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THE KNOCK-LIMITED PERFORMANCE OF FUEL BLENDS CONTAINING AROMATICS

II - ISOPROPYLBENZENE, BENZENE, AND o-XYLENE

By J. Robert Branstetter and Carl L. Meyer

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NACA

WASHINGTON

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

THE KNOCK-LIMITED PERFORMANCE OF FUEL BLENDS CONTAINING AROMATICS

II - ISOPROPYLBENZENE, BENZENE, AND o-XYLENE

By J. Robert Branstetter and Carl L. Meyer

SUMMARY

Knock-limited small-scale-engine tests were made of isopropylbenzene, benzene, and o-xylene blended individually in various concentrations with selected base fuels. Data were obtained for the aromatics to determine: (a) the blending sensitivity, (b) the lead susceptibility, and (c) the sensitivity of the blends to inlet-air temperature. Published full-scale-cylinder data for the aromatics are presented for comparative purposes.

Of the three aromatics tested, isopropylbenzene was, in general, more effective than benzene as an antiknock agent whereas o-xylene acted as a proknock agent under nearly all conditions tested.

INTRODUCTION

An investigation to determine the antiknock effectiveness of additions of pure aromatic hydrocarbons to aircraft-engine fuels is being conducted by the NACA. A detailed description of this program may be found in reference 1.

The over-all objectives of the knock-limited engine tests consist in determining: (a) the blending sensitivity of the aromatics in the base reference fuels, (b) the lead susceptibility of the aromatic blends, (c) the sensitivity to inlet-air temperature of the aromatic blends, and (d) the correlation of full-scale and small-scale results.

The full-scale-cylinder data and the F-3 and F-4 ratings of blends containing 75 percent of a base fuel (85 percent S-3 plus 15 percent M-4) and 25 percent of each of the following aromatics

are presented in reference 2: 1,3,5-trimethylbenzene (mesitylene), m-diethylbenzene, p-xylene, 1-ethyl-4-methylbenzene, tert-butylbenzene, isopropylbenzene (cumene), toluene, ethylbenzene, sec-butylbenzene, benzene, 1,2,4-trimethylbenzene (pseudocumene), and o-xylene; the final blends contained 4 ml TEL per gallon.

The F-4 performance of blends containing 10, 25, and 50 percent toluene, ethylbenzene, and p-xylene in the S-3 plus M-4 base fuel, together with the 17.6 engine knock-limited performance of blends containing 10 and 20 percent of each of these three aromatics in S-3 reference fuel and the F-3 ratings of a portion of the aforementioned blends, are presented in reference 1.

The present report (a continuation of reference 1) is part II of a series of five reports and contains data on isopropylbenzene, benzene, and o-xylene. These aromatics were purified by T. W. Reynolds under the supervision of Dr. L. C. Gibbons. The tests were conducted at the NACA Cleveland laboratory from March through May 1944.

APPARATUS AND TEST PROCEDURE

For the F-4 engine tests, blends were prepared containing 10, 25, and 50 percent by volume of aromatics in a base fuel consisting of 85 percent S-3 plus 15 percent M-4; the final blends contained 4 ml TEL per gallon. For the 17.6 engine tests, each aromatic was blended with S-3 reference fuel in concentrations of 10 and 20 percent by volume and a portion of each blend was leaded to 4 ml TEL per gallon. In addition, the 25-percent blends in the S-3 plus M-4 base fuel were tested in the 17.6 engine, the F-3 engine, and the full-scale cylinder. Whenever the quantity permitted, the blends were tested in the F-3 engine. The physical constants of isopropylbenzene, benzene, and o-xylene after purification are presented in the following table and serve to indicate the purity of the engine samples:

Aromatic	Freezing point (°C)	Boiling point (°C)	Index of refraction n_D^{20}	Density at 20° C (grams/ml)
Isopropylbenzene	-96.16	152.4	1.4913	0.8619
Benzene	5.49	80.1	1.5012	.8790
o-Xylene	-25.34	144.4	1.5052	.8799

Operation of the research F-4 engine (not a package unit) conformed to CRC designation F-4-443 except for the use of two independent fuel systems and the detection of knock by a cathode-ray oscilloscope in conjunction with a magnetostriction pickup unit. Because of these alterations the curves of knock-limited indicated mean effective pressure against fuel-air ratio deviate from the F-4 background curves; rich ratings in the research engine, however, are in line with those of a standard F-4 engine. (Hereinafter the research F-4 engine will be referred to as an F-4 engine.)

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

The F-3 engine operation conformed to CRC designation F-3-544 with the exception of a barometrically controlled dry-air source in place of a dehydrating ice tower.

The conditions under which tests in the R-1820 G200 single cylinder were made were tentatively recommended by the Coordinating Research Council and are given in reference 2.

DISCUSSION OF RESULTS

Table I is an index of the figures showing in detail the order of discussing the results presented herein.

Figure 1 (reproduced from fig. 7 of reference 1) presents F-4 results for the 85 percent S-3 plus 15 percent M-4 base fuel with 4 ml TEL per gallon. Shifts in the knock-limited power level that accompanied engine operation had little if any effect on the F-4 rating of the base fuel. This fact was determined by several check tests made during the course of the program.

The F-4 results for blends of 10, 25, and 50 percent aromatics in the S-3 plus M-4 base fuel are shown in figures 2, 3, and 4 for isopropylbenzene, benzene, and o-xylene, respectively. When the

concentration of isopropylbenzene and benzene was increased, the rich-mixture response increased. For the 50-percent concentration of isopropylbenzene (fig. 2(c)), the curve of knock-limited indicated mean effective pressure became almost vertical at a fuel-air ratio of about 0.100. This trend was observed with the 50-percent blends in reference 1. At the high powers it was often impracticable to bracket the rich-mixture results in terms of S-3 plus tetraethyl lead.

Plots of the variation of knock-limited imep ratio $\left(\text{imep ratio} = \frac{\text{imep of aromatic blend}}{\text{imep of base fuel}}\right)$ with aromatic concentration for the blends tested in the F-4 engine are presented in figures 5, 6, and 7. At a fuel-air ratio of 0.100 the rate of increase of knock-limited imep ratio increased as the aromatic concentration increased from 25 to 50 percent. The rate of increase for isopropylbenzene was much greater than for either benzene or o-xylene.

The F-4 and the F-3 ratings of the various blends are recorded in table II in terms of percentage S-3 in M-4, S-3 plus tetraethyl lead, or octane number. All ratings are also converted to accepted Army-Navy performance numbers.

The 17.6 engine knock-limited performance of blends of the aromatics in the S-3 and the S-3 plus M-4 base fuel are presented in figures 8 to 16: isopropylbenzene (figs. 8, 9, and 10), benzene (figs. 11, 12, and 13), and o-xylene (figs. 14, 15, and 16). For each aromatic, the data are given in the following order: unleaded blends in S-3, leaded blends in S-3, and leaded blends in S-3 plus M-4; inlet-air temperatures of 250° F and 100° F were used. Each plot presents data obtained during the period of 1 day.

Figure 8(a) shows the knock-limited performance of unleaded blends containing isopropylbenzene at an inlet-air temperature of 250° F. The knock-limited indicated mean effective pressure of the 20-percent blend is believed to be approximately 7 to 8 pounds per square inch low at a fuel-air ratio of 0.075 and 2 to 3 pounds per square inch low at a fuel-air ratio of 0.110 (as judged from a plot of imep against air flow). Because of an engine failure during this test and an engine overhaul immediately thereafter, no direct comparison can be made between the absolute values of the data of this figure and those of the following figures.

At an inlet-air temperature of 250° F with the unleaded blends (figs. 8(a), 11(a), and 14(a)), the knock-limited indicated mean effective pressure of S-3 was not increased through the addition of the aromatics at fuel-air ratios in the neighborhood of 0.065 and 0.070 but was increased at higher fuel-air ratios through the addition of isopropylbenzene and benzene. When the inlet-air temperature was decreased to 100° F (figs. 8(b), 11(b), and 14(b)), the knock-limited power of S-3 was increased at all fuel-air ratios through the addition of these two aromatics. Additions of o-xylene decreased the knock-limited power of S-3 at fuel-air ratios leaner than 0.110 at the higher inlet-air temperature and at fuel-air ratios leaner than 0.090 at the lower inlet-air temperature.

With the leaded blends at an inlet-air temperature of 250° F (figs. 9(a), 12(a), and 15(a)), additions of isopropylbenzene increased the knock-limited power of the base fuel even at lean mixtures. Benzene blends did not show this apparent susceptibility to tetraethyl lead, but additions of benzene did increase the knock-limited power of the base fuel at fuel-air ratios richer than 0.0675. When the inlet-air temperature was decreased to 100° F (figs. 9(b), 12(b), and 15(b)), additions of isopropylbenzene and benzene increased the knock-limited power of the base fuel at all fuel-air ratios to an extent which would indicate that blends containing these two aromatics have a lead susceptibility greater than that of S-3. Greater percentage decreases in knock-limited power at both inlet-air temperatures were observed for the leaded than for the unleaded o-xylene blends, which indicates that the lead response of o-xylene blends was less than that of S-3.

Figures 10, 13, and 16 present the knock-limited performance of the 25-percent leaded blends of aromatics in the S-3 plus M-4 base fuel at inlet-air temperatures of 250° and 100° F. Additions of isopropylbenzene and benzene increased the knock-limited power of the base fuel at all fuel-air ratios and at both inlet-air temperatures; o-xylene acted as a proknock agent at all fuel-air ratios.

In unleaded or leaded blends, isopropylbenzene was generally more effective than benzene in increasing the knock-limited indicated mean effective pressures of the base fuels. The response of o-xylene was exceptional in that it acted as a proknock agent under nearly all conditions tested.

Plots of knock-limited imep ratio against aromatic concentration are presented in figures 17, 18, and 19 for the blends of the aromatics in S-3 tested in the 17.6 engine. These data show the comparative effect of the addition of aromatics at fuel-air ratios of 0.070, 0.085, and 0.100 as well as the effect of inlet-air temperature and tetraethyl lead.

A summarization of the knock-limited data for the 17.6 engine, the full-scale cylinder (reference 2), and the F-4 engine is presented in table III. In order to calculate the imep ratios presented therein, it was necessary to determine the daily performance of the base fuel. Because the S-3 plus M-4 base fuel was not tested each day on the F-4 engine, an assumed daily knock-limited performance curve for this fuel was estimated from the daily performance of the F-4 reference fuels and from the data of figure 1.

The temperature sensitivities are summarized in table IV. With few exceptions the sensitivity to inlet-air temperature is greater for the aromatic blends than for the base fuels.

The lead susceptibilities of the blends containing isopropylbenzene and benzene (see table V) were, in nearly all cases, greater than that of S-3. The response of o-xylene blends to the addition of tetraethyl lead was very poor.

SUMMARY OF RESULTS

From knock-limited tests of fuel blends containing isopropylbenzene, benzene, and o-xylene, the following results were obtained:

1. Isopropylbenzene was, in general, more effective than benzene in increasing the knock-limited power of the base fuels. o-Xylene acted as a proknock agent under nearly all of the conditions tested.

2. Isopropylbenzene and benzene increased the lead susceptibility of S-3 reference fuel, but the addition of lead to o-xylene blends resulted in power improvements that were smaller than those observed for S-3.

3. The knock-limited performance of the aromatic blends was generally more susceptible to changes in inlet-air temperature than was either S-3 reference fuel or a blend of S-3 and M-4.

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REFERENCES

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

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

TABLE I. - INDEX OF FIGURES

Figure	Aromatic	Percentage aromatic in blend	Base fuel	Tetra-ethyl lead (ml/gal)	Inlet-air temper-ature (°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)	Isopropylbenzene	10 25 50	85% S-3 + 15% M-4	4	225
3(a) (b) (c)	Benzene	10 25 50	85% S-3 + 15% M-4	4	225
4(a) (b) (c)	o-Xylene	10 25 50	85% S-3 + 15% M-4	4	225
F-4 engine (knock-limited imep ratio against aromatic concentration)					
5	Isopropylbenzene	0,10,25,50	85% S-3 + 15% M-4	4	225
6	Benzene	0,10,25,50	85% S-3 + 15% M-4	4	225
7	o-Xylene	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)	Isopropylbenzene	0,10,20 0,20	S-3	0	250 100
9(a) (b)	Isopropylbenzene	0,10,20 0,20	S-3	4	250 100
10	Isopropylbenzene	0,25	85% S-3 + 15% M-4	4	250
11(a) (b)	Benzene	0,10,20 0,20	S-3	0	250 100
12(a) (b)	Benzene	0,10,20 0,20	S-3	4	250 100
13(a) (b)	Benzene	0,25 0,25	85% S-3 + 15% M-4	4	250 100
14(a) (b)	o-Xylene	0,10,20 0,20	S-3	0	250 100
15(a) (b)	o-Xylene	0,10,20 0,20	S-3	4	250 100
16(a) (b)	o-Xylene	0,25 0,25	85% S-3 + 15% M-4	4	250 100
17.6 engine (knock-limited imep ratio against aromatic concentration)					
17	Isopropylbenzene	0,10,20	S-3	0,4	250,100
18	Benzene	0,10,20	S-3	0,4	250,100
19	o-Xylene	0,10,20	S-3	0,4	250,100

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TABLE II. - F-4 AND F-3 RATINGS OF ISOPROPYLBENZENE, BENZENE, AND o-XYLENE BLENDS

Compound	Blend composition (percent by volume)			Tetraethyl lead (ml/gal)	F-4 ratings				F-3 ratings	
					Lean		Rich			
	Pure aromatic	S-3 reference fuel	85 percent S-3 plus 15 percent M-4		S-3 + ml TEL	Performance number	S-3 + ml TEL	Performance number	S-3 + ml TEL	Performance number
Base fuel	0	0	100	4	0.36	112	0.26	109	0.39	113
Isopropylbenzene	10	0	90	4	0.73	121	1.2	129	0.51	116
Benzene	10	0	90	4	.46	115	.59	118	.47	115
o-Xylene	10	0	90	4	.37	113	[a]98.3	95	.18	107
Isopropylbenzene	25	0	75	4	0.42	114	3.92	152	0.53	117
Benzene	25	0	75	4	.18	107	1.90	137	.31	111
o-Xylene	25	0	75	4	[a]96.1	90	[a]98.1	94	[b]100.0	100
Isopropylbenzene	50	0	50	4	0.21	108	>6.0	--------	--------	--------
Benzene	50	0	50	4	[a]98.0	94	>6.0	--------	[b,c]98±2	94±6
o-Xylene	50	0	50	4	[a]93.2	83	.5	116	[b]93.4	81
o-Xylene	10	90	0	4	------	--------	------	--------	1.80	136
o-Xylene	20	80	0	4	------	--------	------	--------	0.58	118
Isopropylbenzene	10	90	0	0	------	--------	------	--------	[b]99.3	98
Benzene	10	90	0	0	------	--------	------	--------	[b]98.8	96
o-Xylene	10	90	0	0	------	--------	------	--------	[b]97.8	93
Benzene	20	80	0	0	------	--------	------	--------	[b]97.4	92
o-Xylene	20	80	0	0	------	--------	------	--------	[b]95.4	86

[a]Percentage S-3 in M-4.
[b]Octane number.
[c]Estimated value because of limited supply of fuel.

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TABLE III. - SUPERCHARGED-ENGINE TESTS OF BLENDS CONTAINING ISOPROPYLBENZENE, BENZENE, OR o-XYLENE

Fuel composition					Engine conditions		Test results									
	Blend composition (percent by volume)			Tetra-ethyl lead (ml/gal)			Fuel-air ratio									
							0.065		0.070		0.085		0.100		0.110	
Compound	Pure aromatic	S-3 reference fuel	85 percent S-3 plus 15 percent M-4		Engine speed (rpm)	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																
Isopropylbenzene	10	90	0	0	1800	250	131	1.01	132	1.00	163	1.09	188	1.14	194	1.16
Benzene	10	90	0	0			109	1.00	111	1.01	138	1.02	157	1.03	160	1.04
o-Xylene	10	90	0	0			105	.95	105	.95	124	.93	149	.97	154	1.00
Isopropylbenzene	20	80	0	0	1800	250	136	1.05	130	0.98	160	1.07	198	1.20	216	1.29
Benzene	20	80	0	0			109	1.00	111	1.01	138	1.02	168	1.10	180	1.17
o-Xylene	20	80	0	0			99	.90	99	.89	116	.87	142	.93	153	.99
Isopropylbenzene	20	80	0	0	1800	100	184	1.15	190	1.20	212	1.29	224	1.32	226	1.34
Benzene	20	80	0	0			171	1.08	165	1.06	176	1.08	188	1.12	192	1.15
o-Xylene	20	80	0	0			154	.97	150	.96	160	1.00	171	1.02	177	1.06
Isopropylbenzene	10	90	0	4	1800	250	206	1.04	226	1.10	259	1.12	282	1.16	288	1.20
Benzene	10	90	0	4			199	1.00	211	1.02	245	1.06	265	1.08	268	1.09
o-Xylene	10	90	0	4			177	.89	186	.91	204	.88	214	.87	212	.86
Isopropylbenzene	20	80	0	4	1800	250	216	1.10	230	1.12	275	1.19	318	1.31	331	1.38
Benzene	20	80	0	4			198	.99	214	1.04	256	1.10	279	1.14	288	1.17
o-Xylene	20	80	0	4			153	.77	168	.82	195	.84	205	.83	202	.82
Isopropylbenzene	20	80	0	4	1800	100	341	1.33	345	1.35	356	1.35	365	1.38	367	1.41
Benzene	20	80	0	4			286	1.11	288	1.11	312	1.17	322	1.21	322	1.23
o-Xylene	20	80	0	4			210	.81	212	.82	226	.84	229	.86	228	.87
Isopropylbenzene	25	0	75	4	1800	250	168	1.25	176	1.27	225	1.40	245	1.45	248	1.48
Benzene	25	0	75	4			142	1.04	153	1.08	187	1.15	209	1.22	218	1.28
o-Xylene	25	0	75	4			110	.81	118	.84	143	.89	155	.91	157	.92
Isopropylbenzene	25	0	75	4	1800	100	-----	-------	-----	-------	-----	-------	-----	-------	-----	-------
Benzene	25	0	75	4			206	1.18	211	1.21	229	1.23	240	1.27	241	1.28
o-Xylene	25	0	75	4			155	.89	157	.90	168	.91	172	.92	174	.94
Full-scale cylinder (data from reference 2)																
Isopropylbenzene	25	0	75	4	2500	250	194	1.25	199	1.27	260	1.39	318	1.47	330	1.43
Benzene	25	0	75	4			150	.97	146	.93	214	1.14	258	1.19	276	1.20
o-Xylene	25	0	75	4			119	.77	111	.71	184	.98	213	.99	229	.99
Isopropylbenzene	25	0	75	4	2000	210	207	1.40	206	1.36	278	1.52	316	1.48	321	1.41
Benzene	25	0	75	4			177	1.20	180	1.19	215	1.17	263	1.23	283	1.25
o-Xylene	25	0	75	4			114	.77	124	.82	180	.98	211	.99	222	.98
F-4 engine																
Isopropylbenzene	10	0	90	4	1800	225	121	1.14	135	1.13	172	1.13	189	1.11	193	1.12
Benzene	10	0	90	4			129	1.03	141	1.01	168	1.04	182	1.05	186	1.07
o-Xylene	10	0	90	4			119	.95	130	.94	154	.95	159	.92	158	.91
Isopropylbenzene	25	0	75	4	1800	225	111	1.05	127	1.07	174	1.14	209	1.23	225	1.30
Benzene	25	0	75	4			107	1.06	126	1.10	171	1.12	196	1.15	206	1.19
o-Xylene	25	0	75	4			90	.76	105	.80	141	.89	155	.91	156	.91
Isopropylbenzene	50	0	50	4	1800	225	99	0.93	121	1.02	215	1.41	326	1.92	447	2.58
Benzene	50	0	50	4			77	.74	87	.73	187	1.23	237	1.39	261	1.51
o-Xylene	50	0	50	4			77	.68	92	.73	133	.87	162	.95	173	1.00

