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KNOCK-LIMITED BLENDING CHARACTERISTICS OF BLENDS OF TRIPTANE AND 28-R AVIATION FUEL

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Materiel Command

KNOCK-LIMITED BLENDING CHARACTERISTICS OF BLENDS OF TRIPTANE AND 28-R AVIATION FUEL

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SUMMARY

F-3 and F-4 knock data are presented for blends of 0, 20, 40, 60, and 80 percent by volume of triptane in 28-R reference fuel plus approximately 4.6 ml TEL per gallon in the final blends. For comparison of knock-limited performance, 28-R reference fuel containing 2.7 percent by volume of xylidines and leaded to 6 ml TEL per gallon is included. In order to provide information on temperature sensitivities, two sets of modified conditions were used in addition to the standard F-4 engine conditions.

The reciprocal of the knock-limited indicated mean effective pressure of the triptane blends was found to vary approximately linearly with percentage triptane at all the F-4 engine conditions and fuel-air ratios investigated.

INTRODUCTION

The data presented in this report are part of a general program to determine the knock-limited performance characteristics of fuel blends containing triptane. This work was requested by the Army Air Forces and is being conducted at the Aircraft Engine Research Laboratory of the NACA, Cleveland, Ohio. The data for the tests reported herein were obtained during March 1944.

APPARATUS AND TEST PROCEDURE

The F-3 and the F-4 engines used to obtain the data presented in this report conformed to the package units with the following exceptions:

1. The F-3 engine operated from a barometrically controlled dry-air supply instead of with the dehydrating ice tower.

2. The F-4 engine employed electronic knock detection.

The data presented cover two series of tests on the F-4 engine run to evaluate the knock-limited performance of blends containing triptane and 28-R aviation fuel. The first series was undertaken to determine the F-4 engine specified ratings of the triptane blends. For comparison, a test was run on 28-R fuel containing approximately 3 percent xylidines by volume and a lead concentration of 6 ml per gallon. The second series of tests was run to determine the blending characteristics, under a series of engine operating conditions, of the blends containing triptane and 28-R aviation fuel.

No single small-scale engine, operating at a fixed set of conditions, can predict the knock-limited performance of a full-scale engine operating under a wide variety of conditions. Unpublished tests on fuels containing xylidines indicated that the following three sets of CFR engine conditions would represent a reasonably broad range of full-scale single-cylinder knock-limited operation:

	Inlet-air temperature (°F)	Coolant temperatue (°F)	Spark advance (deg B.T.C.)
F-4 specified	225	375	45
Modified condition A	250	250	30
Modified condition B	150	250	30

At each of these conditions the blends containing 0, 20, 40, 60, and 80 percent by volume leaded triptane and 28-R aviation fuel were tested on the same day. The knock-limited indicated mean effective pressures for the different blends at a given condition can therefore be assumed to be relatively consistent. In addition, F-3 tests were made on the blends tested.

DISCUSSION OF RESULTS

Figures 1, 2, and 3 present the knock-limited F-4 performance data for the triptane blends and, within reference-fuel limits, the corresponding bracketing reference curves. When rich-mixture performance of the blends was better than that of S-3 plus 6 ml TEL per gallon, only the reference curve for S-3 plus 6 ml was plotted. The test results on 28-R fuel containing 2.7 percent xylidines and leaded to 5.96 ml TEL per gallon are shown in figure 4. An engine failure (piston and cylinder scuffing) prevented the test of 28-R fuel. This piston and cylinder failure was attributed to insufficient clearance, and a 106360D piston was installed in a new cylinder for the subsequent tests.

The estimated lean and rich performance numbers of the first series of blends tested are presented in table I. Lean-mixture as well as rich-mixture knock-limited performance improved with increasing triptane content. The fuel containing xylidines gave lower knock-limited F-3 performance than anticipated.

After the F-4 engine was overhauled, the second series of tests on the triptane blends was begun. These tests are presented in the chronological order of engine testing. Figure 5 shows the data compiled on March 21 for the blends containing 0, 20, 40, 60, and 80 percent leaded triptane and 28-R aviation fuel tested at an inlet-air temperature of 250° F, a coolant temperature of 250° F, and a spark advance of 30° B.T.C. A steady increase in the lean- and the rich-mixture knock-limited performance accompanied an increase in triptane concentration.

Heron and Beatty (reference 1) have suggested that, with supercharged engines, the plot of reciprocal of knock-limited indicated mean effective pressure against octane number is a straight line. The graph of reciprocal of knock-limited indicated mean effective pressure against percentage composition has been found convenient in the prediction of blend performance of paraffinic fuels (reference 2). Figure 6 shows such a cross plot of the data in figure 5 at four fuel-air ratios. These data indicate that a reciprocal relation is approximately satisfied by the blends of triptane and 28-R aviation fuel.

The knock-limited performance data of the triptane blends tested on March 22 at an inlet-air temperature of 150° F, a coolant temperature of 250° F, and a spark advance of 30° B.T.C. are presented in figure 7, and a cross plot of the knock-limited indicated mean effective pressure (reciprocal scale) against the percentage composition is presented in figure 8. The progressive gains in knock-limited indicated mean effective pressure for each additional 20-percent increase in triptane concentration at a fuel-air ratio of 0.0625 were 43, 46, 71, and 103 pounds per square inch, respectively (fig. 7).

In order to give an indication of the temperature sensitivity of triptane, the ratio of the knock-limited indicated mean effective pressure at an inlet-air temperature of 150° F to that at an inlet-air temperature of 250° F is presented in table II. The change in knock-limited indicated mean effective pressure accompanying the 100° F change in the inlet-air temperature is also tabulated. The knock-limited indicated mean effective pressure was less affected by inlet-air temperatures at rich mixtures than at lean mixtures. Although no consistent trend other than a decrease with increasing fuel-air ratio was observed in the ratio of the indicated mean effective pressures, the actual difference in the indicated mean effective pressure accompanying the 100° F change in inlet-air temperature steadily increased with triptane concentration at low fuel-air ratios.

In order to estimate performance numbers and check the condition of the engine after the high-power runs, 28-R fuel was rated (fig. 9). The S-3 reference fuel plus 2 ml TEL was about 10-pounds-per-square-inch indicated mean effective pressure below the standard grid at the peak, but part of this discrepancy is caused by the use of electronic rather than audible means of indicating knock. The following performance numbers with corresponding fuel-air ratios have been assumed on the basis of this test for 28-R fuel: 0.0625, 111; 0.070, 113; 0.090, 132; 0.110, 132.

Figure 10 presents the knock-limited performance of the triptane blends tested at F-4 conditions on March 25. The knock-limited indicated mean effective pressure (reciprocal scale) is cross-plotted against percentage composition in figure 11. Here again, the relation is approximately linear. Even at the relatively extreme F-4 conditions, addition of triptane caused a corresponding increase in the lean-mixture knock-limited performance.

The relative knock-limited indicated mean effective pressures of figure 10 and the performance numbers of the triptane blends (estimated by multiplying the assumed performance numbers of 28-R fuel from figure 9 and the relative knock-limited indicated mean effective pressures of figure 10) are presented in table III. Although these values cannot be expected to agree precisely with those of table I, the two sets of values are of the same order of magnitude at rich fuel-air mixtures. If the assumed value of the 28-R performance number at a fuel-air ratio of 0.110 of table III were changed to 125, the two sets (tables I and III) would agree almost exactly.

The estimated performance numbers at a fuel-air ratio of 0.0625 in table III do not agree with the lean-mixture performance numbers that might be estimated from figures 1, 2, and 3. Because all the data in figure 10 were recorded on one day, it is believed that they are the more consistent. The lack of reproducibility of lean-mixture performance under the F-4 conditions is well recognized.

The knock-limited indicated mean effective pressure against percentage composition for leaded triptane and 28-R fuel blends in the F-4 engine can be approximately represented by the equation (cf. figs. 6, 8, and 11):

$$P(N - A) = B \tag{1}$$

where

P knock-limited indicated mean effective pressure of the final blend
N percentage triptane in 28-R fuel
B constant depending upon fuel-air ratio and engine conditions
A the value of N corresponding to infinite P

Experimentally, the value of A was approximately 137 for all fuel-air ratios and conditions tested on the F-4 engine. The value 137 is the abscissa of the intersection of all the curves of figures 6, 8, and 11 with the ordinate corresponding to infinite knock-limited indicated mean effective pressure and, hence, would not be expected to be affected by engine conditions. For convenience in estimating lean-mixture performance characteristics at the three sets of engine conditions, the 0.0625 fuel-air-ratio curves of figures 6, 8, and 11 are replotted in figure 12.

