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F-3 AND F-4 ENGINE TESTS OF SEVERAL HIGH-ANTIKNOCK COMPONENTS OF AVIATION FUEL

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and Russell S. Genco

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NACA

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

F-3 AND F-4 ENGINE TESTS OF SEVERAL HIGH-ANTIKNOCK COMPONENTS OF AVIATION FUEL

By Harry S. Imming, Henry C. Barnett, and Russell S. Genco

SUMMARY

Knock-limited performance data for various fuels were obtained in F-3 and F-4 engines at standard operating conditions. Triptane, hot-acid octane, diisopropyl, neohexane, mixed xylenes, cumene, benzene, toluene, and methyl tert-butyl ether were investigated in 0- to 100-percent blends with virgin base stock, aviation alkylate, and one-pass catalytic stock; isopentane in 0- to 60-percent blends with virgin base stock and in 0- to 40-percent blends with aviation alkylate and one-pass catalytic stock was also investigated. All fuels and blends were leaded to 4 ml TEL per gallon.

Laboratory inspection data were obtained for all pure fuel stocks and blends.

Results of the F-3 engine study indicated that methyl tert-butyl ether, neohexane, triptane, and diisopropyl were the most satisfactory blending agents for increasing the lean-mixture knock-limited performance. Results of the F-4 engine study indicated that methyl tert-butyl ether and toluene were the most satisfactory blending agents for increasing the rich-mixture knock-limited performance.

INTRODUCTION

An investigation is being conducted at the Cleveland laboratory of the NACA in order to evaluate the advantages in knock-limited engine performance to be gained by the use of high-antiknock compounds as components of aviation fuel. As part of the program, binary blends of 10 compounds blended with each of three base fuels were tested in F-3 and F-4 rating engines. These compounds, the base fuels, and the blend concentrations are listed in the following table:

Component[1]	Percentage in base fuel		
	Virgin base stock	Aviation Alkylate	One-pass catalytic stock
Triptane (2,2,3-trimethylbutane) Hot-acid octane	0,20,40, 60,100	0,20,40,60, 80,100	0,20,40,60, 80,100
Isopentane (2-methylbutane)	0,20, 40,60	0,20,40	0,20,40
Diisopropyl (2,3-dimethylbutane) Neohexane (2,2-dimethylbutane) Mixed xylenes Cumene (isopropylbenzene) Benzene Toluene (methylbenzene) Methyl tert-butyl ether	0,20,40 60,80,100	0,20,40,60, 80,100	0,20,40,60, 80,100

[1]All blends and pure fuel stocks were leaded to 4 ml TEL/gal.

The fuel base stocks and high-performance compounds were obtained through the Army Air Forces, Air Technical Service Command.

The purpose of the present report is to summarize in the form of tables and figures the F-3 and F-4 performance data and the laboratory inspection data for all of the blends tested.

APPARATUS AND TEST PROCEDURE

The blends and blending agents were tested in F-3 and F-4 rating engines (CRC designations F-3-544 and F-4-443). The F-3 engine was provided with a barometrically controlled dry-air supply instead of the dehydrating ice tower. The F-4 engine was installed with a 1063600 piston instead of a 1063606 piston and was provided with a cathode-ray oscilloscope in conjunction with a magnetostriction pickup unit for detecting knock. In the F-4 engine tests, the fuel-air ratio was enriched from 0.055 to a value past that at which maximum knock-limited indicated mean effective pressure was obtained unless the limit of fuel flow was reached or the test fuel preignited.

Because of the numerous fuel blends tested, the F-4 ratings were estimated from a reference-fuel framework (fig. 1). All of the F-4 performance ratings for the fuels were estimated from the reference-fuel framework in figure 1 with the exception of the ratings for the three base fuels, which were obtained by standard F-4 procedure and are superimposed on figure 1.

TEST RESULTS

Laboratory inspection data obtained for all pure fuel stocks and for all blends are presented in table I. Table II lists the F-3 and knock-limited F-4 performance ratings for the fuels tested. Performance numbers are given for all values below 161. Performance numbers between 161 and 200 were estimated by multiplying the performance number of S-3 reference fuel plus 6 ml TEL per gallon by the ratio of the knock-limited indicated mean effective pressure of the test fuel to the knock-limited indicated mean effective pressure of S-3 reference fuel plus 6 ml TEL per gallon.

Figure 2 shows the day-to-day variation of the F-4 engine. Figures 3 to 12 present the knock-limited performance data for binary blends of the 10 high-antiknock compounds with each of the three base fuels. With the exception of the data for fuels and fuel blends shown in figures 3(a) and (b); 5(a), (b), and (c); 6(a) and (b); 9(a); and 11(a), each group of tests of an antiknock component and one base fuel were made on a single operating day.

The data presented in figure 2 allow an estimate of the reproducibility of the F-4 rating engine. For each of the three base fuels, the average indicated mean effective pressure, the arithmetical mean deviation from the average indicated mean effective pressure, and the ratio of arithmetical mean deviation to average indicated mean effective pressure (expressed as percentage) have been calculated. The results are summarized in table III. A curve (fig.13) faired through the weighted averages of the percentage mean deviations of the three base fuels shows that knock-limited performance tests in an F-4 engine are considerably less reproducible at low fuel-air ratios than at high ratios.

Testing of each of the aromatics (mixed xylenes, cumene, benzene, and toluene, data presented in figs. 8 to 11) in the F-4 engine caused severe burning of the second piston land and excessive ring wear. The following table indicates the ring wear that resulted from aromatic blending agents as compared with the wear that resulted from paraffinic blending agents:

Engine running time (hr)	Blending agent tested	Ring-gap clearance (in.)				
		Compression rings			Oil rings	
		Top	Center	Bottom	Top	Bottom
[a]0	----------	0.020	0.020	0.020	0.018	0.018
150	Paraffins	.042	.045	.078	.035	.050
70	Mixed xylenes	.100	.118	.121	.058	.066
80	Methyl tert-butyl ether and benzene	.100	.153	.189	.072	.057
54	Toluene	.125	.132	.161	.078	.074

[a]Maximum ring-gap clearances specified for F-4 rating engine.

SUMMARY OF RESULTS

Results of knock-limited performance tests of binary blends of 10 high-antiknock compounds with each of three base fuels in F-3 and F-4 rating engines are summarized as follows:

1. Tests by the F-3 rating method indicated that methyl tert-butyl ether, neohexane, triptane, and diisopropyl were the most satisfactory blending agents for increasing the lean-mixture knock-limited performance.

2. Tests by the F-4 rating method indicated that methyl tert-butyl ether and toluene were the most satisfactory blending agents for increasing the rich-mixture knock-limited performance.

3. Inspection tests indicate that all blending agents examined can be used in aviation-fuel blends without digression from present Army-Navy fuel specifications. The concentrations in which any given blending agent can be used will necessarily be determined by specific properties such as heat of combustion, freezing point, and volatility. Mixed xylenes, cumene, benzene, toluene, and methyl tert-butyl ether had low heats of combustion; triptane, mixed xylenes, and benzene had high freezing points; isopentane, neohexane, methyl tert-butyl ether, and diisopropyl had high Reid vapor pressures.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, November 27, 1944.

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

TABLE I - INSPECTION DATA FOR PURE

[The following abbreviations are used throughout the table: one-pass stock for one-pass catalytic stock;

Fuel	Fuel composition		A.S.T.M. distillation data								
	Components	TEL concentration (ml/gal)	Initial boiling point (°F)	10% point (°F)	40% point (°F)	50% point (°F)	90% point (°F)	Final boiling point (°F)	Sum of 10 and 50% points (°F)	Residue (percent)	Loss (percent)
A-202	VBS	0	114	145	172	180	229	298	325	0.4	1.1
A-118	50% alkylate + 50% VBS	4.04	112	150	188	200	254	336	350	0.7	1.1
A-203	Alkylate	0	113	160	215	226	272	364	386	.5	1.0
A-132	30% one-pass stock + 70% VBS	4.08	112	140	170	182	251	319	322	0.5	1.3
A-116	50% one-pass stock + 50% VBS	4.06	103	134	170	184	269	321	318	.5	1.0
A-119	80% one-pass stock + 20% VBS	4.05	116	130	171	190	285	326	320	.4	1.4
A-122	30% one-pass stock + 70% alkylate	3.96	110	147	202	218	272	345	365	0.6	1.2
A-117	50% one-pass stock + 50% alkylate	4.00	105	140	194	213	280	341	353	.5	1.0
A-121	80% one-pass stock + 20% alkylate	4.04	106	131	181	204	288	334	335	.7	1.3
A-204	One-pass stock	0	105	128	170	193	287	332	321	.5	1.0
A-136	20% triptane + 80% VBS	4.10	124	150	172	178	218	299	328	0.7	0.8
A-137	40% triptane + 60% VBS	4.05	128	156	172	177	205	287	333	.6	.6
A-138	60% triptane + 40% VBS	4.08	142	162	174	176	194	274	338	.7	.5
A-272	20% triptane + 80% alkylate	(d)	122	164	202	210	259	346	374	0.9	0.6
A-273	40% triptane + 60% alkylate	(d)	130	167	192	198	251	335	365	.7	.8
A-274	60% triptane + 40% alkylate	(d)	144	169	183	188	230	326	357	.8	.7
A-275	80% triptane 20% alkylate	(d)	158	172	178	180	202	296	352	.8	.2
A-276	20% triptane + 80% one-pass stock	(d)	107	136	172	186	281	321	322	0.4	1.4
A-277	40% triptane + 60% one-pass stock	(d)	120	147	174	183	275	320	330	.9	.9
A-278	60% triptane + 40% one-pass stock	(d)	128	156	174	179	234	316	335	.4	.6
A-279	80% triptane + 20% one-pass stock	(d)	141	166	177	179	196	304	345	.5	.5
A-206	Triptane	0	172	174	174	174	175	180	348	.4	.8
A-397	20% diisopropyl + 80% VBS	(d)	120	143	160	168	224	287	311	0.9	0.8
A-398	40% diisopropyl + 60% VBS	(d)	123	138	151	156	214	285	294	.7	1.5
A-399	60% diisopropyl + 40% VBS	(d)	128	138	146	148	197	258	286	.9	1.1
A-400	80% diisopropyl + 20% VBS	(d)	130	136	140	142	165	254	278	.7	1.0
A-405	20% diisopropyl + 80% alkylate	(d)	120	151	187	202	263	344	353	1.1	0.7
A-406	40% diisopropyl + 60% alkylate	(d)	120	140	155	162	252	330	302	1.2	.3
A-407	60% diisopropyl + 40% alkylate	(d)	127	140	150	156	246	322	296	1.1	.6
A-408	80% diisopropyl + 20% alkylate	(d)	130	136	141	143	208	295	279	1.0	.6
A-401	20% diisopropyl + 80% one-pass stock	(d)	112	132	157	172	287	322	304	0.5	1.5
A-402	40% diisopropyl + 60% one-pass stock	(d)	117	133	150	157	277	321	290	.8	.9
A-403	60% diisopropyl + 40% one-pass stock	(d)	121	133	143	147	257	315	280	.4	1.2
A-404	80% diisopropyl + 20% one-pass stock	(d)	127	134	138	140	169	305	274	.7	.7
A-433	Diisopropyl	0	132	134	135	135	135	136	269	None	1.2
A-411	20% neohexane + 80% VBS	(d)	118	138	157	165	227	289	303	0.9	0.9
A-412	40% neohexane + 60% VBS	(d)	118	133	145	151	219	285	284	.8	.9
A-413	60% neohexane + 40% VBS	(d)	113	127	135	138	201	266	265	.6	1.3
A-414	80% neohexane + 20% VBS	(d)	118	123	126	128	161	241	251	.9	1.1
A-415	20% neohexane + 80% alkylate	(d)	116	146	183	203	265	345	349	1.1	0.8
A-416	40% neohexane + 60% alkylate	(d)	117	134	157	169	257	332	303	1.2	.8
A-417	60% neohexane + 40% alkylate	(d)	116	125	136	142	247	322	267	1.1	1.1
A-418	80% neohexane + 20% alkylate	(d)	116	122	127	129	220	290	251	.9	1.4
A-420	20% neohexane + 80% one-pass stock	(d)	107	127	151	167	283	323	294	0.6	1.3
A-421	40% neohexane + 60% one-pass stock	(d)	110	125	140	148	275	318	273	.5	1.4
A-422	60% neohexane + 40% one-pass stock	(d)	112	121	130	134	259	313	255	.5	1.2
A-423	80% neohexane + 20% one-pass stock	(d)	116	120	125	126	181	302	246	.6	1.6
A-500	Neohexane	0	119	120	120	120	121	123	240	None	1.2
A-123	20% isopentane + 80% VBS	4.06	102	122	148	160	224	297	282	0.7	1.3
A-124	40% isopentane + 60% VBS	4.06	96	108	124	134	216	291	242	.7	2.8
A-134	60% isopentane + 40% VBS	4.16	90	98	106	110	200	266	208	.8	2.4
A-375	20% isopentane + 80% alkylate	(d)	104	127	175	208	262	344	335	0.9	2.0
A-376	40% isopentane + 60% alkylate	(d)	97	110	134	154	256	335	264	.7	1.4
A-388	20% isopentane + 80% one-pass stock	(d)	102	118	146	167	288	322	285	0.4	2.4
A-389	40% isopentane + 60% one-pass stock	(d)	96	106	121	129	278	318	235	.6	2.1
A-209	Isopentane	0	80	82	85	86	90	92	168	None	3.5

[a]Estimated by change in refractive index following adsorption on silica gel. Correction made for olefins.
[b]Calculated by using average molecular weight from distillation curve (Universal Oil Products Method H-173-40).