[a] imep ratio = $\frac{\text{imep of aromatic blend}}{\text{imep of base fuel}}$. For the blends tested in 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 IV. - TEMPERATURE SENSITIVITY OF ISOPROPYLBENZENE, BENZENE AND o-XYLENE BLENDS RELATIVE TO THAT OF THE BASE FUEL

[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]				
					Fuel-air ratio				
	Pure aromatic	S-3 reference fuel	85 percent S-3 plus 15 percent M-4		0.065	0.070	0.085	0.100	0.110
S-3	0	100	0	0	1.00	1.00	1.00	1.00	1.00
Isopropylbenzene	20	80	0	0	1.10	1.22	1.21	1.10	1.04
Benzene	20	80	0	0	1.08	1.05	1.06	1.02	.98
o-Xylene	20	80	0	0	1.08	1.10	1.15	1.10	1.07
S-3	0	100	0	4	1.00	1.00	1.00	1.00	1.00
Isopropylbenzene	20	80	0	4	1.21	1.21	1.13	1.05	1.02
Benzene	20	80	0	4	1.12	1.07	1.06	1.06	1.05
o-Xylene	20	80	0	4	1.05	1.00	1.00	1.04	1.06
85 percent S-3 + 15 percent M-4	0	0	100	4	1.00	1.00	1.00	1.00	1.00
Isopropylbenzene	25	0	75	4	———	———	———	———	———
Benzene	25	0	75	4	1.13	1.12	1.07	1.04	1.00
o-Xylene	25	0	75	4	1.10	1.07	1.02	1.01	1.02

[a]Relative temperature sensitivity = $\frac{\text{imep ratio (inlet-air temperature, 100° F)}}{\text{imep ratio (inlet-air temperature, 250° F)}}$

Temperature sensitivity (as defined in reference 1) = relative temperature sensitivity multiplied by $\frac{\text{imep of base fuel (inlet-air temperature, 100° F)}}{\text{imep of base fuel (inlet-air temperature, 250° F)}}$

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TABLE V. - LEAD SUSCEPTIBILITY OF ISOPROPYLBENZENE, BENZENE,

AND o-XYLENE 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)	Blend composition (percent by volume)		Relative lead susceptibility[a]				
		Pure aromatic	S-3 reference fuel	Fuel-air ratio				
				0.065	0.070	0.085	0.100	0.110
S-3	250	0	100	1.00	1.00	1.00	1.00	1.00
Isopropylbenzene	250	10	90	1.03	1.10	1.03	1.02	1.03
Benzene	250	10	90	1.00	1.01	1.04	1.05	1.05
o-Xylene	250	10	90	.94	.96	.95	.90	.86
Isopropylbenzene	250	20	80	1.05	1.14	1.11	1.09	1.07
Benzene	250	20	80	.99	1.03	1.08	1.04	1.00
o-Xylene	250	20	80	.86	.92	.97	.89	.83
S-3	100	0	100	1.00	1.00	1.00	1.00	1.00
Isopropylbenzene	100	20	80	1.16	1.13	1.05	1.05	1.05
Benzene	100	20	80	1.03	1.05	1.08	1.08	1.07
o-Xylene	100	20	80	.84	.84	.84	.84	.82

[a] Relative lead susceptibility = $\frac{\text{imep ratio of blend plus 4 ml TEL/gal}}{\text{imep ratio of blend plus 0 ml TEL/gal}}$.

Lead susceptibility (as defined in reference 1) = relative lead susceptibility multiplied by $\frac{\text{imep of S-3 plus 4 ml TEL/gal}}{\text{imep of S-3 plus 0 ml TEL/gal}}$.

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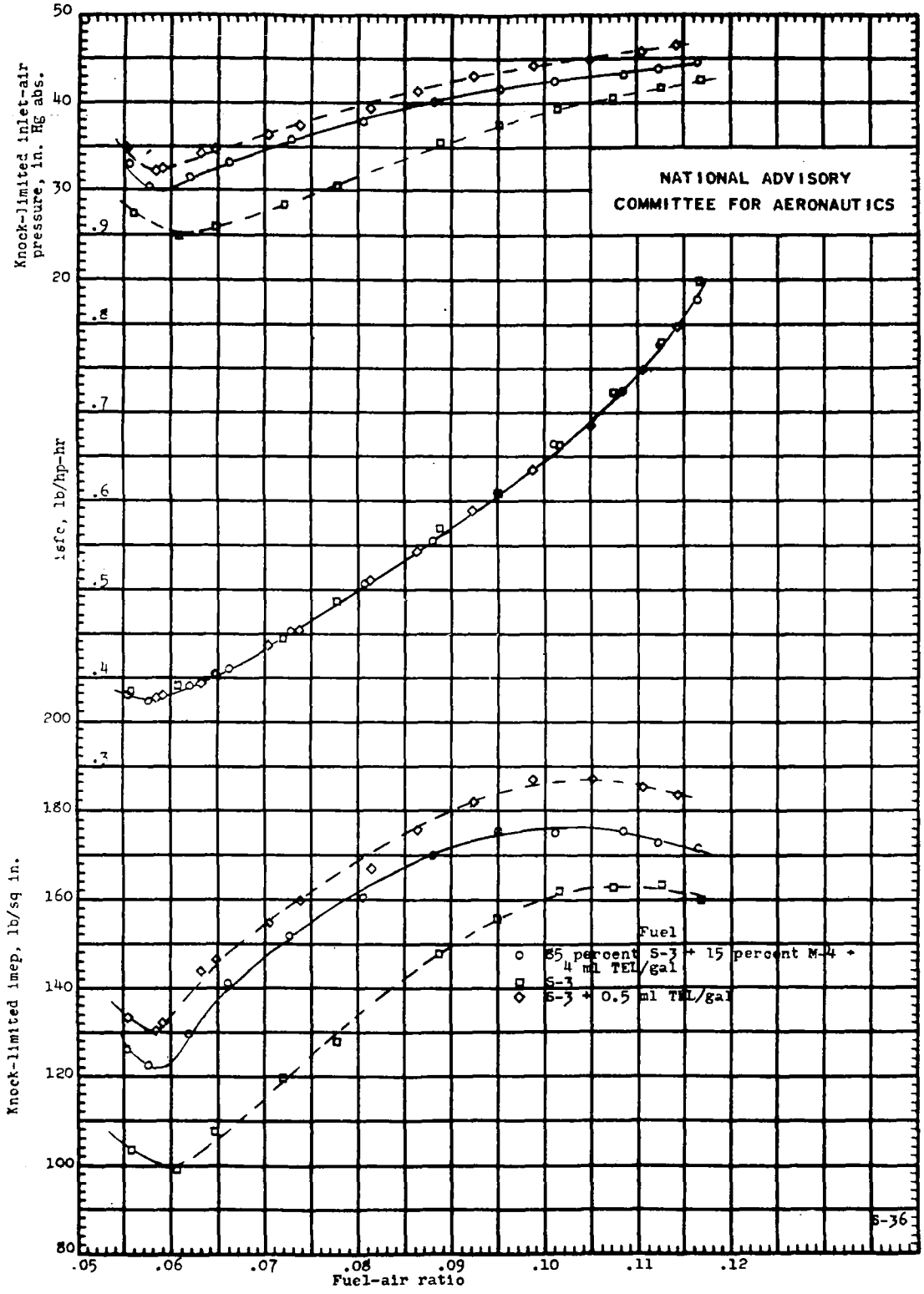
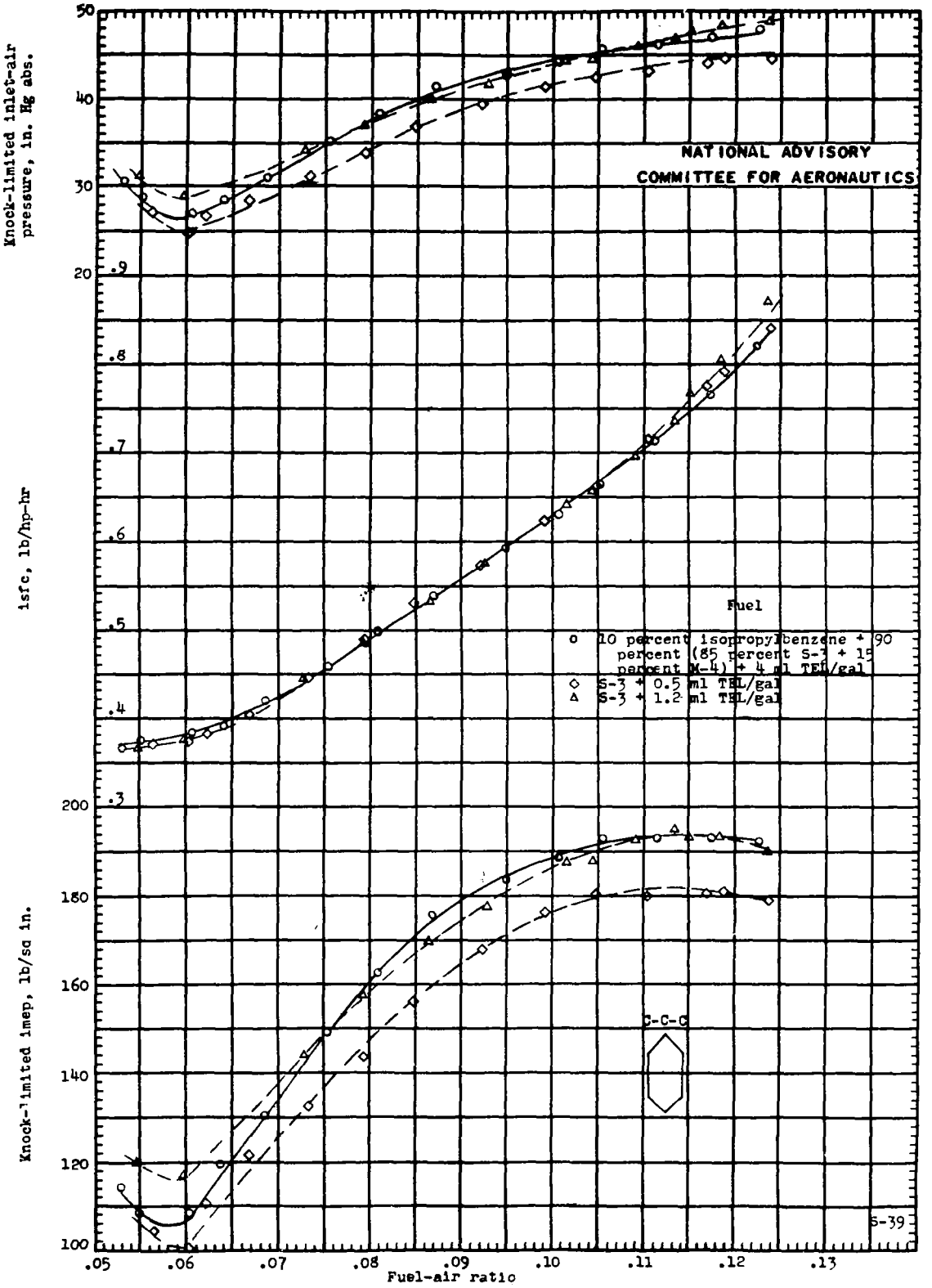
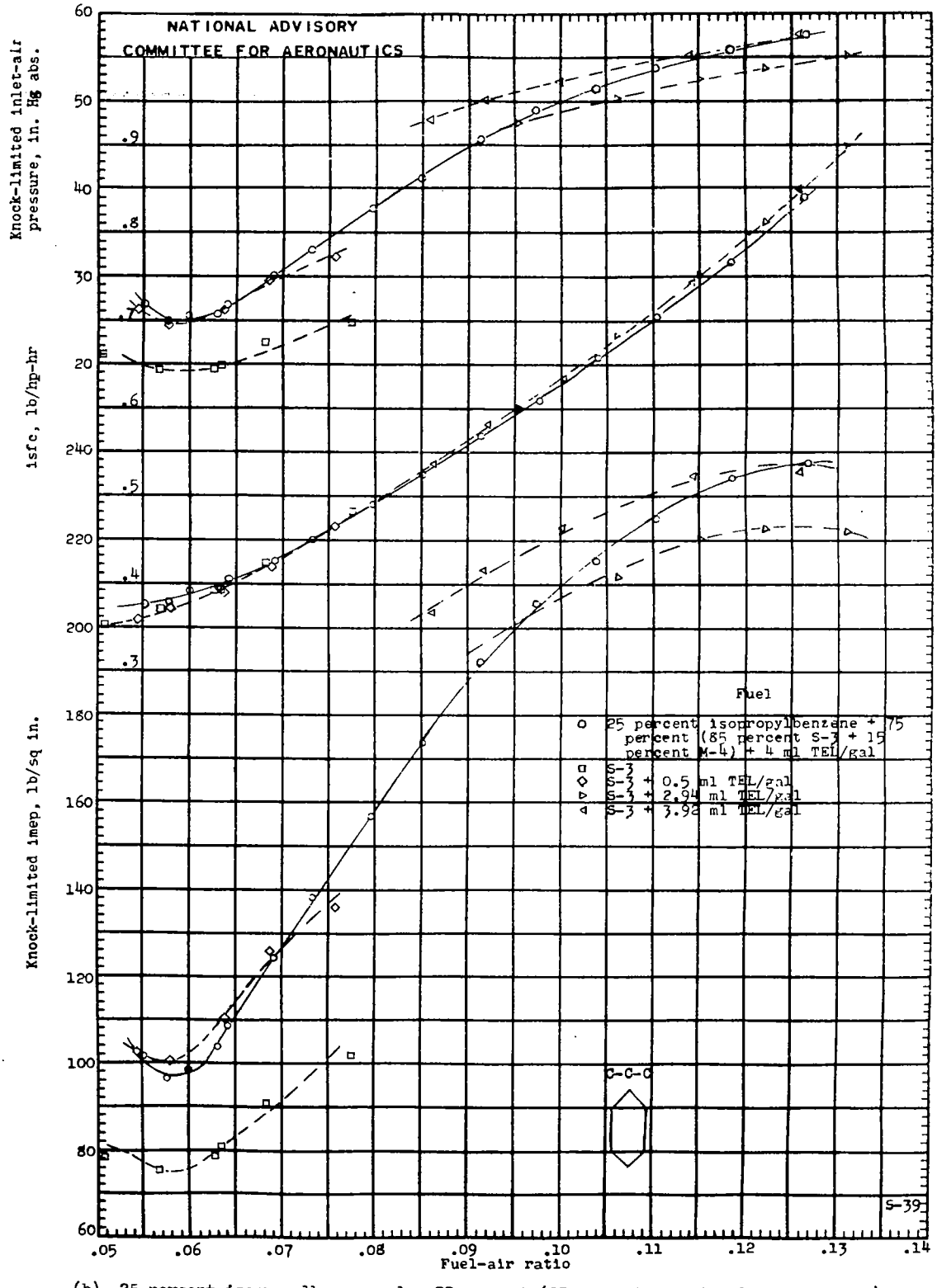


Figure 1. - Knock-limited performance of 85 percent S-3 plus 15 percent M-4 plus 4 ml TEL per gallon in an F-4 engine. (Reproduced from fig. 7 of reference 1.)



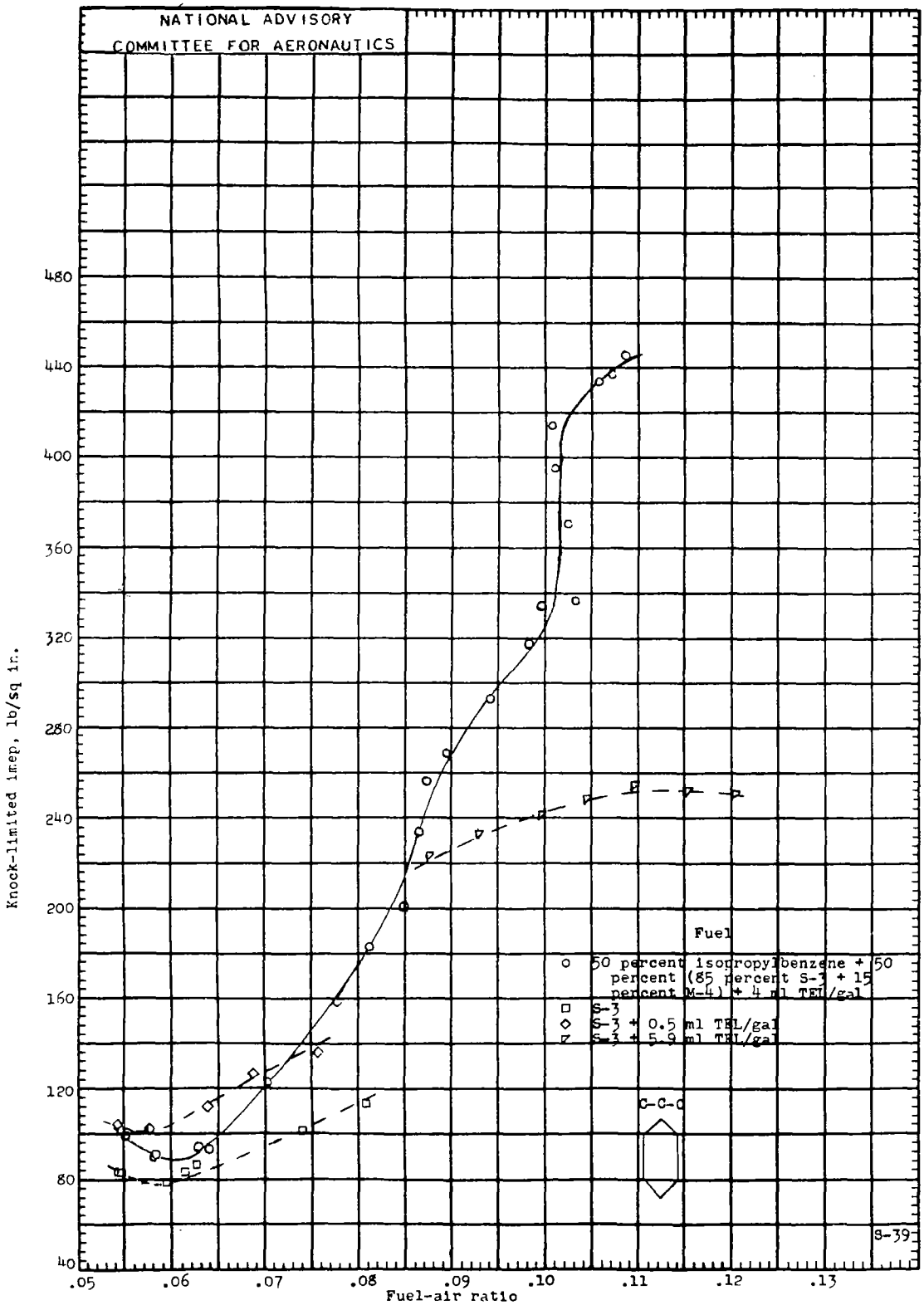
(a) 10 percent isopropylbenzene plus 90 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.

