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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

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IV - DATA FOR m-DIETHYLBENZENE, 1-ETHYL-4-METHYLBENZENE AND sec-BUTYLBENZENE TOGETHER WITH A SUMMARIZATION OF DATA FOR 12 AROMATIC HYDROCARBONS

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SUMMARY

Knock-limited performance data obtained with several small-scale engines for blends containing nine aromatic hydrocarbons blended individually in various concentrations with selected base fuels have previously been published. The present report presents similar knock-limited data on m-diethylbenzene, 1-ethyl-4-methylbenzene, and sec-butylbenzene. This report also includes a summarization and discussion of the relative performance of the 12 aromatics based on results of the small-scale-engine data and comparative published full-scale-cylinder data.

Although no relative order of rating has been definitely established, 1,3,5-trimethylbenzene, m-diethylbenzene, tert-butylbenzene, p-xylene, and 1-ethyl-4-methylbenzene in most instances appeared to be the best of the 12 aromatics at fuel-air ratios of 0.10.

At lean mixtures, under most of the operating conditions examined, m-diethylbenzene and tert-butylbenzene showed the highest antiknock effectiveness.

In general, the aromatic blends were more sensitive to changes of inlet-air temperature and additions of tetraethyl lead than were the base fuels.

INTRODUCTION

An investigation is being conducted at the NACA Cleveland laboratory to determine the effectiveness of aromatic hydrocarbons as antiknock blending agents for aviation fuels. The program and the over-all objectives are described in detail in reference 1. In brief, the investigation consists in determining: (a) the blending sensitivity, (b) the sensitivity of the aromatic blends to inlet-air temperature, (c) the lead susceptibility of the blends, and (d) the correlation of small-scale and full-scale engine results.

The aromatic hydrocarbons selected for investigation in the first phase of the program (conducted from Jan. to Oct. 1944) are as follows:

Toluene
Ethylbenzene
p-Xylene
Isopropylbenzene (cumene)
Benzene
o-Xylene
1,3,5-Trimethylbenzene (mesitylene)
tert-Butylbenzene
1,2,4-Trimethylbenzene (pseudocumene)
m-Diethylbenzene.
1-Ethyl-4-methylbenzene
sec-Butylbenzene

Each aromatic, after purification, was individually blended with selected base fuels and the resulting blends were tested in 17.6, F-4, and F-3 engines.

Data on the first nine aromatics are presented in references 1 to 3. Data on m-diethylbenzene, 1-ethyl-4-methylbenzene, and sec-butylbenzene are reported with a summarization of data for the 12 aromatics in this report, which is part IV of a series of five reports presenting test results on aromatic fuels. In references 1 to 3 as well as in the present report, comparative R-1820 G200 cylinder data from reference 4 are included to determine the correlation of data from the three small-scale engines and the one full-scale cylinder.

The material presented herein is divided into two main sections. Section A presents and discusses original F-4 and 17.6 engine data on the three aromatics. Section B presents a summarization of data on the 12 aromatics (from tests with 17.6, F-4, and F-3 engines and from comparative published full-scale-cylinder data), a correlation of knock-limited data from the three small-scale engines and the one full-scale single-cylinder engine, and a discussion of the relative performance of the 12 aromatics based on small-scale and full-scale single-cylinder results.

A - TESTS AND RESULTS FOR m-DIETHYLBENZENE, 1-ETHYL-4-METHYLBENZENE, AND sec-BUTYLBENZENE

Apparatus, Fuels, and Test Procedure

A complete description of the engines and the engine conditions used for the tests may be found in reference 1 for the 17.6 engine, for the F-3 engine, and the "research" F-4 engine. The 17.6 engine conditions are also given hereinafter in the figures and tables. The F-4 engine is not a package unit but is operated under F-4 test conditions and is, for convenience, designated the F-4 engine in this series of reports.

The samples of m-diethylbenzene, 1-ethyl-4-methylbenzene, and sec-butylbenzene were prepared in the Organic Synthesis Section of the Fuels and Lubricants Division. The physical constants of the samples used for engine tests are presented in the following table:

Aromatic	Freezing point (°C)	Boiling point (°C)	Index of refraction n_D^{20}	Density at 20° C (gram/ml)
m-Diethylbenzene	-84.72	181.6	1.4955	0.8641
1-Ethyl-4-methylbenzene	-63.60	162.3	1.4950	.8610
sec-Butylbenzene	-75.73	173.3	1.4900	.8618

Each of the three aromatics was blended with three base fuels before being tested in small-scale engines. The composition of the test fuel blends and an outline of the tests with the 17.6 and F-4 engines are given in the following table:

Engine	Inlet-air temperature (°F)	Percentage aromatic in blend	Base fuel	Tetraethyl lead in final blend (ml/gal)
17.6	250	0,10,20	S-3	0
	100	0,20	S-3	0
	250	0,10,20	S-3	4
	100	0,20	S-3	4
	250	0,25	85% S-3 + 15% M-4	4
	100	0,25	85% S-3 + 15% M-4	4
F-4	225	0,10,25,50	85% S-3 + 15% M-4	4

Whenever fuel quantity permitted, the blends were also tested in the F-3 engine.

Presentation and Discussion of Results

Table I is an index of figures showing in detail the order of discussing the results obtained for m-diethylbenzene, 1-ethyl-4-methylbenzene, and sec-butylbenzene. The table presents the blend compositions, the engines, the variable engine condition (inlet-air temperature), and the figure numbers.

F-4 and F-3 engine data. - The knock-limited performance of the base fuel (consisting of 85 percent S-3 plus 15 percent M-4 plus 4 ml TEL/gal) in the F-4 engine is presented in figure 1 (reproduced from fig. 7 of reference 1); the results for blends containing 10, 25, and 50 percent aromatics with this base fuel are shown in figures 2, 3, and 4 for m-diethylbenzene, 1-ethyl-4-methylbenzene, and sec-butylbenzene, respectively.

In the 50-percent concentration, additions of 1-ethyl-4-methylbenzene resulted in higher knock-limited powers at fuel-air ratios above 0.112 than did either m-diethylbenzene or sec-butylbenzene. In the 50-percent concentration, m-diethylbenzene was more effective than the other two aromatics at fuel-air ratios from 0.09 to 0.11 and, in the 10- and 25-percent concentrations, at all fuel-air ratios tested above 0.07.

Graphs of knock-limited imep ratio (where imep ratio is the ratio of the imep of the aromatic blend to that of the base fuel) against aromatic concentration are presented in figures 5, 6, and 7 for the blends tested in the F-4 engine. These data show the comparative effect of the addition of each of the three aromatics at fuel-air ratios of 0.07, 0.085, and 0.10. At lean mixtures, only small or negative gains were obtained by additions of the aromatics to the base fuel; substantial rich-mixture improvements relative to the base fuel were, however, observed.

The F-4 and the F-3 ratings of the various blends are, for convenience, presented in section B of the present report.

17.6 engine data. - The knock-limited performance in the 17.6 engine of blends containing each of the three aromatics is presented in figures 8 to 10 for m-diethylbenzene, in figures 11 to 13 for 1-ethyl-4-methylbenzene, and in figures 14 to 16 for sec-butylbenzene. For each aromatic, the unleaded blends with S-3 are presented first, followed by the leaded blends with S-3, and then by the leaded blends with the S-3 plus M 4 base fuel; tests were run at inlet-air temperatures of 250° and 100° F. The order corresponds with that in which the tests were conducted. Each figure sheet presents data obtained during the period of one day.

In the unleaded blends (figs. 8, 11, and 14) only m-diethylbenzene increased the knock-limited power of S-3 at fuel-air ratios from 0.06 to 0.07 at the higher inlet-air temperature; each of the three aromatics, however, permitted substantial improvements at rich mixtures and at the higher inlet-air temperature. When the inlet-air temperature was lowered to 100° F, m-diethylbenzene and sec-butylbenzene appreciably increased the knock-limited power of S-3 at all fuel-air ratios tested. Unleaded 1-ethyl-4-methylbenzene did not show this marked sensitivity to inlet-air temperature, but leaded blends of this aromatic were comparable in this respect with the leaded blends of the other two aromatics. (Cf. figs. 11 and 12.)

When tetraethyl lead was added to the blends (figs. 9, 12, and 15), the three aromatics increased the knock-limited power of the base fuel an appreciable amount even at lean mixtures at the higher inlet-air temperature, which indicates that the blends were more responsive to the lead addition than was the base fuel. This lead response of the aromatic blends was also noted at the lower inlet-air temperature.

In leaded blends with the S-3 plus M-4 base fuel (figs. 10, 13, and 16), each of the three aromatics increased the knock-limited power of the base fuel at all fuel-air ratios tested and at both inlet-air temperatures. Although an engine failure occurred during the testing period in which the data of figure 13(a) were obtained, the data are considered valid and are presented for completeness.

Figures 17, 18, and 19 present graphs of the variation of the knock-limited imep ratio with aromatic concentration for the aromatics blended with S-3 and tested (with and without tetraethyl lead) in the 17.6 engine. The results indicate the comparative effect of additions of each of the three aromatics at fuel-air ratios of 0.07, 0.085, and 0.10 as well as the effects of inlet-air temperature and tetraethyl lead.

B - SUMMARIZATION AND DISCUSSION OF DATA FOR 12 AROMATIC HYDROCARBONS

Summarization of Data

F-4 and F-3 ratings. - Table II presents the F-4 and F-3 ratings of blends containing each of the 12 aromatics in various concentrations with the three base fuels. These ratings are recorded in terms of S-3 plus milliliters of tetraethyl lead, percentage S-3 in M-4, or octane number, and also in terms of Army-Navy performance number. It will be noted that improved performance was obtained in the rich-mixture region by the use of the aromatics and that the effectiveness increased with increasing aromatic concentration. The performance of the aromatic blends in the lean-mixture region with F-4 and F-3 engines was poor, particularly at the higher aromatic concentrations.

17.6, full-scale-cylinder, and F-4 engine data. - Knock-limited performance data for each of the 12 aromatics individually blended with the three base fuels, are presented in table III. Data are included from tests conducted with the 17.6 engine, the full-scale cylinder (from reference 4), and the F-4 engine. Because reference-fuel bracketing curves were omitted in tests with the 17.6 engine and because certain of the aromatic blends permitted knock-limited powers in excess of the powers that can be represented by the present system of fuel ratings, indicated mean effective pressures and imep ratios are recorded. Before the imep ratios were calculated, the daily performance of the base fuels had to be determined. Inasmuch as the S-3 plus M-4 base fuel was not tested each day on the F-4 engine, the daily knock-limited performance of this base fuel was estimated from the daily performance of S-3 or S-3 plus tetraethyl lead and from the data of figure 1.

Sensitivity of the aromatic blends to inlet-air temperature. - Table IV presents a summary of the temperature sensitivities of blends containing each of the 12 aromatics. With few exceptions, the aromatic blends were more sensitive to changes of inlet-air temperature than the base fuels. Although the results are not entirely consistent, it appears that blends containing the aromatics which are good antiknock agents are the most sensitive to changes of inlet-air temperature.

Lead susceptibility of the blends. - The lead susceptibilities are summarized in table V. With the exception of o-xylene and 1,2,4-trimethylbenzene blends, the aromatic blends were usually more susceptible to the addition of tetraethyl lead than was S-3 reference fuel. In general, the blends containing aromatics with good antiknock characteristics are also the most susceptible to tetraethyl-lead additions.

Correlation of Knock-Limited Performance Data from Three Small-Scale Engines and a Full-Scale Cylinder

The 17.6 engine performance is compared in figure 20 with the full-scale-cylinder performance (data from reference 4) on a basis of imep ratios at fuel-air ratios of 0.07 and 0.10. Because the aromatic concentration and the base fuel differed in the two cases (20 percent aromatic with S-3 for the 17.6 tests and 25 percent aromatic with the S-3 plus M-4 base fuel for the full-scale-cylinder tests), no "match" line was drawn. Fair correlation is indicated at both fuel-air ratios and at both sets of engine conditions; the correlation is better at the less severe test conditions of the two engines.

The 17.6 engine performance is compared with the full-scale-cylinder performance in figure 21; the F-4 engine performance is compared with that of the full-scale cylinder in figure 22; and the F-4 engine performance is compared with that of the 17.6 engine in figure 23. These three comparisons are made on a basis of imep ratios for blends containing 25 percent aromatic with the S-3 plus M-4 base fuel. Because of the limited supply of fuel, complete 17.6 engine data are unavailable for some of the 12 aromatics blended with this base fuel.

In figures 21 to 23 the correlation is better at a fuel-air ratio of 0.10 than at a fuel-air ratio of 0.07. In general, the increase in knock-limited power of the base fuel resulting from the addition of 25 percent aromatics is less for the F-4 engine than for either the full-scale cylinder or the 17.6 engine. Apparently the results from the 17.6 engine tests agree more closely with those from the full-scale-cylinder tests than do the results from the F-4 engine tests. Although the correlation is not absolute, it does appear possible to predict the performance of aromatic fuel blends in a full-scale cylinder from performance data obtained in small-scale engines.

Figure 24 presents a comparison of the F-3 ratings with the full-scale-cylinder ratings (at a fuel-air ratio of 0.07). Performance numbers for blends that rated greater than S plus 3 ml TEL per gallon at a fuel-air ratio of 0.07 in the full-scale cylinder were estimated as follows:

$$\text{Estimated PN} = \frac{\text{imep}_A}{\text{imep}_S} \times \text{PN}_S$$

where PN is performance number and subscripts A and S designate aromatic blend and S reference fuel plus 3 ml TEL per gallon, respectively. The range of full-scale-cylinder performance numbers is much greater than that of F-3 performance numbers. With two exceptions all of the F-3 performance numbers were considerably less than those of the full-scale cylinder. The F-3 engine is therefore considered to be relatively insensitive for comparing the merits of fuels containing aromatics.

Relative Knock-Limited Performance of the 12 Aromatics

Figures 20 to 24, which are based entirely upon data obtained from tests of leaded blends, summarize the knock-limited performance of the 12 purified aromatics tested thus far at the Cleveland laboratory. At a fuel-air ratio of 0.10, the following 5 aromatics were, in most instances, rated the best of the 12 with respect to antiknock effectiveness: 1,3,5-trimethylbenzene, m-diethylbenzene, tert-butylbenzene, p-xylene, and 1-ethyl-4-methylbenzene. (See figs. 20 to 23.) Arranging these five aromatics in the order of their increasing antiknock effectiveness in fuel blends is, unfortunately, impossible. The correlation between engines is not absolute and, for a given engine, the relative order of rating of the aromatics varies with changes of engine conditions or blend composition. In the 25-percent blends with the S-3 plus M-4 base fuel at a fuel-air ratio of 0.10, the five aromatics increased the knock-limited performance of the base fuel 53 to 72 percent in the full-scale cylinder, 34 to 42 percent in the F-4 engine, and 41 to 60 percent in the 17.6 engine (incomplete data). In the 20-percent leaded blends with S-3 tested with the 17.6 engine at a fuel-air ratio of 0.10, the knock-limited performance of the base fuel was increased 33 to 55 percent by these five aromatics. Such percentage values depend upon the specific aromatic tested as well as upon the engine operating conditions.

At a fuel-air ratio of 0.10, the least effective antiknock agents of the 12 aromatics tested appear to be benzene, 1,2,4-trimethylbenzene, and o-xylene, given in order of decreasing antiknock effectiveness. (See figs. 20 to 23.) In the 25-percent blends with the S-3 plus M-4 base fuel at a fuel-air ratio of 0.10, the effect of these three aromatics on the knock-limited performance of the base fuel varied from -1 to 23 percent in the full-scale cylinder, from -9 to 15 percent in the F-4 engine, and from -9 to 27 percent in the 17.6 engine. In the 20-percent leaded blends with S-3 at a fuel-air ratio of 0.10, the effect of these aromatics on the knock-limited power of the base fuel varied from -17 to 21 percent in the 17.6 engine.

Isopropylbenzene, toluene, ethylbenzene, and sec-butylbenzene appear to fall between the two aforementioned groups and also appear to rate quite closely together. No definite order of rating was established. In the 25-percent blends with the S-3 plus M-4 base fuel at a fuel-air ratio of 0.10, these aromatics increased the knock-limited power of the base fuel 35 to 49 percent in the full-scale cylinder, 23 to 29 percent in the F-4 engine, and 33 to 45 percent in the 17.6 engine (incomplete data). In tests of 20-percent leaded blends with S-3 at a fuel-air ratio of 0.10, these aromatics increased the knock-limited power of the base fuel 19 to 38 percent in the 17.6 engine.

It must be noted that the dividing of the 12 aromatics into three groups was done on the basis of graphs that compare the performance, in three engines, of leaded blends containing either 20 or 25 percent of an aromatic in two base fuels. A study of table III indicates that three groups as given do not apply for every blend composition nor for every engine condition. For example, isopropylbenzene, toluene, and ethylbenzene each appears as one of the better five of the 12 aromatics in certain blends. Specific analysis of the data should be made at the aromatic concentration of interest.

A study of the data in tables II and III for leaded blends containing the aromatics indicates that m-diethylbenzene and tert-butylbenzene were the best antiknock agents of the 12 aromatics at fuel-air ratios of 0.065 and 0.07 in most cases. Both of these hydrocarbons were effective antiknock agents at these fuel-air ratios in the 17.6 engine and the full-scale cylinder. Of the two aromatics, tert-butylbenzene appeared to be the more effective in the tests with the F-4 and F-3 engines. In certain blend concentrations and under certain engine operating conditions, ethylbenzene, isopropylbenzene, and 1-ethyl-4-methylbenzene are also effective antiknock agents in the lean region.

SUMMARY OF RESULTS

Knock-limited tests of 12 aromatics, each individually blended with selected base fuels and tested with and without tetraethyl lead were conducted with 17.6, F-4, and F-3 engines. From these tests and from comparative published tests conducted with a full-scale cylinder, the following results were obtained:

1. The following five aromatics were in most instances rated as the best antiknock agents at a fuel-air ratio of 0.10: 1,3,5-trimethylbenzene, m-diethylbenzene, tert-butylbenzene, p-xylene, and 1-ethyl-4-methylbenzene. No relative order of rating of these five aromatics has been definitely established.

2. At lean mixtures m-diethylbenzene and tert-butylbenzene almost always showed the highest antiknock effectiveness.

3. The knock-limited performance of the aromatic blends was ordinarily more sensitive to changes of inlet-air temperature than that of the base fuels.

4. All of the aromatic blends except those containing either o-xylene of 1,2,4-trimethylbenzene were ususlly more susceptible to tetraethyl-lead additions than S-3 reference fuel.

5. Although the correlation of full-scale and small-scale engine results was not absolute, the results indicate the possibility of predicting the performance of aromatic fuel blends in a full-scale cylinder from performance data obtained in small-scale engines.

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TABLE I. - INDEX OF FIGURES PRESENTING DATA FOR m-DIETHYLBENZENE, 1-ETHYL-4-METHYLBENZENE, AND sec-BUTYLBENZENE

Figure	Aromatic	Percentage aromatic in blend	Base fuel	Tetra-ethyl lead (ml/gal)	Inlet-air temperature (°F)
F-4 engine (knock-limited imep against fuel-air ratio)					
1	-----------------	0	85% S-3 + 15% M-4	4	225
2(a) (b) (c)	m-Diethylbenzene	10 25 50	85% S-3 + 15% M-4	4	225
3(a) (b) (c)	1-Ethyl-4-methyl-benzene	10 25 50	85% S-3 + 15% M-4	4	225
4(a) (b) (c)	sec-Butylbenzene	10 25 50	85% S-3 + 15% M-4	4	225
F-4 engine (knock-limited imep ratio against aromatic concentration)					
5	m-Diethylbenzene	0,10,25,50	85% S-3 + 15% M-4	4	225
6	1-Ethyl-4-methyl-benzene	0,10,25,50	85% S-3 + 15% M-4	4	225
7	sec-Butylbenzene	0,10,25,50	85% S-3 + 15% M-4	4	225
17.6 engine (knock-limited imep against fuel-air ratio)					
8(a) (b)	m-Diethylbenzene	0,10,20 0,20	S-3	0	250 100
9(a) (b)	m-Diethylbenzene	0,10,20 0,20	S-3	4	250 100
10(a) (b)	m-Diethylbenzene	0,25 0,25	85% S-3 + 15% M-4	4	250 100
11(a) (b)	1-Ethyl-4-methyl-benzene	0,10,20 0,20	S-3	0	250 100
12(a) (b)	1-Ethyl-4-methyl-benzene	0,10,20 0,20	S-3	4	250 100
13(a) (b)	1-Ethyl-4-methyl-benzene	0,25 0,25	85% S-3 + 15% M-4	4	250 100
14(a) (b)	sec-Butylbenzene	0,10,20 0,20	S-3	0	250 100
15(a) (b)	sec-Butylbenzene	0,10,20 0,20	S-3	4	250 100
16(a) (b)	sec-Butylbenzene	0,25 0,25	85% S-3 + 15% M-4	4	250 100
17.6 engine (knock-limited imep ratio against aromatic concentration)					
17	m-Diethylbenzene	0,10,20	S-3	0,4	250,100
18	1-Ethyl-4-methyl-benzene	0,10,20	S-3	0,4	250,100
19	sec-Butylbenzene	0,10,20	S-3	0,4	250,100

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TABLE II. - F-4 AND F-3 RATINGS OF AROMATIC BLENDS

Compound	Blend composition (percent by volume)			Tetraethyl lead (ml/gal)	F-4 ratings				F-3 ratings	
					Lean		Rich			
	Aromatic	S-3 reference fuel	85 percent S-3 plus 15 percent M-4		S-3 + ml TEL per gal	Performance number	S-3 + ml TEL per gal	Performance number	S-3 + ml TEL per gal	Performance number
Base fuel	0	0	100	4	0.36	112	0.26	109	0.39	113
Toluene	10	0	90	4	0.46	115	0.89	124	0.44	114
Ethylbenzene					0.63	119	1.02	126	0.42	114
p-Xylene					0.50	116	1.03	126	0.61	118
Isopropylbenzene					0.73	121	1.20	129	0.51	116
Benzene					0.46	115	0.59	116	0.47	115
o-Xylene					0.37	113	[a]98.3	95	0.18	107
1,3,5-Trimethylbenzene					0.37	113	1.55	134	0.53	117
tert-Butylbenzene					0.87	124	1.28	130	0.63	119
1,2,4-Trimethylbenzene					0.20	107	0.05	102	0.18	107
m-Diethylbenzene					0.50	116	1.43	132	-------	--------
1-Ethyl-4-methylbenzene					0.45	115	1.26	130	0.51	116
sec-Butylbenzene					0.39	113	0.74	121	0.54	117
Toluene	25	0	75	4	0.34	112	3.85	152	0.34	112
Ethylbenzene					0.50	116	4.36	154	0.40	113
p-Xylene					0.35	112	6.00	161	0.53	117
Isopropylbenzene					0.42	114	3.92	152	0.53	117
Benzene					0.18	107	1.90	137	0.31	111
o-Xylene					[a]96.1	90	[a]98.1	94	0.00	100
1,3,5-Trimethylbenzene					0.32	111	>6.00	[b]174	0.76	121
tert-Butylbenzene					0.98	125	5.72	160	0.77	122
1,2,4-Trimethylbenzene					0.00	100	0.31	111	[c]98.8	96
m-Diethylbenzene					0.29	110	>6.00	[b]163	0.60	118
1-Ethyl-4-methylbenzene					0.41	114	5.80	160	0.47	115
sec-Butylbenzene					0.50	116	2.86	146	0.54	117
Toluene	50	0	50	4	0.08	103	>6.00	[b] >290	0.28	110
Ethylbenzene					0.37	113	>6.00	[b] >260	0.07	103
p-Xylene					0.20	107	>6.00	[b] >300	-------	--------
Isopropylbenzene					0.21	108	>6.00	[b] >280	-------	--------
Benzene					[a]98.0	94	>6.00	[b]190	[c,e]98±2	94±6
o-Xylene					[a]93.2	83	0.50	116	[c]93.4	81
1,3,5-Trimethylbenzene					0.50	116	>6.00	[b] >300	-------	--------
tert-Butylbenzene					0.45	115	>6.00	[b]290	0.80	122
1,2,4-Trimethylbenzene					0.13	105	3.71	151	[c]98.0	93
m-Diethylbenzene					[a,d]96.0	90	>6.00	[b]230	-------	--------
1-Ethyl-4-methylbenzene					0.50	116	>6.00	[b]260	-------	--------
sec-Butylbenzene					0.42	114	>6.00	[b]185	0.24	109
p-Xylene	10	90	0	4	-------	--------	-------	--------	3.24	148
o-Xylene					-------	--------	-------	--------	1.80	136
1,3,5-Trimethylbenzene					-------	--------	-------	--------	3.50	150
tert-Butylbenzene					-------	--------	-------	--------	3.77	151
1,2,4-Trimethylbenzene					-------	--------	-------	--------	2.25	141
m-Diethylbenzene					-------	--------	-------	--------	2.75	145
sec-Butylbenzene					-------	--------	-------	--------	2.98	146
Toluene	20	80	0	4	2.48	143	>6.00	[b]187	2.07	139
Ethylbenzene					2.06	139	>6.00	[b] >200	1.97	133
p-Xylene					-------	--------	-------	--------	1.97	138
o-Xylene					-------	--------	-------	--------	0.58	118
tert-Butylbenzene					-------	--------	-------	--------	2.43	142
1,2,4-Trimethylbenzene					-------	--------	-------	--------	0.72	121
sec-Butylbenzene					-------	--------	-------	--------	1.95	138
Ethylbenzene	10	90	0	0	-------	--------	-------	--------	[c]99.2	97
p-Xylene					-------	--------	-------	--------	[c]99.5	98
Isopropylbenzene					-------	--------	-------	--------	[c]99.3	98
Benzene					-------	--------	-------	--------	[c]98.8	96
o-Xylene					-------	--------	-------	--------	[c]97.8	93
tert-Butylbenzene					-------	--------	-------	--------	[c]99.5	98
1,2,4-Trimethylbenzene					-------	--------	-------	--------	[c]97.2	91
m-Diethylbenzene					-------	--------	-------	--------	[c]98.8	96
1-Ethyl-4-methylbenzene					-------	--------	-------	--------	[c]98.8	96
sec-Butylbenzene					-------	--------	-------	--------	[c]98.8	96
Toluene	20	80	0	0	-------	--------	-------	--------	[c]98.3	94
Ethylbenzene					-------	--------	-------	--------	[c]95.6	95
p-Xylene					-------	--------	-------	--------	[c]99.6	99
Benzene					-------	--------	-------	--------	[c]97.4	92
o-Xylene					-------	--------	-------	--------	[c]95.4	86
tert-Butylbenzene					-------	--------	-------	--------	[c]99.8	99
1,2,4-Trimethylbenzene					-------	--------	-------	--------	[c]95.8	87
m-Diethylbenzene					-------	--------	-------	--------	[c]97.6	92
1-Ethyl-4-methylbenzene					-------	--------	-------	--------	[c]96.2	88
sec-Butylbenzene					-------	--------	-------	--------	[c]97.8	93

[a]Percentage S-3 in M-4.