FUEL STOCKS AND FOR FUEL BLENDS

VBS for virgin base stock; alkylate for aviation alkylate; and MTB ether for methyl tert-butyl ether.]

Fuel	Specific gravity at 60° F	Copper-dish gum (mg/100 ml)	Reid vapor pressure (lb/sq in.)	Aromatics[a] (percent by volume)	Freezing point (°F)	Hydrogen-carbon ratio	Net heat of combustion (Btu/lb)	Refractive index n_D at 68° F	Bromine number (cg/g)	Olefins[b] (percent by weight)
A-202	0.713	None	5.9	7.3	Below -76	0.175	19,000	1.3988	2.8	1.7
A-118	0.707	-------	5.9	----------	---------	---------	--------	1.3957	-------	----------
A-203	.698	2	4.7	None	Below -76	0.189	19,100	1.3928	0.2	0.1
A-132	0.723	-------	6.0	----------	---------	---------	--------	1.4043	-------	----------
A-116	.727	-------	7.1	----------	---------	---------	--------	1.4080	-------	----------
A-119	.735	-------	7.4	----------	---------	---------	--------	1.4141	-------	----------
A-122	0.718	-------	5.8	----------	---------	---------	--------	1.4005	-------	----------
A-117	.721	-------	6.5	----------	---------	---------	--------	1.4051	-------	----------
A-121	.732	-------	7.2	----------	---------	---------	--------	1.4123	-------	----------
A-204	.739	-------	7.9	24.8	Below -76	0.155	18,700	1.4177	30.4	17.6
A-136	0.712	-------	6.0	----------	Below -76	---------	--------	1.3969	-------	----------
A-137	.707	-------	5.3	----------	Below -76	---------	--------	1.3953	-------	----------
A-138	.704	-------	4.5	----------	[c]Below -76	---------	--------	1.3938	-------	----------
A-272	0.701	-------	4.4	----------	Below -76	---------	--------	----------	-------	----------
A-273	.701	-------	4.1	----------	Below -76	---------	--------	----------	-------	----------
A-274	.700	-------	4.0	----------	Below -76	---------	--------	----------	-------	----------
A-275	.699	-------	3.6	----------	Below -76	---------	--------	----------	-------	----------
A-276	0.734	-------	6.7	----------	Below -76	---------	--------	----------	-------	----------
A-277	.725	-------	5.9	----------	Below -76	---------	--------	----------	-------	----------
A-278	.716	-------	5.1	----------	Below -76	---------	--------	----------	-------	----------
A-279	.710	-------	4.2	----------	Below -76	---------	--------	----------	-------	----------
A-206	.694	1	3.0	----------	-18	0.191	19,200	1.3896	-------	----------
A-397	0.705	-------	6.6	----------	---------	---------	--------	----------	-------	----------
A-398	.695	-------	5.8	----------	---------	---------	--------	----------	-------	----------
A-399	.686	-------	5.8	----------	---------	---------	--------	----------	-------	----------
A-400	.677	-------	7.0	----------	---------	---------	--------	----------	-------	----------
A-405	0.695	-------	5.5	----------	---------	---------	--------	----------	-------	----------
A-406	.687	-------	6.3	----------	---------	---------	--------	----------	-------	----------
A-407	.681	-------	6.4	----------	---------	---------	--------	----------	-------	----------
A-408	.675	-------	6.8	----------	---------	---------	--------	----------	-------	----------
A-401	0.728	-------	6.9	----------	---------	---------	--------	----------	-------	----------
A-402	.713	-------	7.1	----------	---------	---------	--------	----------	-------	----------
A-403	.698	-------	7.2	----------	---------	---------	--------	----------	-------	----------
A-404	.683	-------	7.3	----------	---------	---------	--------	----------	-------	----------
A-433	.666	None	7.4	----------	Below -76	0.196	19,100	----------	-------	----------
A-411	0.705	-------	7.0	----------	---------	---------	--------	----------	-------	----------
A-412	.694	-------	7.5	----------	---------	---------	--------	----------	-------	----------
A-413	.683	-------	8.1	----------	---------	---------	--------	----------	-------	----------
A-414	.672	-------	9.1	----------	---------	---------	--------	----------	-------	----------
A-415	0.693	-------	5.9	----------	---------	---------	--------	----------	-------	----------
A-416	.686	-------	6.0	----------	---------	---------	--------	----------	-------	----------
A-417	.677	-------	7.9	----------	---------	---------	--------	----------	-------	----------
A-418	.670	-------	9.8	----------	---------	---------	--------	----------	-------	----------
A-420	0.728	-------	7.9	----------	---------	---------	--------	----------	-------	----------
A-421	.712	-------	8.3	----------	---------	---------	--------	----------	-------	----------
A-422	.696	-------	8.5	----------	---------	---------	--------	----------	-------	----------
A-423	.678	-------	9.1	----------	---------	---------	--------	----------	-------	----------
A-500	.658	1	9.7	----------	----------	0.197	19,100	----------	-------	----------
A-123	0.702	-------	9.3	----------	---------	---------	--------	1.3907	-------	----------
A-124	.679	-------	11.8	----------	---------	---------	--------	1.3822	-------	----------
A-134	.664	-------	14.4	----------	---------	---------	--------	1.3732	-------	----------
A-375	0.687	-------	8.4	----------	---------	---------	--------	----------	-------	----------
A-376	.673	-------	11.6	----------	---------	---------	--------	----------	-------	----------
A-388	0.720	-------	9.9	----------	---------	---------	--------	----------	-------	----------
A-389	.699	-------	12.5	----------	---------	---------	--------	----------	-------	----------
A-209	.624	None	19.6	----------	Below -76	0.202	19,100	1.3544	-------	----------

[c]Cloudy.
[d]Approximately 3 ml TEL/gal.

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TABLE I - INSPECTION DATA FOR PURE FUEL

Fuel	Fuel composition		A.S.T.M. distillation data								
	Components	TEL concentration (ml/gal)	Initial boiling point (°F)	10% point (°F)	40% point (°F)	50% point (°F)	90% point (°F)	Final boiling point (°F)	Sum of 10 and 50% points (°F)	Residue (percent)	Loss (percent)
A-139	20% hot-acid octane + 80% VBS	4.10	118	154	184	193	232	298	347	0.5	1.0
A-140	40% hot-acid octane + 60% VBS	4.04	123	166	198	206	234	290	372	.6	1.2
A-141	60% hot-acid octane + 40% VBS	4.02	122	176	209	216	234	272	392	.7	.5
A-367	20% hot-acid octane + 80% alkylate	(d)	112	169	218	225	259	341	394	1.2	0.6
A-368	40% hot-acid octane + 60% alkylate	(d)	124	184	223	227	253	342	411	.8	1.2
A-369	60% hot-acid octane + 40% alkylate	(d)	132	193	224	226	243	315	419	.8	1.5
A-370	80% hot-acid octane + 20% alkylate	(d)	144	208	224	225	239	279	433	.8	1.4
A-371	20% hot-acid octane + 80% one-pass stock	(d)	114	142	189	208	282	322	350	0.4	1.4
A-372	40% hot-acid octane + 60% one-pass stock	(d)	124	155	206	218	269	321	373	.6	1.4
A-373	60% hot-acid octane + 40% one-pass stock	(d)	115	165	215	222	250	310	387	.8	1.1
A-374	80% hot-acid octane + 20% one-pass stock	(d)	129	195	222	224	240	294	419	.7	.5
A-205	Hot-acid octane	0	174	216	224	224	230	257	440	.6	.9
A-148	20% mixed xylenes + 80% VBS	4.07	116	152	191	203	272	296	355	0.4	0.6
A-444	40% mixed xylenes + 60% VBS	(d)	122	167	215	232	277	288	399	.3	.5
A-445	60% mixed xylenes + 40% VBS	(d)	128	196	252	264	277	287	460	.3	.4
A-446	80% mixed xylenes + 20% VBS	(d)	140	220	266	270	278	283	490	.4	.6
A-149	20% mixed xylenes + 80% alkylate	3.96	121	176	234	242	276	342	418	0.8	0.7
A-262	40% mixed xylenes + 60% alkylate	(d)	124	191	249	255	281	320	446	.5	1.3
A-263	60% mixed xylenes + 40% alkylate	(d)	130	217	262	266	280	306	483	.5	.5
A-264	80% mixed xylenes + 20% alkylate	(d)	136	238	268	271	279	295	509	.8	.8
A-150	20% mixed xylenes + 80% one-pass stock	4.10	106	146	200	230	285	315	376	0.3	0.9
A-266	40% mixed xylenes + 60% one-pass stock	(d)	115	159	244	262	284	311	421	.8	.8
A-267	60% mixed xylenes + 40% one-pass stock	(d)	115	154	251	264	282	303	418	.1	1.1
A-268	80% mixed xylenes + 20% one-pass stock	(d)	126	222	273	275	280	294	497	.2	.8
A-237	Mixed xylenes	0	273	275	276	276	277	278	551	.2	None
A-163	20% cumene + 80% VBS	4.12	116	152	188	202	294	321	354	0.5	0.7
A-244	40% cumene + 60% VBS	(d)	123	161	218	238	300	330	399	.4	.9
A-246	60% cumene + 40% VBS	(d)	126	180	265	284	302	335	464	.6	.6
A-247	80% cumene + 20% VBS	(d)	130	228	296	298	306	339	526	.5	.5
A-164	20% cumene + 80% alkylate	3.99	116	170	234	244	300	342	414	0.7	0.5
A-249	40% cumene + 60% alkylate	(d)	118	188	257	267	302	340	455	.4	.8
A-250	60% cumene + 40% alkylate	(d)	124	206	271	280	304	339	486	.5	.5
A-251	80% cumene + 20% alkylate	(d)	140	262	293	296	304	342	558	.5	.5
A-165	20% cumene + 80% one-pass stock	3.91	106	136	203	234	299	325	370	0.6	0.4
A-253	40% cumene + 60% one-pass stock	(d)	110	144	240	268	301	330	412	1.0	1.0
A-254	60% cumene + 40% one-pass stock	(d)	120	174	285	289	303	336	463	.4	1.1
A-255	80% cumene + 20% one-pass stock	(d)	125	216	292	295	305	340	511	1.0	1.0
A-238	Cumene[e]	0	293	298	300	300	305	349	598	.5	.5
A-170	20% benzene + 80% VBS	4.11	118	148	167	174	218	299	322	0.5	0.5
A-342	40% benzene + 60% VBS	(d)	126	154	168	173	204	286	327	.5	1.0
A-343	60% benzene + 40% VBS	(d)	144	164	171	174	185	266	338	.4	1.1
A-344	80% benzene + 20% VBS	(d)	148	168	172	174	179	238	342	.4	.6
A-168	20% benzene + 80% alkylate	3.92	120	156	190	200	258	345	356	0.7	0.3
A-359	40% benzene + 60% alkylate	(d)	126	162	180	186	245	333	348	.8	1.2
A-360	60% benzene + 40% alkylate	(d)	143	166	177	179	219	324	345	.6	.9
A-361	80% benzene + 20% alkylate	(d)	154	170	175	176	185	293	346	.6	.6
A-169	20% benzene + 80% one-pass stock	4.08	107	134	170	182	282	321	316	0.3	0.9
A-363	40% benzene + 60% one-pass stock	(d)	117	147	171	179	273	318	326	.5	1.0
A-364	60% benzene + 40% one-pass stock	(d)	122	153	173	177	227	314	330	.4	1.1
A-365	80% benzene + 20% one-pass stock	(d)	143	164	173	175	191	316	339	.4	.8
A-210	Benzene	0	170	173	173	173	174	175	346	.2	.8

[a]Estimated by change in refractive index following adsorption on silica gel. Correction made for olefins.