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



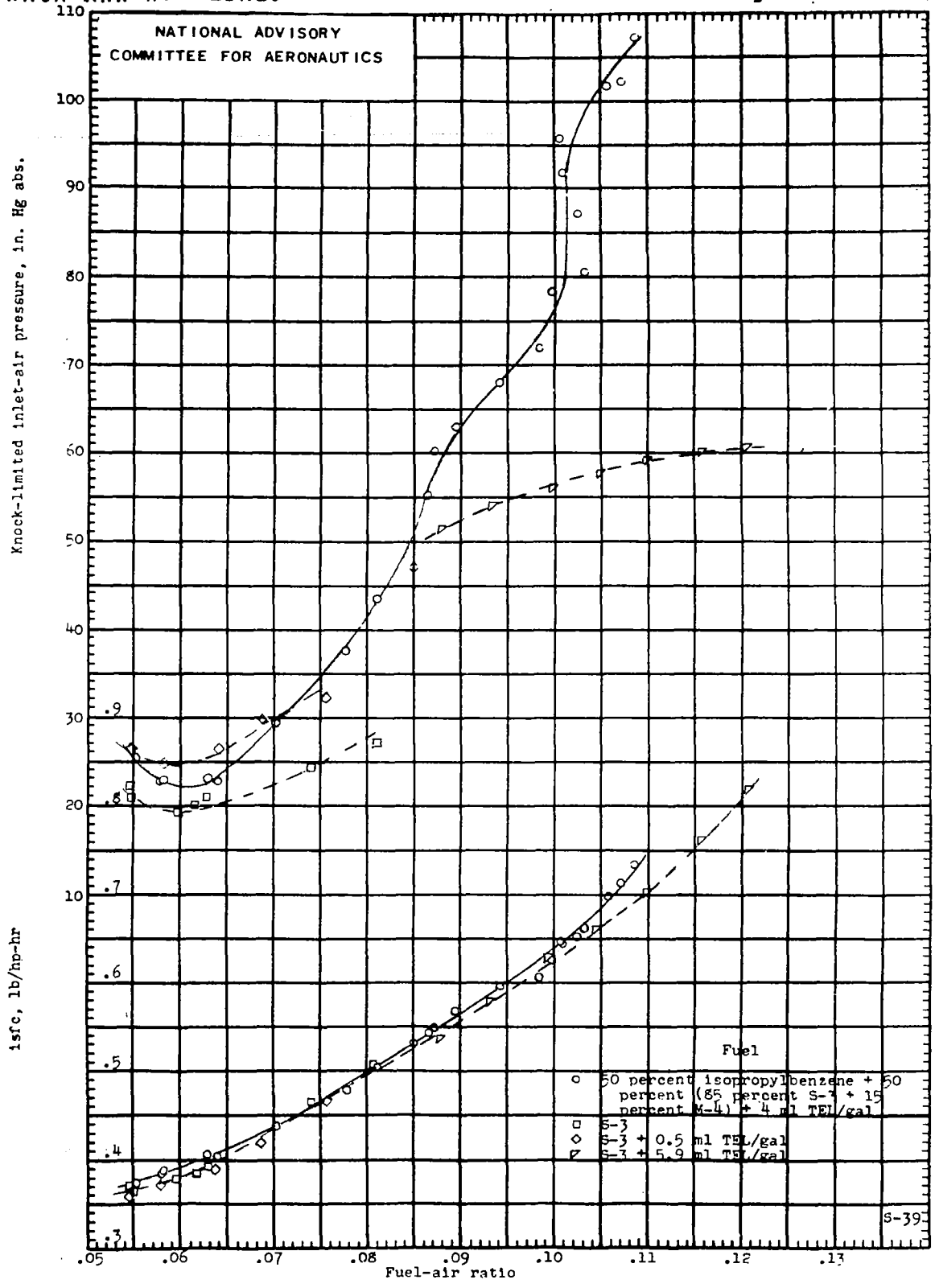
(b) 25 percent isopropylbenzene plus 75 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.

Figure 2.- Continued.

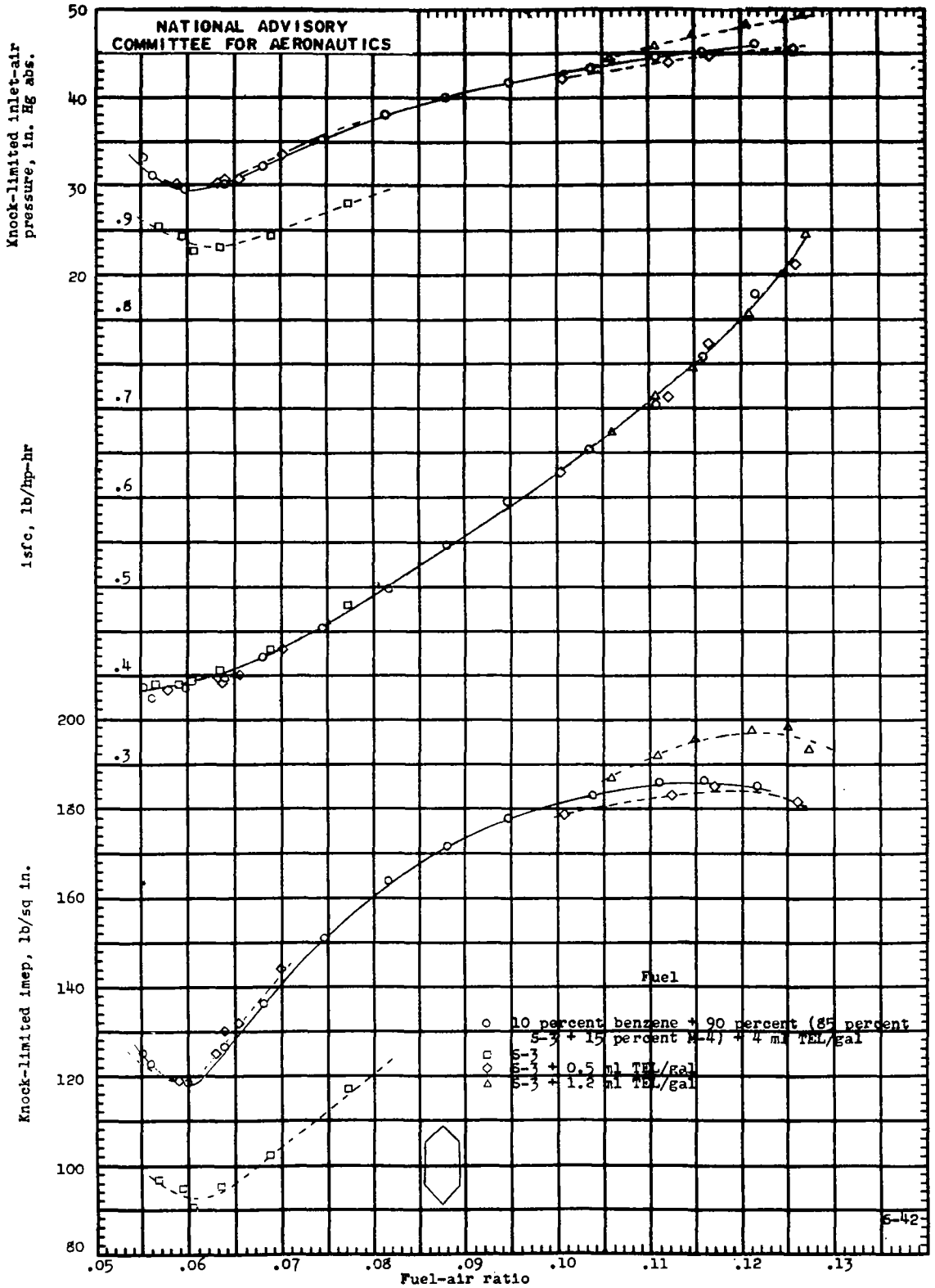


(c) 50 percent isopropylbenzene plus 50 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.

Figure 2. - Continued.

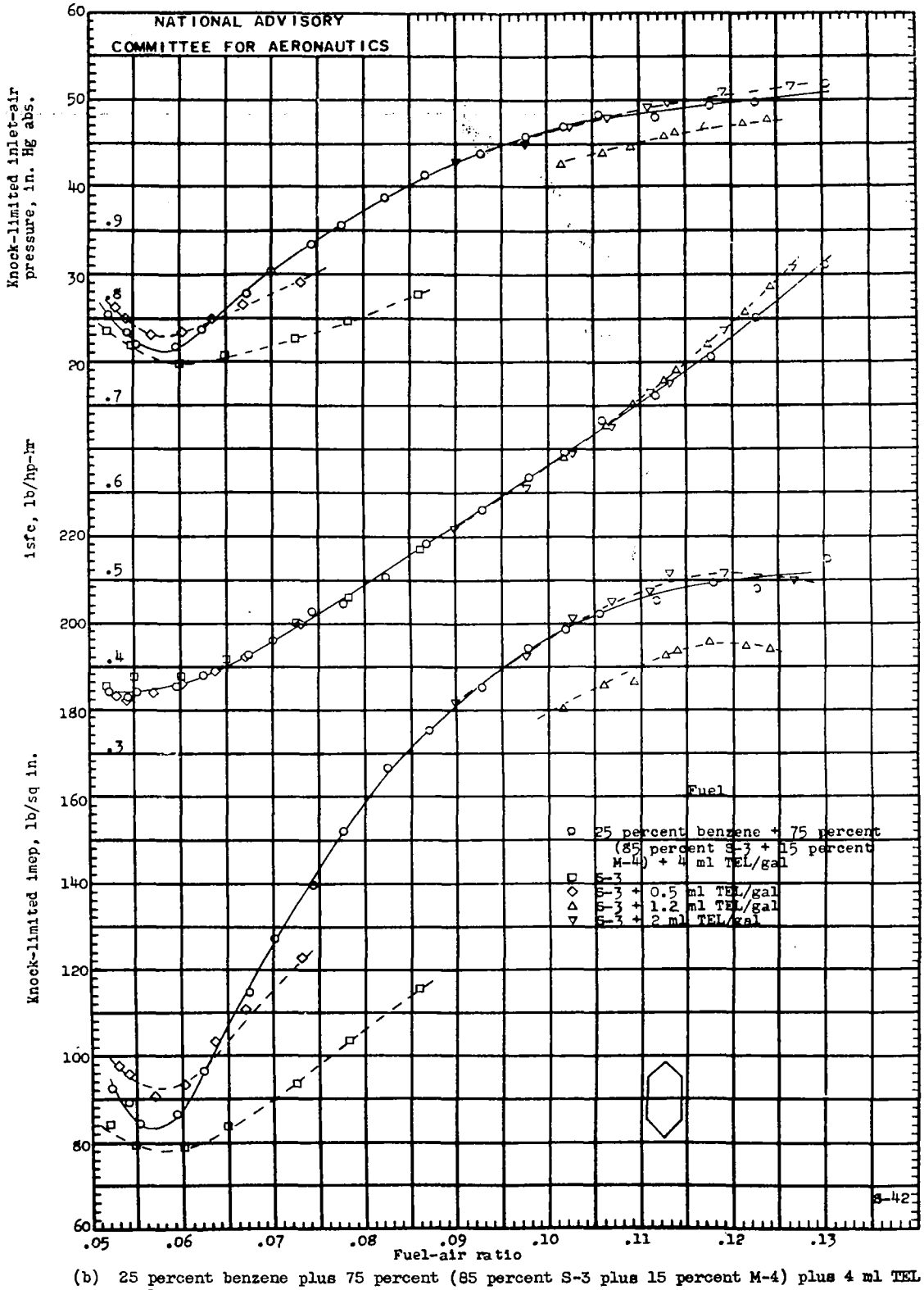


(c) Concluded.
Figure 2. - Concluded.



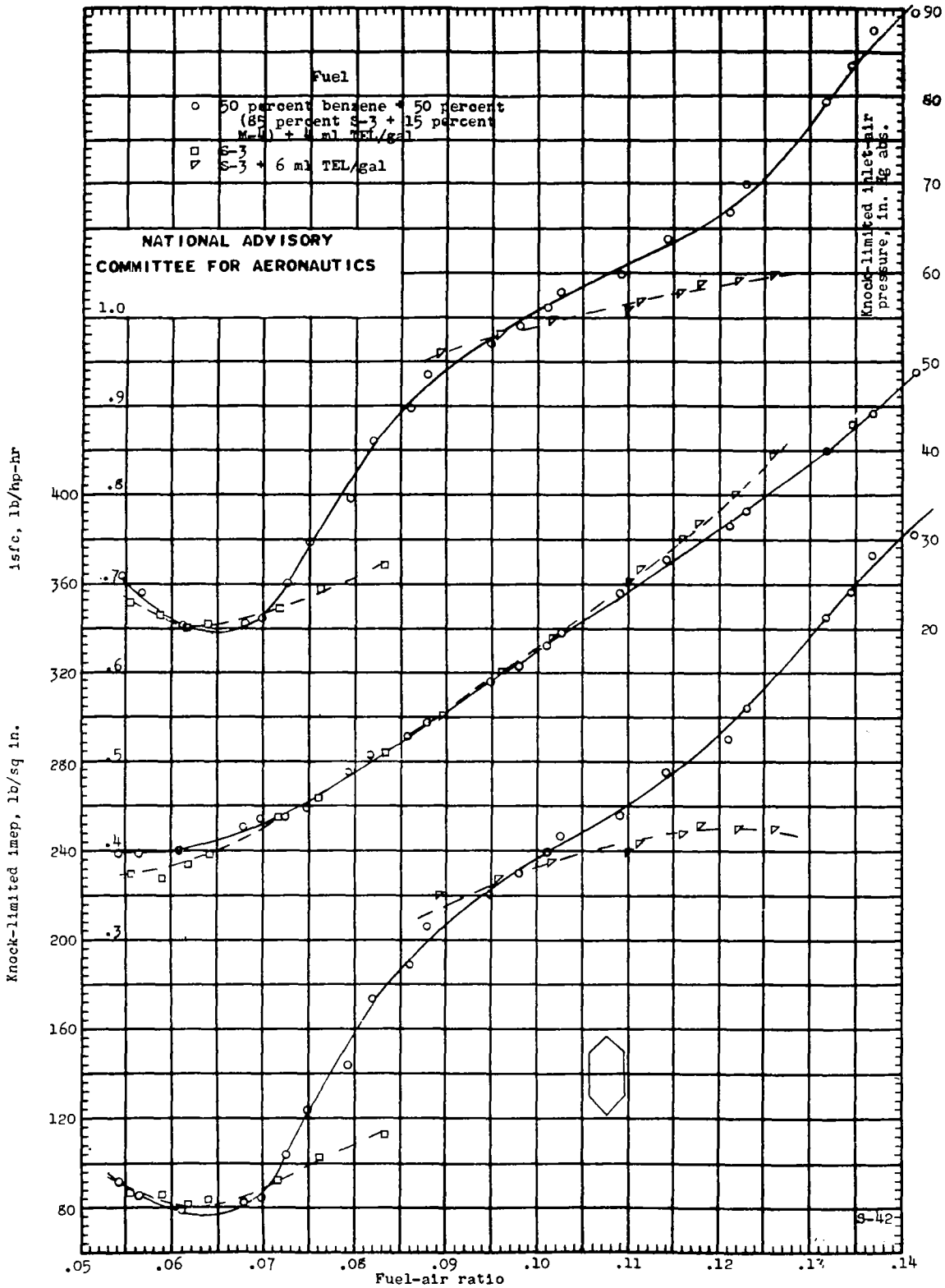
(a) 10 percent benzene plus 90 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.

Figure 3. - Knock-limited performance of blends containing benzene in an F-4 engine.



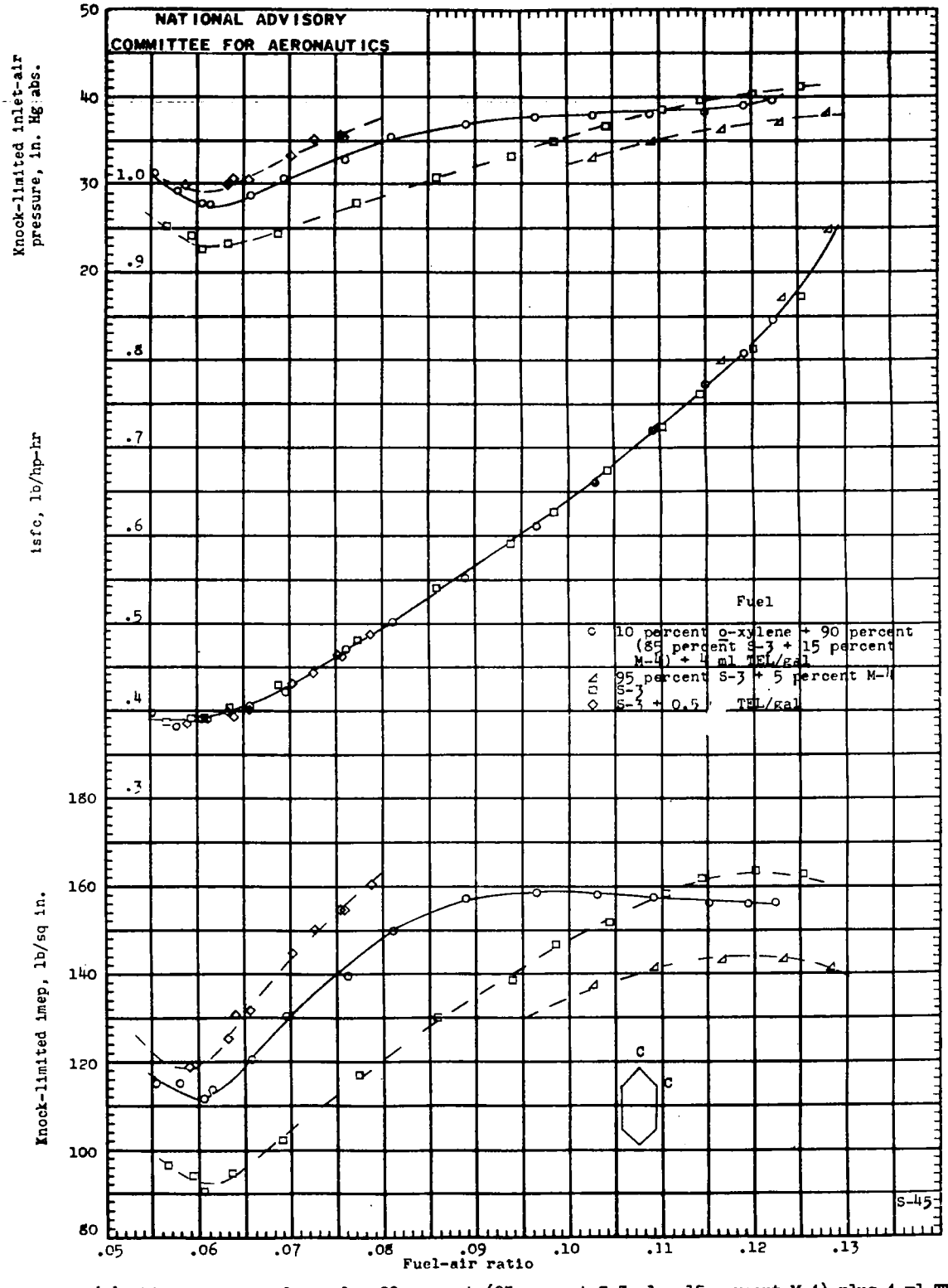
(b) 25 percent benzene plus 75 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.

Figure 3. - Continued.



