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KNOCK-LIMITED PERFORMANCE TESTS OF 2,2,3,4-TETRAMETHYLPENTANE, 2,3,3,4-TETRAMETHYLPENTANE 3,4,4-TRIMETHYL-2-PENTENE, AND 2,3,4-TRIMETHYL-2-PENTENE IN SMALL-SCALE AND FULL-SCALE CYLINDERS

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ADVANCE RESTRICTED REPORT

KNOCK-LIMITED PERFORMANCE TESTS OF 2,2,3,4-TETRAMETHYLPENTANE 2,3,3,4-TETRAMETHYLPENTANE, 3,4,4-TRIMETHYL-2-PENTENE, AND 2,3,4-TRIMETHYL-2-PENTENE IN SMALL-SCALE AND FULL-SCALE CYLINDERS

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SUMMARY

Knock-limited tests were conducted with F-4, F-3, and 17.6 small-scale engines and with a full-scale cylinder on blends containing the following purified hydrocarbons:

2,2,3,4-Tetramethylpentane
2,3,3,4-Tetramethylpentane
3,4,4-Trimethyl-2-pentene
2,3,4-Trimethyl-2-pentene

Each of the four hydrocarbons was individually blended in various concentrations with three base fuels: S-4 reference fuel, S-4 plus 4 ml TEL per gallon in the final blend, and a blend of 87.5 percent S-4 plus 12.5 percent n-heptane plus 4 ml TEL per gallon in the final blend. Data were obtained for the four hydrocarbons to determine the following antiknock characteristics: (a) blending sensitivity, (b) sensitivity of the blends to inlet-air temperature, (c) lead susceptibility of the blends, and (d) correlation of full-scale and small-scale engine results.

From these knock-limited tests of two paraffinic and two olefinic hydrocarbons, the following results were obtained:

In general, the two paraffins — 2,2,3,4-tetramethylpentane and 2,3,3,4-tetramethylpentane — were effective in increasing the knock-limited performance of the base fuels, particularly at rich mixtures. In most instances the 2,3,3,4-tetramethylpentane blend gave the higher knock-limited performance at rich mixtures.

With some exception, the olefin 3,4,4-trimethyl-2-pentene increased the knock-limited performance of the base fuels only at mild conditions, and 2,3,4-trimethyl-2-pentene acted as a proknock agent under most of the conditions tested.

The knock-limited performance of the hydrocarbon blends was ordinarily more sensitive to changes of inlet-air temperature than the knock-limited performance of the base fuel. At rich mixtures, the temperature sensitivity of the olefinic blends was considerably greater than that of the paraffinic blends.

In most cases, the hydrocarbon blends showed greater lead susceptibility than the base fuel. At the higher inlet-air temperature tested and at lean mixtures, the paraffins were more susceptible to lead additions than the olefins.

The correlations of the full-scale and small-scale engine results indicate that the test results agree more closely with the full-scale cylinder operating at the modified cruise conditions. In general, the F-3 and F-4 engines rated the hydrocarbons considerably lower than the full-scale cylinder and the 17.6 engine somewhat higher than the full-scale cylinder.

INTRODUCTION

A general investigation to determine the antiknock effectiveness of additions of pure compounds to aircraft-engine fuels is being conducted by the NACA Cleveland laboratory. The program includes tests with F-4, F-3, and 17.6 small-scale engines and a full-scale aircraft-engine cylinder. The investigation consists in determining: (a) the blending sensitivity, (b) the sensitivity of the fuel blends to changes in inlet-air temperature, (c) the lead susceptibility of the blends, and (d) the correlation of full-scale and small-scale engine results.

Knock-limited data from tests in a full-scale aircraft-engine cylinder and in the F-3 and the F-4 engines are reported in reference 1 for eight paraffins and two olefins when blended with a base fuel. Similar full-scale-cylinder data for 12 pure aromatic hydrocarbons are presented in reference 2. A summary of the F-4, F-3, and 17.6 engine data for the 12 aromatics when blended with selected base fuels is presented in reference 3.

Supplies of two pure paraffinic and two pure olefinic hydrocarbons were submitted to the NACA by the National Bureau of Standards for the tests which are presented in this report; the tests were conducted between February and June 1945.

APPARATUS AND METHODS

Apparatus. - A description of the three small-scale engines used for the tests is given in reference 4. The R-1820 G200 cylinder apparatus was the same as that used in reference 1 except that a heat exchanger was installed in the cooling-air duct to control the cooling-air temperature and the exhaust system was modified to permit operation of the engine either at atmospheric exhaust pressure or at a reduced exhaust pressure.

Fuels. - The National Bureau of Standards prepared and furnished small quantities (8 to 10 gal) of two paraffins, 2,2,3,4-tetramethylpentane and 2,3,3,4-tetramethylpentane, and two olefins, 3,4,4-trimethyl-2-pentene and 2,3,4-trimethyl-2-pentene.

The four hydrocarbons were blended individually in various concentrations with S-4 reference fuel, S-4 plus 4 ml TEL per gallon in the final blend, and a base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane plus 4 ml TEL per gallon in the final blend. The base fuel used in these tests differs from that used in previous tests (references 1, 2, and 3) in that only paraffinic compounds were used. The original base fuel contained 85 percent S-3 reference fuel and 15 percent M-4 reference fuel plus 4 ml TEL per gallon. Because M-4 reference fuel contains approximately 8 percent aromatics and does not meet the requirement of reproducibility of the fuel (reference 4), this component was replaced by the paraffin n-heptane. Tests on an F-4 engine showed the base-fuel blend of 87.5 percent S-4 and 12.5 percent n-heptane to be approximately equivalent in knock-limited power to the original base fuel.

The reference fuels used to bracket the test fuels in the full-scale-cylinder tests were:

S-4
S-4 plus 0.5 ml TEL per gallon
S-4 plus 1.25 ml TEL per gallon
S-4 plus 2.5 ml TEL per gallon
S-4 plus 4 ml TEL per gallon

Test procedure. - An outline of the tests with the 17.6 and the F-4 engines and the composition of the test fuel blends are given in the following table:

Engine	Inlet-air temperature (°F)	Hydrocarbon in blend (percent by volume)	Base fuel	TEL in final blend (ml/gal)
17.6	250	0,10,20	S-4	0
	100	0,20	S-4	0
	250	0,10,20	S-4	4
	100	0,20	S-4	4
	250	0,25	87.5% S-4 + 12.5% n-heptane	4
	100	0,25	87.5% S-4 + 12.5% n-heptane	4
F-4	225	0,10,25,50	87.5% S-4 + 12.5% n-heptane	4

All the hydrocarbon blends were tested in the F-3 engine; operation of this engine conformed to Army specification AN-VV-F-746, Amendment-1.

Operation of the F-4 engine conformed to Army specification AN-VV-F-748a, Amendment-1, except for the use of two independent fuel systems and the detection of knock by a magnetostriction pickup unit used in conjunction with a cathode-ray oscilloscope.

The 17.6 engine was operated with the following conditions maintained constant:

Engine speed, rpm	1800
Compression ratio	7.0
Outlet-coolant temperature, °F	212
Inlet-air temperature, °F	100,250
Spark advance, deg B.T.C.	30
Injection timing, deg A.T.C. on intake stroke	60

In the full-scale cylinder, mixture-response curves for leaded blends of 25 percent by volume hydrocarbon in the base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane were determined at two operating conditions: (a) simulated cruise conditions recommended by the Coordinating Research Council, and (b) a modification of the CRC cruise conditions. The operating conditions are as follows:

	CRC cruise conditions	Modified CRC cruise conditions
Engine speed, rpm	2000	2000
Inlet-air temperature, °F	210	250
Compression ratio	7.3	7.3
Oil flow to piston jets, lb/min	8	8
Fuel temperature at entrance of injection pump, °F	60-80	60-80
Cooling-air temperature, °F	80 ±3	80 ±3
Spark advance, deg B.T.C. (both plugs)	20	30
Exhaust pressure, in. Hg absolute	29 ±0.5	15 ±0.2

The valve timing for both conditions is:

Intake opens, deg B.T.C.	15
Intake closes, deg A.B.C.	44
Exhaust opens, deg B.B.C.	74
Exhaust closes, deg A.T.C.	25

The reduced exhaust pressure for the modified cruise conditions was chosen because data obtained at this laboratory indicate the existence of a critical relation between manifold and exhaust pressures and knock-limited power in the lean region where the manifold pressure is within +10 or -5 inches of mercury of the exhaust pressure. The advanced spark and increased inlet-air temperature were chosen in an effort to obtain a more severe operating condition than the normal CRC cruise rating.

The cooling-air flow was determined for each test by operating the engine at a brake mean effective pressure of 140 pounds per square inch and a fuel-air ratio of 0.10 and by adjusting the damper valve in the cooling-air line until a rear spark-plug-bushing temperature of 365° F was reached. The cooling-air pressure drop across the cylinder thus determined was maintained constant for each test. In order to obtain complete mixture-response curves with the limited amount of fuel blends available, the special procedures described in reference 1 were used. The reproducibility of the data was checked before each test fuel run by obtaining four or five knock points with the fuel blend consisting of 85 percent S-4 plus 15 percent M-4 plus 4 ml TEL per gallon.

RESULTS AND DISCUSSION

Table I is an index of figures showing in detail the order of discussing the results obtained for the hydrocarbon blends. The table presents the blend composition, the engines, the variable engine conditions, and the figure numbers. Table II compares the 17.6 engine, the F-4, and the full-scale cylinder ratings on the basis of knock-limited indicated mean effective pressure and the imep ratio (the ratio of the imep of the hydrocarbons blend to the imep of the base fuel). The F-4 and F-3 ratings of blends containing each of the hydrocarbons in various concentrations with the three base fuels are presented in table III. The F-4 data are presented in terms of percentage S-4 plus 4 ml TEL per gallon in n-heptane plus 4 ml TEL per gallon and in terms of Army-Navy performance number. The procedure for determining these ratings is given in reference 5. The F-3 data are presented in terms of S-4 plus ml TEL per gallon or octane number. Table IV compares the F-3 ratings, the F-4 ratings, and the full-scale-cylinder ratings of the hydrocarbon blends in the base fuel consisting of S-4 plus n-heptane on the basis of S-4 plus ml TEL, or percentage S-4 plus 4 ml TEL per gallon in n-heptane plus 4 ml TEL per gallon, and on the basis of performance number.

Small-Scale-Engine Data

F-4 and F-3 engine data. - The knock-limited performance of the base fuel (87.5 percent S-4 plus 12.5 percent n-heptane plus 4 ml TEL/gal) in the F-4 engine is presented in figure 1. The results for the blends containing 0, 10, 25, and 50 percent hydrocarbon with this base fuel are shown in figures 2, 3, 4, and 5 for 2,2,3,4-tetramethylpentane, 2,3,3,4-tetramethylpentane, 3,4,4-trimethyl-2-pentene, and 2,3,4-trimethyl-2-pentene, respectively. The test results for S-4 reference fuel plus 4 ml TEL per gallon are included in each figure. All data in each figure were obtained during a single day.

At fuel-air ratios higher than approximately 0.09, the two paraffins increased the knock-limited power of the base fuel; for fuel-air ratios lower than 0.09, the power was decreased. A 10-percent addition of either olefin increased the performance of the base fuel by a small amount at fuel-air ratios greater than 0.10; however, 25- and 50-percent additions of the olefins gave decidedly lower power than the base fuel. At lean mixtures the knock-limited power was progressively decreased with increasing olefinic concentration. This loss in power at lean mixtures was greater for the olefins than for the paraffins. At fuel-air ratios above 0.085, the 50-percent blend of 2,3,3,4-tetramethylpentane gave the highest knock-limited performance and, at all fuel-air ratios, 2,3,4-trimethyl-2-pentene gave the lowest knock-limited performance of the fuels tested.

Graphs of knock-limited imep ratio against hydrocarbon concentration are presented in figures 6 to 9 for the blends tested in the F-4 engine. These data show the comparative effect of the addition of each of the hydrocarbons at fuel-air ratios of 0.07, 0.085, 0.10, and 0.11. At fuel-air ratios of 0.07 and 0.085, only small or negative gains were obtained by additions of the hydrocarbons. At fuel-air ratios of 0.10 and 0.11, substantial improvements relative to the base fuel were observed with the paraffins at all concentrations, but reductions in the knock limit were observed with the olefins for concentrations greater than 10 percent.

The F-3 ratings of the hydrocarbon blends are presented in table III. For all the blends tested, the highest knock-limited power was obtained with the 2,2,3,4-tetramethylpentane addition and the lowest with the 2,3,4-trimethyl-2-pentene addition. None of the hydrocarbons permitted any significant increase in the knock-limited performance of the base fuels. The 10- and 25-percent blends of 2,2,3,4-tetramethylpentane in the base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane were approximately equivalent in performance to the base fuel; a further increase in the concentration of the hydrocarbon resulted in a decrease in knock-limited performance. These results are comparable with the lean-mixture data (fig. 2) for tests by the F-4 method.

17.6 engine data. - The knock-limited performance in the 17.6 engine of blends containing each of the four hydrocarbons is presented in figures 10 to 12 for 2,2,3,4-tetramethylpentane, in figures 13 to 15 for 2,3,3,4-tetramethylpentane, in figures 16 to 18 for 3,4,4-trimethyl-2-pentene, and in figures 19 to 21 for 2,3,4-trimethyl-2-pentene. For each hydrocarbon, unleaded and leaded blends with S-4 and leaded blends with a base fuel consisting of S-4 plus n-heptane are presented at inlet-air temperatures of 100° F and 250° F.

In the unleaded blends (figs. 10, 13, 16, and 19) at the higher inlet-air temperature the only increases in knock-limited performance over the base fuel were observed with the two paraffins at mixtures richer than a fuel-air ratio of approximately 0.08 and with the olefin 3,4,4-trimethyl-2-pentene at a fuel-air ratio greater than 0.10. When the inlet-air temperature was lowered to 100° F, the two paraffins and 3,4,4-trimethyl-2-pentene increased the knock-limited power of S-4 at all fuel-air ratios. At this milder condition the 2,3,4-trimethyl-2-pentene blend improved the performance of S-4 fuel at mixtures richer than 0.105.

When tetraethyl lead was added to the blends (figs. 11, 14, 17, and 20) the two paraffinic blends increased the knock-limited power of S-4 throughout the entire fuel-air-ratio range at both inlet-air temperatures. At an inlet-air temperature of 250° F, the only increase in knock-limited performance of the olefinic blends over the base fuel was observed with 3,4,4-trimethyl-2-pentene at fuel-air ratios greater than 0.10. At the lower inlet-air temperature 3,4,4-trimethyl-2-pentene increased the knock-limited power of the base fuel at all fuel-air ratios and of 2,3,4-trimethyl-2-pentene at fuel-air ratios greater than 0.085.

In leaded blends with the base fuel consisting of S-4 plus n-heptane (figs. 12, 15, 18, and 21), the two paraffins increased the knock-limited power of the base fuel at all fuel-air ratios and at both inlet-air temperatures. At the higher inlet-air temperature, 3,4,4-trimethyl-2-pentene increased the knock-limited performance of the base fuel at fuel-air ratios richer than 0.075 and 2,3,4-trimethyl-2-pentene decreased the performance of the base fuel at all fuel-air ratios below 0.10. At the inlet-air temperature of 100° F, the olefins increased the knock-limited performance of the base fuel at all fuel-air ratios.

In most cases the paraffin 2,3,3,4-tetramethylpentane gave the highest knock-limited performance and in all cases 2,3,4-trimethyl-2-pentene gave the lowest performance of the hydrocarbons tested.

Figures 22, 23, 24, and 25 present graphs of the variation of knock-limited imep ratio with hydrocarbon concentration for the hydrocarbons blended with S-4 and tested (with and without tetraethyl lead) in the 17.6 engine. The results indicate the comparative effect of additions of each of the four hydrocarbons at fuel-air ratios of 0.07, 0.085, 0.10, and 0.11, as well as the effects of inlet-air temperature and tetraethyl lead.

The temperature sensitivities are summarized in table V. In general, the temperature sensitivities, as expressed, are greater for the hydrocarbon blends than for the base fuels. As the mixture was enriched, the temperature sensitivities of the paraffinic blends approached that of the base fuel and at a fuel-air ratio of 0.11 became equal to or smaller than the temperature sensitivity of the base fuel. The sensitivities of the two olefinic blends remained substantially greater than that of the base fuel at all fuel-air ratios.

Table VI contains data on the lead susceptibility of the hydrocarbon blends. At the higher inlet-air temperature, the blends of the two paraffins showed significant increases in lead susceptibility, as expressed, over the S-4 fuel at lean mixtures. The blends of the two olefins had approximately the same susceptibility as S-4 at all fuel-air ratios examined. At the lower inlet-air temperature, increases in lead susceptibility were observed with 2,2,3,4-tetramethylpentane and 3,4,4-trimethyl-2-pentene at lean mixtures and with

2,3,4-trimethyl-2-pentene at all fuel-air ratios. The data indicate that at the higher inlet-air temperature and lean mixtures the paraffins were more susceptible to lead additions than the olefins.

Full-Scale-Cylinder Data

Precision of tests. - The variation in the knock-limited indicated mean effective pressure of the fuel blend (85 percent S-4 plus 15 percent M-4 plus 4 ml TEL/gal) used for checking full-scale engine conditions from day to day is shown in figure 26. The symbols indicate the check points obtained for each of the represented test fuels. The daily variation in engine behavior was comparable with that in reference 1 and less than that in reference 2. The complete curves shown are averages of several S-4 plus M-4 mixture-response curves obtained at each condition.

Test results. - The reference-fuel framework covering tests at both engine operating conditions is presented in figures 27 and 28. From these figures cross plots were made (fig. 29) to facilitate conversion of the knock-limited indicated mean effective pressure of the test fuels to lead ratings. A definite irregularity is apparent in the lead-susceptibility curve of S-4 reference fuel at the two operating conditions. Tests made to check this irregularity gave identical results.

Figure 30 shows the difference in knock-limited performance of the base fuel used in the present tests (87.5 percent S-4 plus 12.5 percent n-heptane plus 4 ml TEL/gal) and that used in the tests of references 1, 2, and 3 (85 percent S-4 plus 15 percent M-4 plus 4 ml TEL/gal) at both operating conditions.

The knock-limited performance of the blends of each of the four hydrocarbons and the S-4 plus n-heptane base fuel tested in the full-scale cylinder is presented in figures 31 and 32. At the milder conditions (fig. 31), the two paraffins and 3,4,4-trimethyl-2-pentene increased the knock-limited power of the base fuel at all fuel-air ratios. The addition of 2,3,4-trimethyl-2-pentene decreased the knock-limited power in the fuel-air-ratio range from 0.062 to 0.074 and increased the knock-limited performance at fuel-air ratios between 0.074 and 0.095, and above 0.102. At the more severe conditions (fig. 32), only the two paraffins increased the knock-limited power of the base fuel at all fuel-air ratios. The addition of 3,4,4-trimethyl-2-pentene increased the performance of the base fuel at extremely lean mixtures (below 0.063) and at fuel-air ratios greater than 0.095. The olefin 2,3,4-trimethyl-2-pentene decreased the knock-limited power of the base fuel at all fuel-air ratios greater than 0.057.

In general, the best knock-limited performance was observed with the 2,2,3,4-tetramethylpentane blend at lean mixtures, and with the 2,3,3,4-tetramethylpentane blend at fuel-air ratios higher than 0.10. At all conditions, 2,3,4-trimethyl-2-pentene was the least effective antiknock additive of the hydrocarbons tested.

Correlation of Small-Scale and Full-Scale Engine Results

The correlations of the small-scale-engine data with the full-scale-cylinder data are presented in figures 33, 34, and 35 for blends containing 25 percent hydrocarbon and 75 percent base fuel (87.5 percent S-4 plus 12.5 percent n-heptane) plus 4 ml TEL per gallon. Figure 33 compares F-4 ratings with the full-scale-cylinder ratings in terms of imep ratio. The data indicate that at a fuel-air ratio of 0.07 at both operating conditions the full-scale cylinder gives a higher knock-limited rating for the hydrocarbon blends than the F-4 engine. At a fuel-air ratio of 0.10 the F-4 data agree more favorably with the full-scale-cylinder data at the modified-cruise conditions (fig. 33(d)).

The 17.6 engine performance, in terms of imep ratio, is compared with the full-scale-cylinder performance in figure 34. The correlations at the severe conditions of both engines are fair and indicate a closer agreement of the full-scale-cylinder results with the 17.6 engine results than with the F-4 results.

Figure 35 presents the correlation of the F-3 performance data and the full-scale-cylinder performance data on the basis of performance number. The agreement is closer with the full-scale cylinder operating at the more severe conditions.

The full-scale-cylinder ratings, in general, were higher than the F-4 and the F-3 ratings and somewhat lower than the 17.6 engine ratings.

SUMMARY OF RESULTS

From tests to determine the antiknock effectiveness of additions of two paraffinic and two olefinic hydrocarbons to selected base fuels in the 17.6, F-3, and F-4 small-scale engines and in a full-scale-engine cylinder the following results were obtained:

1. In most instances, the two paraffins — 2,2,3,4-tetramethylpentane and 2,3,3,4-tetramethylpentane — were effective in increasing the knock-limited performance of the base fuels, particularly at rich mixtures. In general, the 2,3,3,4-tetramethylpentane blend gave the higher knock-limited performance at rich mixtures.

2. With some exceptions, the olefin 3,4,4-trimethyl-2-pentene increased the knock-limited performance of the base fuels only at mild conditions and 2,3,4-trimethyl-2-pentene acted as a proknock agent under most of the conditions tested.

3. The knock-limited performance of the hydrocarbon blends was ordinarily more sensitive to changes of inlet-air temperature than the knock-limited performance of the base fuel. At rich mixtures, the temperature sensitivity of the olefinic blends was considerably greater than that of the paraffinic blends.

4. In most cases, the hydrocarbon blends showed greater lead susceptibility than the base fuel. At the higher inlet-air temperature tested and at lean mixtures, the paraffins were more susceptible to lead additions than the olefins.

5. The correlations of the full-scale and small-scale engine results indicate that the test results agree more closely with the full-scale cylinder operating at the modified cruise conditions. In general, the F-3 and F-4 engines rated the hydrocarbons considerably lower than the full-scale cylinder and the 17.6 engine somewhat higher than the full-scale cylinder.