If, at constant fuel-air ratio and engine conditions, equation (1) is written first for the blended fuel and then for the 28-R fuel, the factor B can be eliminated. The following equation results:

$$\frac{P}{P_o} = \frac{137}{137 - N} \tag{2}$$

where P_o is knock-limited indicated mean effective pressure of 28-R aviation fuel. This equation held fairly well for all fuel-air ratios and engine conditions tested. As can be seen from table III, the indicated-mean-effective-pressure ratio was fairly independent of fuel-air ratio and agreed reasonably well with the value predicted by equation (2).

Similarly, if at a given triptane concentration equation (1) is written for two sets of engine conditions and the two resulting equations are divided, the ratio of the indicated mean effective pressures at the two conditions gives:

$$\frac{P_1}{P_2} = \frac{B_1}{B_2} \tag{3}$$

In other words, the ratio of the knock-limited indicated mean effective pressures at the two engine conditions is independent of triptane concentration. This trend was roughly verified in table II. Other similar extensions of equation (1), resulting from the fact that A was constant, can easily be derived.

Figure 13 shows a plot of F-3 and F-4 performance numbers (reciprocal scale) of table I against percentage composition. The F-3 engine did not satisfactorily indicate the observed tremendous improvement in lean-mixture performance caused by the addition of triptane to 28-R aviation fuel under supercharged test methods, but the ratings did show progressive improvement with increases in triptane concentration.

SUMMARY OF RESULTS

The following results were obtained from this investigation:

1. The F-4 and the F-3 ratings of blends containing triptane and 28-R aviation fuel are tabulated:

Blend composition[a], percent		Performance number	
Triptane	28-R aviation fuel	F-4 (rich)	F-3
0	100	[b]126	100
20	80	147	109
40	60	179	116
60	40	220	133
80	20	[b]300	145

[a]Final TEL concentration, approximately 4.6 ml/gal.
[b]Extrapolated from reciprocal blending relation.

2. The temperature sensitivities of the triptane blends as represented by the ratio of the knock-limited indicated mean effective pressure under condition B to the knock-limited indicated mean effective pressure under condition A was roughly independent of triptane concentration and varied from 1.25 at a fuel-air ratio of 0.0625 to 1.06 at a fuel-air ratio of 0.090.

3. As a first approximation, the reciprocal of the knock-limited indicated mean effective pressure of the triptane blends varied linearly with the percentage triptane at the various conditions tested.

4. The blend containing 80 percent triptane, 20 percent 28-R aviation fuel, and leaded to 4.6 ml TEL per gallon allowed a knock-limited indicated mean effective pressure of approximately 2.4 times that of 28-R fuel at each fuel-air ratio under the three sets of operating conditions tested in the F-4 engine.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, April 18, 1944.

REFERENCES

1. Heron, S. D., and Beatty, Harold A.: Aircraft Fuels. Jour. Aero. Sci., vol. 5, no. 12, Oct. 1938, pp 463-479.

2. Sanders, Newell D.: A Method of Estimating the Knock Rating of Hydrocarbon Fuel Blends. NACA ARR No. 3H21, 1943.

TABLE I - KNOCK-LIMITED F-3 AND F-4 PERFORMANCE
OF AVIATION-FUEL BLENDS

Blend	F-4 (rich) performance number	F-3 rating	
		S-3 + ml TEL	Performance number
28-R aviation fuel; 4.53 ml TEL/gal	[a]126	----------------	100
20 percent triptane; 80 percent 28-R; 4.58 ml TEL/gal	147	0.25	109
40 percent triptane; 60 percent 28-R; 4.58 ml TEL/gal	[b]179	.55	116
60 percent triptane; 40 percent 28-R; 4.75 ml TEL/gal	[b]220	[c]1.46	133
80 percent triptane; 20 percent 28-R; 4.59 ml TEL/gal	[a]300	2.74	145
2.7 percent by volume xylidines; 97.3 percent 28-R; 5.96 ml TEL/gal	151	99.5 octane number	-------------

[a]Extrapolated from reciprocal blending relation (fig. 13).
[b]Estimated from imep of test fuel and S-3 plus 6 ml TEL at peak of imep against fuel-air ratio for S-3 plus 6 ml.
[c]The F-3 rating was made on a later blend containing 4.64 ml TEL/gal.

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TABLE II - EFFECT OF A CHANGE IN INLET-AIR TEMPERATURE FROM 150° to 250° F ON KNOCK-LIMITED PERFORMANCE OF BLENDS CONTAINING TRIPTANE AND 28-R AVIATION FUEL

[F-4 engine operating at modified conditions; spark advance, 30° B.T.C.; coolant temperature, 250° F; inlet-air temperatures, 150° F and 250° F; lead concentration, approximately 4.60 ml TEL/gal]

Percentage triptane in final blend	Fuel-air ratio							
	0.0625		0.070		0.080		0.090	
	imep ratio	imep difference	imep ratio	imep difference	imep ratio	imep difference	imep ratio	imep difference
0	1.20	32	1.16	27	1.11	22	1.09	18
20	1.28	51	1.19	37	1.10	23	1.07	19
40	1.24	54	1.13	34	1.09	26	1.03	11
60	1.25	68	1.13	40	1.07	25	1.04	14
80	1.21	78	1.13	55	------	-------	------	-------

TABLE III - COMPARISON OF KNOCK-LIMITED PERFORMANCE OF 28-R AVIATION FUEL WITH AND WITHOUT ADDITION OF TRIPTANE AT F-4 CONDITIONS

[Final lead concentration, approximately 4.55 ml TEL/gal]

Percentage triptane in final blend	imep ratio calculated from equation (2)	Fuel-air ratio							
		0.0625		0.070		0.090		0.110	
		Performance number[a]	imep ratio	Performance number[a]	imep ratio	Performance number[a]	imep ratio	Performance number[a]	imep ratio
0	1.00	111	1.00	113	1.00	132	1.00	132	1.00
20	1.17	129	1.16	129	1.14	153	1.16	155	1.17
40	1.41	159	1.43	164	1.45	197	1.49	188	1.43
60	1.78	196	1.77	214	1.89	244	1.85	236	1.79
80	2.40	246	2.22	292	2.59	[b]317	----	[b]317	----
100	3.70	[b]410	----	[b]418	----	[b]488	----	[b]488	----

[a]Calculated by multiplying the assumed performance number of 28-R aviation fuel by the imep ratio.

[b]Estimated from the calculated imep ratio.

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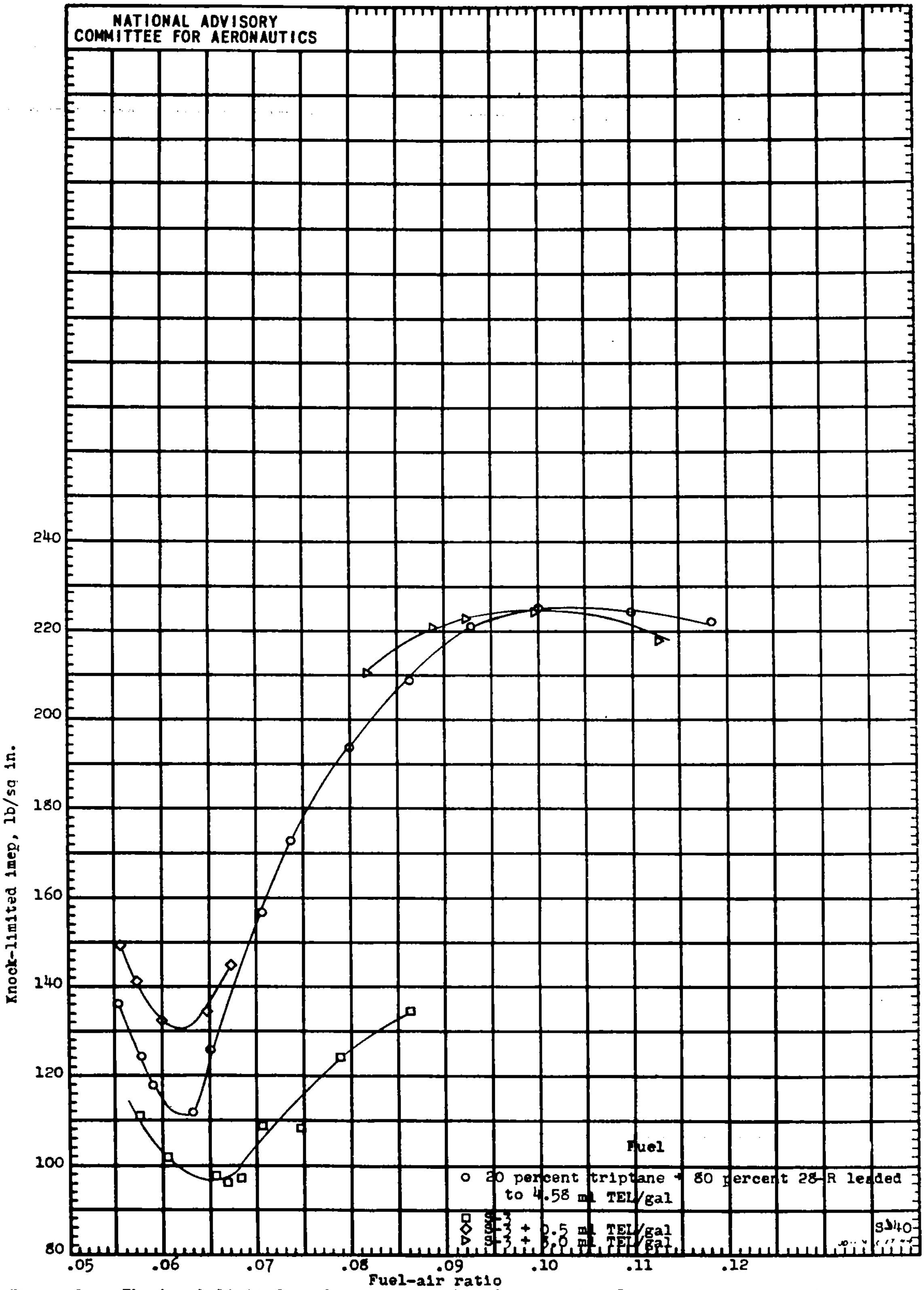

Figure 1. - The knock-limited performance of a blend containing 20 percent triptane plus 80 percent 28-R leaded to 4.58 ml TEL per gallon; operation under F-4 specifications.