[b]Estimated performance number = $\frac{\text{imep of aromatic blend}}{\text{imep of (S-3 + 6 ml TEL/gal)}}$ X performance number of (S-3 + 6 ml TEL/gal).

[c]Octane number.

[d]Extrapolated value.

[e]Estimated value because of limited supply of fuel.

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TABLE III. - SUPERCHARGED-ENGINE TESTS OF BLENDS CONTAINING AROMATICS

Compound	Fuel composition: Blend composition (percent by volume): Aromatic	S-3 reference fuel	85 percent S-3 plus 15 percent M-4	Tetraethyl lead (ml/gal)	Engine conditions: Engine speed (rpm)	Inlet-air temperature (°F)	Test results, Fuel-air ratio 0.065: imep	0.065: imep ratio[a]	0.07: imep	0.07: imep ratio[a]	0.085: imep	0.085: imep ratio[a]	0.10: imep	0.10: imep ratio[a]	0.11: imep	0.11: imep ratio[a]
17.6 engine																
Toluene	10	90	0	0	1800	250	138	1.04	137	1.02	158	1.05	176	1.08	181	1.11
Ethylbenzene							136	1.02	137	1.02	159	1.04	185	1.11	193	1.16
p-Xylene							136	1.01	136	1.01	167	1.10	187	1.12	191	1.14
Isopropylbenzene							131	1.01	132	1.00	163	1.09	188	1.14	194	1.16
Benzene							109	1.00	111	1.01	138	1.02	157	1.03	160	1.04
o-Xylene							105	.95	105	.95	124	.93	149	.97	154	1.00
1,3,5-Trimethylbenzene							118	.96	121	.98	144	1.03	179	1.15	193	1.21
tert-Butylbenzene							107	.98	110	1.00	135	1.05	169	1.12	183	1.19
1,2,4-Trimethylbenzene							96	.91	99	.93	120	.95	148	.99	154	1.01
m-Diethylbenzene							134	1.01	133	1.01	157	1.05	185	1.12	196	1.19
1-Ethyl-4-methylbenzene							132	1.00	132	1.00	156	1.05	178	1.08	182	1.09
sec-Butylbenzene							122	.98	125	1.00	149	1.05	171	1.08	175	1.10
Toluene	20	80	0	0	1800	250	138	1.04	137	1.02	166	1.11	197	1.21	206	1.26
Ethylbenzene							135	1.02	134	1.00	164	1.07	200	1.21	219	1.31
p-Xylene							140	1.04	140	1.04	176	1.16	213	1.28	231	1.38
Isopropylbenzene							136	1.05	130	.98	160	1.07	198	1.20	216	1.29
Benzene							109	1.00	111	1.01	138	1.02	166	1.10	180	1.17
o-Xylene							99	.90	99	.89	116	.87	142	.93	153	.99
1,3,5-Trimethylbenzene							112	.91	118	.95	151	1.08	198	1.27	225	1.42
tert-Butylbenzene							104	.95	105	.95	139	1.08	173	1.15	196	1.27
1,2,4-Trimethylbenzene							91	.87	92	.86	115	.91	143	.96	160	1.05
m-Diethylbenzene							139	1.05	137	1.04	166	1.11	204	1.24	228	1.38
1-Ethyl-4-methylbenzene							132	1.00	132	1.00	164	1.11	188	1.14	197	1.16
sec-Butylbenzene							121	.98	124	.99	153	1.08	184	1.16	200	1.26
Toluene	20	80	0	0	1800	100	170	1.05	173	1.07	201	1.18	215	1.21	218	1.24
Ethylbenzene							196	1.19	199	1.21	221	1.28	237	1.35	238	1.36
p-Xylene							196	1.15	202	1.20	225	1.29	240	1.34	248	1.40
Isopropylbenzene							184	1.15	190	1.20	212	1.29	224	1.32	226	1.34
Benzene							171	1.08	165	1.06	176	1.08	188	1.12	192	1.15
o-Xylene							154	.97	150	.98	160	1.00	171	1.02	177	1.06
1,3,5-Trimethylbenzene							170	1.15	168	1.16	206	1.31	236	1.48	244	1.51
tert-Butylbenzene							176	1.24	172	1.23	199	1.32	224	1.41	226	1.43
1,2,4-Trimethylbenzene							135	.96	132	.95	153	1.02	172	1.07	177	1.10
m-Diethylbenzene							209	1.27	205	1.27	234	1.39	251	1.46	253	1.49
1-Ethyl-4-methylbenzene							162	1.01	162	1.03	180	1.11	195	1.17	200	1.21
sec-Butylbenzene							185	1.14	179	1.12	198	1.19	209	1.23	207	1.23

[a] $\text{imep ratio} = \frac{\text{imep of aromatic blend}}{\text{imep of base fuel}}$. For the blends tested with the 17.6 engine, the base fuel was S-3, S-3 plus 4 ml TEL/gal, or 85 percent S-3 plus 15 percent M-4 plus 4 ml TEL/gal; in all other instances, 85 percent S-3 plus 15 percent M-4 plus 4 ml TEL/gal was used.

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TABLE III.- SUPERCHARGED-ENGINE TESTS OF BLENDS CONTAINING AROMATICS - Continued

Compound	Fuel composition: Blend composition (percent by volume): Aromatic	S-3 reference fuel	85 percent S-3 plus 15 percent M-4	Tetraethyl lead (ml/gal)	Engine conditions: Engine speed (rpm)	Inlet-air temperature (°F)	Test results, Fuel-air ratio 0.065: imep	0.065: imep ratio[a]	0.07: imep	0.07: imep ratio[a]	0.085: imep	0.085: imep ratio[a]	0.10: imep	0.10: imep ratio[a]	0.11: imep	0.11: imep ratio[a]
17.6 engine																
Toluene	10	90	0	4	1800	250	218	1.01	229	1.03	258	1.04	273	1.05	285	1.10
Ethylbenzene							229	1.07	237	1.07	263	1.08	282	1.10	291	1.13
p-Xylene							222	1.04	239	1.08	274	1.12	293	1.14	300	1.16
Isopropylbenzene							206	1.04	226	1.10	259	1.12	282	1.16	288	1.20
Benzene							199	1.00	211	1.02	245	1.06	265	1.08	268	1.09
o-Xylene							177	.89	186	.91	204	.88	214	.87	212	.86
1,3,5-Trimethylbenzene							188	1.00	203	1.03	251	1.12	286	1.16	291	1.17
tert-Butylbenzene							208	1.12	217	1.12	252	1.12	286	1.16	292	1.18
1,2,4-Trimethylbenzene							170	.91	185	.94	221	.97	234	.95	232	.94
m-Diethylbenzene							219	1.08	231	1.11	278	1.18	306	1.22	312	1.25
1-Ethyl-4-methylbenzene							213	1.03	218	1.04	265	1.14	290	1.17	298	1.20
sec-Butylbenzene							220	1.09	223	1.08	251	1.08	286	1.14	294	1.17
Toluene	20	80	0	4	1800	250	227	1.05	239	1.07	276	1.11	308	1.19	327	1.26
Ethylbenzene							243	1.14	259	1.17	297	1.22	336	1.31	351	1.36
p-Xylene							225	1.05	250	1.13	301	1.23	343	1.34	364	1.41
Isopropylbenzene							216	1.10	230	1.12	275	1.19	318	1.31	331	1.38
Benzene							198	.99	214	1.04	256	1.10	279	1.14	288	1.17
o-Xylene							153	.77	168	.82	195	.84	205	.83	202	.82
1,3,5-Trimethylbenzene							192	1.02	211	1.07	278	1.24	344	1.40	364	1.47
tert-Butylbenzene							245	1.32	252	1.30	293	1.31	334	1.36	350	1.41
1,2,4-Trimethylbenzene							159	.85	173	.88	215	.95	232	.94	231	.94
m-Diethylbenzene							237	1.17	259	1.25	310	1.32	371	1.48	384	1.54
1-Ethyl-4-methylbenzene							229	1.11	236	1.12	281	1.21	329	1.33	351	1.41
sec-Butylbenzene							233	1.16	234	1.13	279	1.20	323	1.29	339	1.35
Toluene	20	80	0	4	1800	100	309	1.13	317	1.17	342	1.23	362	1.29	365	1.31
Ethylbenzene							348	1.29	359	1.33	379	1.36	383	1.37	381	1.38
p-Xylene							334	1.23	348	1.28	397	1.42	412	1.47	412	1.48
Isopropylbenzene							341	1.33	345	1.35	356	1.35	365	1.38	367	1.41
Benzene							286	1.11	288	1.11	312	1.17	322	1.21	322	1.23
o-Xylene							210	.81	212	.82	226	.84	229	.86	228	.87
1,3,5-Trimethylbenzene							335	1.26	340	1.29	400	1.49	419	1.55	413	1.55
tert-Butylbenzene							366	1:37	360	1.36	377	1.39	384	1.41	380	1.42
1,2,4-Trimethylbenzene							232	.88	235	.90	253	.94	255	.94	255	.95
m-Diethylbenzene							406	1.45	408	1.47	434	1.53	432	1.53	423	1.53
1-Ethyl-4-methylbenzene							371	1.34	370	1.35	404	1.45	398	1.42	385	1.41
sec-Butylbenzene							339	1.26	348	1.28	357	1.30	358	1.31	354	1.31

[a]imep ratio $= \frac{\text{imep of aromatic blend}}{\text{imep of base fuel}}$. For the blends tested with the 17.6 engine, the base fuel was S-3, S-3 plus 4 ml TEL/gal, or 85 percent S-3 plus 15 percent M-4 plus 4 ml TEL/gal; in all other instances, 85 percent S-3 plus 15 percent M-4 plus 4 ml TEL/gal was used.

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TABLE III.- SUPERCHARGED-ENGINE TESTS OF BLENDS CONTAINING AROMATICS - Continued

Fuel composition					Engine conditions		Test results									
	Blend composition (percent by volume)						Fuel-air ratio									
Compound	Aromatic	S-3 reference fuel	85 percent S-3 plus 15 percent M-4	Tetraethyl lead (ml/gal)	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																
Toluene	25	0	75	4	1800	250	----	------	----	------	----	------	----	------	----	------
Ethylbenzene							----	------	----	------	----	------	----	------	----	------
p-Xylene							----	------	----	------	----	------	----	------	----	------
Isopropylbenzene							168	1.25	176	1.27	225	1.40	245	1.45	248	1.48
Benzene							142	1.04	153	1.08	187	1.15	209	1.22	218	1.28
o-Xylene							110	.81	118	.84	143	.89	155	.91	157	.92
1,3,5-Trimethylbenzene							139	1.13	161	1.22	228	1.45	270	1.58	280	1.66
tert-Butylbenzene							159	1.24	165	1.22	214	1.34	242	1.41	245	1.44
1,2,4-Trimethylbenzene							113	.86	127	.92	162	1.01	179	1.03	177	1.05
m-Diethylbenzene							192	1.25	201	1.26	251	1.43	275	1.48	280	1.51
1-Ethyl-4-methylbenzene							144	1.05	154	1.09	199	1.25	239	1.41	251	1.48
sec-Butylbenzene							180	1.22	186	1.22	216	1.27	240	1.33	250	1.41
Toluene	25	0	75	4	1800	100	----	------	----	------	----	------	----	------	----	------
Ethylbenzene							----	------	----	------	----	------	----	------	----	------
p-Xylene							----	------	----	------	----	------	----	------	----	------
Isopropylbenzene							----	------	----	------	----	------	----	------	----	------
Benzene							206	1.18	211	1.21	229	1.23	240	1.27	241	1.28
o-Xylene							155	.89	157	.90	168	.91	172	.92	174	.94
1,3,5-Trimethylbenzene							----	------	----	------	----	------	----	------	----	------
tert-Butylbenzene							232	1.46	241	1.52	268	1.54	275	1.54	271	1.54
1,2,4-Trimethylbenzene							156	.96	161	.99	184	1.04	188	1.04	188	1.06
m-Diethylbenzene							276	1.47	279	1.48	307	1.57	310	1.60	302	1.60
1-Ethyl-4-methylbenzene							248	1.33	248	1.33	300	1.59	303	1.59	296	1.58
sec-Butylbenzene							241	1.31	245	1.32	258	1.36	267	1.40	262	1.40
Full-scale cylinder (data from reference 4)																
Toluene	25	0	75	4	2500	250	170	1.10	176	1.12	262	1.41	302	1.40	320	1.38
Ethylbenzene							174	1.12	192	1.22	243	1.33	294	1.36	309	1.34
p-Xylene							184	1.19	190	1.21	290	1.55	354	1.64	380	1.64
Isopropylbenzene							194	1.25	199	1.27	260	1.39	318	1.47	330	1.43
Benzene							150	.97	146	.93	214	1.14	258	1.19	278	1.20
o-Xylene							119	.77	111	.71	184	.98	213	.99	229	.99
1,3,5-Trimethylbenzene							184	1.19	196	1.25	304	1.63	371	1.72	----	------
tert-Butylbenzene							192	1.24	204	1.30	281	1.50	331	1.53	352	1.52
1,2,4-Trimethylbenzene							136	.88	136	.87	208	1.11	238	1.10	255	1.10
m-Diethylbenzene							196	1.26	222	1.41	320	1.71	350	1.62	355	1.54
1-Ethyl-4-methylbenzene							184	1.19	185	1.18	297	1.59	351	1.62	365	1.58
sec-Butylbenzene							180	1.16	174	1.11	264	1.41	291	1.35	319	1.38
Toluene	25	0	75	4	2000	210	190	1.28	196	1.30	258	1.41	317	1.49	323	1.42
Ethylbenzene							200	1.35	210	1.39	265	1.45	296	1.39	306	1.35
p-Xylene							182	1.23	198	1.31	307	1.68	345	1.62	358	1.58
Isopropylbenzene							207	1.40	206	1.36	278	1.52	316	1.48	321	1.41
Benzene							177	1.20	180	1.19	215	1.17	263	1.23	283	1.25
o-Xylene							114	.77	124	.82	180	.98	211	.99	222	.98
1,3,5-Trimethylbenzene							199	1.34	210	1.39	282	1.54	344	1.62	372	1.64
tert-Butylbenzene							220	1.49	225	1.49	287	1.57	331	1.55	338	1.49
1,2,4-Trimethylbenzene							110	.74	132	.87	193	1.05	229	1.08	244	1.07
m-Diethylbenzene							248	1.67	258	1.71	326	1.78	348	1.63	352	1.55
1-Ethyl-4-methylbenzene							227	1.53	230	1.52	302	1.65	354	1.66	355	1.56
sec-Butylbenzene							198	1.34	202	1.34	251	1.37	295	1.38	307	1.35

[a]imep ratio = $\frac{\text{imep of aromatic blend}}{\text{imep of base fuel}}$. For the blends tested with the 17.6 engine, the base fuel was S-3, S-3 plus 4 ml TEL/gal, or 85 percent S-3 plus 15 percent M-4 plus 4 ml TEL/gal; in all other instances, 85 percent S-3 plus 15 percent M-4 plus 4 ml TEL/gal was used.

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TABLE III. - SUPERCHARGED-ENGINE TESTS OF BLENDS CONTAINING AROMATICS - Concluded

Compound	Fuel composition: Blend composition (percent by volume): Aromatic	S-3 reference fuel	85 percent S-3 plus 15 percent M-4	Tetra-ethyl lead (ml/gal)	Engine conditions: Engine speed (rpm)	Inlet-air temperature (°F)	Test results, Fuel-air ratio 0.065: imep	0.065: imep ratio[a]	0.07: imep	0.07: imep ratio[a]	0.085: imep	0.085: imep ratio[a]	0.10: imep	0.10: imep ratio[a]	0.11: imep	0.11: imep ratio[a]
F-4 engine																
Toluene	10	0	90	4	1800	225	139	1.01	154	1.05	181	1.08	194	1.10	197	1.13
Ethylbenzene							145	1.06	157	1.07	185	1.11	198	1.12	200	1.14
p-Xylene							128	1.04	143	1.07	178	1.10	192	1.10	194	1.11
Isopropylbenzene							121	1.14	135	1.13	172	1.13	189	1.11	193	1.12
Benzene							129	1.03	141	1.01	168	1.04	182	1.05	166	1.07
o-Xylene							119	.95	130	.94	154	.95	159	.92	158	.91
1,3,5-Trimethylbenzene							114	1.09	128	1.10	171	1.13	197	1.16	203	1.16
tert-Butylbenzene							137	1.06	147	1.06	180	1.10	197	1.14	201	1.15
1,2,4-Trimethylbenzene							120	.92	134	.95	160	.98	169	.98	170	.97
m-Diethylbenzene							128	1.04	150	1.09	187	1.18	201	1.18	205	1.19
1-Ethyl-4-methylbenzene							125	1.01	140	1.04	178	1.11	197	1.15	201	1.15
sec-Butylbenzene							116	1.01	132	.99	164	1.03	192	1.07	188	1.09
Toluene	25	0	75	4	1800	225	137	1.00	153	1.04	197	1.18	227	1.29	240	1.37
Ethylbenzene							140	1.02	159	1.08	202	1.21	227	1.29	240	1.37
p-Xylene							124	1.01	146	1.09	205	1.28	243	1.39	262	1.50
Isopropylbenzene							111	1.05	127	1.07	174	1.14	209	1.23	225	1.30
Benzene							107	1.06	126	1.10	171	1.12	196	1.15	206	1.19
o-Xylene							90	.76	105	.80	141	.89	155	.91	156	.91
1,3,5-Trimethylbenzene							96	.94	109	.95	191	1.26	233	1.39	255	1.49
tert-Butylbenzene							144	1.12	162	1.17	213	1.31	246	1.42	258	1.47
1,2,4-Trimethylbenzene							101	.81	117	.85	161	1.02	174	1.03	176	1.02
m-Diethylbenzene							122	.99	147	1.07	203	1.28	241	1.42	260	1.51
1-Ethyl-4-methylbenzene							119	.98	136	1.01	194	1.21	231	1.34	250	1.43
sec-Butylbenzene							118	1.03	135	1.01	180	1.14	212	1.25	226	1.31
Toluene	50	0	50	4	1800	225	115	0.84	146	0.99	212	1.27	425	2.43	----	------
Ethylbenzene							119	.99	142	1.07	227	1.44	297	1.71	----	------
p-Xylene							115	.94	138	1.03	252	1.57	495	2.83	----	------
Isopropylbenzene							99	.93	121	1.02	215	1.41	326	1.92	447	2.58
Benzene							77	.74	87	.73	187	1.23	237	1.39	261	1.51
o-Xylene							77	.68	92	.73	133	.87	162	.95	173	1.00
1,3,5-Trimethylbenzene							104	1.02	120	1.04	242	1.61	[b]480	[b]2.96	----	------
tert-Butylbenzene							119	1.06	141	1.13	230	1.46	393	2.28	452	2.58
1,2,4-Trimethylbenzene							100	.81	114	.83	166	1.04	206	1.21	230	1.34
m-Diethylbenzene							101	.82	116	.86	196	1.23	307	1.81	359	2.09
1-Ethyl-4-methylbenzene							114	.93	131	.98	204	1.27	260	1.51	336	1.93
sec-Butylbenzene							113	.98	129	.97	186	1.17	243	1.43	281	1.63

[a] $\text{imep ratio} = \dfrac{\text{imep of aromatic blend}}{\text{imep of base fuel}}$. For the blends tested with the 17.6 engine, the base fuel was S-3, S-3 plus 4 ml TEL/gal, or 85 percent S-3 plus 15 percent M-4 plus 4 ml TEL/gal; in all other instances, 85 percent S-3 plus 15 percent M-4 plus 4 ml TEL/gal was used.

[b] Estimated value.

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TABLE III. - TEMPERATURE SENSITIVITY OF THE AROMATIC 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	Blend composition (percent by volume)			Tetraethyl lead (ml/gal)	Relative temperature sensitivity[a]				
	Aromatic	S-3 reference fuel	85 percent S-3 plus 15 percent M-4		Fuel-air ratio				
					0.065	0.07	0.085	0.10	0.11
S-3	0	100	0	0	1.00	1.00	1.00	1.00	1.00
Toluene	20	80	0	0	1.01	1.05	1.06	1.00	.98
Ethylbenzene					1.17	1.21	1.20	1.12	1.04
p-Xylene					1.11	1.15	1.11	1.05	1.01
Isopropylbenzene					1.10	1.22	1.21	1.10	1.04
Benzene					1.08	1.05	1.06	1.02	.98
o-Xylene					1.08	1.10	1.15	1.10	1.07
1,3,5-Trimethylbenzene					1.26	1.22	1.21	1.17	1.06
tert-Butylbenzene					1.31	1.29	1.22	1.23	1.13
1,2,4-Trimethylbenzene					1.10	1.10	1.12	1.11	1.05
m-Diethylbenzene					1.21	1.22	1.25	1.18	1.08
1-Ethyl-4-methylbenzene					1.01	1.03	1.00	1.03	1.03
sec-Butylbenzene					1.16	1.13	1.10	1.06	.98
S-3	0	100	0	4	1.00	1.00	1.00	1.00	1.00
Toluene	20	80	0	4	1.08	1.09	1.11	1.08	1.04
Ethylbenzene					1.13	1.14	1.11	1.05	1.01
p-Xylene					1.17	1.13	1.15	1.10	1.05
Isopropylbenzene					1.21	1.21	1.13	1.05	1.02
Benzene					1.12	1.07	1.06	1.06	1.05
o-Xylene					1.05	1.00	1.00	1.04	1.06
1,3,5-Trimethylbenzene					1.24	1.21	1.20	1.11	1.05
tert-Butylbenzene					1.04	1.04	1.06	1.04	1.01
1,2,4-Trimethylbenzene					1.04	1.02	.99	1.00	1.01
m-Diethylbenzene					1.24	1.18	1.16	1.03	.99
1-Ethyl-4-methylbenzene					1.21	1.21	1.20	1.07	1.00
sec-Butylbenzene					1.09	1.13	1.08	1.02	.97
85 percent S-3 + 15 percent M-4	0	0	100	4	1.00	1.00	1.00	1.00	1.00
Toluene	25	0	75	4	----	----	-----	----	----
Ethylbenzene					----	----	-----	----	----
p-Xylene					----	----	-----	----	----
Isopropylbenzene					----	----	-----	----	----
Benzene					1.13	1.12	1.07	1.04	1.00
o-Xylene					1.10	1.07	1.02	1.01	1.02
1,3,5-Trimethylbenzene					----	----	-----	----	----
tert-Butylbenzene					1.18	1.25	1.15	1.09	1.07
1,2,4-Trimethylbenzene					1.12	1.08	1.03	1.01	1.01
m-Diethylbenzene					1.18	1.17	1.10	1.08	1.06
1-Ethyl-4-methylbenzene					1.27	1.22	1.27	1.13	1.07
sec-Butylbenzene					1.07	1.08	1.07	1.05	.99

[a]Relative temperature sensitivity

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

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

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TABLE X.- LEAD SUSCEPTIBILITY OF THE AROMATIC BLENDS RELATIVE TO THAT OF S-3 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]				
		Aromatic	S-3 reference fuel	Fuel-air ratio				
				0.065	0.07	0.085	0.10	0.11
S-3	250	0	100	1.00	1.00	1.00	1.00	1.00
Toluene	250	10	90	0.97	1.01	0.99	0.97	0.99
Ethylbenzene				1.05	1.05	1.04	.99	.97
p-Xylene				1.03	1.07	1.02	1.02	1.02
Isopropylbenzene				1.03	1.10	1.03	1.02	1.03
Benzene				1.00	1.01	1.04	1.05	1.05
o-Xylene				.94	.96	.95	.90	.86
1,3,5-Trimethylbenzene				1.04	1.05	1.09	1.01	.97
tert-Butylbenzene				1.14	1.12	1.07	1.04	.99
1,2,4-Trimethylbenzene				1.00	1.01	1.02	.96	.93
m-Diethylbenzene				1.07	1.10	1.12	1.09	1.05
1-Ethyl-4-methylbenzene				1.03	1.04	1.09	1.08	1.10
sec-Butylbenzene				1.11	1.08	1.03	1.06	1.06
Toluene	250	20	80	1.01	1.05	1.00	.98	1.00
Ethylbenzene				1.12	1.17	1.14	1.06	1.04
p-Xylene				1.01	1.09	1.06	1.05	1.02
Isopropylbenzene				1.05	1.14	1.11	1.09	1.07
Benzene				.99	1.03	1.08	1.04	1.00
o-Xylene				.86	.92	.97	.89	.83
1,3,5-Trimethylbenzene				1.12	1.13	1.15	1.10	1.04
tert-Butylbenzene				1.39	1.37	1.21	1.18	1.11
1,2,4-Trimethylbenzene				.98	1.02	1.04	.98	.90
m-Diethylbenzene				1.11	1.20	1.19	1.19	1.12
1-Ethyl-4-methylbenzene				1.11	1.12	1.09	1.17	1.20
sec-Butylbenzene				1.18	1.14	1.11	1.11	1.07
S-3	100	0	100	1.00	1.00	1.00	1.00	1.00
Toluene	100	20	80	1.08	1.09	1.04	1.07	1.06
Ethylbenzene				1.08	1.10	1.06	1.01	1.01
p-Xylene				1.07	1.07	1.10	1.10	1.06
Isopropylbenzene				1.16	1.13	1.05	1.05	1.05
Benzene				1.03	1.05	1.06	1.08	1.07
o-Xylene				.84	.84	.84	.84	.82
1,3,5-Trimethylbenzene				1.10	1.11	1.14	1.05	1.03
tert-Butylbenzene				1.10	1.11	1.05	1.00	.99
1,2,4-Trimethylbenzene				.92	.95	.92	.88	.86
m-Diethylbenzene				1.14	1.16	1.10	1.05	1.03
1-Ethyl-4-methylbenzene				1.33	1.31	1.31	1.21	1.17
sec-Butylbenzene				1.11	1.14	1.09	1.07	1.07

$$^{a}\text{Relative lead susceptibility} = \frac{\dfrac{\text{imep of aromatic blend (with 4 ml TEL/gal)}}{\text{imep of aromatic blend (with 0 ml TEL/gal)}}}{\dfrac{\text{imep of S-3 (with 4 ml TEL/gal)}}{\text{imep of S-3 (with 0 ml TEL/gal)}}}$$