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TABLE I. - FIGURES PRESENTING DATA FOR HYDROCARBON BLENDS

Figure	Hydrocarbon	Hydrocarbon in blend (percent by volume)	Base fuel	Tetraethyl lead (ml/gal)	Engine conditions		
					Spark advance (deg B.T.C.)	Exhaust pressure (in. Hg abs.)	Inlet-air temperature (°F)
F-4 engine (knock-limited imep against fuel-air ratio)							
1	---------------------------	0	87.5% S-4 + 12.5% n-heptane	4	45	29 ±0.5	225
2	2,2,3,4-Tetramethylpentane	0,10,25,50	87.5% S-4 + 12.5% n-heptane	4	45	29 ±0.5	225
3	2,3,3,4-Tetramethylpentane	0,10,25,50	87.5% S-4 + 12.5% n-heptane	4	45	29 ±0.5	225
4	3,4,4-Trimethyl-2-pentene	0,10,25,50	87.5% S-4 + 12.5% n-heptane	4	45	29 ±0.5	225
5	2,3,4-Trimethyl-2-pentene	0,10,25,50	87.5% S-4 + 12.5% n-heptane	4	45	29 ±0.5	225
F-4 engine (knock-limited imep ratio against hydrocarbon concentration)							
6	2,2,3,4-Tetramethylpentane	0,10,25,50	87.5% S-4 + 12.5% n-heptane	4	45	29 ±0.5	225
7	2,3,3,4-Tetramethylpentane	0,10,25,50	87.5% S-4 + 12.5% n-heptane	4	45	29 ±0.5	225
8	3,4,4-Trimethyl-2-pentene	0,10,25,50	87.5% S-4 + 12.5% n-heptane	4	45	29 ±0.5	225
9	2,3,4-Trimethyl-2-pentene	0,10,25,50	87.5% S-4 + 12.5% n-heptane	4	45	29 ±0.5	225
17.6 engine (knock-limited imep against fuel-air ratio)							
10(a)	2,2,3,4-Tetramethylpentane	0,10,20	S-4	0	30	29 ±0.5	250
(b)		0,20					100
11(a)	2,2,3,4-Tetramethylpentane	0,10,20	S-4	4	30	29 ±0.5	250
(b)		0,20					100
12(a)	2,2,3,4-Tetramethylpentane	0,25	87.5% S-4 + 12.5% n-heptane	4	30	29 ±0.5	250
(b)							100
13(a)	2,3,3,4-Tetramethylpentane	0,10,20	S-4	0	30	29 ±0.5	250
(b)		0,20					100
14(a)	2,3,3,4-Tetramethylpentane	0,10,20	S-4	4	30	29 ±0.5	250
(b)		0,20					100
15(a)	2,3,3,4-Tetramethylpentane	0,25	87.5% S-4 + 12.5% n-heptane	4	30	29 ±0.5	250
(b)							100
16(a)	3,4,4-Trimethyl-2-pentene	0,10,20	S-4	0	30	29 ±0.5	250
(b)		0,20					100
17(a)	3,4,4-Trimethyl-2-pentene	0,10,20	S-4	4	30	29 ±0.5	250
(b)		0,20					100
18(a)	3,4,4-Trimethyl-2-pentene	0,25	87.5% S-4 + 12.5% n-heptane	4	30	29 ±0.5	250
(b)							100
19(a)	2,3,4-Trimethyl-2-pentene	0,10,20	S-4	0	30	29 ±0.5	250
(b)		0,20					100
20(a)	2,3,4-Trimethyl-2-pentene	0,10,20	S-4	4	30	29 ±0.5	250
(b)		0,20					100
21(a)	2,3,4-Trimethyl-2-pentene	0,25	87.5% S-4 + 12.5% n-heptane	4	30	29 ±0.5	250
(b)							100

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TABLE I. - FIGURES PRESENTING DATA FOR HYDROCARBON BLENDS - Concluded

Figure	Hydrocarbon	Hydrocarbon in blend (percent by volume)	Base fuel	Tetraethyl lead (ml/gal)	Engine conditions		
					Spark advance (deg B.T.C.)	Exhaust pressure (in. Hg abs.)	Inlet-air temperature (°F)
17.6 engine (knock-limited imep ratio against hydrocarbon concentration)							
22(a)	2,2,3,4-Tetramethylpentane	0,10,20	S-4	0	30	29 ±0.5	250,100
(b)				4			
23(a)	2,3,3,4-Tetramethylpentane	0,10,20	S-4	0	30	29 ±0.5	250,100
(b)				4			
24(a)	3,4,4-Trimethyl-2-pentene	0,10,20	S-4	0	30	29 ±0.5	250,100
(b)				4			
25(a)	2,3,4-Trimethyl-2-pentene	0,10,20	S-4	0	30	29 ±0.5	250,100
(b)				4			
Full-scale cylinder (knock-limited imep against fuel-air ratio)							
26(a)	----------------------------	0	85% S-4 + 15% M-4	4	20	29 ±0.5	210
(b)	----------------------------				30	15	250
27	----------------------------	0	S-4 reference fuel	0,0.5,1.25,2.5,4	20	29 ±0.5	210
28	----------------------------	0	S-4 reference fuel	0,0.5,1.25,2.5,4	30	15	250
Full-scale cylinder (knock-limited imep against lead concentration)							
29(a)	----------------------------	0	S-4 reference fuel	0 to 4.0	20	29 ±0.5	210
(b)	----------------------------				30	15	250
Full-scale cylinder (knock-limited imep against fuel-air ratio)							
30(a)	----------------------------	0	{87.5% S-4 + 12.5% n-heptane 85% S-4 + 15% n-heptane	4	20	29 ±0.5	210
(b)	----------------------------				30	15	250
31	2,3,4-Trimethyl-2-pentene 3,4,4-Trimethyl-2-pentene 2,3,3,4-Tetramethylpentane 2,2,3,4-Tetramethylpentane	25	87.5% S-4 + 12.5% n-heptane	4	20	29 ±0.5	210
32	2,3,4-Trimethyl-2-pentene 3,4,4-Trimethyl-2-pentene 2,3,3,4-Tetramethylpentane 2,2,3,4-Tetramethylpentane	25	87.5% S-4 + 12.5% n-heptane	4	30	15	250
Correlations of test results (engine methods compared)							
33	F-4 engine and full-scale cylinder						
34	17.6 engine and full-scale cylinder						
35	F-3 engine and full-scale cylinder						

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TABLE II. - SUPERCHARGED-ENGINE TESTS OF HYDROCARBON BLENDS

Fuel composition					Engine conditions			Test results									
								Fuel-air ratio									
	Blend composition (percent by volume)			Tetra-ethyl lead (ml/gal)				0.065		0.07		0.085		0.10		0.11	
Compound	Hydro-carbon	S-4 reference fuel	87.5 percent S-4 plus 12.5 percent n-heptane		Spark advance (deg B.T.C.)	Exhaust pressure (in.Hg abs.)	Inlet-air temperature (°F)	imep	imep ratio[a]	imep	imep ratio[a]	imep	imep ratio[a]	imep	imep ratio[a]	imep	imep ratio[a]
17.6 engine																	
2,2,3,4-Tetramethylpentane	10	90	0	0	30	29 ±0.5	250	124	0.96	126	0.96	152	1.01	188	1.11	194	1.13
2,3,3,4-Tetramethylpentane								127	.97	131	.98	156	1.03	181	1.06	193	1.13
3,4,4-Trimethyl-2-pentene								124	.96	127	.98	151	.99	171	1.00	182	1.05
2,3,4-Trimethyl-2-pentene								118	.90	118	.90	135	.89	156	.91	167	.96
2,2,3,4-Tetramethylpentane	20	80	0	0	30	29 ±0.5	250	118	0.91	119	0.91	151	1.00	195	1.15	209	1.22
2,3,3,4-Tetramethylpentane								125	.95	128	.96	162	1.07	198	1.16	217	1.27
3,4,4-Trimethyl-2-pentene								120	.93	122	.94	143	.94	167	.98	184	1.06
2,3,4-Trimethyl-2-pentene								104	.79	104	.79	118	.78	140	.82	154	.89
2,2,3,4-Tetramethylpentane	20	80	0	0	30	29 ±0.5	100	178	1.09	177	1.10	197	1.15	217	1.21	219	1.22
2,3,3,4-Tetramethylpentane								191	1.17	191	1.19	211	1.22	224	1.27	223	1.27
3,4,4-Trimethyl-2-pentene								172	1.05	168	1.04	186	1.08	208	1.16	216	1.20
2,3,4-Trimethyl-2-pentene								156	.95	153	.95	164	.96	177	.99	182	1.02
2,2,3,4-Tetramethylpentane	10	90	0	4	30	29 ±0.5	250	207	1.02	216	1.03	250	1.04	287	1.09	294	1.11
2,3,3,4-Tetramethylpentane								219	1.05	226	1.05	267	1.09	298	1.14	305	1.17
3,4,4-Trimethyl-2-pentene								195	.96	200	.96	237	.97	268	1.01	280	1.05
2,3,4-Trimethyl-2-pentene								186	.91	193	.91	221	.89	252	.94	263	.97
2,2,3,4-Tetramethylpentane	20	80	0	4	30	29 ±0.5	250	212	1.04	222	1.06	265	1.10	314	1.19	326	1.23
2,3,3,4-Tetramethylpentane								229	1.10	236	1.10	284	1.15	326	1.24	330	1.27
3,4,4-Trimethyl-2-pentene								188	.93	191	.92	225	.92	264	.99	287	1.07
2,3,4-Trimethyl-2-pentene								166	.81	171	.81	195	.78	226	.85	248	.92
2,2,3,4-Tetramethylpentane	20	80	0	4	30	29 ±0.5	100	327	1.17	329	1.18	346	1.21	347	1.21	339	1.19
2,3,3,4-Tetramethylpentane								329	1.17	328	1.18	345	1.20	346	1.20	338	1.19
3,4,4-Trimethyl-2-pentene								312	1.10	309	1.10	321	1.10	340	1.15	345	1.18
2,3,4-Trimethyl-2-pentene								280	.99	281	1.00	291	1.00	307	1.05	316	1.09
2,2,3,4-Tetramethylpentane	25	0	75	4	30	29 ±0.5	250	181	1.12	183	1.10	211	1.16	237	1.23	241	1.26
2,3,3,4-Tetramethylpentane								185	1.13	187	1.11	222	1.19	252	1.29	251	1.30
3,4,4-Trimethyl-2-pentene								165	.99	170	1.01	195	1.04	216	1.10	221	1.13
2,3,4-Trimethyl-2-pentene								154	.94	157	.94	173	.94	194	.99	204	1.06
2,2,3,4-Tetramethylpentane	25	0	75	4	30	29 ±0.5	100	247	1.20	246	1.21	259	1.24	259	1.24	256	1.24
2,3,3,4-Tetramethylpentane								250	1.22	251	1.22	265	1.27	271	1.30	261	1.28
3,4,4-Trimethyl-2-pentene								253	1.25	249	1.22	254	1.20	259	1.23	260	1.25
2,3,4-Trimethyl-2-pentene								230	1.12	227	1.11	233	1.11	240	1.14	241	1.16

[a] $\text{imep ratio} = \frac{\text{imep of hydrocarbon blend}}{\text{imep of base fuel}}$. For the blends tested with the 17.6 engine, the base fuel was S-4, S-4 plus 4 ml TEL/gal, or 87.5 percent S-4 plus 12.5 percent n-heptane plus 4 ml TEL/gal; in all other instances, 87.5 percent S-4 plus 12.5 percent n-heptane plus 4 ml TEL/gal was used.

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TABLE II. - SUPERCHARGED-ENGINE TESTS OF HYDROCARBON BLENDS - Concluded

Fuel composition					Engine conditions			Test results									
	Blend composition (percent by volume)							Fuel-air ratio									
								0.065		0.07		0.085		0.10		0.11	
Compound	Hydro-carbon	S-4 reference fuel	87.5 percent S-4 plus 12.5 percent n-heptane	Tetra-ethyl lead (ml/gal)	Spark advance (deg B.T.C.)	Exhaust pressure (in. Hg abs.)	Inlet-air temperature (°F)	imep	imep ratio[a]	imep	imep ratio[a]	imep	imep ratio[a]	imep	imep ratio[a]	imep	imep ratio[a]
Full-scale cylinder																	
2,2,3,4-Tetramethylpentane	25	0	75	4	30	15	250	147	1.07	154	1.07	189	1.14	228	1.22	239	1.25
2,3,3,4-Tetramethylpentane								143	1.04	150	1.04	180	1.08	242	1.29	253	1.32
3,4,4-Trimethyl-2-pentene								132	.96	137	.95	162	.98	192	1.03	208	1.08
2,3,4-Trimethyl-2-pentene								125	.91	127	.88	141	.85	162	.87	177	.92
2,2,3,4-Tetramethylpentane	25	0	75	4	20	29 ±0.5	210	193	1.22	192	1.20	230	1.26	275	1.29	274	1.22
2,3,3,4-Tetramethylpentane								191	1.21	184	1.15	220	1.21	271	1.27	288	1.28
3,4,4-Trimethyl-2-pentene								186	1.18	179	1.12	213	1.17	241	1.13	253	1.12
2,3,4-Trimethyl-2-pentene								150	.95	153	.96	191	1.05	212	1.00	233	1.04
F-4 engine																	
2,2,3,4-Tetramethylpentane	10	0	90	4	45	29 ±0.5	225	85	0.90	99	0.93	158	1.04	180	1.08	184	1.10
2,3,3,4-Tetramethylpentane								94	.95	110	.94	160	1.03	185	1.09	188	1.11
3,4,4-Trimethyl-2-pentene								79	.87	90	.87	150	1.00	173	1.02	178	1.03
2,3,4-Trimethyl-2-pentene								82	.84	94	.82	142	.92	168	1.00	169	1.00
2,2,3,4-Tetramethylpentane	25	0	75	4	45	29 ±0.5	225	80	0.85	93	0.88	159	1.05	199	1.19	209	1.24
2,3,3,4-Tetramethylpentane								86	.87	98	.84	165	1.06	209	1.23	217	1.28
3,4,4-Trimethyl-2-pentene								68	.75	75	.73	119	.79	154	.91	166	.97
2,3,4-Trimethyl-2-pentene								68	.69	77	.67	112	.72	145	.86	157	.93
2,2,3,4-Tetramethylpentane	50	0	50	4	45	29 ±0.5	225	75	0.80	80	0.75	133	0.88	243	1.46	268	1.59
2,3,3,4-Tetramethylpentane								74	.75	82	.70	166	1.06	255	1.50	299	1.76
3,4,4-Trimethyl-2-pentene								60	.66	61	.59	88	.59	123	.72	144	.84
2,3,4-Trimethyl-2-pentene								58	.59	58	.50	75	.48	98	.58	113	.67

[a]imep ratio = $\frac{\text{imep of hydrocarbon blend}}{\text{imep of base fuel}}$. For the blends tested with the 17.6 engine, the base fuel was S-4, S-4 plus 4 ml TEL/gal, or 87.5 percent S-4 plus 12.5 percent n-heptane plus 4 ml TEL/gal; in all other instances, 87.5 percent S-4 plus 12.5 percent n-heptane plus 4 ml TEL/gal was used.

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TABLE III. - F-4 AND F-3 RATINGS OF HYDROCARBON BLENDS

Compound	Blend composition (percent by volume)			Tetraethyl lead (ml/gal)	F-4 ratings				F-3 ratings	
					Lean		Rich			
	Hydrocarbon	S-4 reference fuel	87.5 percent S-4 + 12.5 percent n-heptane		S-4 + 4 ml TEL/gal in n-heptane + 4 ml TEL/gal[a] (percent)	Performance number	S-4 + 4 ml TEL/gal in n-heptane + 4 ml TEL/gal[a] (percent)	Performance number	S-4 + ml TEL/gal	Performance number
87.5 percent S-4 + 12.5 percent n-heptane	0	0	100	4	87.5	116	87.5	111	0.63	119
2,2,3,4-Tetramethylpentane	10	0	90	4	83.8	109	91.4	125	0.71	120
2,3,3,4-Tetramethylpentane					85.2	112	91.5	125	.54	117
3,4,4-Trimethyl-2-pentene					80.8	104	89.2	116	.43	114
2,3,4-Trimethyl-2-pentene					82.8	108	87.5	111	.40	113
2,2,3,4-Tetramethylpentane	25	0	75	4	81.6	105	96.2	141	0.60	118
2,3,3,4-Tetramethylpentane					81.3	105	97.0	143	.27	110
3,4,4-Trimethyl-2-pentene					73.2	90	85.9	105	.15	106
2,3,4-Trimethyl-2-pentene					73.8	91	84.2	100	.03	101
2,2,3,4-Tetramethylpentane	50	0	50	4	79.5	102	>100.0	[b]175	0.33	111
2,3,3,4-Tetramethylpentane					77.0	97	>100.0	[b]192	.16	106
3,4,4-Trimethyl-2-pentene					65.0	76	78.6	91	[c]96.2	88
2,3,4-Trimethyl-2-pentene					66.1	77	65.5	73	[c]91.7	77
2,2,3,4-Tetramethylpentane	10	90	0	4	------------	--------	------------	--------	2.80	145
2,3,3,4-Tetramethylpentane					------------	--------	------------	--------	1.83	137
3,4,4-Trimethyl-2-pentene					------------	--------	------------	--------	1.50	133
2,3,4-Trimethyl-2-pentene					------------	--------	------------	--------	1.10	127
2,2,3,4-Tetramethylpentane	20	80	0	4	------------	--------	------------	--------	1.50	133
2,3,3,4-Tetramethylpentane					------------	--------	------------	--------	1.35	131
3,4,4-Trimethyl-2-pentene					------------	--------	------------	--------	.70	120
2,3,4-Trimethyl-2-pentene					------------	--------	------------	--------	.40	113
2,2,3,4-Tetramethylpentane	10	90	0	0	------------	--------	------------	--------	[c]98.8	96
2,3,3,4-Tetramethylpentane					------------	--------	------------	--------	[c]97.8	93
3,4,4-Trimethyl-2-pentene					------------	--------	------------	--------	[c]98.8	96
2,3,4-Trimethyl-2-pentene					------------	--------	------------	--------	[c]94.9	80
2,2,3,4-Tetramethylpentane	20	80	0	0	------------	--------	------------	--------	[c]98.8	96
2,3,3,4-Tetramethylpentane					------------	--------	------------	--------	[c]98.0	93
3,4,4-Trimethyl-2-pentene					------------	--------	------------	--------	[c]97.4	92
2,3,4-Trimethyl-2-pentene					------------	--------	------------	--------	[c]91.5	77

[a]Reciprocal imep cross plots of leaded n-heptane blends in S-4 were used to convert the imep of the test fuel to percentage S-4 in n-heptane.

[b]Estimated performance number $= \frac{\text{imep of hydrocarbon blend}}{\text{imep of (S-4 + 4 ml TEL/gal)}} \times$ performance number of (S-4 + 4 ml TEL/gal).

[c]Octane number.

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TABLE IV. - COMPARISON OF F-3, F-4, AND FULL-SCALE-CYLINDER RATINGS OF HYDROCARBON BLENDS

[For each compound there are two rows of values. The first row is tetraethyl lead in S-4 reference fuel, ml/gal, except as noted; and the second row is performance number.]

Compound	Blend composition (percent by volume)			Tetraethyl lead (ml/gal)	F-3 ratings	F-4 ratings		Full-scale-cylinder ratings (Engine speed, 2000 rpm; compression ratio, 7.3)									
	Hydrocarbon	S-4 reference fuel	87.5 percent S-4 + 12.5 percent n-heptane					Inlet-air temperature, 210° F; spark advance, 20° B.T.C.; atmospheric exhaust					Inlet-air temperature, 250° F; spark advance, 30° B.T.C.; exhaust pressure, 15 in. Hg abs.				
								Fuel-air ratio					Fuel-air ratio				
						Lean	Rich	0.065	0.07	0.085	0.10	0.11	0.065	0.07	0.085	0.10	0.11
Base fuel	0	0	100	4	0.63	[a]87.5	[a]87.5	0.22	0.22	0.19	0.31	0.43	0.28	0.34	0.39	0.36	0.33
					119	116	111	108	108	107	111	114	110	112	113	112	111
2,2,3,4-Tetramethylpentane	25	0	75	4	0.60	[a]81.6	[a]96.2	1.43	1.27	1.54	2.12	1.94	0.41	0.47	0.95	1.99	2.20
					118	105	141	132	130	133	140	138	114	115	125	138	140
2,3,3,4-Tetramethylpentane	25	0	75	4	0.27	[a]81.3	[a]97.0	1.37	0.61	1.25	1.99	2.32	0.35	0.42	0.64	2.77	3.13
					110	105	143	131	118	130	138	141	112	114	119	145	147
3,4,4-Trimethyl-2-pentene	25	0	75	4	0.15	[a]73.2	[a]85.9	1.15	0.44	0.90	1.23	1.43	0.21	0.26	0.34	0.43	0.86
					106	90	105	128	114	124	129	132	108	109	112	114	123
2,3,4-Trimethyl-2-pentene	25	0	75	4	0.03	[a]73.8	[a]84.2	0.15	0.16	0.27	0.29	0.69	0.14	0.16	0.13	0.10	0.11
					101	91	100	106	106	110	110	120	105	106	105	104	104

[a]Percentage S-4 plus 4 ml TEL/gal in n-heptane plus 4 ml TEL/gal. (Reciprocal imep cross plots of leaded n-heptane blends in S-4 were used to convert the imep of the test fuel to percentage S-4 in n-heptane.)