[b]Calculated by using average molecular weight from distillation curve (Universal Oil Products Method H-173-40).

[c]Cloudy.

STOCKS AND FOR FUEL BLENDS - Continued

Fuel	Specific gravity at 60° F	Copper-dish gum (mg/100 ml)	Reid vapor pressure (lb/sq in.)	Aromatics[a] (percent by volume)	Freezing point (°F)	Hydrogen-carbon ratio	Net heat of combustion (Btu/lb)	Refractive index n_D at 68° F	Bromine number (cg/g)	Olefins[b] (percent by weight)
A-139	0.715	5	5.8	----------	----------	----------	--------	1.3992	-------	----------
A-140	.716	6	5.0	----------	----------	----------	--------	1.3997	-------	----------
A-141	.715	6	4.3	----------	----------	----------	--------	1.4002	-------	----------
A-367	0.703	-------	4.4	----------	----------	----------	--------	----------	-------	----------
A-368	.707	-------	3.8	----------	----------	----------	--------	----------	-------	----------
A-369	.710	-------	3.1	----------	----------	----------	--------	----------	-------	----------
A-370	.714	-------	2.9	----------	----------	----------	--------	----------	-------	----------
A-371	0.737	-------	6.5	----------	----------	----------	--------	----------	-------	----------
A-372	.732	-------	5.5	----------	----------	----------	--------	----------	-------	----------
A-373	.727	-------	4.5	----------	----------	----------	--------	----------	-------	----------
A-374	.722	-------	3.6	----------	----------	----------	--------	----------	-------	----------
A-205	.715	6	2.7	None	Below -76	0.188	19,200	1.4009	2.6	1.7
A-148	0.746	-------	5.3	26.4	Below -76	----------	--------	1.4180	-------	----------
A-444	.775	-------	4.2	----------	----------	----------	--------	----------	-------	----------
A-445	.805	-------	3.0	----------	----------	----------	--------	----------	-------	----------
A-446	.824	-------	2.2	----------	----------	----------	--------	----------	-------	----------
A-149	0.731	1	3.9	20.5	Below -76	----------	--------	1.4132	-------	----------
A-262	.768	-------	3.0	----------	----------	----------	--------	----------	-------	----------
A-263	.799	-------	2.2	----------	----------	----------	--------	----------	-------	----------
A-264	.821	-------	1.9	----------	----------	----------	--------	----------	-------	----------
A-150	0.767	-------	6.5	42.3	Below -76	----------	--------	1.4333	-------	----------
A-266	.793	-------	5.2	----------	----------	----------	--------	----------	-------	----------
A-267	.800	-------	4.4	----------	----------	----------	--------	----------	-------	----------
A-268	.838	-------	2.4	----------	----------	----------	--------	----------	-------	----------
A-237	.867	2	.5	----------	-40	0.106	17,600	1.4959	-------	----------
A-163	0.737	-------	5.3	25.6	Below -76	----------	--------	1.4169	-------	----------
A-244	.775	-------	4.4	43.0	Below -76	----------	--------	1.4353	-------	----------
A-246	.804	-------	3.2	62.0	[c]Below -76	----------	--------	1.4538	-------	----------
A-247	.832	-------	2.0	----------	[c]Below -76	----------	--------	----------	-------	----------
A-164	0.732	3	4.0	19.7	Below -76	----------	--------	1.4122	-------	----------
A-249	.767	-------	3.2	39.0	Below -76	----------	--------	1.4320	-------	----------
A-250	.787	-------	2.6	----------	Below -76	----------	--------	----------	-------	----------
A-251	.831	-------	1.4	----------	Below -76	----------	--------	----------	-------	----------
A-165	0.769	-------	6.4	40.0	Below -76	----------	--------	1.4325	-------	----------
A-253	.787	-------	5.3	----------	[c]Below -76	----------	--------	----------	-------	----------
A-254	.815	-------	3.8	----------	Below -76	----------	--------	----------	-------	----------
A-255	.836	-------	2.4	----------	Below -76	----------	--------	----------	-------	----------
A-238	.863	3	.3	----------	[e]Below -76	0.113	17,800	1.4903	-------	----------
A-170	0.748	-------	6.0	26.0	-38	----------	--------	1.4175	-------	----------
A-342	.772	-------	5.6	----------	----------	----------	--------	----------	-------	----------
A-343	.823	-------	4.6	----------	----------	----------	--------	----------	-------	----------
A-344	.844	-------	4.2	----------	----------	----------	--------	----------	-------	----------
A-168	0.734	4	4.8	19.5	-24	----------	--------	1.4124	-------	----------
A-359	.770	-------	4.7	----------	----------	----------	--------	----------	-------	----------
A-360	.803	-------	4.4	----------	----------	----------	--------	----------	-------	----------
A-361	.841	-------	3.7	----------	----------	----------	--------	----------	-------	----------
A-169	0.768	-------	7.0	40.0	-53	----------	--------	1.4333	-------	----------
A-363	.822	-------	6.0	----------	----------	----------	--------	----------	-------	----------
A-364	.841	-------	5.2	----------	----------	----------	--------	----------	-------	----------
A-365	.850	-------	4.4	----------	----------	----------	--------	----------	-------	----------
A-210	.883	1	3.5	----------	45	0.084	17,400	1.4989	-------	----------

[d]Approximately 4 ml TEL/gal.

[e]At 14° F a small quantity of an impurity, probably water, separated and formed a cloud. When sample was dried over sodium, no cloud formation was observed to -76° F.

TABLE I - INSPECTION DATA FOR PURE FUEL

Fuel	Fuel composition		A.S.T.M. distillation data								
	Components	TEL concentration (ml/gal)	Initial boiling point (°F)	10% point (°F)	40% point (°F)	50% point (°F)	90% point (°F)	Final boiling point (°F)	Sum of 10 and 50% points (°F)	Residue (percent)	Loss (percent)
A-145	20% toluene + 80% VBS	4.10	122	157	186	194	230	294	351	0.6	0.9
A-322	40% toluene + 60% VBS	(d)	126	163	193	201	231	282	364	.4	.6
A-323	60% toluene + 40% VBS	(d)	135	179	208	215	230	256	394	.5	1.0
A-324	80% toluene + 20% VBS	(d)	148	203	222	224	230	252	427	.1	.9
A-146	20% toluene + 80% alkylate	3.96	118	172	216	223	254	349	395	1.0	0.5
A-326	40% toluene + 60% alkylate	(d)	119	185	221	224	241	334	409	.8	.7
A-327	60% toluene + 40% alkylate	(d)	131	203	223	225	235	311	428	1.1	.1
A-328	80% toluene + 20% alkylate	(d)	155	216	226	227	231	263	443	1.1	.1
A-147	20% toluene + 80% one-pass stock	4.05	106	140	192	213	274	320	353	0.6	0.9
A-332	40% toluene + 60% one-pass stock	(d)	119	158	212	224	259	322	382	.3	1.2
A-333	60% toluene + 40% one-pass stock	(d)	119	180	223	228	246	313	408	.5	.7
A-334	80% toluene + 20% one-pass stock	(d)	138	209	226	228	244	286	437	.3	.5
A-232	Toluene	0	224	226	226	226	227	228	452	None	.8
A-171	20% MTB ether + 80% VBS	3.99	117	138	157	165	222	294	303	0.6	1.2
A-337	40% MTB ether + 60% VBS	(d)	120	135	147	152	194	282	287	.8	1.0
A-338	60% MTB ether + 40% VBS	(d)	119	130	138	142	190	263	272	.7	.8
A-339	80% MTB ether + 20% VBS	(d)	124	130	134	136	153	242	266	.7	1.1
A-172	20% MTB ether + 80% alkylate	4.02	114	144	181	200	262	346	344	0.8	1.2
A-348	40% MTB ether + 60% alkylate	(d)	116	134	155	167	251	333	301	1.0	1.0
A-349	60% MTB ether + 40% alkylate	(d)	120	132	142	147	240	316	279	1.1	.9
A-350	80% MTB ether + 20% alkylate	(d)	124	130	135	137	191	304	267	.6	.9
A-173	20% MTB ether + 80% one-pass stock	4.04	108	127	152	165	278	321	292	0.4	1.4
A-352	40% MTB ether + 60% one-pass stock	(d)	110	126	143	150	273	318	276	.5	1.5
A-353	60% MTB ether + 40% one-pass stock	(d)	114	127	136	140	252	315	267	.6	1.4
A-354	80% MTB ether + 20% one-pass stock	(d)	121	128	133	134	170	301	262	.5	1.0
A-236	MTB ether	0	125	128	129	129	130	133	257	None	1.0

[a]Estimated by change in refractive index following adsorption on silica gel. Correction made for olefins.

[b]Calculated by using average molecular weight from distillation curve (Universal Oil Products Method H-173-40).

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

STOCKS AND FOR FUEL BLENDS - Concluded

Fuel	Specific gravity at 60° F	Copper-dish gum (mg/100 ml)	Reid vapor pressure (lb/sq in.)	Aromatics[a] (percent by volume)	Freezing point (°F)	Hydrogen-carbon ratio	Net heat of combustion (Btu/lb)	Refractive index n_D at 68° F	Bromine number (cg/g)	Olefins[b] (percent by weight)
A-145	0.746	-------	5.3	26.2	Below -76	---------	--------	1.4178	-------	----------
A-322	.760	-------	5.1	----------	---------	---------	--------	----------	-------	----------
A-323	.792	-------	4.0	----------	---------	---------	--------	----------	-------	----------
A-324	.823	-------	2.6	----------	---------	---------	--------	----------	-------	----------
A-146	0.733	-------	4.0	19.8	Below -76	---------	--------	1.4126	-------	----------
A-326	.766	-------	3.3	----------	---------	---------	--------	----------	-------	----------
A-327	.800	-------	2.6	----------	---------	---------	--------	----------	-------	----------
A-328	.832	-------	2.0	----------	---------	---------	--------	----------	-------	----------
A-147	0.766	-------	6.6	44.0	Below -76	---------	--------	1.4333	-------	----------
A-332	.793	-------	5.1	----------	---------	---------	--------	----------	-------	----------
A-333	.817	-------	3.9	----------	---------	---------	--------	----------	-------	----------
A-334	.848	-------	2.3	----------	---------	---------	--------	----------	-------	----------
A-232	.871	1	1.1	----------	Below -76	0.096	17,500	1.4962	-------	----------
A-171	0.721	-------	5.8	----------	Below -76	---------	--------	1.3924	-------	----------
A-337	.725	-------	7.1	----------	---------	---------	--------	----------	-------	----------
A-338	.731	-------	7.3	----------	---------	---------	--------	----------	-------	----------
A-339	.738	-------	7.3	----------	---------	---------	--------	----------	-------	----------
A-172	0.709	-------	5.7	----------	Below -76	---------	--------	1.3876	-------	----------
A-348	.717	-------	6.5	----------	---------	---------	--------	----------	-------	----------
A-349	.726	-------	6.8	----------	---------	---------	--------	----------	-------	----------
A-350	.736	-------	7.2	----------	---------	---------	--------	----------	-------	----------
A-173	0.742	-------	7.6	----------	Below -76	---------	--------	1.4090	-------	----------
A-352	.744	-------	7.6	----------	---------	---------	--------	----------	-------	----------
A-353	.744	-------	7.6	----------	---------	---------	--------	----------	-------	----------
A-354	.745	-------	7.4	----------	---------	---------	--------	----------	-------	----------
A-236	.747	None	8.8	----------	Below -76	0.201	15,200	1.3697	-------	----------

[d]Approximately 4 ml TEL/gal.