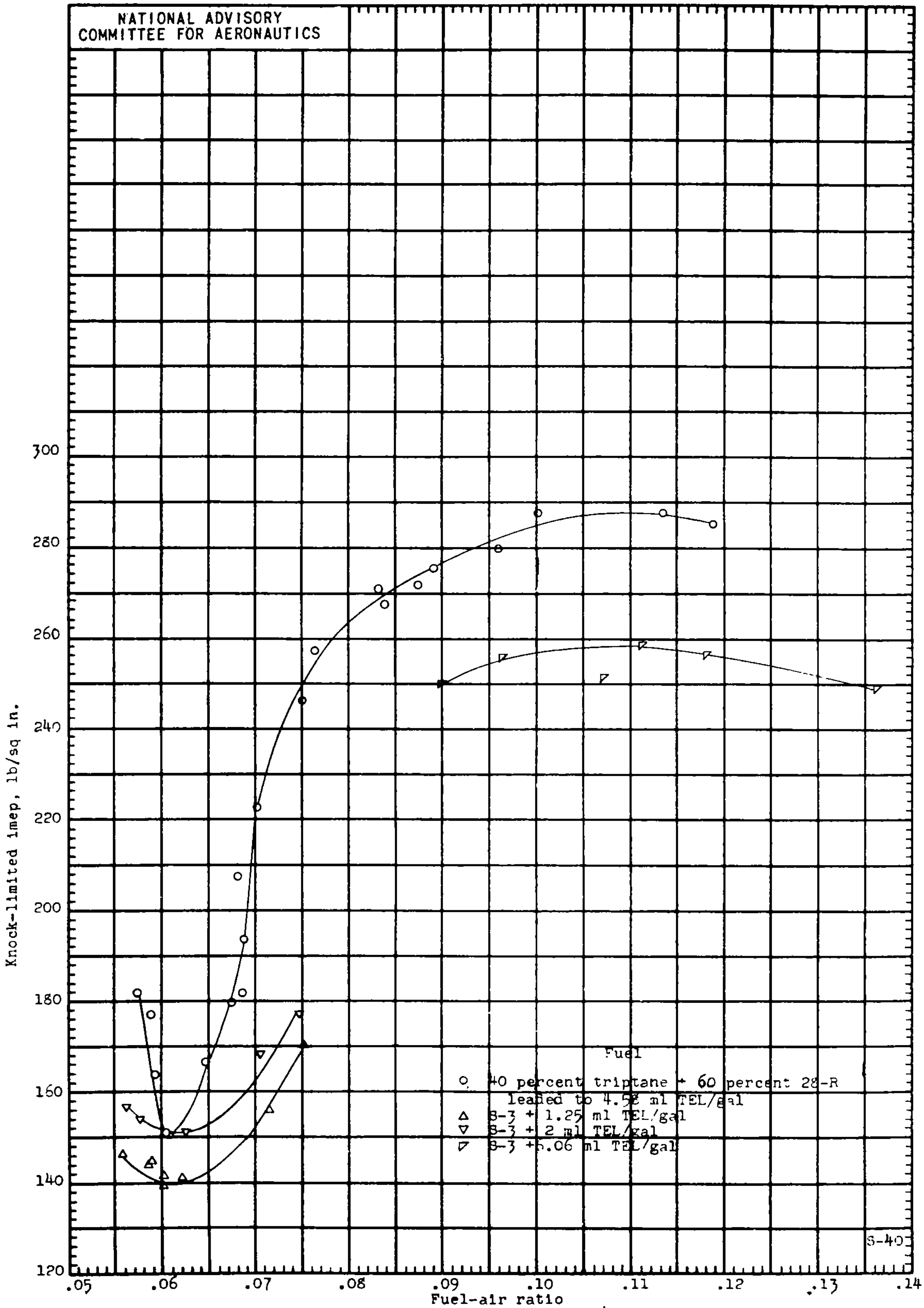

Figure 2. - The knock-limited performance of a blend containing 40 percent triptane plus 60 percent 28-R leaded to 4.58 ml TEL per gallon; operation under F-4 specifications.

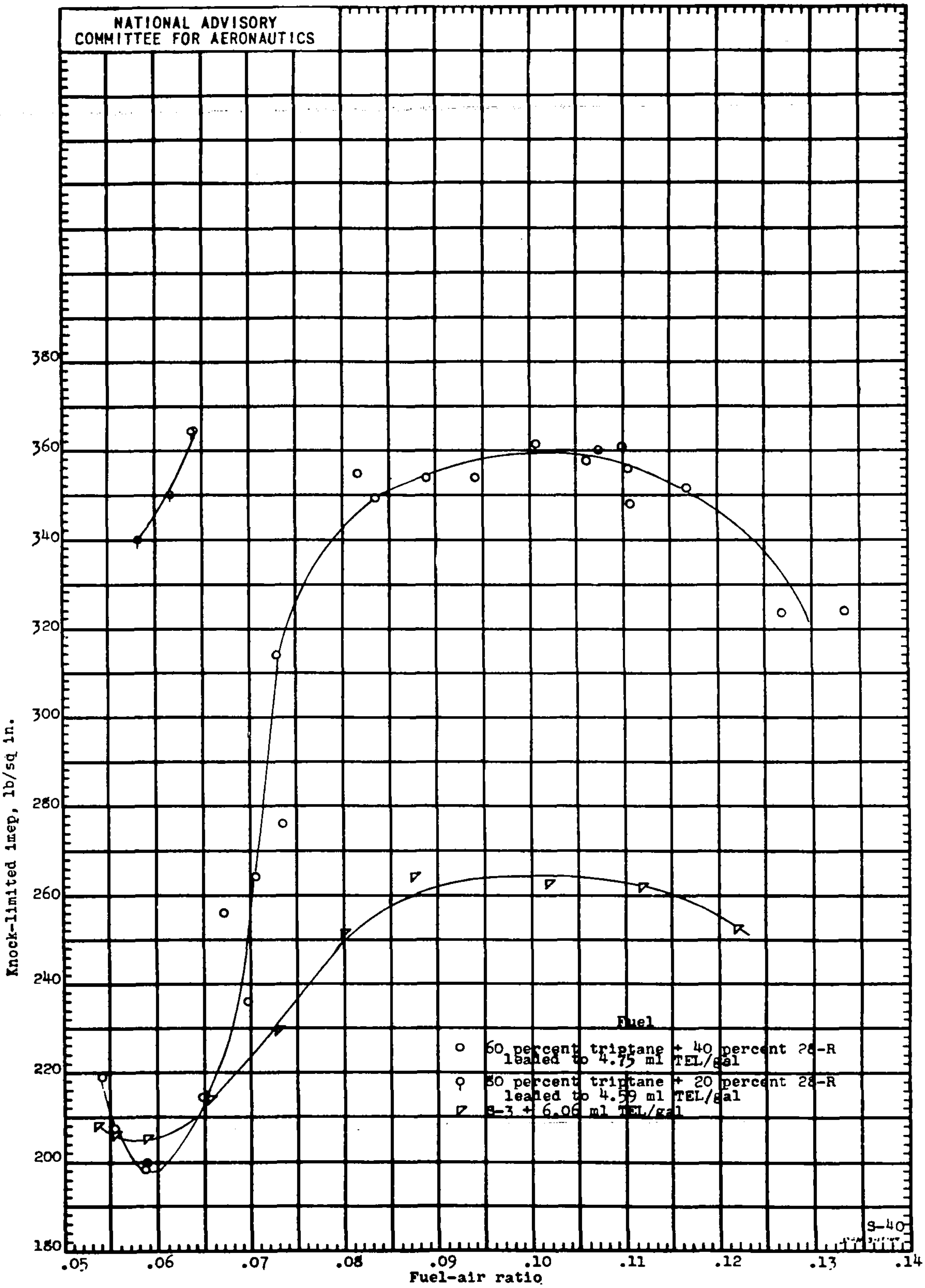

Figure 3. - The knock-limited performance of a blend containing 60 percent triptane plus 40 percent 28-R leaded to 4.75 ml TEL per gallon and a blend containing 80 percent triptane plus 20 percent 28-R leaded to 4.59 ml TEL per gallon; operation under F-4 specifications.

