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COMPARISON OF THE KNOCK-LIMITED PERFORMANCE OF TRIPTANE WITH 23 OTHER PURIFIED HYDROCARBONS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

COMPARISON OF THE KNOCK-LIMITED PERFORMANCE OF TRIPTANE WITH 23 OTHER PURIFIED HYDROCARBONS

By J. Robert Branstetter

SUMMARY

The knock-limited performance of blends containing General Motors triptane in S reference fuel and in an S plus M base fuel was determined in 17.6, F-3, F-4, and full-scale (single cylinder) engines. The results obtained are presented and are compared with published data from similar tests of 12 aromatics, 10 paraffins (including highly purified triptane), and 2 olefins. The comparison of fuels - which is based on a consideration of (a) antiknock blending sensitivity, (b) lead susceptibility, (c) temperature sensitivity, and (d) comparison of small-scale and full-scale engine data - is presented by means of bar graphs.

INTRODUCTION

An investigation to determine the antiknock effectiveness of a number of highly purified components of aviation fuels is being conducted under the sponsorship of the NACA. Each of the components is individually blended with one of several base fuels and is then subjected to knock tests at various operating conditions. Ten paraffinic hydrocarbons (including triptane of high purity received from the National Bureau of Standards) and two olefinic hydrocarbons blended with an 85 percent S plus 15 percent M base fuel and leaded to 4 ml TEL per gallon have been knock-tested in F-3, F-4, and full-scale single-cylinder engines; the results are presented in references 1 and 2. Twelve aromatic hydrocarbons, in addition to being tested in the aforementioned manner, have also been knock-tested in a supercharged 17.6 engine in blends with the S plus M base fuel and S reference fuel. Data for the aromatics are presented in references 3 to 6 and are summarized in reference 7.

A study of the engine performance of General Motors triptane was concurrently undertaken by the Cleveland laboratory at the request of the Army Air Forces, Air Technical Service Command. The program included knock-limited performance tests in laboratory engines (references 8 to 10), in a full-scale single-cylinder engine (references 11 and 12), in full-scale multicylinder engines (unpublished data), and in flight (reference 13).

As a part of the general investigation of General Motors triptane, a comparative evaluation of triptane with numerous other high-performance fuels based on tests with a number of engines was considered desirable. In order to make such an evaluation, blends of General Motors triptane comparable with those of the highly purified hydrocarbons (reported in references 1 to 7) were tested at the NACA Cleveland laboratory during the latter part of 1944. Presented herein are: part I, tests and results for General Motors triptane blended with S reference fuel and the S plus M base fuel obtained with F-3, F-4, and 17.6 engines and a full-scale cylinder; part II, a comparison of General Motors triptane data with National Bureau of Standards triptane data; and part III, a comprehensive comparison of General Motors triptane with the following purified hydrocarbons:

Benzene
Toluene
o-Xylene
p-Xylene
Ethylbenzene
Isopropylbenzene (cumene)
sec-Butylbenzene
tert-Butylbenzene
m-Diethylbenzene
1-Ethyl-4-methylbenzene
1,3,5-Trimethylbenzene (mesitylene)
1,2,4-Trimethylbenzene (pseudocumene)
2-Methylbutane (isopentane)
2,3-Dimethylbutane (diisopropyl)
2,2-Dimethylbutane (neohexane)
2,2,3-Trimethylbutane (triptane)
2,2,3-Trimethylpentane
2,3,4-Trimethylpentane
2,3,3-Trimethylpentane
2,2,3,4-Tetramethylpentane
2,2,3,3-Tetramethylpentane
2,2,4,4-Tetramethylpentane
2,4,4-Trimethyl-1-pentene
2,4,4-Trimethyl-2-pentene

The primary factors considered are (a) antiknock blending sensitivity, (b) lead susceptibility, (c) temperature sensitivity, and (d) correlation of small-scale and full-scale engine results.

ANALYSIS PROCEDURE

Because of the large amount of hydrocarbon data and its complexity, only a portion could be effectively presented. Fuel-air ratios of 0.065 and 0.10 were therefore selected at which to make the comparison; they are considered to be representative of the extreme conditions experienced in flight (cruise and take-off). Because engine-performance data at approximately these fuel-air ratios generally fall on the flat portions of curves showing knock-limited indicated mean effective pressure as a function of fuel-air ratio, the data are consequently not only more reproducible than that at other fuel-air ratios but are also less affected by small shifting of the aromatic curves owing to changes in the stoichiometric fuel-air ratio.

The data are generally analyzed on the basis of knock-limited imep ratio (ratio of imep of the test fuel blend to imep of the base fuel). This method was preferred because in some cases the knock-limited indicated mean effective pressures were so great that an evaluation of data in terms of isooctane and lead was impractical.

For the comparison of triptane with the 23 other fuels (part III), bar graphs are used to present the comparative ratings. The hydrocarbons are, for convenience, usually listed in order of antiknock performance at each set of engine conditions.

I - TESTS AND RESULTS FOR GENERAL MOTORS TRIPTANE

Apparatus, Fuels, and Test Procedure

A description of the 17.6, the F-3, and the "research" F-4 engines and the operating conditions used in the present tests are given in reference 4. The research F-4 engine (called the F-4 engine throughout this report) is not a package unit but was operated at F-4 conditions; a magnetostriction pickup unit in conjunction with a cathode-ray oscilloscope was used to detect knock.

The R-1820 G200 single-cylinder engine and the test conditions used are described in reference 1. The conditions are those tentatively recommended by the Coordinating Research Council for simulated cruise and take-off. Pertinent operating conditions for the aircraft-engine cylinder as well as the 17.6 engine tests are given in the figures and tables.

The fuel-component concentrations and an outline of tests for the blends of General Motors triptane are as follows:

Engine	Inlet-air temperature (°F)	Engine speed (rpm)	Triptane in blend (percent by volume)	Base fuel	TEL in final blend (ml/gal)
17.6	250	1800	0,10,20	S-4	0
	100	1800	0,20	S-4	0
	250	1800	0,10,20	S-4	4
	100	1800	0,20	S-4	4
	250	1800	0,25	85% S-4 + 15% M-4	4
	100	1800	0,25	85% S-4 + 15% M-4	4
F-4	225	1800	0,10,25,50	85% S-4 + 15% M-4	4
Full-scale cylinder	250	2500	0,25	85% S-3 + 15% M-4	4
	210	2000	0,25	85% S-3 + 15% M-4	4

F-3 ratings were also obtained for all the triptane blends as well as for unblended triptane, which was tested with and without 4 ml TEL per gallon.

Presentation of Results

The General Motors triptane data for the 17.6, F-4, and single-cylinder aircraft engines are presented in the conventional manner as curves of knock-limited indicated mean effective pressure and inlet-air pressure against fuel-air ratio. Fuel-consumption data were recorded only for control purposes.

17.6 engine tests. - The 17.6 engine performance with 0-, 10-, and 20-percent unleaded blends of triptane in S-4 reference fuel is presented in figure 1(a) for tests at an inlet-air temperature of 250° F. Figure 1(b) contains data on 0- and 20-percent unleaded blends at an inlet-air temperature of 100° F. Similar data for blends leaded to 4 ml TEL per gallon are shown in figure 2. Figure 3 presents blends of 0 and 25 percent triptane in the S plus M base fuel at inlet-air temperatures of 250° and 100° F; these blends were leaded to 4 ml TEL per gallon. The data on each of the figure sheets showing 17.6 engine tests were obtained the same day.

F-3 and F-4 ratings. - The F-4 curves for the S plus M base fuel and for blends of 10, 25, and 50 percent General Motors triptane in this base stock are presented in figure 4; bracketing reference-fuel curves are also included. The F-4 and F-3 ratings for all the

General Motors triptane blends tested are presented in table I in terms of S-4 plus lead, which are in turn converted to Army-Navy performance numbers.

Inasmuch as the F-4 ratings of the triptane blends were determined on separate days, knock-limited imep ratios may have been affected by day-to-day shifts in the power level of the engine. In order to avoid this possible error, the F-4 triptane tests were repeated and all were made in one day. The resulting curves (unbracketed) are presented in figure 5.

Full-scale single-cylinder tests. - The full-scale cylinder tests, made at simulated take-off and cruise conditions for a 25-percent blend of General Motors triptane in the S plus M base fuel (leaded to 4 ml TEL/gal), are presented in figure 6. Superimposed on these plots are reference-fuel curves that partly bracket the test curves. The positions of the S plus M base-fuel curves in figure 6 were determined from their positions relative to the bracketing reference-fuel curves presented in reference 1.

Summarization. - The knock-limited imep ratios of the General Motors triptane blends obtained with 17.6, F-4, and full-scale engines are summarized in table II for fuel-air ratios of 0.065, 0.07, 0.085, 0.10, and 0.11. Table III summarizes lead susceptibility and temperature sensitivity of triptane blends relative to the base reference fuels, as determined by 17.6 engine tests. A summary of the antiknock blending sensitivity of General Motors triptane, based on F-4, F-3, and full-scale test results, is presented in table IV. Data on National Bureau of Standards purified triptane (from references 1 and 2) are also included and will be discussed in the following section.

II - COMPARISON OF GENERAL MOTORS AND NATIONAL BUREAU OF STANDARDS TRIPTANE

The relative antiknock quality of General Motors and National Bureau of Standards (NBS) triptane may be compared on the basis of the data in table IV. The full-scale cylinder tests show the NBS triptane blends to have the same rich-mixture response as General Motors triptane. At lean fuel-air mixtures the NBS triptane blends gave greater knock-limited power, but a comparison of the reference-fuel curves presented herein with those of reference 1 show considerable variation in performance. At a fuel-air ratio of 0.065 a change in indicated mean effective pressure of 10 pounds per square inch in the knock level of the test fuel would affect the performance number as much as 10 units. Because a variation of 10 pounds per square inch is approximately the experimental error at lean-mixture conditions, a performance number of 141 for the NBS triptane blend as compared with 129 for the General Motors blend was therefore barely exceeding the limits of experimental error. The F-3 ratings gave performance numbers of 130 and 132 for the NBS and the General Motors triptane blends, respectively.

The F-4 ratings in terms of performance number for the two triptane stocks blended in concentrations up to 50 percent are compared in figure 7. This correlation of the knock ratings of the blends at both lean and rich mixtures shows the data to fall close to the 45° line. Differences in the knock-limited power of the two samples of triptane are not significant, as shown by the correlation.

III - COMPARISON OF TRIPTANE AND OTHER HIGH-PERFORMANCE HYDROCARBONS

Comparative Ratings and Discussion

Bar graphs of triptane and the purified hydrocarbon performance data from tests with 17.6, F-4, F-3, and full-scale single-cylinder engines are presented in figures 8 to 14. For emphasis, triptane is printed in capital letters on all graphs. A discussion of the data follows.

17.6 engine data. - Data from the 17.6 engine are presented in figure 8 for unleaded aromatic and triptane blends and in figure 9 for leaded aromatic and triptane blends. Figure 9 contains data on triptane and the aromatics tested in both the S plus M base fuel and in S reference fuel. The unleaded 20-percent triptane blend at an inlet-air temperature of 250° F showed improvement over the best of the 12 aromatic blends at lean mixtures; at a fuel-air ratio of 0.10, 6 aromatics gave higher knock-limited power than triptane. For leaded blends, except for the lean-mixture ratings at an inlet-air temperature of 250° F, 8 of the 12 aromatics had better antiknock blending sensitivity than triptane. (See fig. 9.)

Further comparison of figures 8 and 9 shows that triptane is listed lower relative to the aromatics in the leaded blends than in the unleaded blends. It is thus apparent that the "better" aromatics are more susceptible to lead than triptane. The position in which triptane (both clear and leaded) rated at fuel-air ratios of 0.065 and 0.10 lowered when the inlet-air temperature was reduced to 100° F which indicates that, in general, the temperature sensitivity of the aromatics was greater than that of triptane.

F-4 engine data. - Data from the F-4 engine on the paraffins, olefins, and aromatics are presented in figures 10 and 11 for 0-, 10-, 25-, and 50-percent blends in the S plus M base fuel. Lean ratings in terms of performance numbers are shown in figure 10 and rich ratings (fuel-air ratio of 0.10) expressed as knock-limited imep ratios are shown in figure 11. In both figures the hydrocarbons are listed in the order of blending performance in the 25-percent blends. Because the response curve for the 50-percent blend of 2,2,3,3-tetramethylpentane became vertical before a fuel-air ratio of 0.10 was reached, the imep ratio could not be determined. The imep ratio at 0.10 fuel-air ratio is at least 2.0, as indicated by an arrowhead in figure 11.

At lean mixtures the antiknock blending sensitivity of triptane was higher for concentrations greater than 10 percent than that of the other hydrocarbons. An increase in power at lean mixtures was observed for seven of the paraffins (including triptane) when the ratio of blending agent to base fuel was increased. Neither the aromatics nor the olefins showed promise in this respect.

The increase in performance of triptane blends over that of the base fuel at a fuel-air ratio of 0.10 was greater than at lean mixtures but was exceeded by that of several aromatics (six at the 25-percent concentration) and a nonane; these aromatics and the nonane gave relatively low lean-mixture response. The olefin 2,4,4-trimethyl-1-pentone had lower antiknock blending sensitivity than triptane at a fuel-air ratio of 0.10; if the comparison is made at a fuel-air ratio corresponding to that for F-4 ratings (approximately 0.11), however, the olefin would rate higher than triptane.

A three-dimensional plot showing the effect of fuel-air ratio and blend concentration on the knock-limited imep ratio of triptane and a typical aromatic is presented in figure 12. Because of current interest toluene was selected for this comparison. At each blend concentration the sensitivity of the toluene blend to fuel-air ratio was greater than for the triptane blend. At the 50-percent concentration and a fuel-air ratio of 0.10, toluene showed a rapid rise in the rate-of-power increase. This effect was also observed for the nonane 2,2,3,3-tetramethylpentane and a number of the better aromatics. It should be pointed out, however, that for blend concentrations of 25 percent or less, F-4 results are not materially affected by changing the parameter of the comparison from a fuel-air ratio of 0.10 to that corresponding to F-4 ratings.

F-3 engine data. - F-3 ratings of the hydrocarbon blends in both S reference fuel and the S plus M base fuel are presented in figure 13. (The data are incomplete owing to the limited supply of fuel.) Triptane, clear and leaded, usually had better antiknock blending sensitivity than any of the other purified hydrocarbons tested. Several of the purified paraffins showed responses nearly as high as triptane. Leaded S-4 reference fuel had higher antiknock performance than leaded triptane. (See table I.)

Full-scale single-cylinder data. - The full-scale single-cylinder data for 25-percent blends of hydrocarbon blending agents in the S plus M base fuel are presented in figure 14. The blends, leaded to 4 ml TEL per gallon, are presented in the order of their knock-limited power at the engine speed and inlet-air temperature simulating cruise conditions. As also observed for the F-3 and F-4 lean performance of the blends, triptane permitted higher lean-mixture knock-limited power at the higher speed and inlet-air temperature than any of the other hydrocarbons tested. Three paraffins and three aromatics, however, had comparable responses.

When the engine conditions were moderated, the lean imep ratios of triptane as well as of the other paraffins were but slightly affected; whereas the imep ratios of the aromatics and olefins showed improvement. For example, two of the aromatics at a fuel-air ratio of 0.065 showed improvements in the performance of the base fuel that were greater than twice that obtainable with triptane. At the same conditions, six other aromatics gave better response than triptane, and two of the paraffins and the two olefins showed a blending sensitivity equal to that of triptane.

At a fuel-air ratio of 0.10, 2,4,4-trimethyl-1-pentene and nine aromatics showed greater response than triptane. In fact, five of the aromatics permitted improvements in the performance of the base fuel approximately twice that permitted by triptane. Only one of the eight paraffins equaled the blending ability of triptane. The knock-limited imep ratios of the aromatics and olefins were sensitive to the lean-mixture conditions and also showed improvement with increasing fuel-air ratio, whereas triptane had almost the same imep ratios at both fuel-air ratios and both engine conditions. The three trimethylpentanes were similarly affected. Reference 10 indicates that this small effect of changing the operating variables may not hold true for triptane over a broader range of engine conditions.

Correlation of Engine Data

Changes in engines and operating conditions have a greater effect on the antiknock blending ability of the aromatics than on that of triptane. A more thorough summarization of the hydrocarbons can be made by comparing the fuels at the various degrees of severity at which the blends were rated. Correlations for the full-scale cylinder data at fuel-air ratios of 0.065 and 0.10 with the F-3, F-4 (at 0.10 fuel-air ratio), and the 17.6 engine data are presented in figures 15 to 17. These plots are similar to those used in references 1, 3, and 7.

The full-scale cylinder data plotted against the F-3 and F-4 (0.10 fuel-air ratio) data for the 25-percent blends of paraffinic, olefinic, and aromatic hydrocarbons in the S plus M base fuel are presented in figures 15 and 16. The lean-mixture ratings for the paraffinic blends (fig. 15) fall along the match line, but at a fuel-air ratio of 0.10 (fig. 16) the paraffins are more responsive in the full-scale cylinder than in the F-4 engine. Triptane falls close to the match line. The aromatics, like the two olefins, are more sensitive in the full-scale cylinder than in the F-3 and F-4 rating engines. This fact is most obvious in the lean-mixture chart comparing the F-3 and full-scale cylinder simulated cruise data (fig. 15).