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COMMITTEE FOR AERONAUTICS

TABLE II - PERFORMANCE RATINGS OBTAINED IN F-3 AND F-4 ENGINES

[For each fuel there are three rows of values: The first row is imep, lb/sq in.; the second row for F-3 ratings is octane number or tetraethyl lead in S-3 reference fuel, ml/gal; the second row for F-4 ratings is percentage S-3 reference fuel in M-4 reference fuel or tetraethyl lead in S-3 reference fuel, ml/gal; the third row is performance number. The following abbreviations are used throughout the table: VBS for virgin base stock; alkylate for aviation alkylate; one-pass stock for one-pass catalytic stock; and MTB ether for methyl tert-butyl ether.]

Fuel	Fuel composition[a] (by volume)	F-3 ratings	F-4 ratings					
			Fuel-air ratio					
			0.065	0.070	0.085	0.095	0.100	0.110
A-355	VBS	-------	73	83	122	137	141	143
		90.7	96.6	99.8	0.08	99.8	99.0	97.8
		75	91	99	103	99	97	94
A-118	50% alkylate + 50% VBS	-------	86	99	143	159	162	165
		98.8	0.10	0.19	0.34	0.33	0.29	0.24
		96	104	107	111	111	110	109
A-356	Alkylate	-------	104	129	176	190	195	201
		0.64	0.55	0.93	1.57	1.71	1.87	2.14
		119	117	124	134	135	137	140
A-152	30% one-pass stock + 70% VBS	-------	72	71	116	130	136	145
		90.6	93.8	90.0	100	98.0	97.5	97.7
		75	84	78	100	94	94	94
A-116	50% one-pass stock + 50% VBS	-------	64	76	116	137	145	156
		90.9	88.6	93.1	100	0.01	0.01	0.06
		76	76	84	100	101	101	103
A-119	80% one-pass stock + 20% VBS	-------	67	76	114	142	154	165
		92.7	90.6	93.1	99.2	0.09	0.16	0.24
		79	78	84	97	104	106	109
A-122	30% one-pass stock + 70% alkylate	-------	82	103	152	172	178	182
		0.15	100	0.26	0.45	0.58	0.75	0.83
		106	100	110	114	117	121	123
A-117	50% one-pass stock + 50% alkylate	-------	76	91	143	167	176	186
		100	96.3	0.06	0.34	0.44	0.58	1.17
		100	91	103	111	114	117	129
A-121	80% one-pass stock + 20% alkylate	-------	72	79	123	149	160	177
		96.3	93.8	95	0.09	0.19	0.26	0.48
		88	84	96	104	107	110	115
A-410	One-pass stock	-------	73	83	125	151	164	179
		93.4	96.6	99.8	0.12	0.16	0.28	0.49
		81	91	99	105	106	110	115
A-136	20% triptane + 80% VBS	-------	74	90	134	155	162	167
		94.2	95.0	0.05	0.23	0.27	0.27	0.28
		83	88	102	108	110	110	110
A-137	40% triptane + 60% VBS	-------	100	119	164	191	201	205
		0.18	0.43	0.55	0.96	1.75	2.07	2.07
		107	114	117	125	136	139	139
A-138	60% triptane + 40% VBS	-------	117	142	224	260	264	269
		0.67	1.20	1.58	5.54	-------	-------	-------
		120	129	134	160	175	175	175
A-272	20% triptane + 80% alkylate	-------	90	126	185	213	225	237
		1.08	0.19	0.88	2.13	3.17	3.79	4.57
		127	106	123	140	148	152	156
A-273	40% triptane + 60% alkylate	-------	98	126	225	262	274	283
		2.43	0.38	0.88	5.69	-------	-------	-------
		142	113	123	160	177	182	184
A-274	60% triptane + 40% alkylate	-------	111	159	275	316	326	334
		2.70	0.90	2.76	------	-------	-------	-------
		145	124	145	195	213	216	218
A-275	80% triptane + 20% alkylate	-------	139	190	314	-------	-------	-------
		3.06	2.59	5.90	------	-------	-------	-------
		147	144	161	------	-------	-------	-------

[a]Each fuel contains approximately 4 ml TEL/gal.

TABLE II - PERFORMANCE RATINGS OBTAINED IN F-3 AND F-4 ENGINES - Continued

Fuel	Fuel composition[a] (by volume)	F-3 ratings	F-4 ratings					
			Fuel-air ratio					
			0.065	0.070	0.085	0.095	0.100	0.110
A-276	20% triptane + 80% one-pass stock[b]	-------	66	72	117	146	160	186
		98.8	90.0	90.7	0.01	0.14	0.26	1.17
		96	77	78	101	105	110	135
A-277	40% triptane + 60% one-pass stock[b]	-------	81	89	139	176	195	231
		0.08	99.4	0.05	0.29	0.88	1.77	3.86
		103	99	101	111	124	136	152
A-278	60% triptane + 40% one-pass stock[b]	-------	100	109	171	218	244	291
		0.48	0.43	0.36	1.36	3.52	------	------
		115	114	113	131	150	162	190
A-279	80% triptane + 20% one-pass stock[b]	-------	126	147	290	361	391	------
		1.80	1.63	1.82	------	------	------	------
		136	134	137	------	------	------	------
A-271	Triptane[b]	-------	204	262	[c]393	------	------	------
		3.30	------	------	------	------	------	------
		149	191	------	------	------	------	------
A-397	20% diisopropyl + 80% VBS	-------	77	91	132	149	154	165
		96.6	96.9	0.08	0.20	0.19	0.16	0.04
		90	91	103	108	107	106	101
A-398	40% diisopropyl + 60% VBS	-------	81	96	143	167	175	180
		0.09	99.4	0.16	0.34	0.44	0.50	0.67
		103	98	106	112	114	116	120
A-399	60% diisopropyl + 40% VBS	-------	96	108	163	187	197	207
		0.33	0.33	0.34	0.90	1.55	1.86	2.21
		111	111	112	124	134	137	141
A-400	80% diisopropyl + 20% VBS	-------	111	141	202	226	236	250
		1.17	1.10	1.56	3.23	4.14	5.07	------
		128	127	134	148	153	158	163
A-405	20% diisopropyl + 80% alkylate	-------	125	146	192	210	217	222
		0.90	1.78	1.78	2.58	2.97	3.21	3.24
		124	136	136	144	146	146	148
A-406	40% diisopropyl + 60% alkylate	-------	138	158	206	227	234	240
		1.45	2.47	2.67	3.49	4.29	4.80	5.00
		132	143	144	150	154	156	157
A-407	60% diisopropyl + 40% alkylate	-------	132	154	212	240	252	263
		1.40	1.91	2.29	3.87	------	------	------
		132	138	141	152	162	167	171
A-408	80% diisopropyl + 20% alkylate	-------	136	162	226	261	275	292
		2.10	2.24	3.05	5.85	------	------	------
		139	141	147	161	176	182	190
A-401	20% diisopropyl + 80% one-pass stock	-------	79	89	132	163	177	195
		96.1	98.1	0.05	0.20	0.39	0.67	1.60
		88	95	102	108	113	120	134
A-402	40% diisopropyl + 60% one-pass stock	-------	84	99	150	177	189	209
		0.06	0.05	0.20	0.43	0.95	1.48	2.34
		102	102	108	114	125	133	142
A-403	60% diisopropyl + 40% one-pass stock	-------	96	114	165	196	210	235
		0.24	0.33	0.44	1.02	2.00	2.72	4.29
		108	111	114	126	138	145	154
A-404	80% diisopropyl + 20% one-pass stock	-------	120	143	197	229	245	272
		0.68	1.34	1.65	2.90	4.57	------	------
		120	131	135	146	155	162	177
A-398	Diisopropyl[d]	-------	147	173	246	289	304	324
		2.41	3.53	4.11	------	------	------	------
		142	150	153	175	195	------	------

[a]Each fuel contains approximately 4 ml TEL/gal.
[b]Knock-limited performance of the engine with one-pass catalytic stock was low on the day these fuels were tested.
[c]Estimated value.
[d]Values for knock-limited imep were averaged from three curves.

TABLE II - PERFORMANCE RATINGS OBTAINED IN F-3 AND F-4 ENGINES - Continued

Fuel	Fuel composition[a] (by volume)	F-3 ratings	F-4 ratings					
			Fuel-air ratio					
			0.065	0.070	0.085	0.095	0.100	0.110
A-411	20% neohexane + 80% VBS	-------	74	86	124	142	147	150
		94.5	95.0	100	0.10	0.09	0.05	99.2
		84	88	100	104	103	102	96
A-412	40% neohexane + 60% VBS	-------	81	97	138	138	164	167
		0.05	99.4	0.17	0.28	0.31	0.32	0.28
		102	98	106	110	111	111	110
A-413	60% neohexane + 40% VBS	-------	93	108	159	178	183	187
		0.36	0.26	0.34	0.67	1.03	1.17	1.25
		112	110	112	120	126	128	130
A-414	80% neohexane + 20% VBS	-------	108	130	182	203	208	210
		2.00	0.75	1.06	1.95	2.48	2.57	2.41
		138	121	127	138	143	143	142
A-415	20% neohexane + 80% alkylate	-------	112	130	172	193	199	202
		1.10	0.95	1.06	1.41	1.85	1.95	1.91
		127	125	127	132	137	138	138
A-416	40% neohexane + 60% alkylate	-------	118	137	186	203	207	209
		1.50	1.25	1.38	2.19	2.48	2.50	2.35
		133	130	131	140	143	143	142
A-417	60% neohexane + 40% alkylate	-------	124	146	195	212	215	216
		2.57	1.53	1.78	2.78	3.10	3.07	2.83
		143	133	136	145	147	147	145
A-418	80% neohexane + 20% alkylate	-------	137	158	208	224	227	226
		3.36	2.35	2.67	3.61	3.93	3.93	3.52
		149	142	144	151	152	152	150
A-420	20% neohexane + 80% one-pass stock	-------	79	95	146	171	180	190
		96.6	98.1	0.14	0.38	0.50	0.92	1.38
		90	95	105	113	116	124	131
A-421	40% neohexane + 60% one-pass stock	-------	86	107	165	190	197	203
		0.10	0.10	0.33	1.02	1.70	1.86	1.96
		104	104	111	126	135	137	138
A-422	60% neohexane + 40% one-pass stock	-------	108	138	192	210	215	217
		0.33	0.75	1.43	2.58	2.97	3.07	2.90
		111	121	132	143	146	147	146
A-423	80% neohexane + 20% one-pass stock	-------	132	162	214	230	233	234
		1.66	1.91	3.05	4.00	4.72	4.67	4.14
		135	138	147	153	156	156	153
A-394	Neohexane[e]	-------	159	187	230	240	242	243
		6.00	4.76	5.58	------	------	5.87	5.43
		161	156	160	163	162	161	159
A-123	20% isopentane + 80% VBS	-------	72	87	127	141	146	149
		94.4	93.8	0.02	0.14	0.07	0.03	98.9
		83	84	101	106	103	101	99
A-124	40% isopentane + 60% VBS	-------	80	99	139	151	155	159
		99.1	98.8	0.20	0.29	0.21	0.18	0.12
		97	96	108	110	108	107	105
A-134	60% isopentane + 40% VBS	-------	87	112	153	168	172	174
		0.23	0.12	0.41	0.46	0.46	0.45	0.42
		108	105	114	114	114	114	113
A-375	20% isopentane + 80% alkylate	-------	121	144	186	201	204	204
		0.92	1.39	1.69	2.19	2.34	2.29	2.00
		124	131	135	140	142	141	138
A-376	40% isopentane + 60% alkylate	-------	121	144	191	203	205	204
		0.99	1.39	1.69	2.52	2.48	2.36	2.00
		125	131	135	143	143	142	138
A-388	20% isopentane + 80% one-pass stock	-------	78	87	132	160	173	188
		95.8	97.5	0.02	0.20	0.34	0.47	1.29
		87	94	101	108	111	115	130
A-389	40% isopentane + 60% one-pass stock	-------	85	97	140	168	180	192
		100	0.07	0.17	0.30	0.46	0.92	1.47
		100	103	107	111	115	124	133

[a]Each fuel contains approximately 4 ml TEL/gal.
[e]Values for knock-limited imep were averaged from two curves.