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TABLE V. - TEMPERATURE SENSITIVITY OF HYDROCARBON BLENDS

RELATIVE TO THAT OF THE BASE FUELS

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

Compound	Composition (percent by volume)			Tetraethyl lead (ml/gal)	Relative temperature sensitivity[a]				
	Hydrocarbon	S-4 reference fuel	87.5 percent S-4 plus 12.5 percent n-heptane		Fuel-air ratio				
					0.065	0.07	0.085	0.10	1.11
S-4 reference fuel	0	100	0	0	1.00	1.00	1.00	1.00	1.00
2,2,3,4-Tetramethylpentane	20	80	0	0	1.20	1.21	1.15	1.05	1.00
2,3,3,4-Tetramethylpentane					1.23	1.24	1.14	1.09	1.00
3,4,4-Trimethyl-2-pentene					1.13	1.11	1.15	1.18	1.13
2,3,4-Trimethyl-2-pentene					1.20	1.20	1.23	1.21	1.15
S-4 reference fuel	0	100	0	4	1.00	1.00	1.00	1.00	1.00
2,2,3,4-Tetramethylpentane	20	80	0	4	1.12	1.11	1.10	1.02	0.97
2,3,3,4-Tetramethylpentane					1.06	1.07	1.04	.97	.94
3,4,4-Trimethyl-2-pentene					1.18	1.20	1.20	1.16	1.10
2,3,4-Trimethyl-2-pentene					1.22	1.23	1.28	1.24	1.18
87.5 percent S-4 plus 12.5 percent n-heptane	0	0	100	4	1.00	1.00	1.00	1.00	1.00
2,2,3,4-Tetramethylpentane	25	0	75	4	1.07	1.10	1.07	1.01	0.98
2,3,3,4-Tetramethylpentane					1.08	1.10	1.07	1.01	.98
3,4,4-Trimethyl-2-pentene					1.26	1.21	1.15	1.12	1.11
2,3,4-Trimethyl-2-pentene					1.19	1.18	1.18	1.15	1.10

[a]Relative temperature sensitivity

$$= \frac{\dfrac{\text{imep of hydrocarbon blend (inlet-air temperature, } 100^\circ \text{ F)}}{\text{imep of hydrocarbon blend (inlet-air temperature, } 250^\circ \text{ F)}}}{\dfrac{\text{imep of base fuel (inlet-air temperature, } 100^\circ \text{ F)}}{\text{imep of base fuel (inlet-air temperature, } 250^\circ \text{ F)}}}$$

$$= \frac{\text{imep ratio (inlet-air temperature, } 100^\circ \text{ F)}}{\text{imep ratio (inlet-air temperature, } 250^\circ \text{ F)}}$$

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TABLE VI. - LEAD SUSCEPTIBILITY OF HYDROCARBON BLENDS

RELATIVE TO THAT OF S-4 REFERENCE FUEL

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

Compound	Inlet-air temperature (°F)	Composition (percent by volume)		Relative lead susceptibility[a]				
				Fuel-air ratio				
		Hydrocarbon	S-4 reference fuel	0.065	0.07	0.085	0.10	0.11
S-4 reference fuel	250	0	100	1.00	1.00	1.00	1.00	1.00
2,2,3,4-Tetramethylpentane	250	10	90	1.06	1.07	1.03	0.98	0.98
2,3,3,4-Tetramethylpentane				1.08	1.07	1.06	1.08	1.04
3,4,4-Trimethyl-2-pentene				1.00	.98	.98	1.01	1.00
2,3,4-Trimethyl-2-pentene				1.01	1.01	1.00	1.03	1.01
2,2,3,4-Tetramethylpentane	250	20	80	1.14	1.16	1.10	1.03	1.01
2,3,3,4-Tetramethylpentane				1.16	1.15	1.07	1.07	1.00
3,4,4-Trimethyl-2-pentene				1.00	.98	.98	1.01	1.01
2,3,4-Trimethyl-2-pentene				1.03	1.03	1.00	1.04	1.03
S-4 reference fuel	100	0	100	1.00	1.00	1.00	1.00	1.00
2,2,3,4-Tetramethylpentane	100	20	80	1.07	1.07	1.05	1.00	0.98
2,3,3,4-Tetramethylpentane				1.00	.99	.98	.94	.94
3,4,4-Trimethyl-2-pentene				1.05	1.06	1.02	.99	.98
2,3,4-Trimethyl-2-pentene				1.04	1.05	1.04	1.06	1.07

[a]Relative lead susceptibility

$$= \frac{\dfrac{\text{imep of hydrocarbon blend (with 4 ml TEL/gal)}}{\text{imep of hydrocarbon blend (with 0 ml TEL/gal)}}}{\dfrac{\text{imep of S-4 (with 4 ml TEL/gal)}}{\text{imep of S-4 (with 0 ml TEL/gal)}}}$$

$$= \frac{\text{imep ratio of hydrocarbon blend (with 4 ml TEL/gal)}}{\text{imep ratio of hydrocarbon blend (with 0 ml TEL/gal)}}$$

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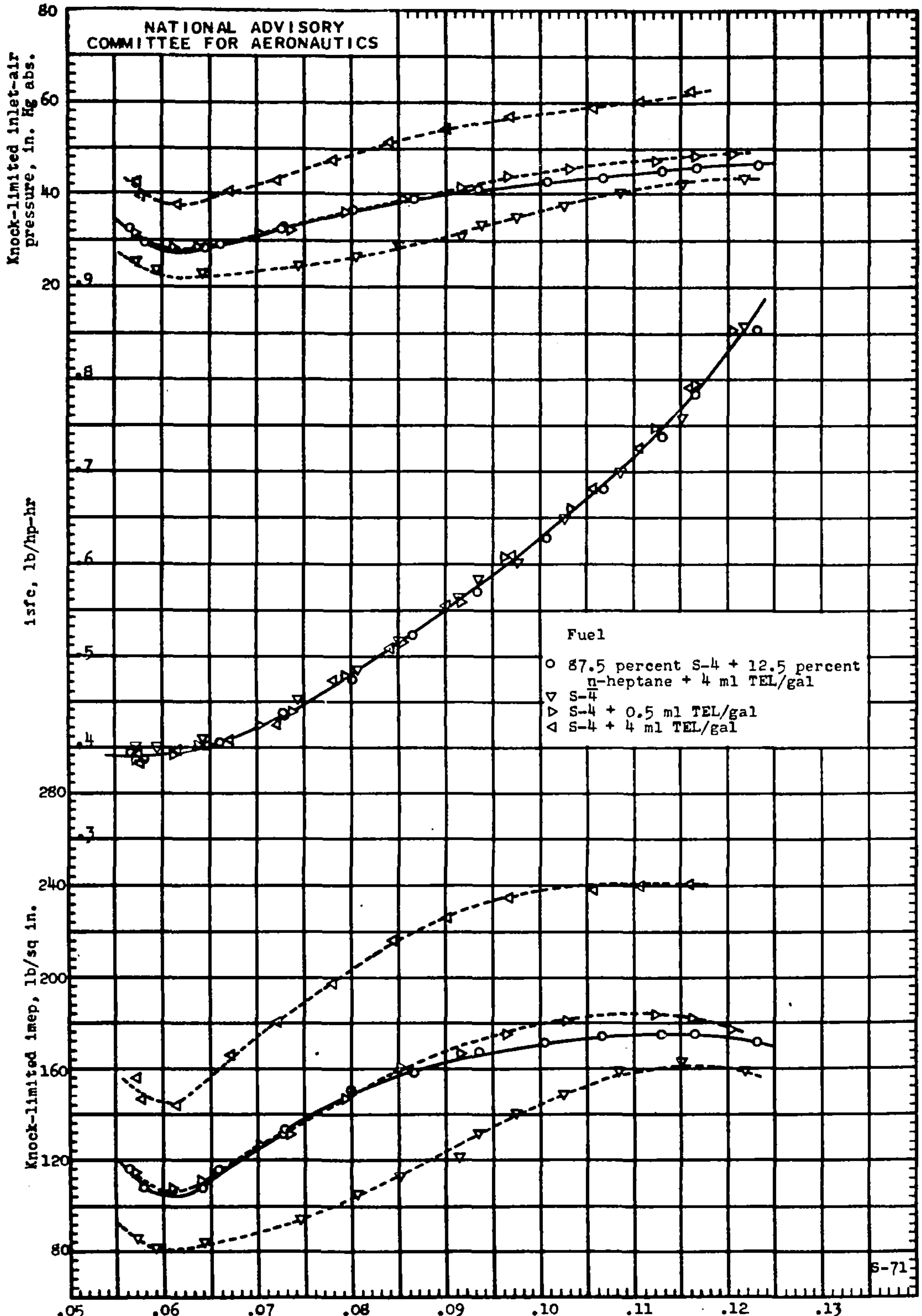


Figure 1. - The knock-limited performance of 87.5 percent S-4 plus 12.5 percent n-heptane plus 4 ml TEL per gallon in an F-4 engine.

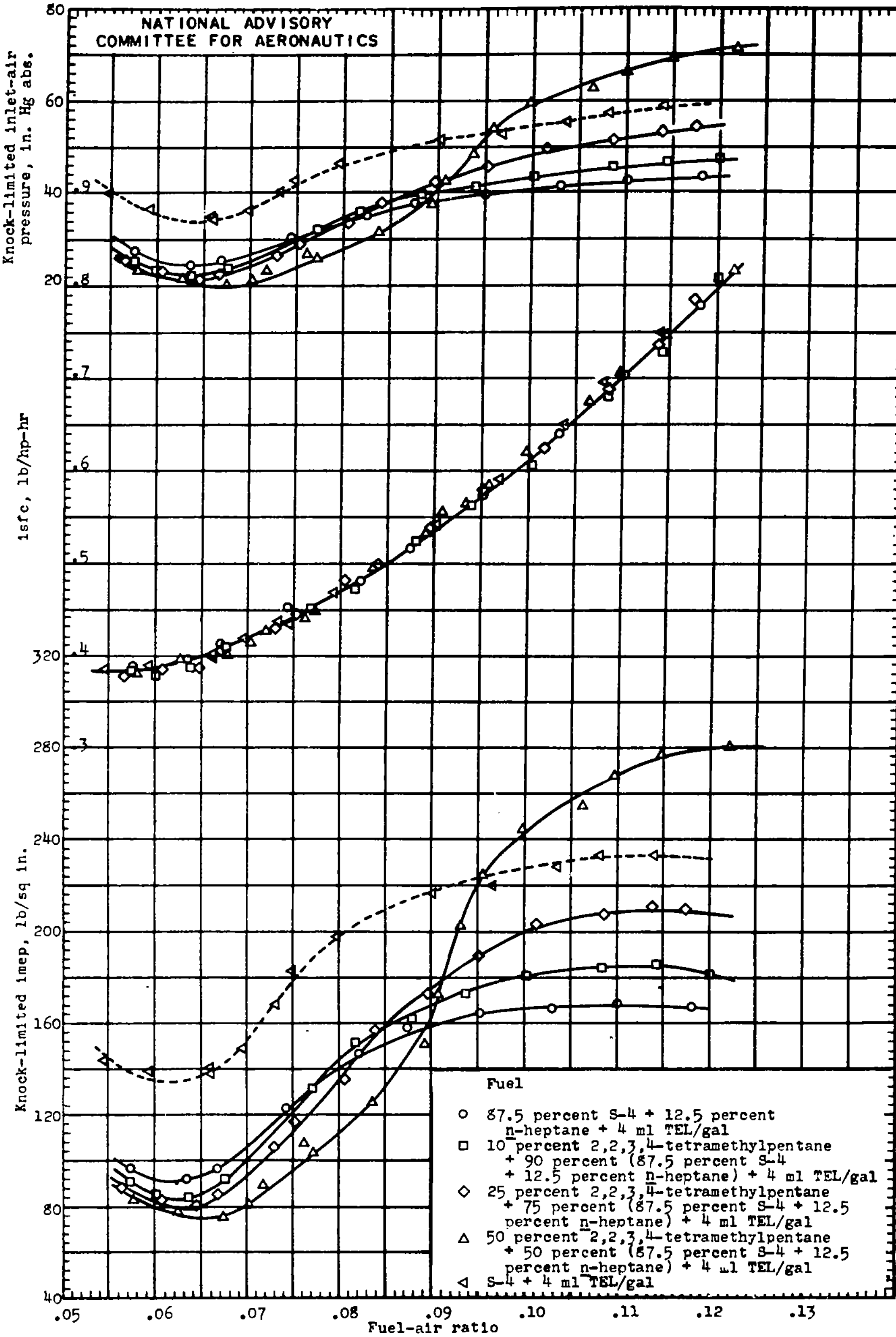


Figure 2. - The knock-limited performance of leaded blends of 2,2,3,4-tetramethylpentane and a base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane in an F-4 engine.

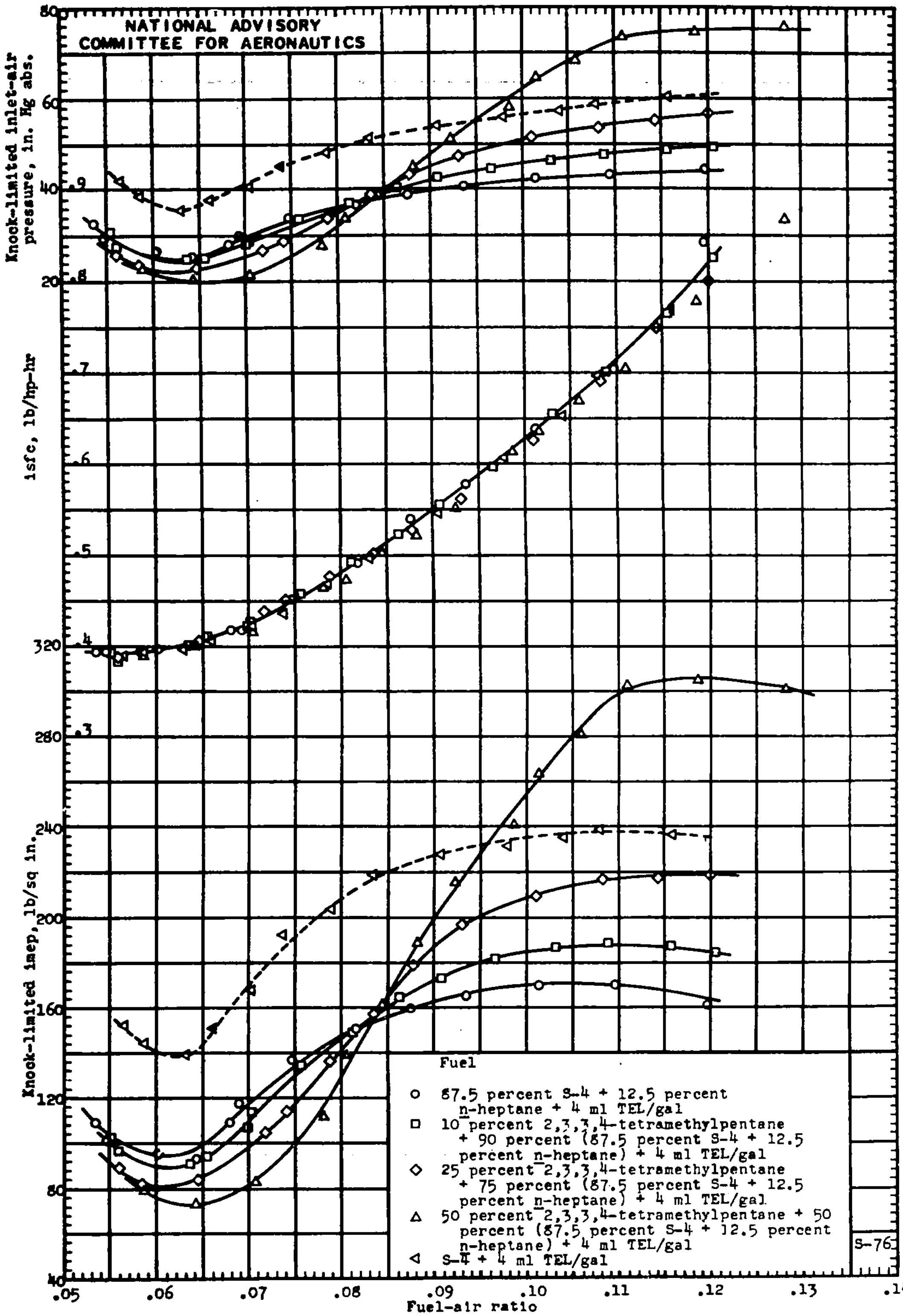


Figure 3. - The knock-limited performance of leaded blends of 2,3,3,4-tetramethylpentane and a base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane in an F-4 engine.

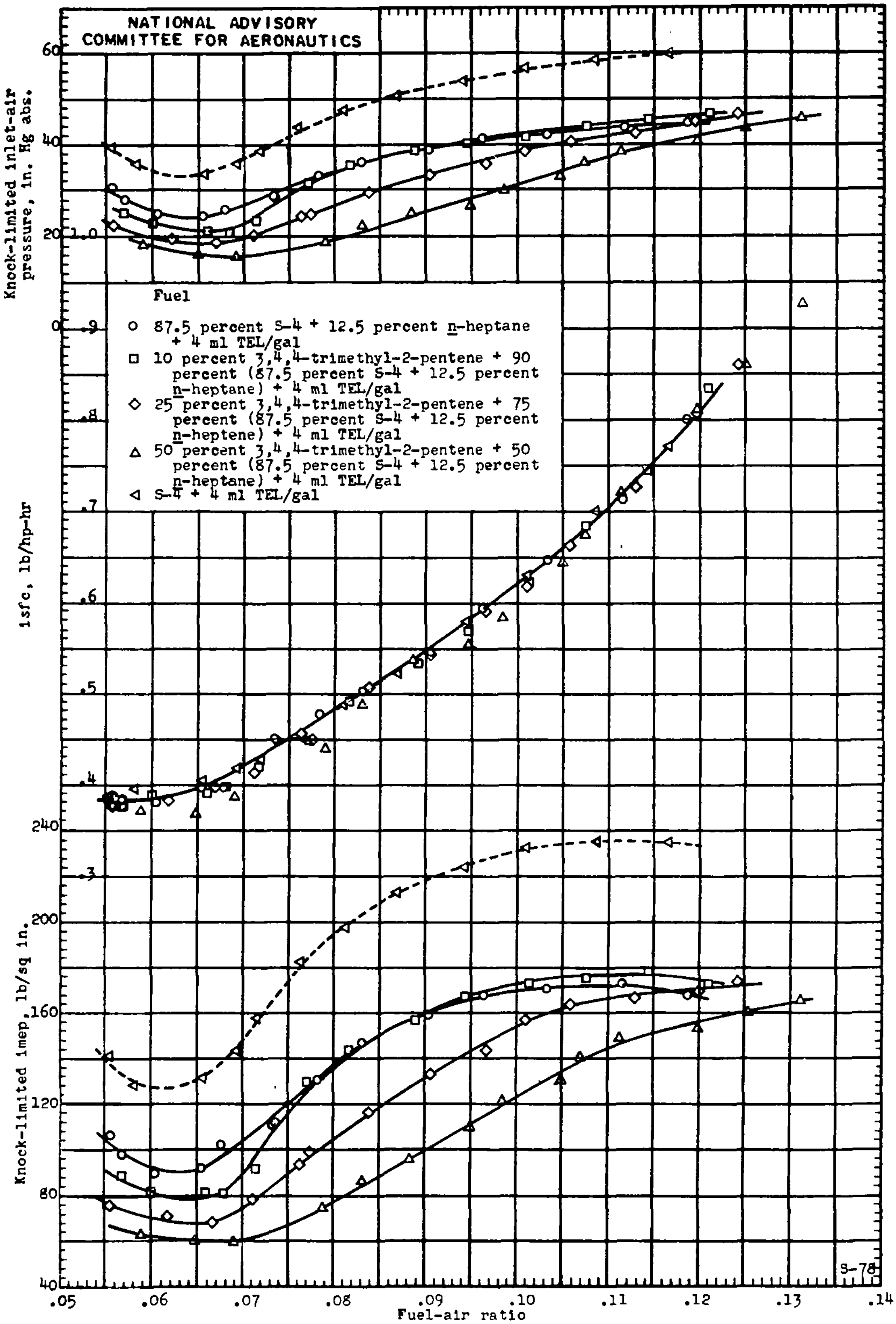


Figure 4. - The knock-limited performance of leaded blends of 3,4,4-trimethyl-2-pentene and a base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane in an F-4 engine.

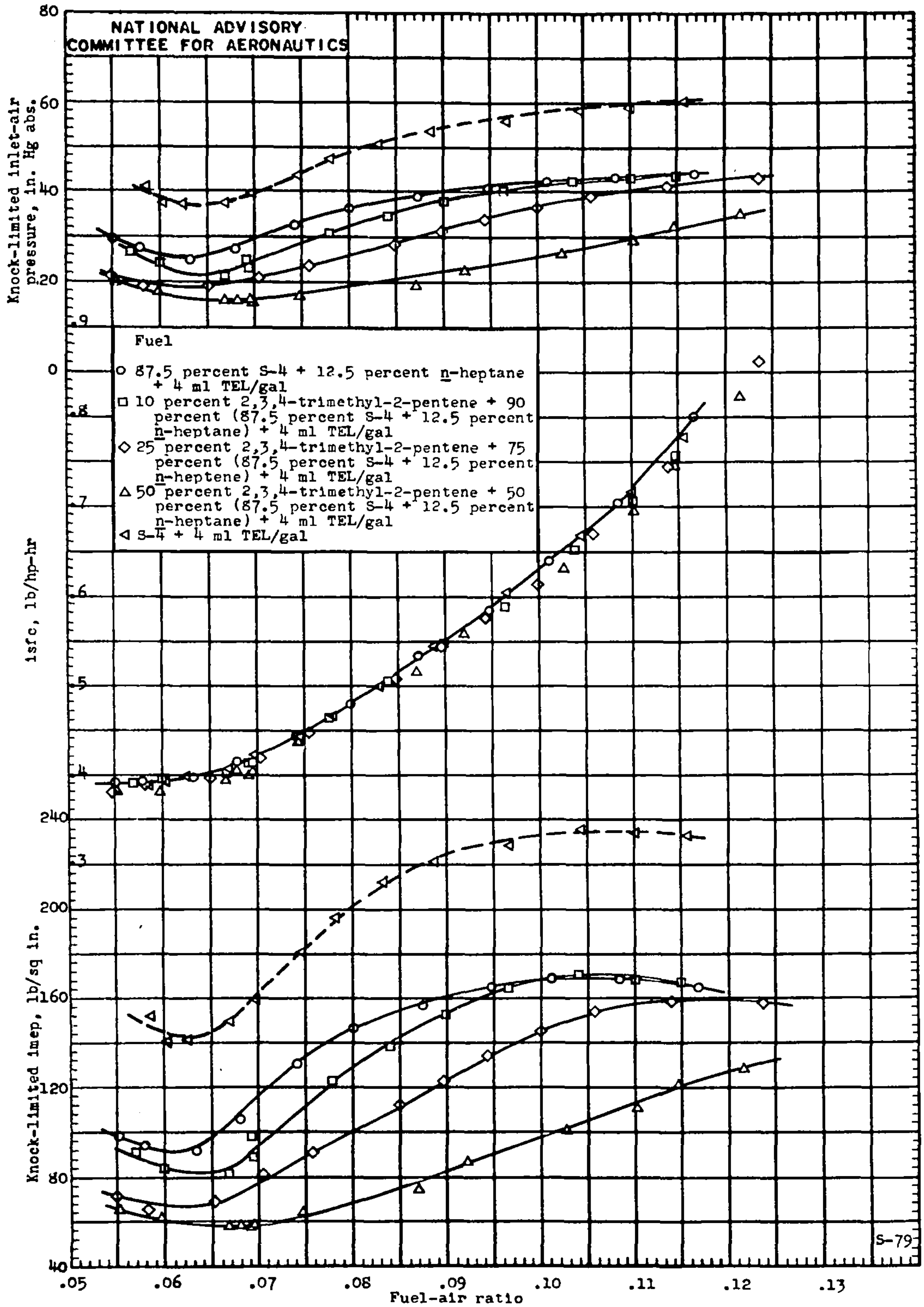


Figure 5. - The knock-limited performance of leaded blends of 2,3,4-trimethyl-2-pentene and a base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane in an F-4 engine.

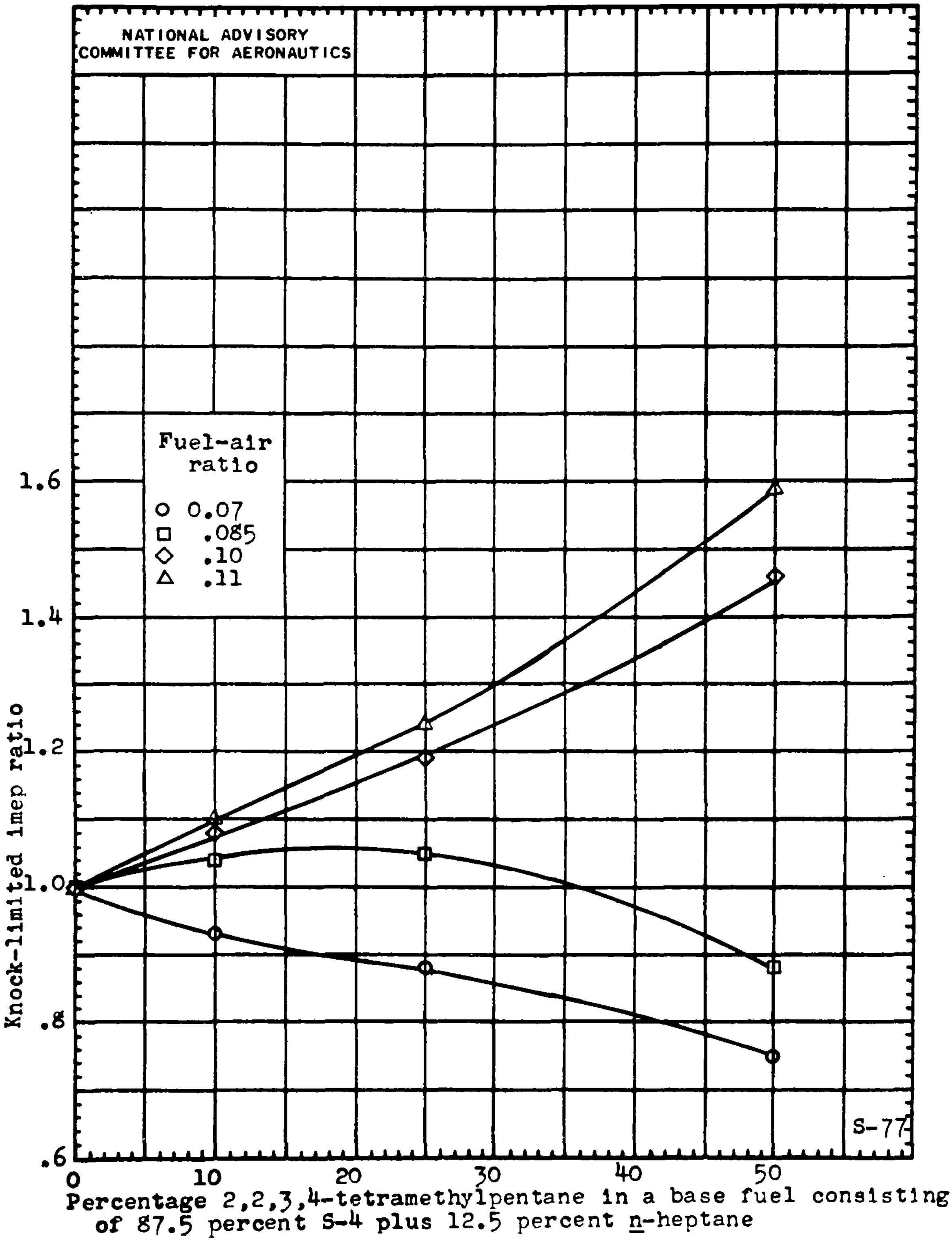


Figure 6. - The blending sensitivity of 2,2,3,4-tetramethylpentane in a base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane. F-4 engine; final blends leaded to 4 ml TEL per gallon.