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

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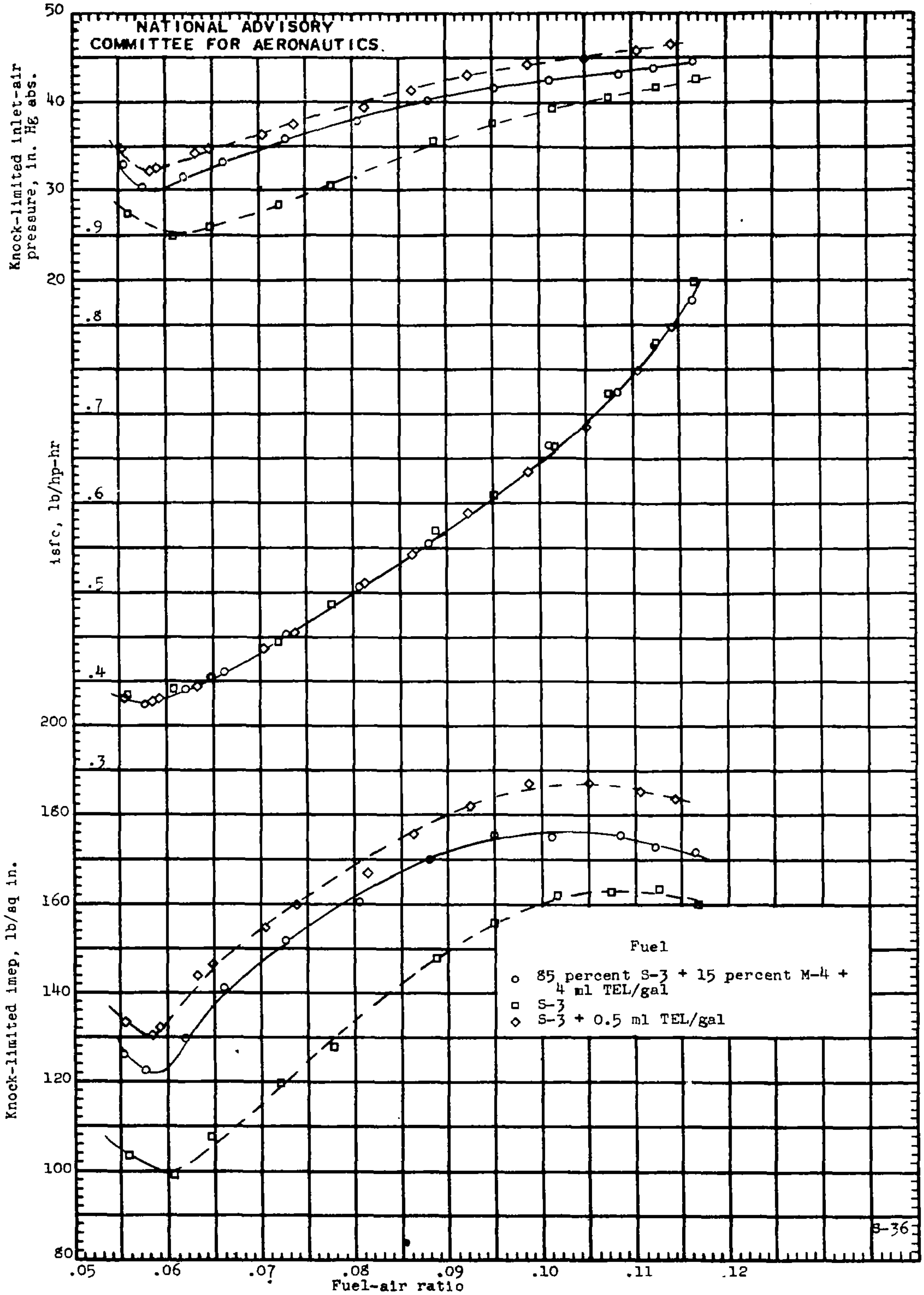
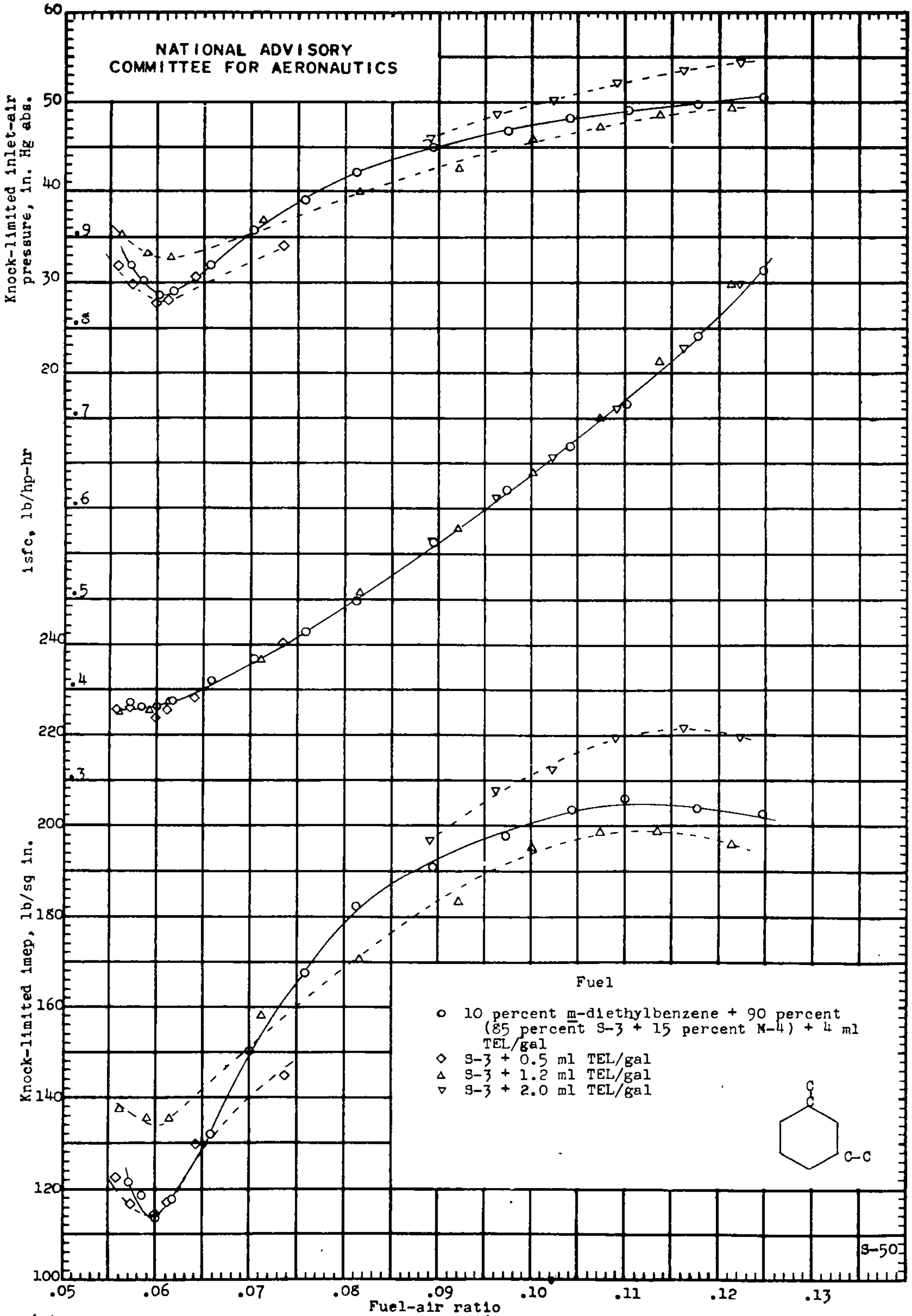
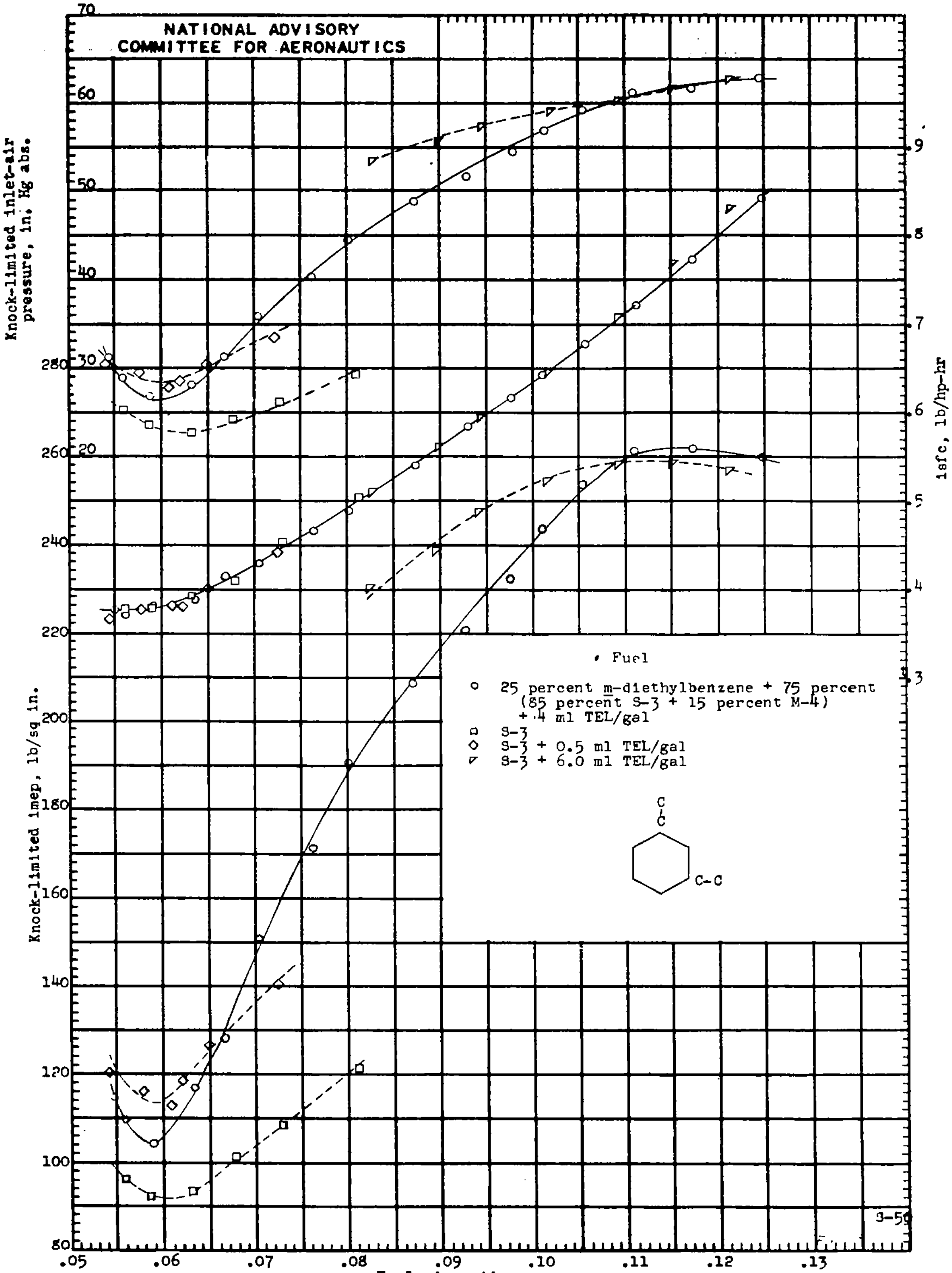


Figure 1. - Knock-limited performance of 85 percent S-3 plus 15 percent M-4 plus 4 ml TEL per gallon in an F-4 engine. (Reproduced from fig. 7 of reference 1.)



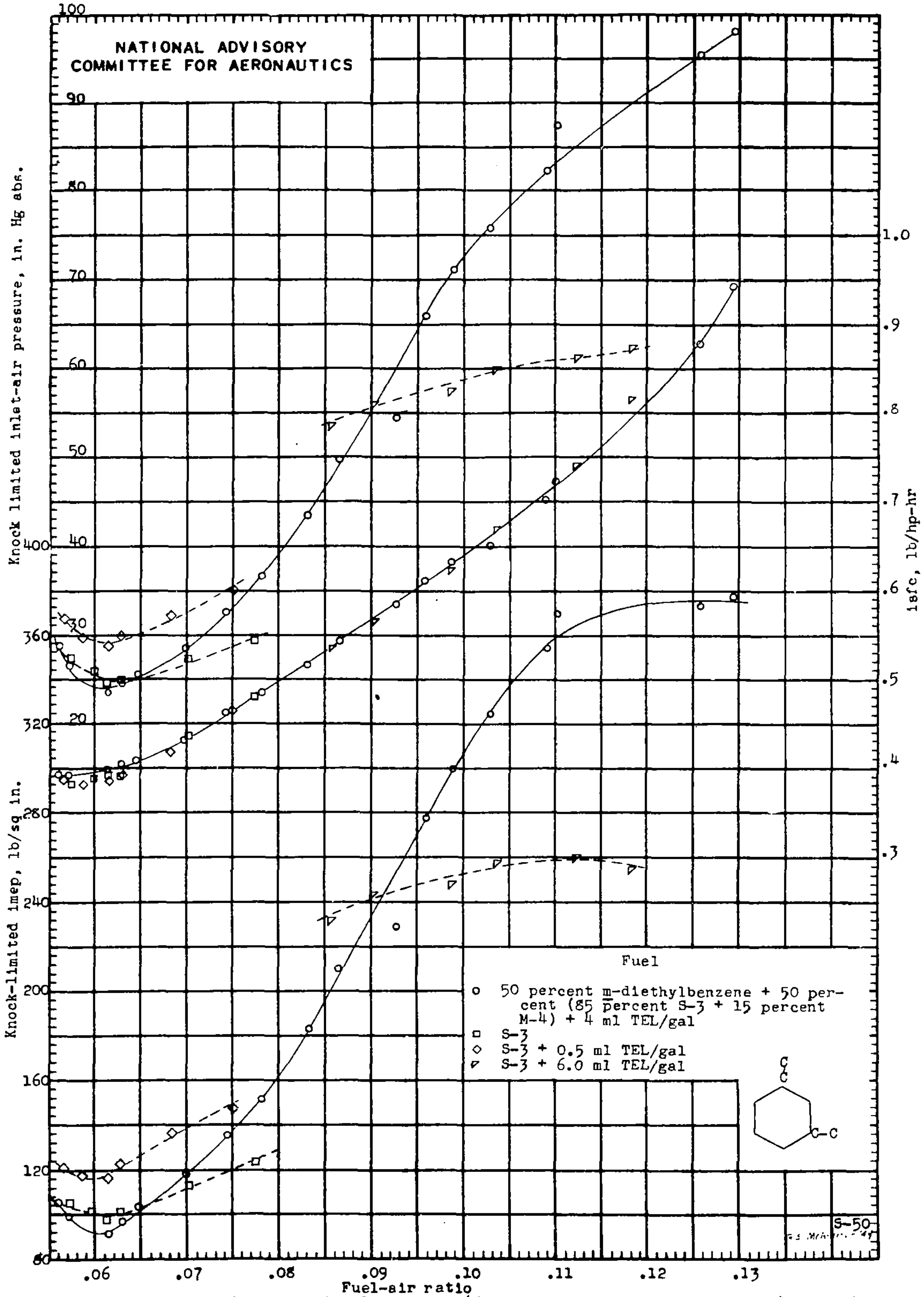
(a) 10 percent m-diethylbenzene plus 90 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.

Figure 2. - Knock-limited performance of blends containing m-diethylbenzene in an F-4 engine.

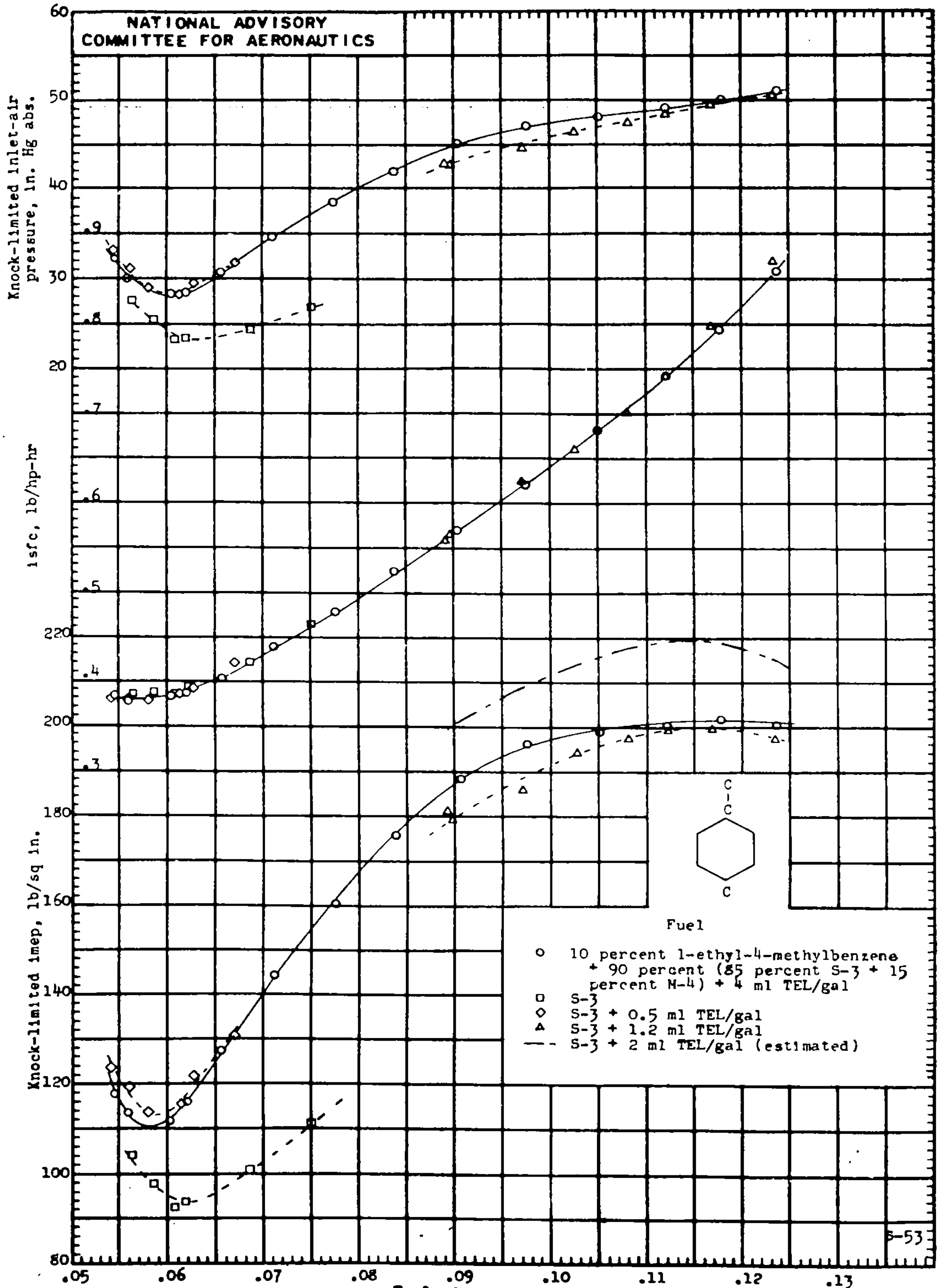


(b) 25 percent m-diethylbenzene plus 75 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.

Figure 2. - Continued.

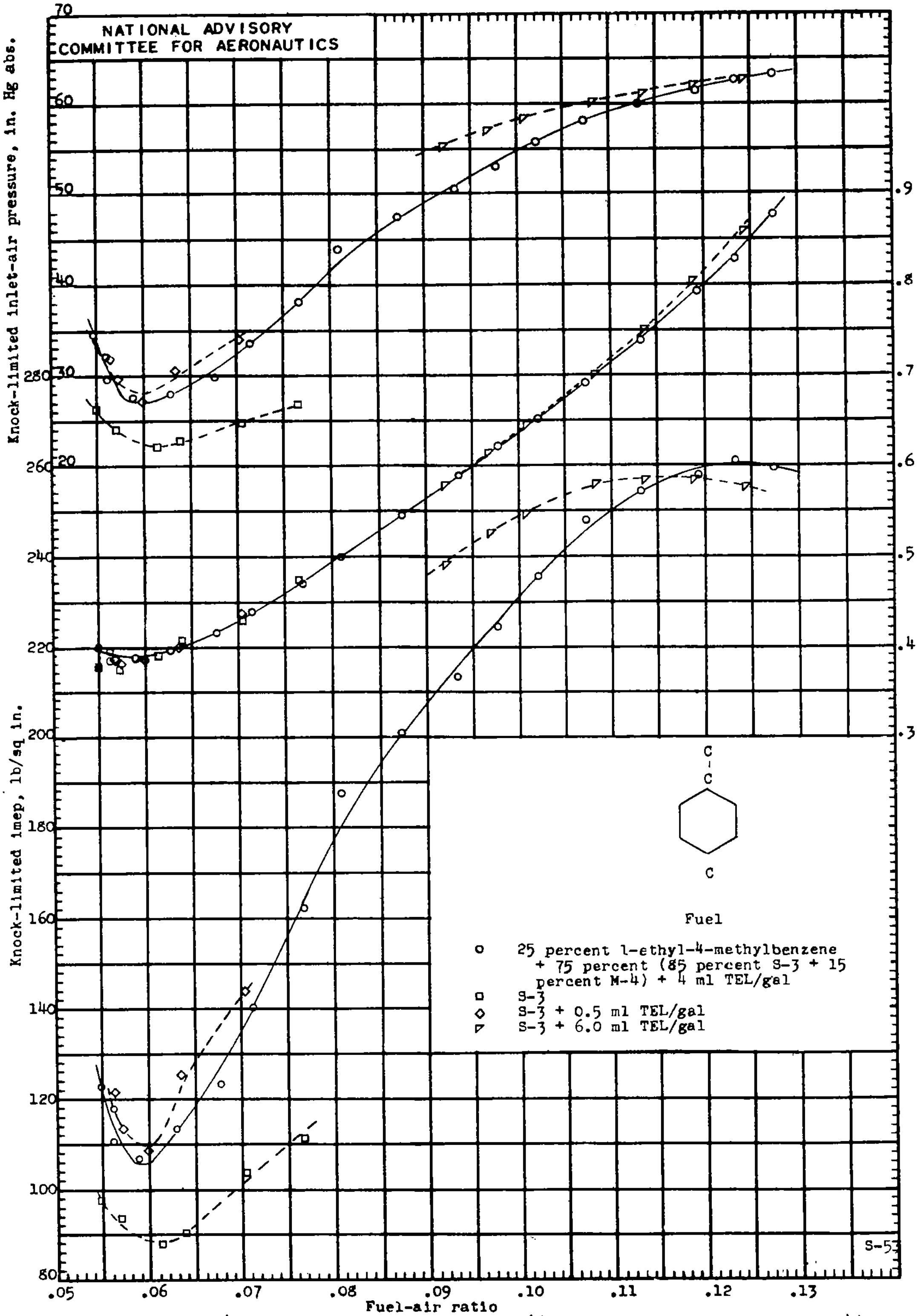


(c) 50 percent m-diethylbenzene plus 50 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.
Figure 2. - Concluded.

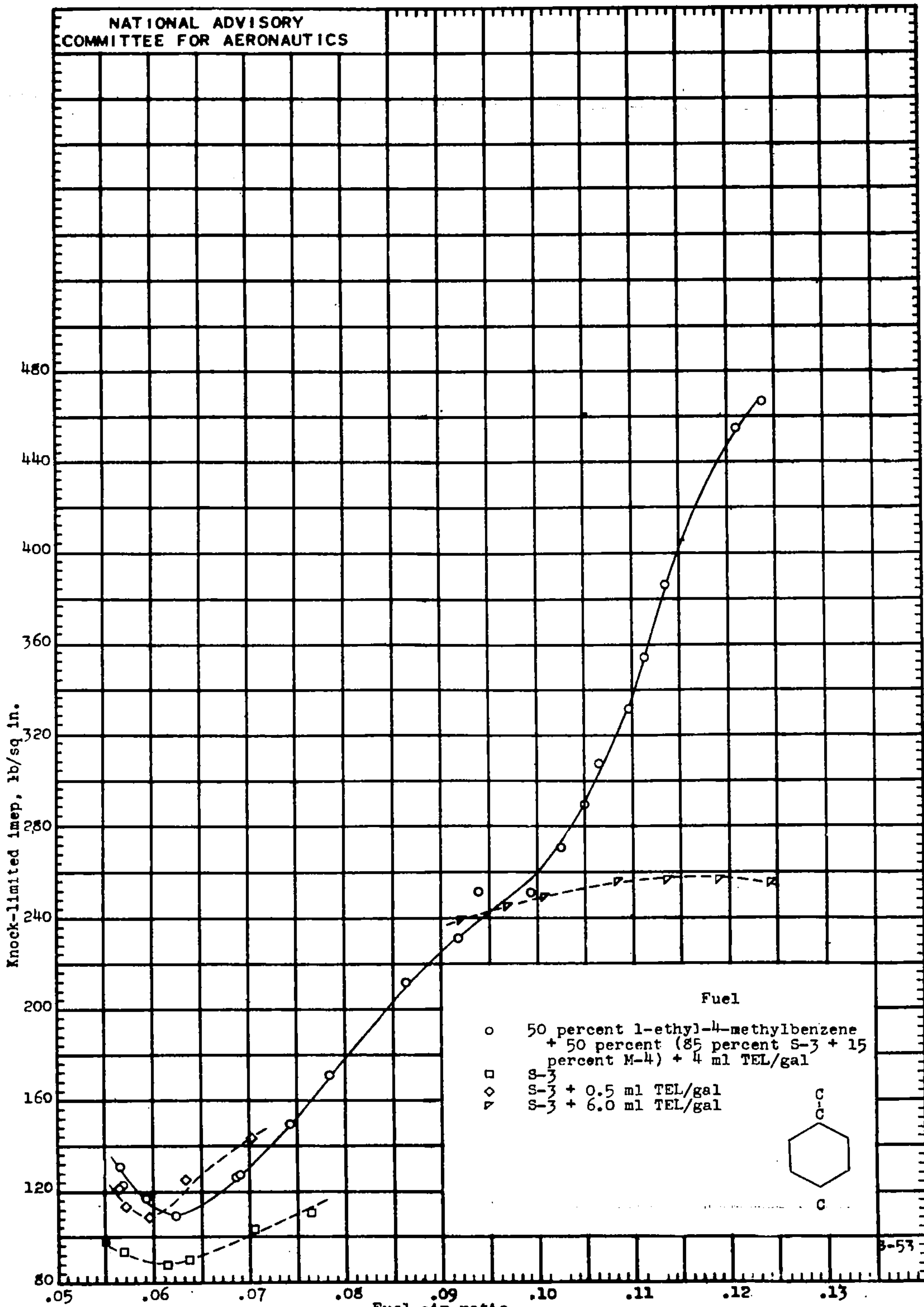


(a) 10 percent 1-ethyl-4-methylbenzene plus 90 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.