TABLE II - PERFORMANCE RATINGS OBTAINED IN F-3 AND F-4 ENGINES - Continued

Fuel	Fuel composition[a] (by volume)	F-3 ratings	F-4 ratings					
			Fuel-air ratio					
			0.065	0.070	0.085	0.095	0.100	0.110
A-139	20% hot-acid octane + 80% VBS	-------	70	83	128	147	151	154
		94.3	92.5	98.0	0.15	0.16	0.11	0.02
		83	83	94	106	106	105	101
A-140	40% hot-acid octane + 60% VBS	-------	74	89	143	168	173	179
		100	95.0	0.03	0.34	0.46	0.47	0.58
		100	94	101	111	114	115	117
A-141	60% hot-acid octane + 40% VBS	-------	84	106	165	191	198	207
		0.18	0.05	0.31	1.02	1.75	1.91	2.21
		107	102	111	126	136	138	140
A-367	20% hot-acid octane + 80% alkylate	-------	121	142	188	205	210	215
		0.82	1.39	1.60	2.32	2.62	2.72	2.76
		123	131	134	141	144	145	145
A-368	40% hot-acid octane +60% alkylate	-------	125	148	200	219	226	235
		0.72	1.58	1.87	3.10	3.59	3.86	4.29
		121	134	137	147	150	152	154
A-369	60% hot-acid octane + 40% alkylate	-------	129	154	216	240	248	257
		0.88	1.77	2.29	4.31	------	------	------
		124	136	141	154	162	164	168
A-370	80% hot-acid octane + 20% alkylate	-------	129	154	238	269	276	280
		0.72	1.77	2.29	------	------	------	------
		121	136	141	169	182	183	182
A-371	20% hot-acid octane + 80% one-pass stock	-------	80	90	138	170	185	206
		95.1	98.8	0.06	0.28	0.49	1.30	2.14
		86	95	102	110	115	130	140
A-372	40% hot-acid octane + 60% one-pass stock	-------	88	97	154	192	208	229
		100	0.14	0.17	0.48	1.80	2.57	3.73
		100	105	107	115	136	143	151
A-373	60% hot-acid octane + 40% one-pass stock	-------	90	101	164	203	220	245
		0.18	0.19	0.23	0.96	2.48	3.43	5.71
		107	107	108	125	143	149	160
A-374	80% hot-acid octane + 20% one-pass stock	-------	99	115	187	224	240	268
		0.45	0.41	0.45	2.26	3.93	5.60	------
		115	114	115	141	152	160	175
A-330	Hot-acid octane[c]	-------	131	159	250	289	304	317
		1.08	1.86	2.76	------	------	------	------
		127	137	145	178	195	------	------
A-257	20% mixed xylenes + 80% VBS	-------	68	78	114	132	138	148
		92.6	91.3	94.7	99.2	98.7	98.1	98.6
		79	79	86	97	96	94	96
A-258	40% mixed xylenes + 60% VBS	-------	69	78	117	147	160	182
		95.5	91.9	94.7	0.03	0.16	0.26	0.83
		86	80	86	101	106	110	123
A-259	60% mixed xylenes + 40% VBS	-------	74	85	146	194	216	253
		95.2	95.0	99.3	0.38	1.90	3.14	------
		86	87	99	113	137	148	165
A-260	80% mixed xylenes + 20% VBS	-------	84	95	214	------	------	------
		0.04	0.05	0.14	4.00	------	------	------
		101	102	105	153	------	------	------
A-261	20% mixed xylenes + 80% alkylate	-------	88	101	158	194	208	227
		0.52	0.14	0.23	0.65	1.90	2.87	3.69
		116	105	108	119	137	143	150
A-262	40% mixed xylenes + 60% alkylate	-------	82	95	153	206	252	287
		0.27	100	0.14	0.46	2.69	------	------
		110	100	105	115	144	167	187
A-263	60% mixed xylenes + 40% alkylate	-------	85	98	181	274	------	------
		0.14	0.07	0.19	1.89	------	------	------
		106	103	107	137	185	------	------
A-264	80% mixed xylenes + 20% alkylate	-------	87	103	260	336	370	------
		0.27	0.12	0.27	------	------	------	------
		110	105	110	185	------	------	------

[a]Each fuel contains approximately 4 ml TEL/gal.
[c]Values for knock-limited imep were averaged from two curves.

TABLE II - PERFORMANCE RATINGS OBTAINED IN F-3 AND F-4 ENGINES - Continued

Fuel	Fuel composition[a] (by volume)	F-3 ratings	F-4 ratings					
			Fuel-air ratio					
			0.065	0.070	0.085	0.095	0.100	0.110
A-265	20% mixed xylenes + 80% one-pass stock[b]	-------	71	74	111	138	151	178
		94.7	93.1	92.0	97.9	0.03	0.11	0.50
		84	83	81	94	101	105	116
A-266	40% mixed xylenes + 60% one-pass stock[b]	-------	80	86	133	172	196	246
		97.5	98.8	100	0.21	0.58	1.81	5.86
		92	95	100	108	118	136	161
A-267	60% mixed xylenes + 40% one-pass stock[b]	-------	95	100	184	251	282	339
		98.8	0.31	0.22	2.06	------	------	------
		96	111	108	139	169	187	------
A-268	80% mixed xylenes + 20% one-pass stock[b]	-------	102	106	351	------	------	------
		0.16	0.48	0.31	------	------	------	------
		106	115	111	------	------	------	------
A-256	Mixed xylenes[b,d]	-------	105	122	------	------	------	------
		0.92	0.60	0.69	------	------	------	------
		124	118	120	------	------	------	------
A-245	20% cumene + 80% VBS	-------	67	72	98	123	134	154
		92.4	90.6	90.7	92.5	95.7	96.9	0.02
		78	78	78	82	88	91	101
A-244	40% cumene + 60% VBS	-------	67	70	95	117	130	160
		92.7	90.6	89.3	91.3	93.7	95.6	0.14
		79	78	76	80	84	88	105
A-246	60% cumene + 40% VBS	-------	67	72	94	118	132	174
		94.2	90.6	90.7	90.8	94.0	96.3	0.42
		83	78	78	78	85	91	114
A-247	80% cumene + 20% VBS	-------	77	76	90	120	151	------
		96.0	96.9	93.3	89.2	94.7	0.11	------
		88	91	84	76	86	105	------
A-248	20% cumene + 80% alkylate	-------	98	102	143	172	187	215
		0.32	0.38	0.25	0.34	0.58	1.39	2.76
		111	113	109	111	117	131	145
A-249	40% cumene + 60% alkylate	-------	71	76	113	148	171	233
		0.11	93.1	93.3	98.8	0.17	0.44	4.00
		105	84	84	95	106	114	153
A-250	60% cumene + 40% alkylate	-------	77	76	94	124	149	277
		0.03	96.9	93.3	90.8	96.0	0.08	------
		101	91	84	78	90	103	180
A-251	80% cumene + 20% alkylate	-------	74	73	86	114	160	------
		97.7	95.0	91.3	87.5	92.7	0.26	------
		93	87	80	73	82	110	------
A-252	20% cumene + 80% one-pass stock	-------	70	69	91	120	137	175
		93.0	92.5	88.6	89.6	94.3	97.8	0.44
		80	82	75	76	85	93	114
A-253	40% cumene + 60% one-pass stock	-------	70	67	75	95	112	168
		93.6	92.5	87.4	82.9	86.3	90.0	0.30
		82	82	74	67	72	77	111
A-254	60% cumene + 40% one-pass stock	-------	66	62	65	81	94	153
		93.0	90.0	84.0	78.8	81.3	84.4	100
		80	78	68	62	65	69	100
A-255	80% cumene + 20% one-pass stock	-------	66	63	70	98	141	------
		95.0	90.0	84.8	80.8	87.3	99.1	------
		85	78	69	64	74	98	------
A-240	Cumene[d]	-------	77	75	87	122	------	------
		95.0	96.9	92.7	87.9	95.3	------	------
		85	91	83	74	88	------	------

[a]Each fuel contains approximately 4 ml TEL/gal.

[b]Knock-limited performance of the engine with one-pass catalytic stock was low on the day these fuels were tested.

[d]Values for knock-limited imep were averaged from three curves.

TABLE II - PERFORMANCE RATINGS OBTAINED IN F-3 AND F-4 ENGINES - Continued

Fuel	Fuel composition[a] (by volume)	F-3 ratings	F-4 ratings					
			Fuel-air ratio					
			0.065	0.070	0.085	0.095	0.100	0.110
A-341	20% benzene + 80% VBS	-------	78	85	134	155	162	168
		91.4	97.5	99.4	0.22	0.27	0.29	0.30
		76	93	97	108	110	110	111
A-342	40% benzene + 60% VBS	-------	81	89	146	178	190	206
		92.4	99.4	0.05	0.37	1.03	1.63	2.28
		78	97	102	112	126	134	141
A-343	60% benzene + 40% VBS	-------	78	85	244	346	384	------
		94.2	97.5	99.4	------	------	------	------
		83	93	97	173	------	------	------
A-344	80% benzene + 20% VBS	-------	98	115	------	------	------	------
		96.2	0.38	0.45	------	------	------	------
		88	113	115	------	------	------	------
A-358	20% benzene + 80% alkylate	-------	117	127	182	212	222	234
		0.43	1.20	0.92	.95	3.10	3.57	4.14
		114	129	124	137	147	150	153
A-359	40% benzene + 60% alkylate	-------	102	112	182	230	253	295
		0.12	0.48	0.41	1.95	4.72	------	------
		105	115	114	137	156	168	192
A-360	60% benzene + 40% alkylate	-------	102	110	336	------	------	------
		100	0.48	0.38	------	------	------	------
		100	115	113	------	------	------	------
A-361	80% benzene + 20% alkylate	-------	119	178	------	------	------	------
		98.3	1.30	4.63	------	------	------	------
		94	130	156	------	------	------	------
A-362	20% benzene + 80% one-pass stock	-------	77	86	142	172	184	203
		93.8	96.9	100	0.33	0.58	1.25	1.96
		82	91	100	111	118	130	138
A-363	40% benzene + 60% one-pass stock	-------	82	79	160	213	238	264
		92.0	100	95.3	0.73	3.17	5.33	------
		78	100	88	121	148	159	172
A-364	60% benzene + 40% one-pass stock	-------	68	72	191	254	280	328
		91.5	91.3	90.7	2.52	------	------	------
		77	80	78	143	172	196	------
A-365	80% benzene + 20% one-pass stock	-------	94	93	------	------	------	------
		93.0	0.29	0.11	------	------	------	------
		80	110	105	------	------	------	------
A-340	Benzene[e]	-------	199	------	------	------	------	------
		87	------	------	------	------	------	------
		68	186	196	------	------	------	------
A-321	20% toluene + 80% VBS	-------	85	96	137	156	164	172
		93.7	0.07	0.16	0.26	0.29	0.32	0.27
		82	103	106	110	110	111	110
A-322	40% toluene + 60% VBS	-------	92	96	175	228	245	266
		95.1	0.24	0.16	1.57	4.43	------	------
		85	109	106	134	155	162	173
A-323	60% toluene + 40% VBS	-------	88	95	204	303	346	425
		97.0	0.14	0.14	3.36	------	------	------
		91	105	105	149	------	------	------
A-324	80% toluene + 20% VBS	-------	101	113	340	------	------	------
		98.8	0.45	0.42	------	------	------	------
		96	115	114	------	------	------	------

[a]Each fuel contains approximately 4 ml TEL/gal.

[e]Values for knock-limited imep were averaged from two curves.