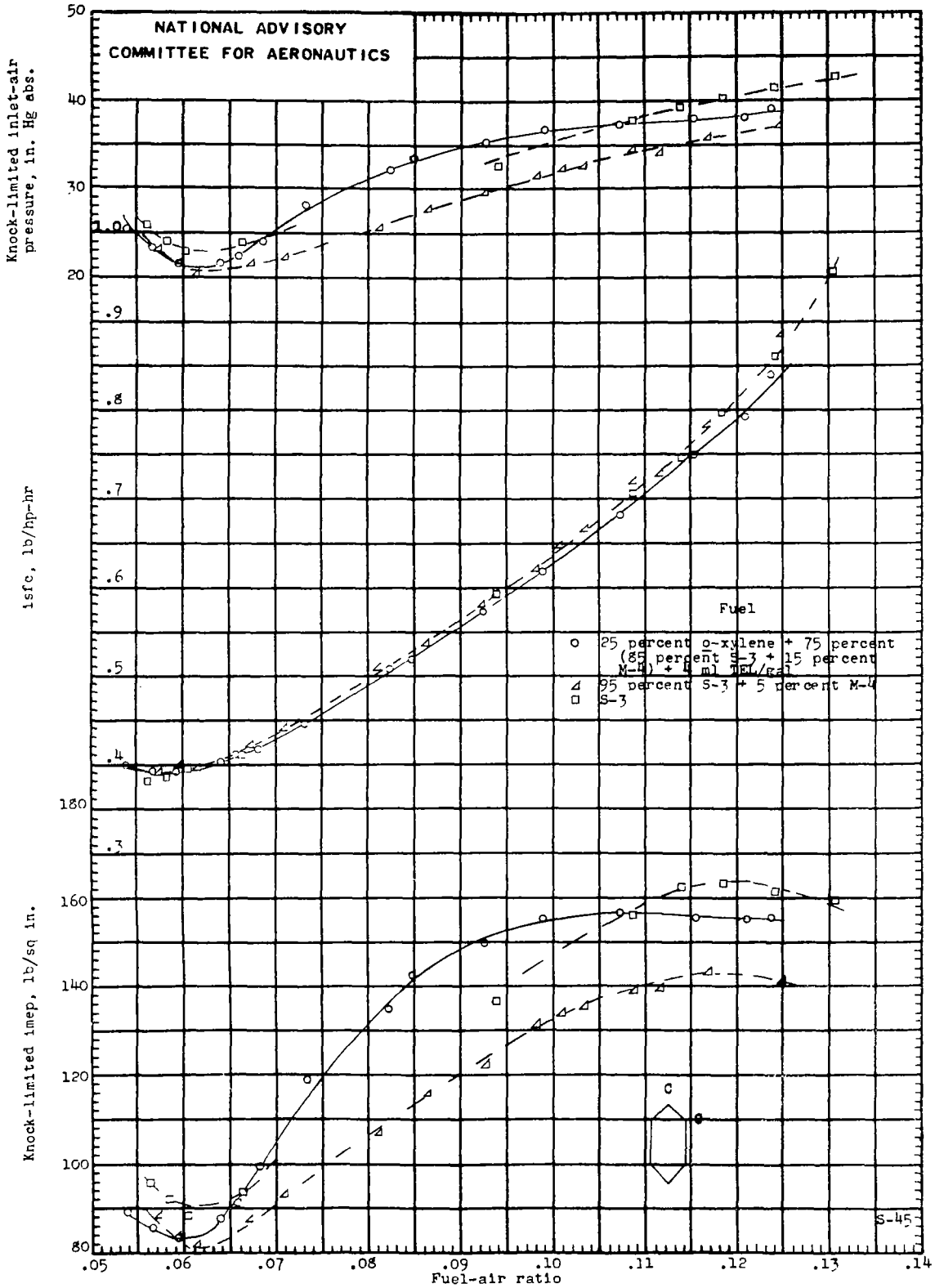
(c) 50 percent benzene plus 50 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.

Figure 3. - Concluded.



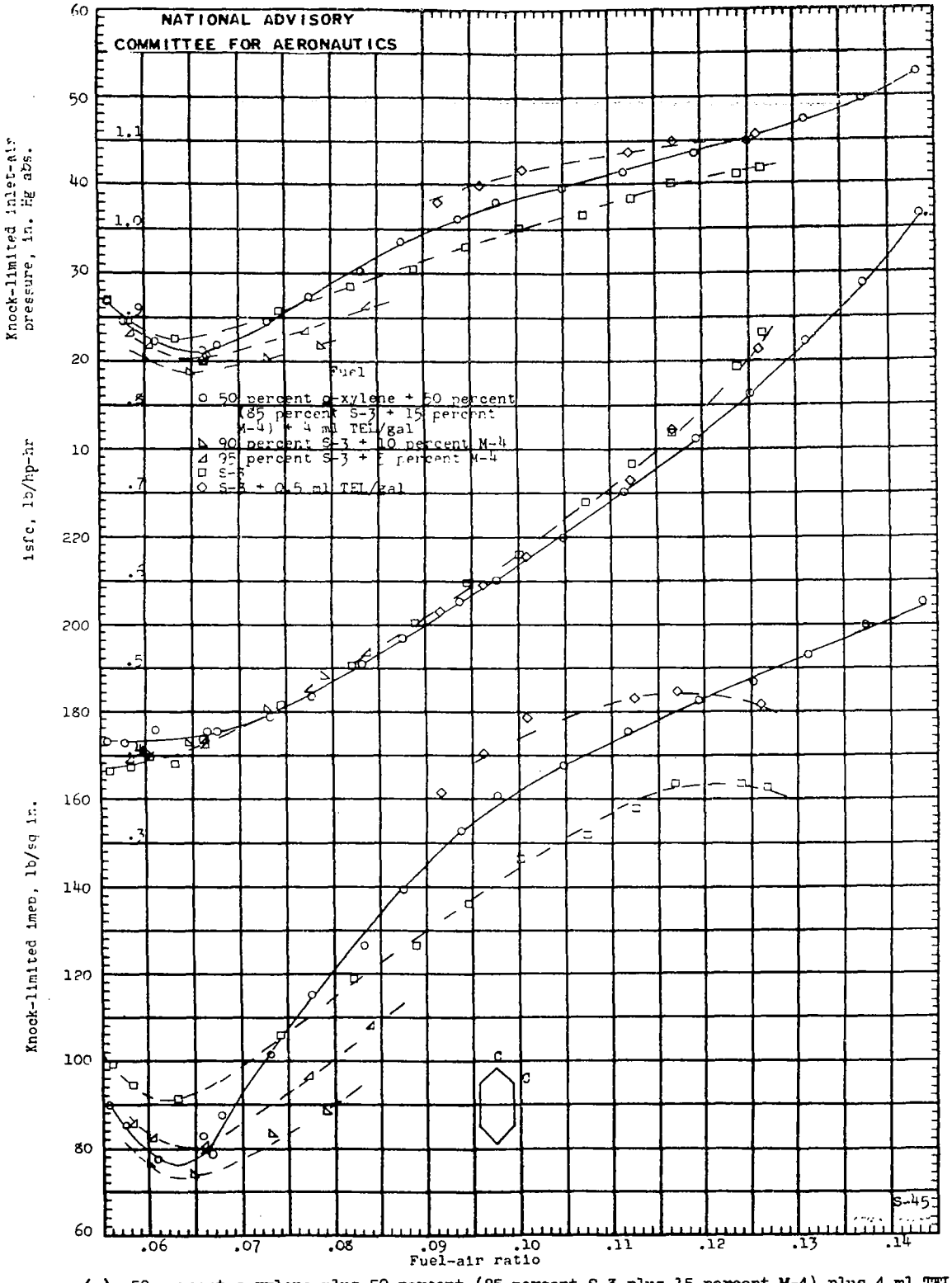
(a) 10 percent o-xylene plus 90 percent (85 percent S-3 plus 15 percent M-4) plus 4 ml TEL per gallon.

Figure 4. - Knock-limited performance of blends containing o-xylene in an F-4 engine.



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

Figure 4. - Continued.



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

Figure 4. - Concluded.

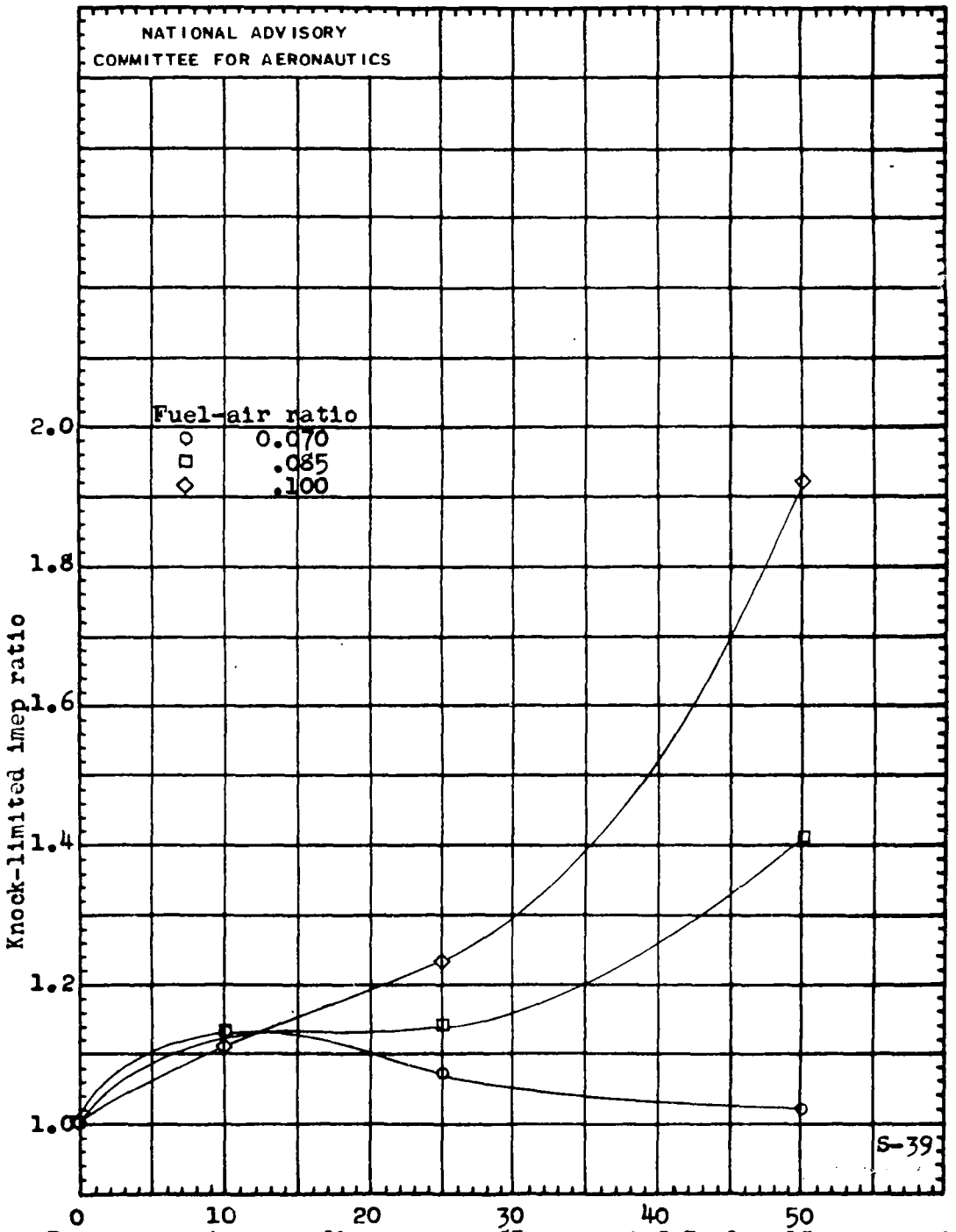
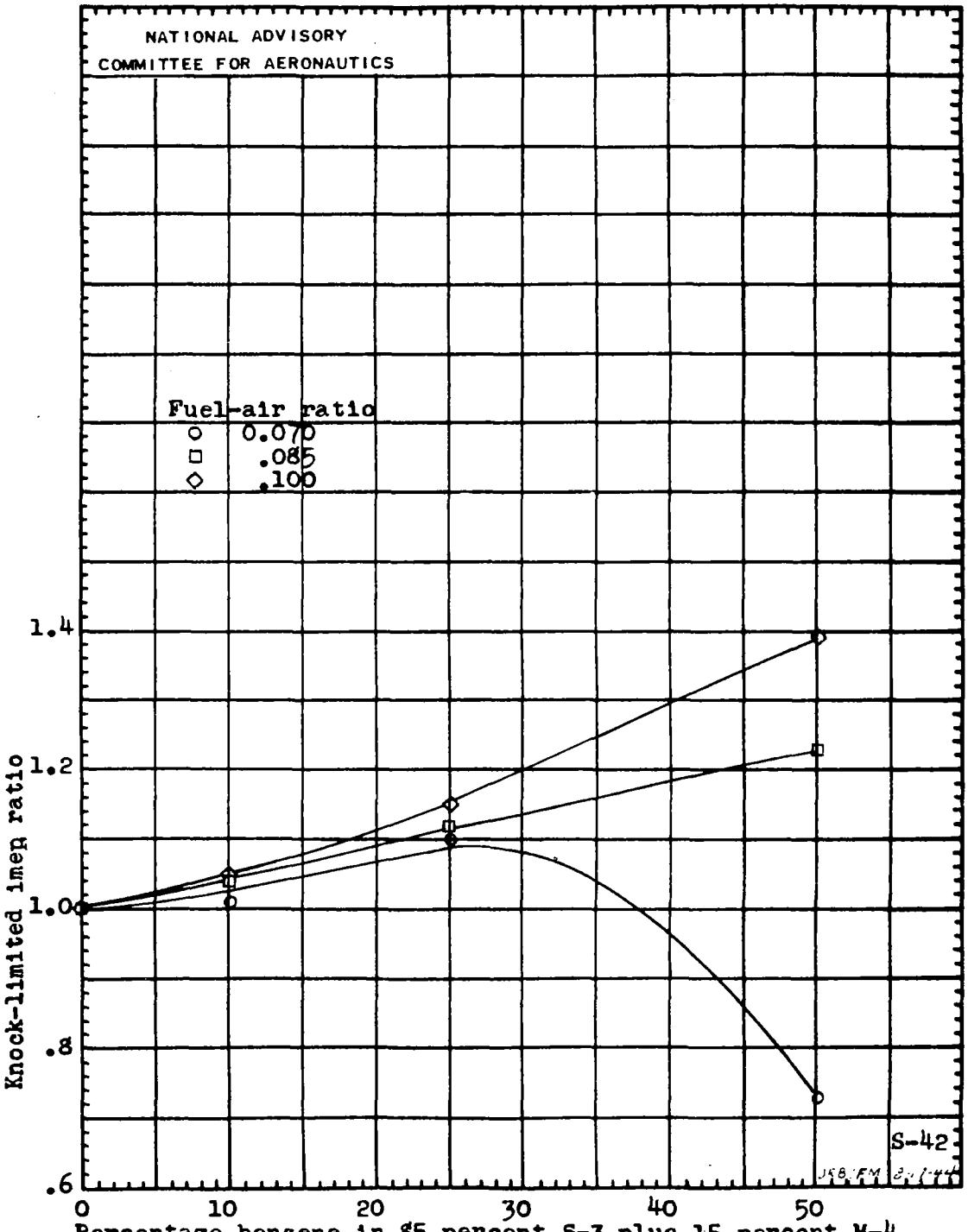


Figure 5. - The blending sensitivity of isopropylbenzene in 85 percent S-3 plus 15 percent M-4. F-4 engine; final blends leaded to 4 ml TEL per gallon.