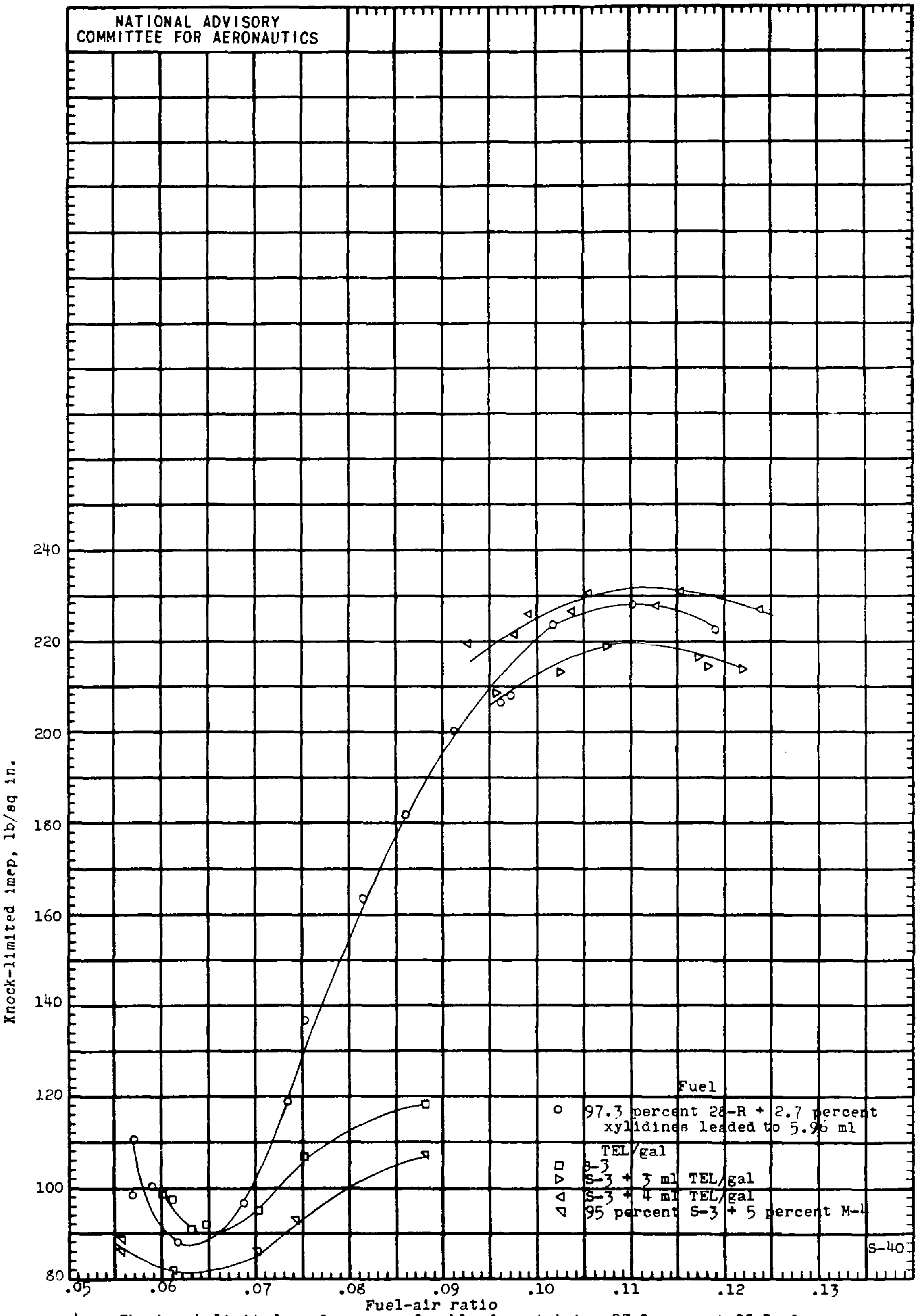

Figure 4. - The knock-limited performance of a blend containing 97.3 percent 28-R plus 2.7 percent xylidines leaded to 5.96 ml TEL per gallon; operation under F-4 specifications.

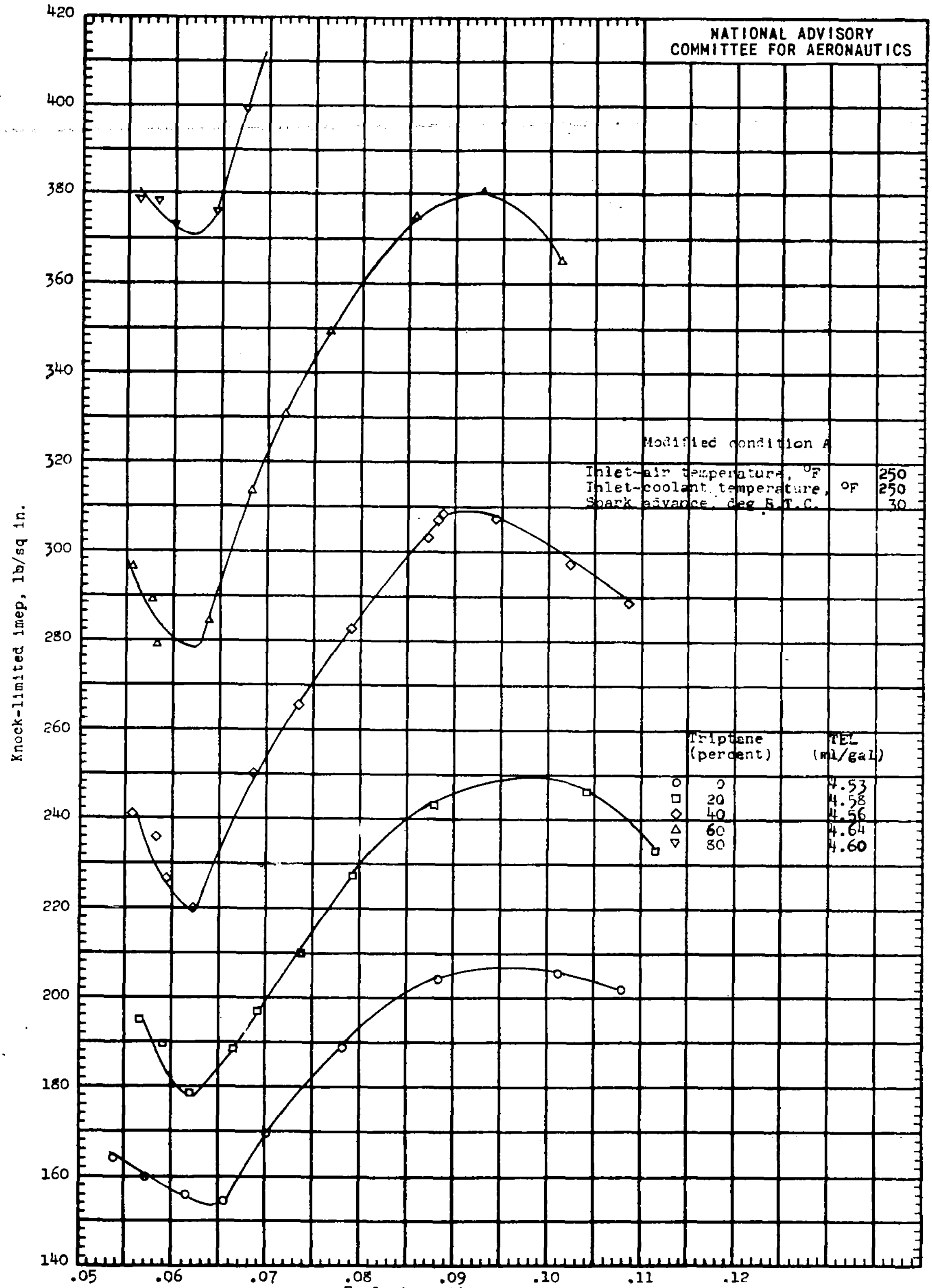

Figure 5. - The knock-limited performance of blends containing triptane and 28-R aviation fuel in an F-4 engine operating at modified condition A.