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TABLE II - PERFORMANCE RATINGS OBTAINED IN F-3 AND F-4 ENGINES - Concluded

Fuel	Fuel composition[a] (by volume)	F-3 ratings	F-4 ratings					
			Fuel-air ratio					
			0.065	0.070	0.085	0.095	0.100	0.110
A-325	20% toluene + 80% alkylate	-------	121	139	191	221	232	249
		0.48	1.39	1.47	2.52	3.73	4.53	------
		115	131	132	143	151	155	162
A-326	40% toluene + 60% alkylate	-------	108	128	223	275	308	348
		0.54	0.75	0.97	5.38	------	------	------
		116	121	125	159	186	------	------
A-327	60% toluene + 40% alkylate	-------	100	105	300	------	------	------
		0.25	0.43	0.30	------	------	------	------
		109	114	111	------	------	------	------
A-328	80% toluene + 20% alkylate	-------	108	116	------	------	------	------
		0.16	0.75	0.47	------	------	------	------
		106	121	115	------	------	------	------
A-331	20% toluene + 80% one-pass stock	-------	80	90	137	169	184	212
		95.1	98.8	0.06	0.26	0.47	1.25	2.55
		85	95	103	110	115	130	143
A-332	40% toluene + 60% one-pass stock	-------	85	92	151	202	224	262
		95.3	0.07	0.09	0.44	2.41	3.72	------
		86	103	103	114	142	151	171
A-333	60% toluene + 40% one-pass stock	-------	91	95	178	270	319	------
		97.4	0.21	0.14	1.73	------	------	------
		91	108	105	135	182	------	------
A-334	80% toluene + 20% one-pass stock	-------	102	106	------	------	------	------
		0.10	0.48	0.31	------	------	------	------
		104	115	111	------	------	------	------
A-320	Toluene[e]	-------	134	140	------	------	------	------
		0.57	2.00	1.51	------	------	------	------
		118	138	133	------	------	------	------
A-336	20% MTB ether + 80% VBS	-------	95	101	144	170	179	187
		98.8	0.31	0.23	0.30	0.49	0.83	1.25
		96	111	108	111	115	121	130
A-337	40% MTB ether + 60% VBS	-------	112	113	165	204	223	253
		0.12	0.95	0.42	1.02	2.55	3.64	------
		105	125	114	126	143	151	165
A-338	60% MTB ether + 40% VBS	-------	192	163	228	281	307	355
		0.92	------	3.14	------	------	------	------
		124	180	148	162	190	------	------
A-339	80% MTB ether + 20% VBS	-------	------	239	309	379	------	------
		2.61	------	------	------	------	------	------
		144	------	------	------	------	------	------
A-347	20% MTB ether + 80% alkylate	-------	143	155	230	258	268	281
		1.68	3.06	2.38	------	------	------	------
		135	146	142	163	174	178	183
A-348	40% MTB ether + 60% alkylate	-------	166	174	256	312	338	377
		2.30	5.43	4.21	------	------	------	------
		141	159	154	183	------	------	------
A-349	60% MTB ether + 40% alkylate	-------	258	229	327	406	442	------
		2.50	------	------	------	------	------	------
		143	------	193	------	------	------	------
A-350	80% MTB ether + 20% alkylate	-------	307	271	374	------	------	------
		6.0	------	------	------	------	------	------
		161	------	------	------	------	------	------
A-351	20% MTB ether + 80% one-pass stock	-------	87	91	144	179	194	218
		96.1	0.12	0.08	0.35	1.10	1.72	2.97
		88	105	103	112	127	135	146
A-352	40% MTB ether + 60% one-pass stock	-------	113	112	163	204	225	269
		0.14	1.00	0.41	0.85	2.55	3.79	------
		105	126	114	123	143	152	175
A-353	60% MTB ether + 40% one-pass stock	-------	185	160	230	289	319	376
		0.47	------	2.86	------	------	------	------
		115	173	146	163	195	------	------
A-354	80% MTB ether + 20% one-pass stock	-------	269	237	301	370	------	------
		1.00	------	------	------	------	------	------
		126	------	200	------	------	------	------
A-335	MTB ether[e]	-------	------	330	406	------	------	------
		>6.00	------	------	------	------	------	------
		> 161	------	------	------	------	------	------

[a]Each fuel contains approximately 4 ml TEL/gal.
[e]Values for knock-limited imep were averaged from two curves.

TABLE III - REPRODUCIBILITY OF THE F-4 RATING ENGINE

Item	Fuel-air ratio							
	0.065	0.070	0.075	0.085	0.095	0.100	0.110	0.120
Virgin base stock plus 4 ml TEL per gallon								
Average imep	73	82	95	118	133	137	140	136
Mean deviation	4.0	4.8	5.2	5.2	4.2	3.4	2.1	2.3
Percentage mean deviation	5.5	5.9	5.5	4.4	3.1	2.5	1.5	1.7
Aviation alkylate plus 4 ml TEL per gallon								
Average imep	112	129	147	175	193	198	200	196
Mean deviation	9.1	8.2	7.4	6.8	6.1	5.1	3.6	3.4
Percentage mean deviation	8.1	6.4	5.1	3.9	3.2	2.6	1.8	1.7
One-pass catalytic stock plus 4 ml TEL per gallon[1]								
Average imep	75	82	95	124	153	165	181	183
Mean deviation	4.7	4.1	4.3	5.6	5.8	5.0	4.0	3.3
Percentage mean deviation	6.3	5.0	4.5	4.5	3.8	3.0	2.2	1.8

[1]The knock-limited indicated mean effective pressures for one-pass catalytic stock plus 4 ml TEL/gal (from figs. 3(c) and 8(c)) were omitted in making the calculations because the engine operation was unsatisfactory when these data were obtained.

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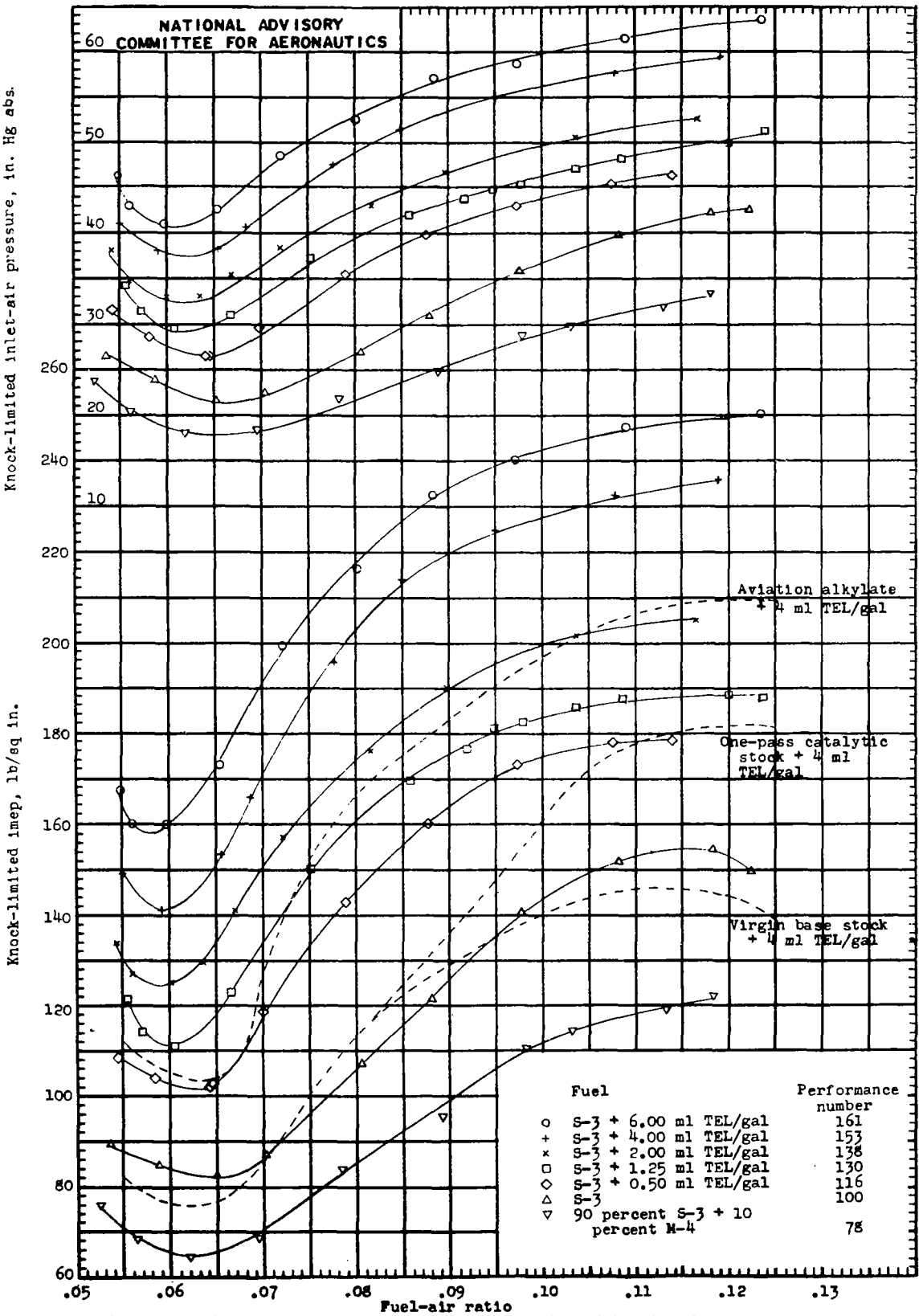


Figure 1. - Knock-limited performance of reference fuels and bracketed performance of base fuels as determined in an F-4 rating engine.