Percentage benzene in 85 percent S-3 plus 15 percent M-4

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

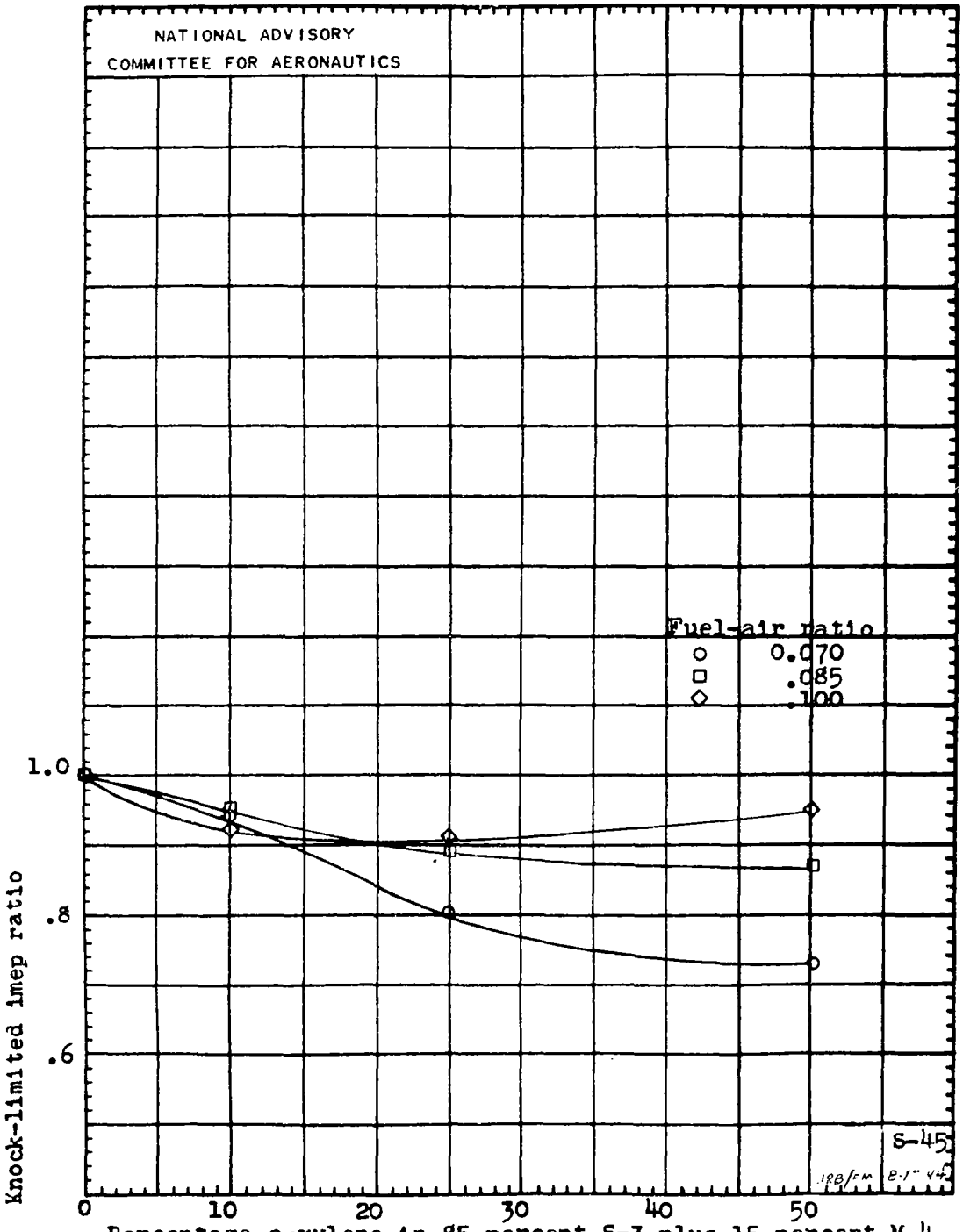
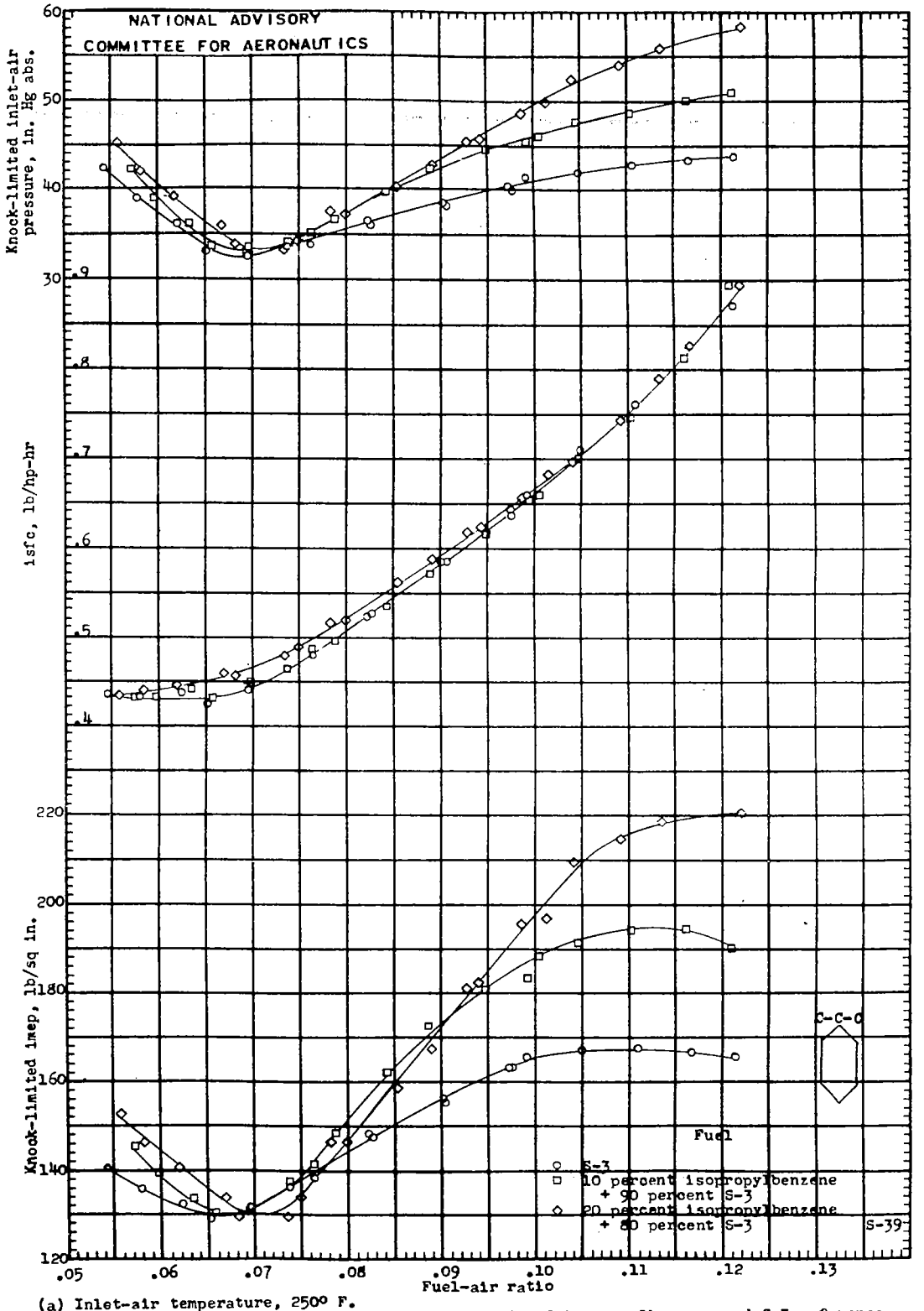
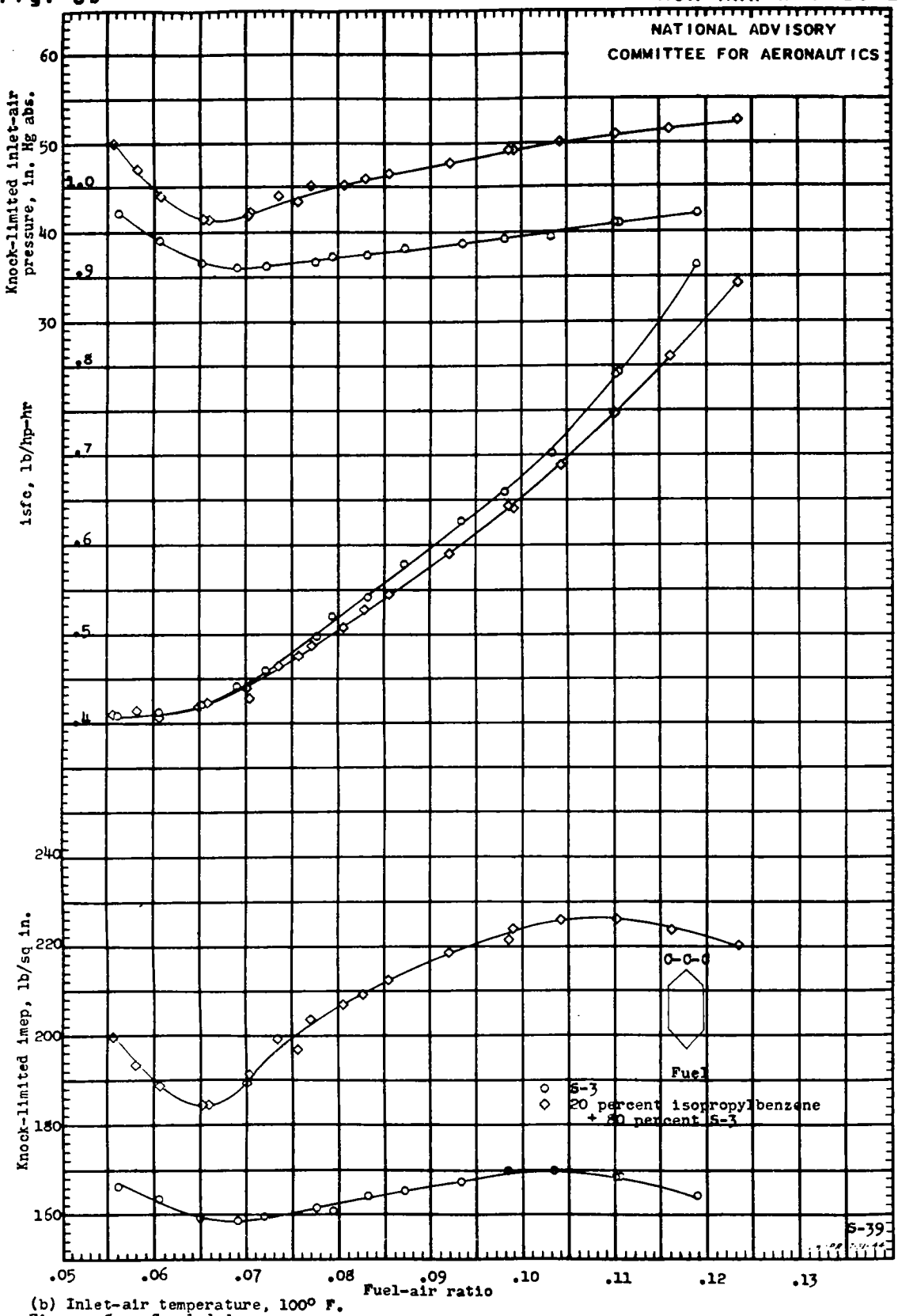


Figure 7. - The blending sensitivity of o-xylene in 85 percent S-3 plus 15 percent M-4. F-4 engine; final blends leaded to 4 ml TEL per gallon.

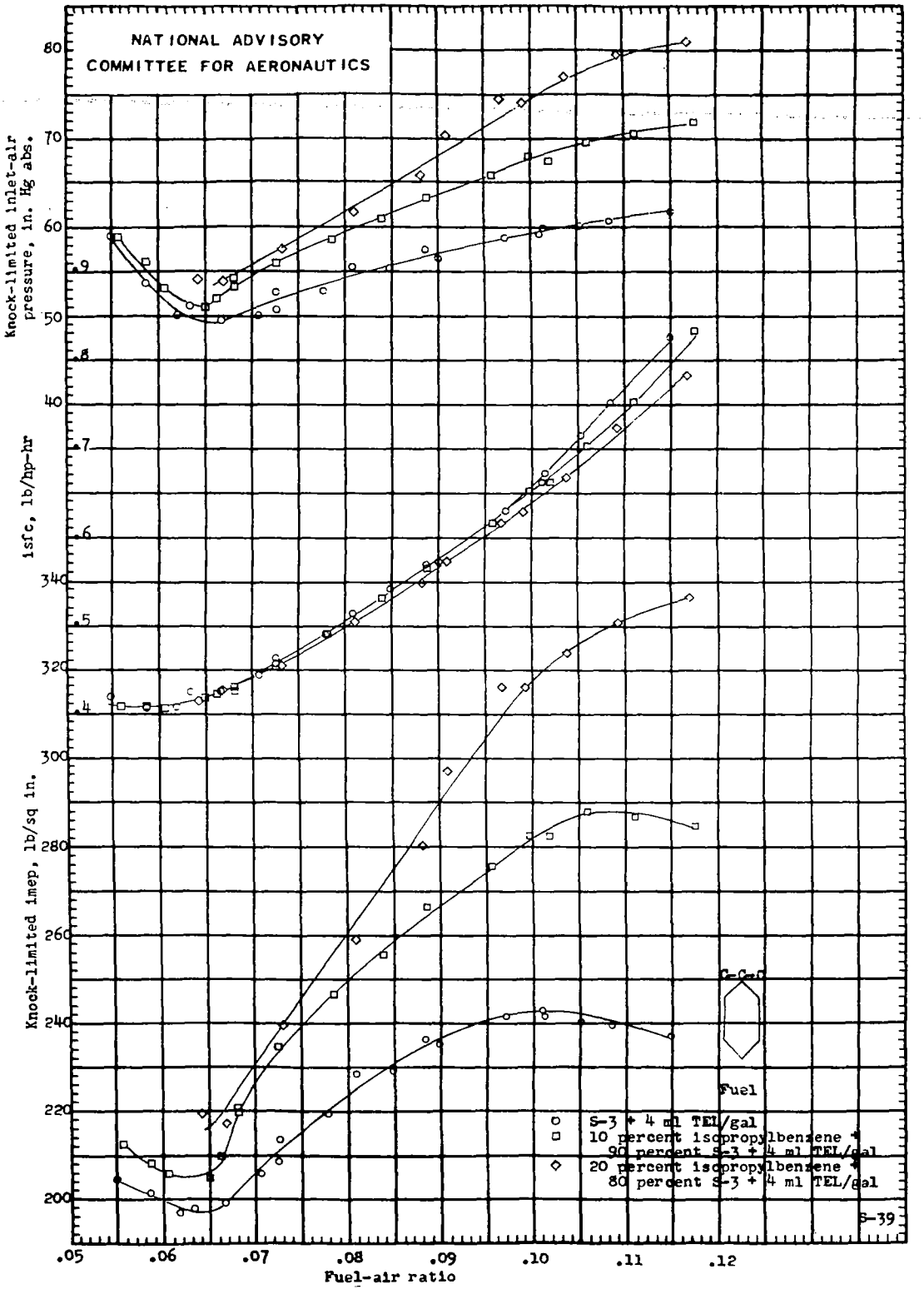


(a) Inlet-air temperature, 250° F.

Figure 8. - Knock-limited performance of blends of isopropylbenzene 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.

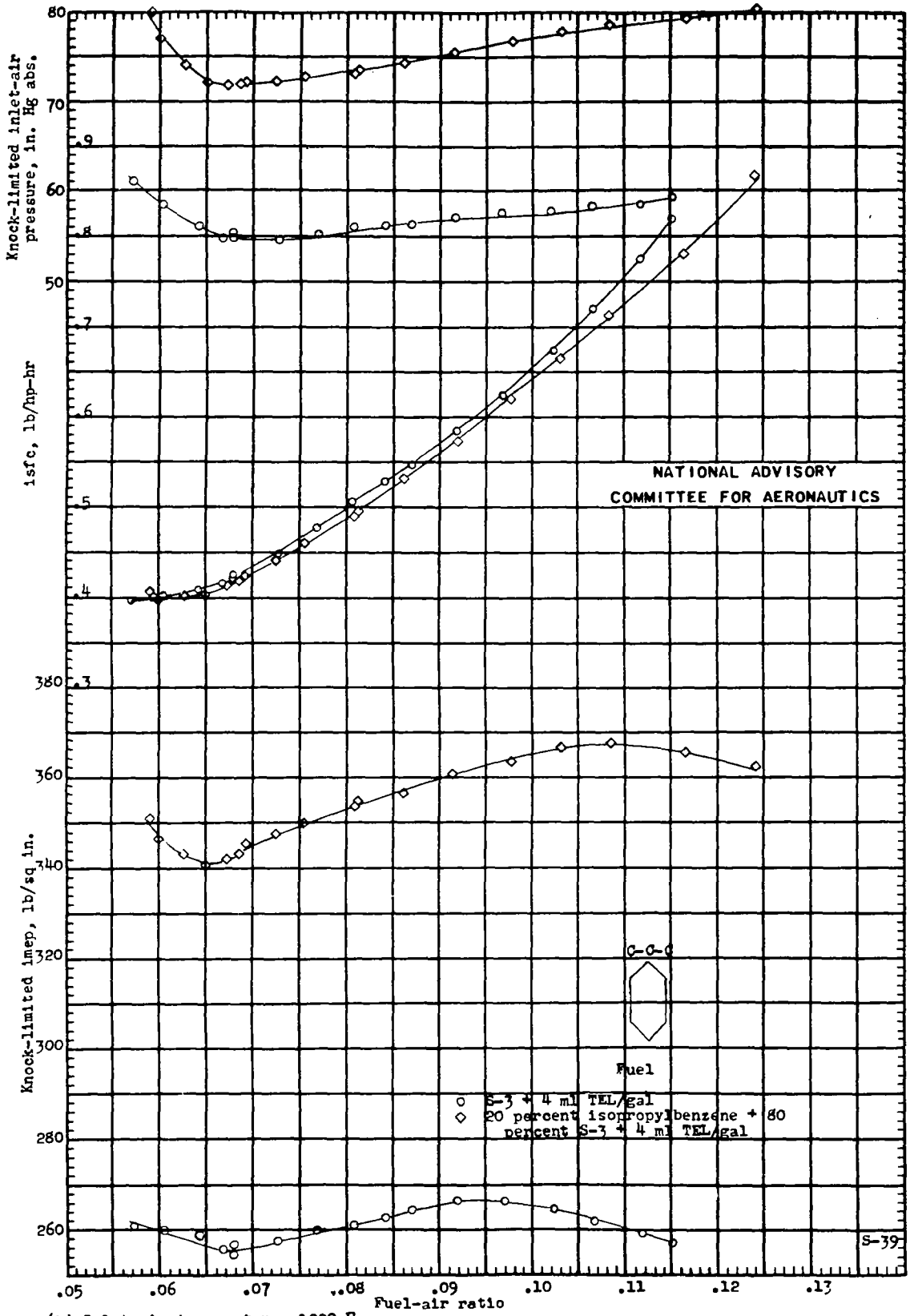


(b) Inlet-air temperature, 100° F.
Figure 8. - Concluded.



(a) Inlet-air temperature, 250° F.

Figure 9. - Knock-limited performance of blends of isopropylbenzene 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 9. - Concluded.