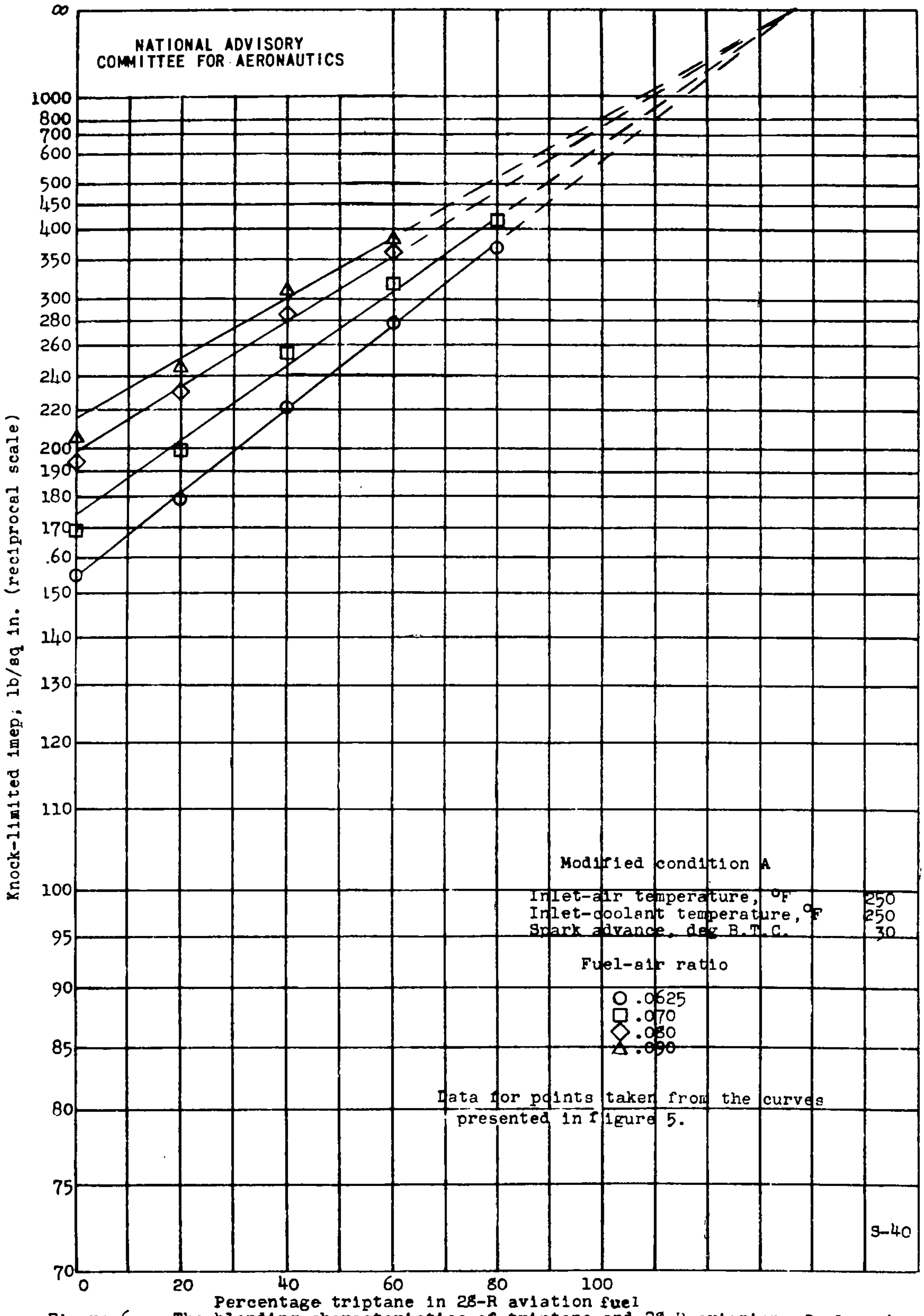

Figure 6. - The blending characteristics of triptane and 28-R aviation fuel in an F-4 engine at modified condition A. Lead concentration of final blend approximately 4.60 ml per gallon.

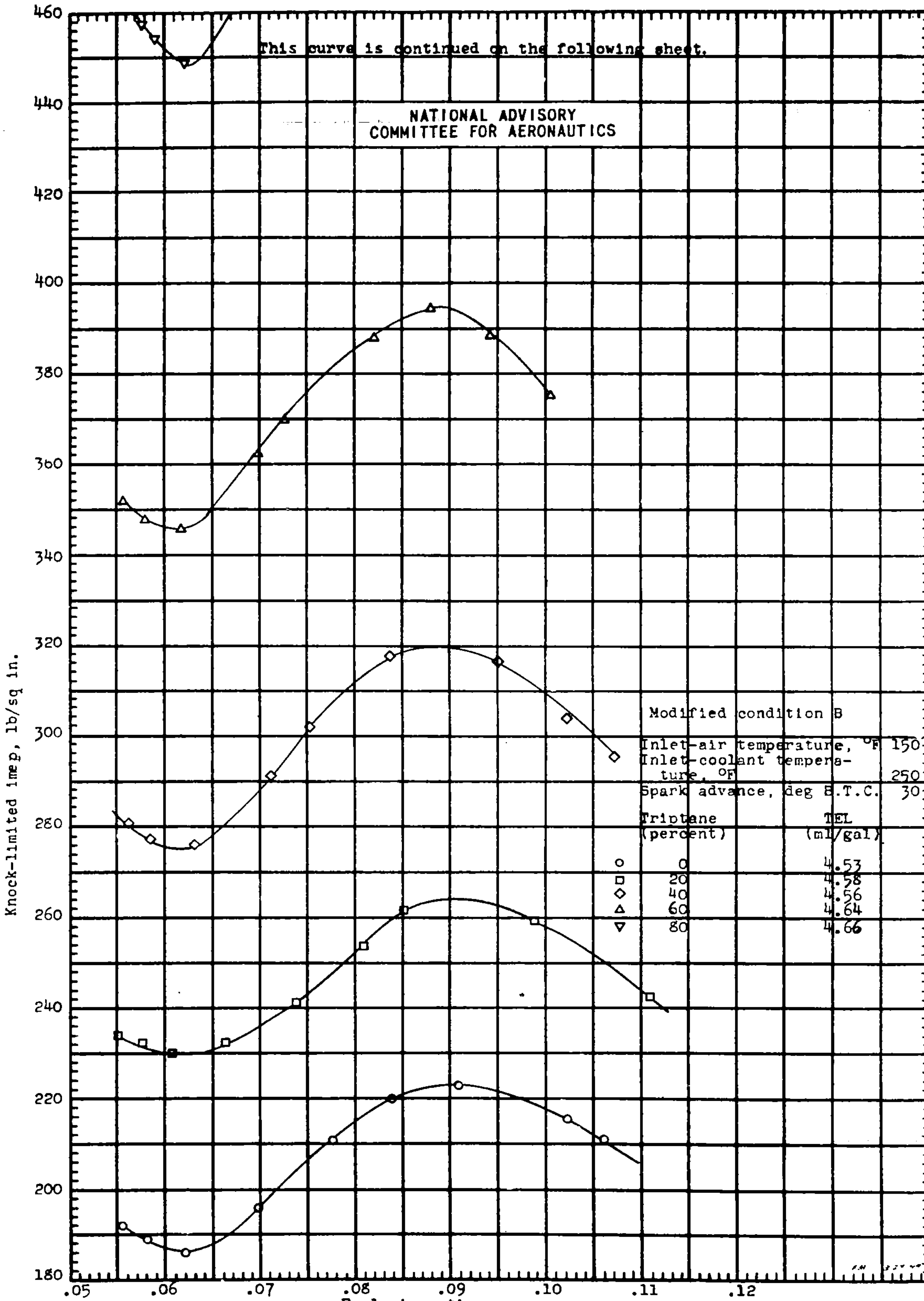

Figure 7. - The knock-limited performance of blends containing triptane and 28-R aviation fuel in an F-4 engine operating at modified condition B.