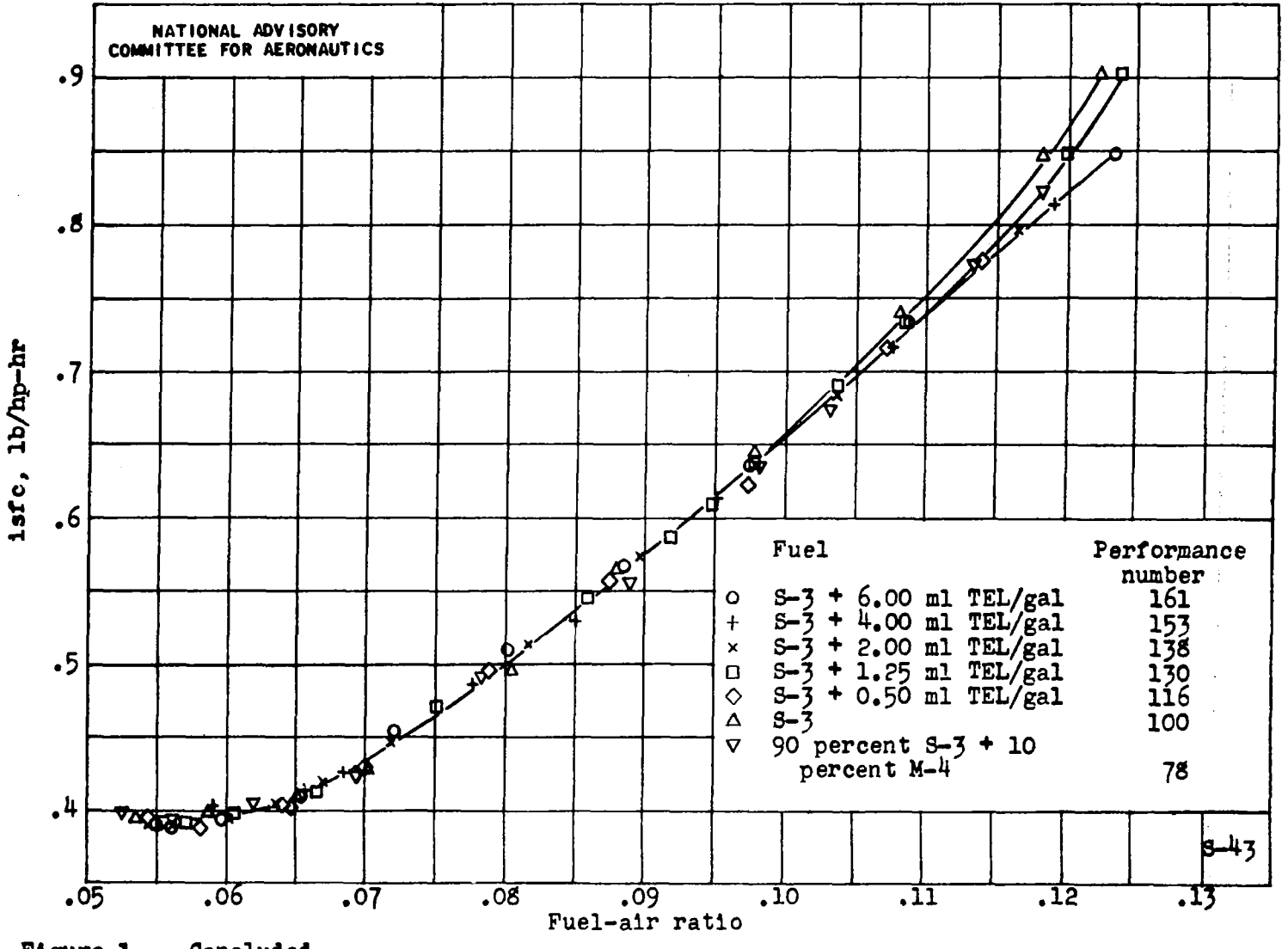
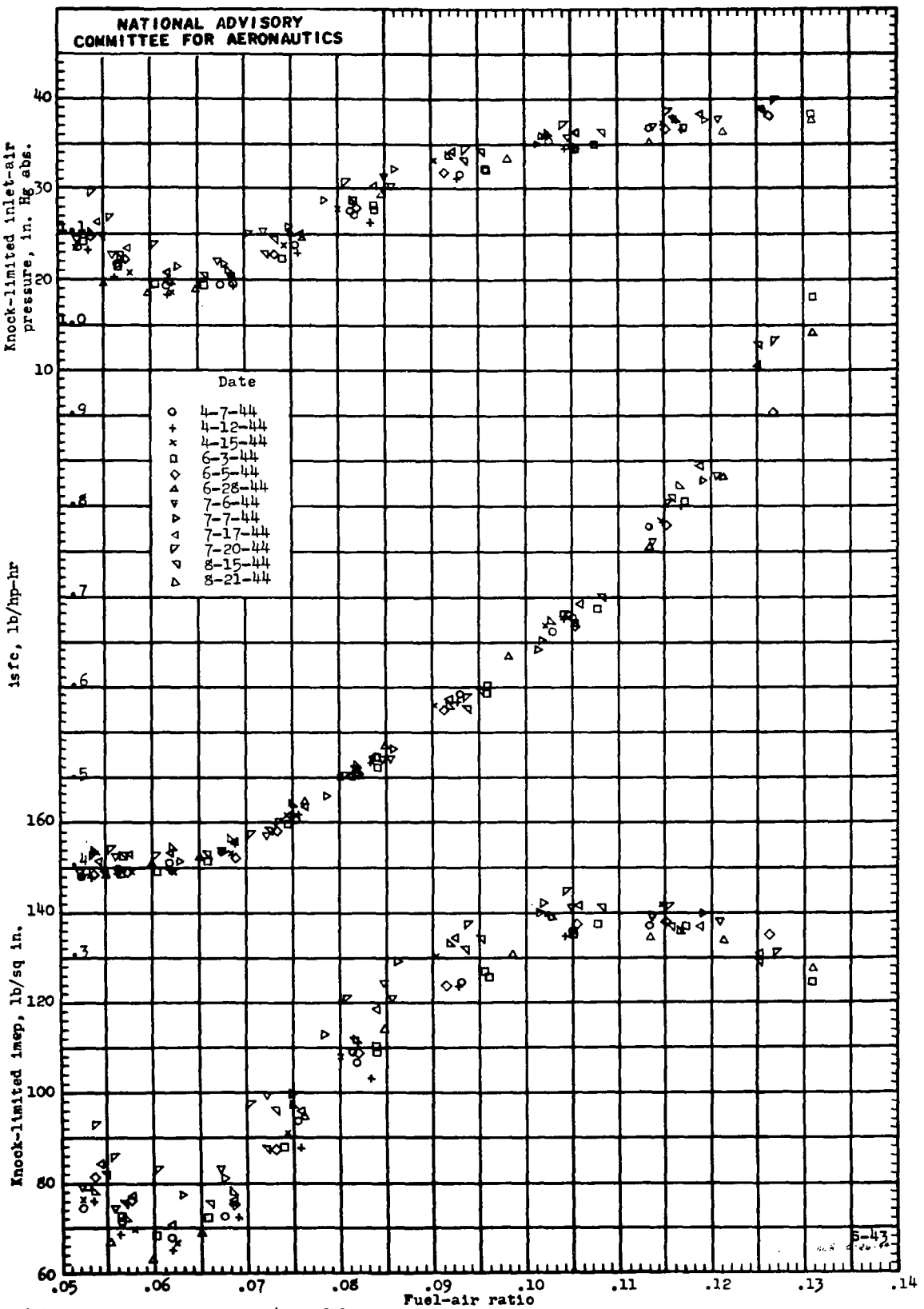
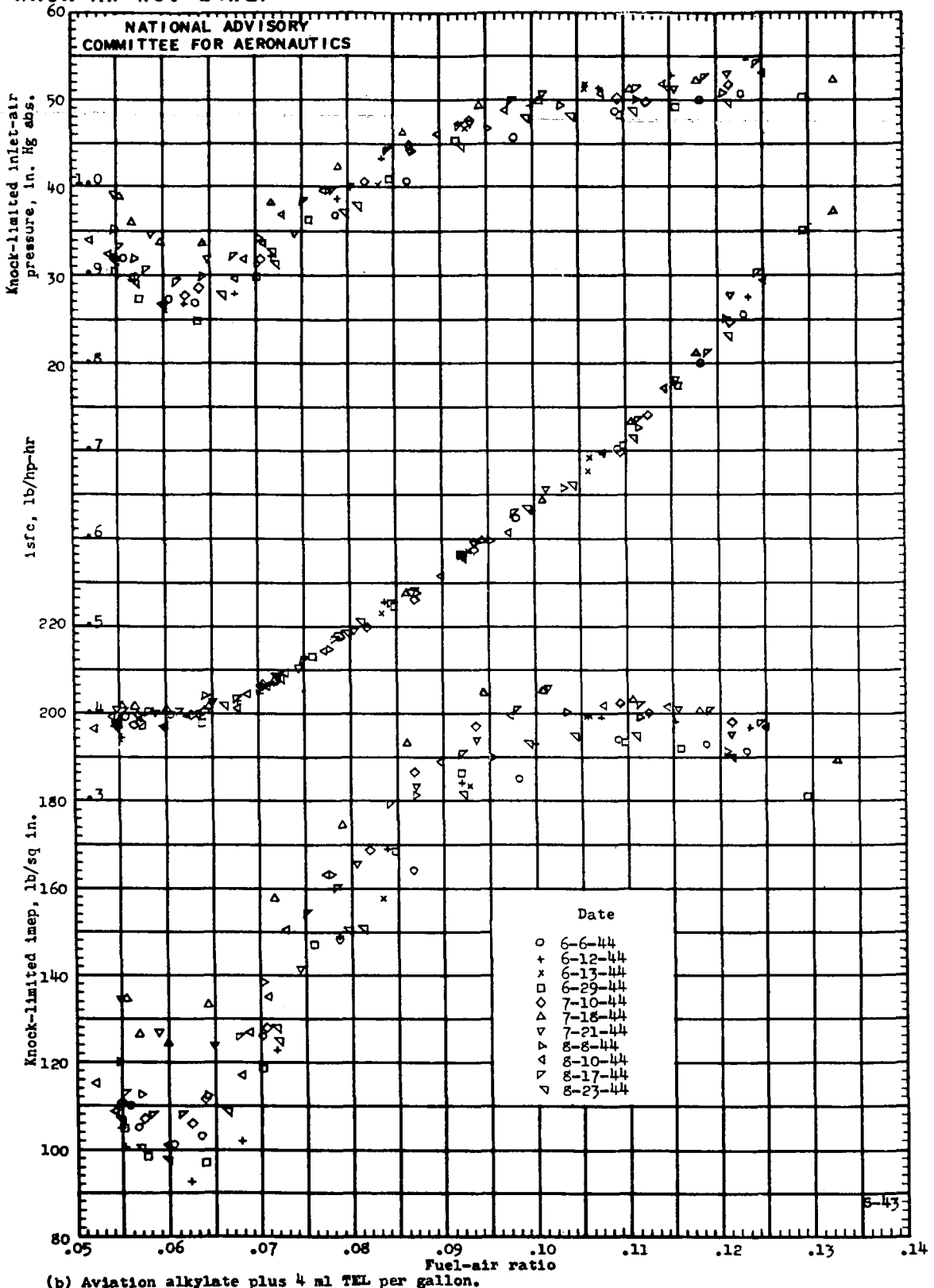


Figure 1. - Concluded.

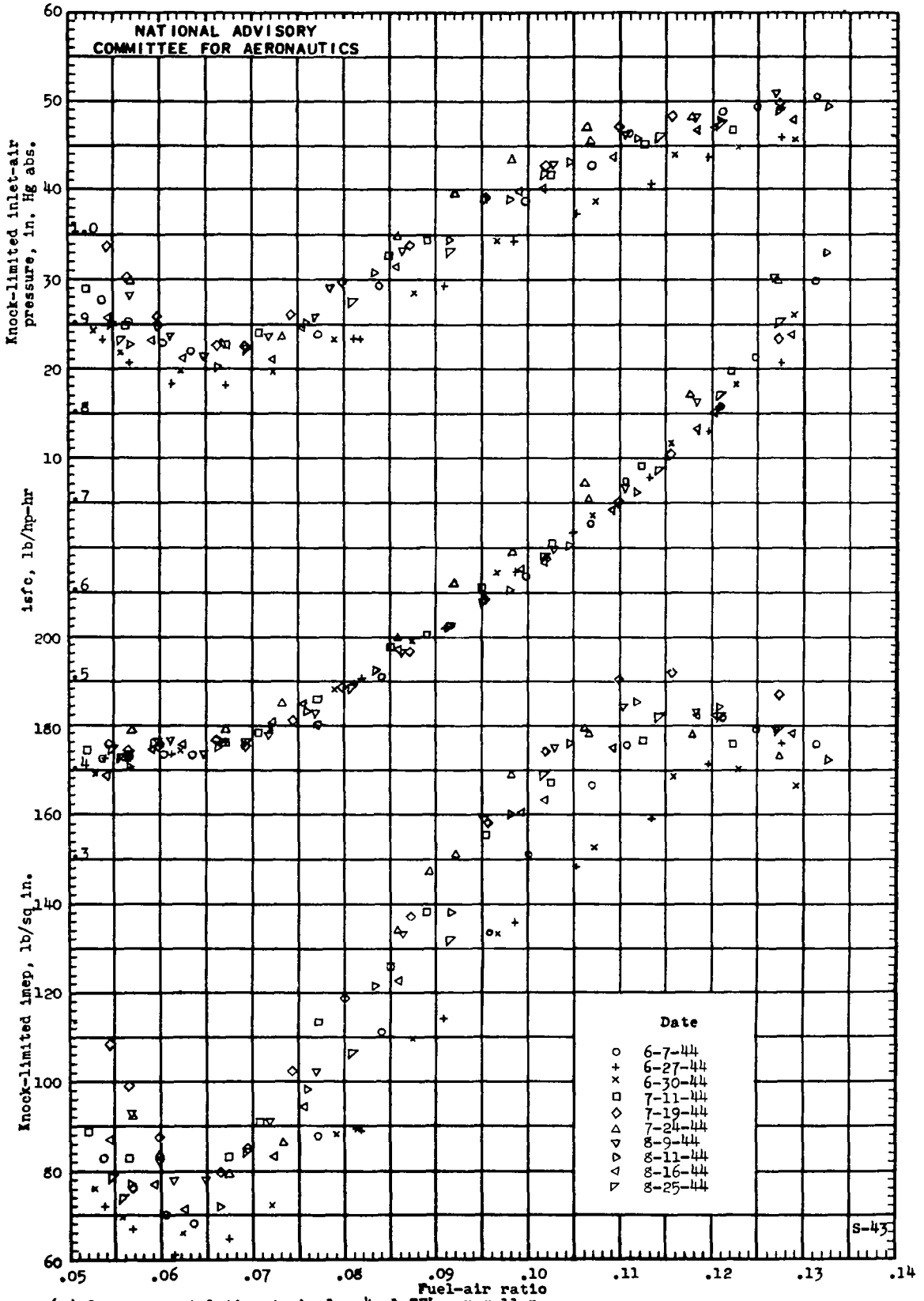


(a) Virgin base stock plus 4 ml TEL per gallon.