Figure 17 is a correlation of the 17.6 engine data with full-scale cylinder data for the 12 aromatics and triptane. The 20-percent blends of the hydrocarbons in S reference fuel tested in the 17.6 engine are plotted against 25-percent blends in the S plus M base fuel tested in the full-scale cylinder; final blends contained 4 ml TEL per gallon. Because of the difference in blend compositions, no theoretical correlation line could be drawn. Nevertheless, from the figure the correlation between the two sets of aromatic data at simulated cruise conditions is approximately linear. (It is at full-scale cylinder cruise conditions that the F-3 engine fails to differentiate between aromatics of wide antiknock ability as measured on the full-scale cylinder.) On the basis of figure 17, triptane rates in nearly the same order among the aromatics tested with the 17.6 engine as with the full-scale cylinder.

SUMMARIZATION OF THE ANTIKNOCK CHARACTERISTICS OF 24 HYDROCARBONS

At the most severe lean-mixture conditions (F-4 and F-3) triptane had better antiknock blending sensitivity than any of the other compounds tested. At milder conditions, as represented by tests on the full-scale cylinder (cruise), the performance of aromatics was improved compared with that of triptane. Under these conditions *tert*-butylbenzene, *m*-diethylbenzene, 1-ethyl-4-methylbenzene, isopropylbenzene, and several less outstanding lean-mixture aromatics (ethylbenzene, *sec*-butylbenzene, and 1,3,5-trimethylbenzene) had greater antiknock blending sensitivities than triptane. The paraffins 2,3-dimethylbutane and 2,2,3-trimethylpentane as well as the two olefins had blending sensitivities comparable with that of triptane in the full-scale cylinder (cruise) tests.

In the 17.6 engine tests the behavior of the aromatics was similar to the full-scale cylinder tests. In both engines <u>tert</u>-butylbenzene and <u>m</u>-diethylbenzene had about twice the blending sensitivity of triptane at cruise conditions.

At rich mixtures (leaded blends) the order in which triptane rated among the hydrocarbons was about the same in the full-scale cylinder, 17.6, and F-4 engines. A nonane 2,2,3,3-tetramethylpentane (tested only on the F-4 engine), an olefin 2,4,4-trimethyl-1-pentene, and at least seven aromatics had better antiknock blending sensitivity than triptane. Five of these aromatics - <u>m</u>-diethylbenzene, <u>tert</u>-butylbenzene, 1,3,5-trimethylbenzene, <u>p</u>-xylene, and 1-ethyl-4-methylbenzene - were the best rich-mixture blending agents tested; 2,2,3-trimethylpentane was slightly lower in antiknock blending ability than triptane.

At rich mixtures, decreasing the inlet-air temperature of the 17.6 engine had little effect on the performance of triptane relative to the base fuel but did improve the performance of the aromatics. The effect of lowering the engine speed and inlet-air temperature on the imep ratios of the 22 hydrocarbons tested on the full-scale cylinder was insignificant.

Figures 18 and 19 present, in the form of bar graphs, relative lead susceptibility and relative temperature sensitivity of the aromatics and triptane as determined with the 17.6 engine. In general, the lead response of triptane was lower than that of the better aromatics; the lead susceptibility of the aromatics apparently increased with antiknock blending ability. From reference 14 the lead susceptibility of one paraffin relative to another is approximate unity.

The foregoing remarks on lead susceptibility are applicable to a comparison of the temperature-sensitivity data of triptane and the aromatics. At a fuel-air ratio of 0.065 the aromatics that showed considerable sensitivity to inlet-air temperature in the 17.6 engine (fig. 19) were, in general, sensitive to the change in full-scale cylinder operating conditions (fig. 14).

Although the lean-mixture imep ratios of the two olefins were greatly improved by modifying the full-scale cylinder operating conditions, the performance of the paraffins was comparatively unaffected.

From this discussion it can be expected that the olefins and the paraffins would, in general, respond to inlet-air temperature in the 17.6 engine much the same as they did to operating conditions in the full-scale cylinder.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, May 15, 1945.

REFERENCES

1. Jones, Anthony W., and Bull, Arthur W.: Knock-Limited Performance of Pure Hydrocarbons Blended with a Base Fuel in a Full-Scale Aircraft-Engine Cylinder. I - Eight Paraffins, Two Olefins. NACA ARR No. E4E25, 1944.

2. Bogen, J. S.: NACA Pure Hydrocarbon Study. Res. and Development Lab., Universal Oil Products Co. (Riverside, Ill.), Nov. 8, 1943.

3. Bull, Arthur W., and Jones, Anthony W.: Knock-Limited Performance of Pure Hydrocarbons Blended with a Base Fuel in a Full-Scale Aircraft-Engine Cylinder. II - Twelve Aromatics. NACA ARR No. E4I09, 1944.

4. Meyer, Carl L., and Branstetter, J. Robert: The Knock-Limited Performance of Fuel Blends Containing Aromatics. I - Toluene, Ethylbenzene, and p-Xylene. NACA ARR No. E4J05, 1944.

5. Branstetter, J. Robert, and Meyer, Carl L.: The Knock-Limited Performance of Fuel Blends Containing Aromatics. II - Isopropylbenzene, Benzene, and o-Xylene. NACA ARR No. E5A20, 1945.

6. Meyer, Carl L., and Branstetter, J. Robert: The Knock-Limited Performance of Fuel Blends Containing Aromatics. III - 1,3,5-Trimethylbenzene, tert-Butylbenzene, and 1,2,4-Trimethylbenzene. NACA ARR No. E5D16, 1945.

7. Meyer, Carl L., and Branstetter, J. Robert: The Knock-Limited Performance of Fuel Blends Containing Aromatics. IV - Data for m-Diethylbenzene, 1-Ethyl-4-methylbenzene, and sec-Butylbenzene Together with a Summarization of Data for 12 Aromatic Hydrocarbons. NACA ARR No. E5D16a, 1945.

8. Imming, Harry S., Barnett, Henry C., and Genco, Russell S.: F-3 and F-4 Engine Tests of Several High-Antiknock Components of Aviation Fuel. NACA MR No. E4K27, 1944.

9. Evvard, John C., Imming, Harry S., and Genco, Russell S.: Knock-Limited Blending Characteristics of Blends of Triptane and 28-R Aviation Fuel. NACA Memo. rep., April 18, 1944.

10. Alquist, Henry E., and Tower, Leonard K.: The Effect of Compression Ratio on Knock Limits of High-Performance Fuels in a CFR Engine. I - Blends of Triptane and 28-R Fuel. NACA MR No. E4J10, 1944.

11. Sanders, Newell D., Wear, Jerrold D., and Stricker, Edward G.: Knock-Limited Blending Characteristics of Fuel Components in a Pratt & Whitney R-2800 Cylinder. I - Triptane, Hot-Acid Octanes, Isopentane, Diisopropyl, Neohexane, and Xylidines. NACA MR No. E4J01, Army Air Forces, Oct. 1, 1944. (Available as NACA TN No. 1374, 1947.)

12. Breitwieser, Roland, and Hensley, Reece V.: Knock-Limited Blending Characteristics of Fuel Components in a Pratt & Whitney R-2800 Cylinder. III - Tests at Advanced Spark Setting with Triptane, Hot-Acid Octanes, Isopentane, Diisopropyl, Alkylate, Neohexane, and 2,2,3-Trimethylpentane. NACA MR No. E5C14, Army Air Forces, March 14, 1945. (Available as NACA TN No. 1374, 1947.)

13. White, H. Jack, Blackman, Calvin C., and Werner, Milton: Flight and Test-Stand Investigation of High-Performance Fuels in 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. E4L30, 1944.

14. Barnett, Henry C.: Lead Susceptibility of Paraffins, Cycloparaffins, and Olefins. NACA ARR No. 3E26, 1943.

TABLE I - F-4 AND F-3 RATINGS OF GENERAL MOTORS TRIPTANE BLENDS

Blend composition (percent by volume)			Tetraethyl lead (ml/gal)	F-4 ratings				F-3 ratings	
				Lean		Rich			
Triptane	S-4 reference fuel	85 percent S-4 + 15 percent M-4		S-4 + TEL (ml/gal)	Performance number	S-4 + TEL (ml/gal)	Performance number	S-4 + TEL (ml/gal)	Performance number
0	0	100	4	0.50	116	0.21	108	0.31	111
10	0	90	4	.80	122	1.14	128	.5	116
25	0	75	4	1.85	137	2.66	144	1.4	132
50	0	50	4	3.53	150	>6.00	[a]185	1.89	137
10	90	0	0	---------	--------	---------	--------	0.02	101
20	80	0	0	---------	--------	---------	--------	.10	104
100	0	0	0	---------	--------	---------	--------	.08	103
10	90	0	4	---------	--------	---------	--------	3.8	151
20	80	0	4	---------	--------	---------	--------	3.65	151
100	0	0	4	---------	--------	---------	--------	3.3	149

[a] Estimated performance number of test fuel = $\frac{161 \times \text{imep of test fuel}}{\text{imep of S + 6 ml TEL/gal}}$.

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TABLE II - TEST RESULTS OF SUPERCHARGED ENGINE TESTS OF GENERAL MOTORS TRIPTANE BLENDS

Blend composition (percent by volume)			Tetraethyl lead (ml/gal)	Engine conditions		Fuel-air ratio									
Triptane	S reference fuel	85 percent S + 15 percent M		Engine speed (rpm)	Inlet-air temperature (°F)	0.065		0.07		0.085		0.10		0.11	
						imep	imep ratio[a]	imep	imep ratio[a]	imep	imep ratio[a]	imep	imep ratio[a]	imep	imep ratio[a]
17.6 engine															
10	90	0	0	1800	250	121	1.02	123	1.02	142	1.03	169	1.09	173	1.10
20	80	0	0			129	1.08	130	1.07	150	1.09	181	1.17	189	1.20
20	80	0	0	1800	100	182	1.16	177	1.15	191	1.21	196	1.20	196	1.20
10	90	0	4	1800	250	216	1.05	222	1.06	252	1.09	276	1.10	277	1.10
20	80	0	4			233	1.13	242	1.16	279	1.22	309	1.23	312	1.24
20	80	0	4	1800	100	330	1.20	318	1.18	324	1.22	325	1.20	320	1.19
25	0	75	4	1800	250	184	1.24	185	1.24	219	1.32	231	1.30	227	1.28
25	0	75	4	1800	100	240	1.28	239	1.29	248	1.31	246	1.31	237	1.28
F-4 engine															
10	0	90	4	1800	225	113	1.02	132	1.05	172	1.08	187	1.09	190	1.11
25	0	75	4			124	1.12	153	1.21	200	1.26	222	1.29	224	1.30
50	0	50	4			165	1.49	190	1.51	264	1.66	297	1.73	299	1.74
Full-scale cylinder															
25	0	75	4	2500	250	182	1.28	192	1.26	251	1.34	278	1.28	289	1.25
25	0	75	4	2000	210	193	1.26	201	1.26	238	1.28	275	1.27	286	1.25

$$^{a}\text{imep ratio} = \frac{\text{imep of triptane blend}}{\text{imep of base fuel}}.$$

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TABLE III - LEAD SUSCEPTIBILITY AND TEMPERATURE SENSITIVITY OF GENERAL MOTORS TRIPTANE BLENDS

[17.6 engine; compression ratio, 7.0; engine speed, 1800 rpm; outlet-coolant temperature, 212° F; spark advance, 30° B.T.C.]

(a) Lead Susceptibility

Blend composition (percent by volume)		Inlet-air temperature (°F)	Relative lead susceptibility[a]				
			Fuel-air ratio				
Triptane	S reference fuel		0.065	0.07	0.085	0.10	0.11
0	100	250	1.00	1.00	1.00	1.00	1.00
10	90	250	1.03	1.04	1.06	1.01	1.00
20	80	250	1.05	1.08	1.12	1.05	1.03
0	100	100	1.00	1.00	1.00	1.00	1.00
20	80	100	1.03	1.03	1.01	1.00	.99

[a] Relative lead susceptibility equals imep ratio of blend plus 4 ml TEL/gal divided by imep ratio of blend plus 0 ml TEL/gal.

(b) Temperature Sensitivity

Blend composition (percent by volume)			Tetraethyl lead (ml/gal)	Relative temperature sensitivity[a]				
				Fuel-air ratio				
Triptane	S reference fuel	85 percent S + 15 percent M		0.065	0.07	0.085	0.10	0.11
0	100	0	0	1.00	1.00	1.00	1.00	1.00
20	80	0	0	1.07	1.07	1.11	1.03	1.00
0	100	0	4	1.00	1.00	1.00	1.00	1.00
20	80	0	4	1.06	1.02	1.00	.98	.96
0	0	100	4	1.00	1.00	1.00	1.00	1.00
25	0	75	4	1.03	1.04	.99	1.01	1.00

[a] Relative temperature sensitivity equals imep ratio at inlet-air temperature of 100° F divided by imep ratio at inlet-air temperature of 250° F.

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TABLE IV - COMPARISON OF ANTIKNOCK BLENDING SENSITIVITY DATA ON GENERAL MOTORS TRIPTANE AND NATIONAL BUREAU OF STANDARDS TRIPTANE

Blend composition (percent by volume)		Engine conditions		Source of triptane	Test results											
Triptane + 4 ml TEL/gal	85 percent S + 15 percent M + 4 ml TEL/gal	Engine speed (rpm)	Inlet-air temperature (°F)		Performance number		Fuel-air ratio									
							0.065		0.07		0.085		0.10		0.11	
					Lean mixture	Rich mixture	imep	imep ratio[a]	imep	imep ratio[a]	imep	imep ratio[a]	imep	imep ratio[a]	imep	imep ratio[a]
F-4 engine																
10	90	1800	225	GM	122	128	113	1.02	132	1.05	172	1.08	187	1.09	190	1.11
				NBS[b]	130	127	148	1.09	157	1.08	179	1.08	195	1.09	195	1.08
25	75	1800	225	GM	137	144	124	1.12	153	1.21	200	1.26	222	1.29	224	1.30
				NBS[b]	139	146	149	1.10	178	1.22	208	1.25	227	1.27	229	1.27
50	50	1800	225	GM	150	-------	165	1.49	190	1.51	264	1.66	297	1.73	299	1.74
				NBS[b]	150	-------	178	1.31	198	1.36	276	1.66	307	1.72	312	1.73
F-3 engine																
25	75	1200	-------	GM	132	-------	------	------	------	------	------	------	------	------	------	-------
				NBS[c]	130	-------	------	------	------	------	------	------	------	------	------	-------
Full-scale cylinder																
25	75	2500	250	GM	[d]129	[e]144	182	1.28	192	1.26	251	1.34	278	1.28	289	1.25
				NBS[c]	[d]141	[e]141	201	1.40	202	1.31	249	1.33	272	1.28	281	1.27
25	75	2000	210	GM	[d]130	[e]147	193	1.26	201	1.26	238	1.28	275	1.27	286	1.25
				NBS[c]	[d]135	[e]144	202	1.35	204	1.31	232	1.26	272	1.30	282	1.25

[a] $\text{imep ratio} = \frac{\text{imep of test fuel}}{\text{imep of base fuel}}$.

[b] Data from reference 2.

[c] Data from reference 1.

[d] Performance number determined at fuel-air ratio of 0.065.

[e] Performance number determined at fuel-air ratio of 0.10.

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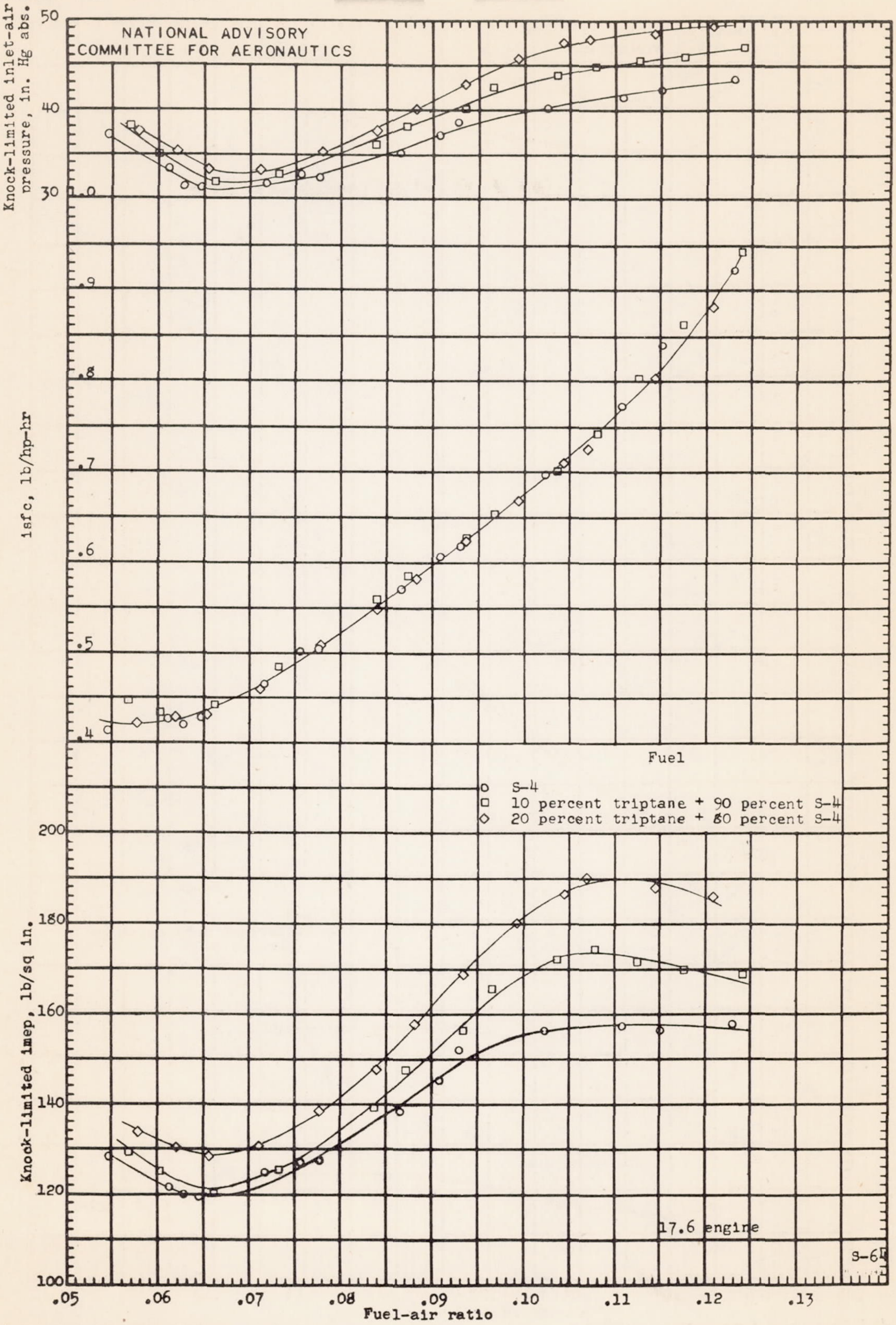

(a) Inlet-air temperature, 250° F.