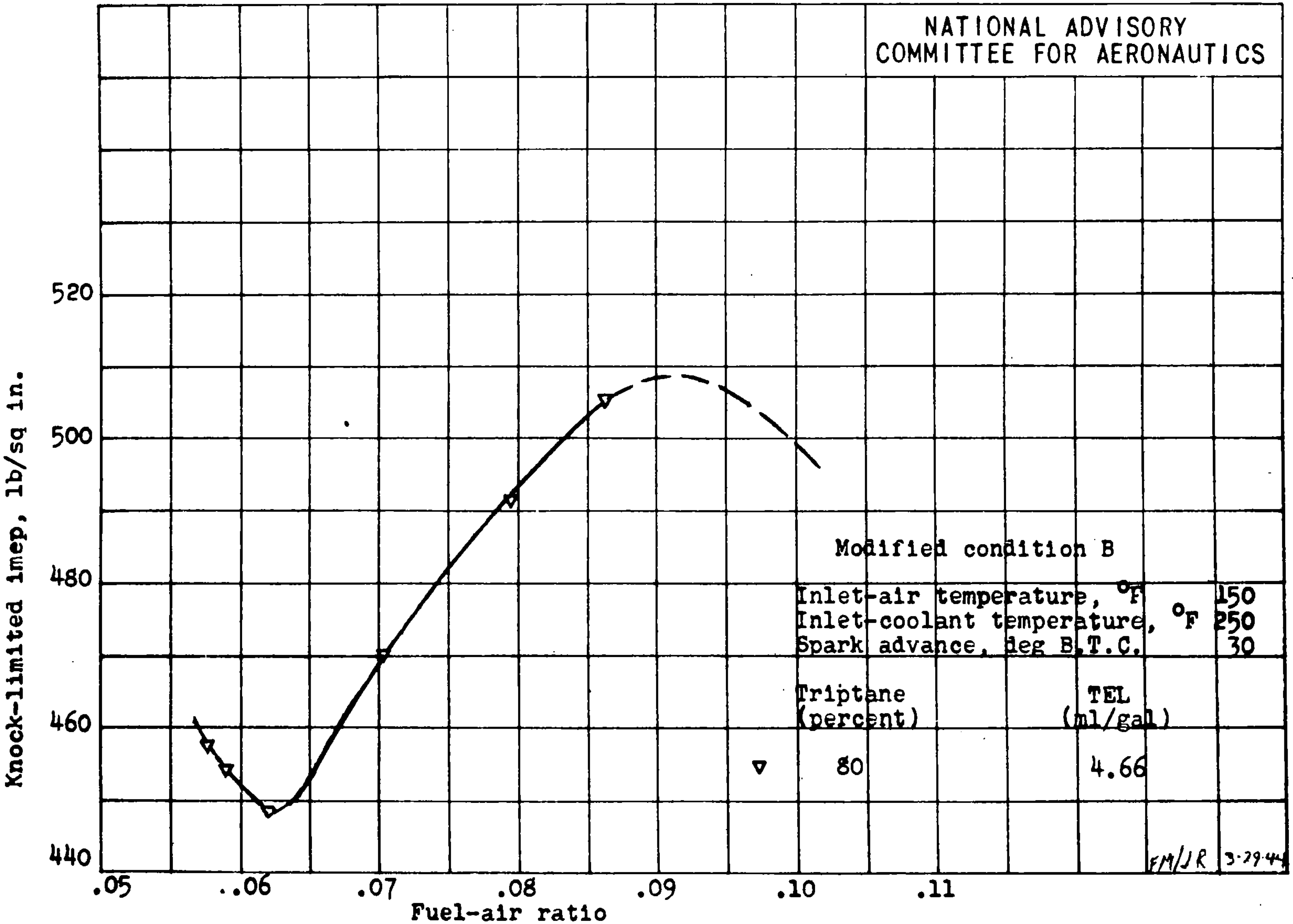

Figure 7. - Concluded.

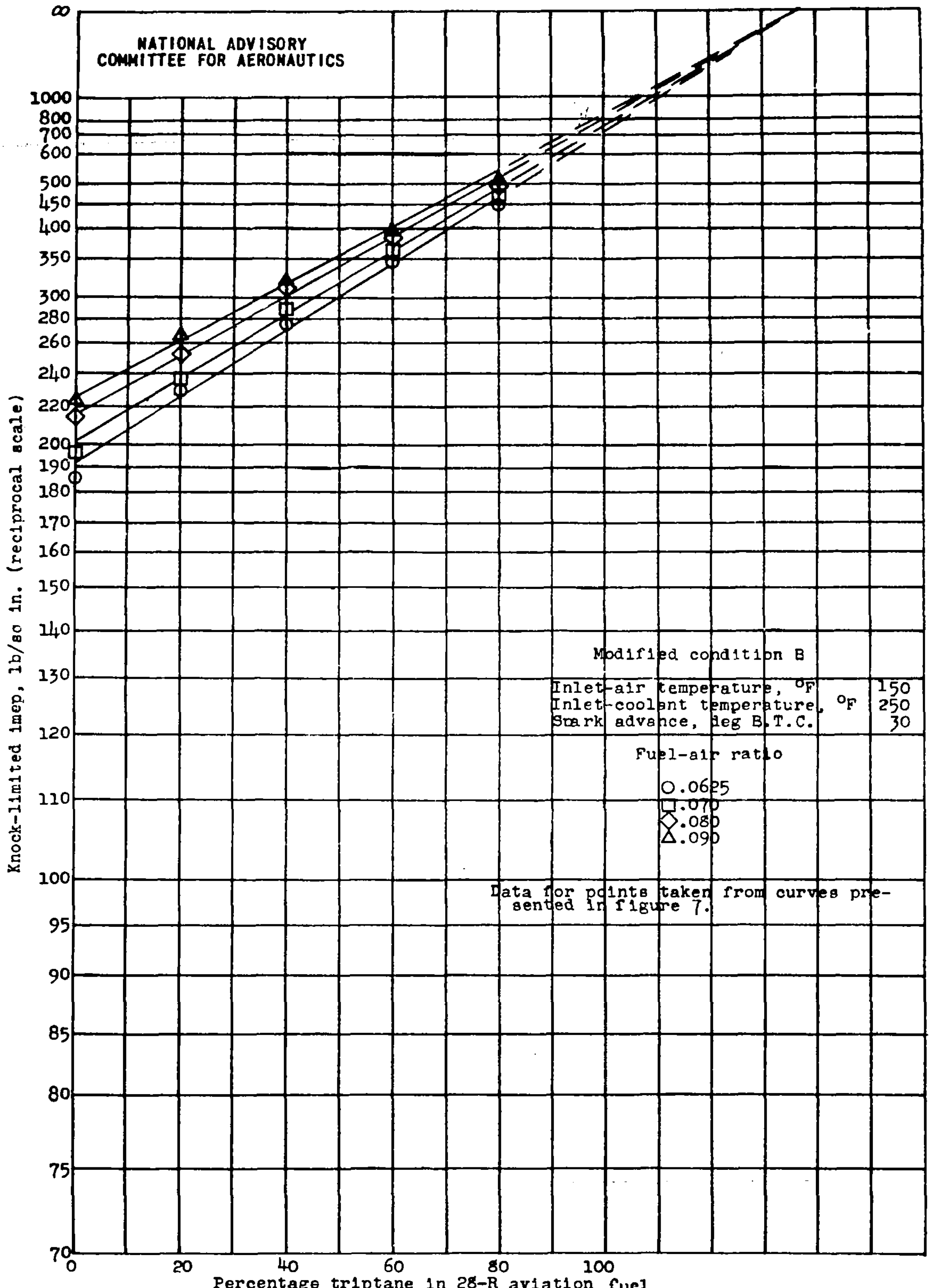

Figure 8. - The blending characteristics of triptane and 28-R aviation fuel in an F-4 engine at modified condition B. Lead concentration of final blend approximately 4.60 ml per gallon.