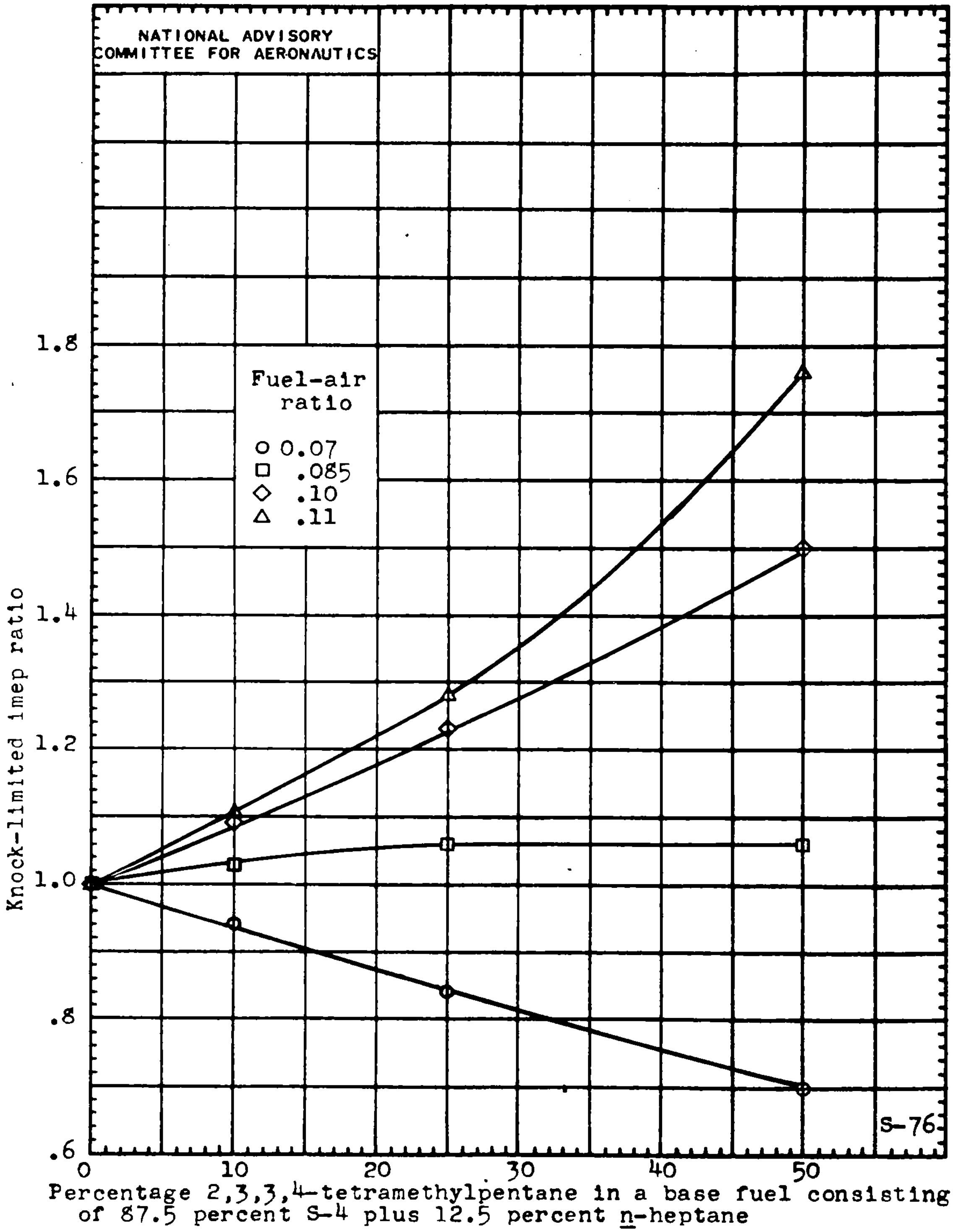
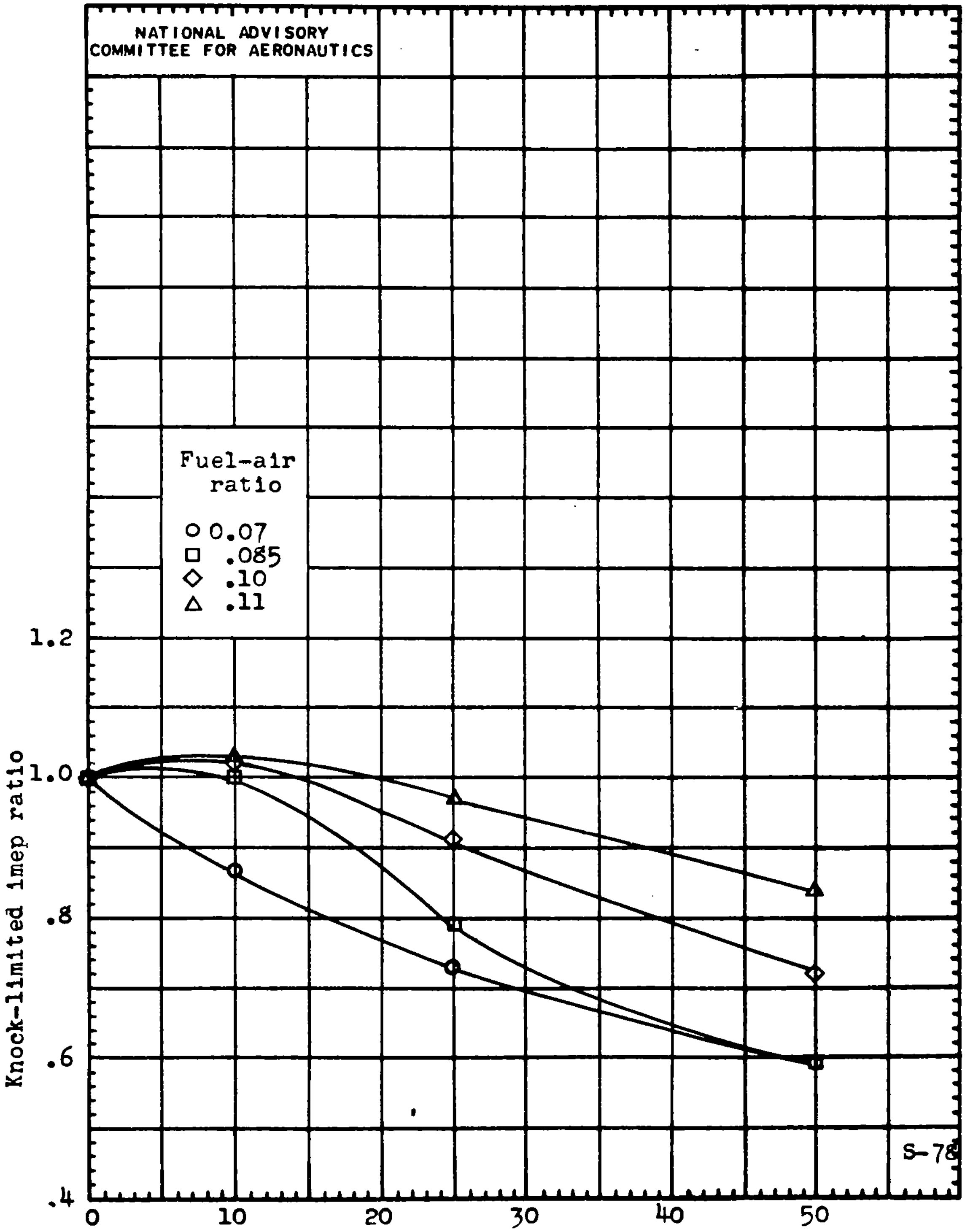


Figure 7. - The blending sensitivity of 2,3,3,4-tetramethylpentane in a base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane. F-4 engine; final blends leaded to 4 ml TEL per gallon.



Percentage 3,4,4-trimethyl-2-pentene in a base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane

Figure 8. - The blending sensitivity of 3,4,4-trimethyl-2-pentene in a base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane. F-4 engine; final blends leaded to 4 ml TEL per gallon.

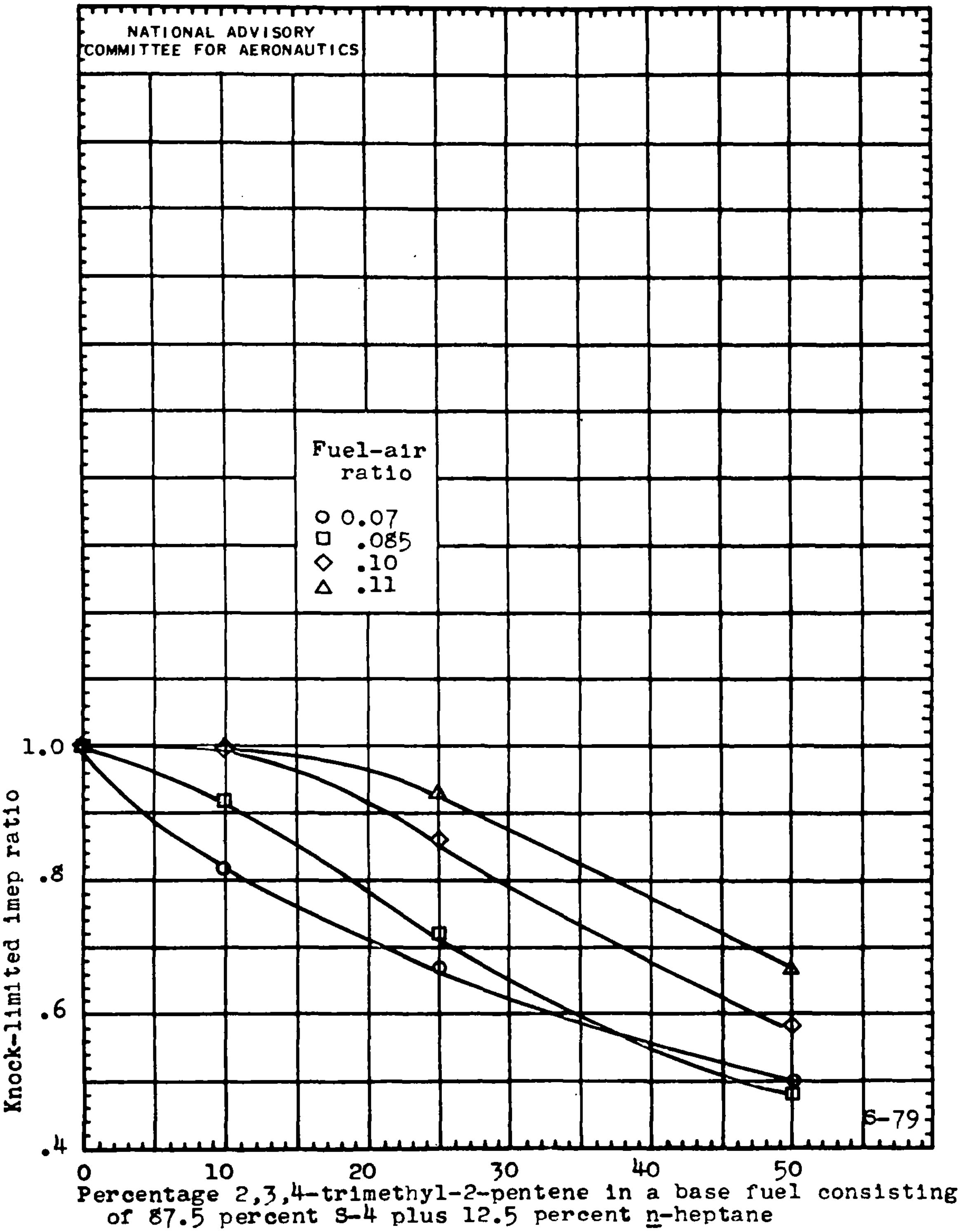


Figure 9. - The blending sensitivity of 2,3,4-trimethyl-2-pentene in a base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane. F-4 engine; final blends leaded to 4 ml TEL per gallon.

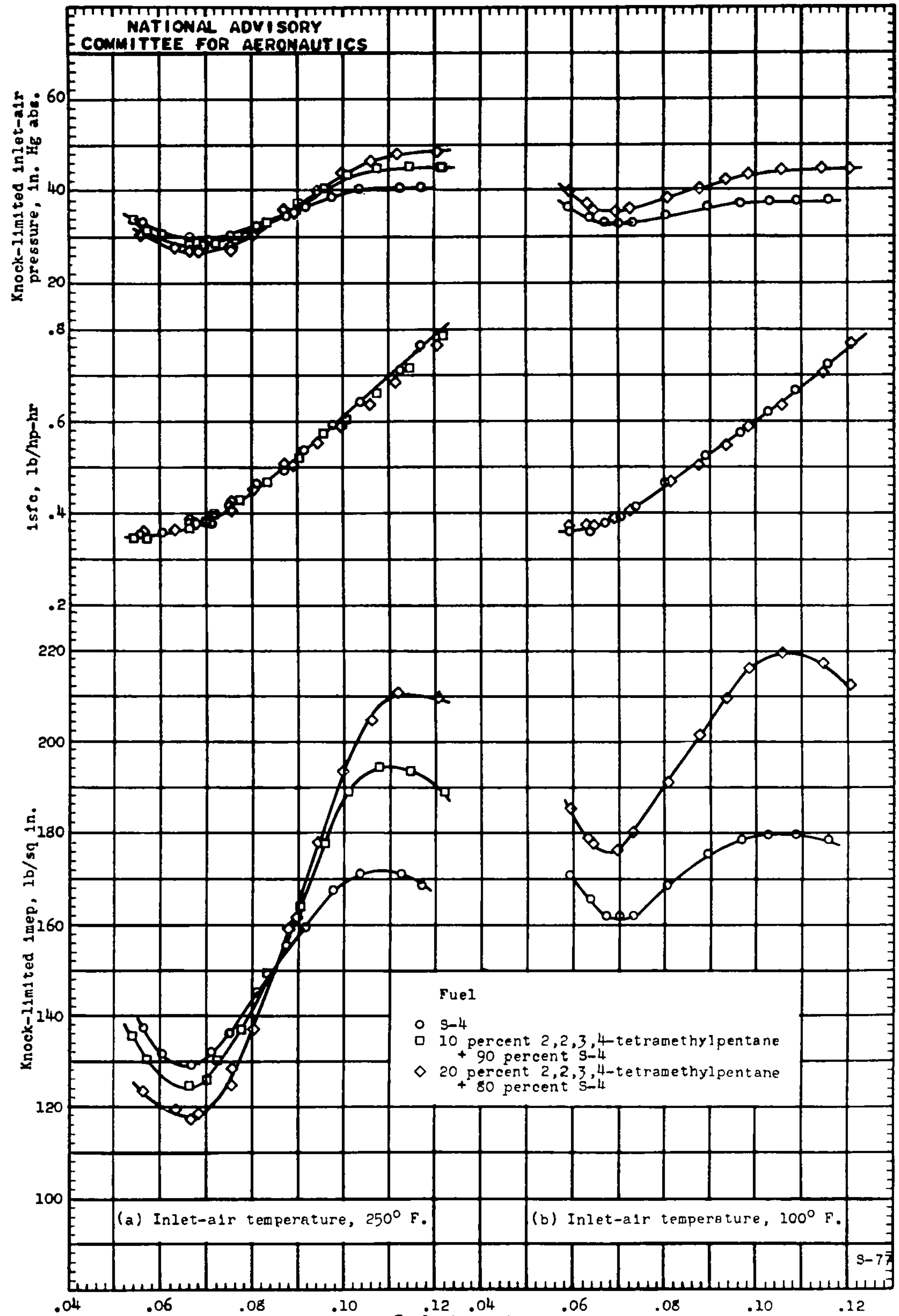


Figure 10. - The knock-limited performance of unleaded blends of 2,2,3,4-tetramethylpentane and S-4 reference fuel in a 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

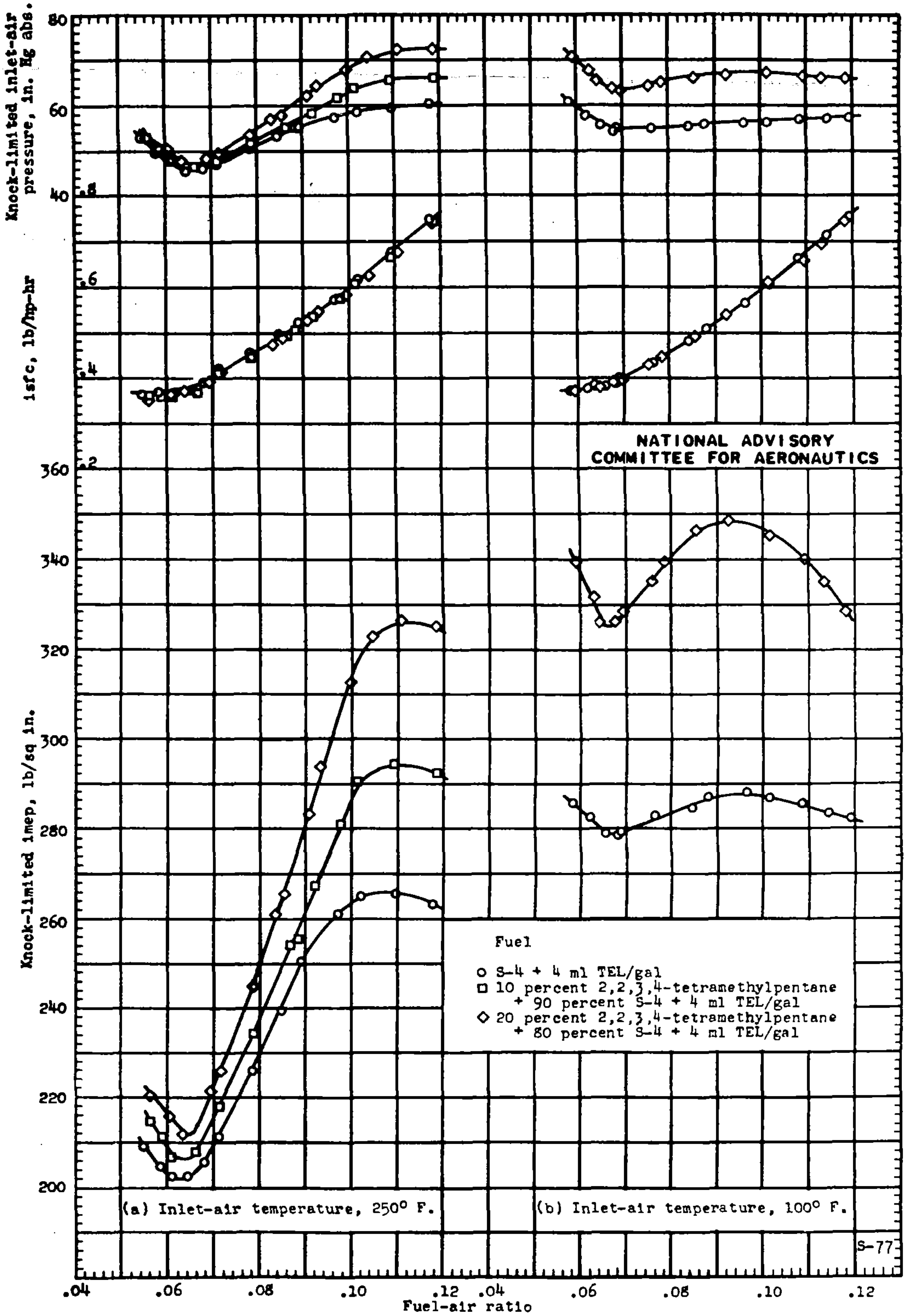


Figure 11. - The knock-limited performance of leaded blends of 2,2,3,4-tetramethylpentane and S-4 reference fuel in a 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

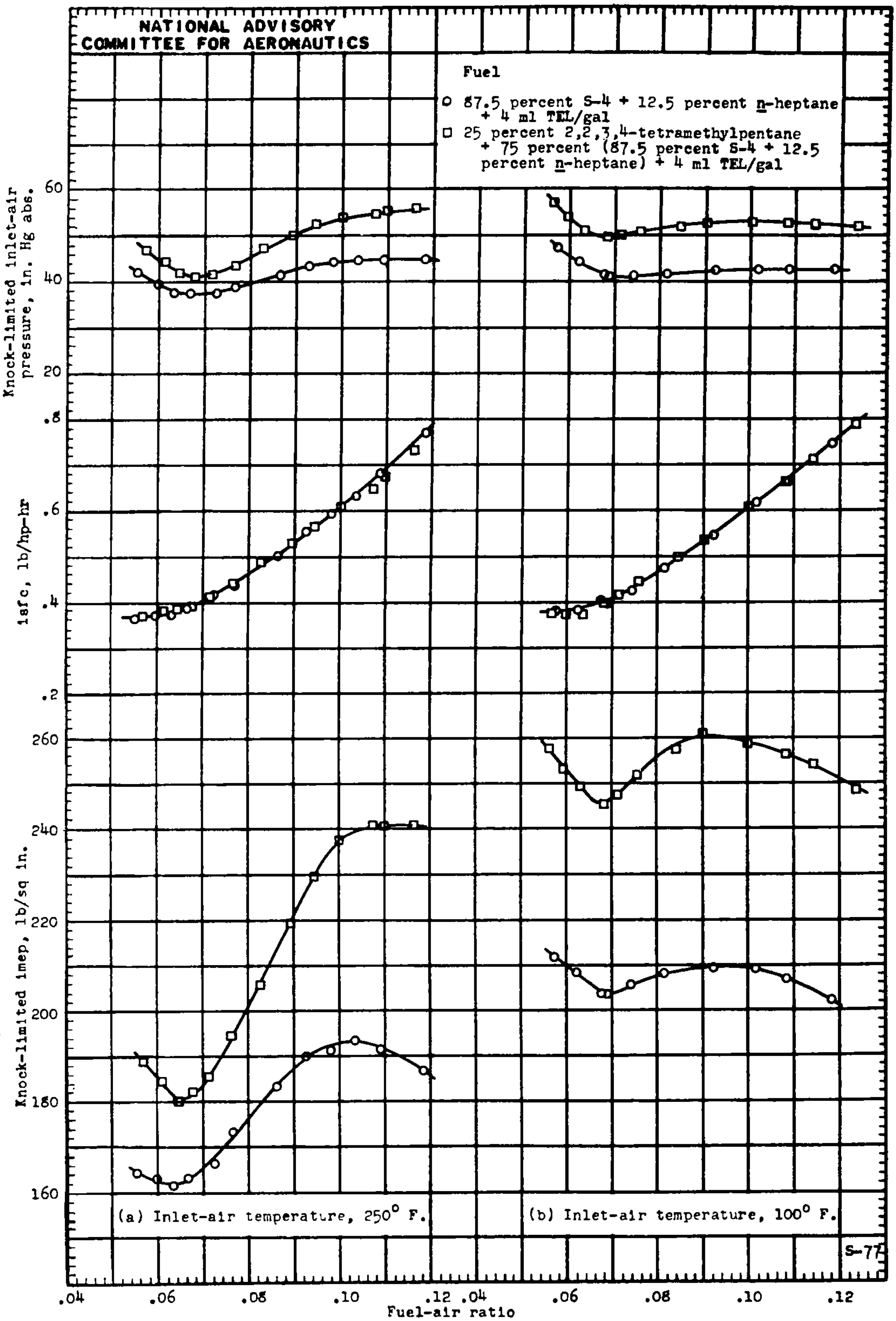


Figure 12. - The knock-limited performance of leaded blends of 2,2,3,4-tetramethylpentane and a base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane in a 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