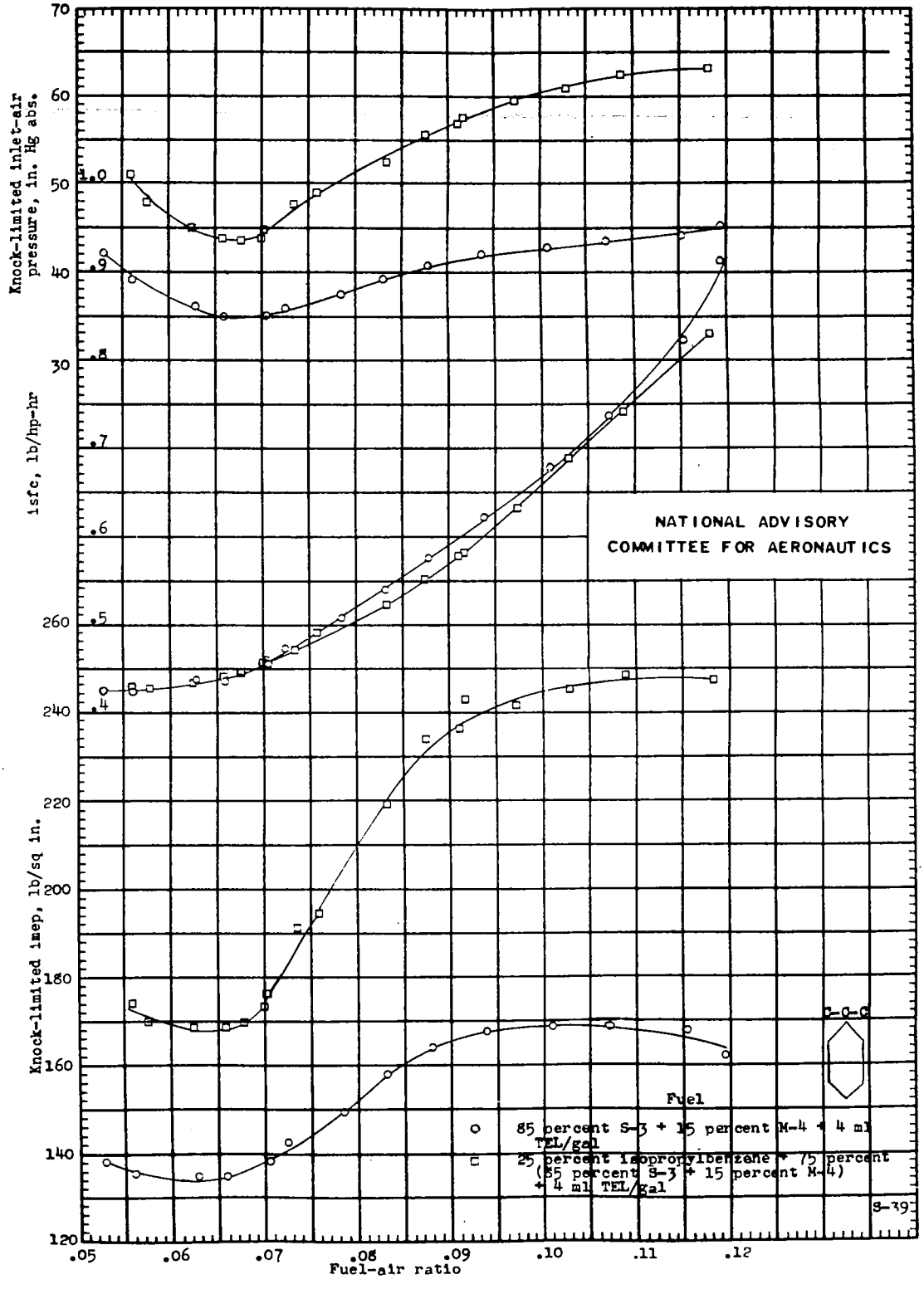
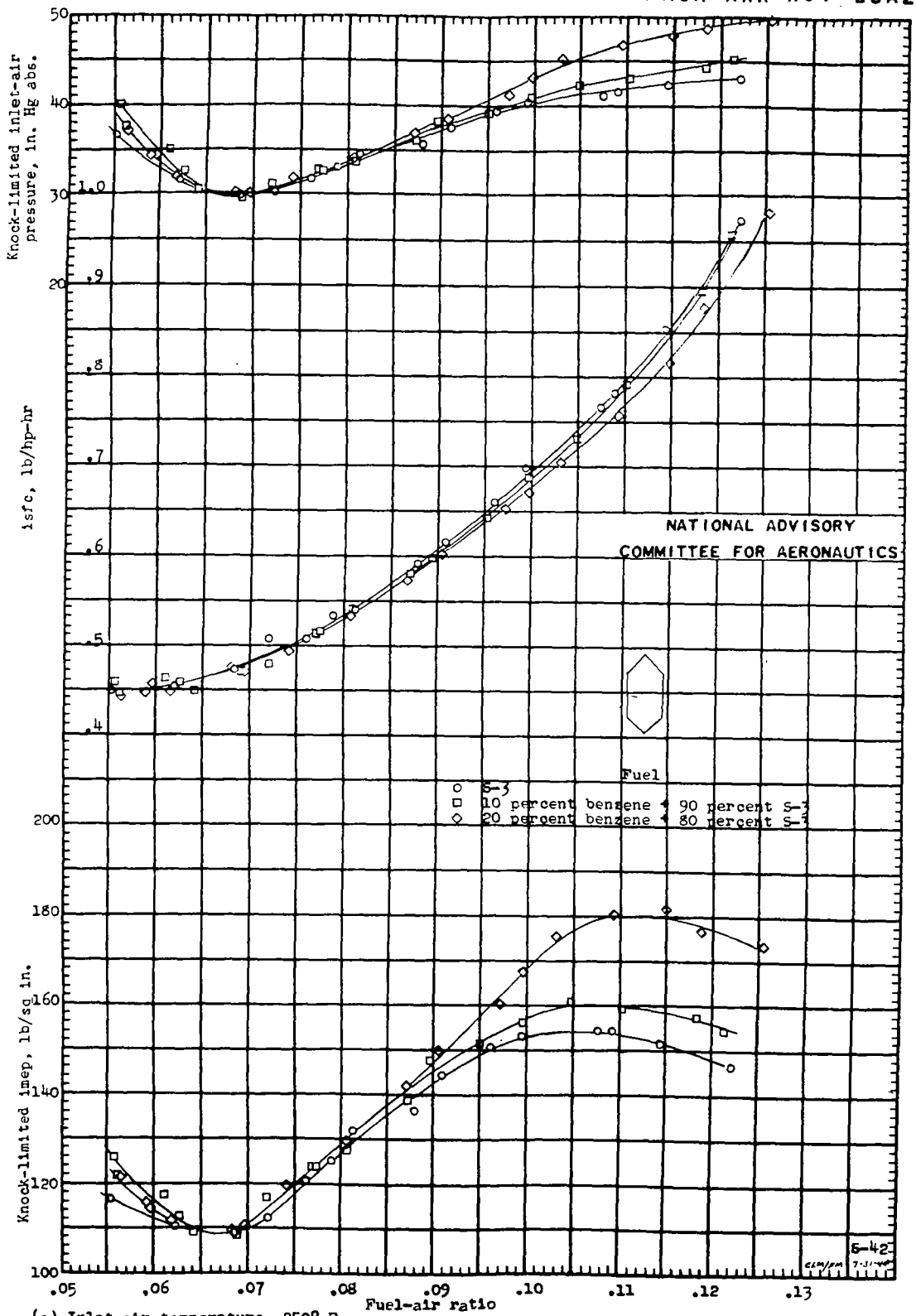
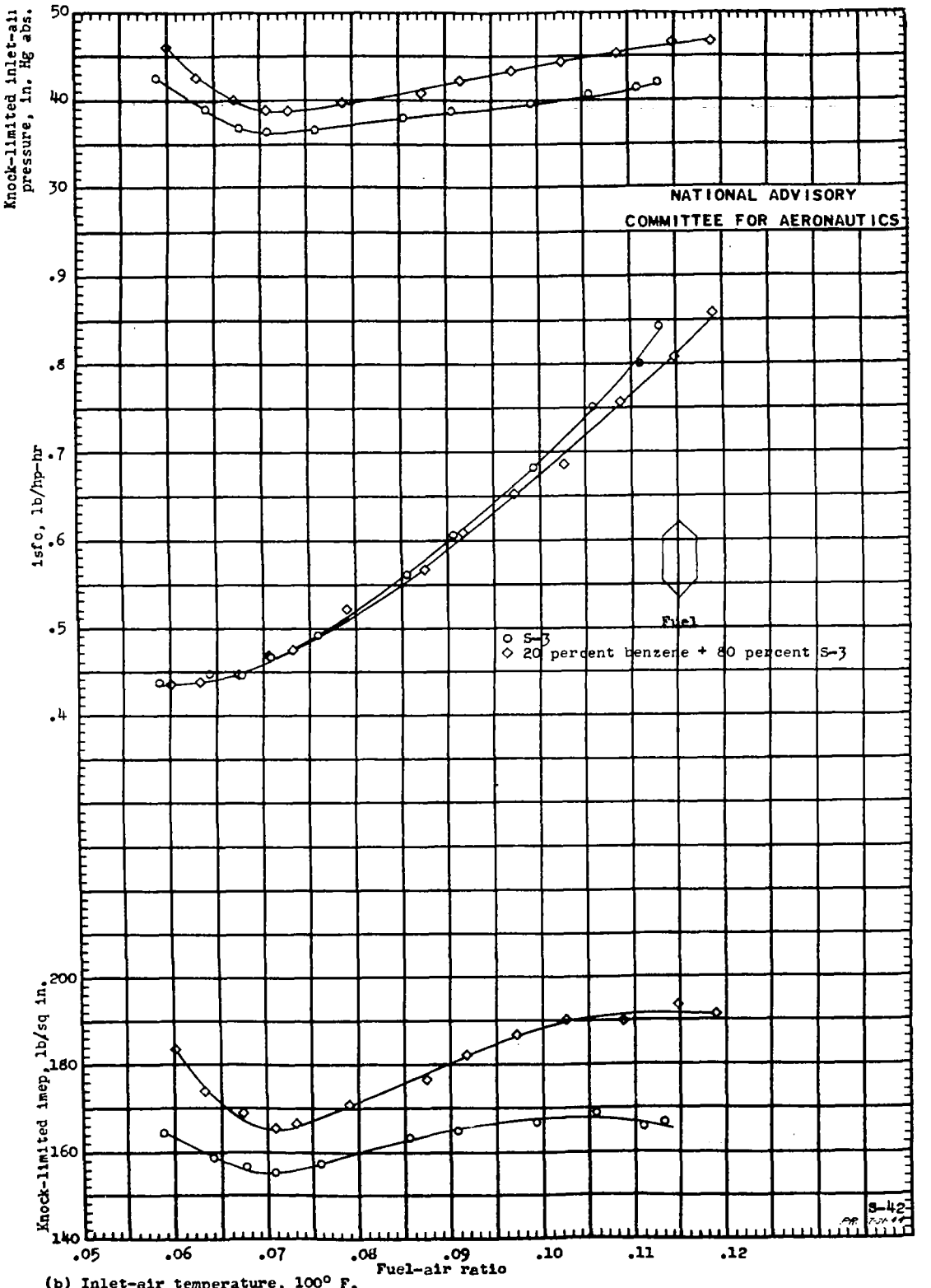


Figure 10. - Knock-limited performance of blends of isopropylbenzene and 85 percent S-3 plus 15 percent M-4 plus 4 ml TEL per gallon. 17.6 engine; compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; outlet-coolant temperature, 212° F; inlet-air temperature, 250° F.

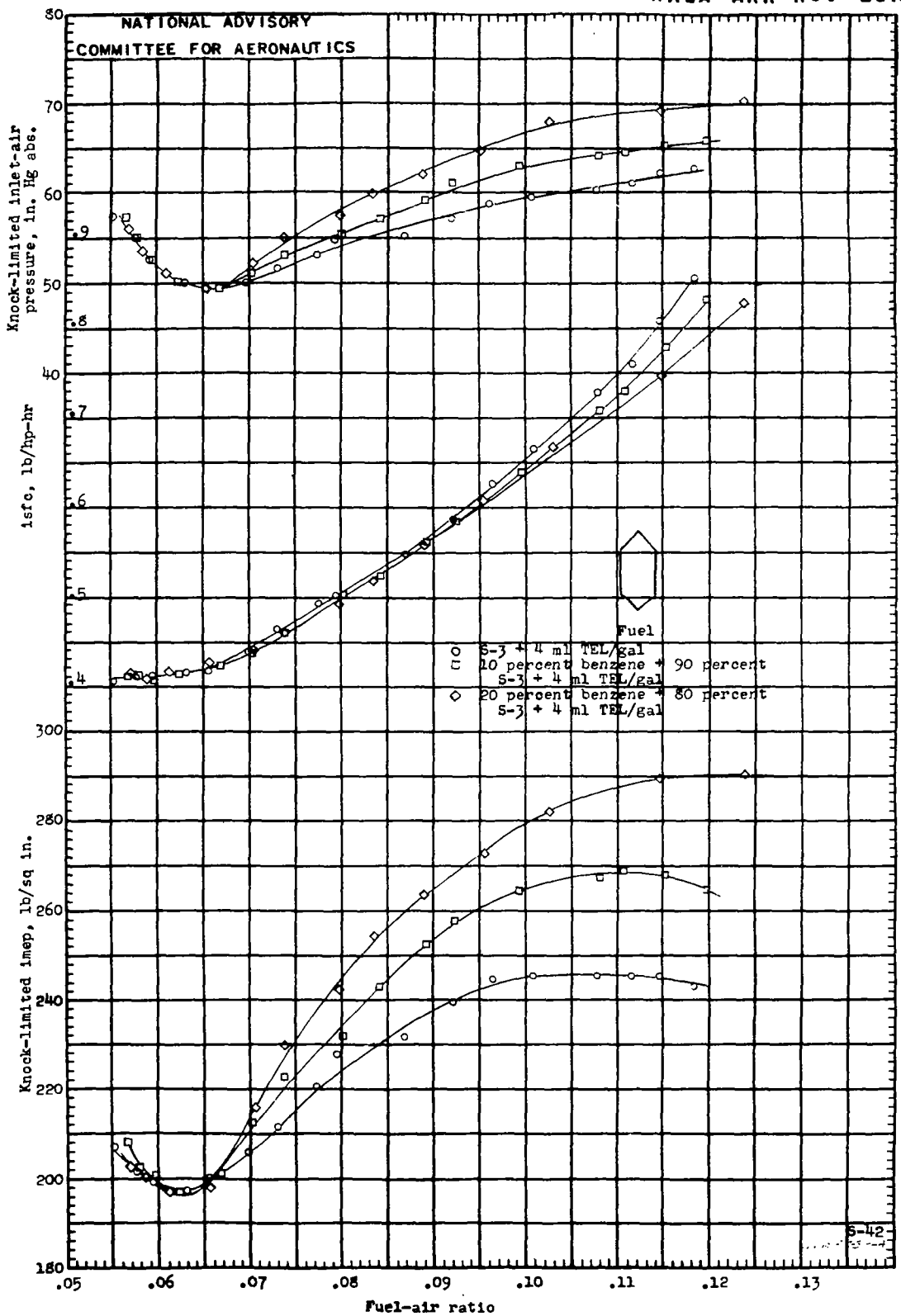


(a) Inlet-air temperature, 250° F.

Figure 11. - Knock-limited performance of blends of benzene 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.

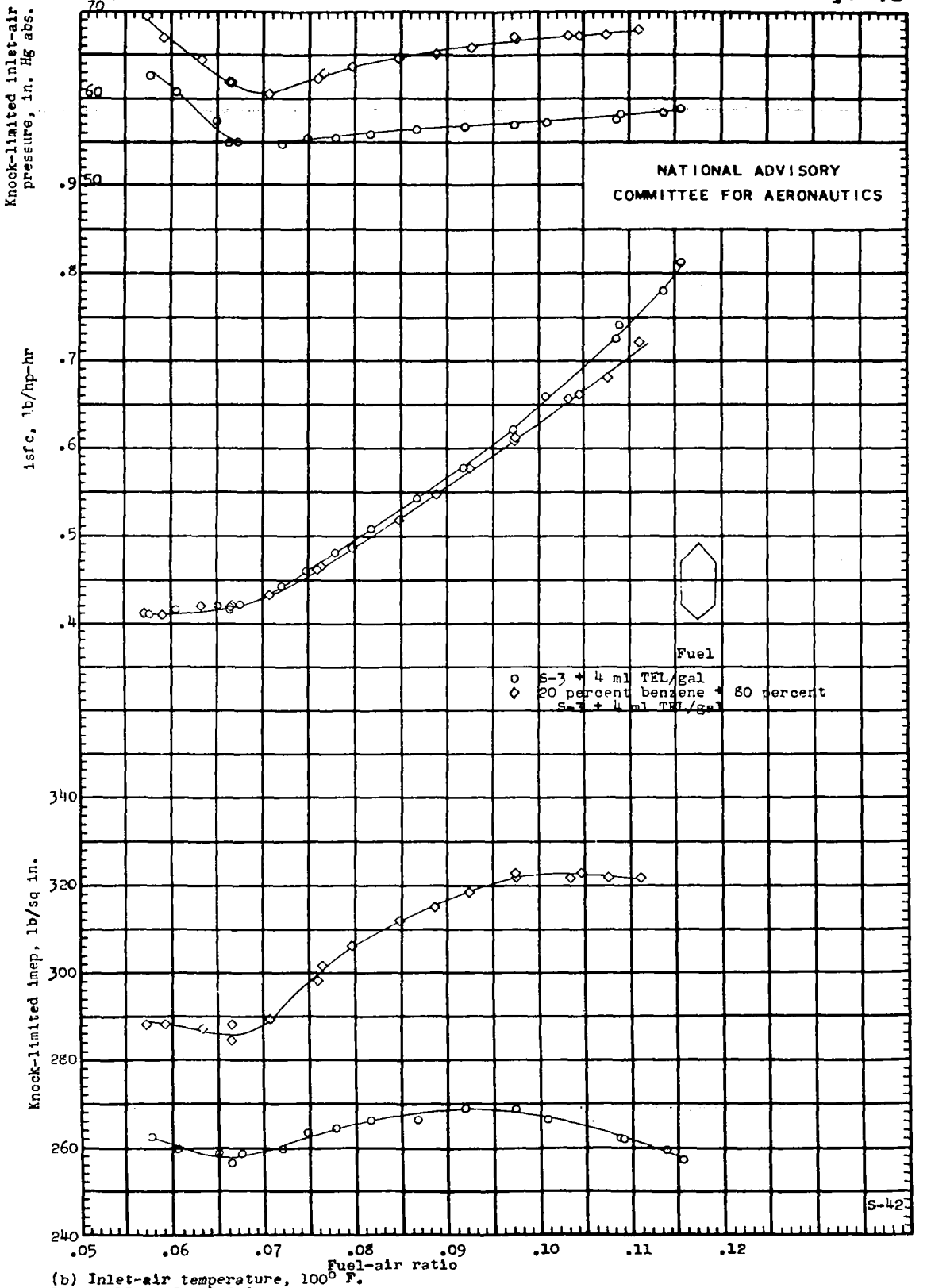


(b) Inlet-air temperature, 100° F.
Figure 11. - Concluded.

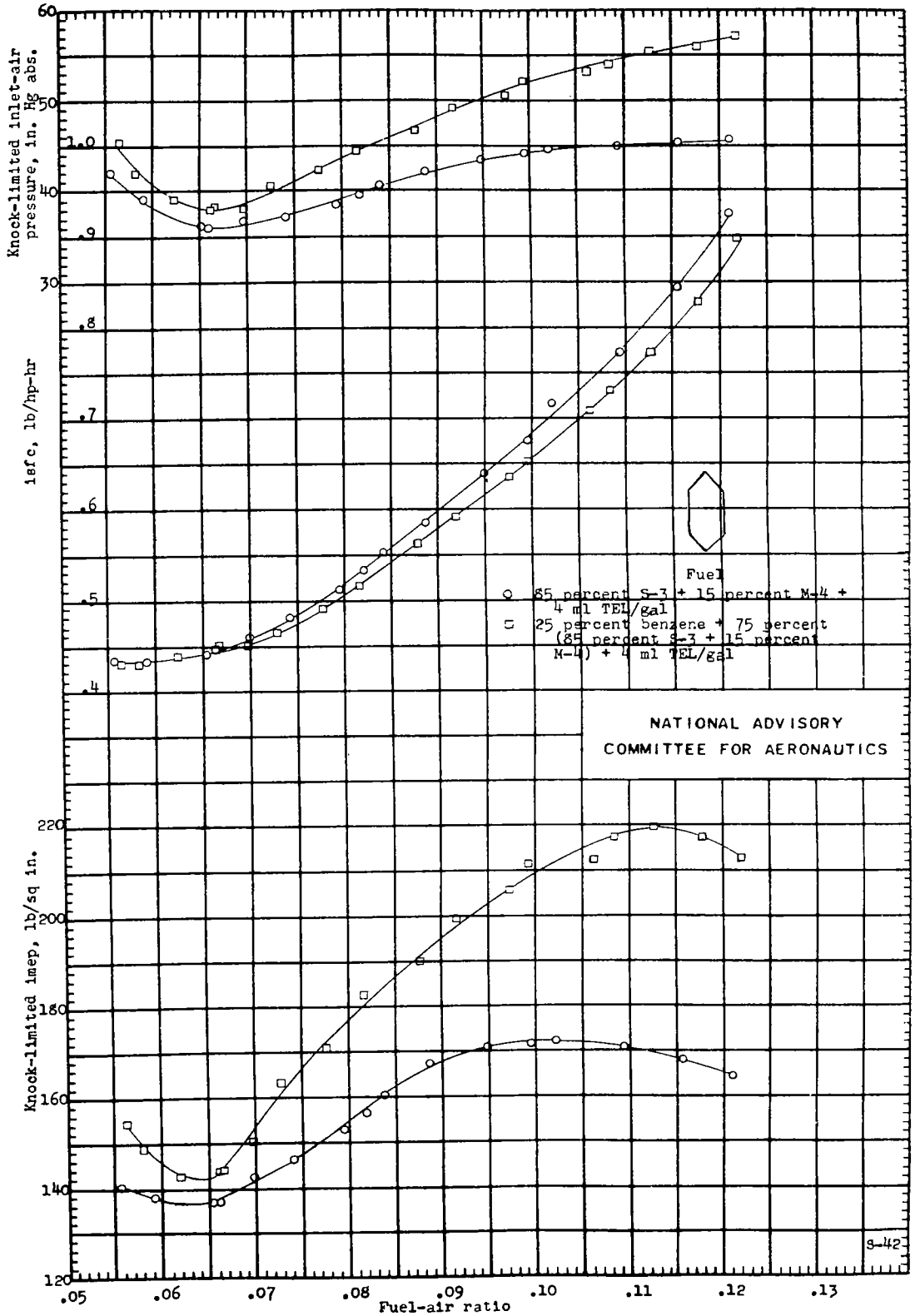


(a) Inlet-air temperature, 250° F.

Figure 12. - Knock-limited performance of blends of benzene 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.