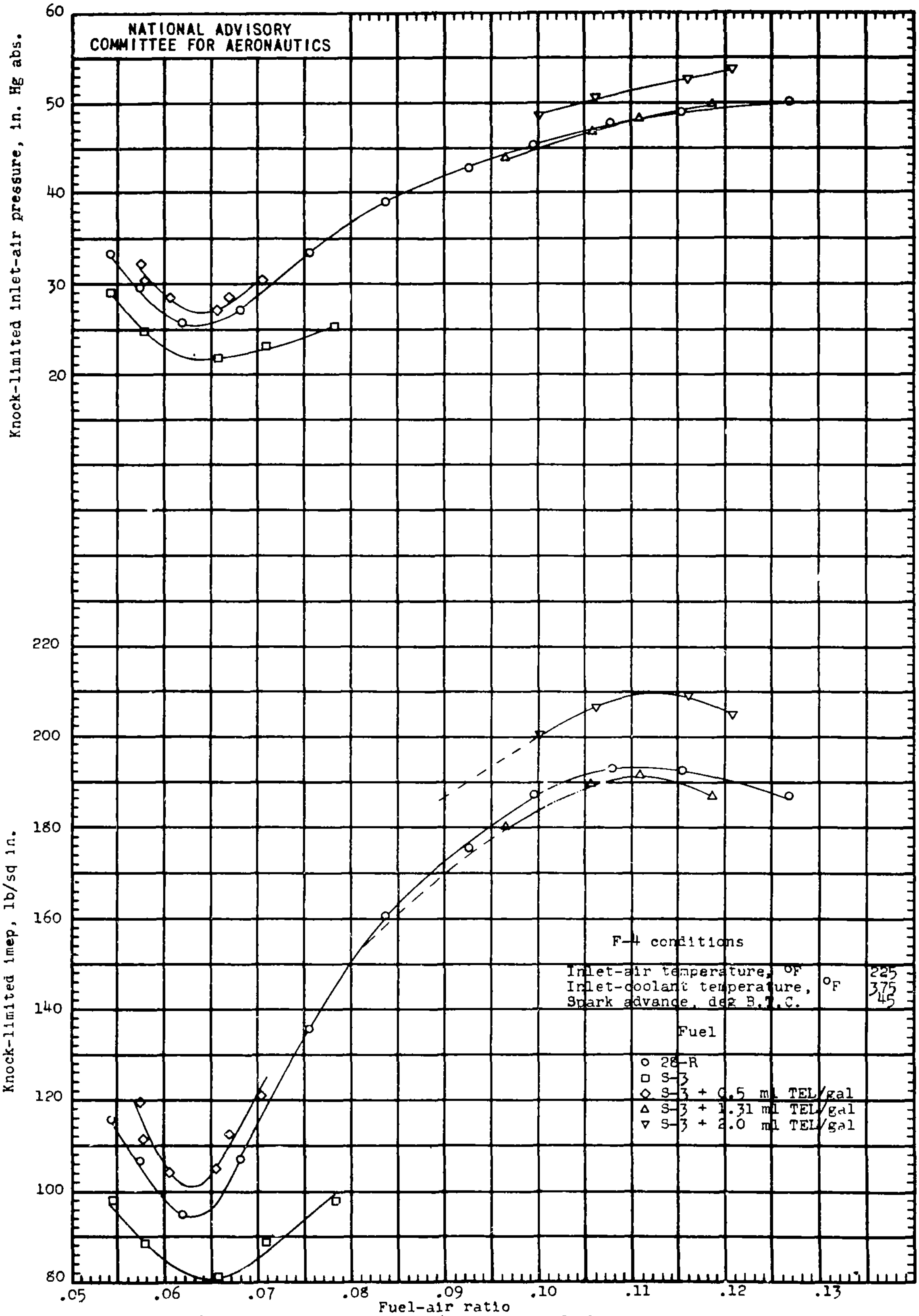

Figure 9. - The F-4 performance rating of 28-R aviation fuel.

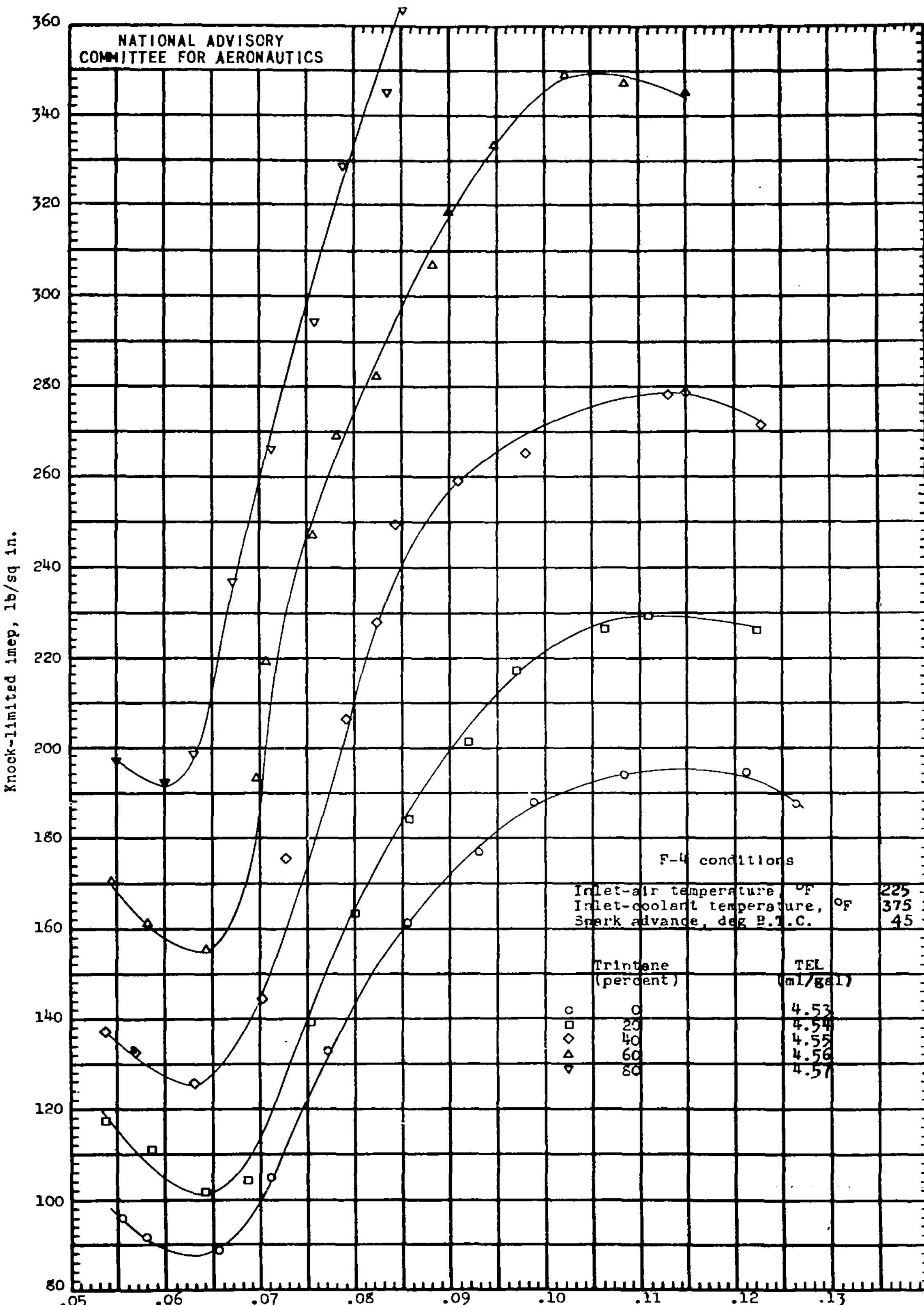

Figure 10. - The knock-limited performance of blends containing triptane and 28-R aviation fuel in an F-4 engine operating at specified conditions.

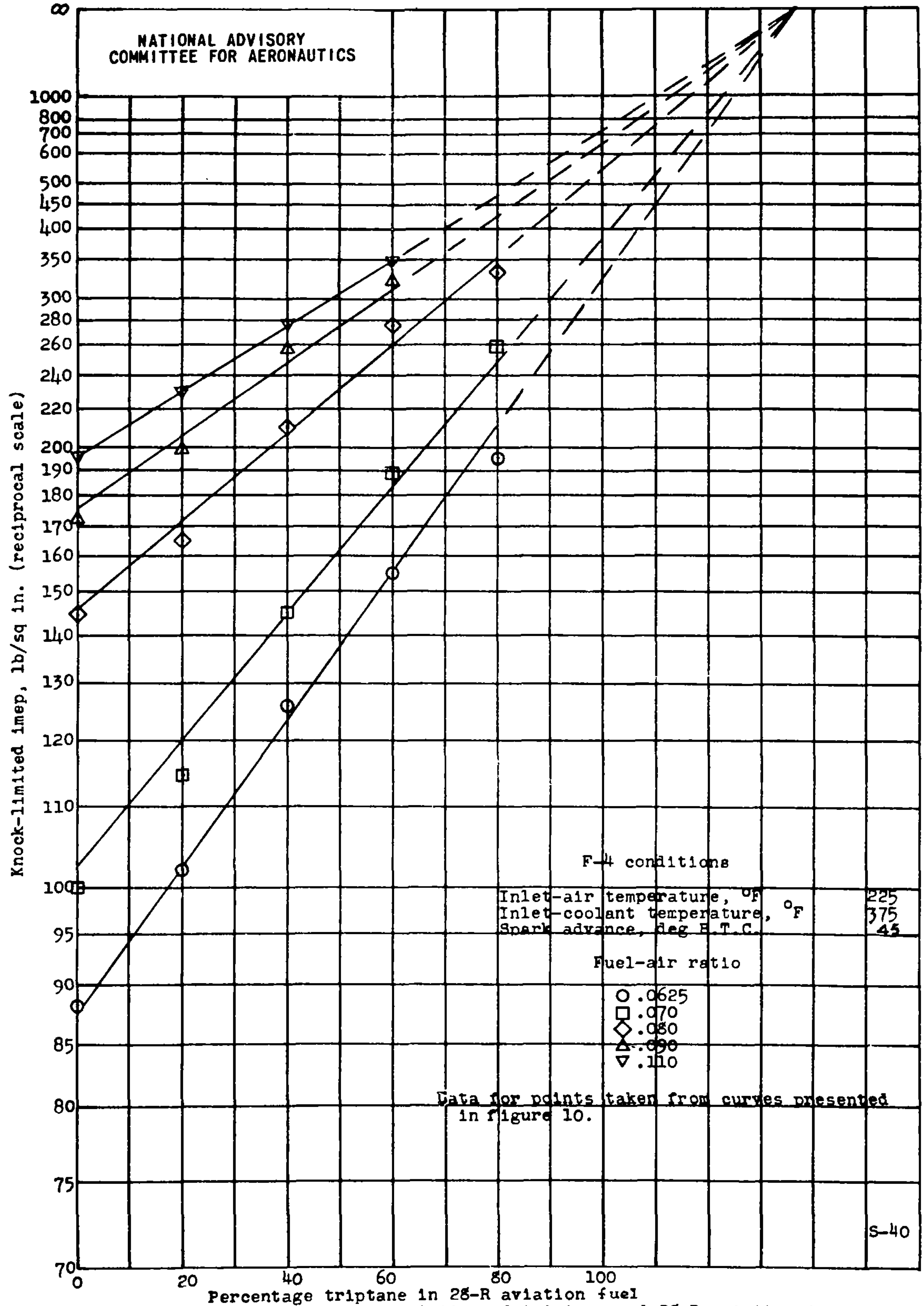

Figure 11. - The blending characteristics of triptane and 28-R aviation fuel in an F-4 engine operating at specified conditions. Lead concentration of final blends approximately 4.55 ml TEL per gallon.