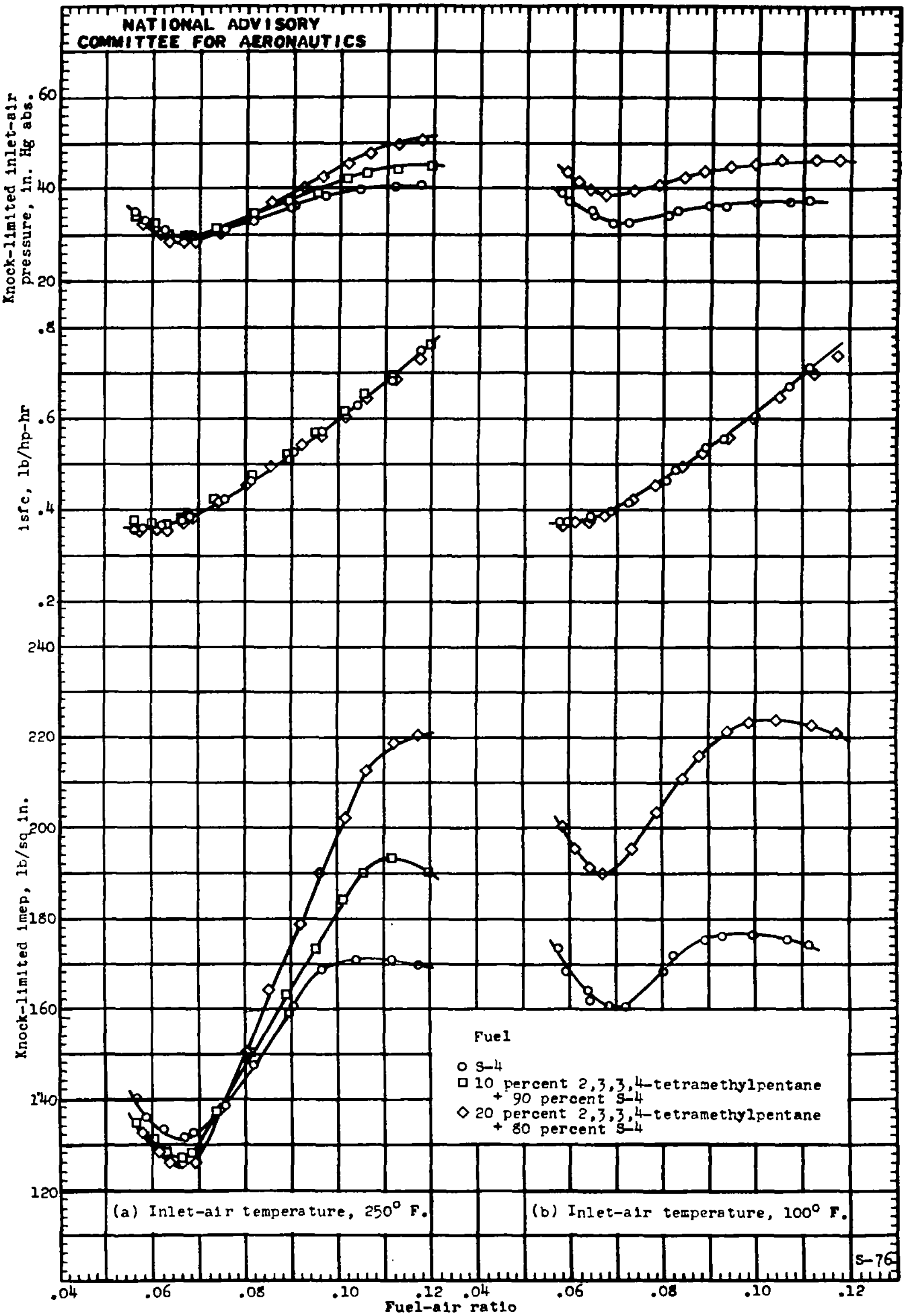


Figure 13. - The knock-limited performance of unleaded blends of 2,3,3,4-tetramethylpentane and S-4 reference fuel in a 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

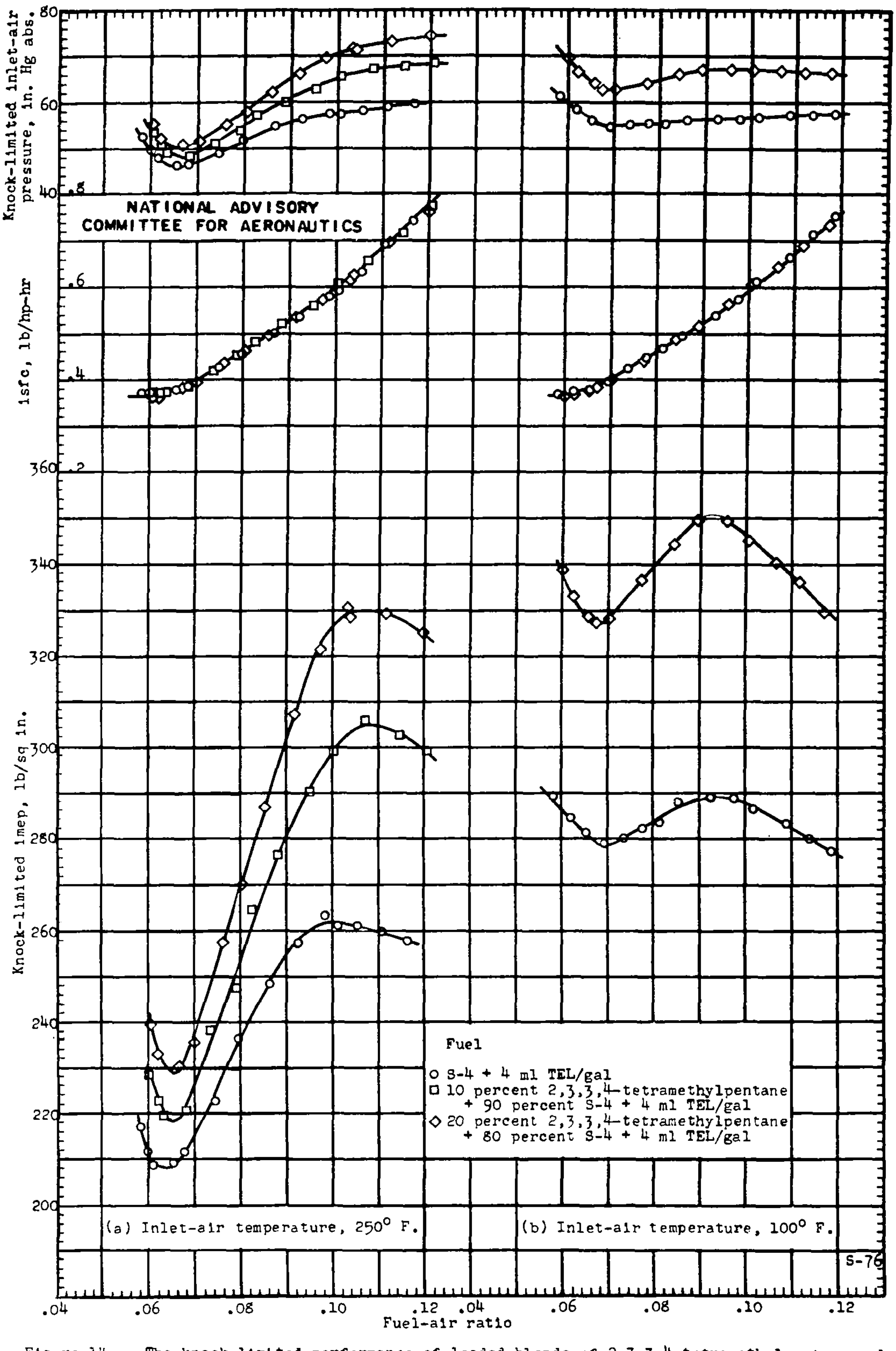


Figure 14. - The knock-limited performance of leaded blends of 2,3,3,4-tetramethylpentane and S-4 reference fuel in a 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

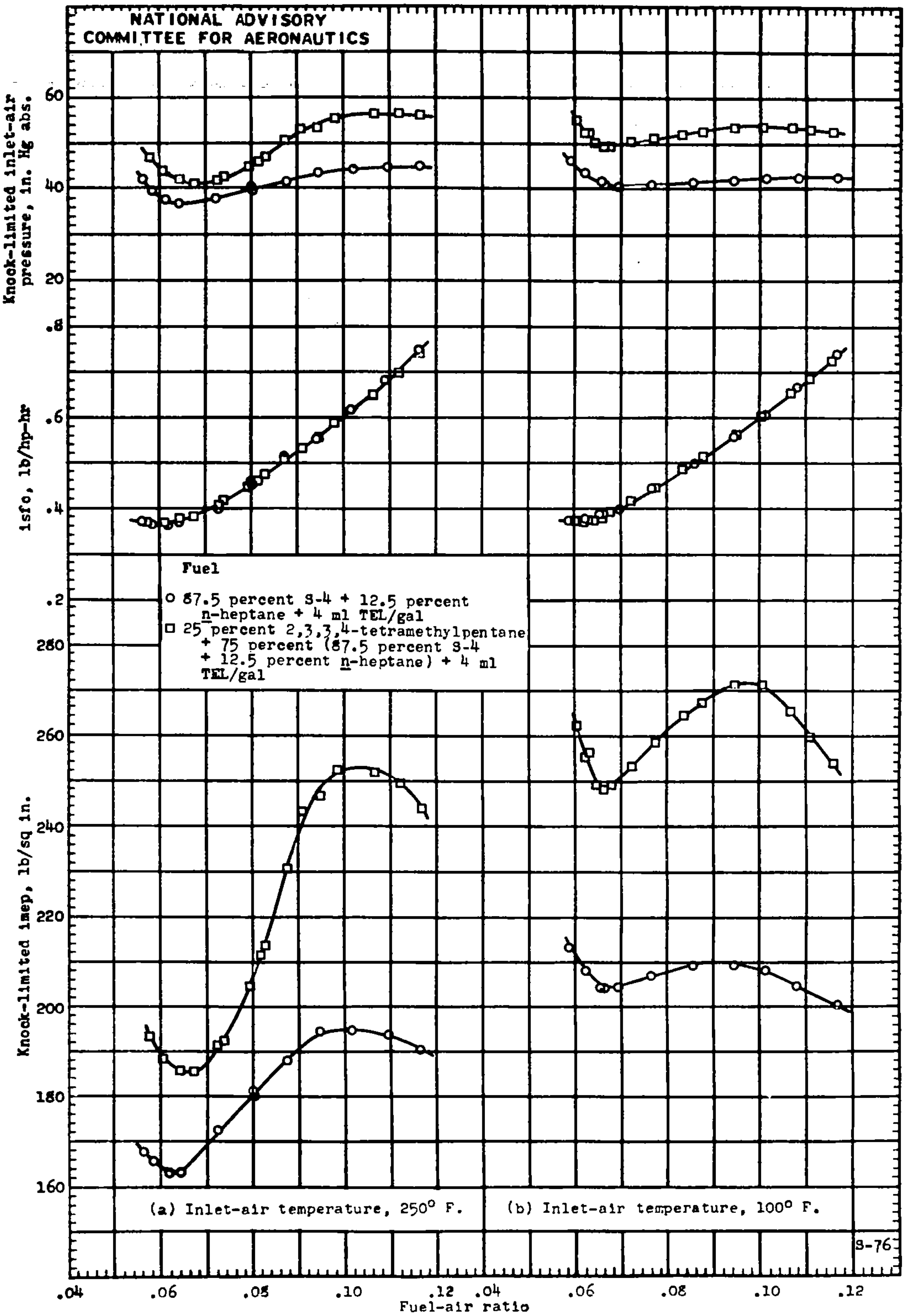


Figure 15. - The knock-limited performance of leaded blends of 2,3,3,4-tetramethylpentane and a base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane in a 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

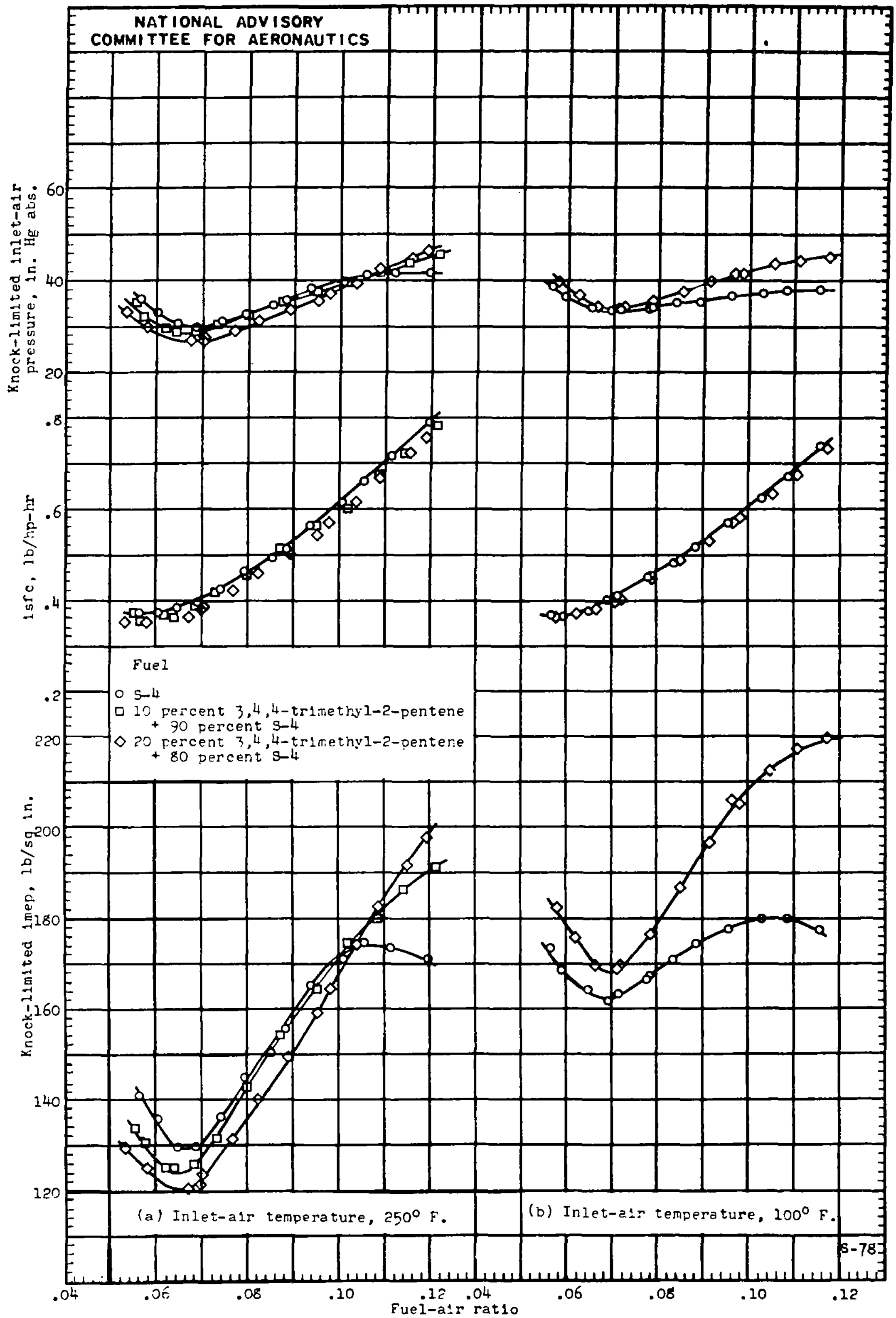


Figure 16. - The knock-limited performance of unleaded blends of 3,4,4-trimethyl-2-pentene and S-4 reference fuel in a 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

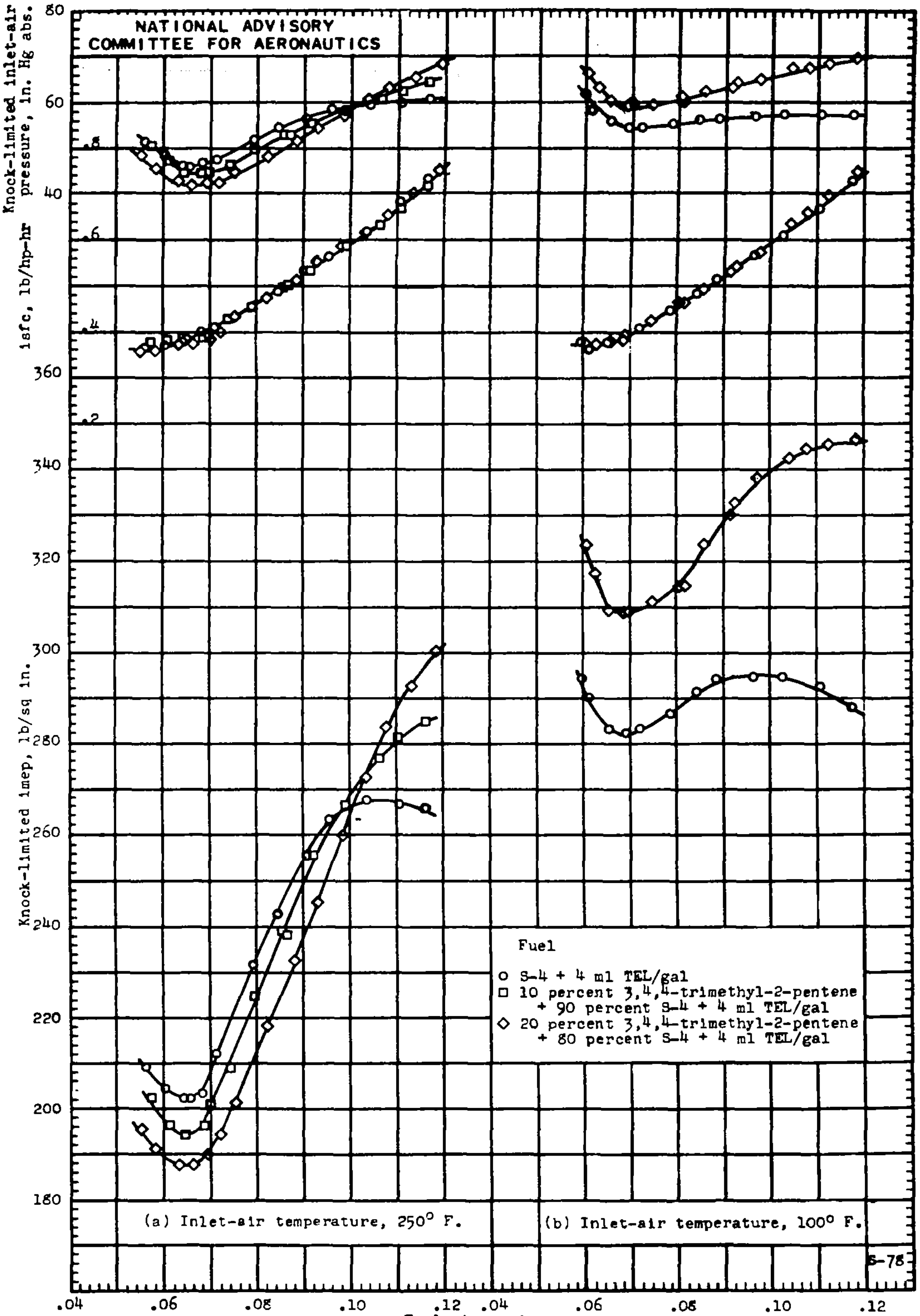


Figure 17. - The knock-limited performance of leaded blends of 3,4,4-trimethyl-2-pentene and S-4 reference fuel in a 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

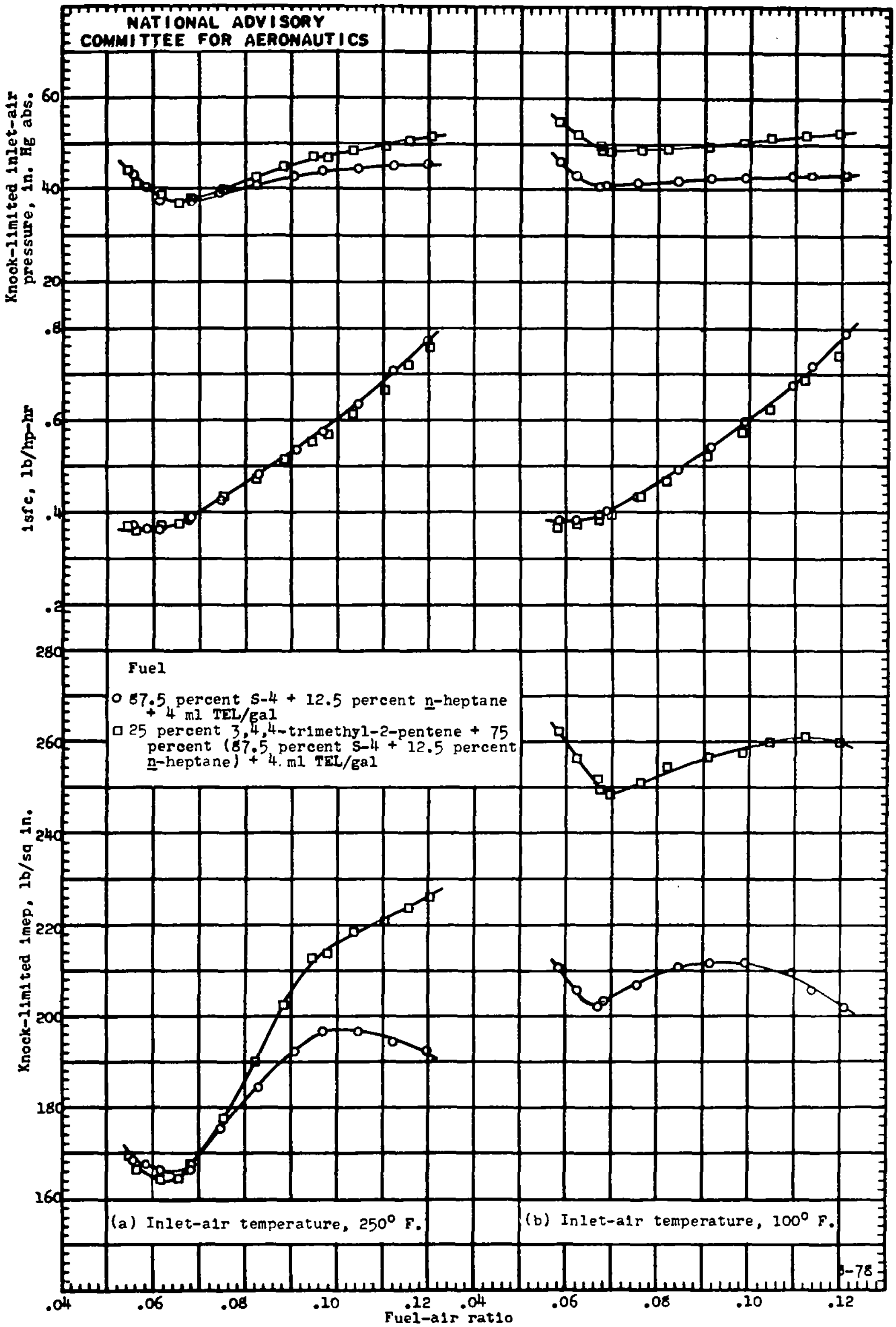


Figure 18. - The knock-limited performance of leaded blends of 3,4,4-trimethyl-2-pentene and a base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane in a 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