Figure 3. - Knock-limited performance of blends containing 1-ethyl-4-methylbenzene in an F-4 engine.

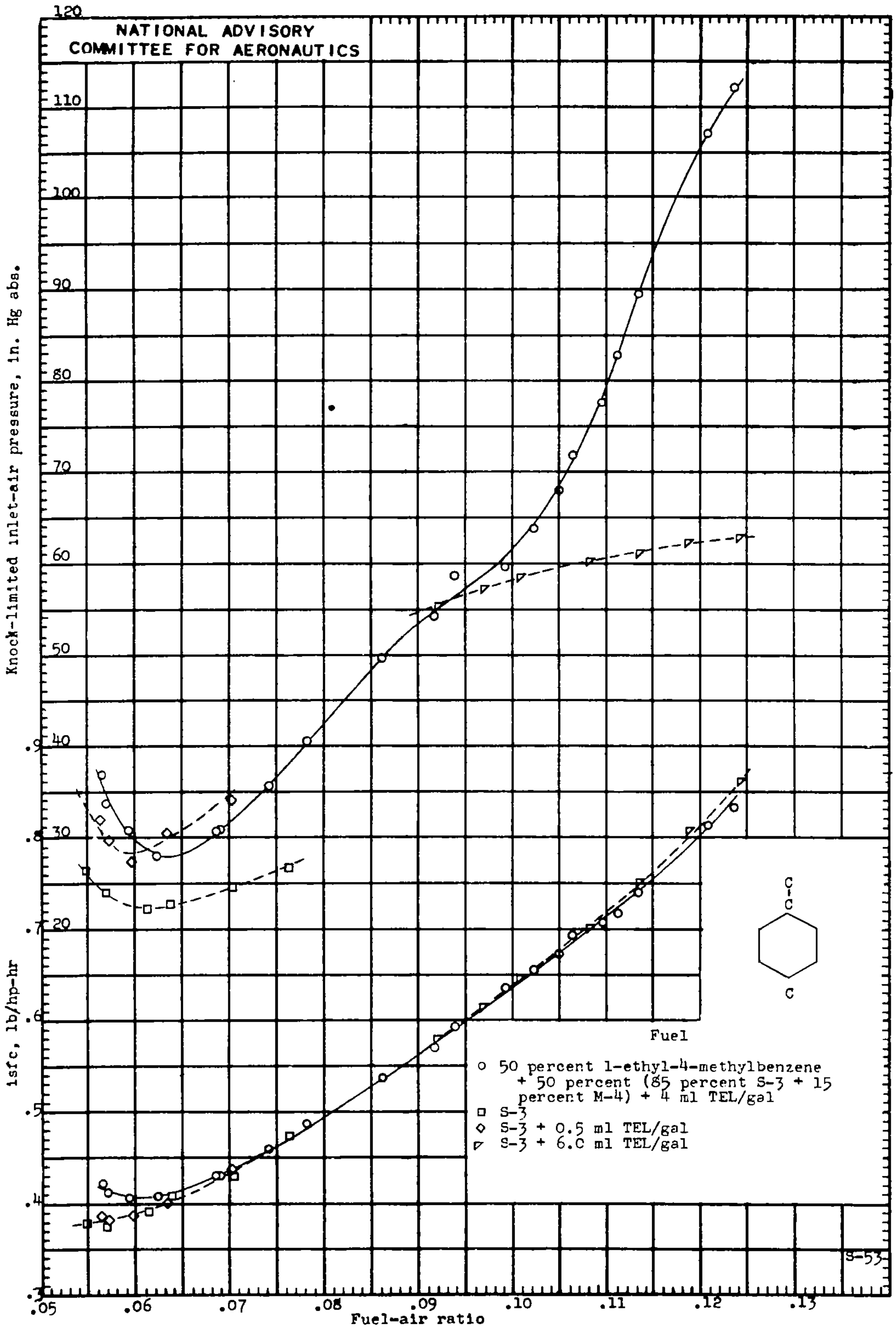


(b) 25 percent 1-ethyl-4-methylbenzene plus 75 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.
Figure 3 . - Continued.

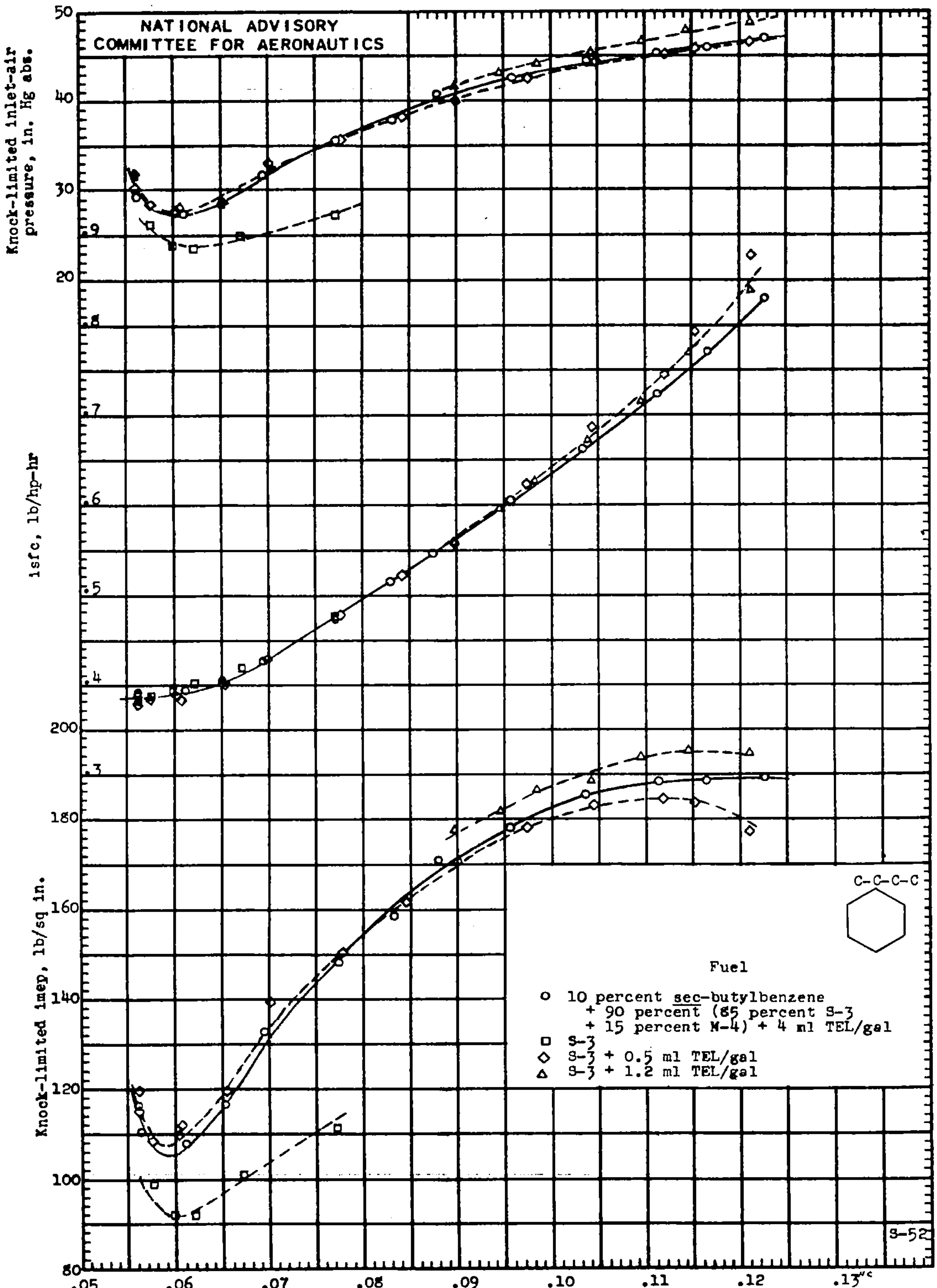


(c) 50 percent 1-ethyl-4-methylbenzene plus 50 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.

Figure 3. - Continued.

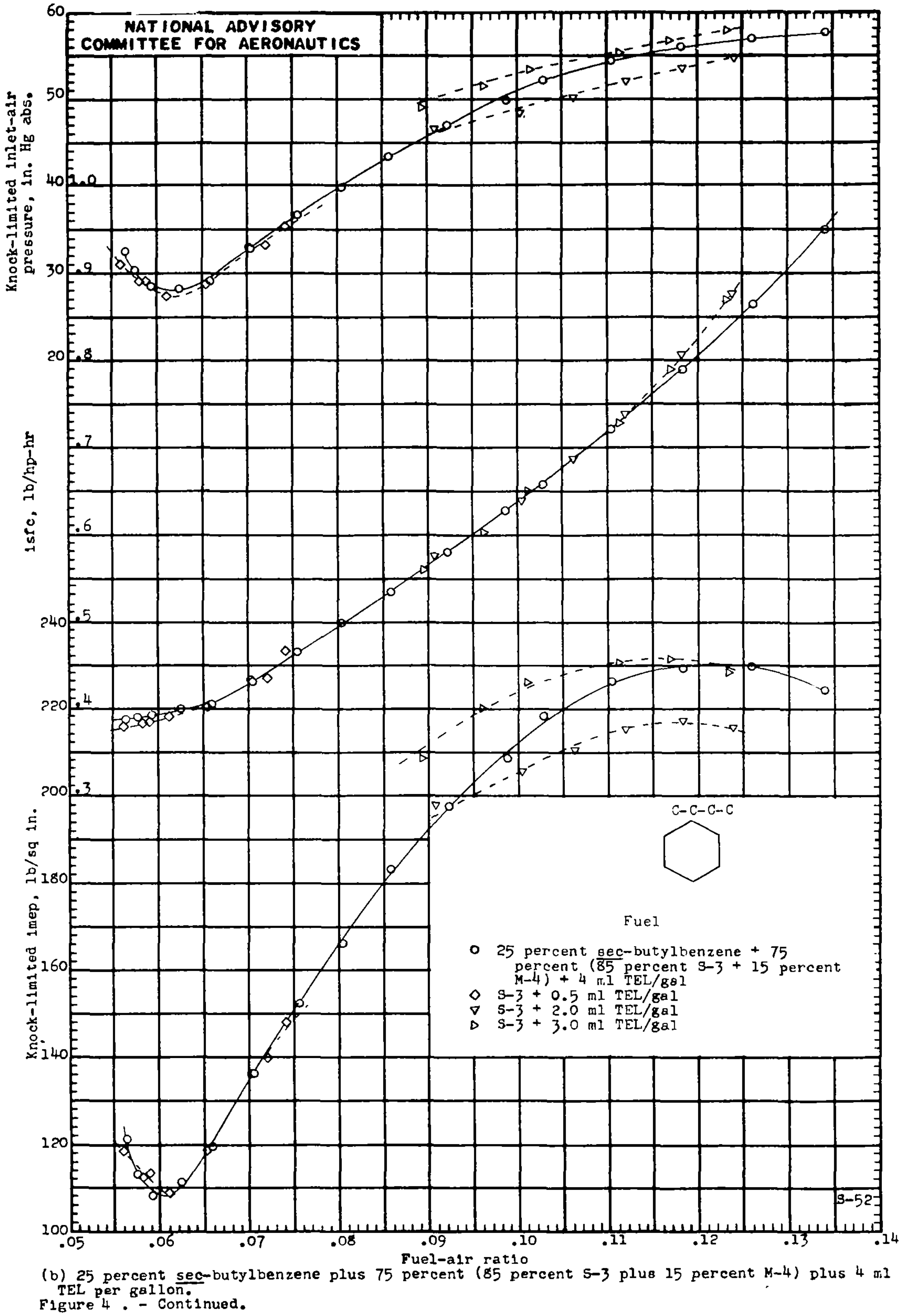


(c) Concluded.
Figure 3. - Concluded.



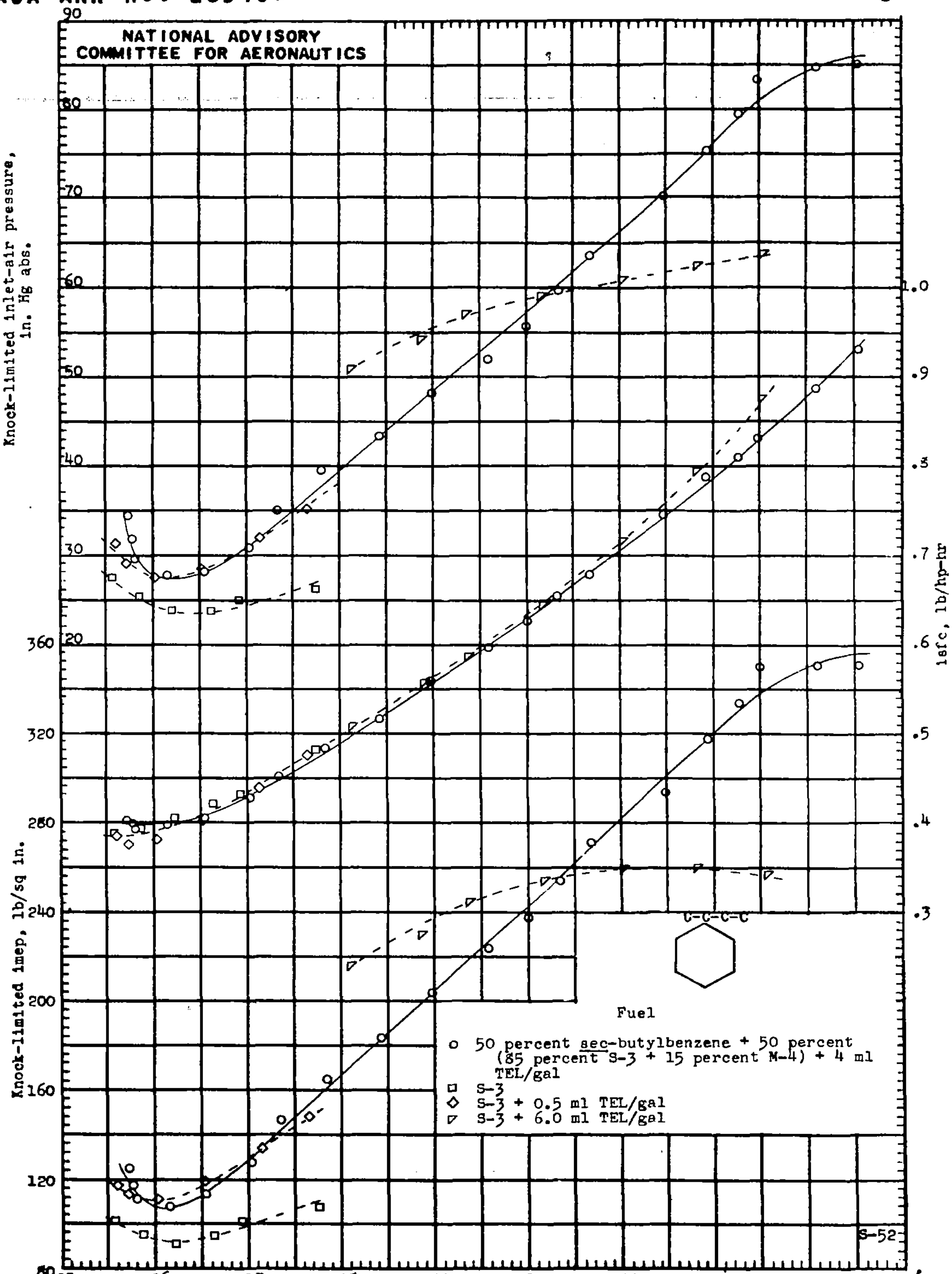
(a) 10 percent sec-butylbenzene plus 90 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.

Figure 4 . - Knock-limited performance of blends containing sec-butylbenzene in an F-4 engine.



(b) 25 percent sec-butylbenzene plus 75 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.

Figure 4 . - Continued.



(c) 50 percent sec-butylbenzene plus 50 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.

Figure 4 . - Concluded.

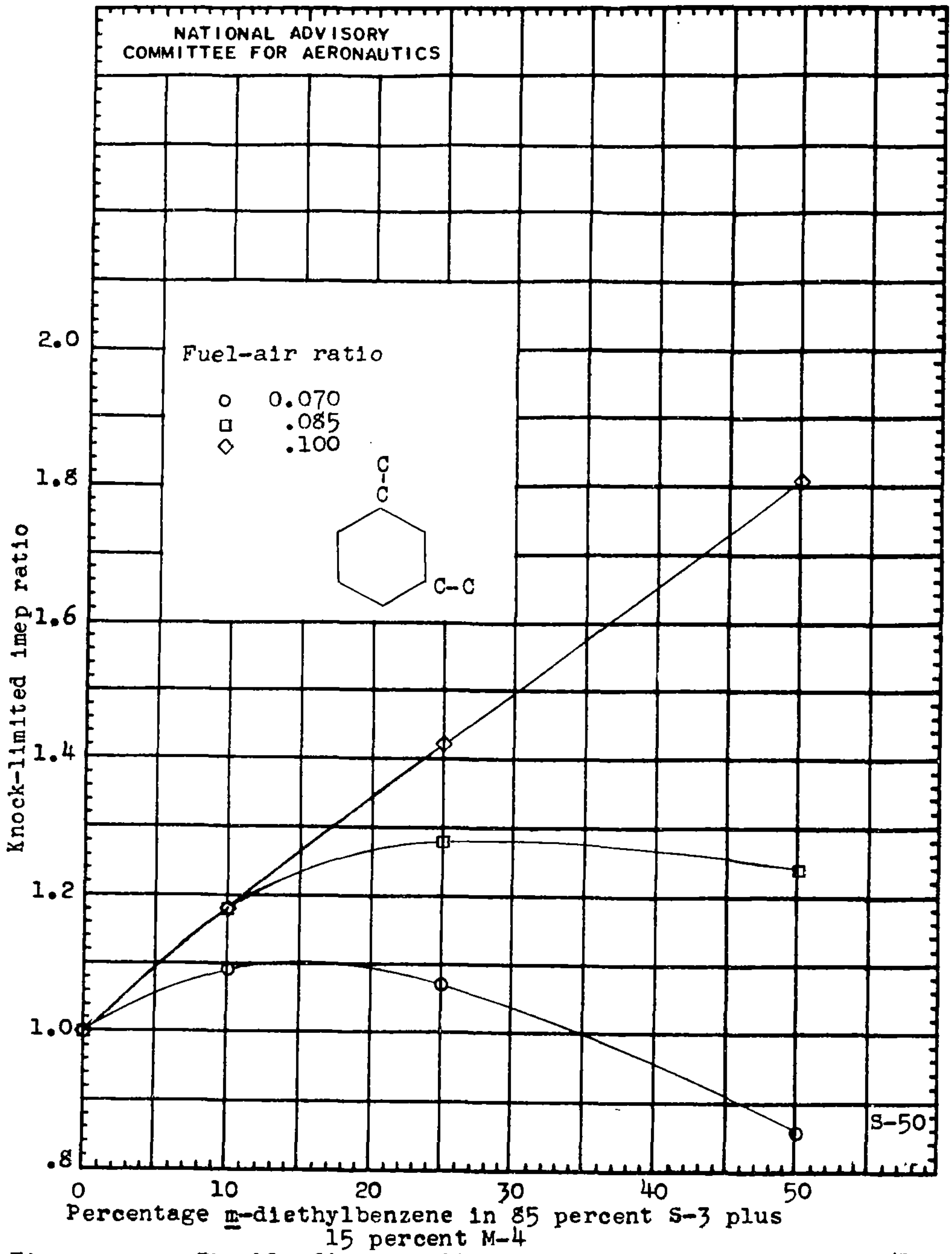


Figure 5. - The blending sensitivity of m-diethylbenzene in 85 percent S-3 plus 15 percent M-4. F-4 engine; final blends leaded to 4 ml TEL per gallon.

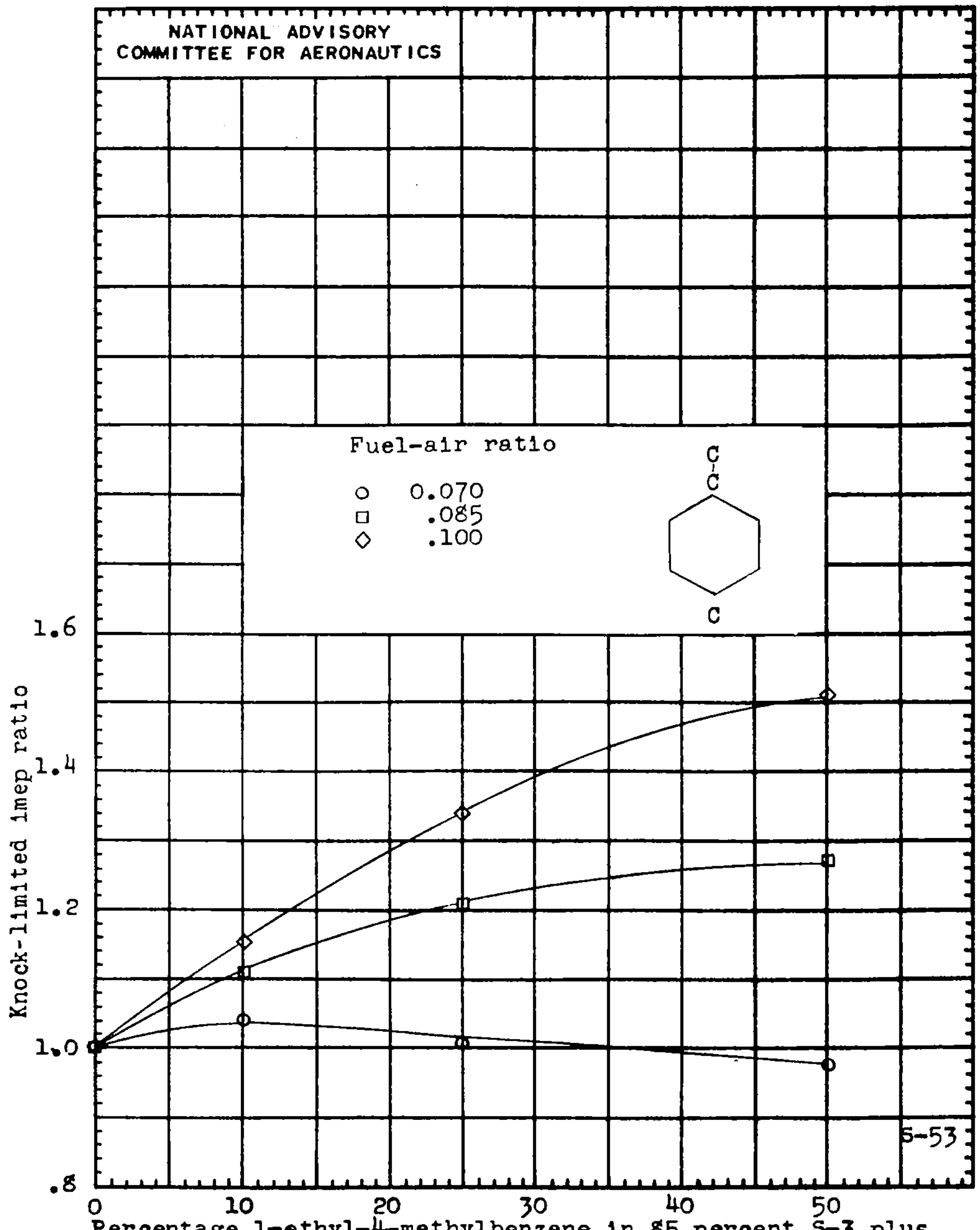


Figure 6. - The blending sensitivity of 1-ethyl-4-methylbenzene in 85 percent S-3 plus 15 percent M-4. F-4 engine; final blends leaded to 4 ml TEL per gallon.