Figure 1. - The knock-limited performance of blends of General Motors triptane and S-4 reference fuel in a 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

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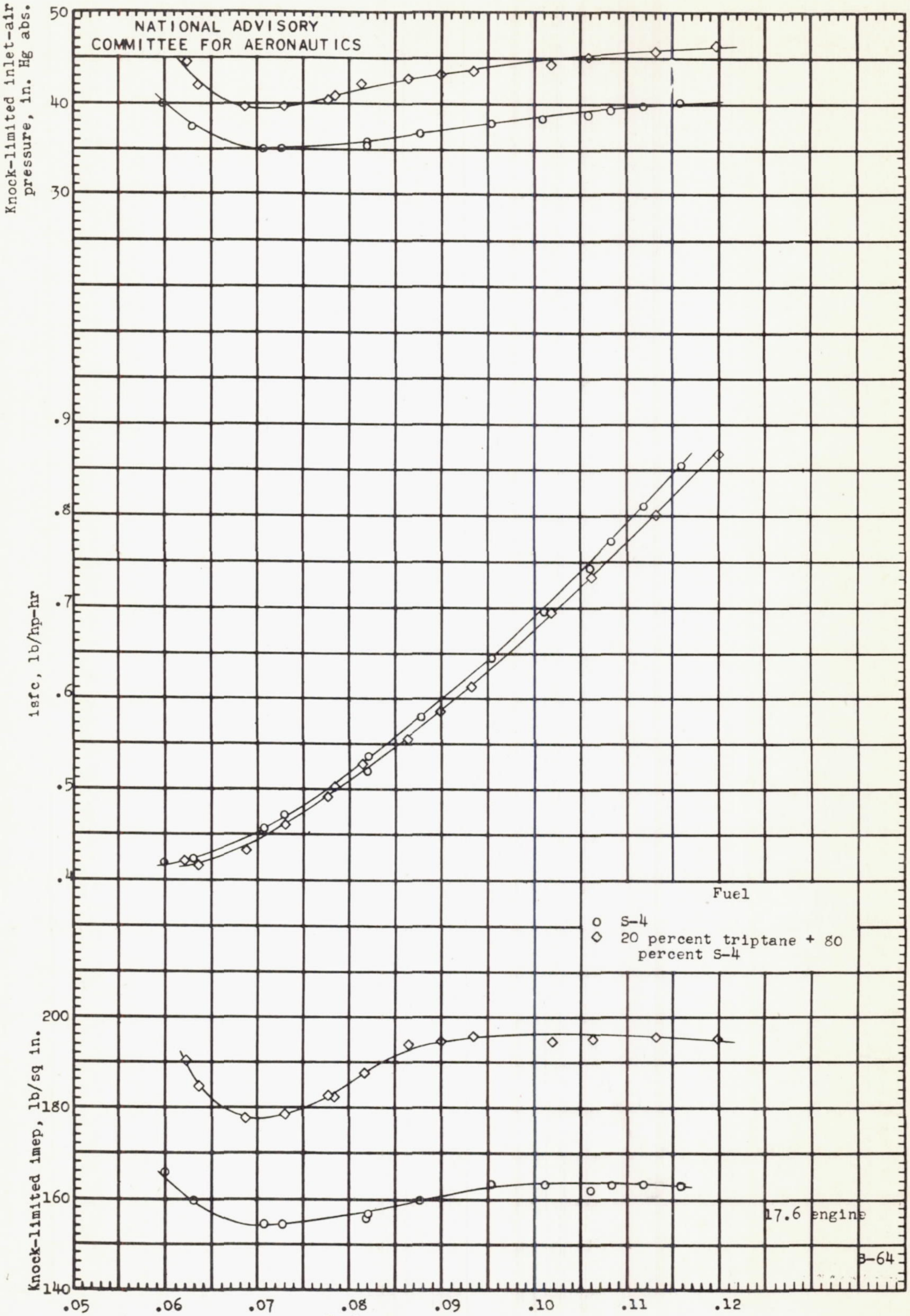

(b) Inlet-air temperature, 100° F.
Figure 1. - Concluded.

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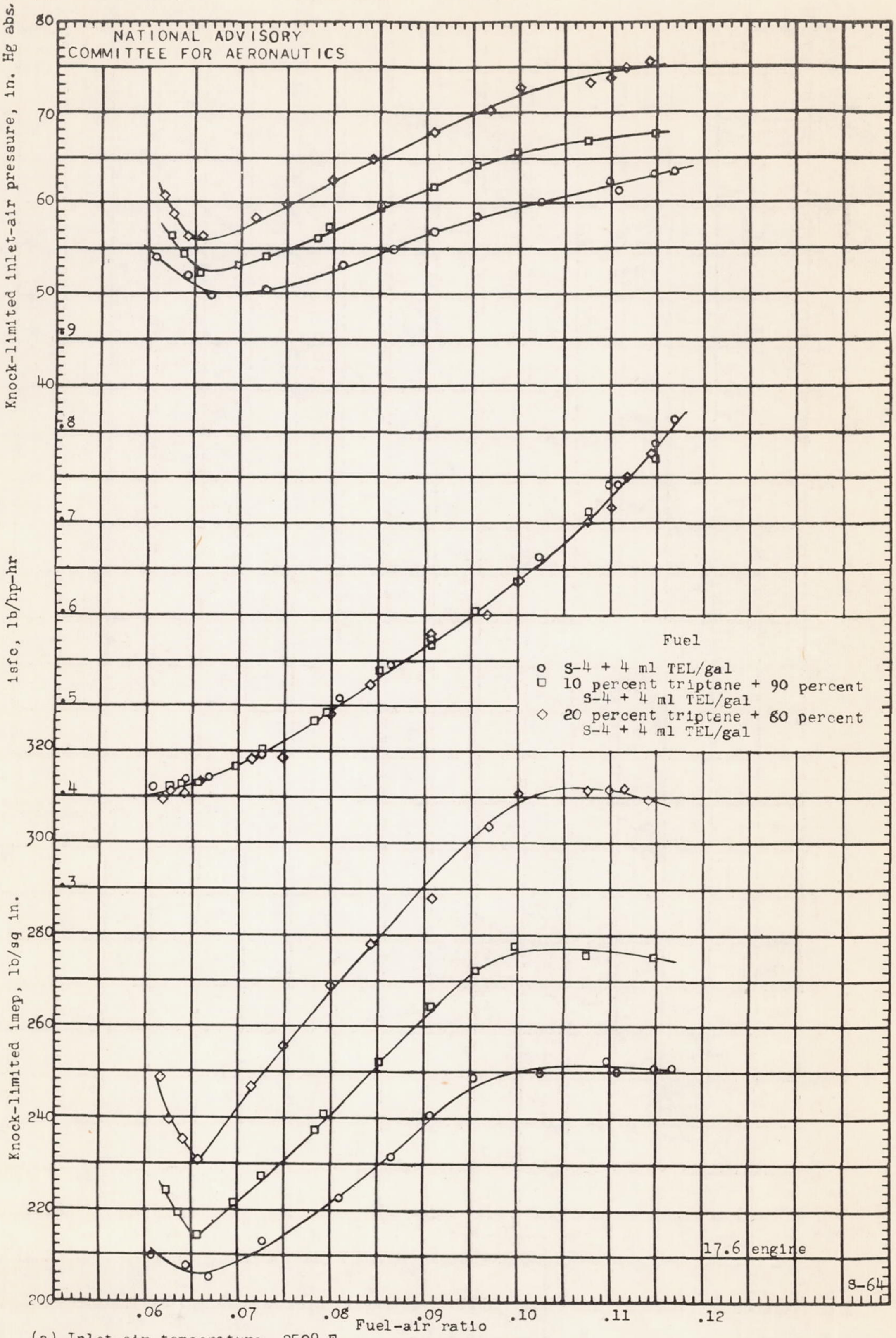
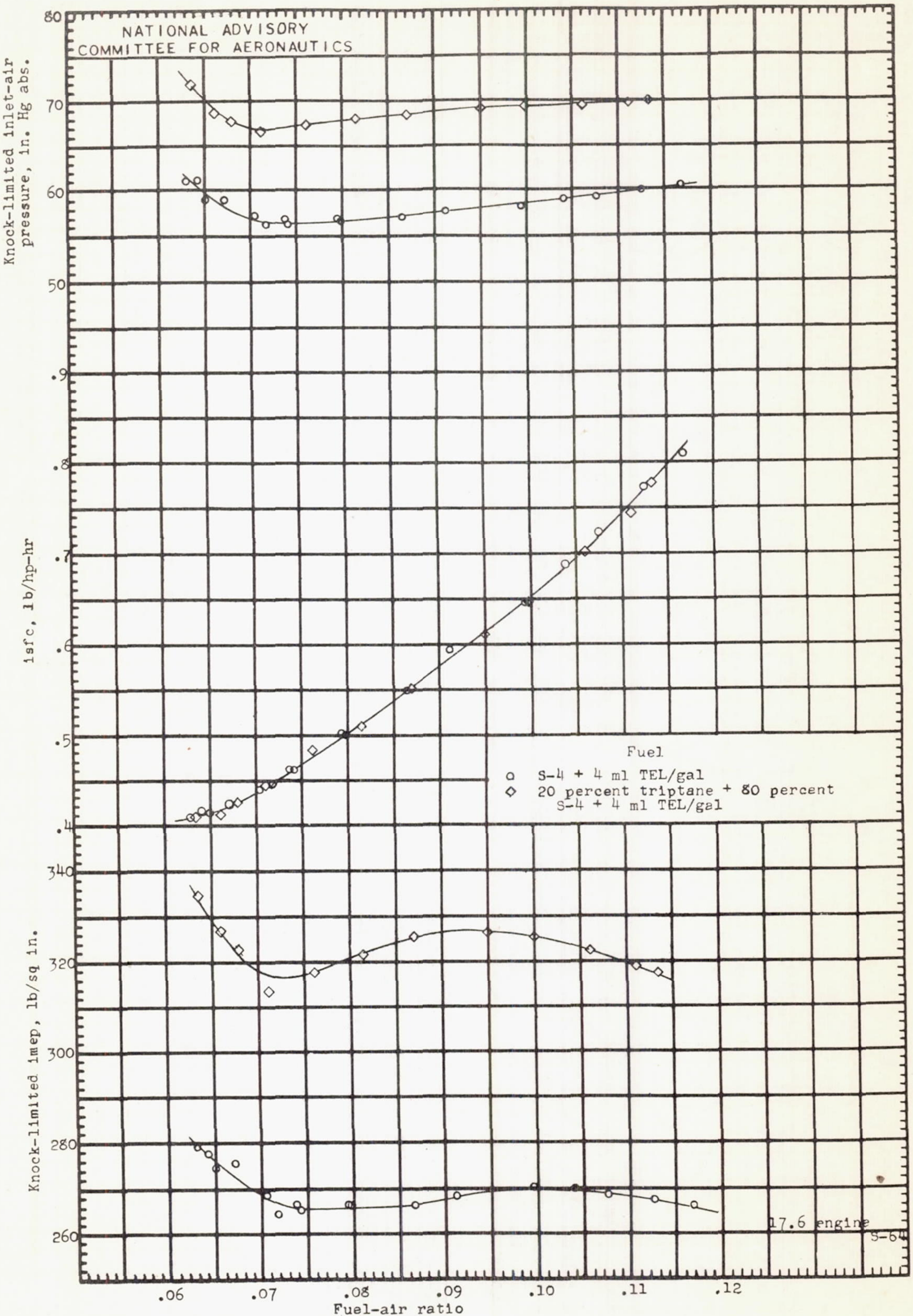


(a) Inlet-air temperature, 250° F.

Figure 2. - The knock-limited performance of leaded blends of General Motors triptane and S-4 reference fuel in a 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.



(b) Inlet-air temperature, 100° F.
Figure 2. - Concluded.

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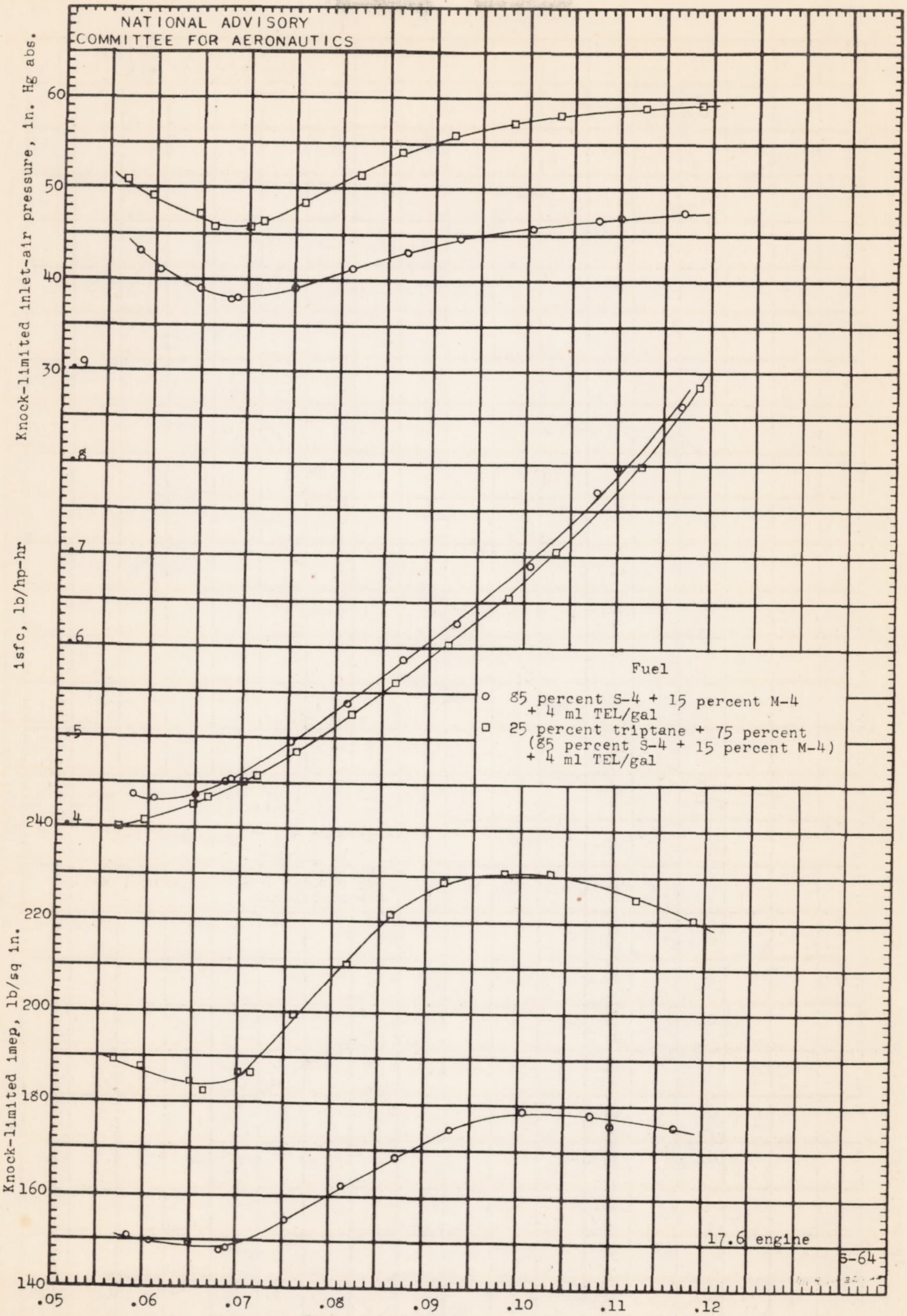

(a) Inlet-air temperature, 250° F.