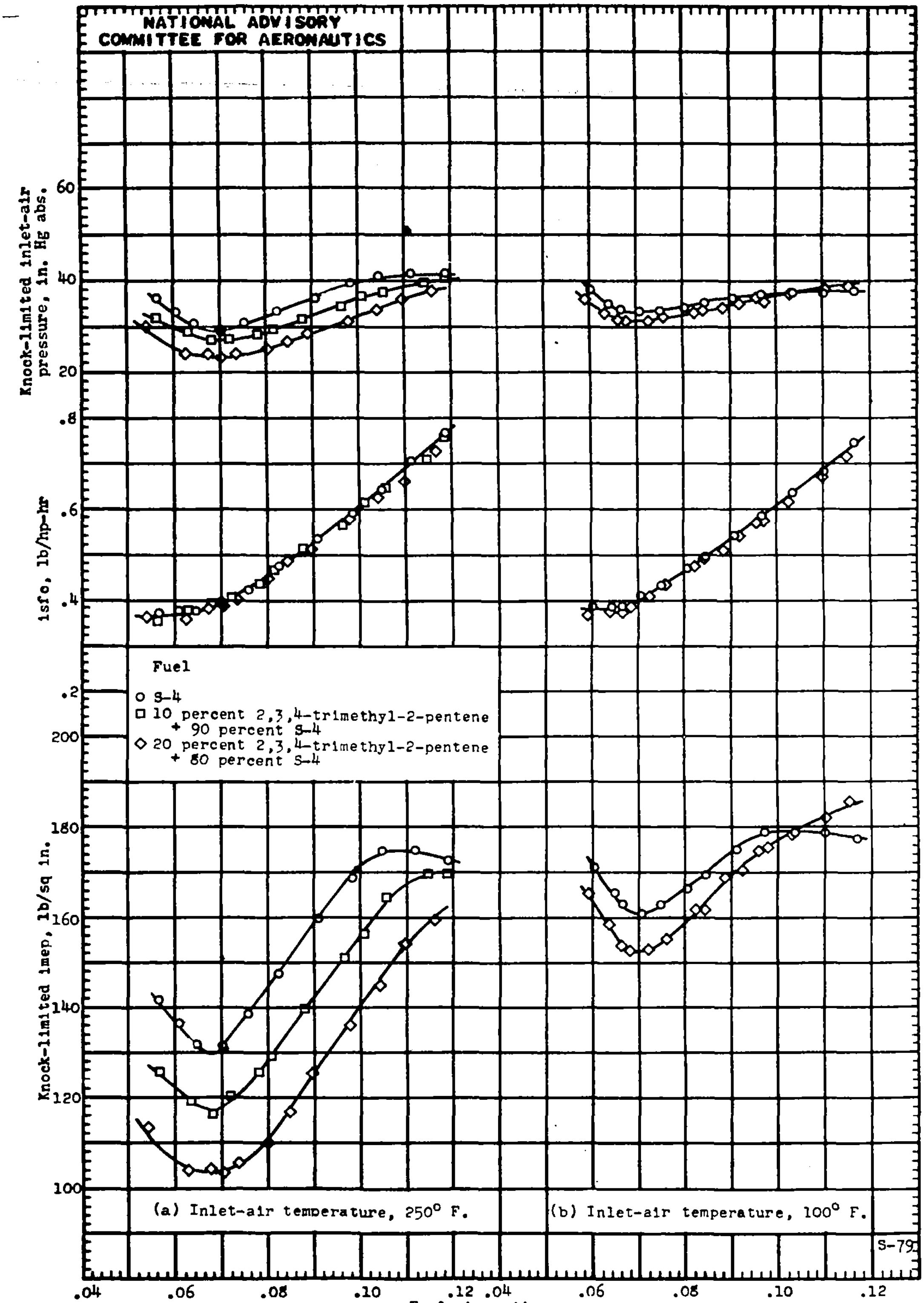


Figure 19. - The knock-limited performance of unleaded blends of 2,3,4-trimethyl-2-pentene and S-4 reference fuel in a 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

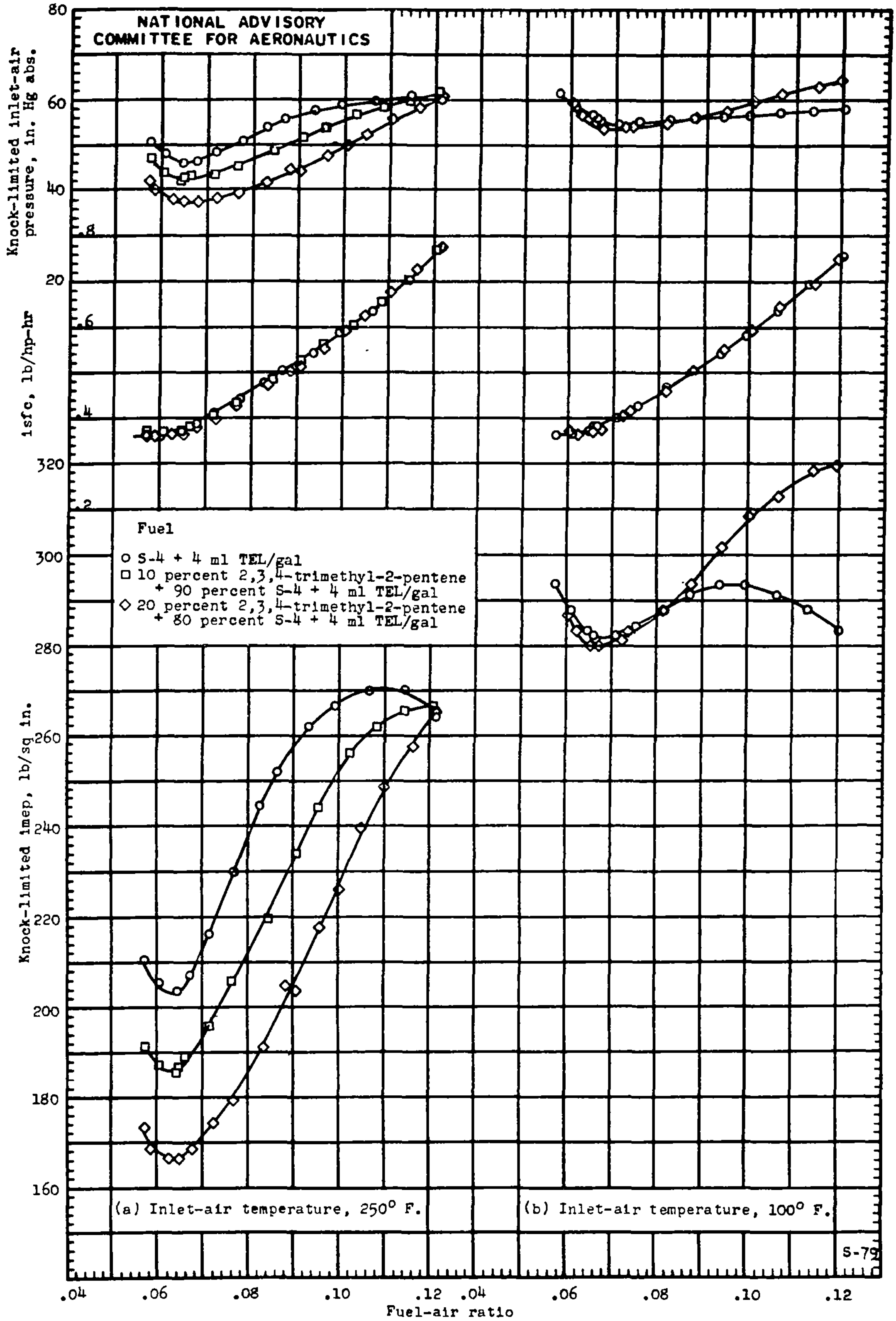


Figure 20. - The knock-limited performance of leaded blends of 2,3,4-trimethyl-2-pentene and S-4 reference fuel in a 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

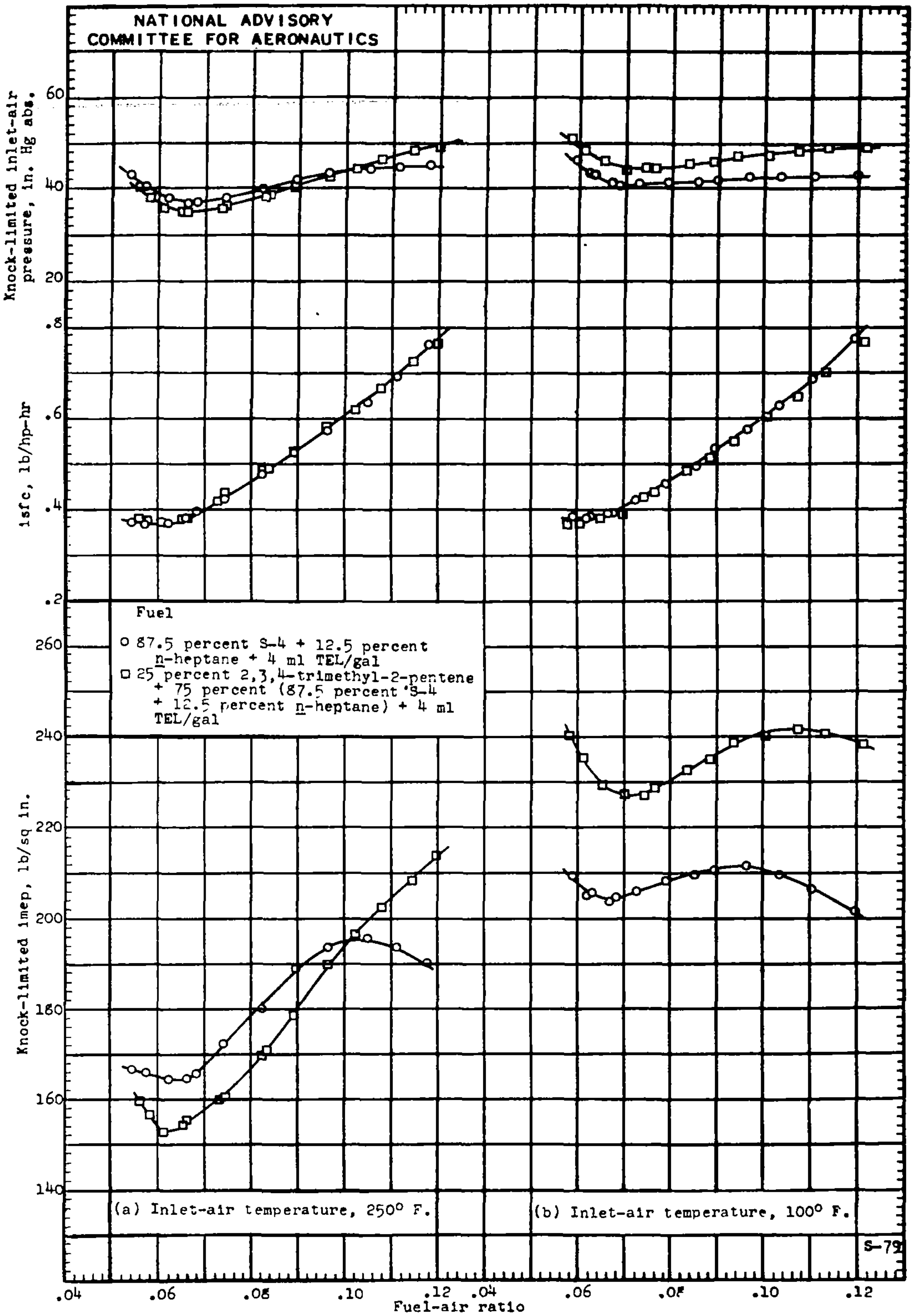


Figure 21. - The knock-limited performance of leaded blends of 2,3,4-trimethyl-2-pentene and a base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane in a 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

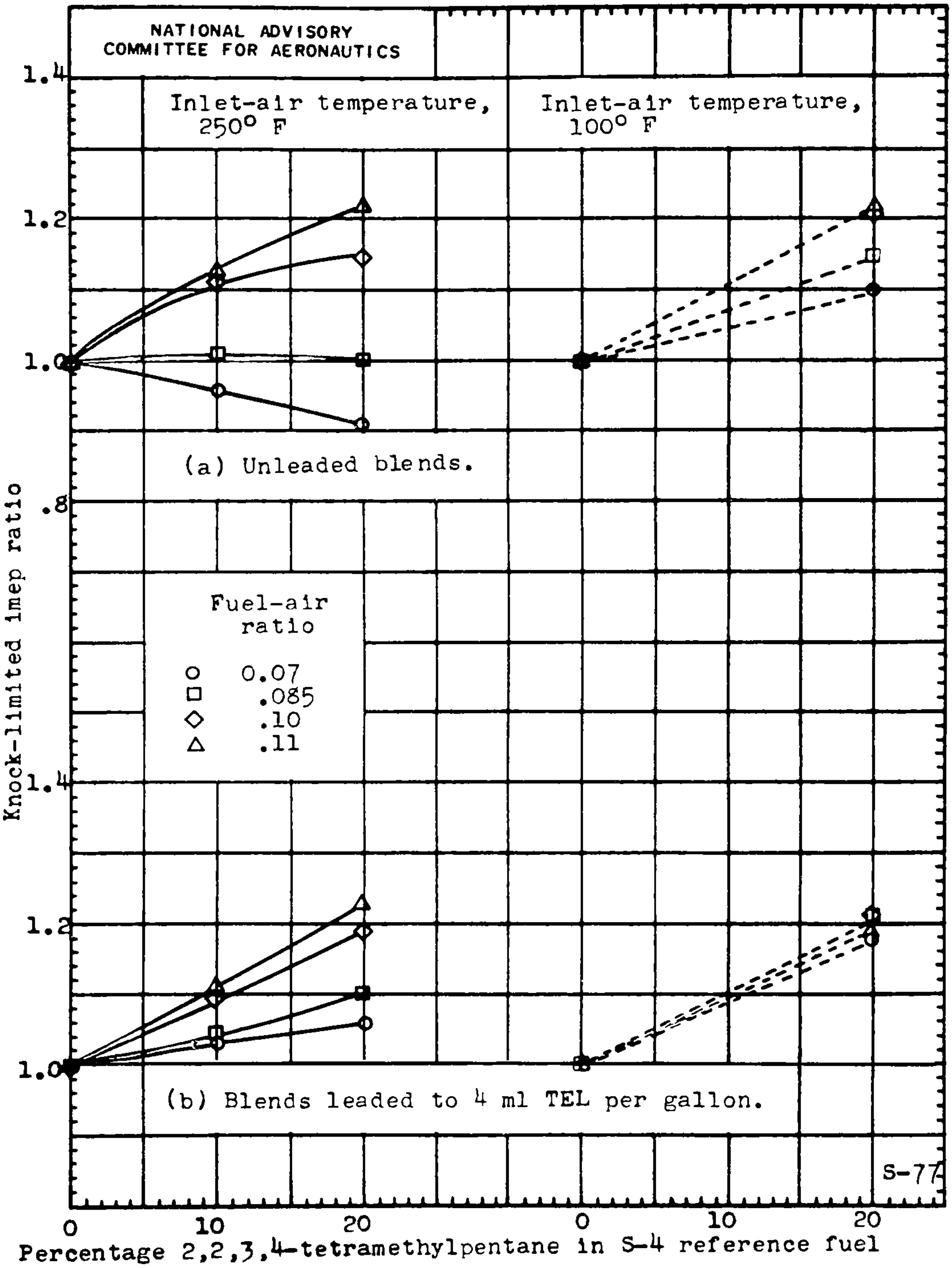


Figure 22. - The blending sensitivity of 2,2,3,4-tetramethylpentane in S-4 reference fuel. 17.6 engine.

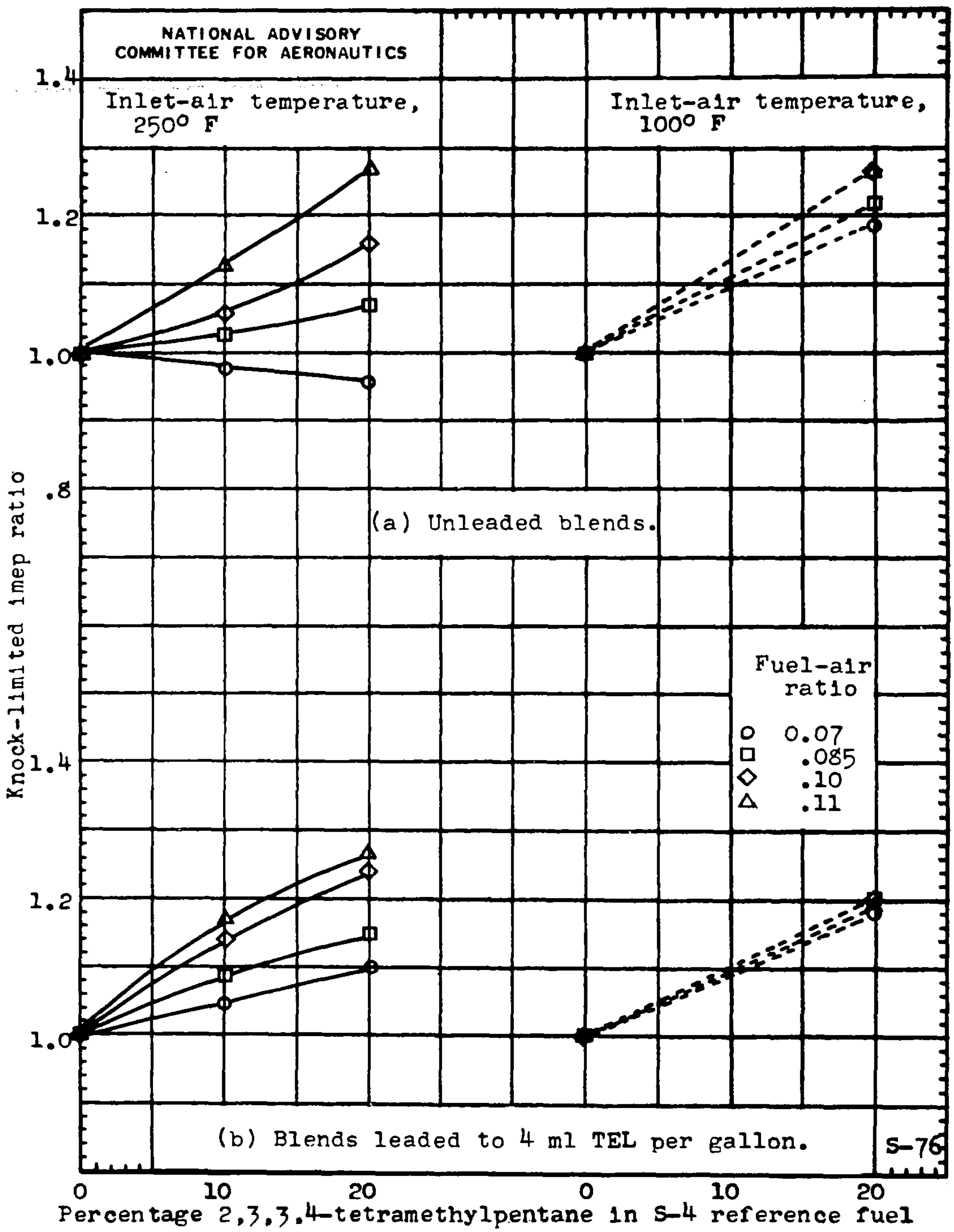


Figure 23. - The blending sensitivity of 2,3,3,4-tetramethylpentane in S-4 reference fuel. 17.6 engine.

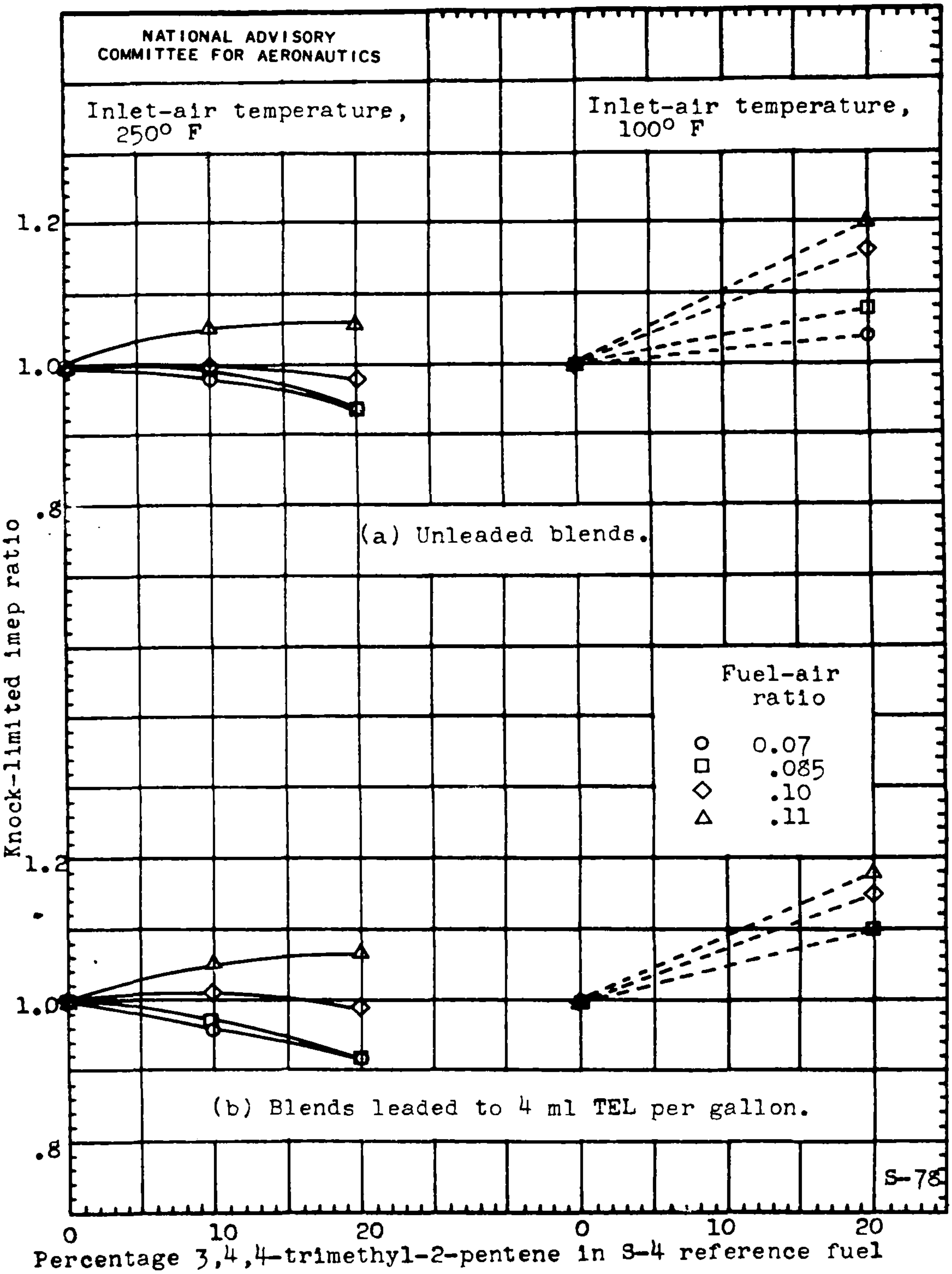


Figure 24. - The blending sensitivity of 3,4,4-trimethyl-2-pentene in S-4 reference fuel. 17.6 engine.