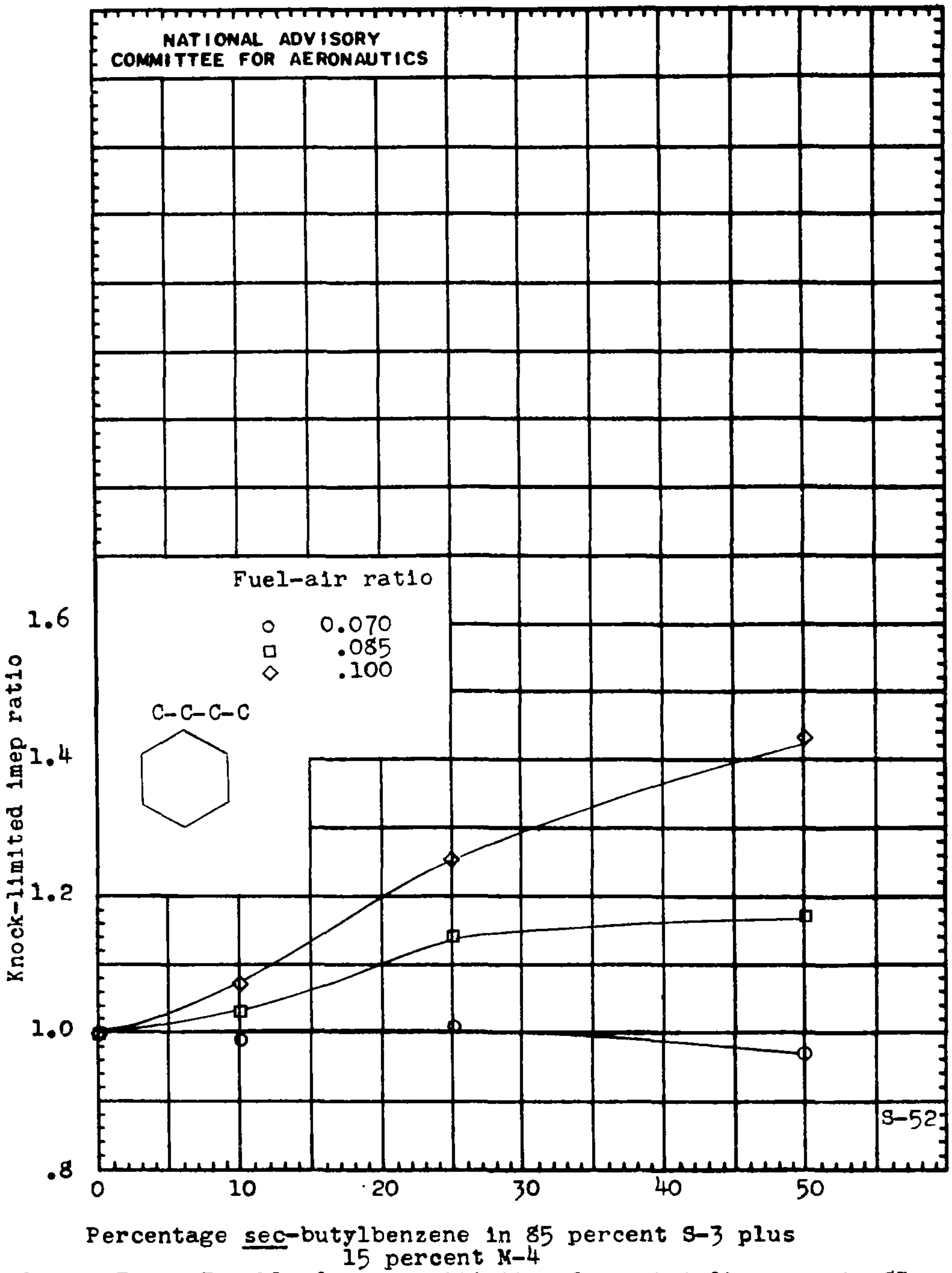
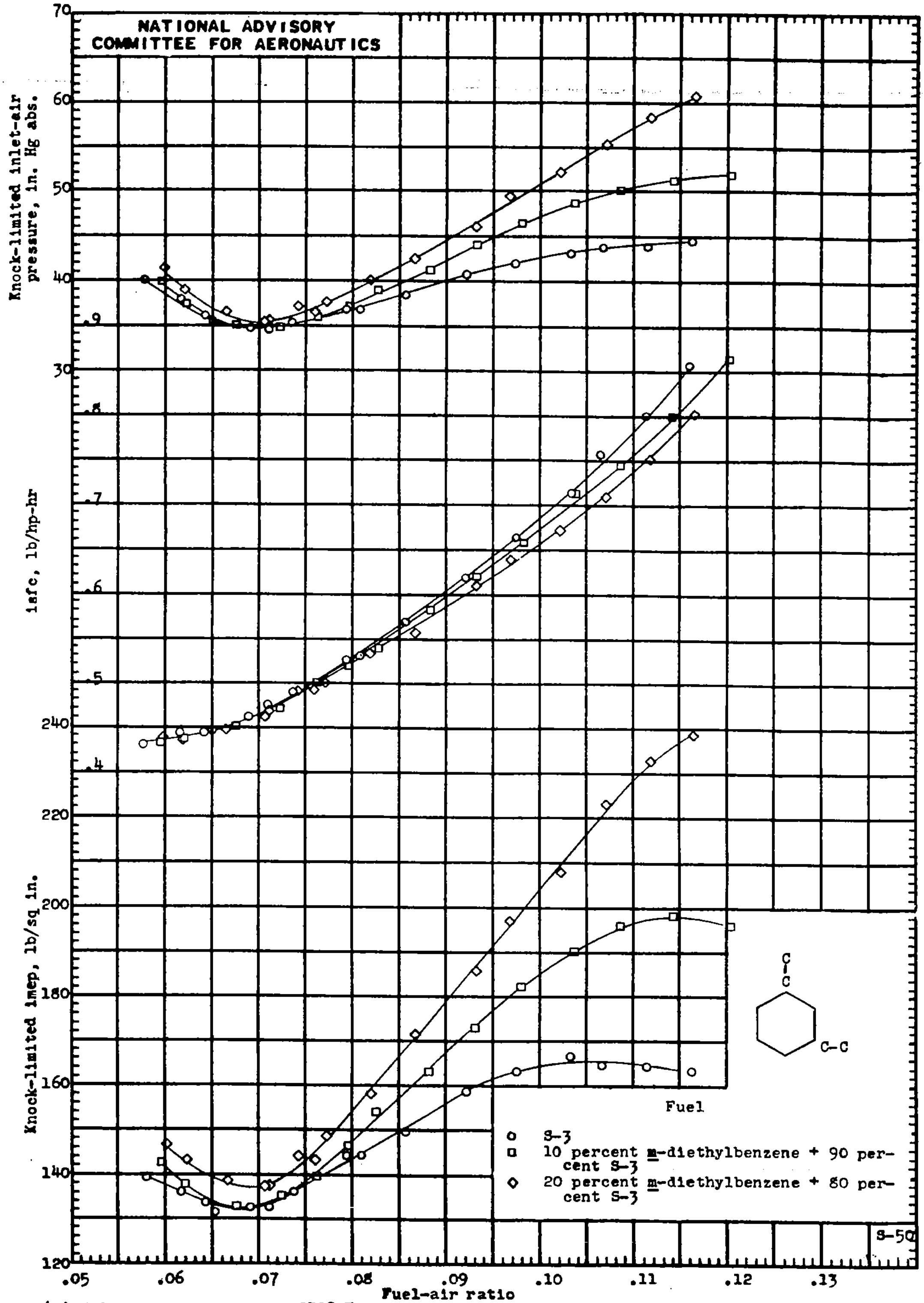
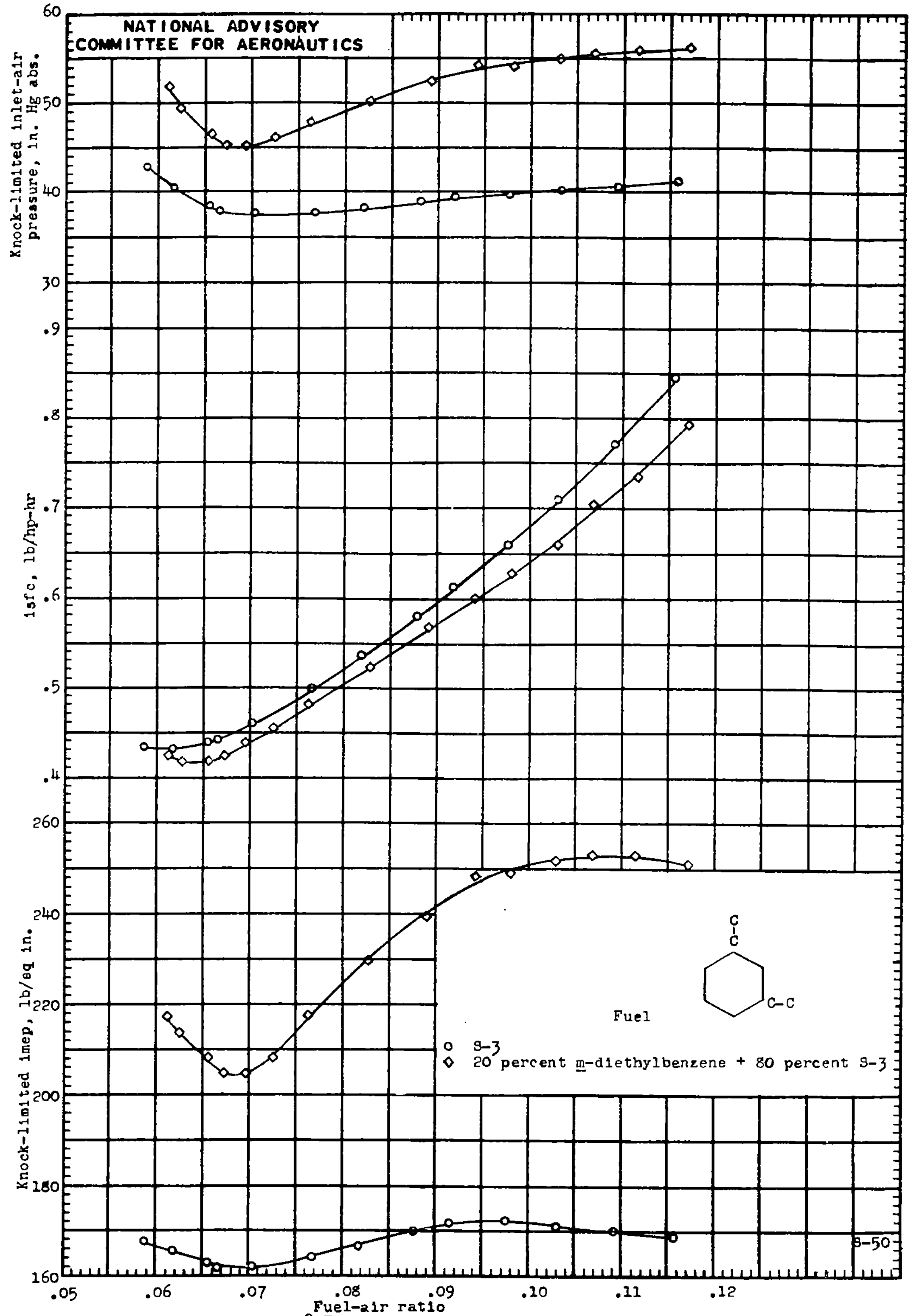


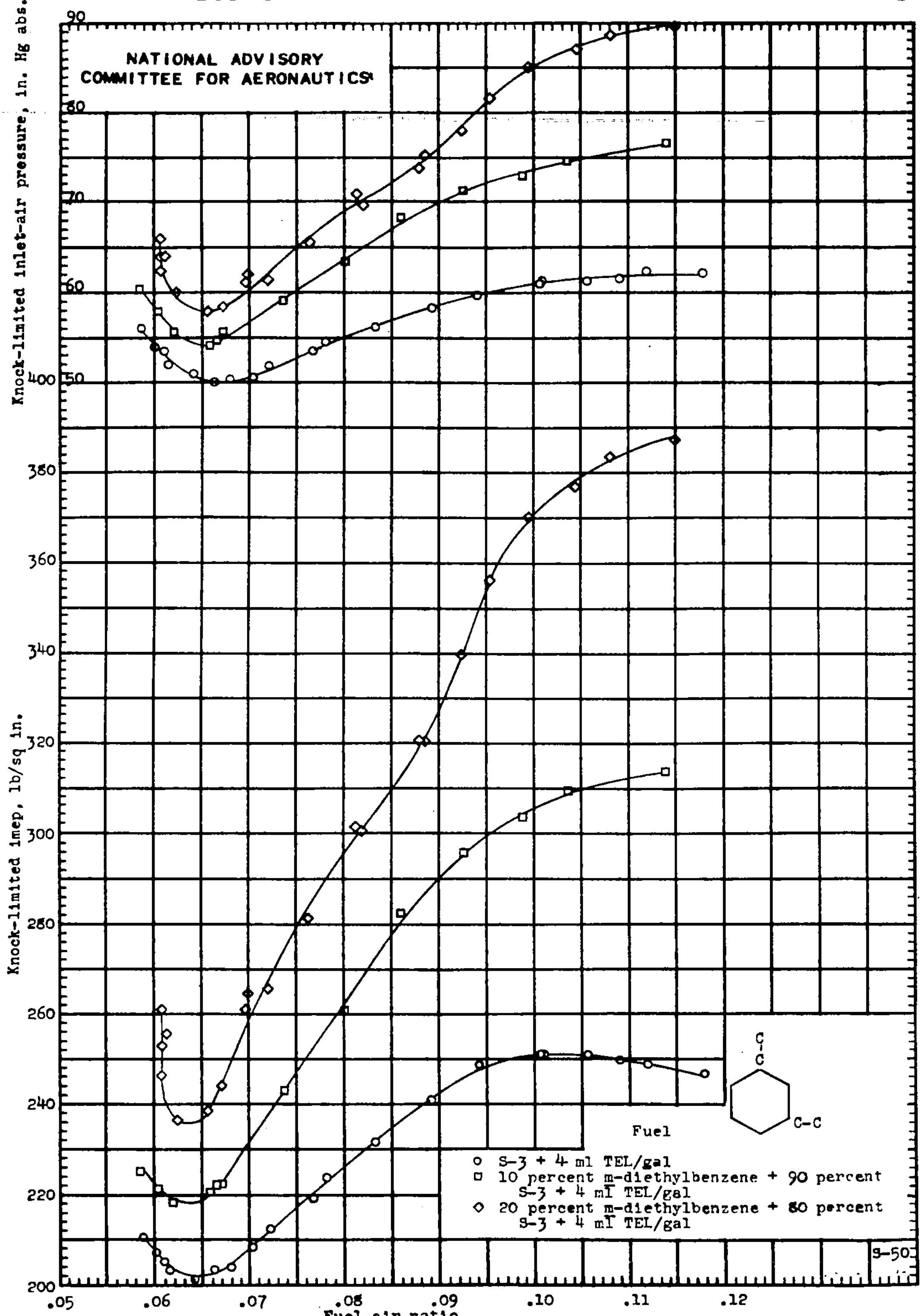
Figure 7 . - The blending sensitivity of sec-butylbenzene in 85 percent S-3 plus 15 percent M-4. F-4 engine; final blends leaded to 4 ml TEL per gallon.



(a) Inlet-air temperature, 250° F.
Figure 8. - Knock-limited performance of blends of m-diethylbenzene and S-3 reference fuel. 17.6 engine; compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

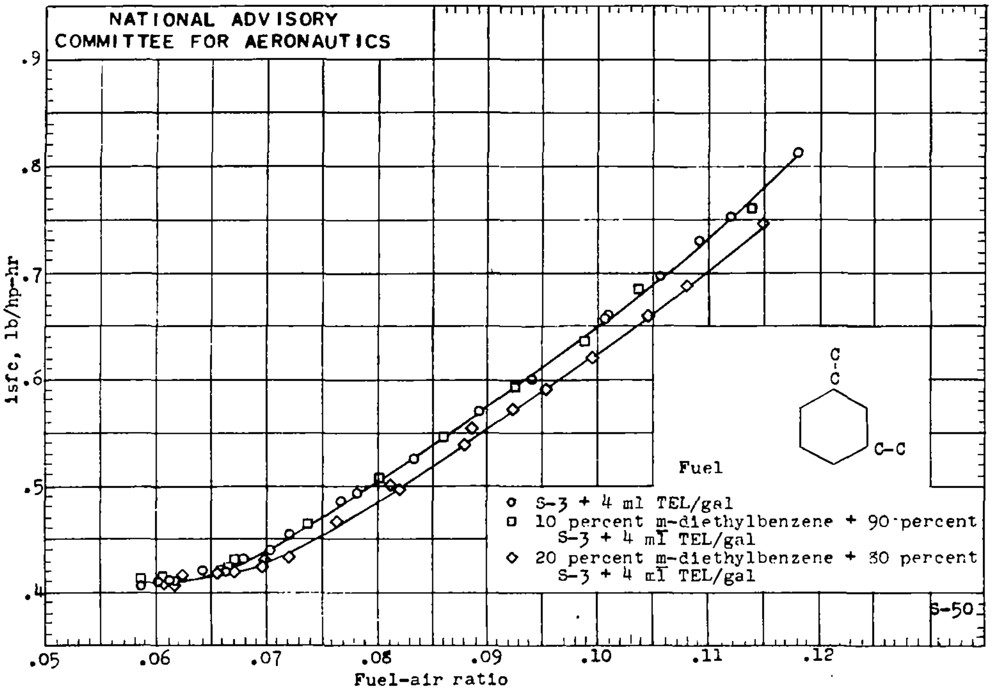


(b) Inlet-air temperature, 100° F.
Figure 8 . - Concluded.

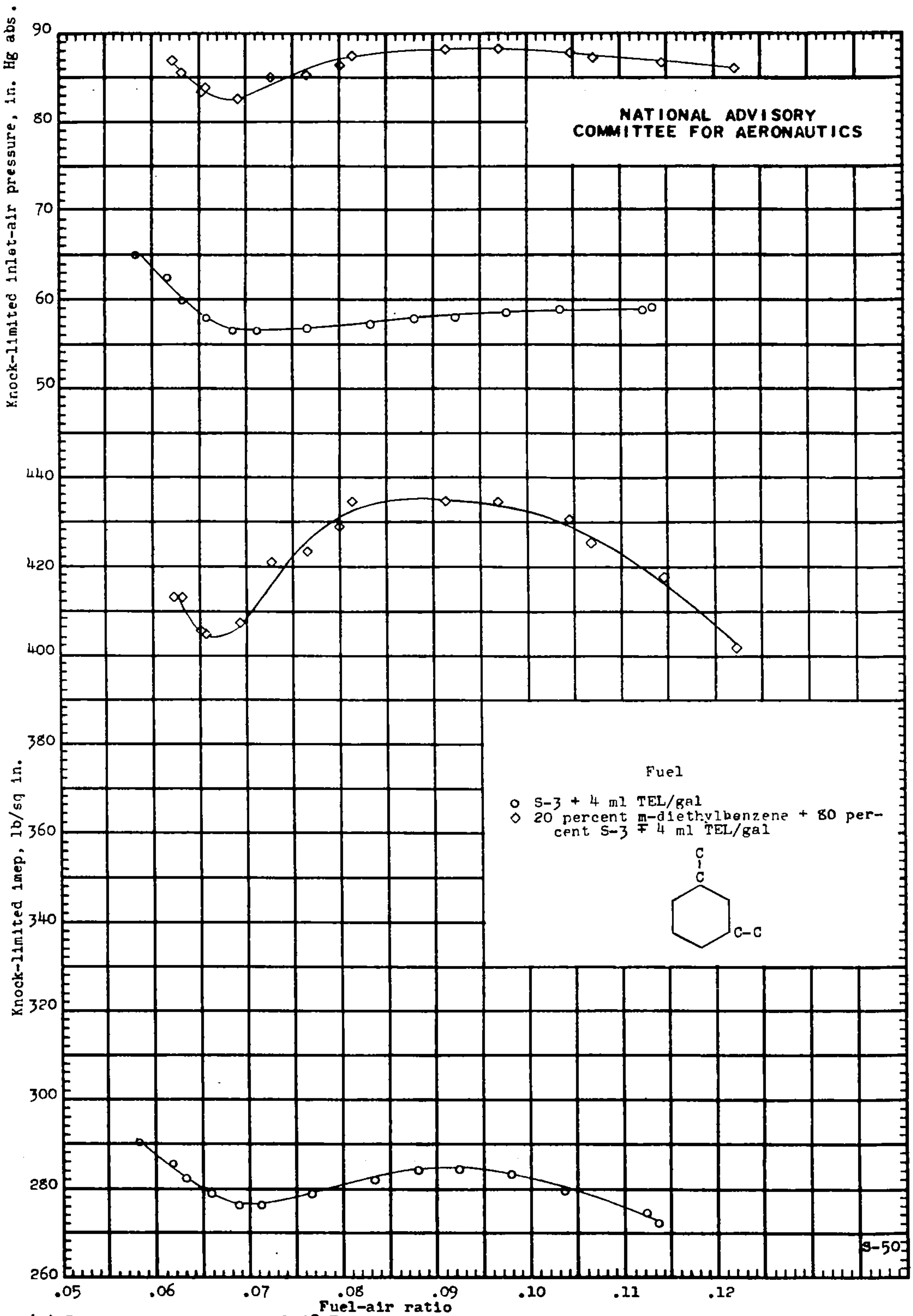


(a) Inlet-air temperature, 250° F.

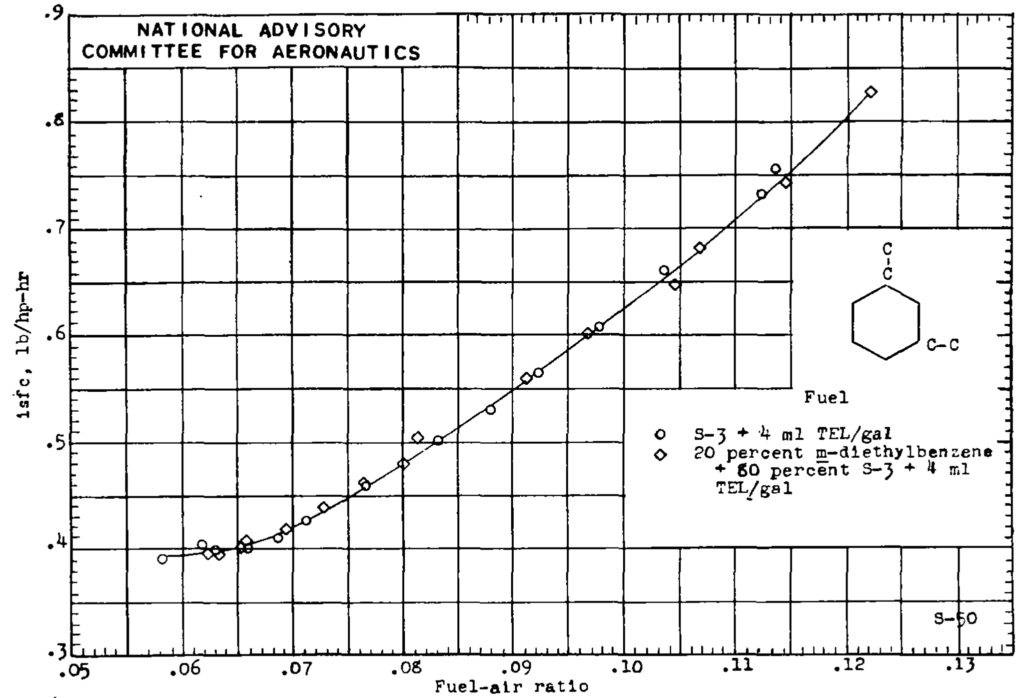
Figure 9. - Knock-limited performance of blends of m-diethylbenzene and S-3 reference fuel plus 4 ml TEL per gallon. 17.6 engine; compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.



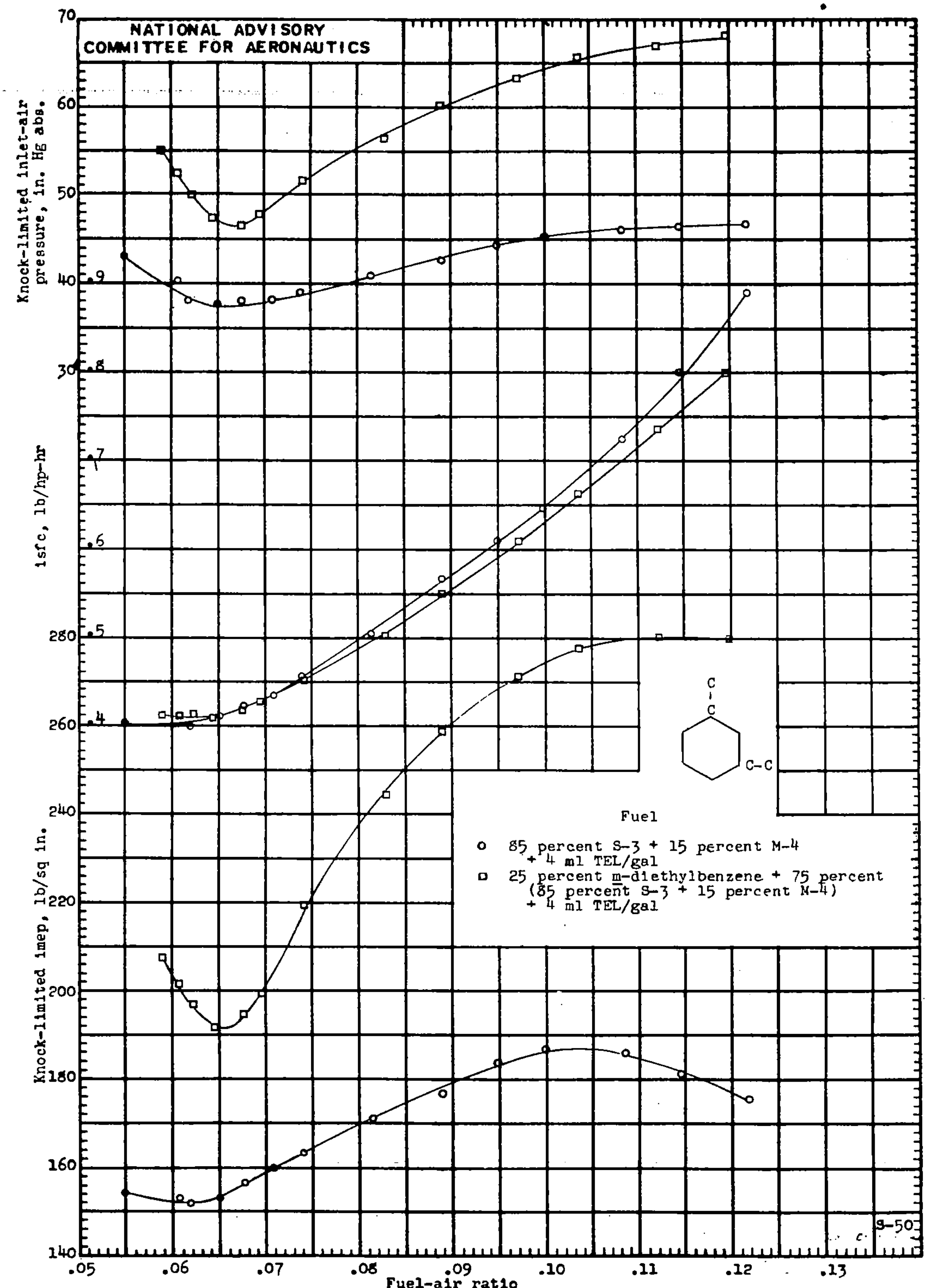
(a) Concluded.
Figure 9 . - Continued.



(b) Inlet-air temperature, 100° F.
Figure 9 . - Continued.

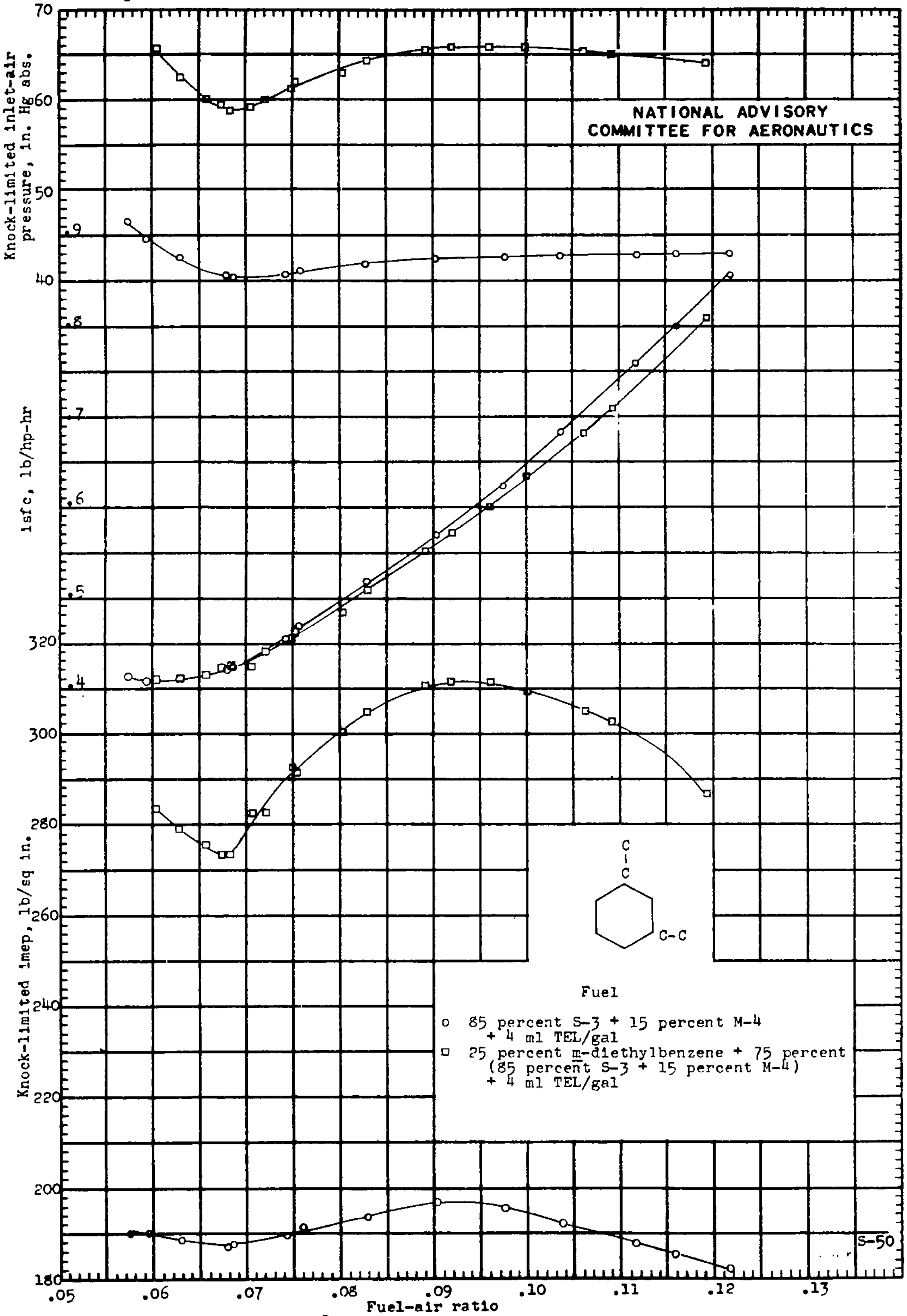


(b) Concluded.
Figure 9 . - Concluded.