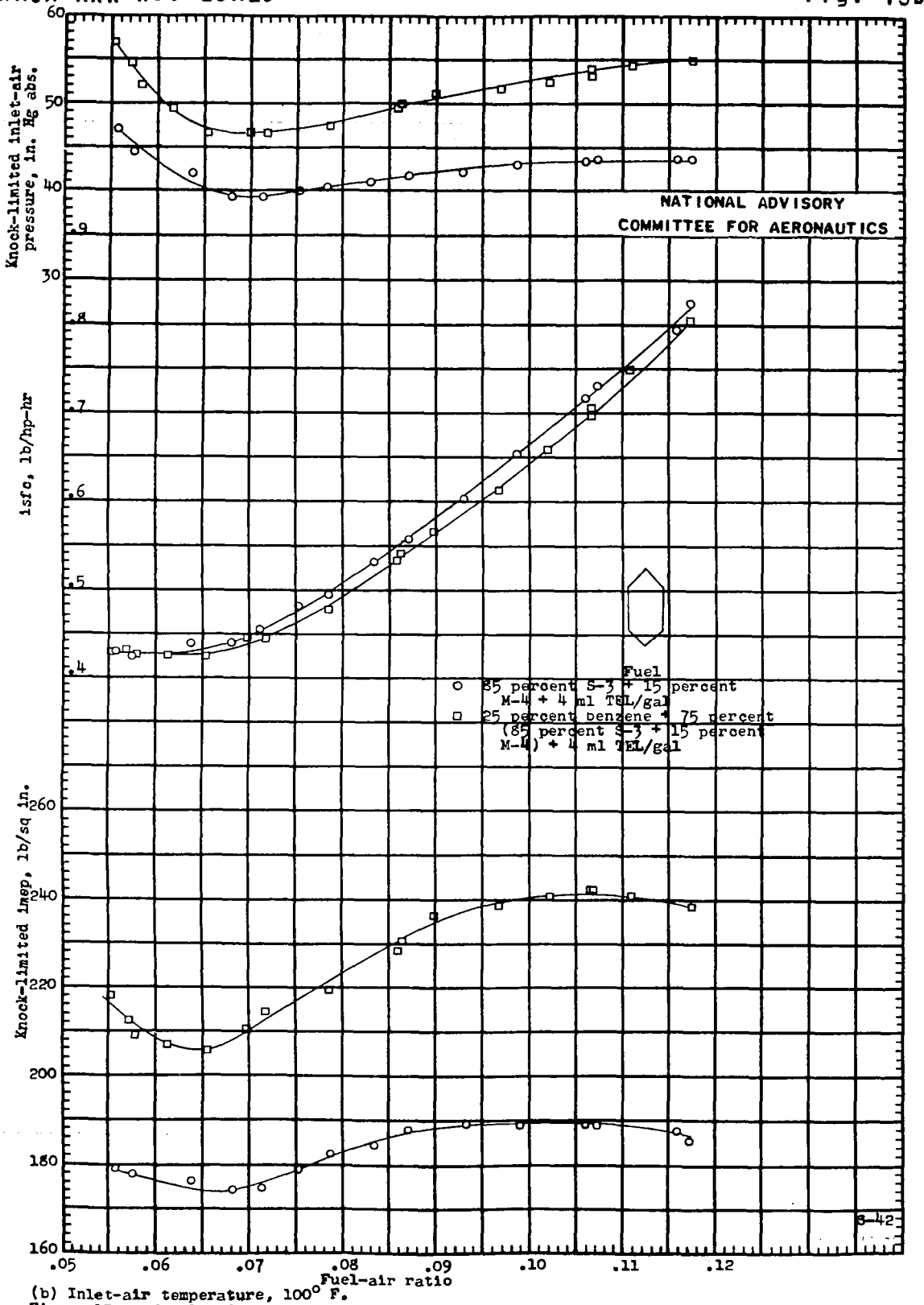


(b) Inlet-air temperature, 100° F.
Figure 12. - Concluded.

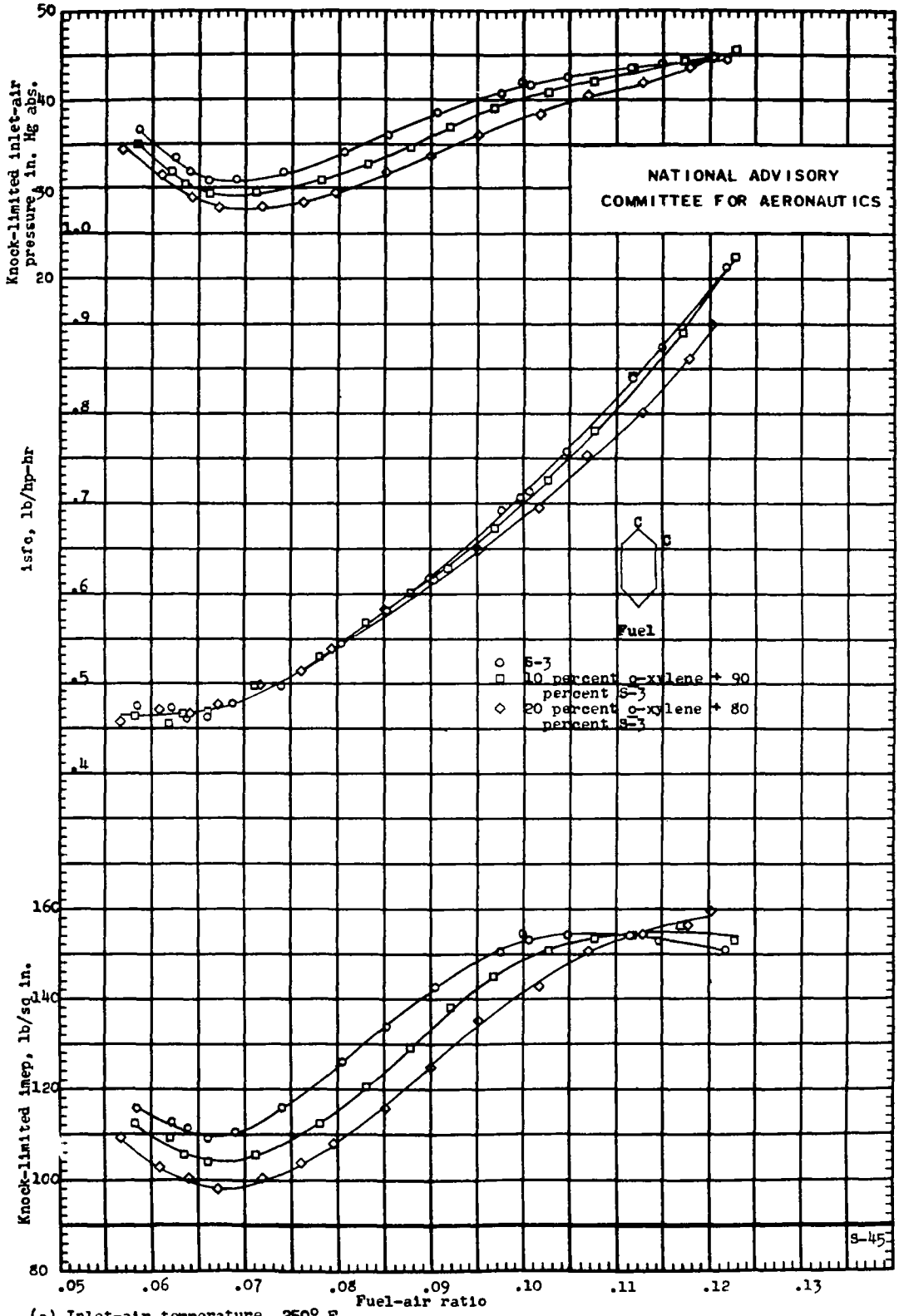


(a) Inlet-air temperature, 250° F.

Figure 13. - Knock-limited performance of blends of benzene 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.

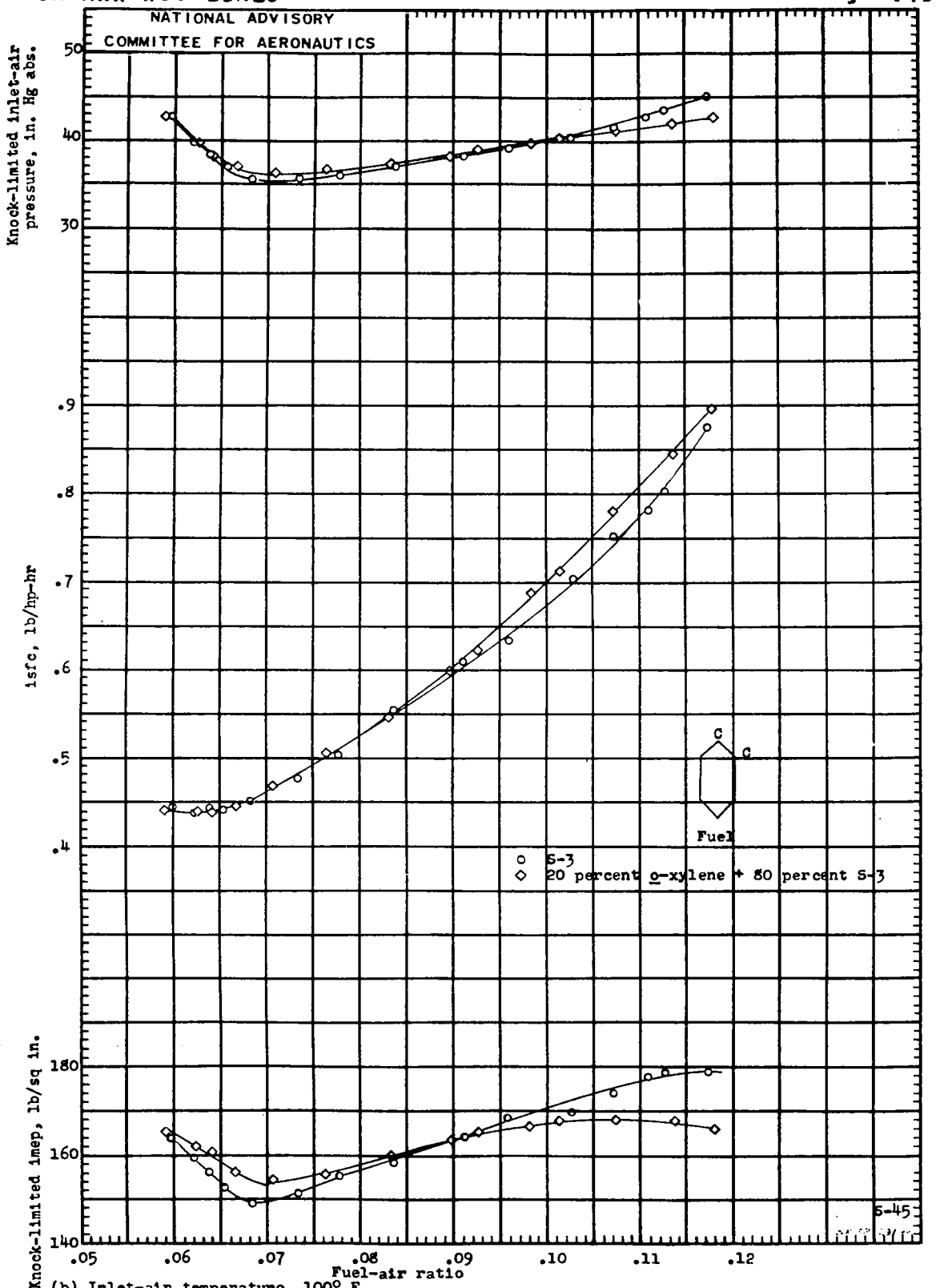


(b) Inlet-air temperature, 100° F.
Figure 13. - Concluded.

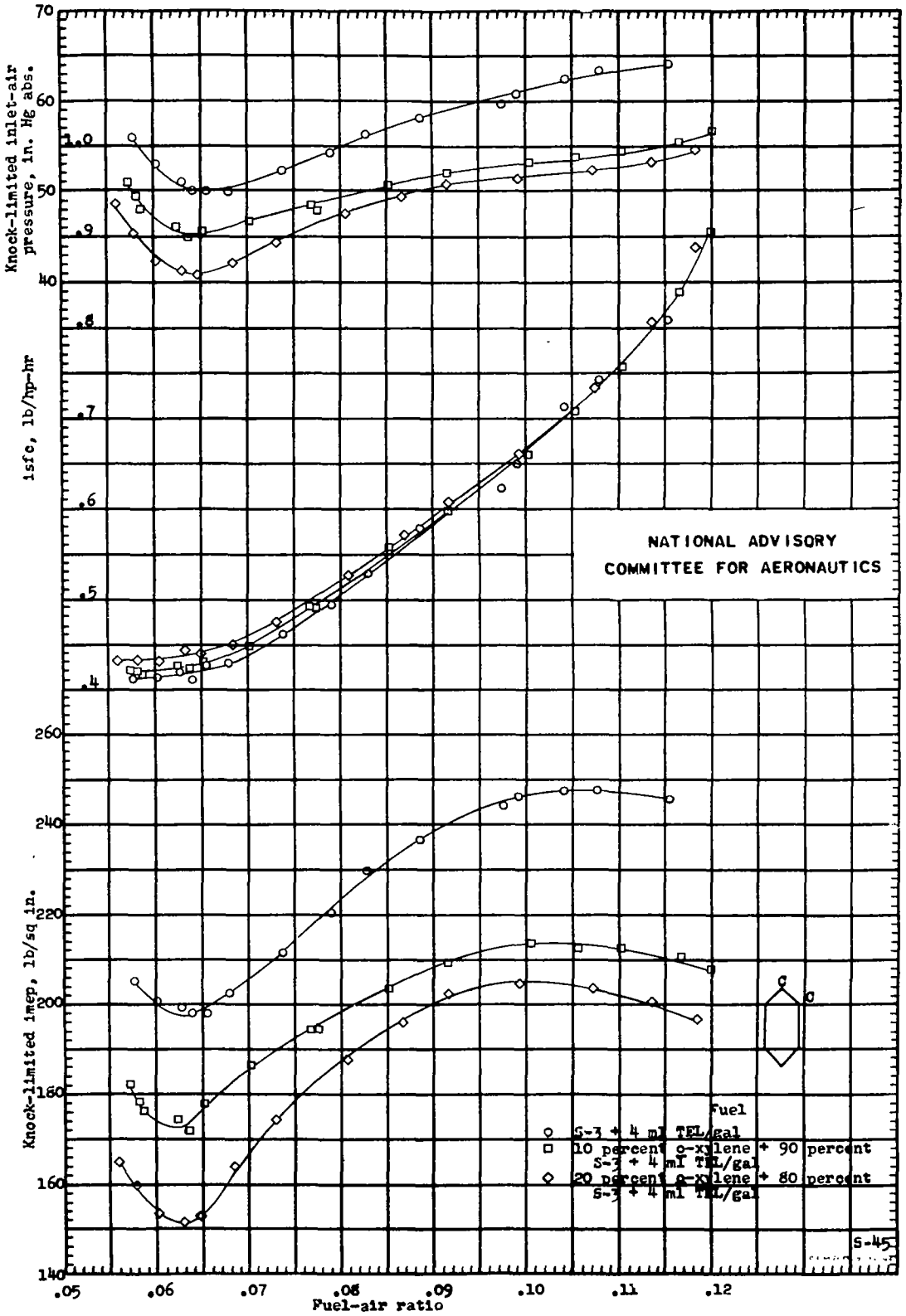


(a) Inlet-air temperature, 250° F.

Figure 14.- Knock-limited performance of blends of o-xylene 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.

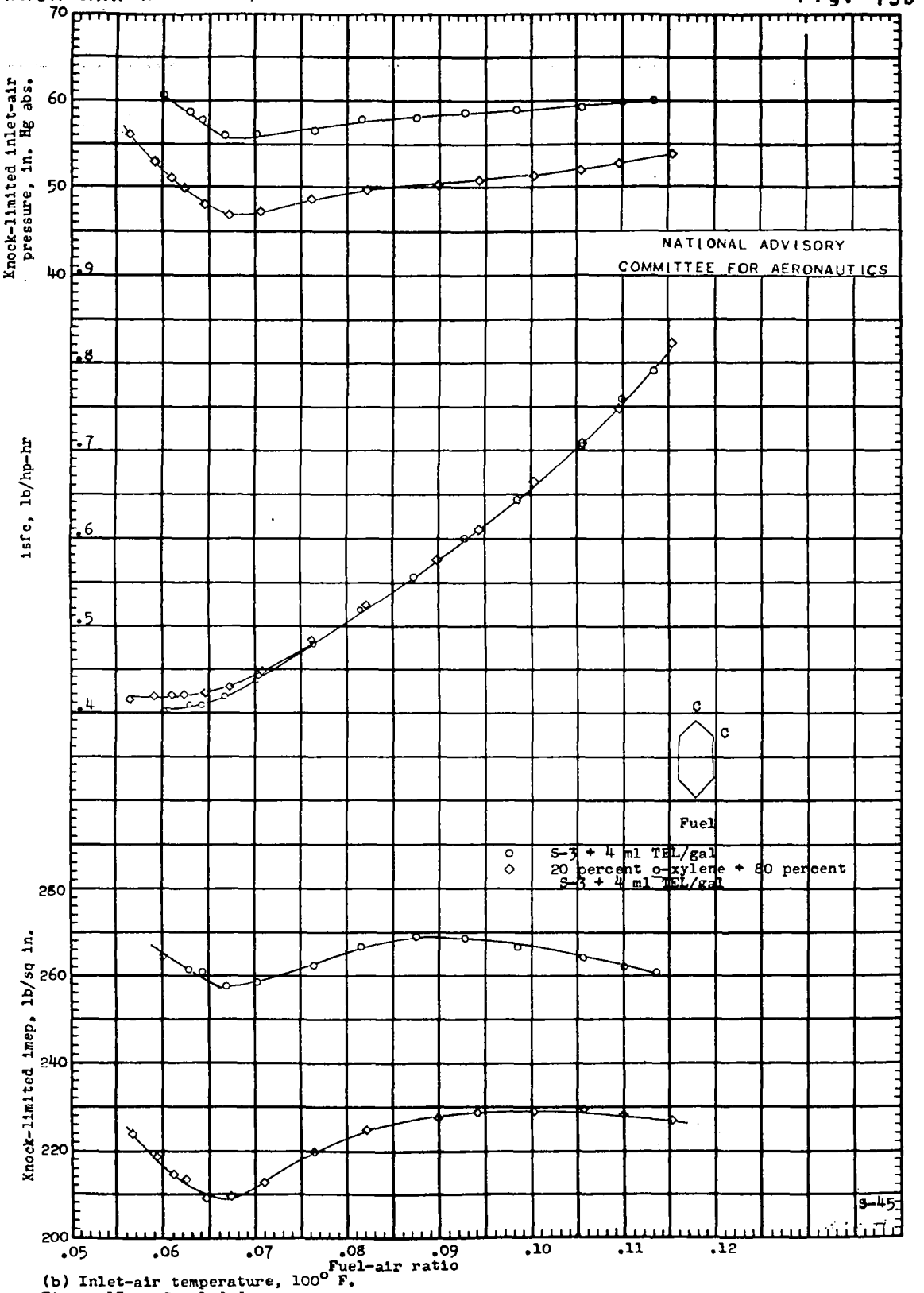


(b) Inlet-air temperature, 100° F.
Figure 14. - Concluded.