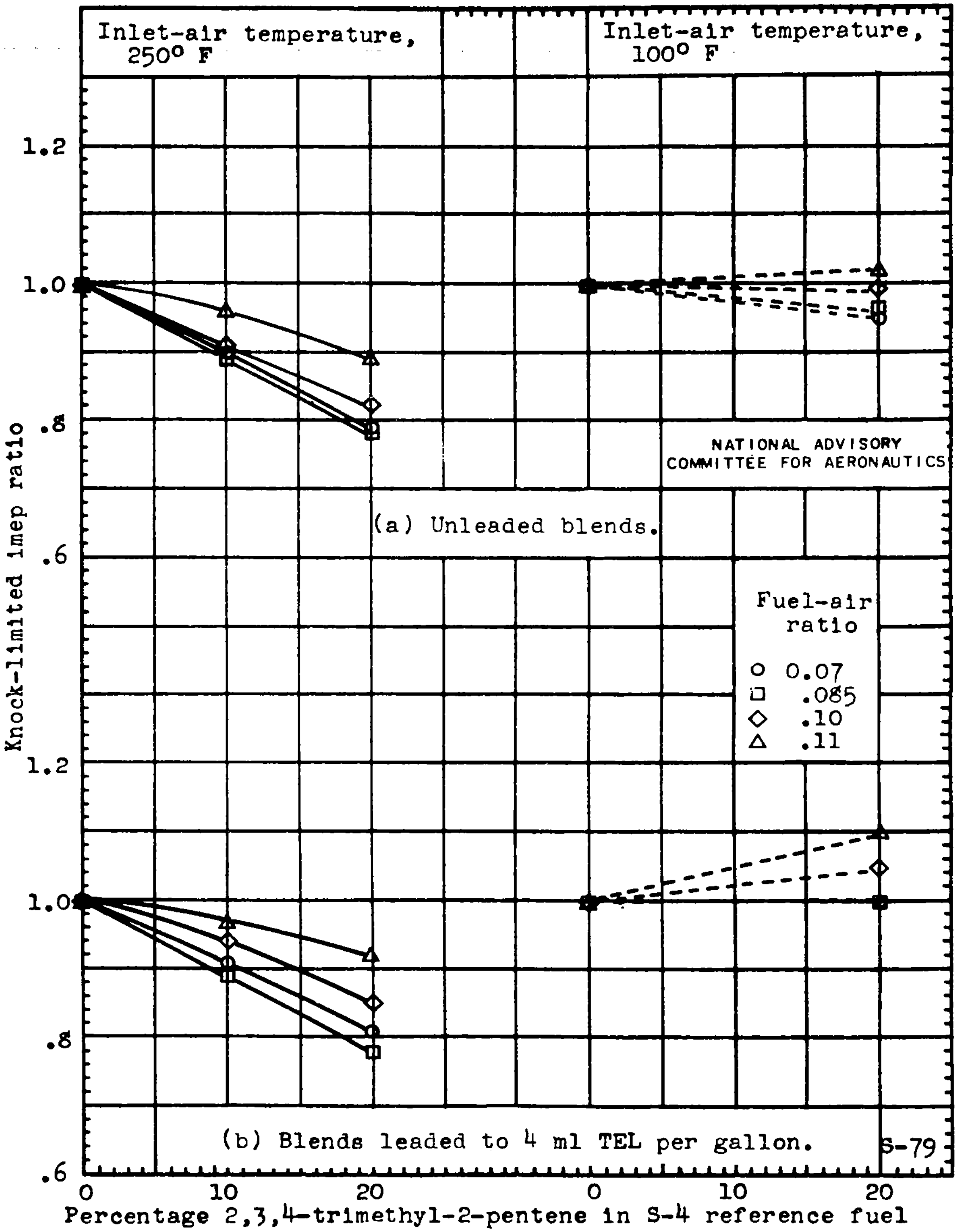


Figure 25. - The blending sensitivity of 2,3,4-trimethyl-2-pentene in S-4 reference fuel. 17.6 engine.

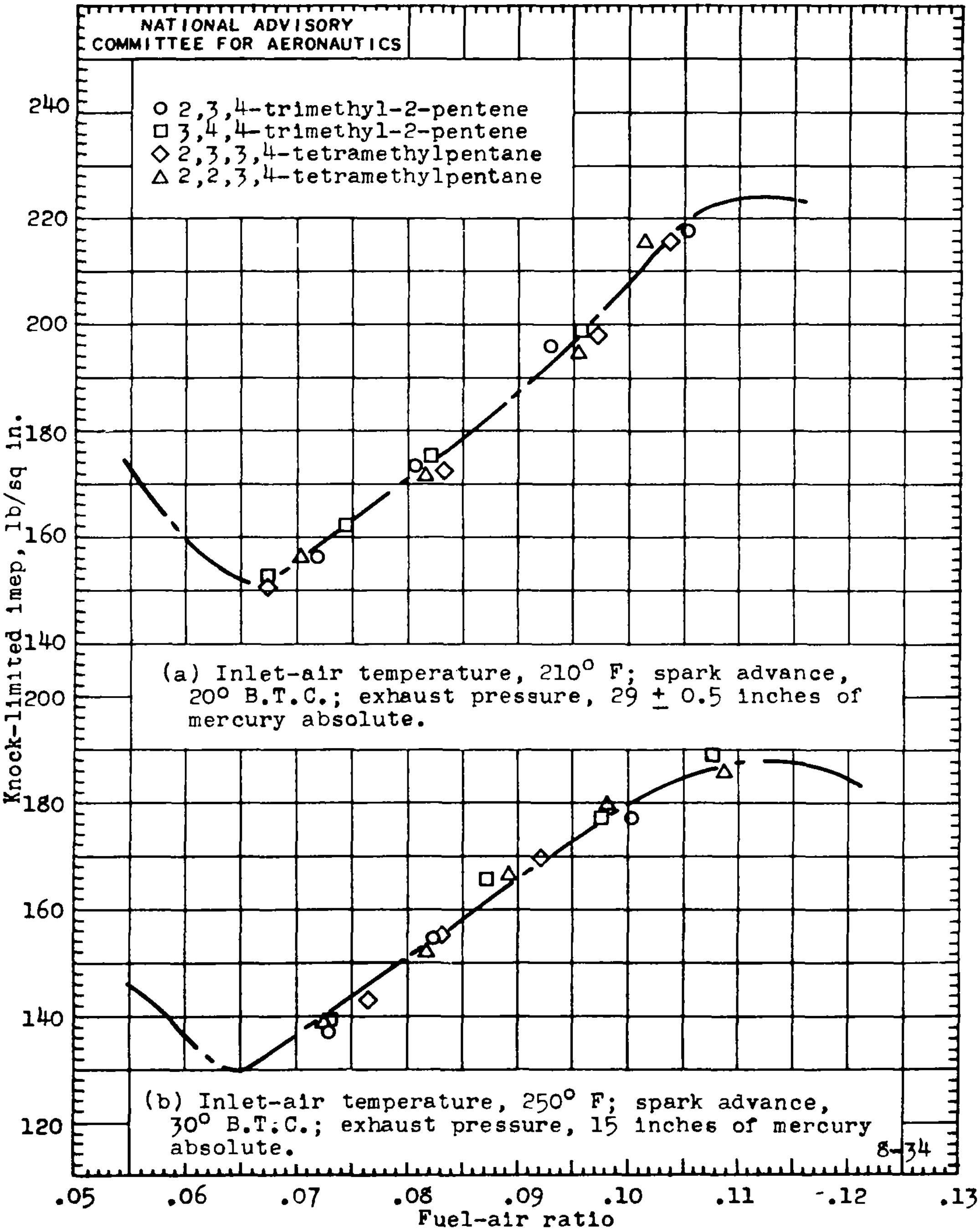


Figure 26. - Reproducibility of knock-limited indicated mean effective pressure with check runs. Fuel, 85 percent S-4 plus 15 percent M-4 plus 4 ml TEL per gallon. (Symbols correspond to those in figs. 31 and 32 and indicate the check points for the test fuels.) The mixture-response curves shown are averages of several complete curves and do not include the check points. Full-scale cylinder; compression ratio, 7.3; engine speed, 2000 rpm.

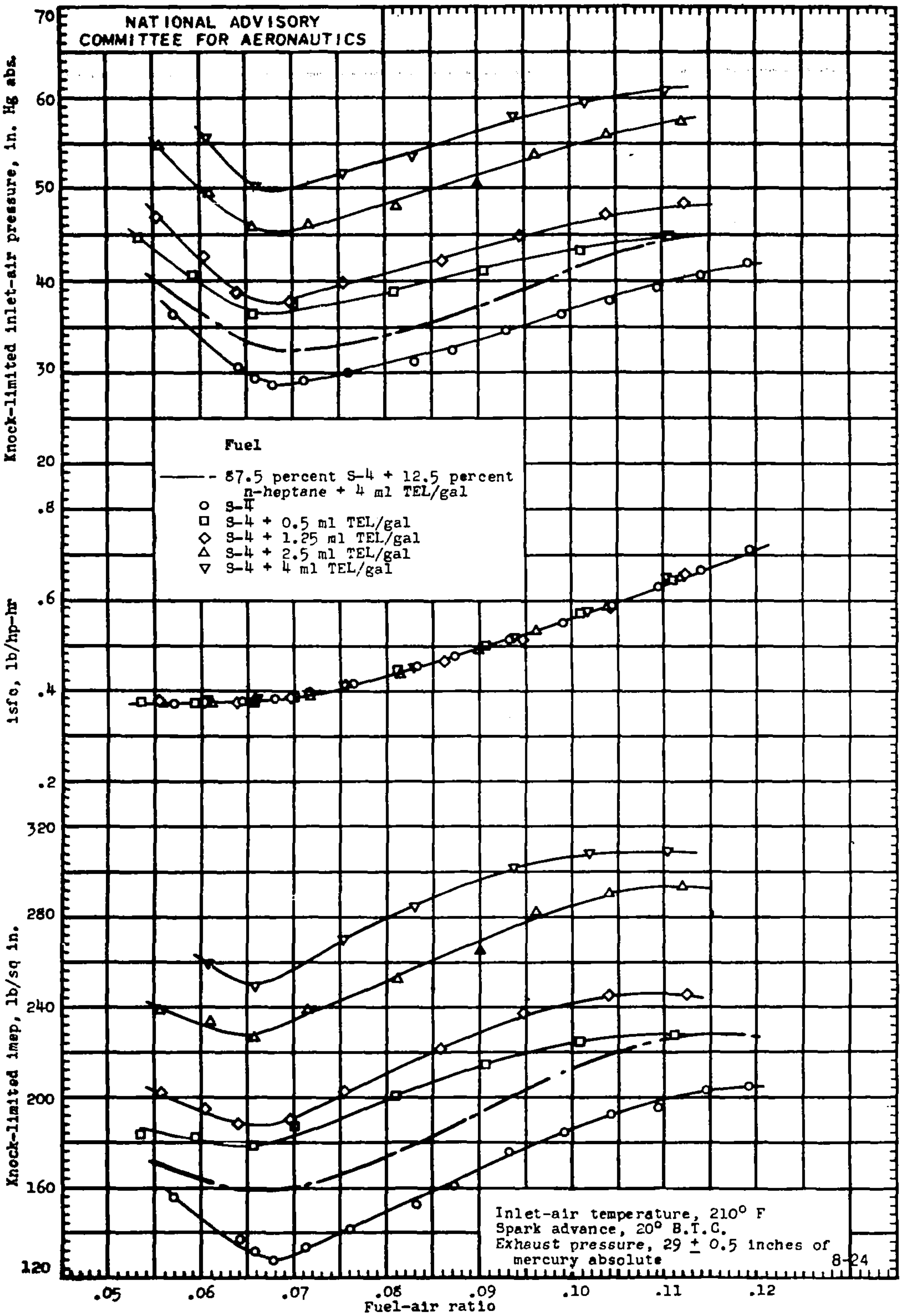


Figure 27. - Reference-fuel framework at an inlet-air temperature of 210° F, a spark advance of 20° B.T.C., and an exhaust pressure of 29 ± 0.5 inches of mercury absolute. Full-scale cylinder; compression ratio, 7.3; engine speed, 2000 rpm; cooling air adjusted at 140 bmep and 0.10 fuel-air ratio to give a rear spark-plug-bushing temperature of 365° F.

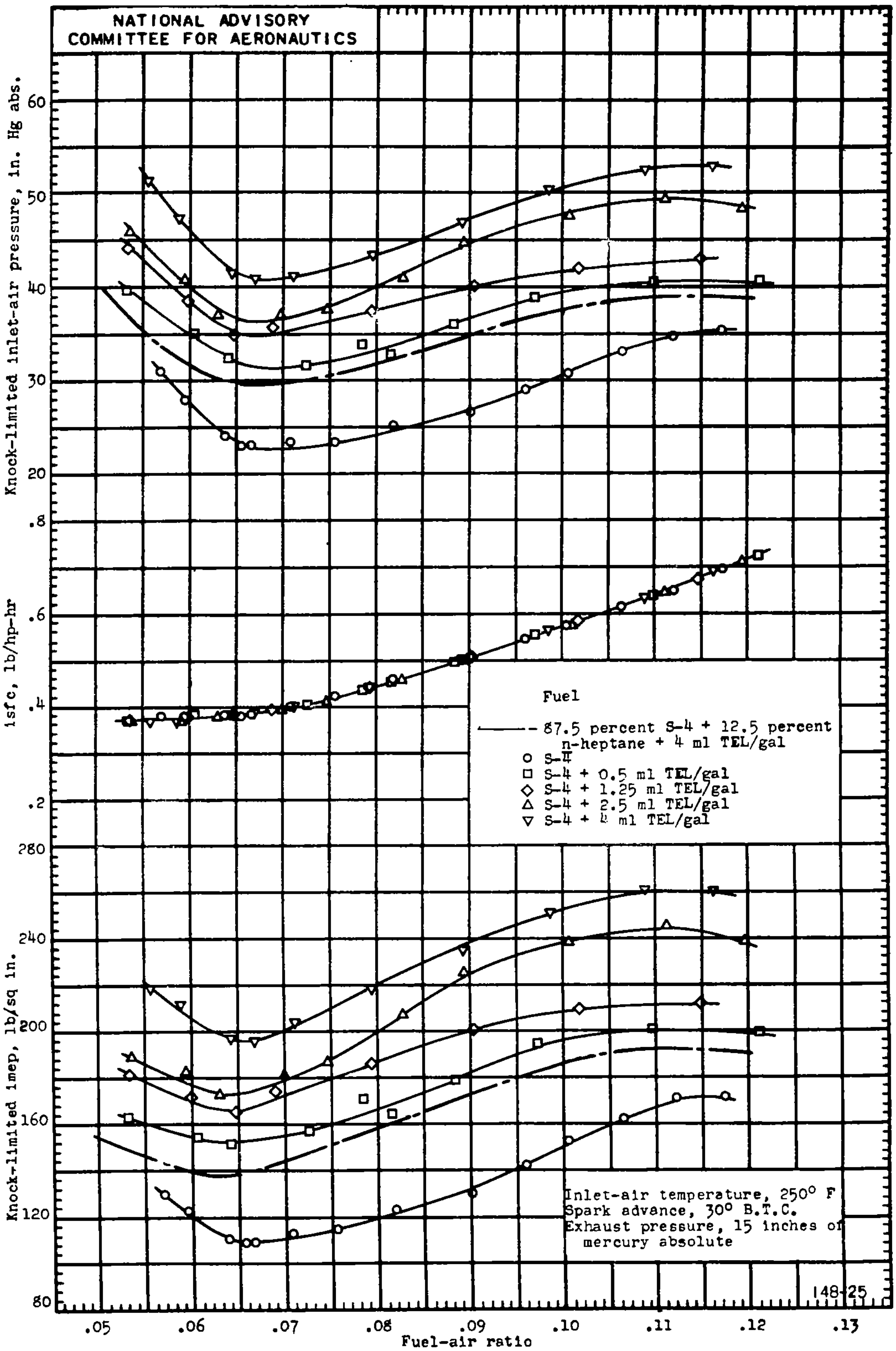


Figure 28. - Reference-fuel framework at an inlet-air temperature of 250° F, a spark advance of 30° B.T.C., and an exhaust pressure of 15 inches of mercury absolute. Full-scale cylinder; compression ratio, 7.3; engine speed, 2000 rpm; cooling air adjusted at 140 bmep and 0.10 fuel-air ratio to give a rear spark-plug-bushing temperature of 365° F.

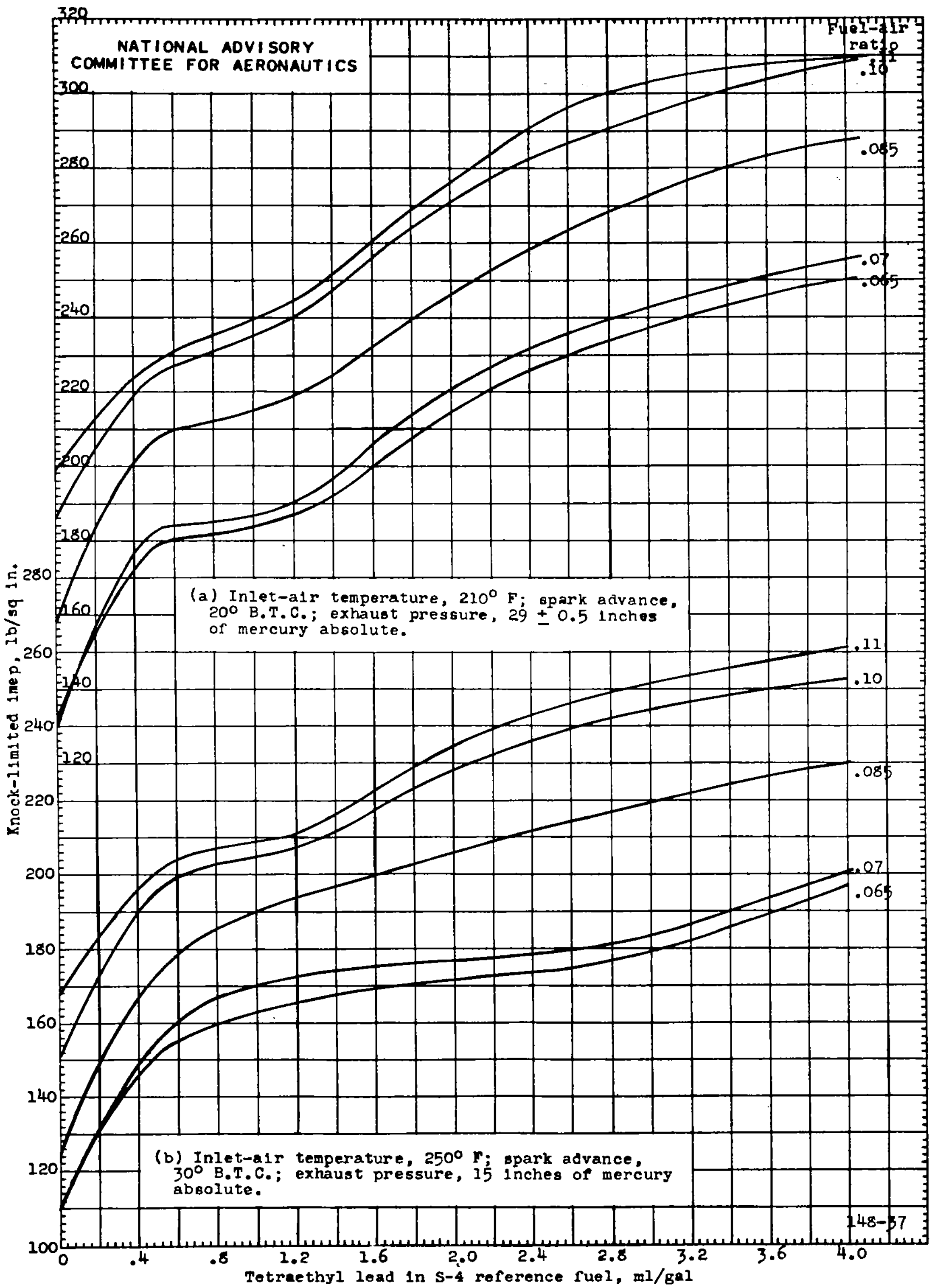


Figure 29. - Relation between knock-limited indicated mean effective pressure and lead concentration in S-4 reference fuel for different fuel-air ratios. Full-scale cylinder; compression ratio, 7.3; engine speed, 2000 rpm.

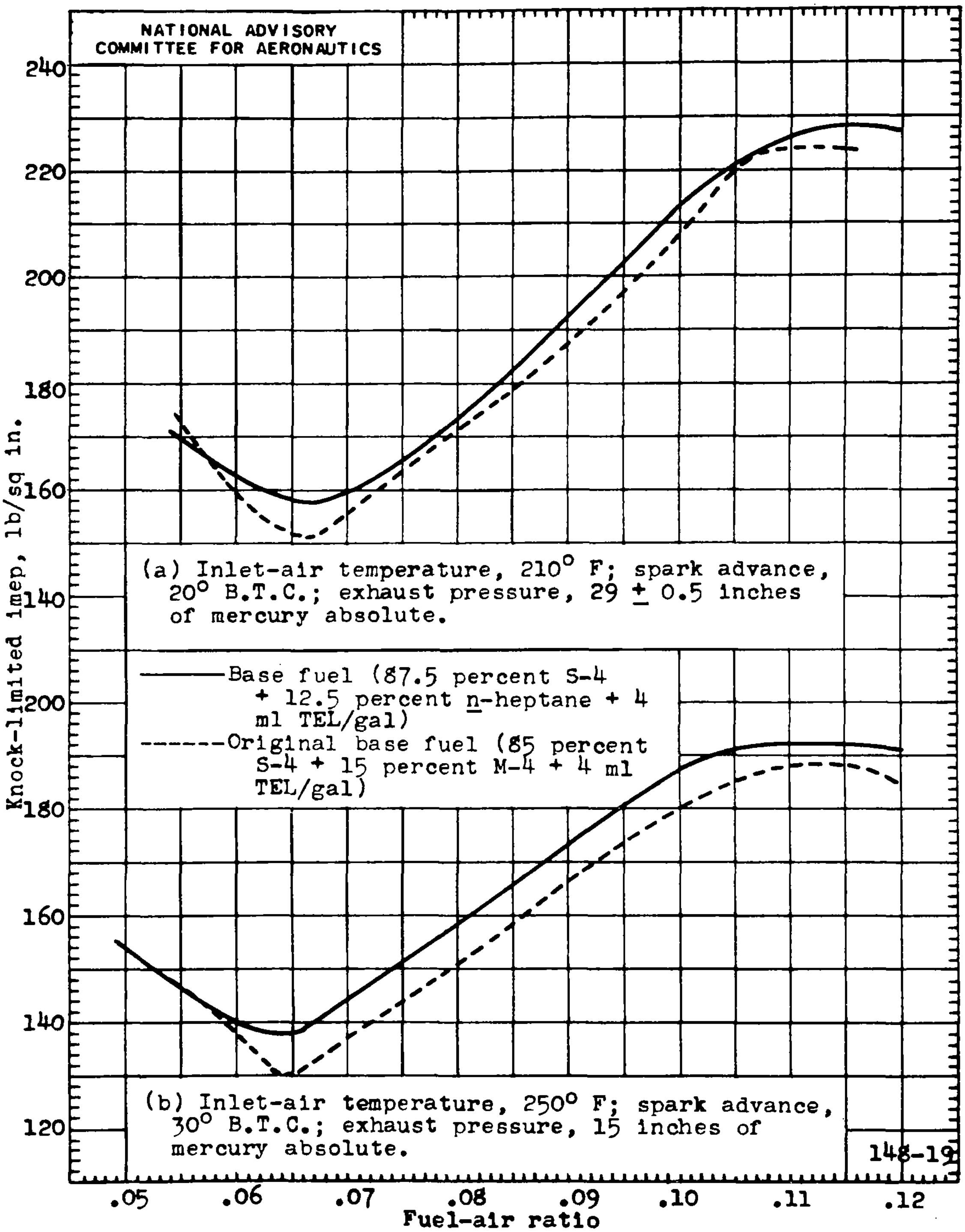


Figure 30. - Comparison of knock-limited performance of the base fuel used in present tests (87.5 percent S-4 + 12.5 percent n-heptane + 4 ml TEL/gal) and the original base fuel (85 percent S-4 + 15 percent M-4 + 4 ml TEL/gal). Full-scale cylinder; compression ratio, 7.3; engine speed, 2000 rpm; cooling air adjusted at 140 bmep and 0.10 fuel-air ratio to give a rear spark-plug-bushing temperature of 365° F.