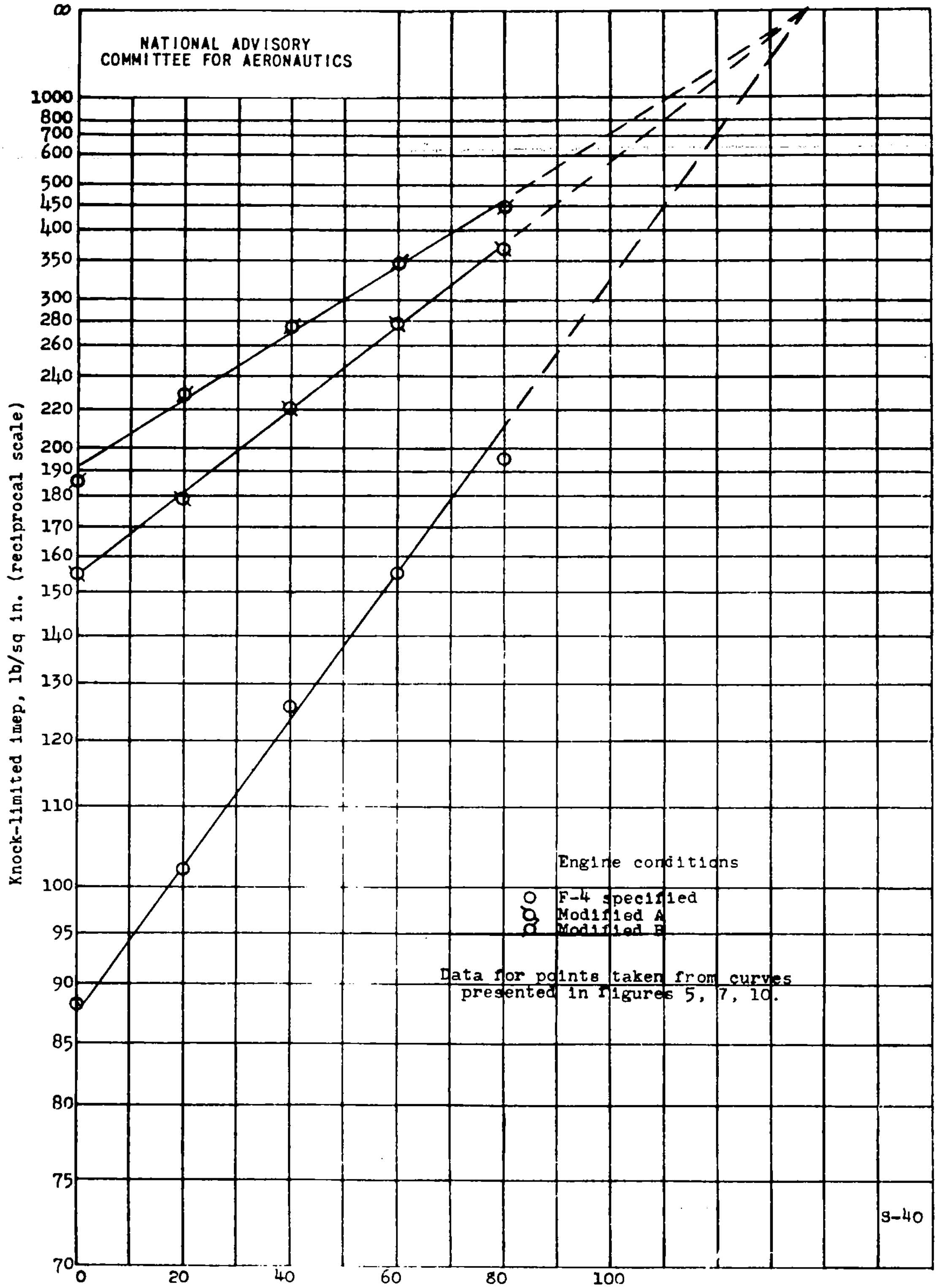

Figure 12. - The blending characteristics of triptane at .0625 fuel-air ratio. F-4 engine operating at specified and modified conditions. Lead concentration of final blend approximately 4.60 ml TEL per gallon.

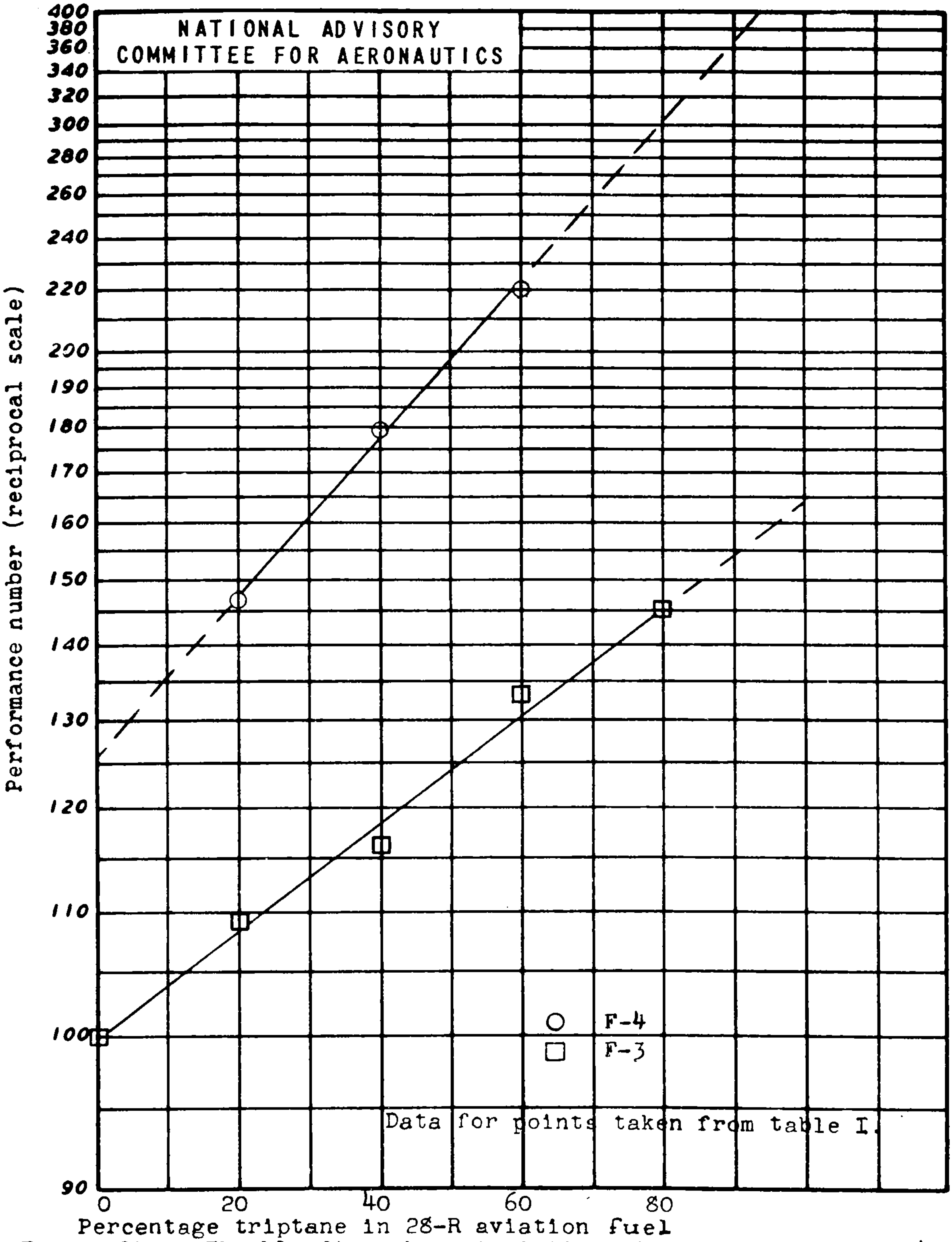

Figure 13. - The blending characteristics of triptane in the F-4 and F-3 rating engines.