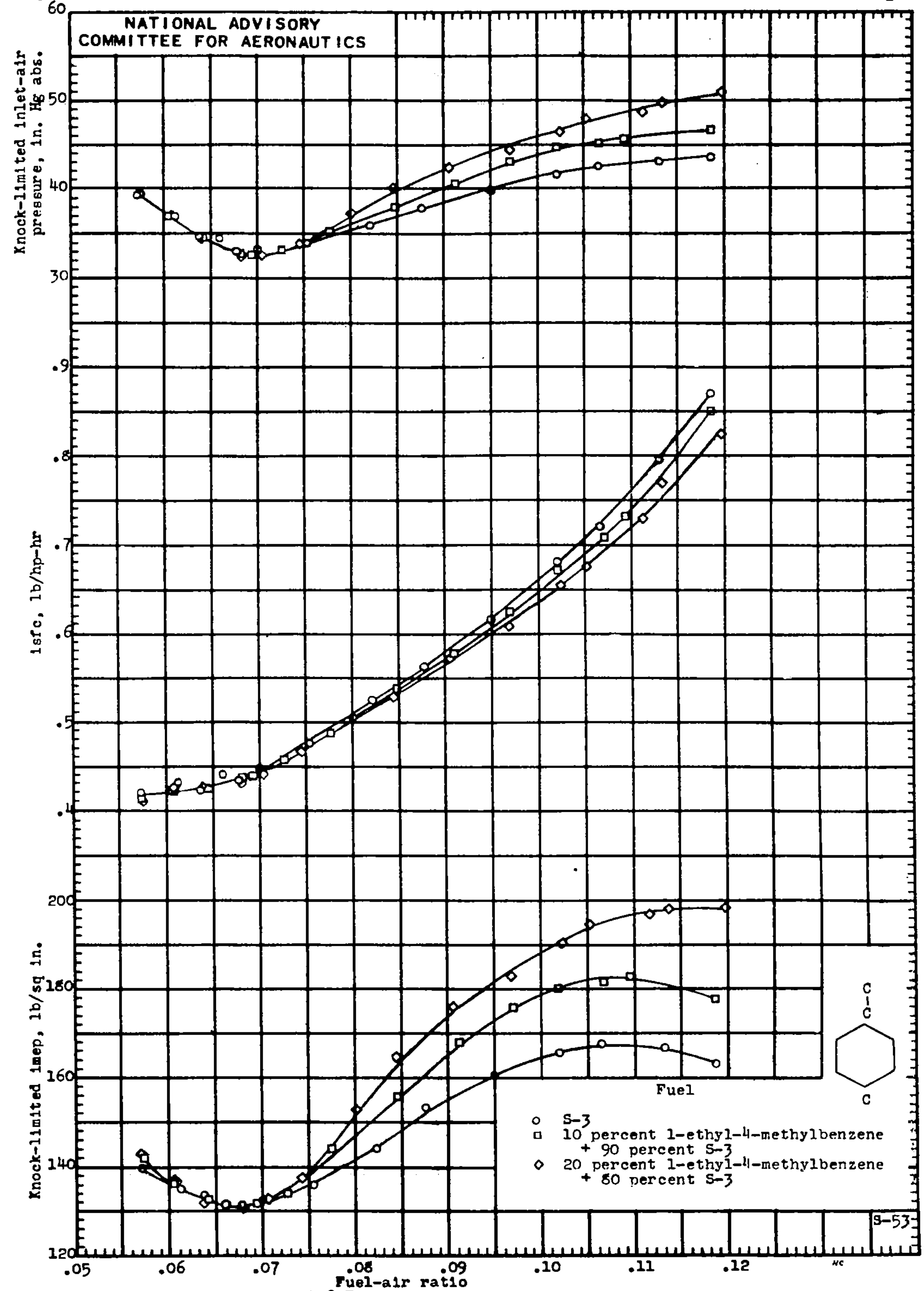


(a) Inlet-air temperature, 250° F.

Figure 10. - Knock-limited performance of blends of m-diethylbenzene and 85 percent S-3 plus 15 percent M-4 plus 4 ml TEL per gallon. 17.6 engine; compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

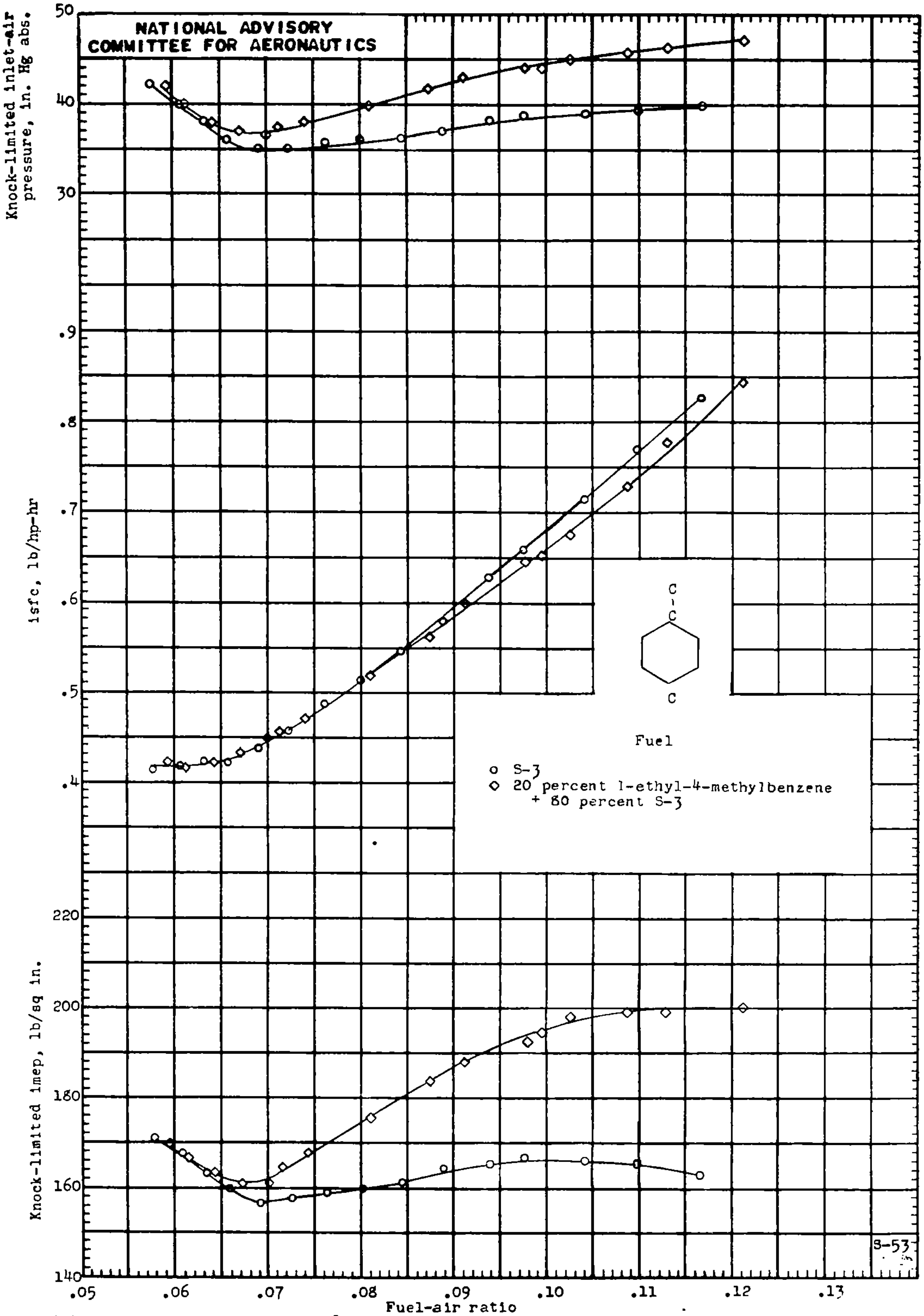


(b) Inlet-air temperature, 100° F.
Figure 10. - Concluded.

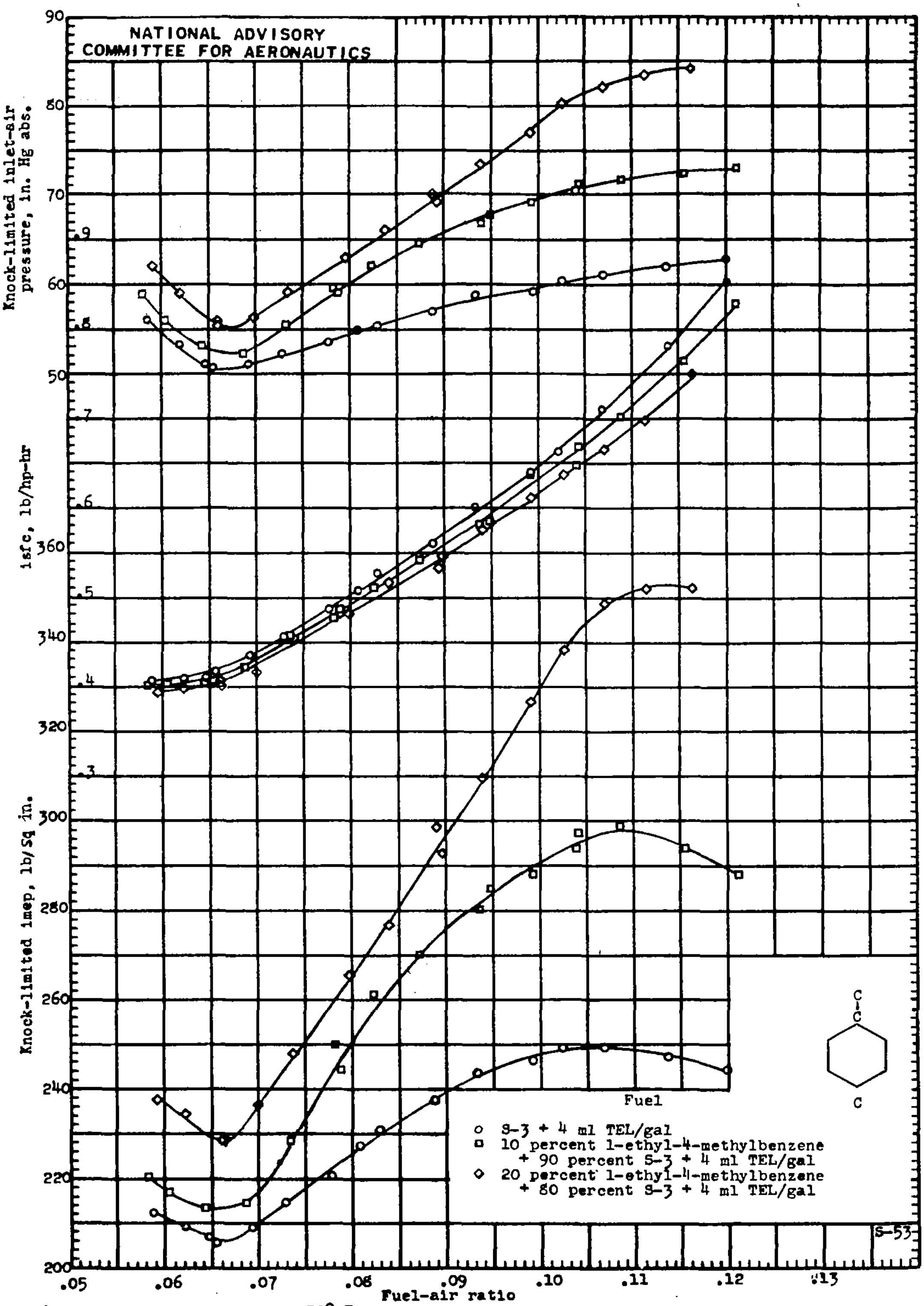


(a) Inlet-air temperature, 250° F.

Figure 11. - Knock-limited performance of blends of 1-ethyl-4-methylbenzene and S-3 reference fuel. 17.6 engine; compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

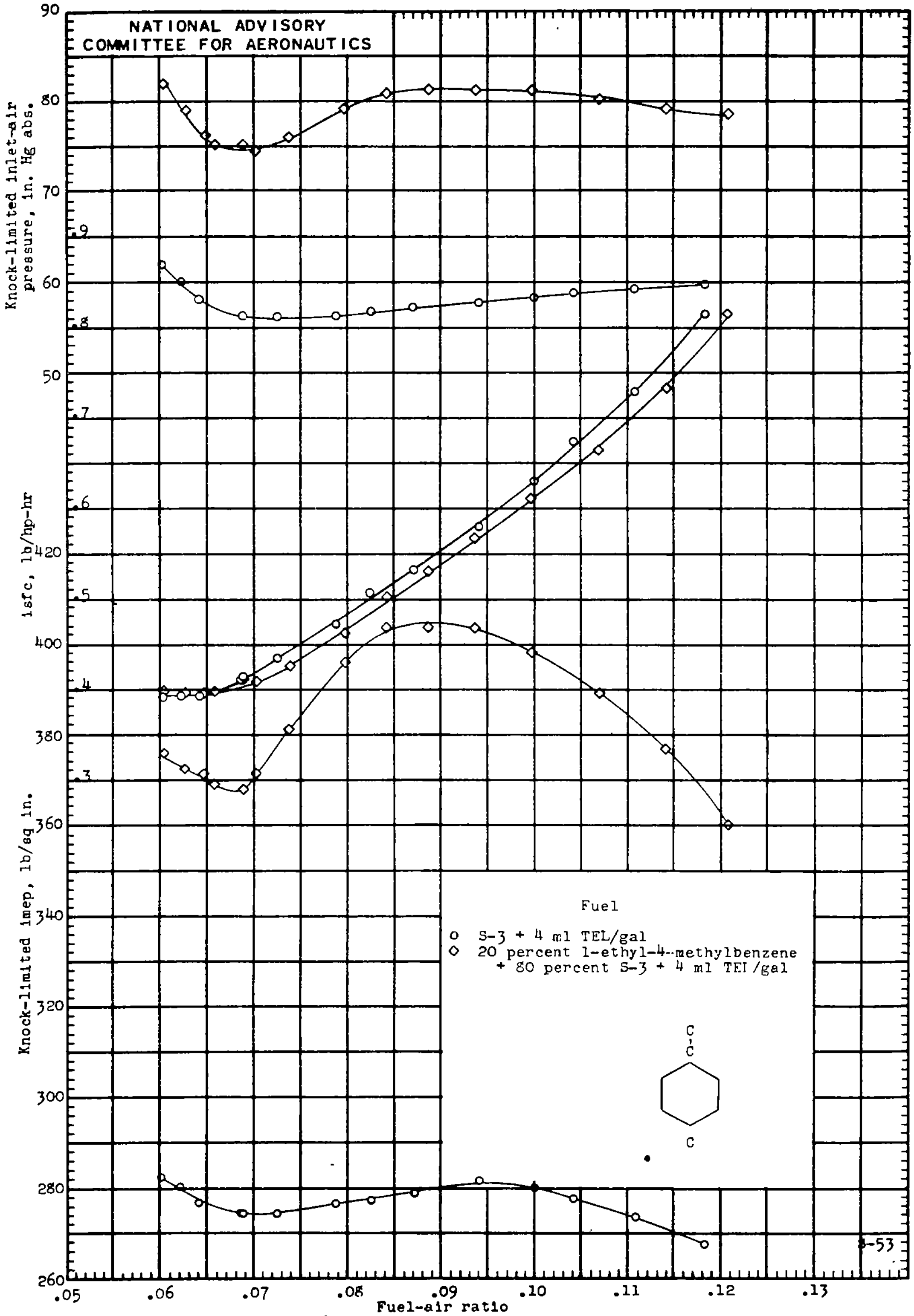


(b) Inlet-air temperature, 100° F.
Figure 11. - Concluded.

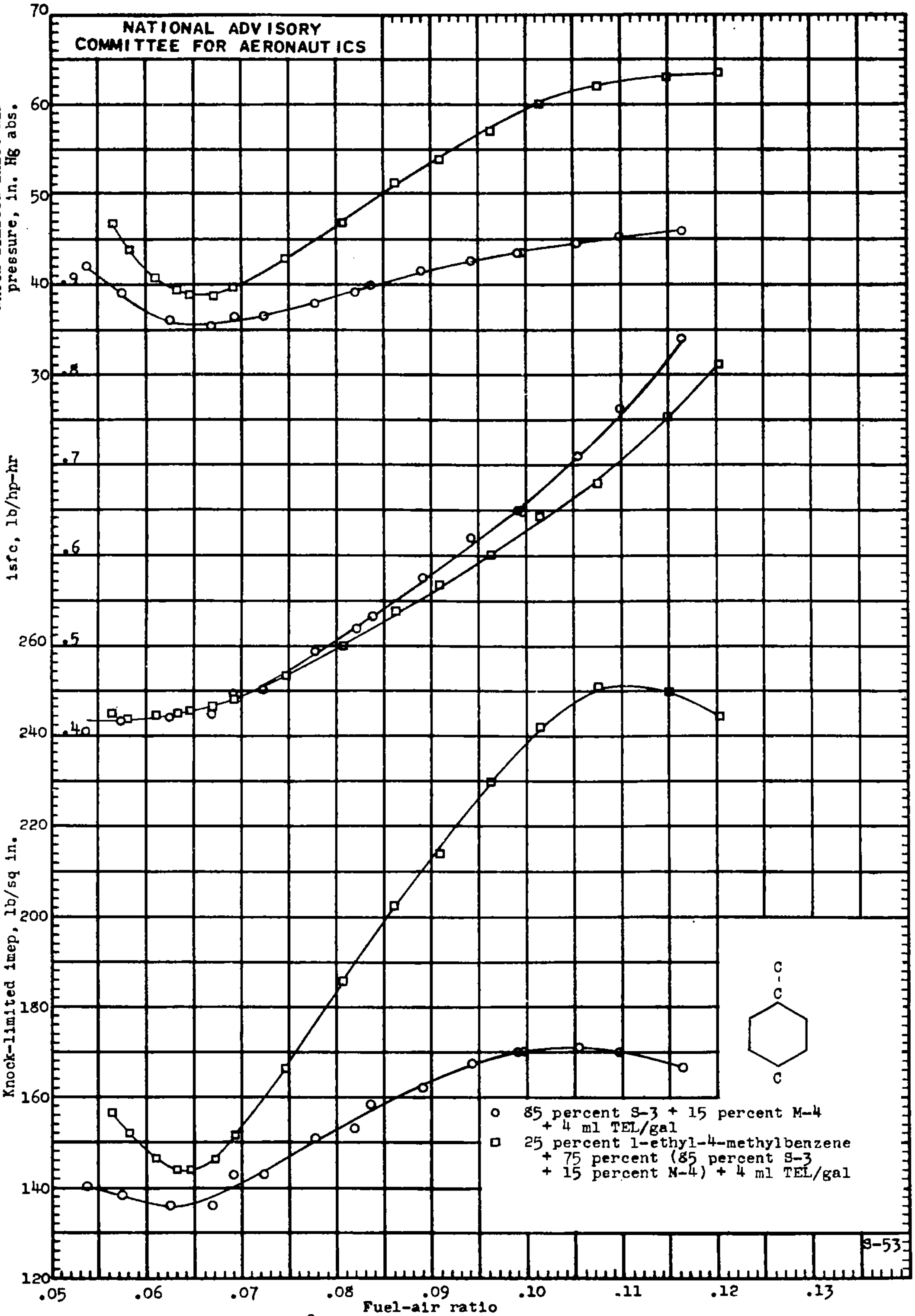


(a) Inlet-air temperature, 250° F.

Figure 12. - Knock-limited performance of blends of 1-ethyl-4-methylbenzene and S-3 reference fuel plus 4 ml TEL per gallon. 17.6 engine; compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

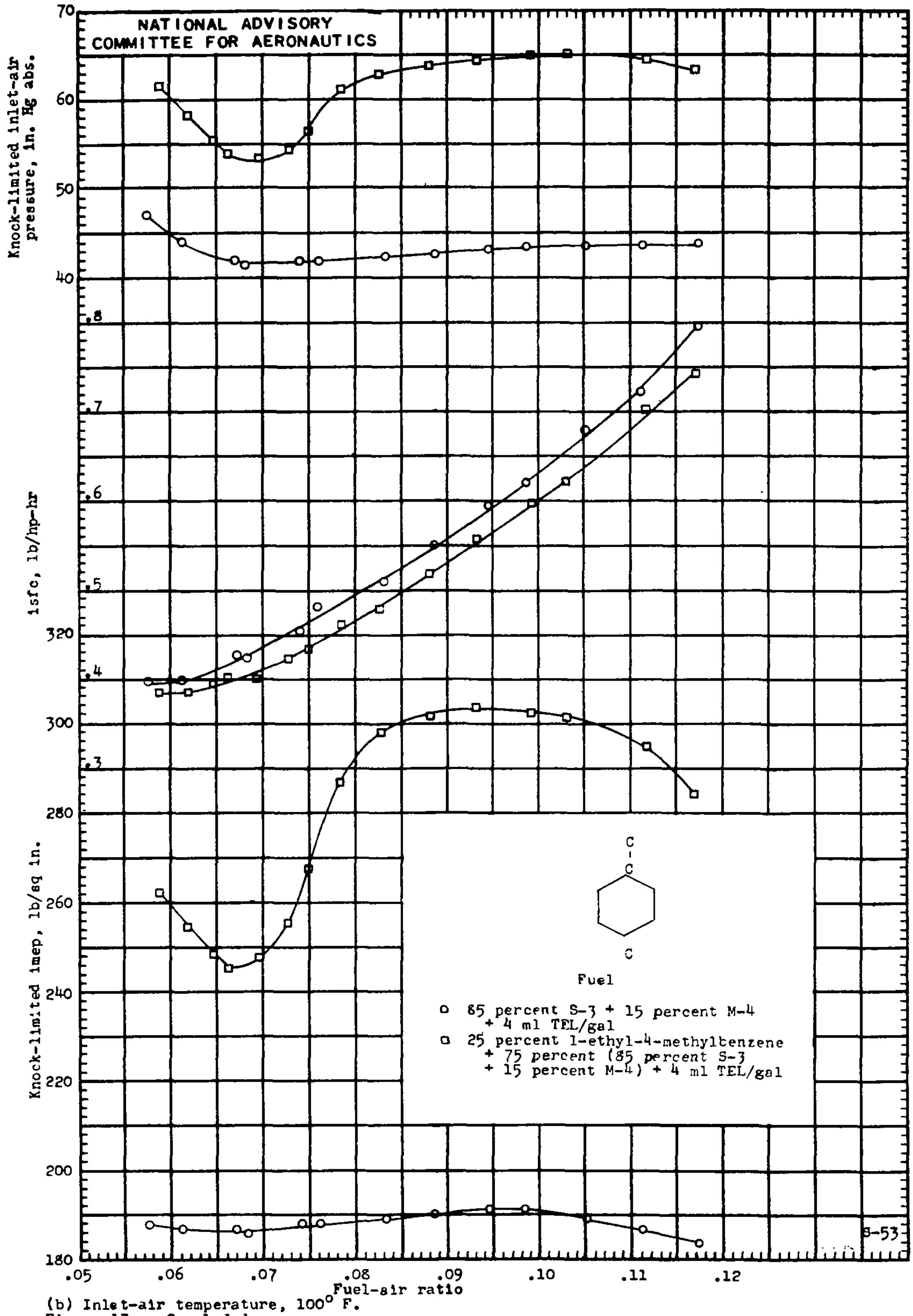


(b) Inlet-air temperature, 100° F.
Figure 12. - Concluded.