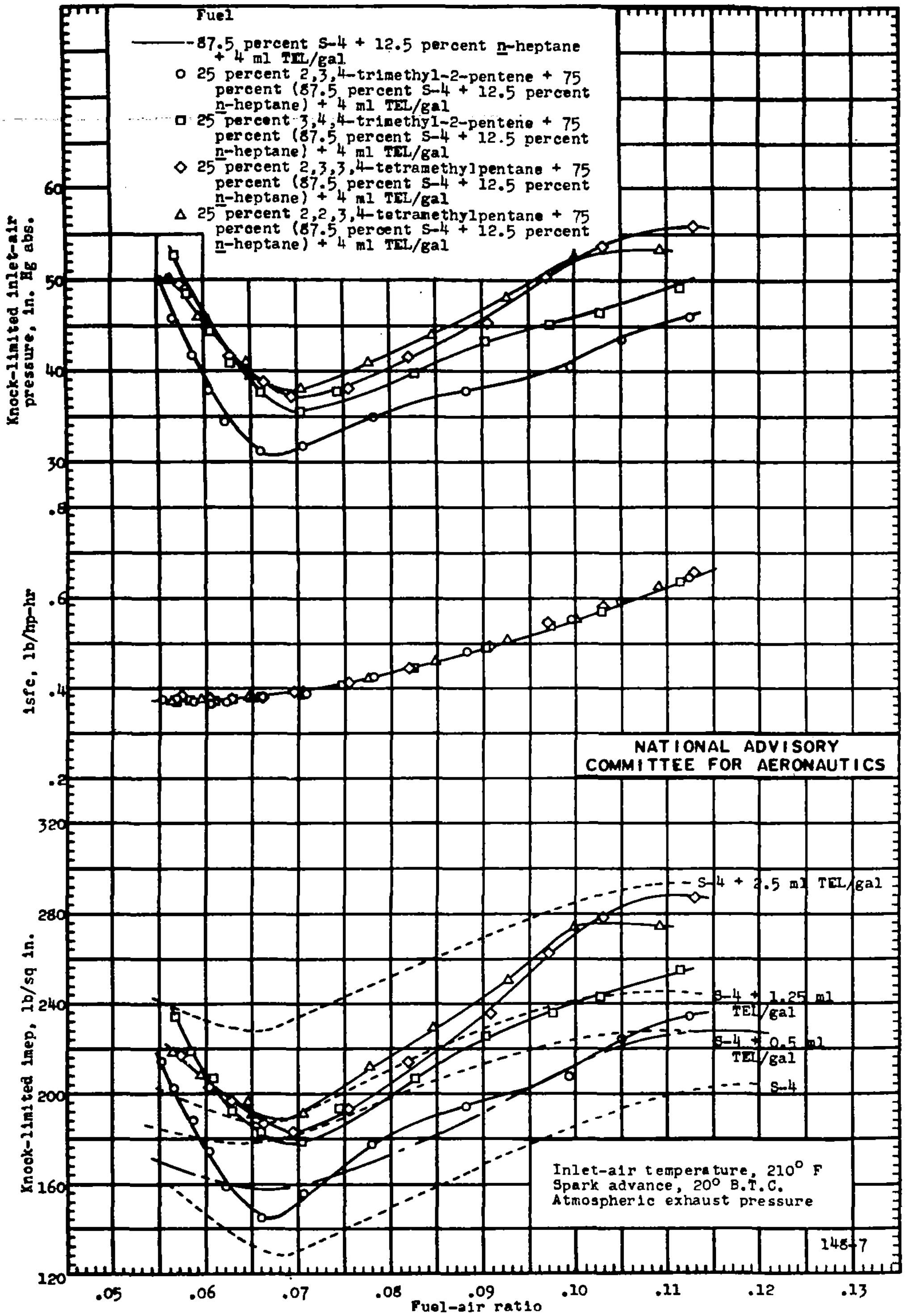


Figure 31. - The knock-limited performance of leaded blends of four pure hydrocarbons and a base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane at an inlet-air temperature of 210° F, a spark advance of 20° B.T.C., and atmospheric exhaust pressure. Full-scale cylinder; compression ratio, 7.3; engine speed, 2000 rpm; cooling air adjusted at 140 bmep and 0.10 fuel-air ratio to give a rear spark-plug-bushing temperature of 365° F.

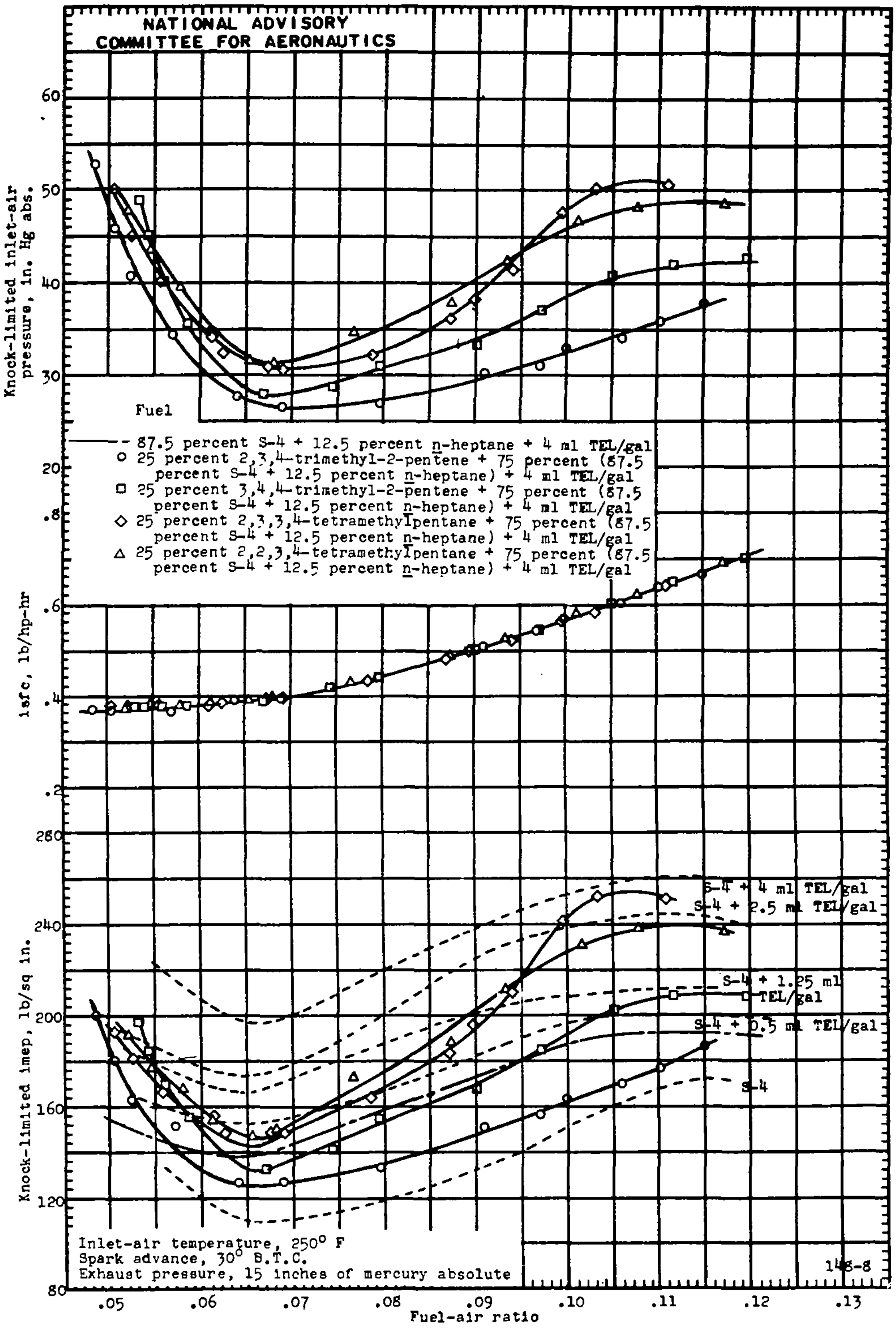


Figure 32. - The knock-limited performance of leaded blends of four pure hydrocarbons and a base fuel consisting of 87.5 percent S-4 plus 12.5 percent n-heptane at an inlet-air temperature of 250° F, a spark advance of 30° B.T.C., and an exhaust pressure of 15 inches of mercury absolute. Full-scale cylinder; compression ratio, 7.3; engine speed, 2000 rpm; cooling air adjusted at 140 bmep and 0.10 fuel-air ratio to give a rear spark-plug-bushing temperature of 365° F.

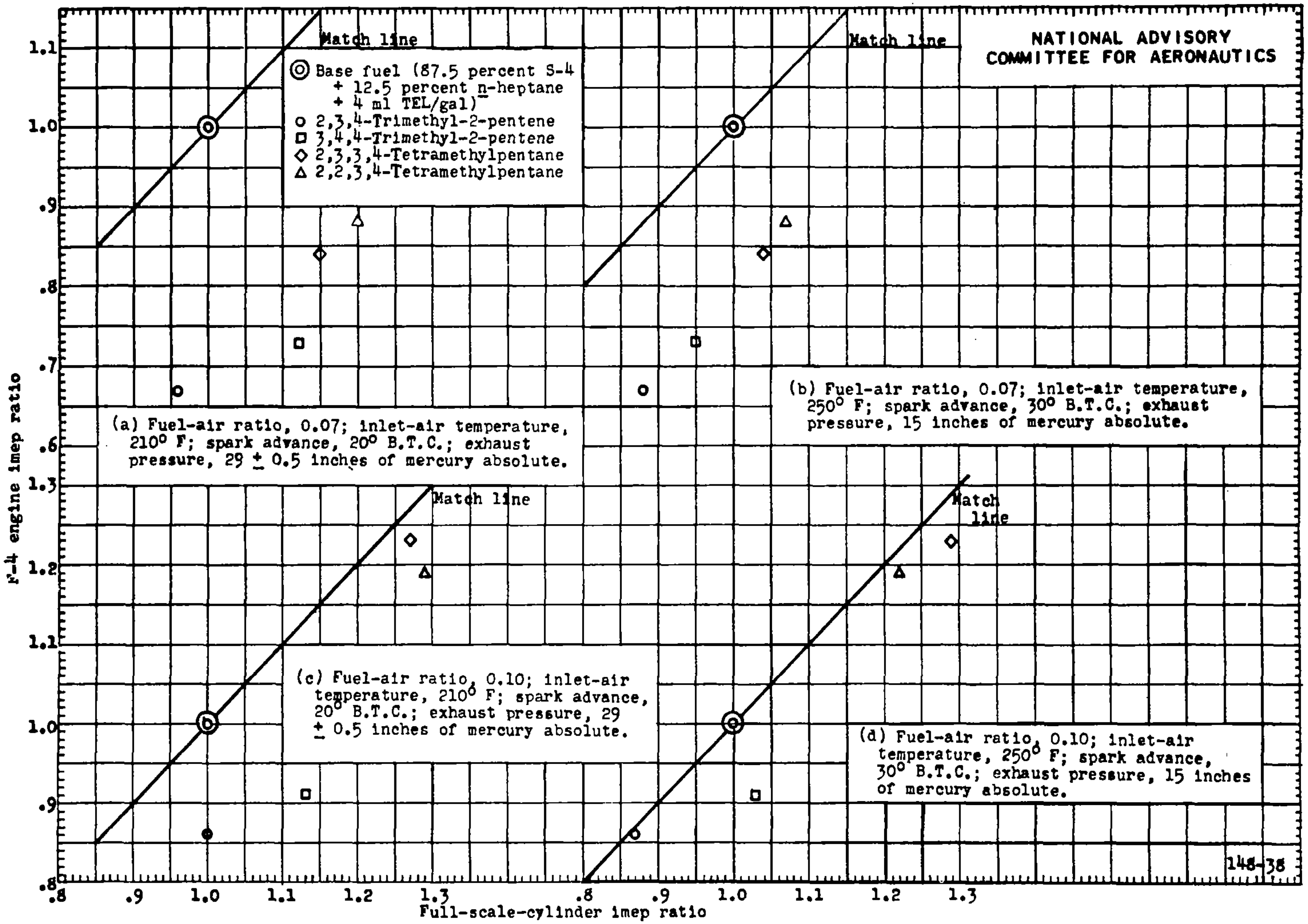
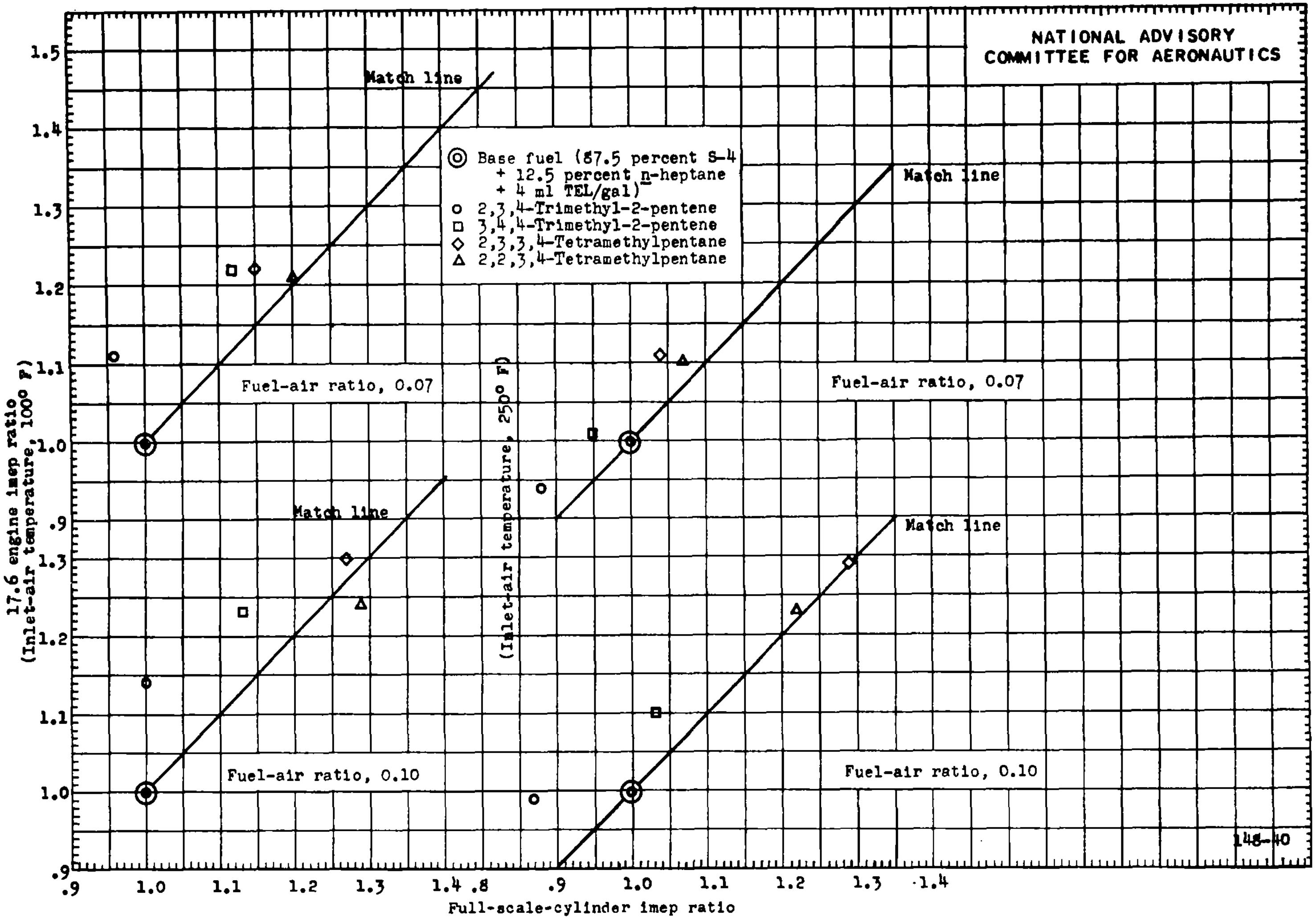


Figure 33. - Correlation of the F-4 engine data with the full-scale-cylinder data at various operating conditions for blends containing 25 percent hydrocarbons and 75 percent (87.5 percent S-4 plus 12.5 percent n-heptane) plus 4 ml TEL per gallon. Full-scale-cylinder conditions: compression ratio, 7.3; engine speed, 2000 rpm; cooling air adjusted at 140 bmep and 0.10 fuel-air ratio to give a rear spark-plug-bushing temperature of 365° F. F-4 conditions: inlet-air temperature, 225° F; spark advance, 45° B.T.C.; coolant temperature, 375° F.



(Inlet-air temperature, 210° F; spark advance, 20° B.T.C.; exhaust pressure, 29 ±0.5 in. Hg absolute)

(Inlet-air temperature, 250° F; spark advance, 30° B.T.C.; exhaust pressure, 15 in. Hg absolute)

Figure 34. - Correlation of the 17.6 engine data with the full-scale-cylinder data at two operating conditions for blends containing 25 percent hydrocarbon and 75 percent (87.5 percent S-4 plus 12.5 percent n-heptane) plus 4 ml TEL per gallon. Full-scale-cylinder conditions: compression ratio, 7.3; engine speed, 2000 rpm; cooling air adjusted at 140 bmep and 0.10 fuel-air ratio to give a rear spark-plug-bushing temperature of 365° F. 17.6 engine conditions: compression ratio, 7.0; engine speed, 1800 rpm; outlet-coolant temperature, 212° F.

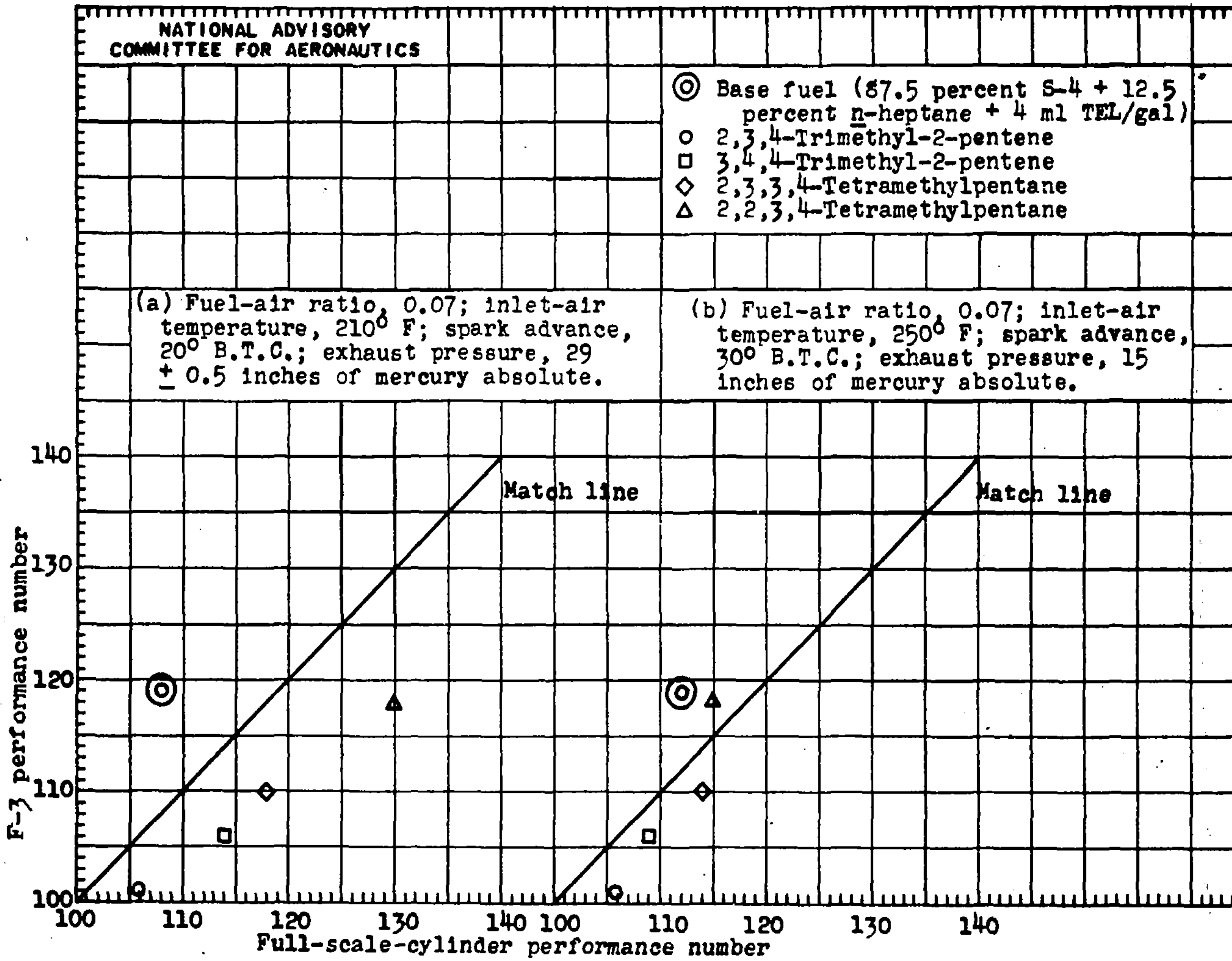


Figure 35. - Correlation of F-3 engine data with the full-scale-cylinder data for blends containing 25 percent hydrocarbon and 75 percent (87.5 percent S-4 plus 12.5 percent n-heptane) plus 4 ml TEL per gallon. Full-scale cylinder conditions: compression ratio, 7.3; engine speed, 2000 rpm; cooling air adjusted at 140 bmep and 0.10 fuel-air ratio to give a rear spark-plug-bushing temperature of 365° F.