Figure 3. - The knock-limited performance of leaded blends of General Motors triptane and S plus M base fuel in a 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

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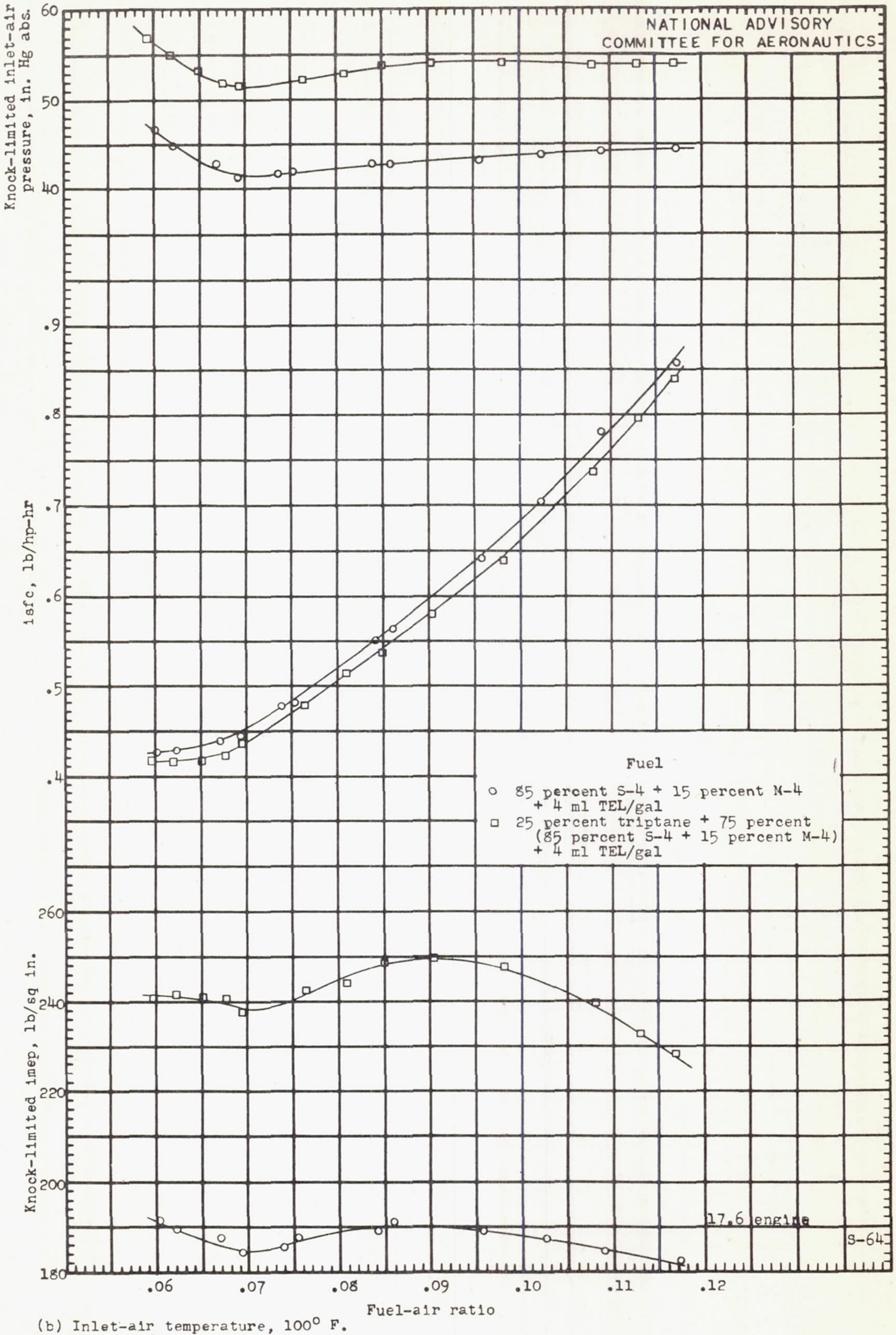

(b) Inlet-air temperature, 100° F.
Figure 3. - Concluded.

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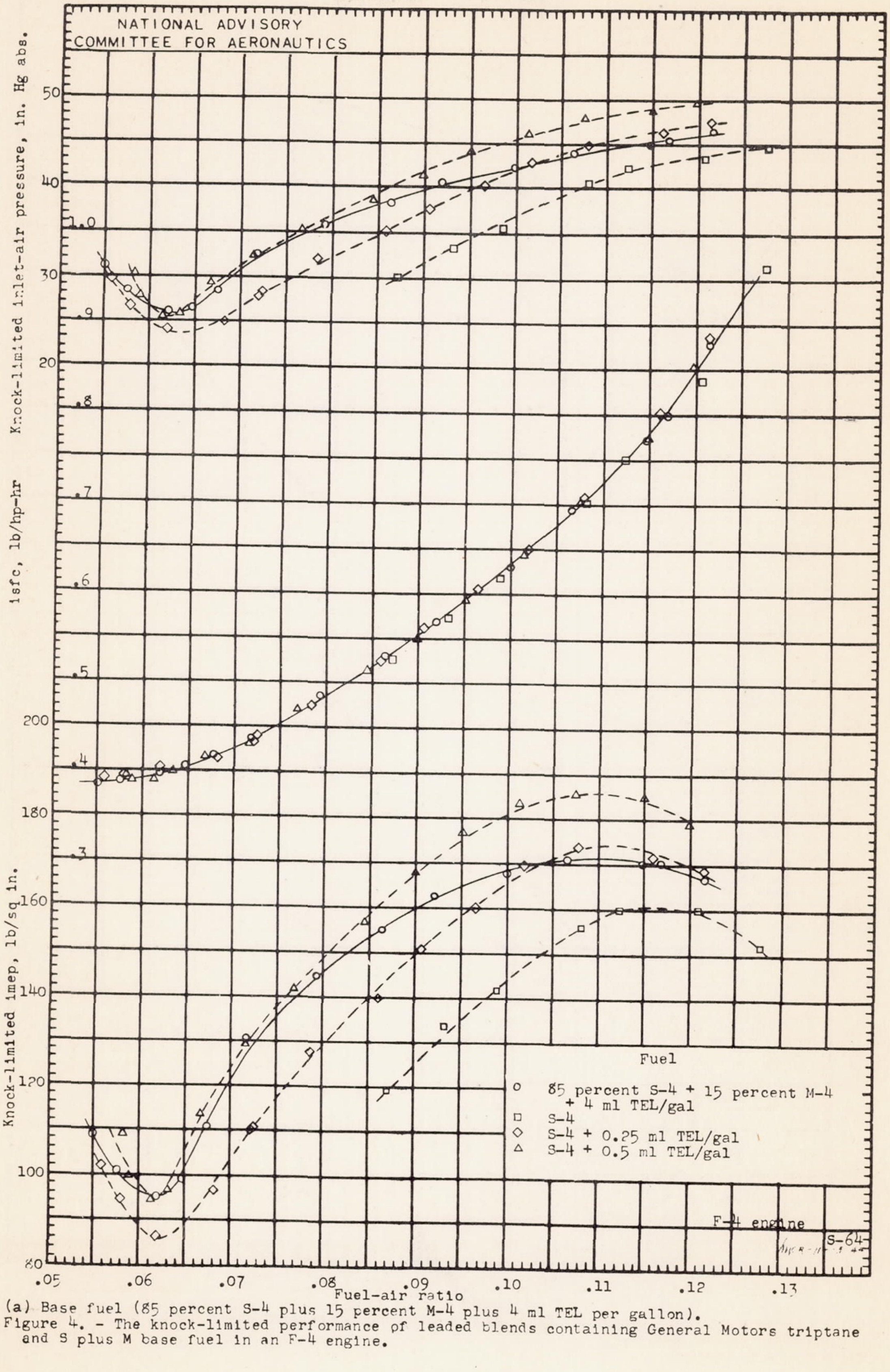

(a) Base fuel (85 percent S-4 plus 15 percent M-4 plus 4 ml TEL per gallon).

Figure 4. - The knock-limited performance of leaded blends containing General Motors triptane and S plus M base fuel in an F-4 engine.

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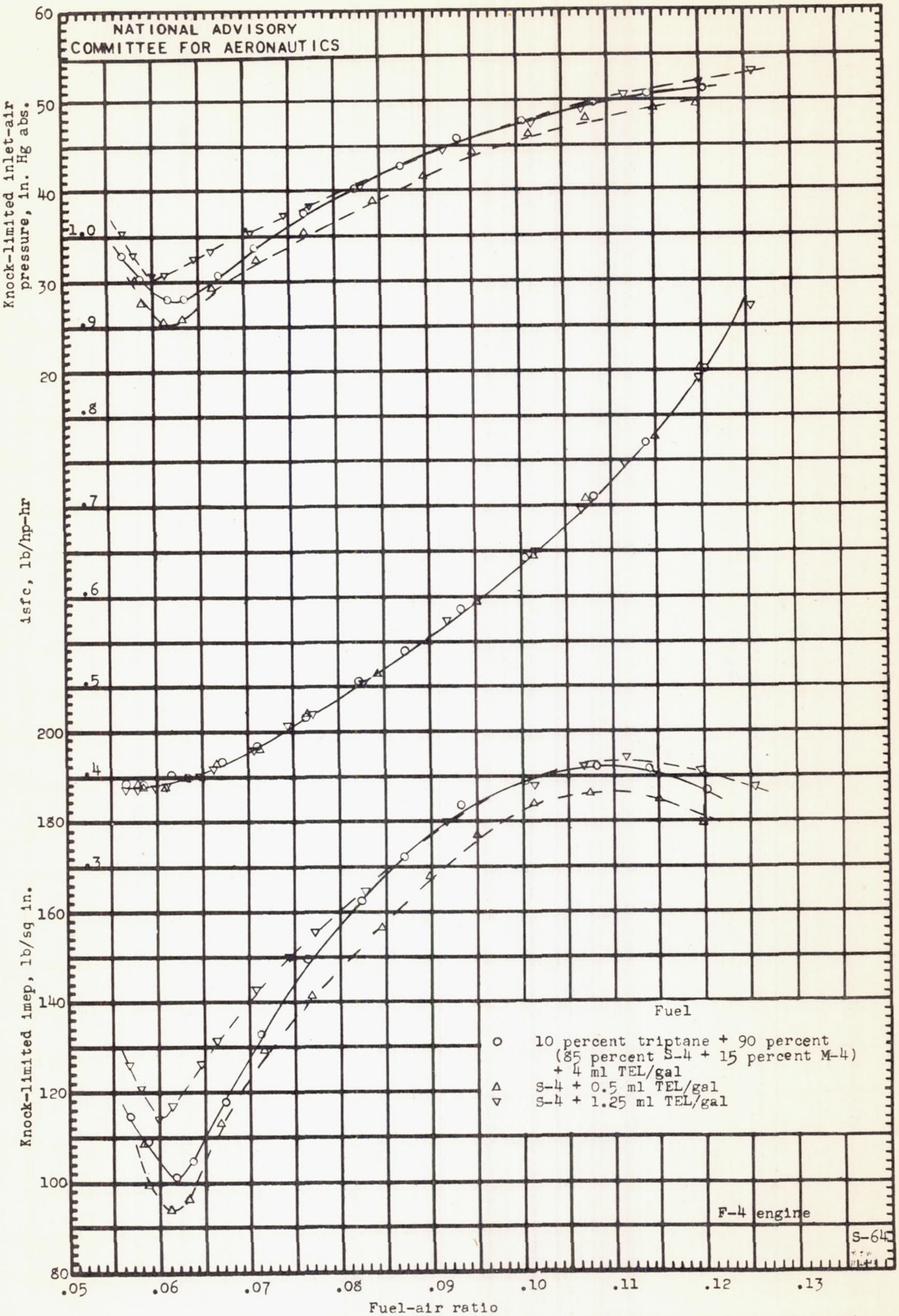

(b) 10 percent General Motors triptane plus 90 percent (85 percent S-4 plus 15 percent M-4) plus 4 ml TEL per gallon.

Figure 4. - Continued.

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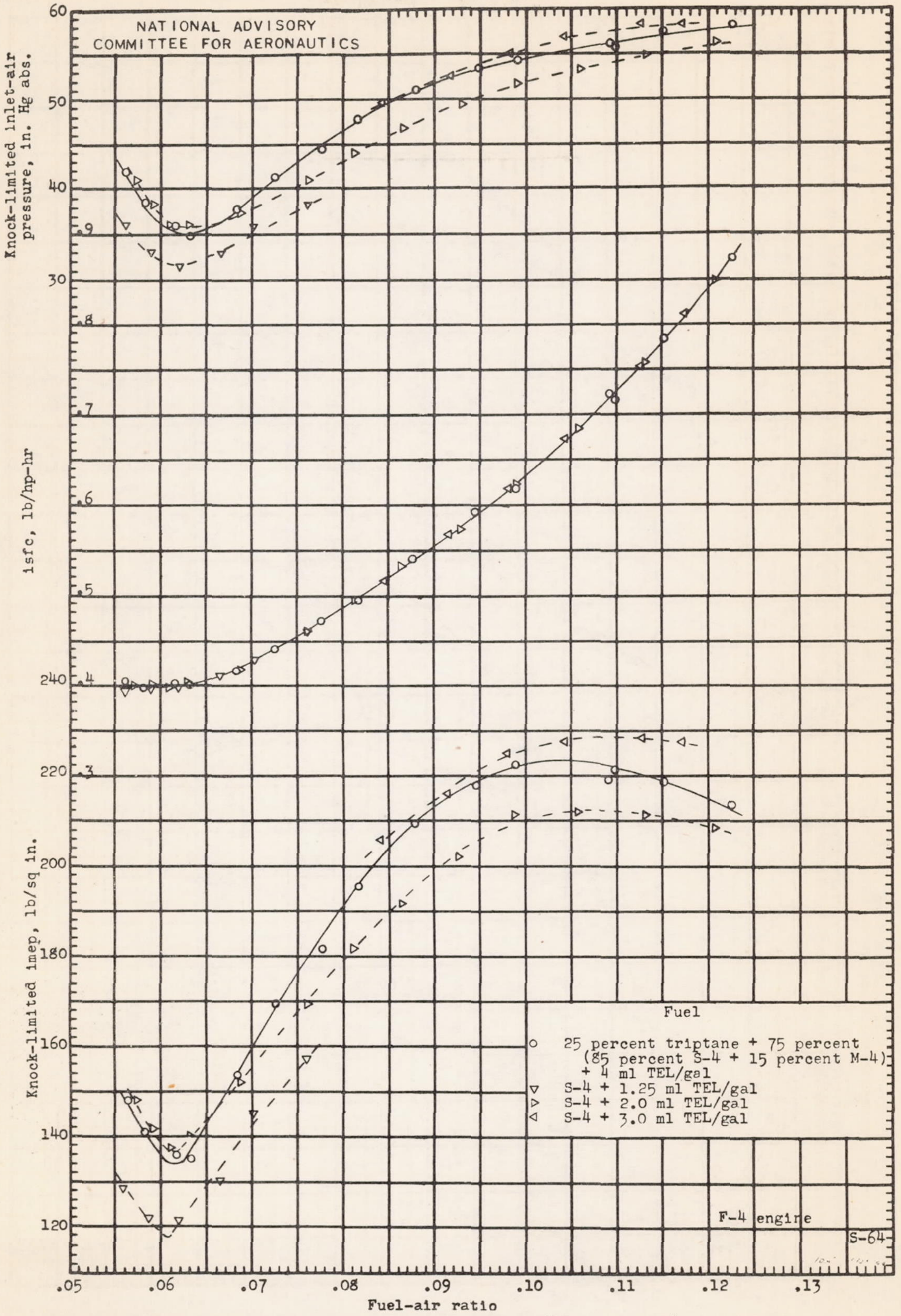

(c) 25 percent General Motors triptane plus 75 percent (85 percent S-4 plus 15 percent M-4) plus 4 ml TEL per gallon.
Figure 4. - Continued.

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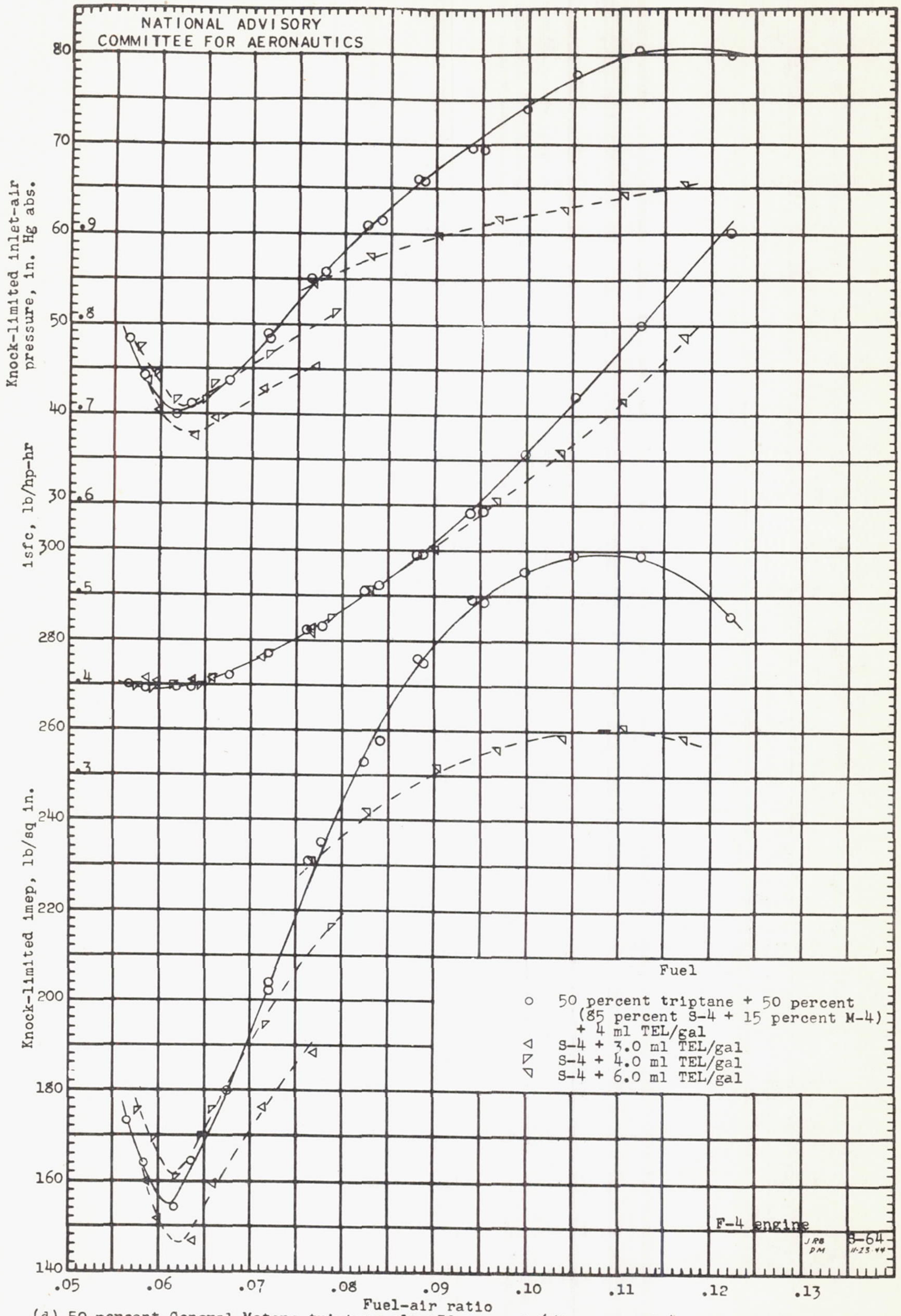

(d) 50 percent General Motors triptane plus 50 percent (85 percent S-4 plus 15 percent M-4) plus 4 ml TEL per gallon.