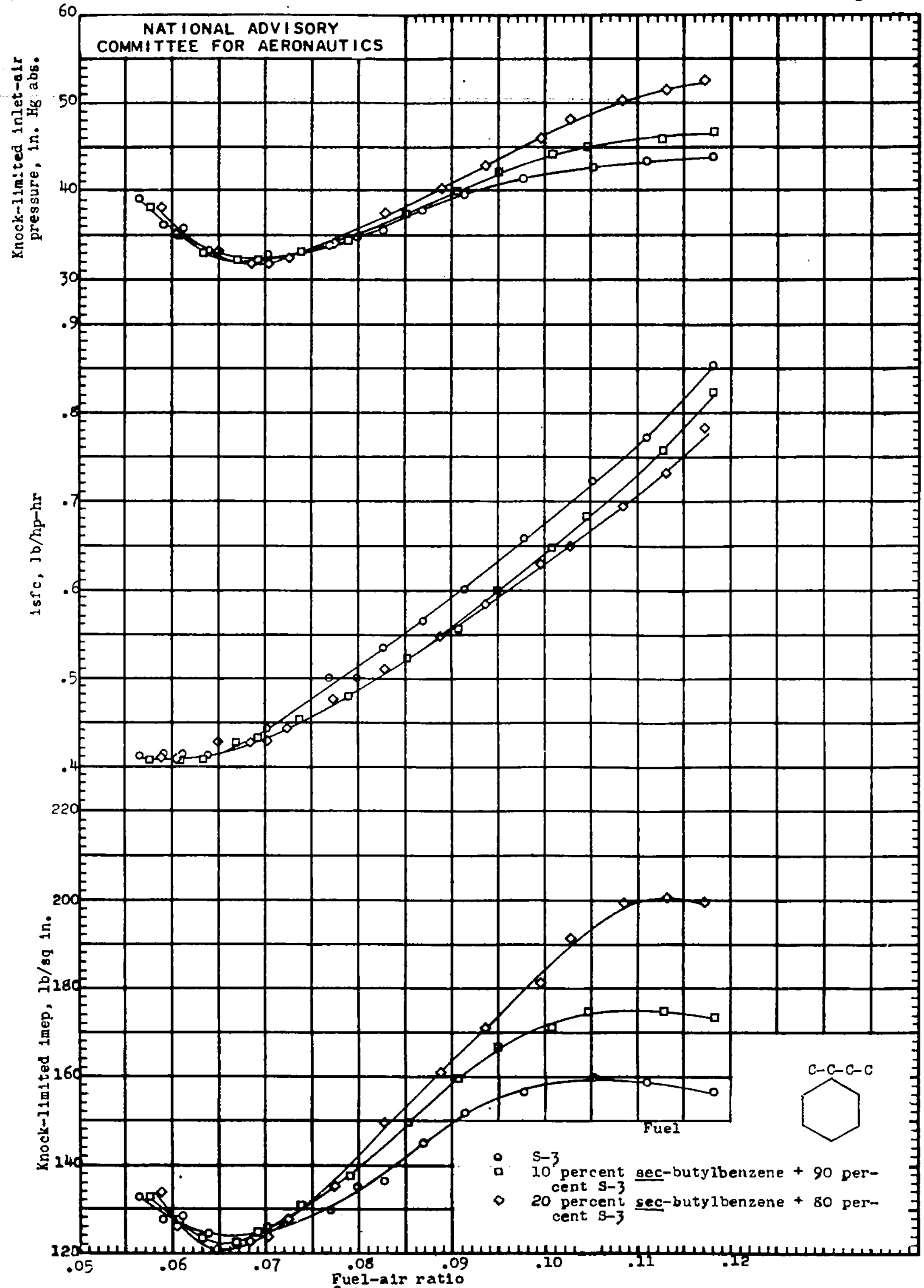


(a) Inlet-air temperature, 250° F.

Figure 13. - Knock-limited performance of blends of 1-ethyl-4-methylbenzene and 85 percent S-3 plus 15 percent M-4 plus 4 ml TEL per gallon. 17.6 engine; compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

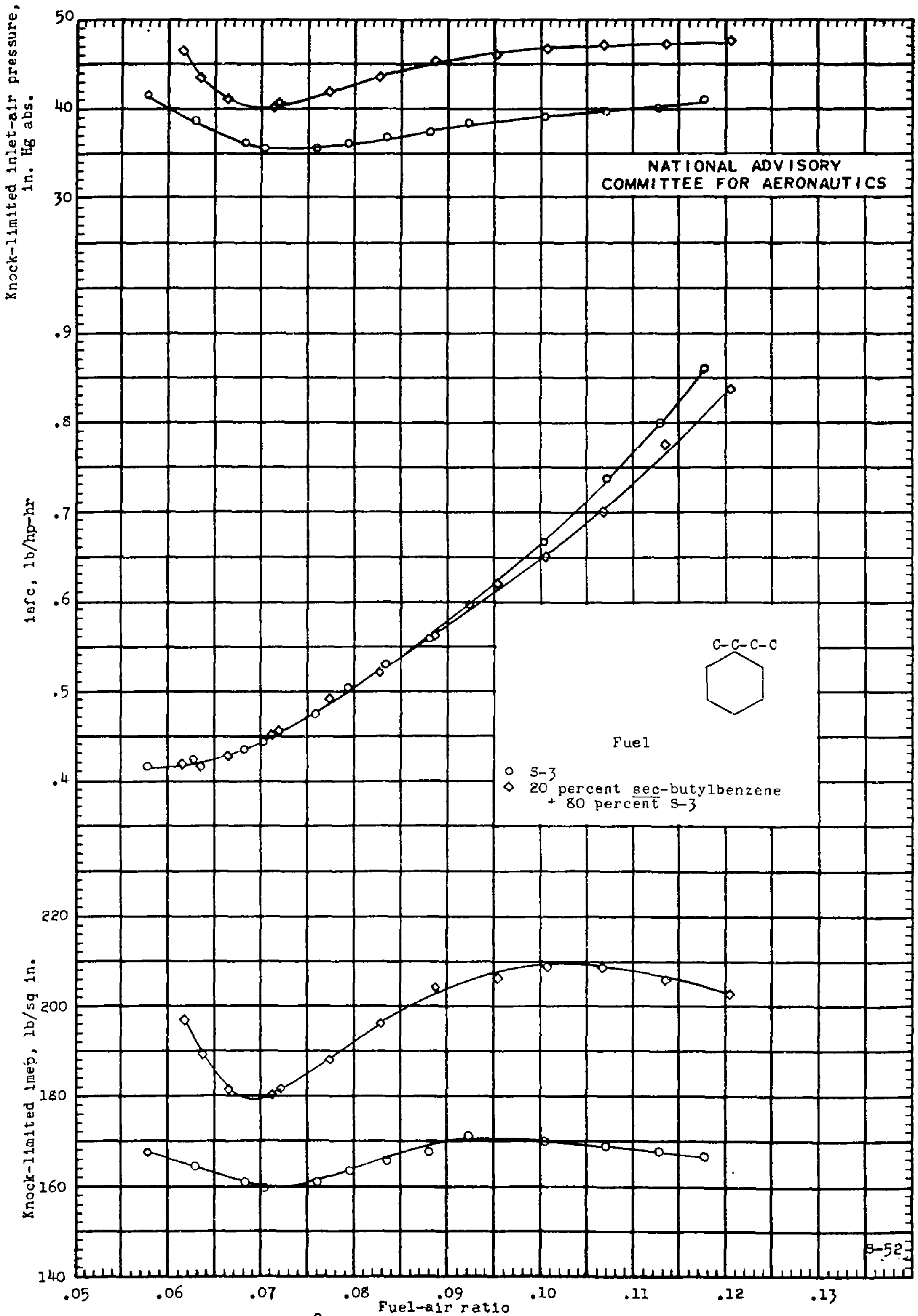


(b) Inlet-air temperature, 100° F.
Figure 13. - Concluded.

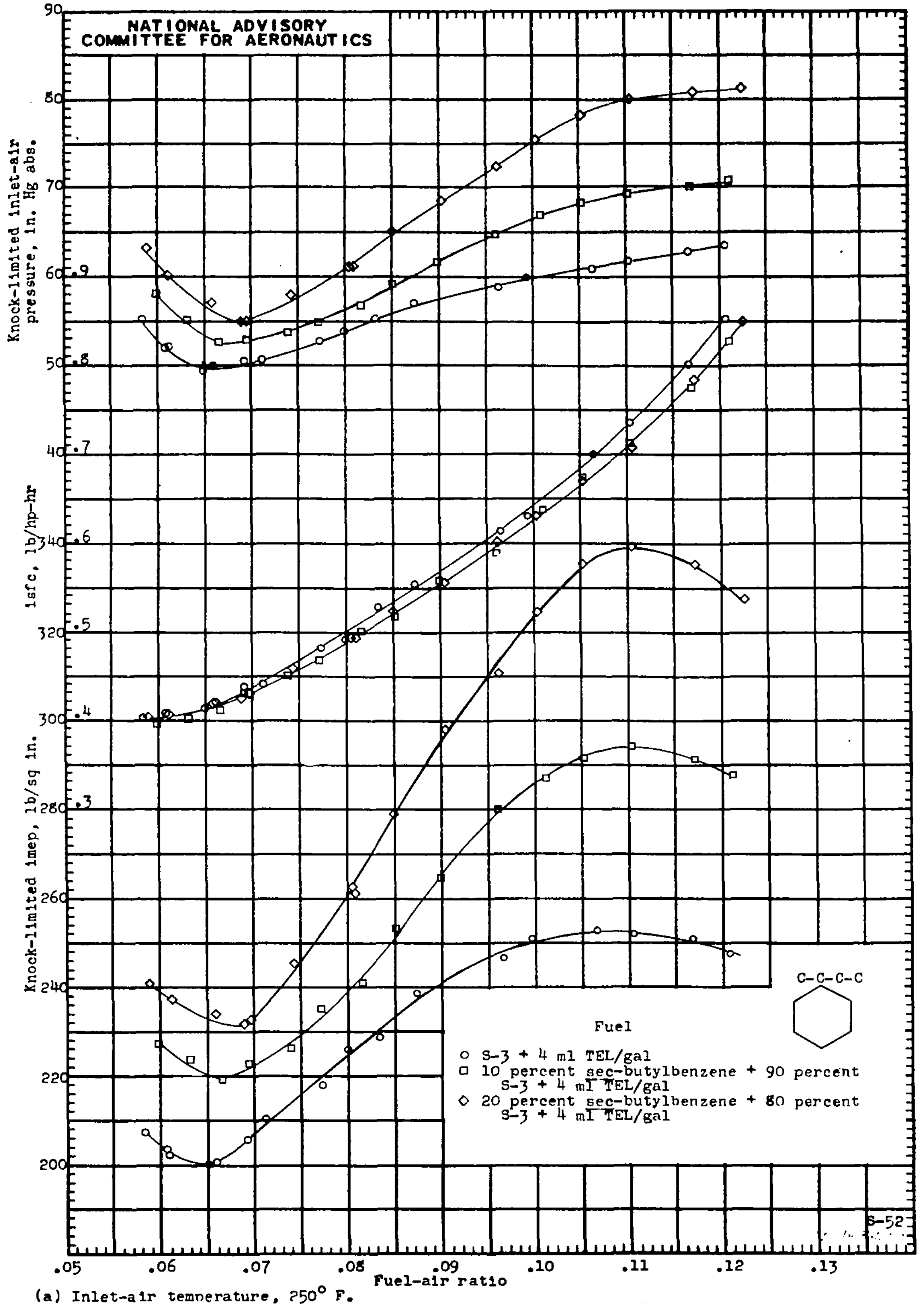


(a) Inlet-air temperature, 250° F.

Figure 14. - Knock-limited performance of blends of sec-butylbenzene and S-3 reference fuel. 17.6 engine; compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

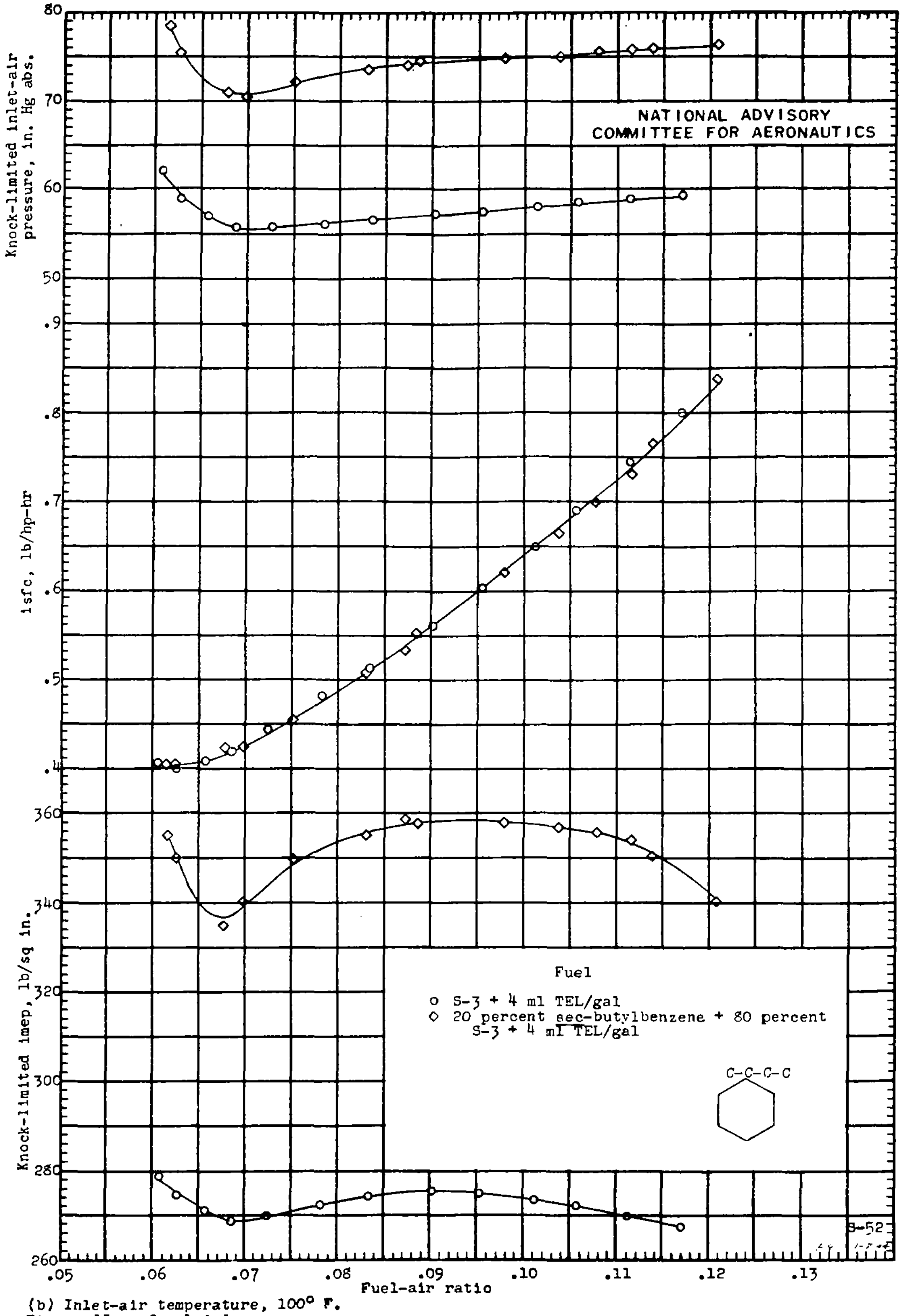


(b) Inlet-air temperature, 100° F.
Figure 14. - Concluded.

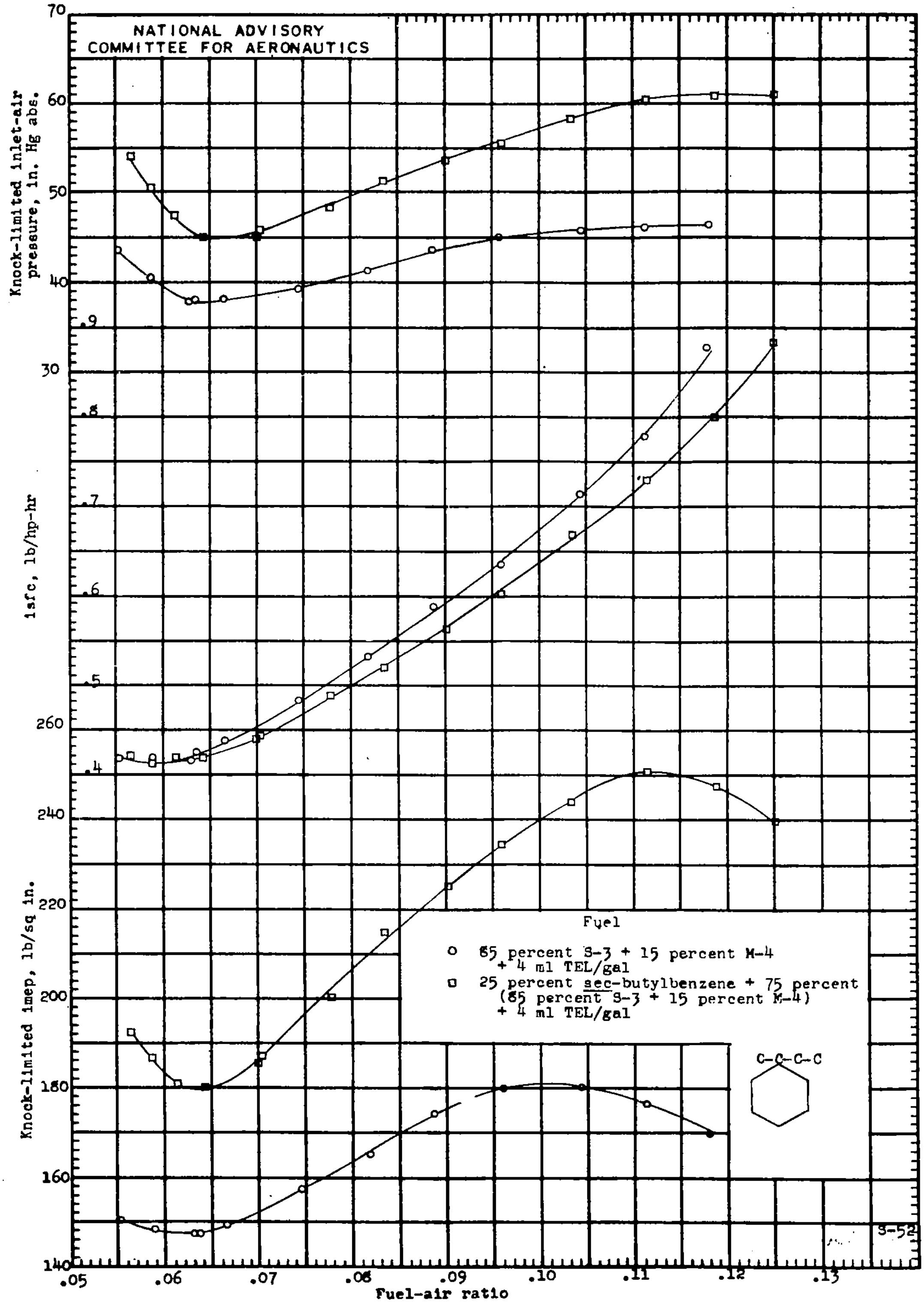


(a) Inlet-air temperature, 250° F.

Figure 15. - Knock-limited performance of blends of sec-butylbenzene and S-3 reference fuel plus 4 ml TEL per gallon. 17.6 engine; compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F.

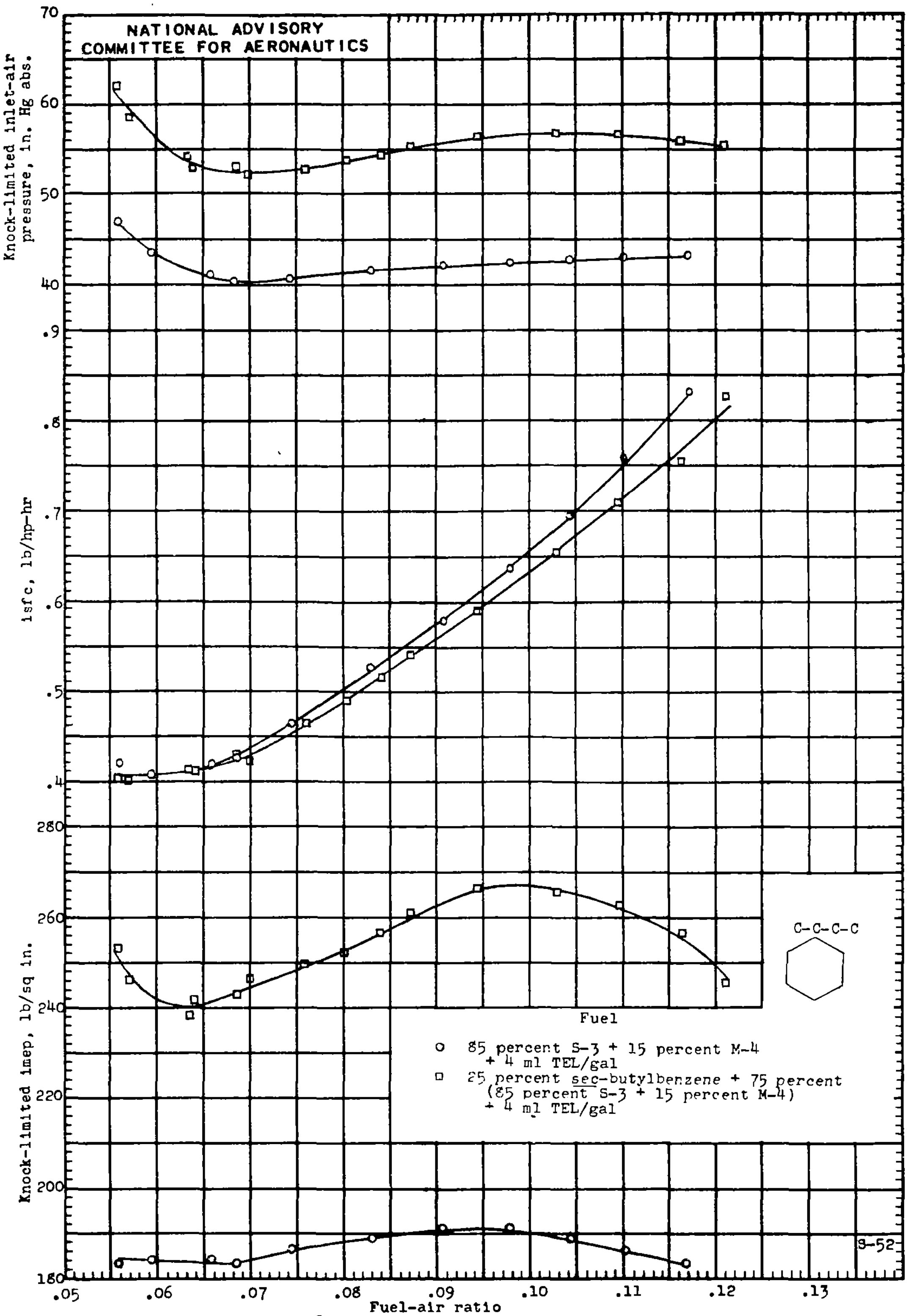


(b) Inlet-air temperature, 100° F.
Figure 15. - Concluded.



(a) Inlet-air temperature, 250° F.

Figure 16. - Knock-limited performance of blends of sec-butylbenzene and 85 percent S-3 plus 15 percent M-4 plus 4 ml TEL per gallon. 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 16. - Concluded.

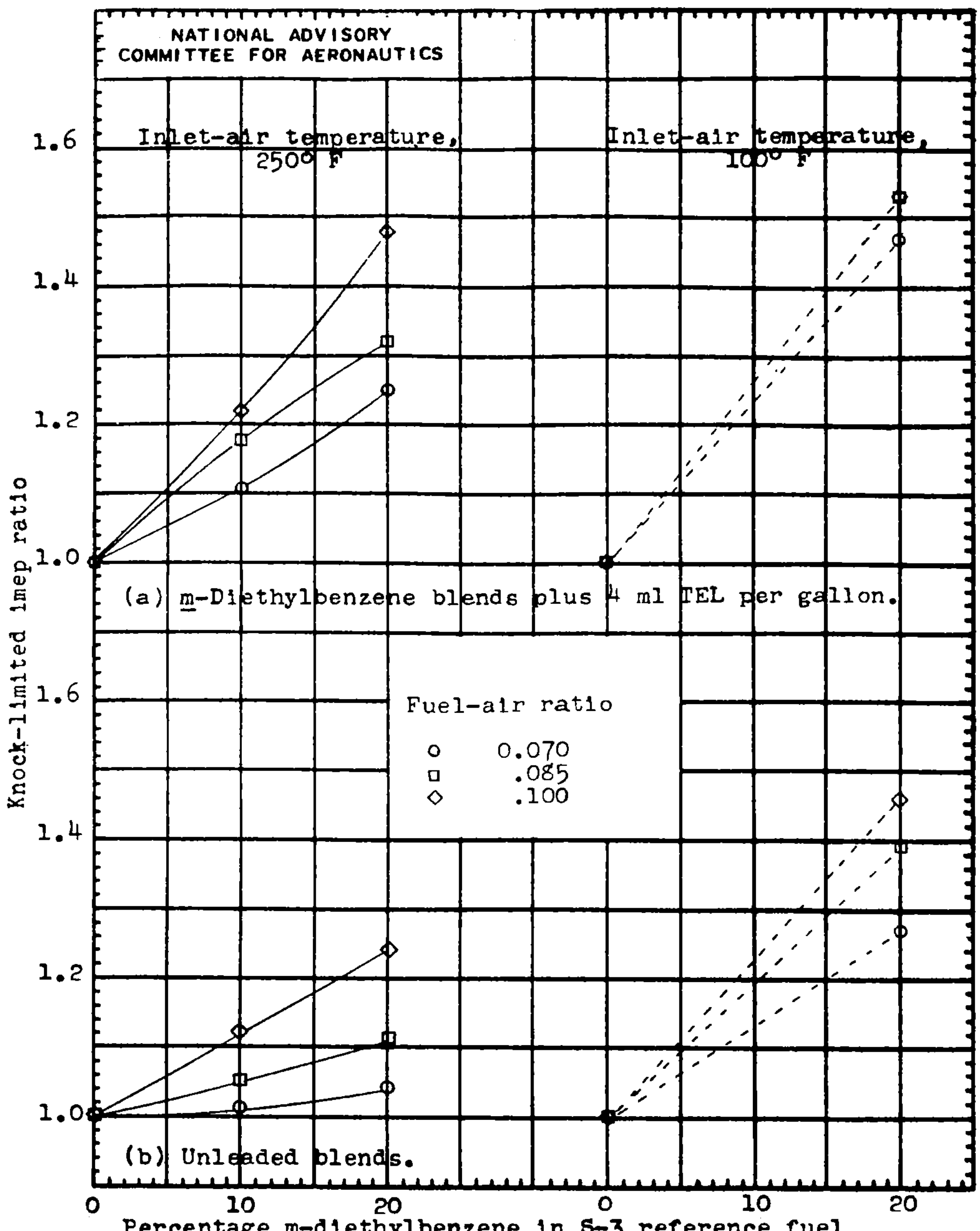


Figure 17. - The blending sensitivity of m-diethylbenzene in S-3 reference fuel. 17.6 engine.