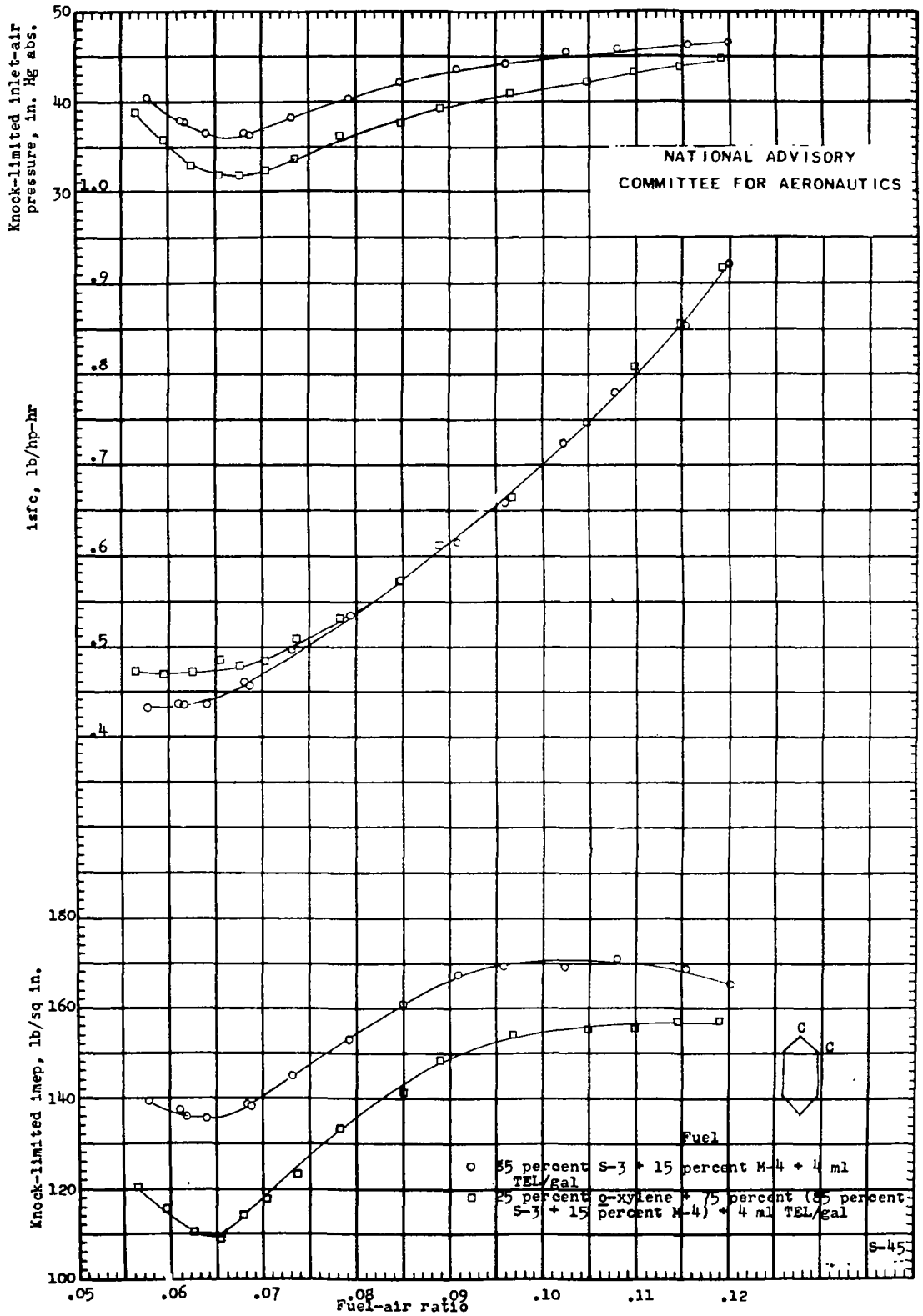
(a) Inlet-air temperature, 250° F.

Figure 15. - Knock-limited performance of blends of o-xylene 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.



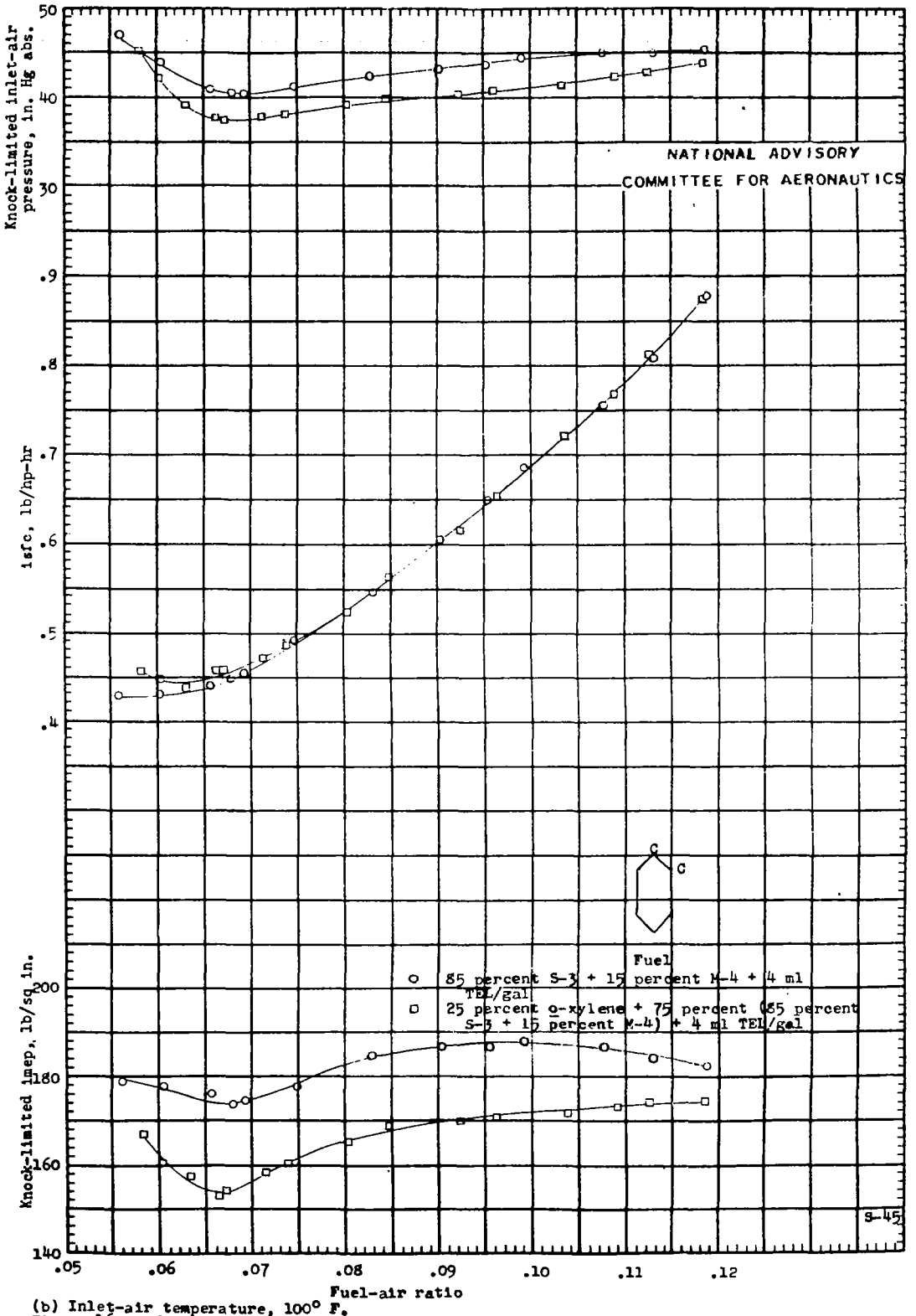
(b) Inlet-air temperature, 100° F.

Figure 15. - Concluded.



(a) Inlet-air temperature, 250° F.

Figure 16. - Knock-limited performance of blends of o-xylene 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.

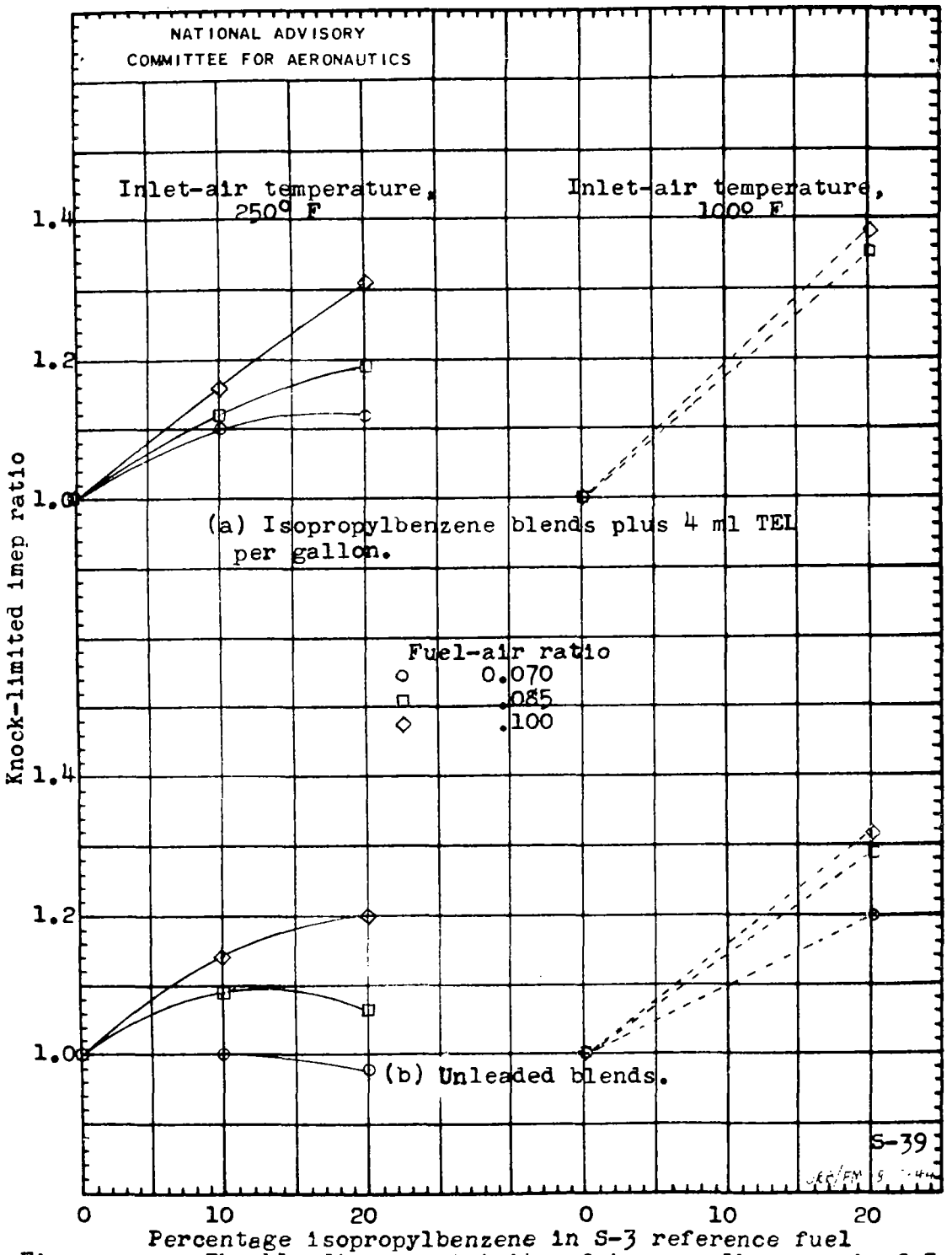


Figure 17. - The blending sensitivity of isopropylbenzene in S-3 reference fuel. 17.6 engine.

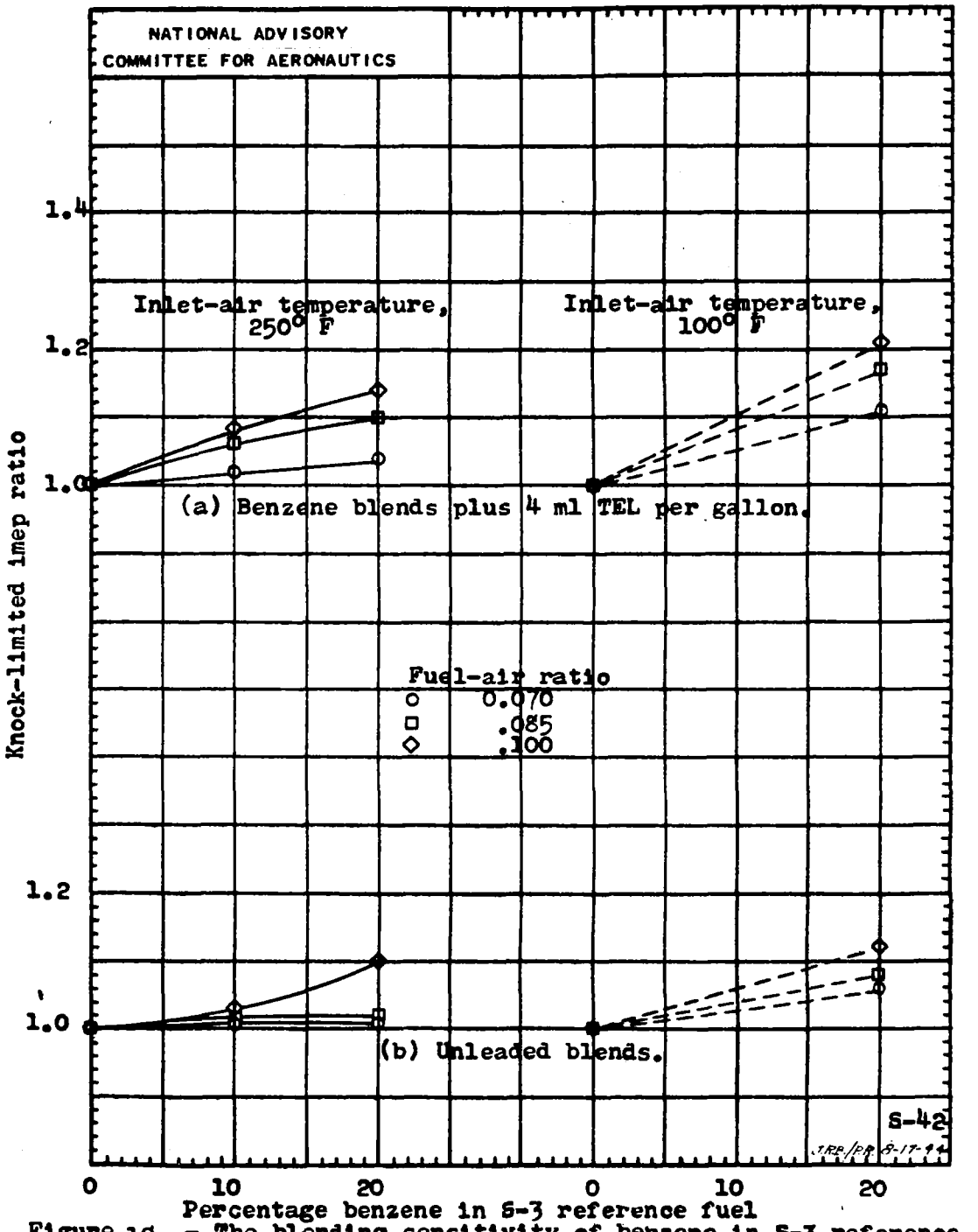


Figure 18. - The blending sensitivity of benzene in S-3 reference fuel. 17.6 engine.

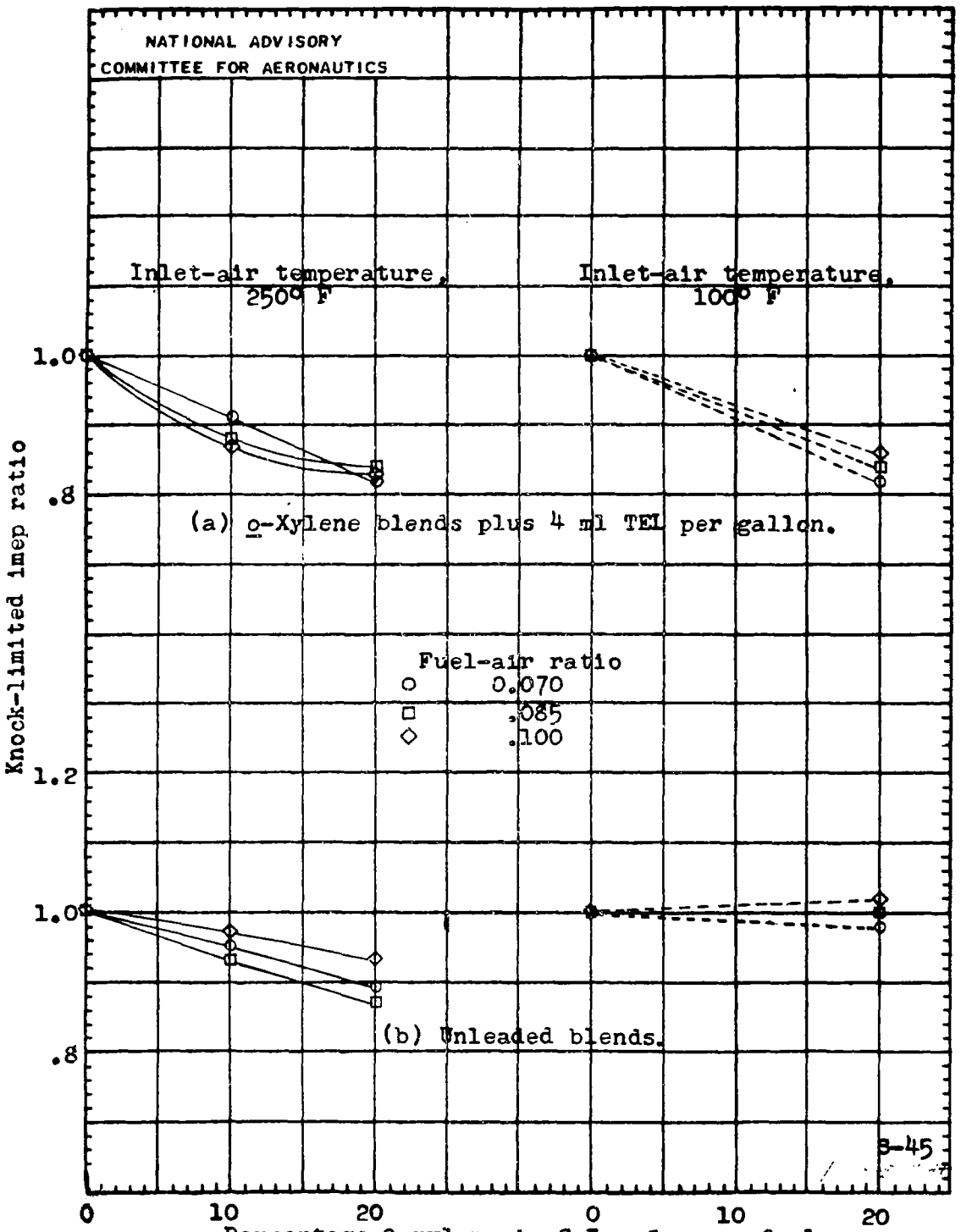


Figure 19. - The blending sensitivity of o-xylene in S-3 reference fuel. 17.6 engine.

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ABSTRACT

Knock-limited tests were made of isopropylbenzene, benzene, and O-xylene blended individually with base fuels. Data were obtained for the aromatics to determine the blending sensitivity, the lead susceptibility, and sensitivity of the blends to inlet—air temperature. Of the three aromatics tested. isopropylbenzene was, in general, more effective than benzene as an antiknock agent whereas O-xylene acted as a proknock agent under nearly all conditions tested. Published full-scale-cylinder data for the aromatics are presented for comparative purposes.

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Signature and Grade

Date APR 22 1949

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Knocking

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