Figure 4. - Concluded.

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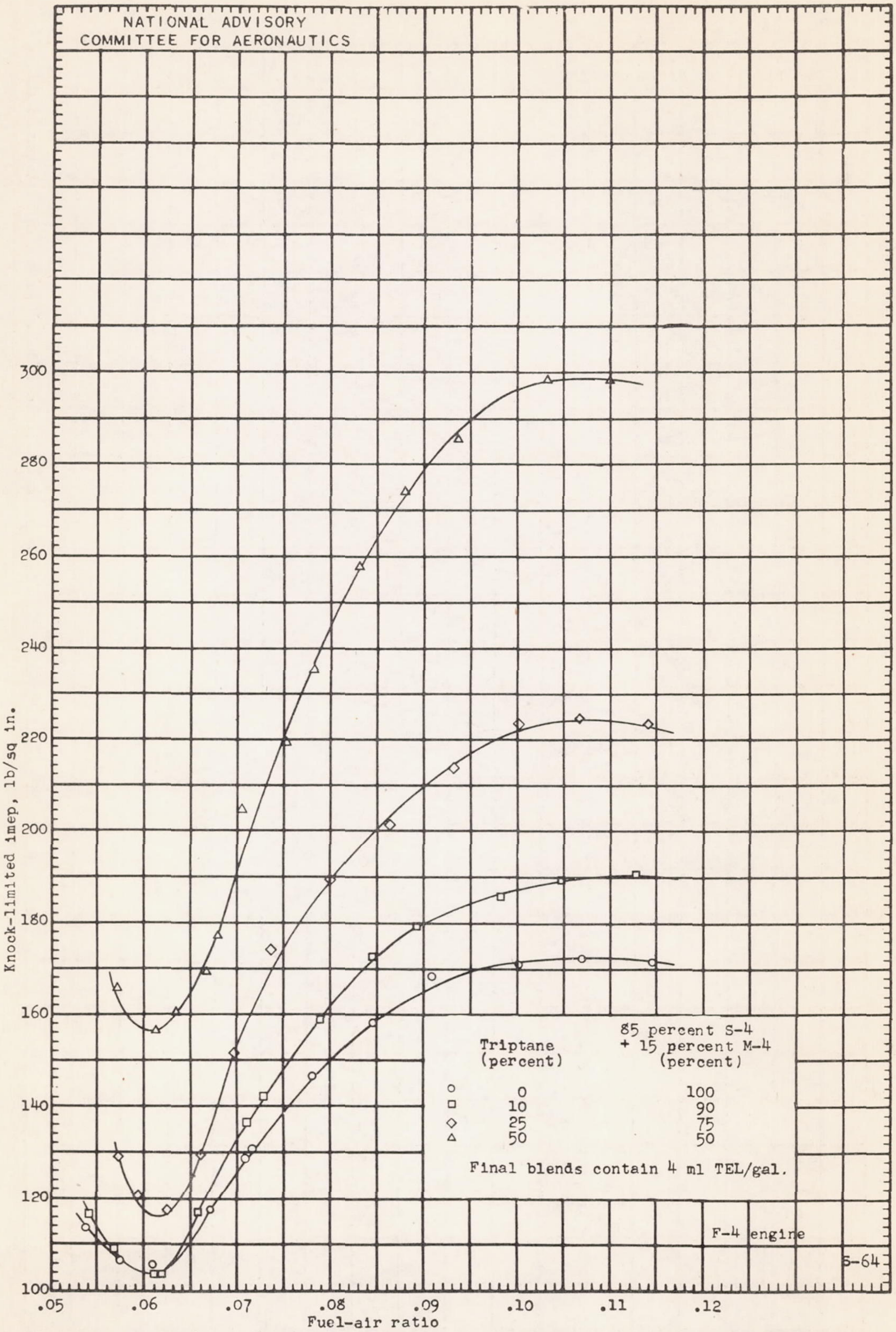

Figure 5. - The F-4 knock-limited performance of leaded blends containing General Motors triptane and S plus M base fuel tested in a single operating day.

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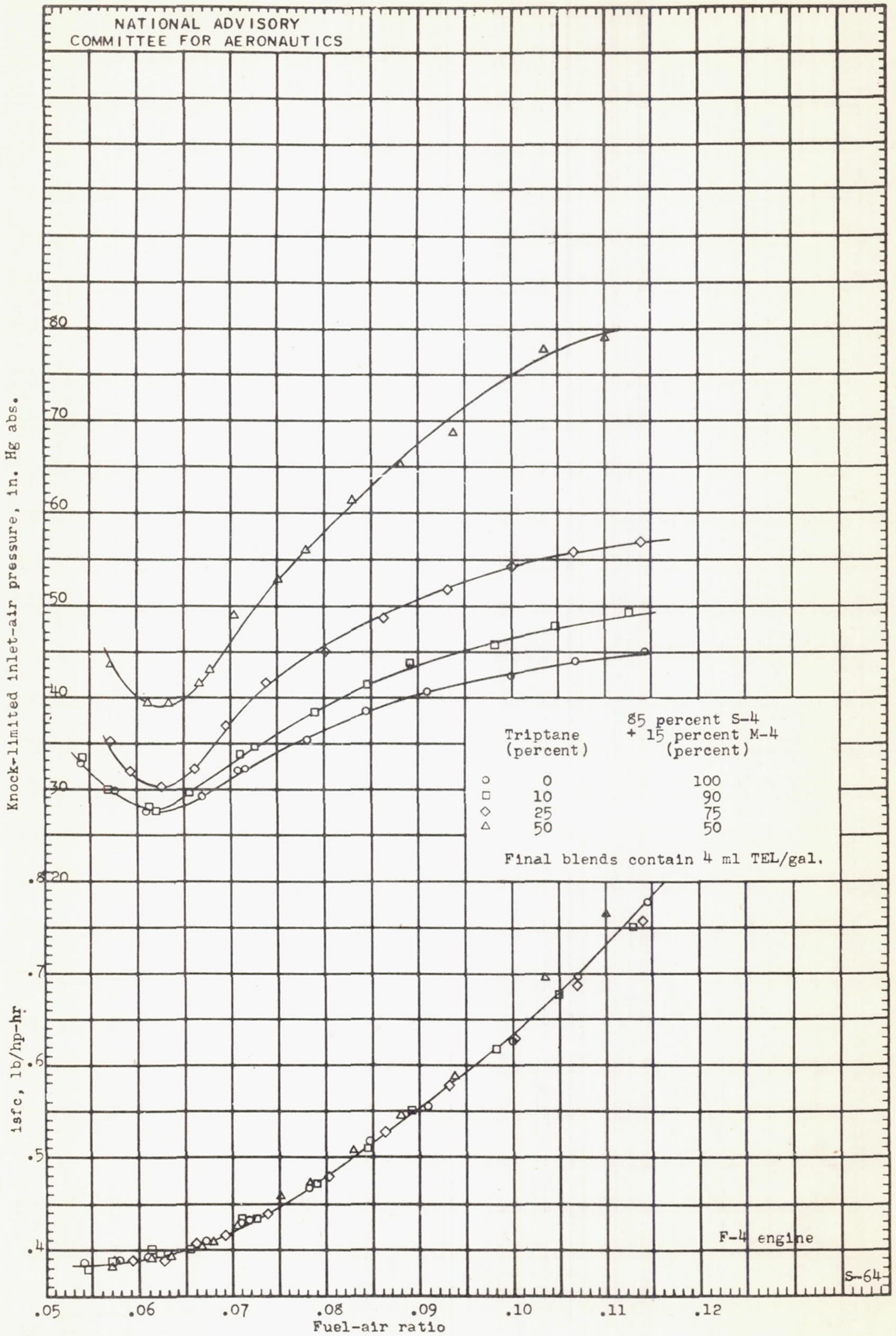

Figure 5. - Concluded.

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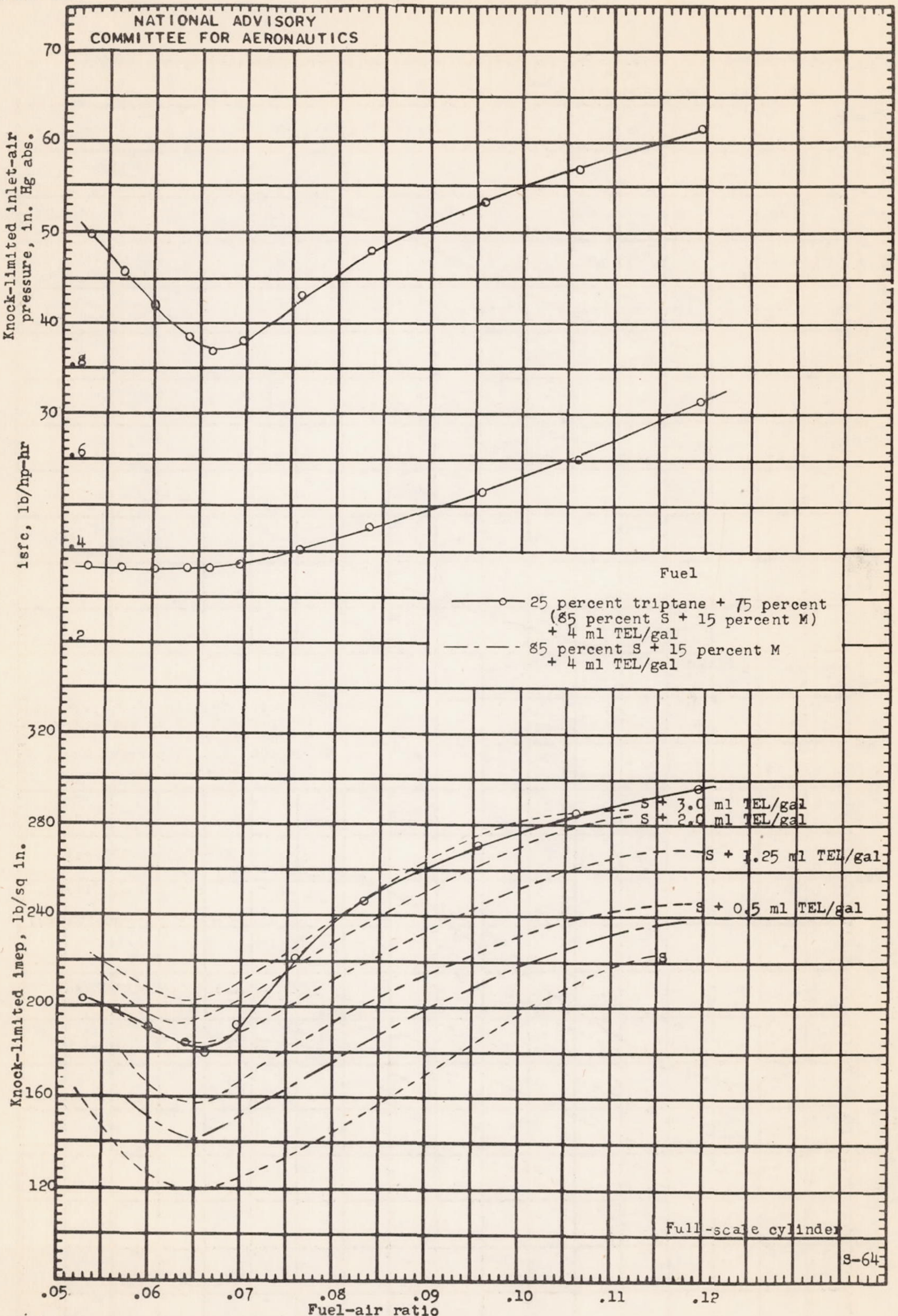

(a) Engine speed, 2500 rpm; inlet-air temperature, 250° F.

Figure 6. - The knock-limited performance of leaded blends of General Motors triptane and S plus M base fuel in full-scale cylinder. Compression ratio, 7.3; spark advance, 20° B.T.C.; cooling air adjusted at 140 bmep and 0.10 fuel-air ratio to give a rear spark-plug-bushing temperature of 365° F.

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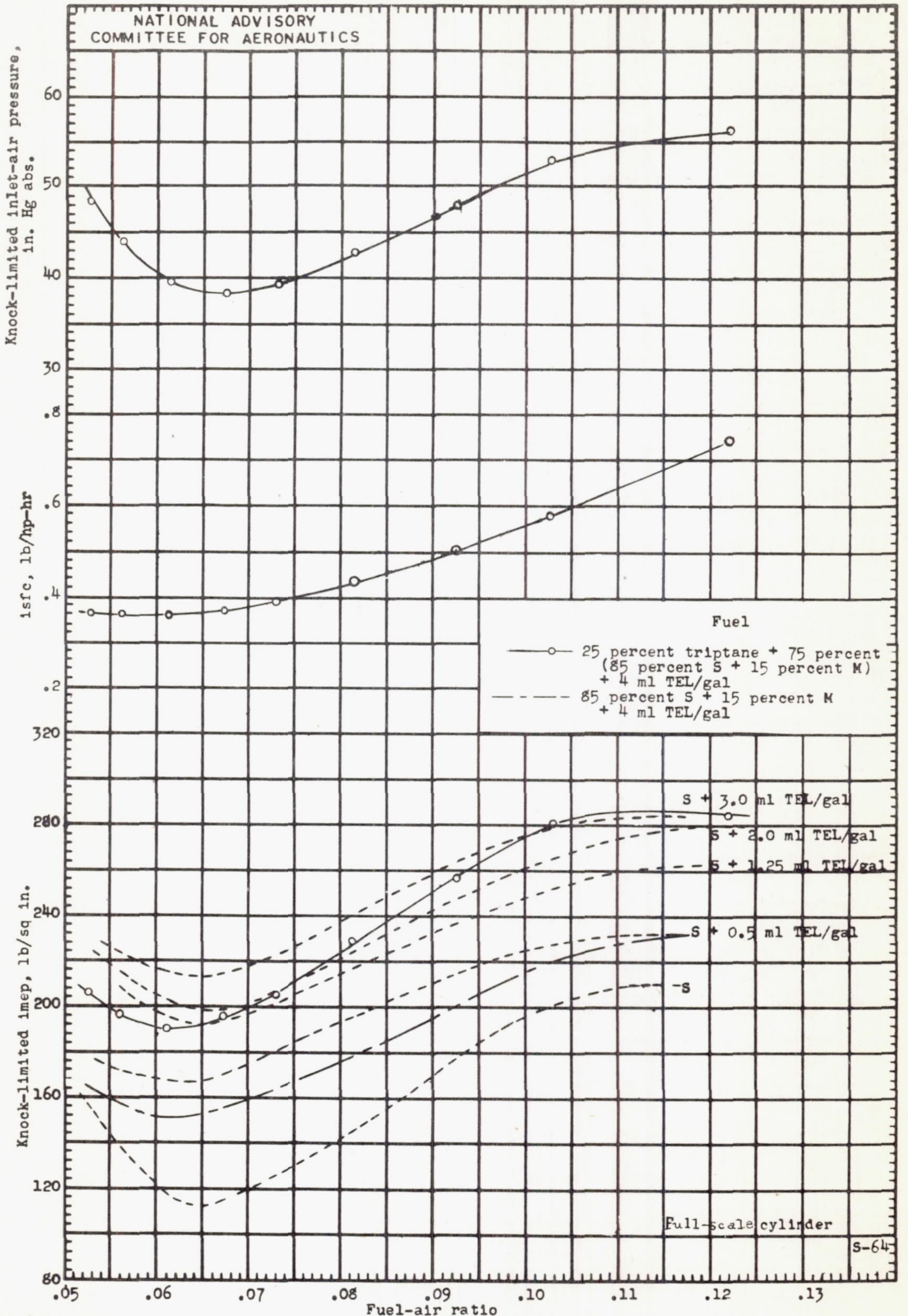

(b) Engine speed, 2000 rpm; inlet-air temperature, 210° F.
Figure 6. - Concluded.

