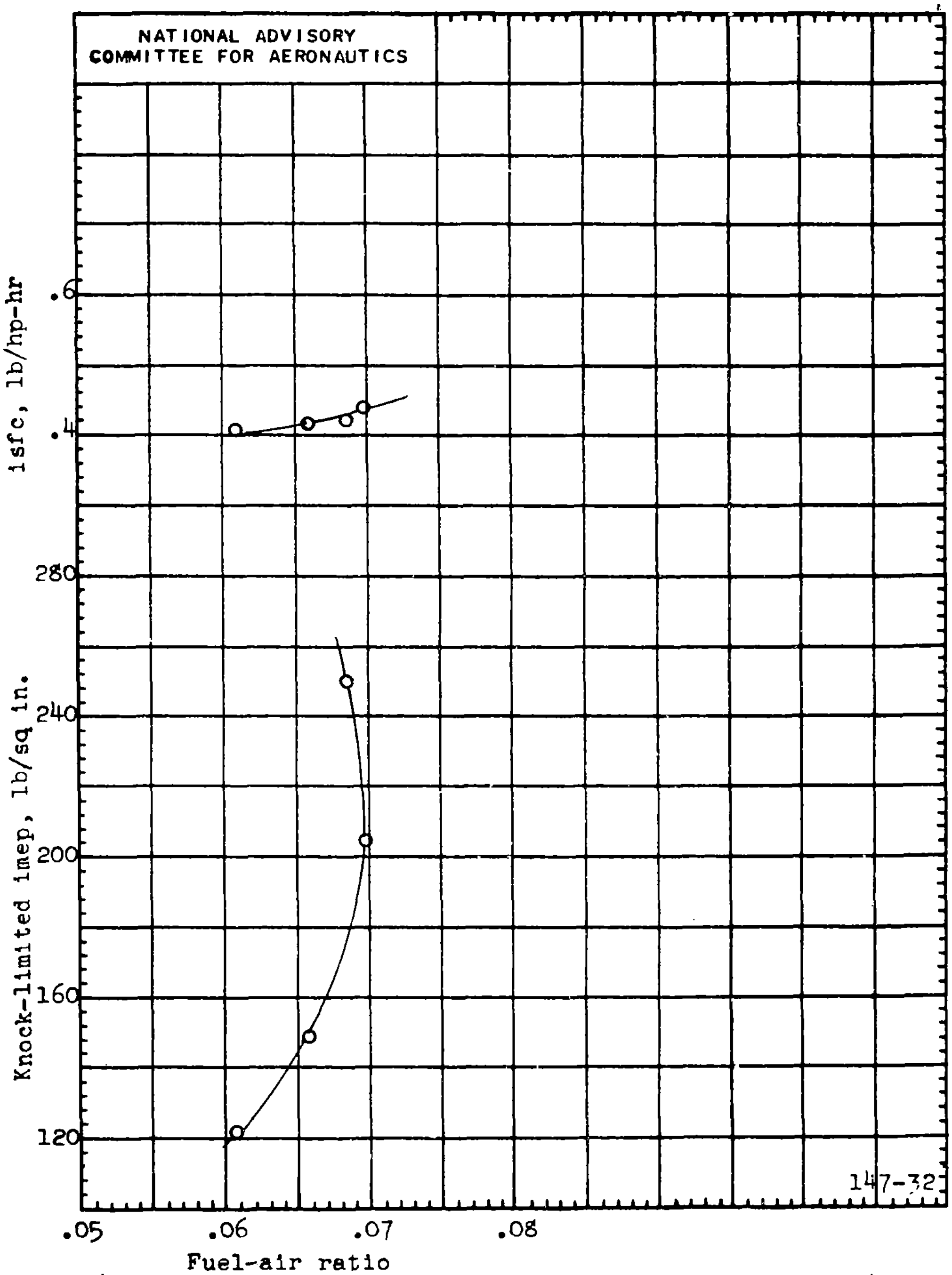


Figure 14. - Knock-limited performance of mixed xylenes plus 4 ml TEL per gallon. Cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F; exhaust back pressure, 15 inches of mercury absolute.