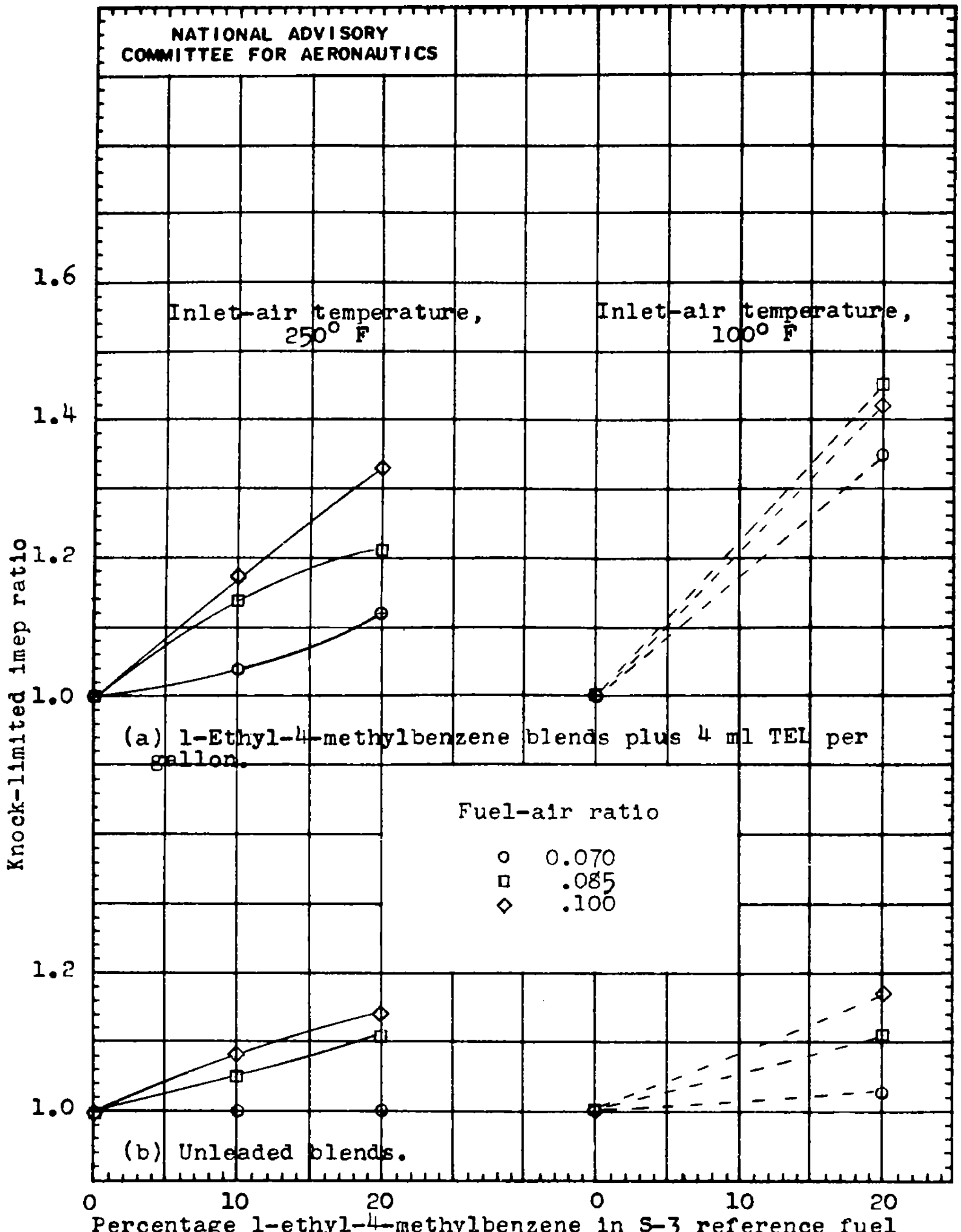


Figure 18. - The blending sensitivity of 1-ethyl-4-methylbenzene in S-3 reference fuel. 17.6 engine.

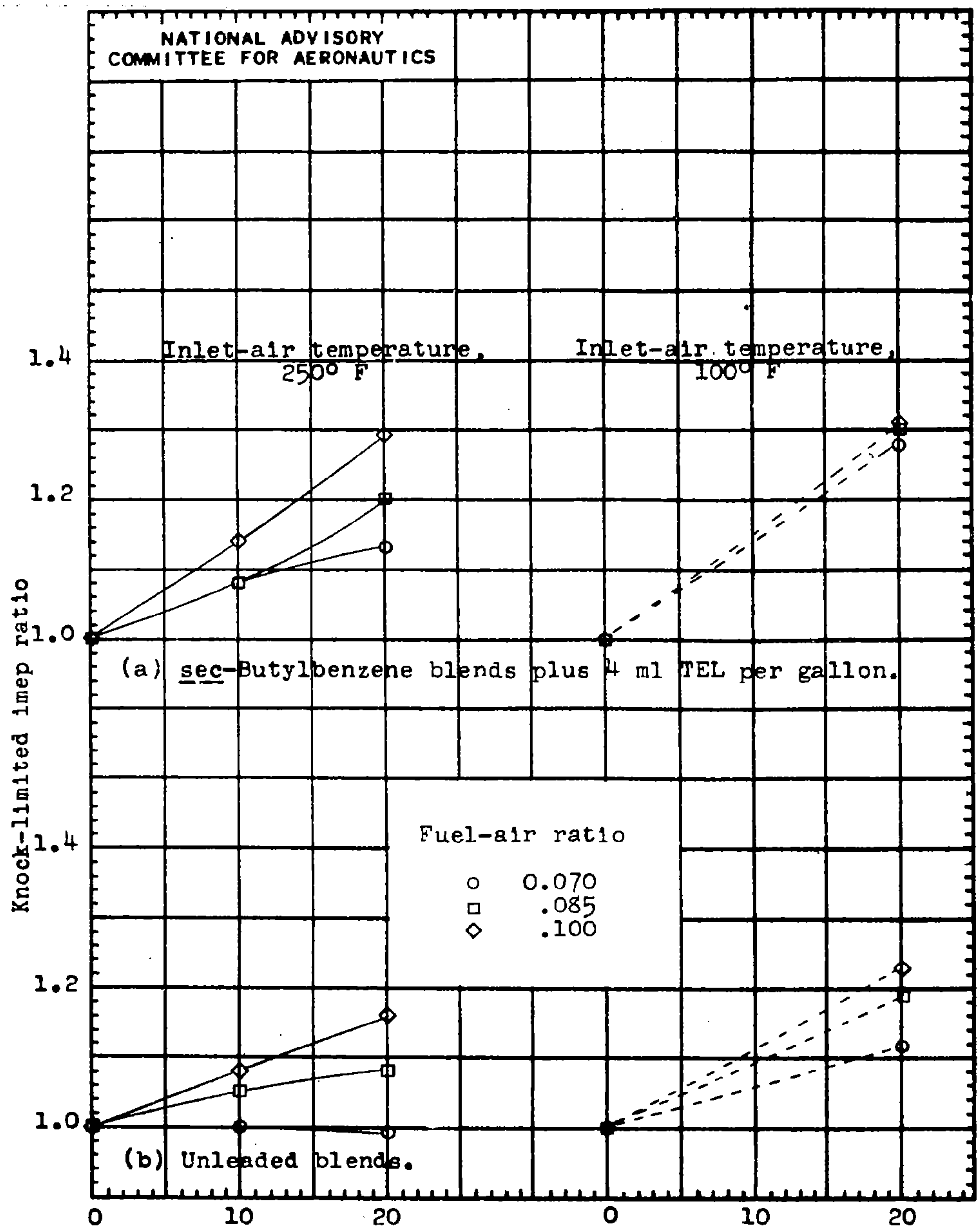


Figure 19. - The blending sensitivity of sec-butylbenzene in S-3 reference fuel. 17.6 engine.

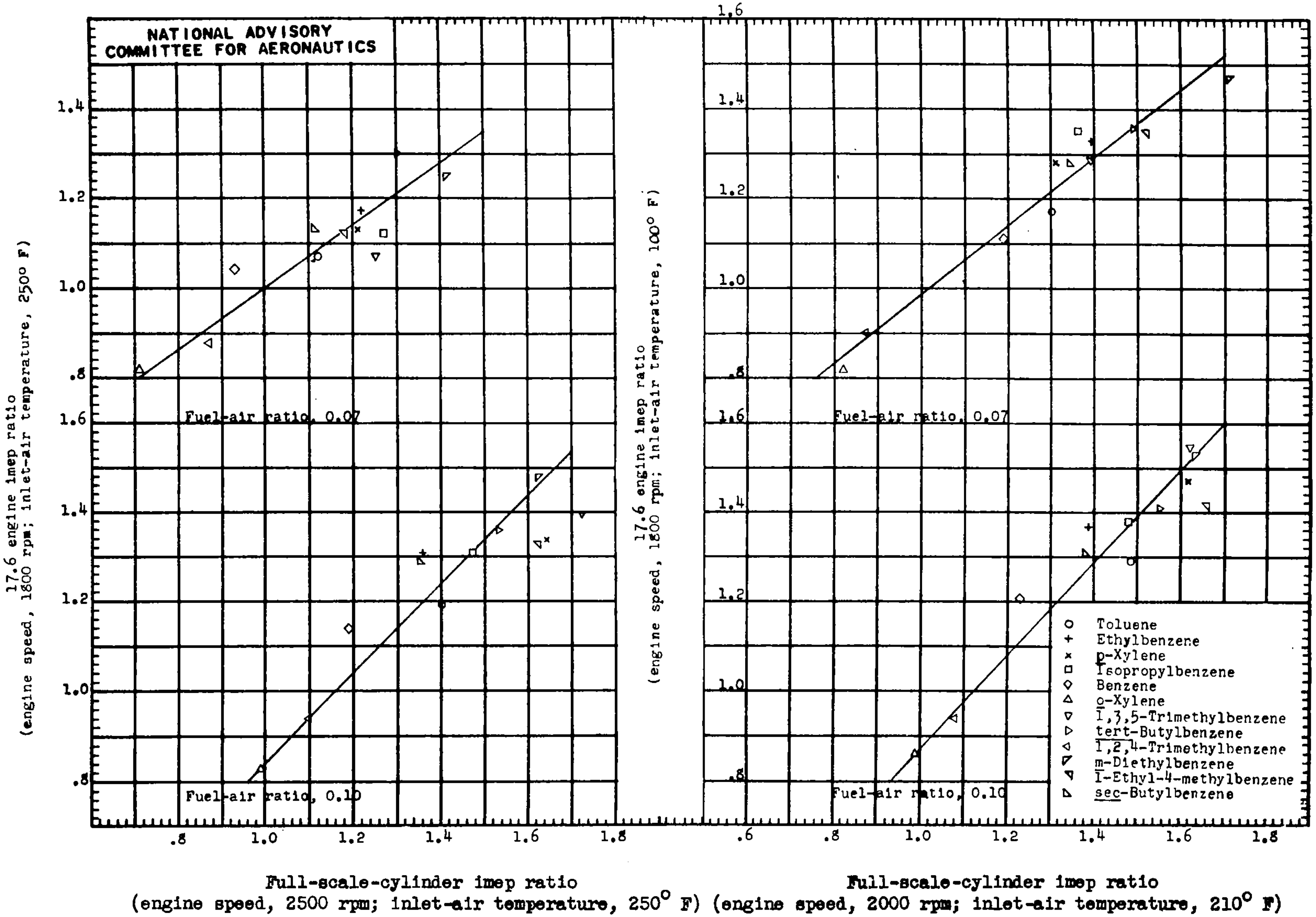


Figure 20. - Comparison of 17.6 engine performance with full-scale-cylinder performance. (Fuels: 20 percent aromatic plus 80 percent S-3 plus 4 ml TEL/gal for 17.6 engine tests; 25 percent aromatic plus 75 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL/gal for full-scale-cylinder tests.)

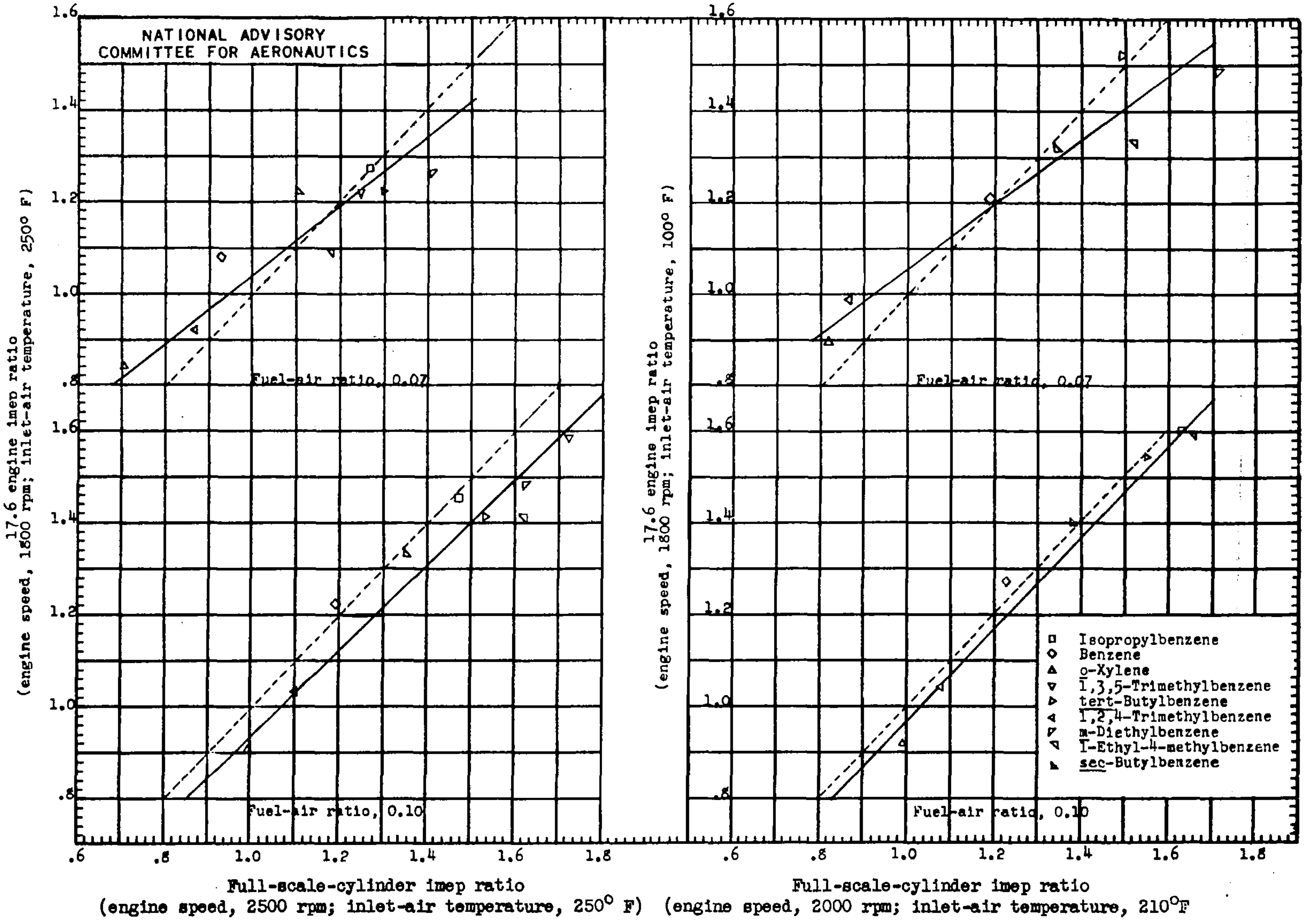


Figure 21. - Comparison of 17.6 engine performance with full-scale-cylinder performance for blends containing 25 percent aromatic plus 75 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.

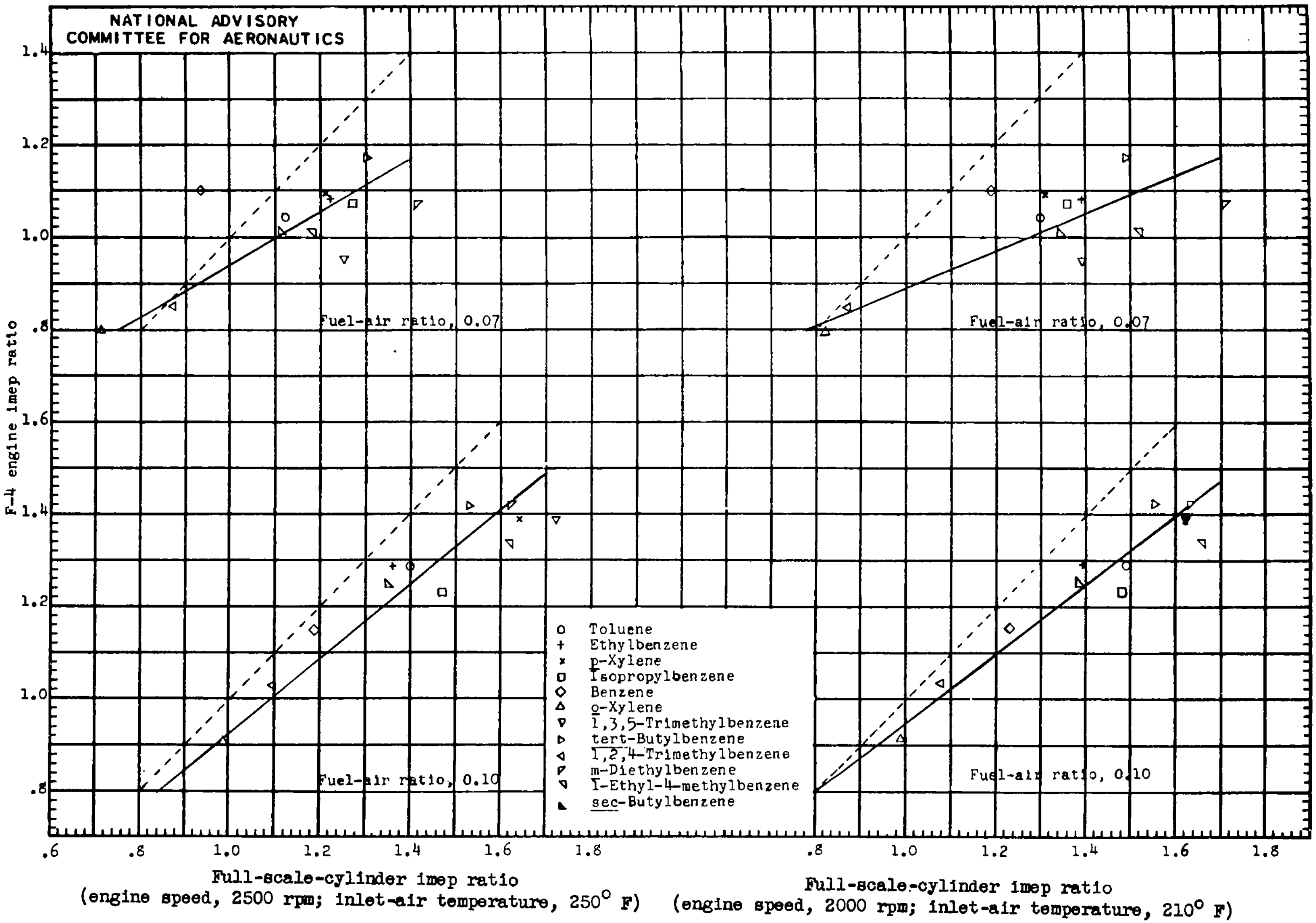


Figure 22. - Comparison of F-4 engine performance with full-scale-cylinder performance for blends containing 25 percent aromatic plus 75 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.

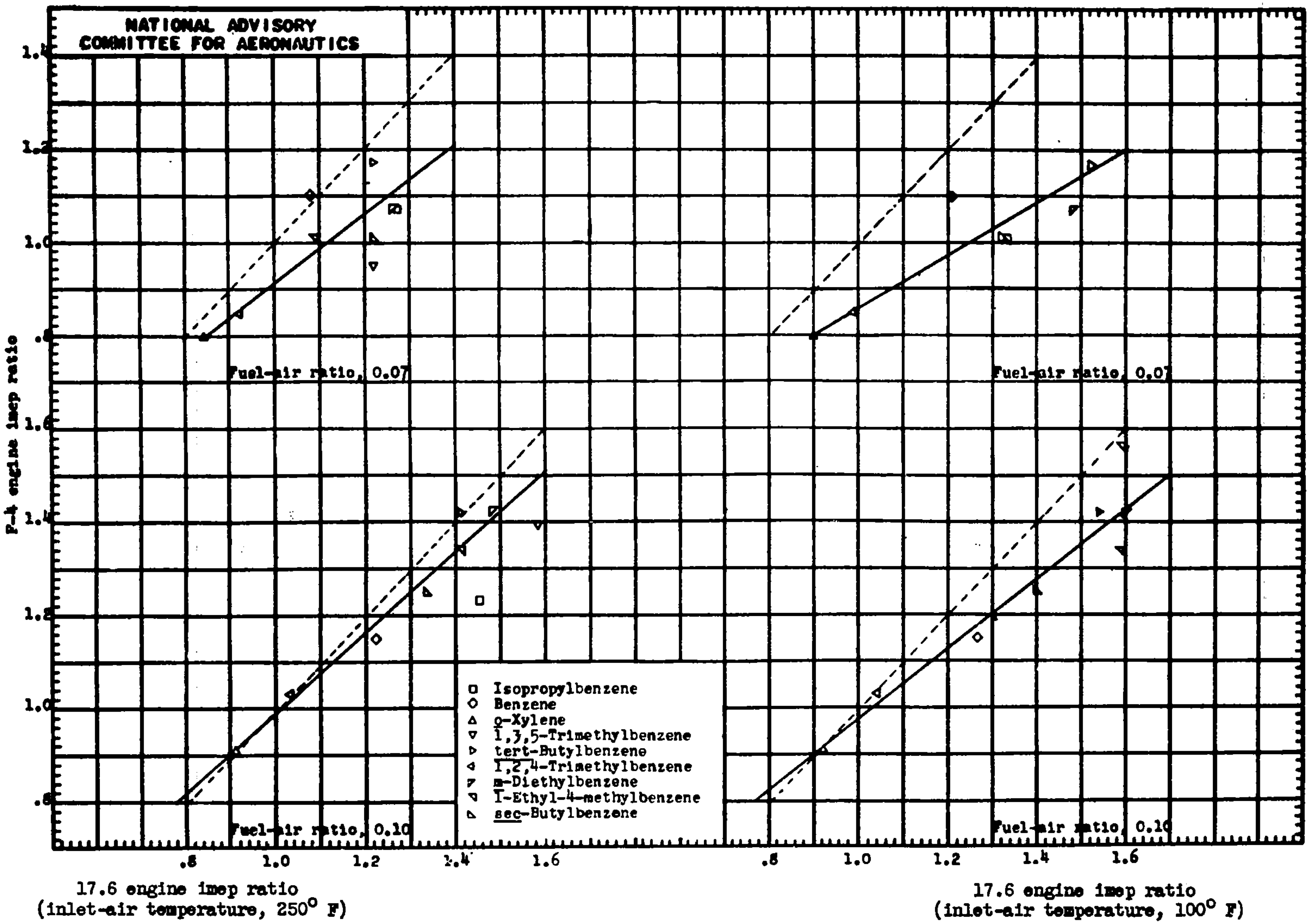
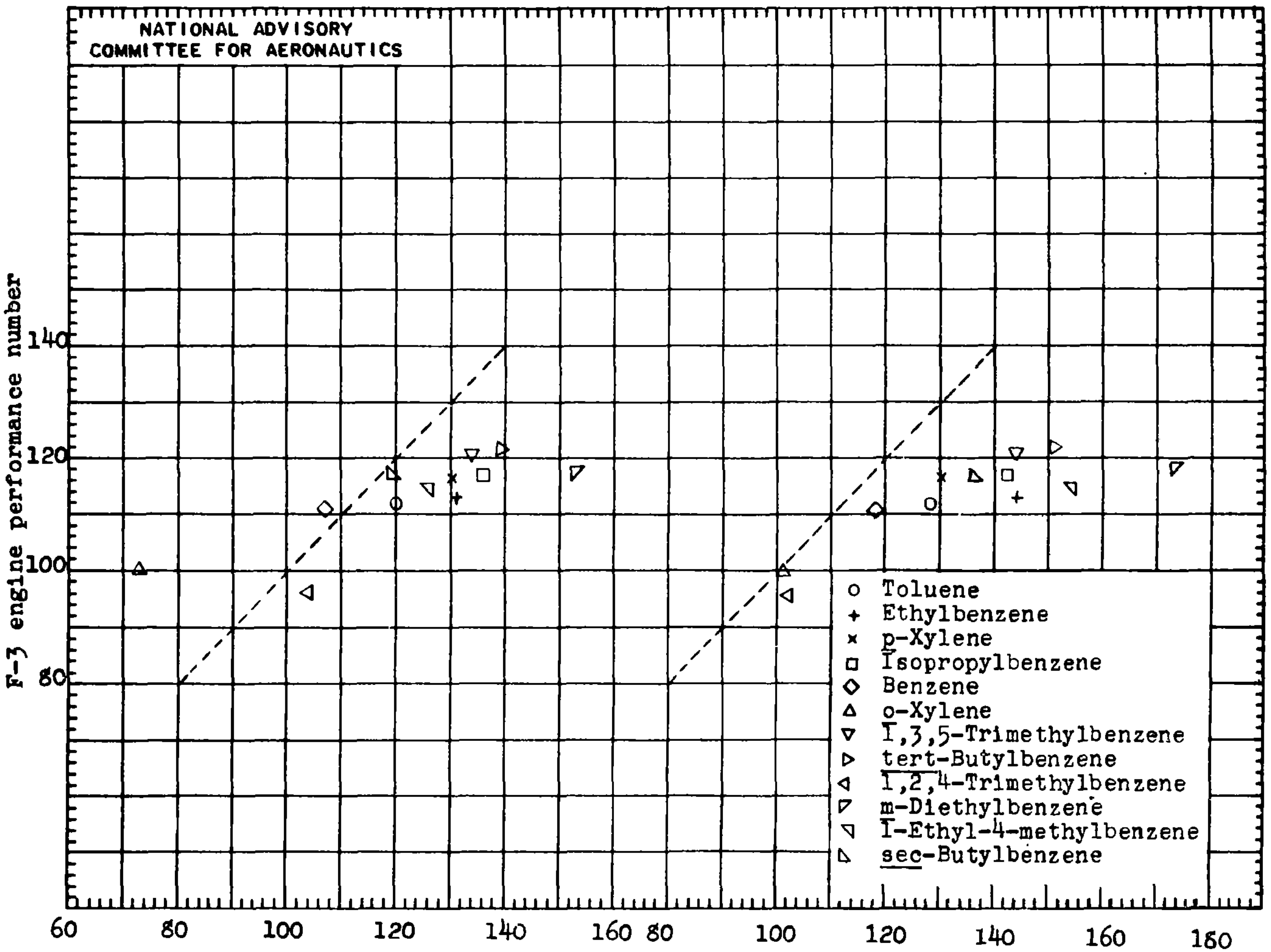


Figure 23. - Comparison of F-4 engine performance with 17.6 engine performance for blends containing 25 percent aromatic plus 75 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.



Full-scale-cylinder performance number (engine speed, 2500 rpm; inlet-air temperature, 250° F; fuel-air ratio, 0.07)

Full-scale-cylinder performance number (engine speed, 2000 rpm; inlet-air temperature, 210° F; fuel-air ratio, 0.07)

Figure 24. - Comparison of F-3 ratings with full-scale-cylinder ratings for blends containing 25 percent aromatic plus 75 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.