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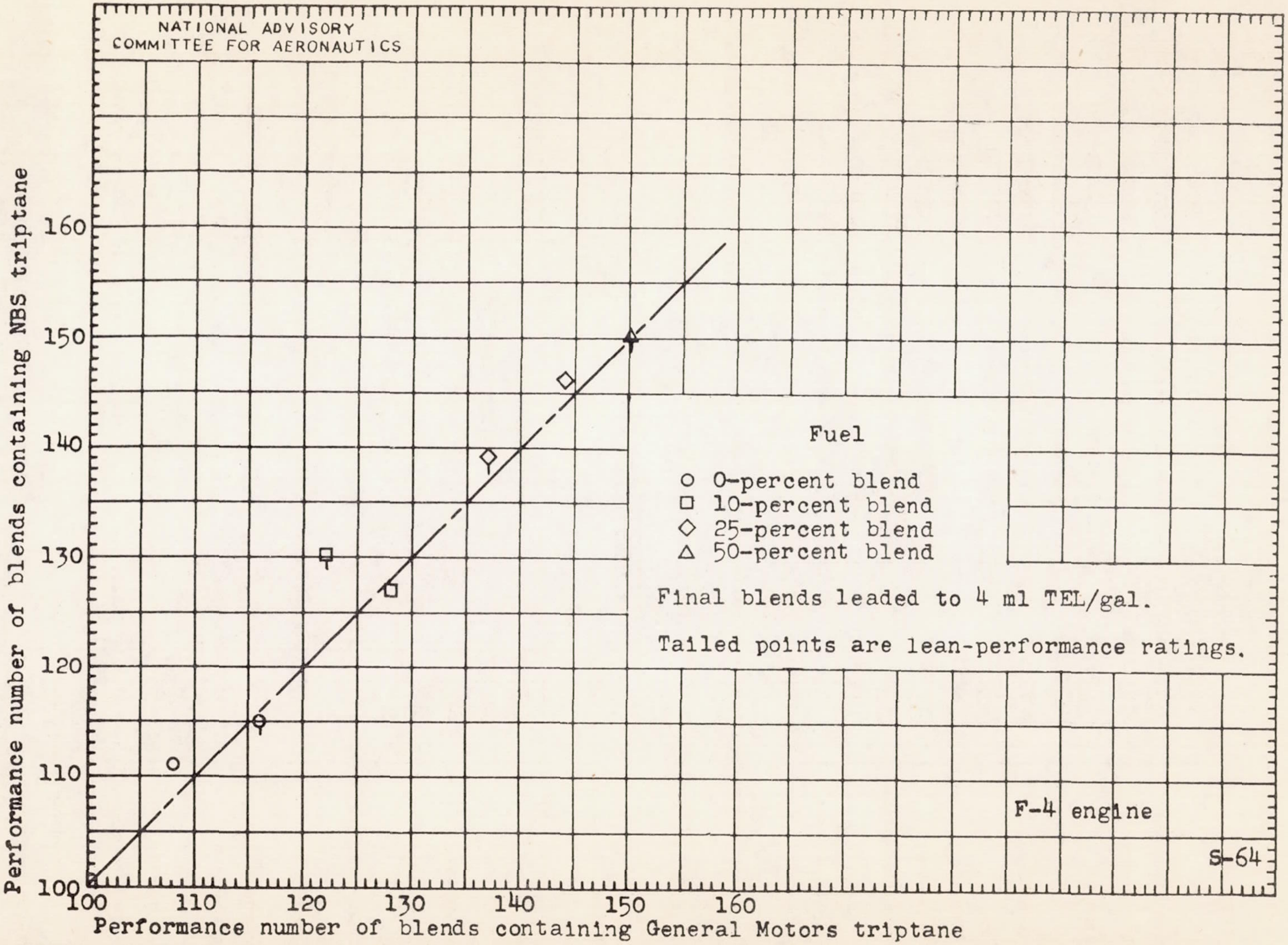

Figure 7. - Correlation of F-4 knock ratings of leaded blends containing General Motors and NBS triptane. Base fuel, 85 percent S plus 15 percent M. (NBS triptane data from reference 2)

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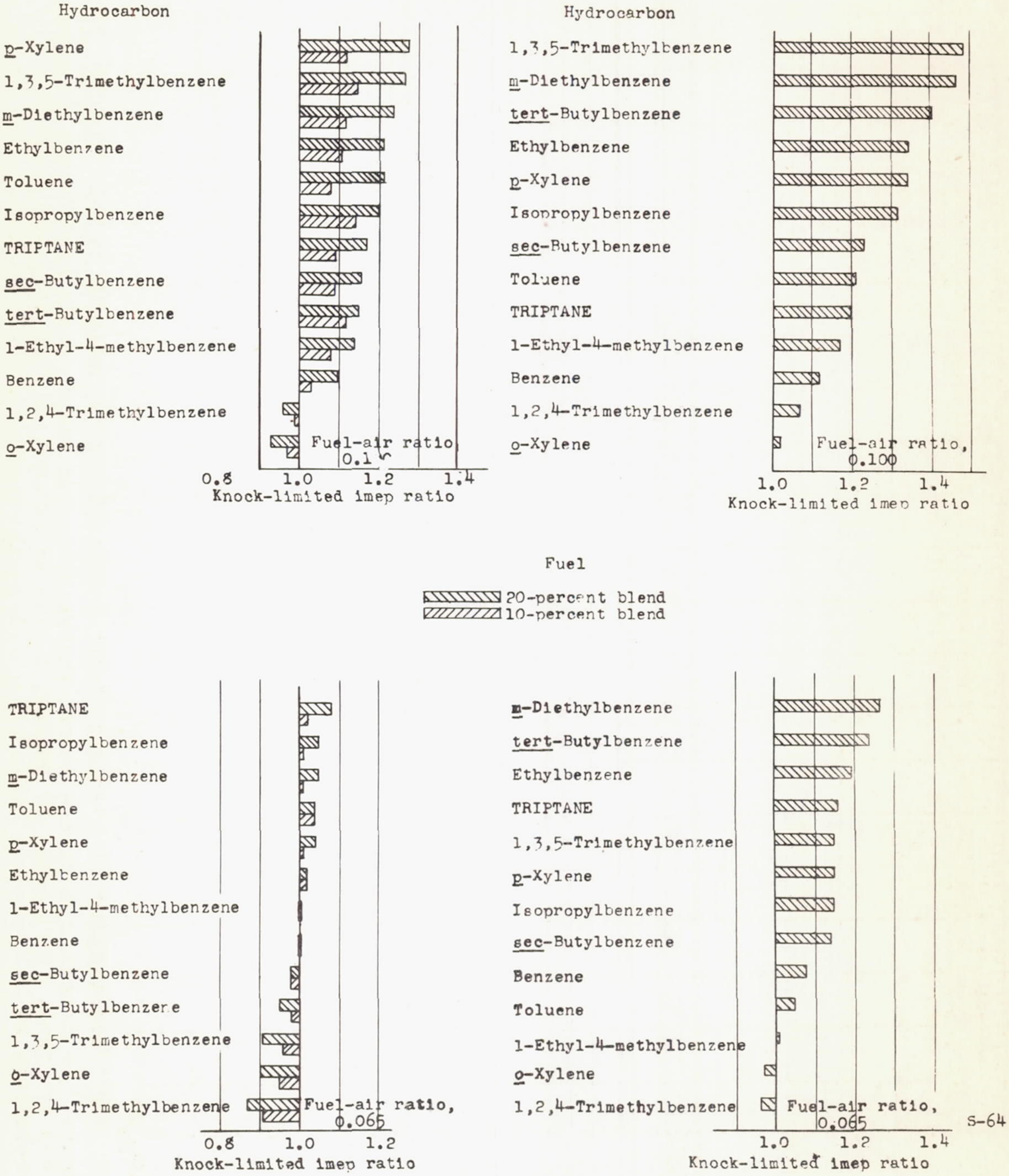

(a) Inlet-air temperature, 250° F. (b) Inlet-air temperature, 100° F.

Figure 8. - Knock-limited imep ratios of unleaded blends of triptane and 12 aromatics in S reference fuel from tests with a 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

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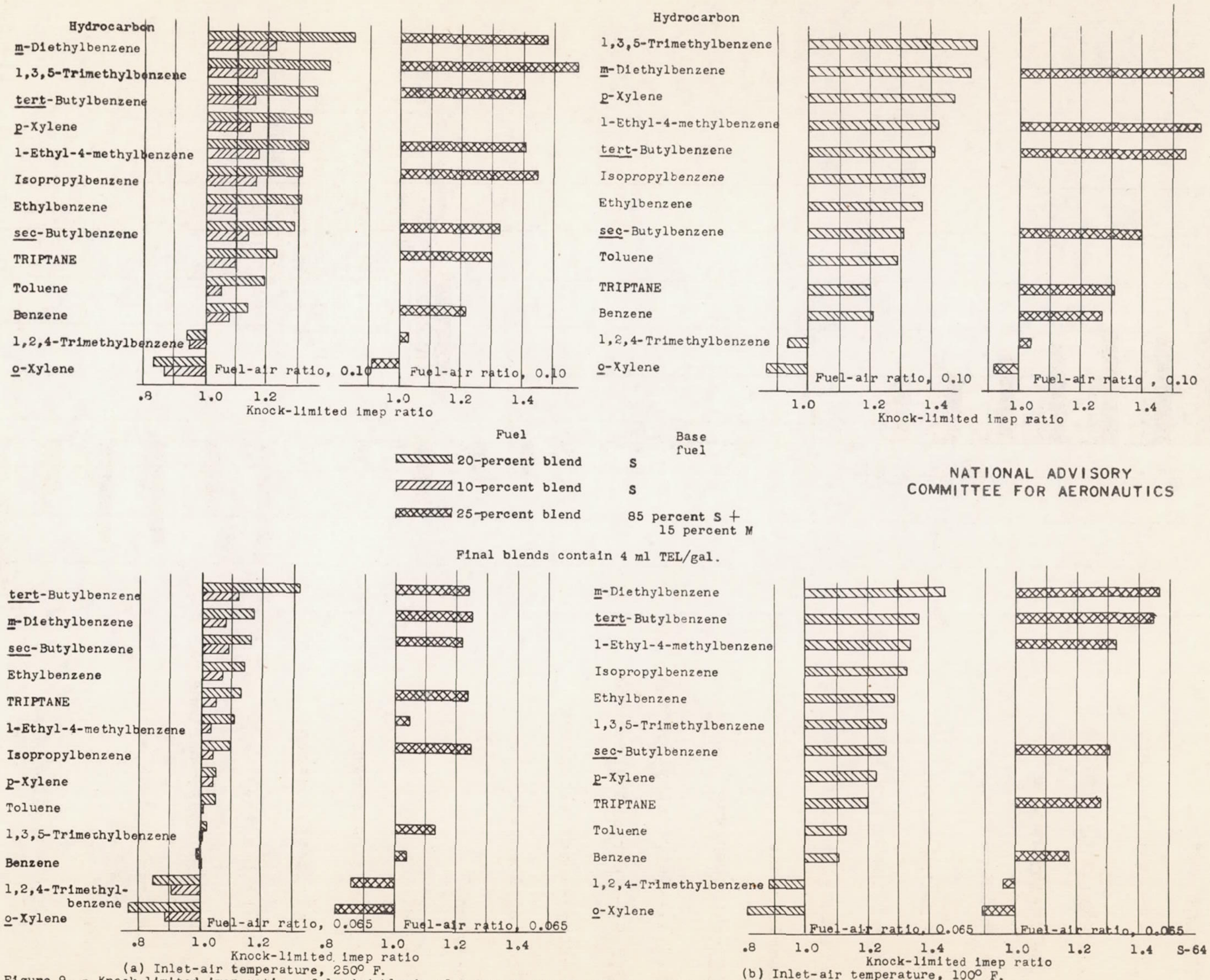

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(a) Inlet-air temperature, 250° F.

(b) Inlet-air temperature, 100° F.

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Figure 9. - Knock-limited imep ratios of leaded blends of triptane and 12 aromatic hydrocarbons in S and S plus M base fuels from 17.6 engine tests. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

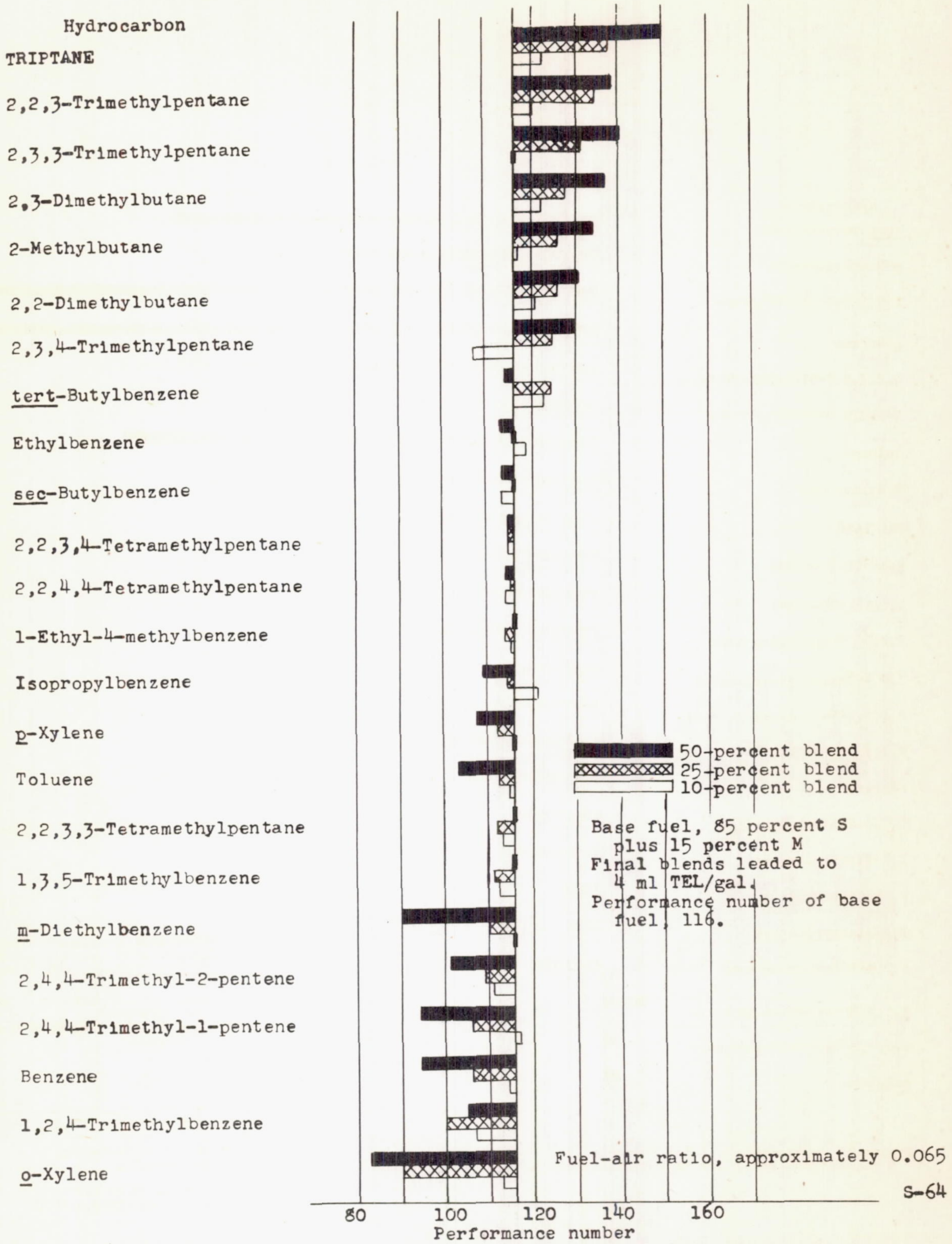

Figure 10. - Lean-mixture F-4 performance numbers of leaded blends of triptane, 12 aromatic, 9 paraffinic, and 2 olefinic hydrocarbons in S plus M base fuel. Ratings made at minimum boost point (approx. 0.065 fuel-air ratio).

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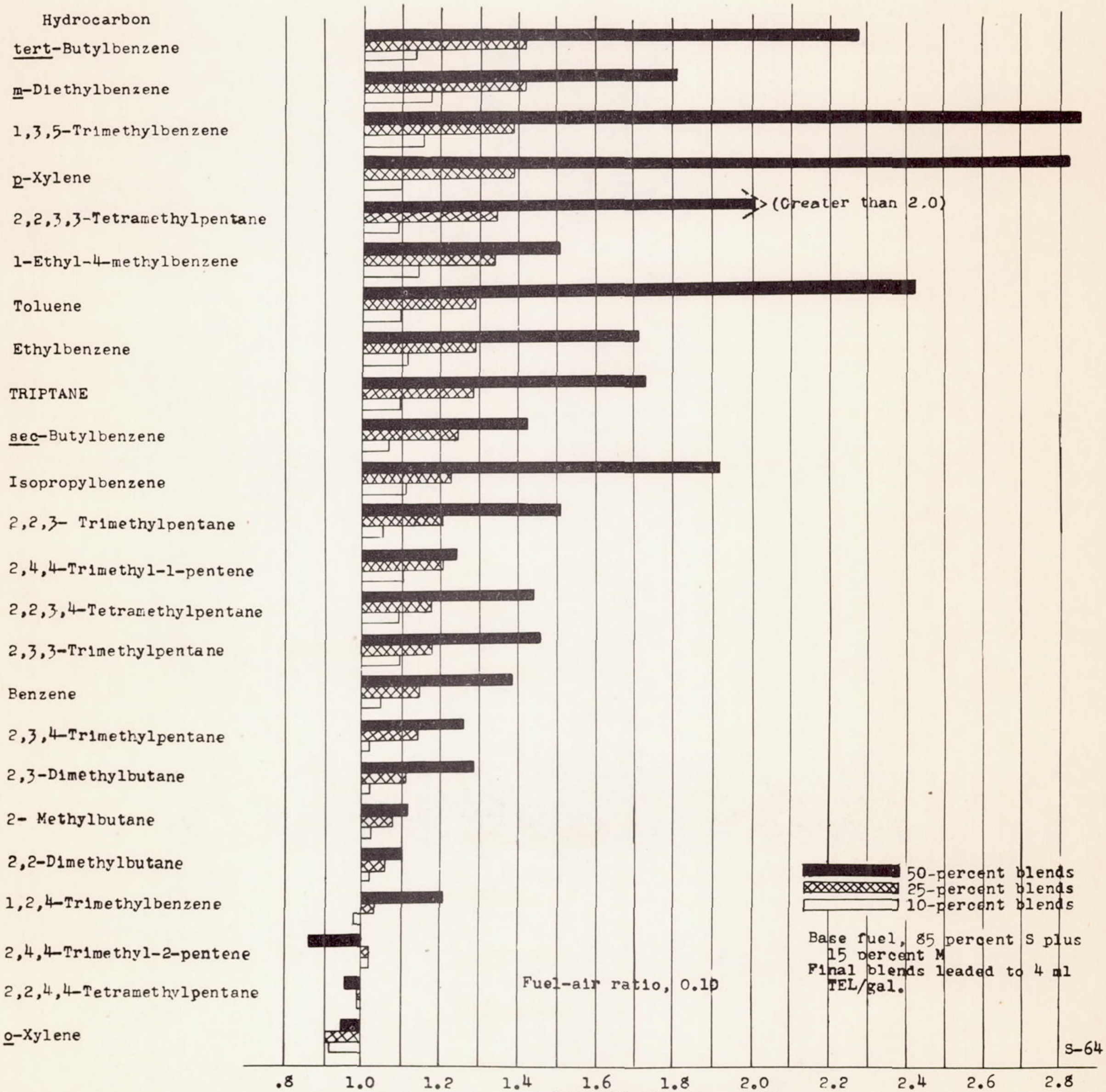

Figure 11. - Rich-mixture F-4 knock-limited imep ratios of leaded blends of triptane and 12 aromatic, 9 paraffinic, and 2 olefinic hydrocarbons in S plus M base fuel at a fuel-air ratio of 0.10.

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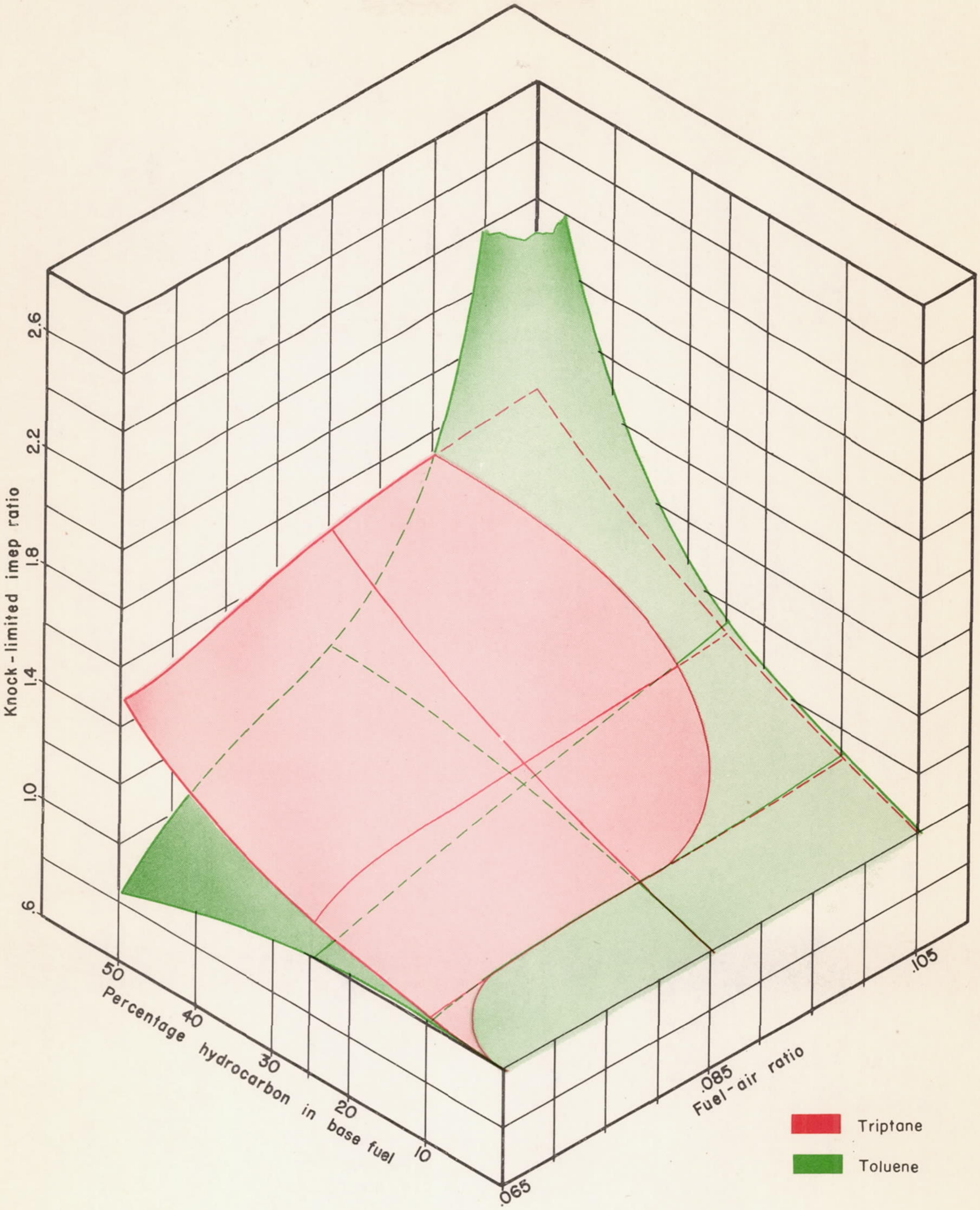
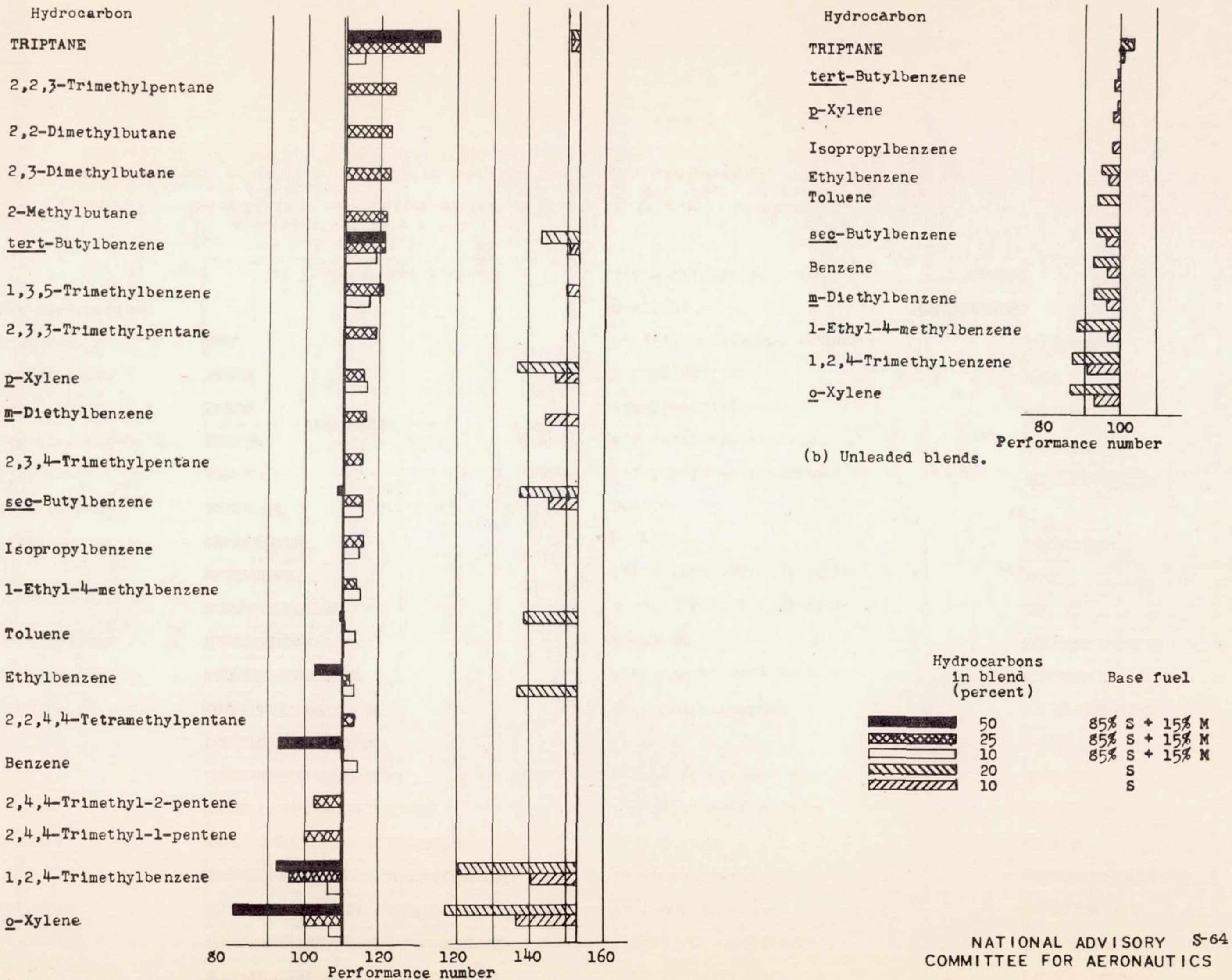


Figure 12. - Three-dimensional plot showing the F-4 knock-limited blending sensitivities of triptane and toluene when individually blended with 85 percent S plus 15 percent M base fuel. Final blends contain 4 ml TEL per gallon.



(a) Blends leaded to 4 ml TEL per gallon.

(b) Unleaded blends.

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Figure 13. - F-3 performance numbers of triptane, 12 aromatic, 7 paraffinic, and 2 olefinic hydrocarbons blended with two base fuels.

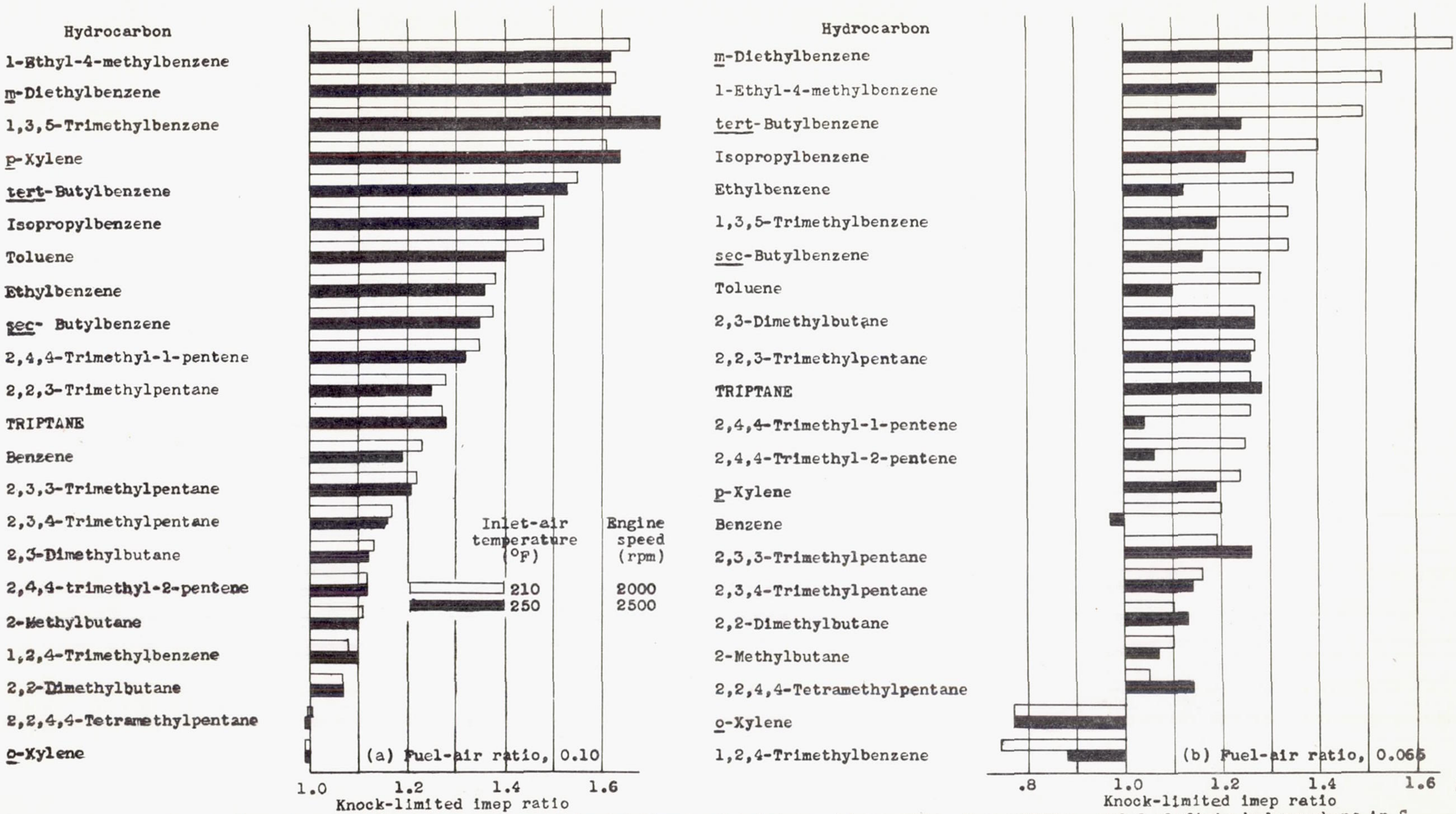

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Figure 14. - Knock-limited imep ratios of leaded blends of triptane, 12 aromatic, 7 paraffinic, and 2 olefinic hydrocarbons in S plus M base fuel determined in full-scale cylinder. Fuel, 25 percent hydrocarbon plus 75 percent (85 percent S plus 15 percent M); final blends leaded to 4 ml TEL per gallon. Compression ratio, 7.3; spark advance, 20° B.T.C.; cooling air adjusted at 140 bmep and 0.10 fuel-air ratio to give a rear spark-plug-bushing temperature of 365° F.

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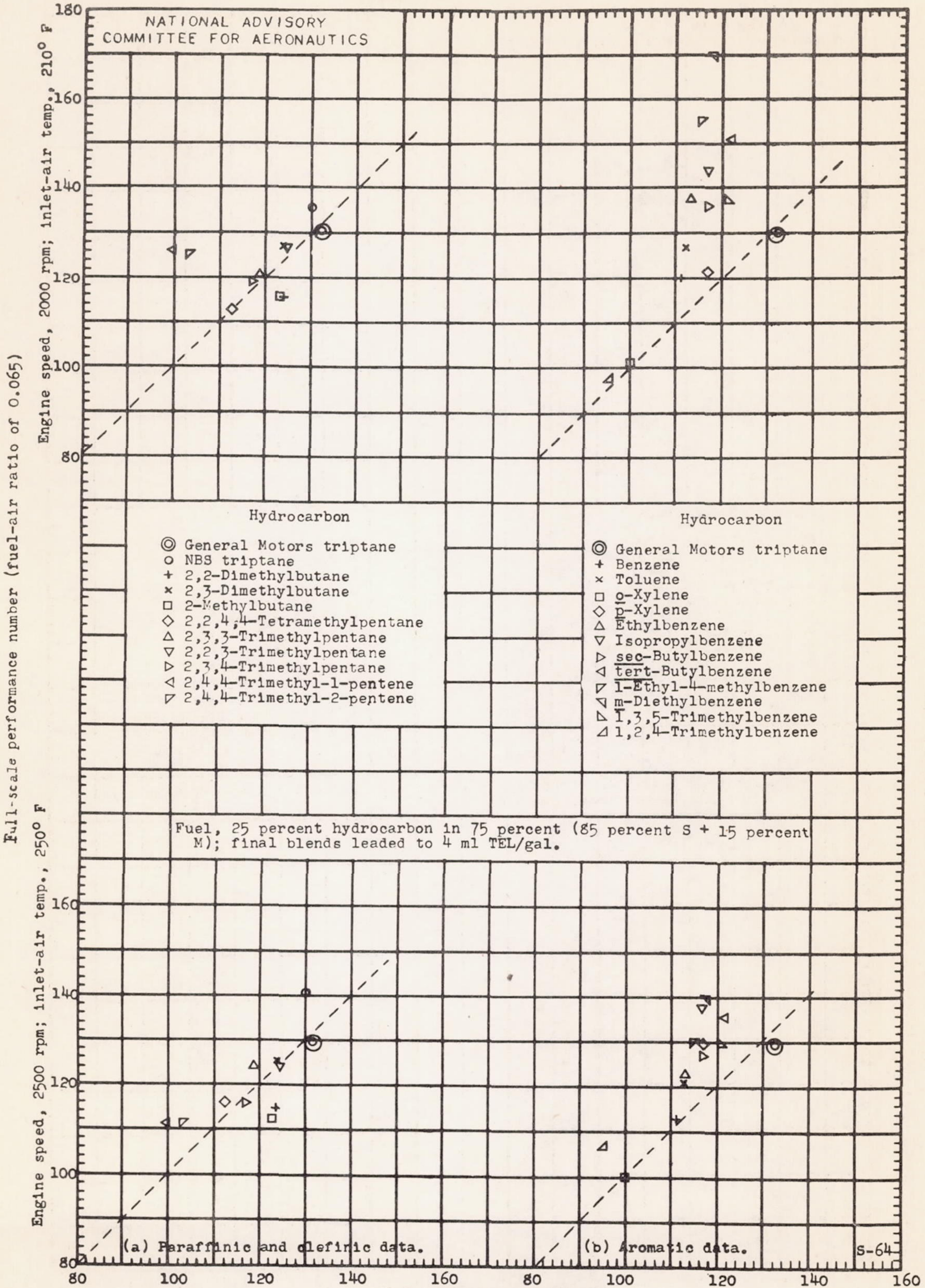

Figure 15. - Correlation between full-scale single-cylinder and F-3 engine data on leaded blends of triptane, 12 aromatics, 2 olefins, and 7 paraffins in S plus M base fuel.

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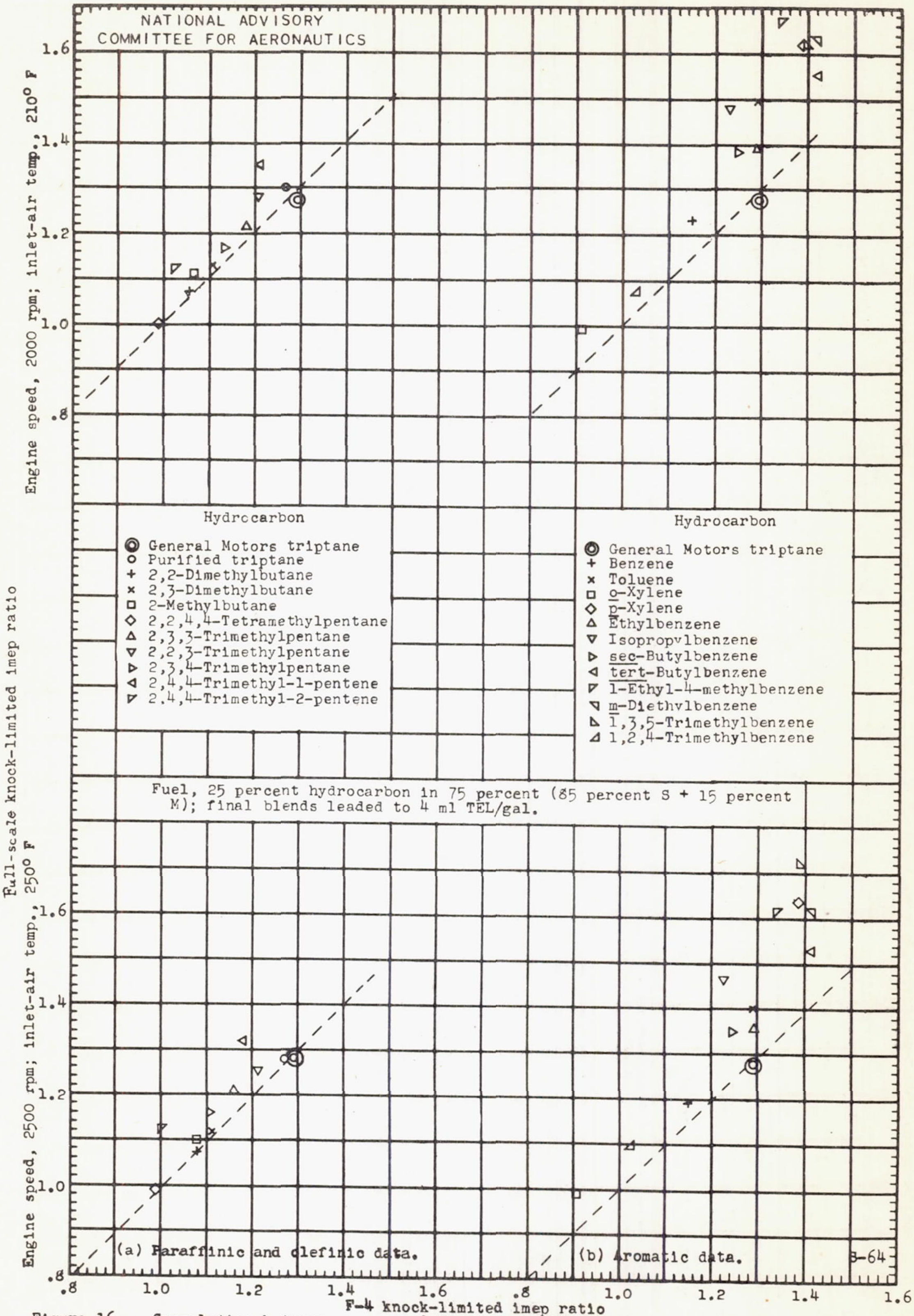


Figure 16. - Correlation between full-scale single-cylinder and F-4 engine data on triptane, 12 aromatics, 2 olefins, and 7 paraffins in S plus M base fuel. Fuel-air ratio, 0.10.

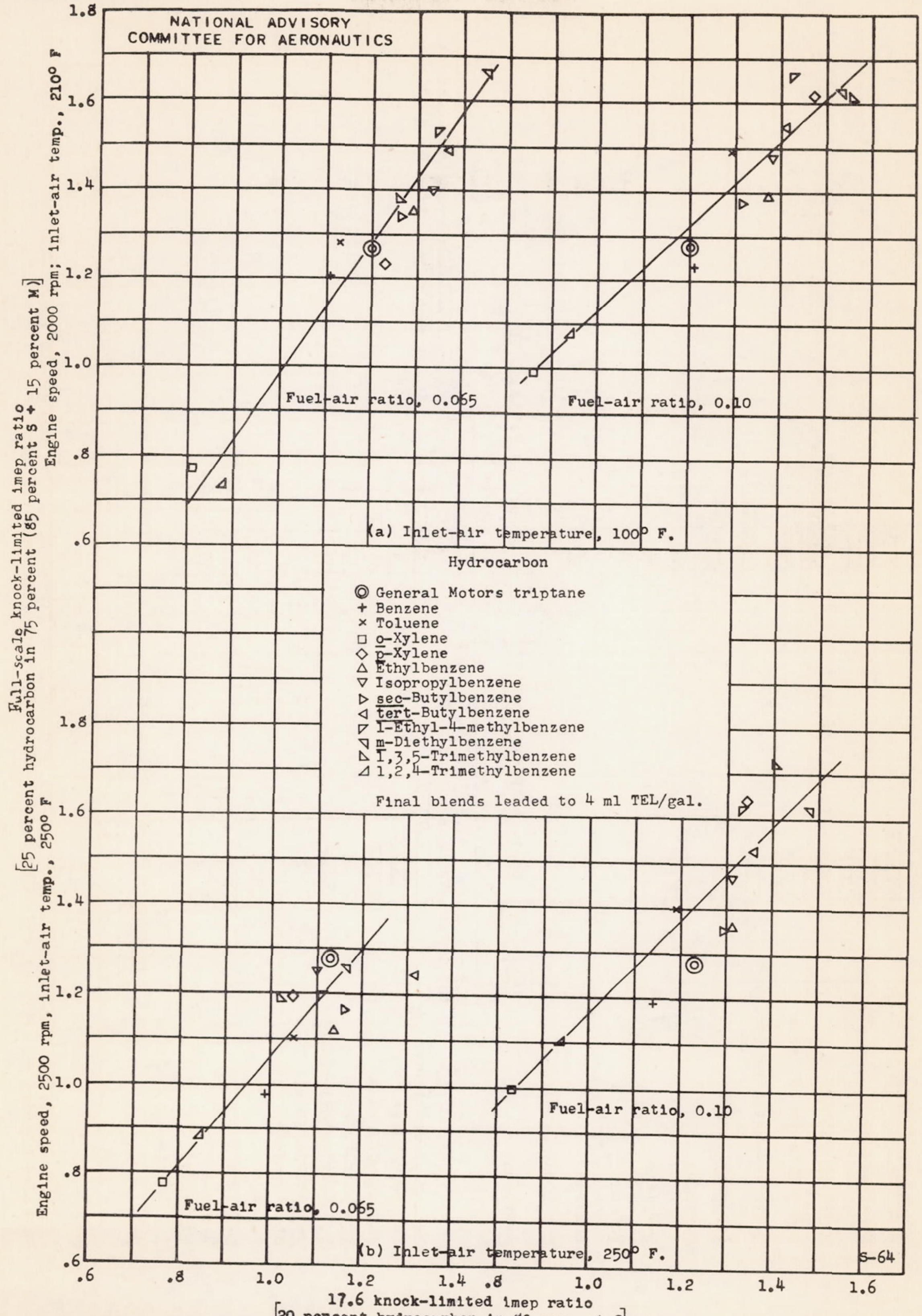
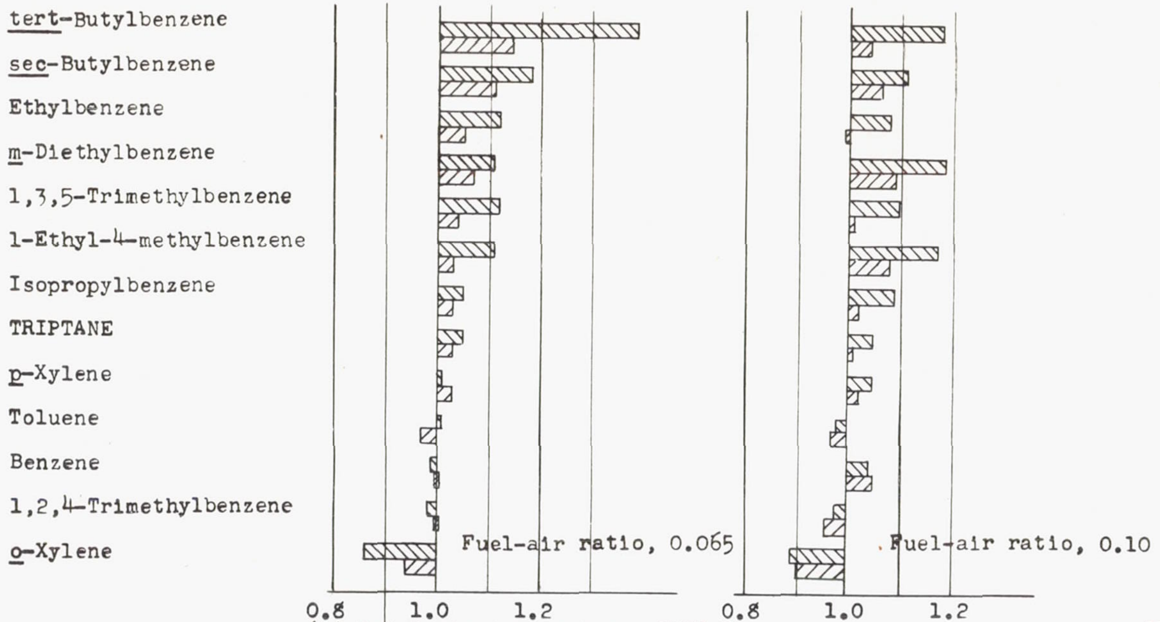
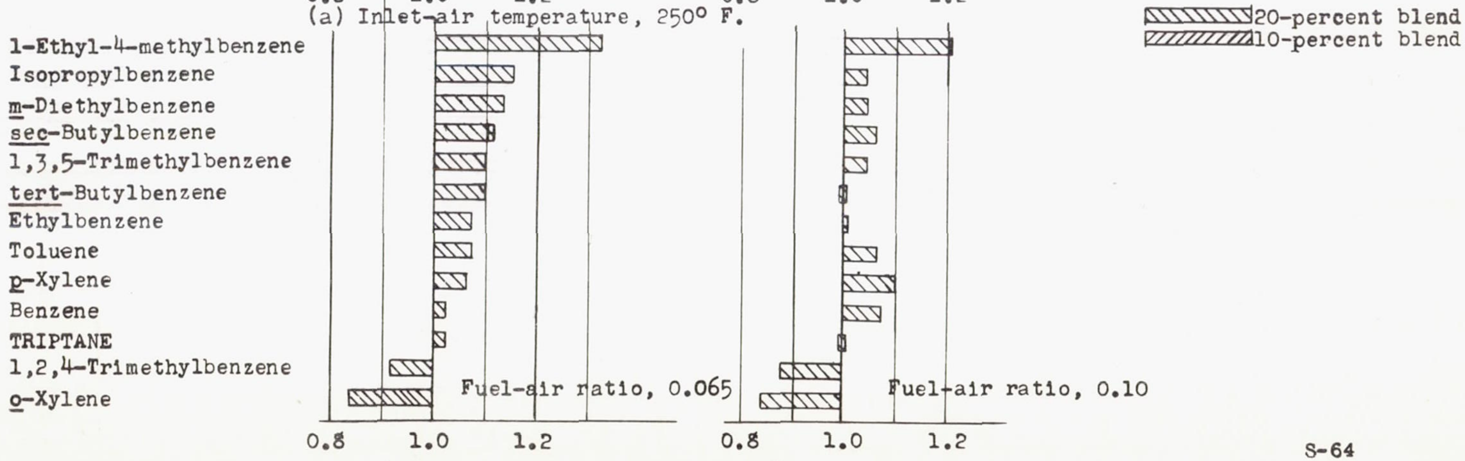


Figure 17. - Correlation between full-scale single-cylinder and 17.6 engine data on triptane and 12 aromatics.



(a) Inlet-air temperature, 250° F.



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(b) Inlet-air temperature, 100° F.

Figure 18. - Relative lead susceptibility (imep ratio of blends leaded to 4 ml TEL/gal to imep ratio of unleaded blends) of triptane and 12 aromatics in S reference fuel as determined in a 17.6 engine.

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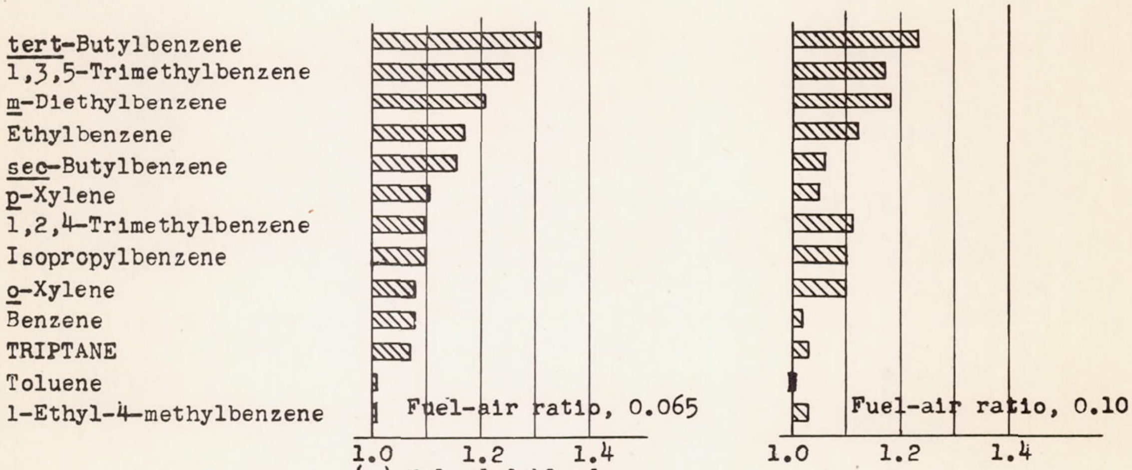
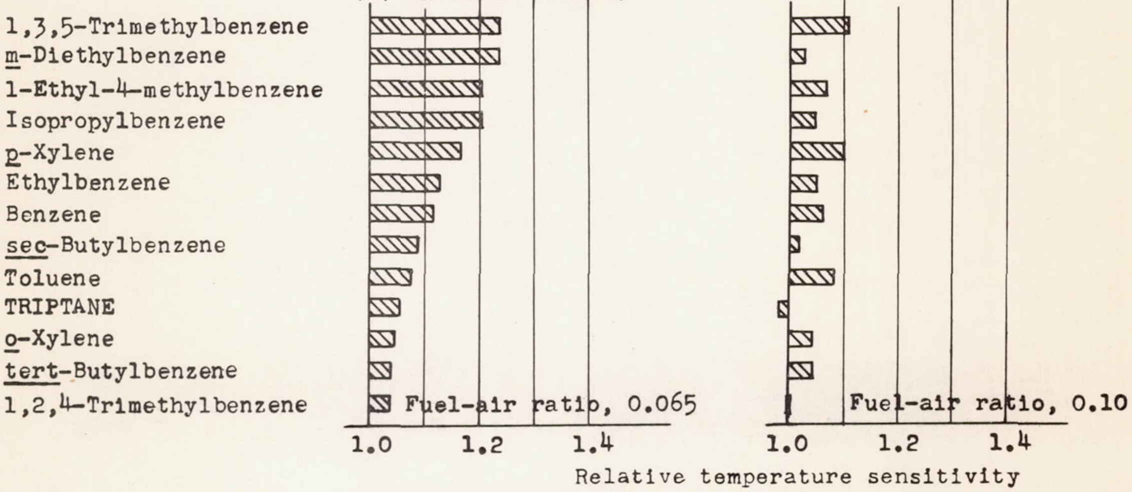


(a) Unleaded blends.



(b) Blends leaded to 4 ml TEL per gallon. S-64

Figure 19. - Relative temperature sensitivity (imep ratio at inlet-air temperature of 100° F to imep ratio at inlet-air temperature of 250° F) of 20-percent blends of triptane and 12 aromatics in S reference fuel as determined in a 17.6 engine.