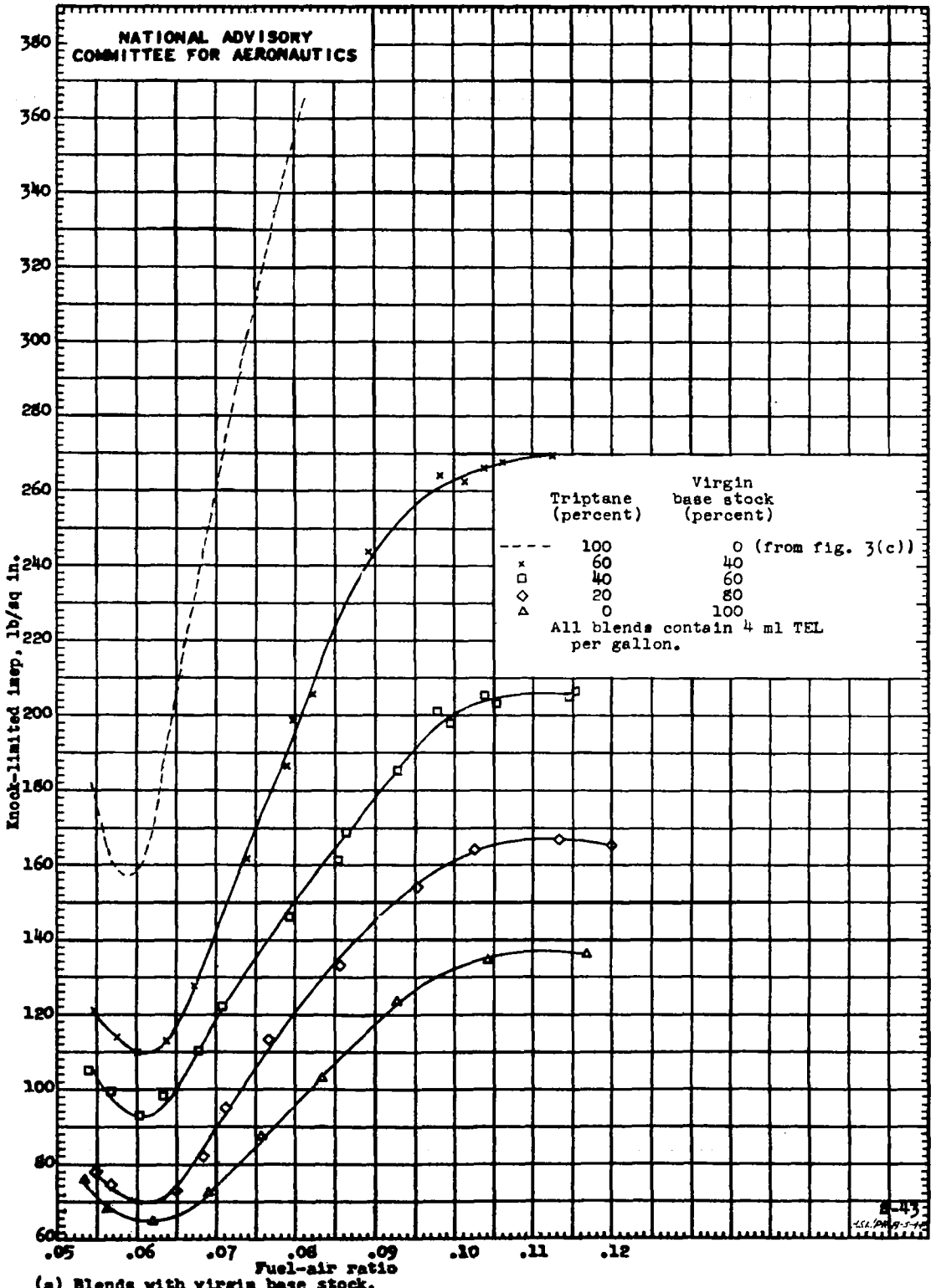
Figure 2. - Reproducibility of engine results obtained in an F-4 rating engine.



(b) Aviation alkylate plus 4 ml TEL per gallon.
Figure 2. - Continued.

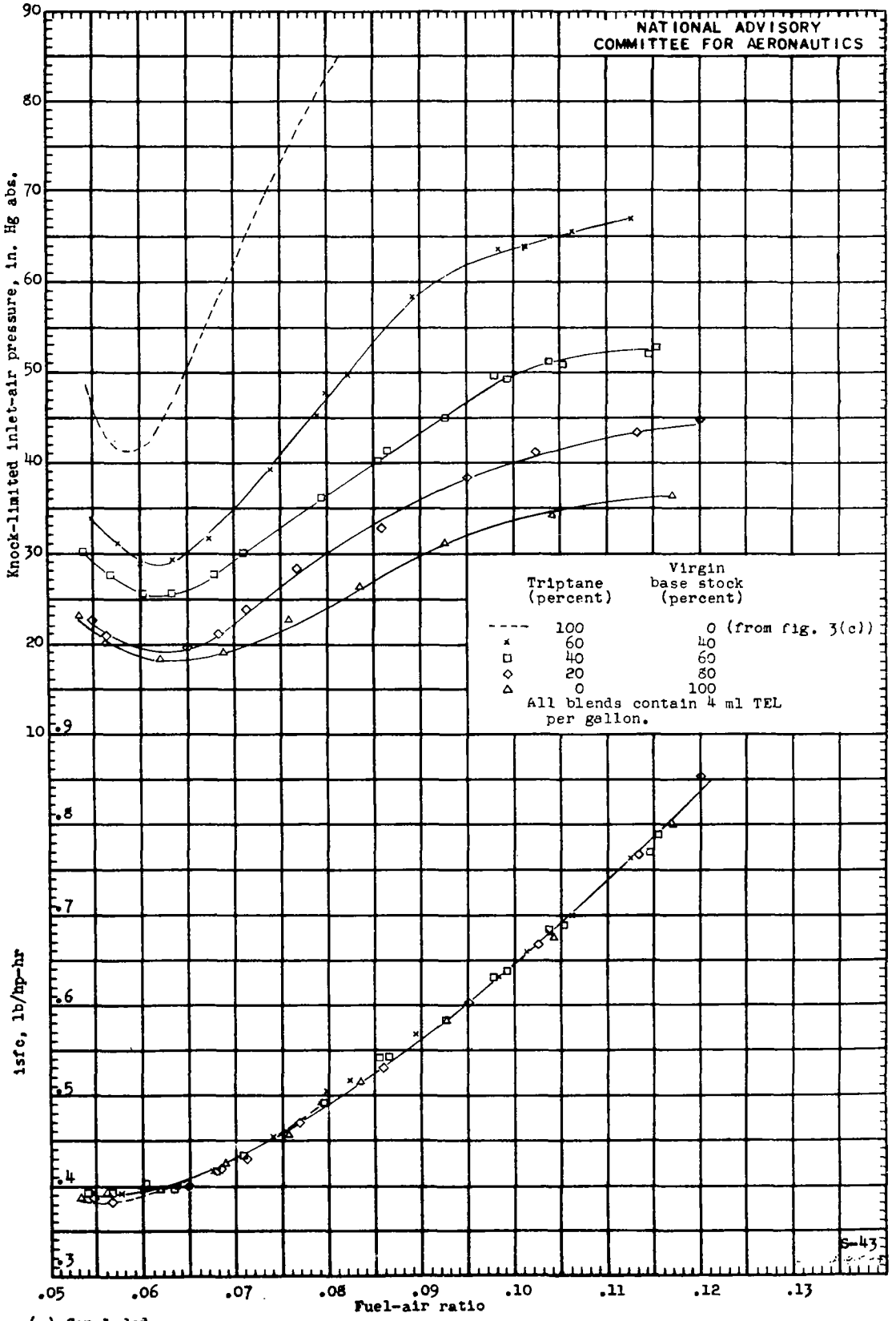


(c) One-pass catalytic stock plus 4 ml TEL per gallon.
Figure 2. - Concluded.

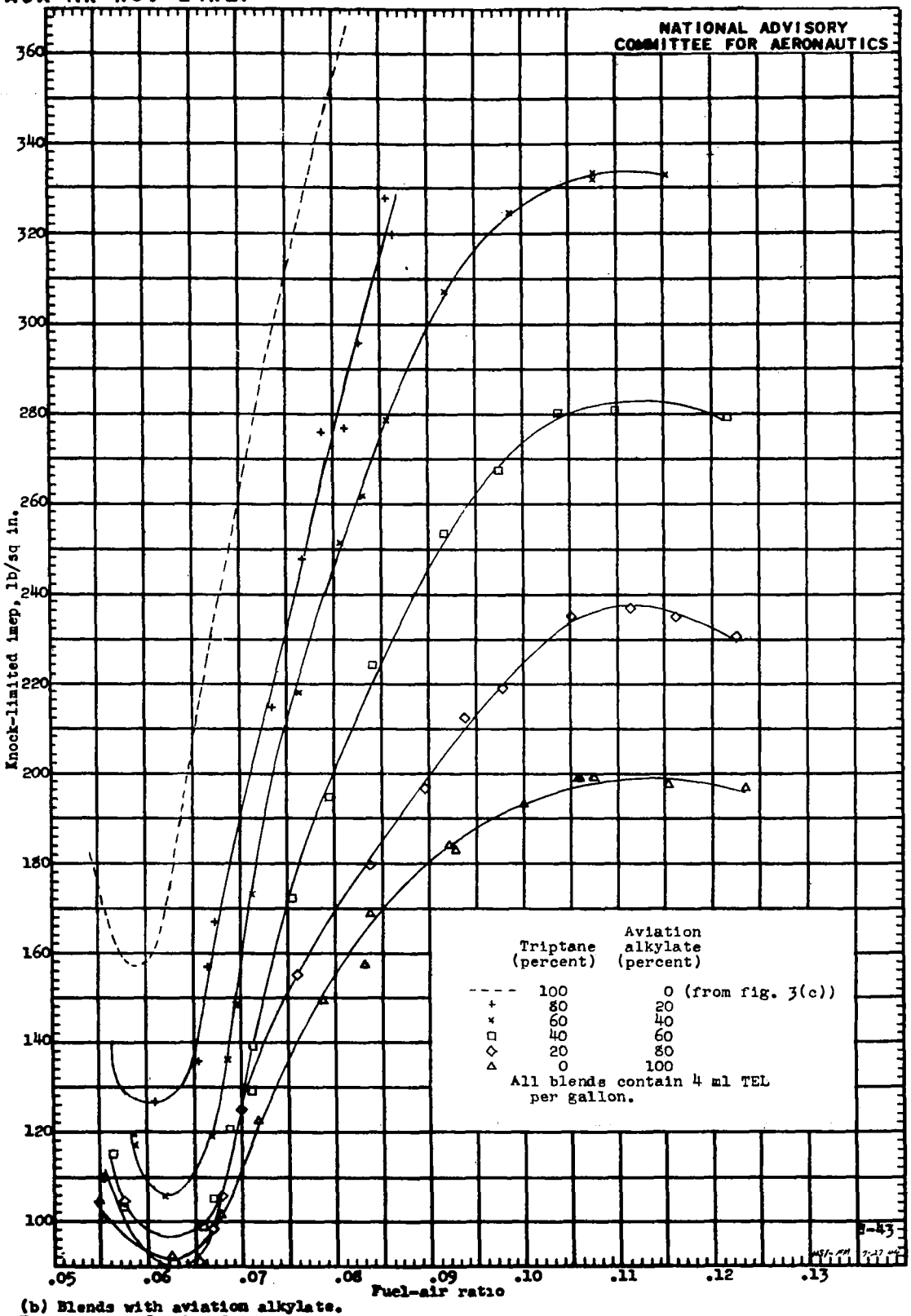


(a) Blends with virgin base stock.

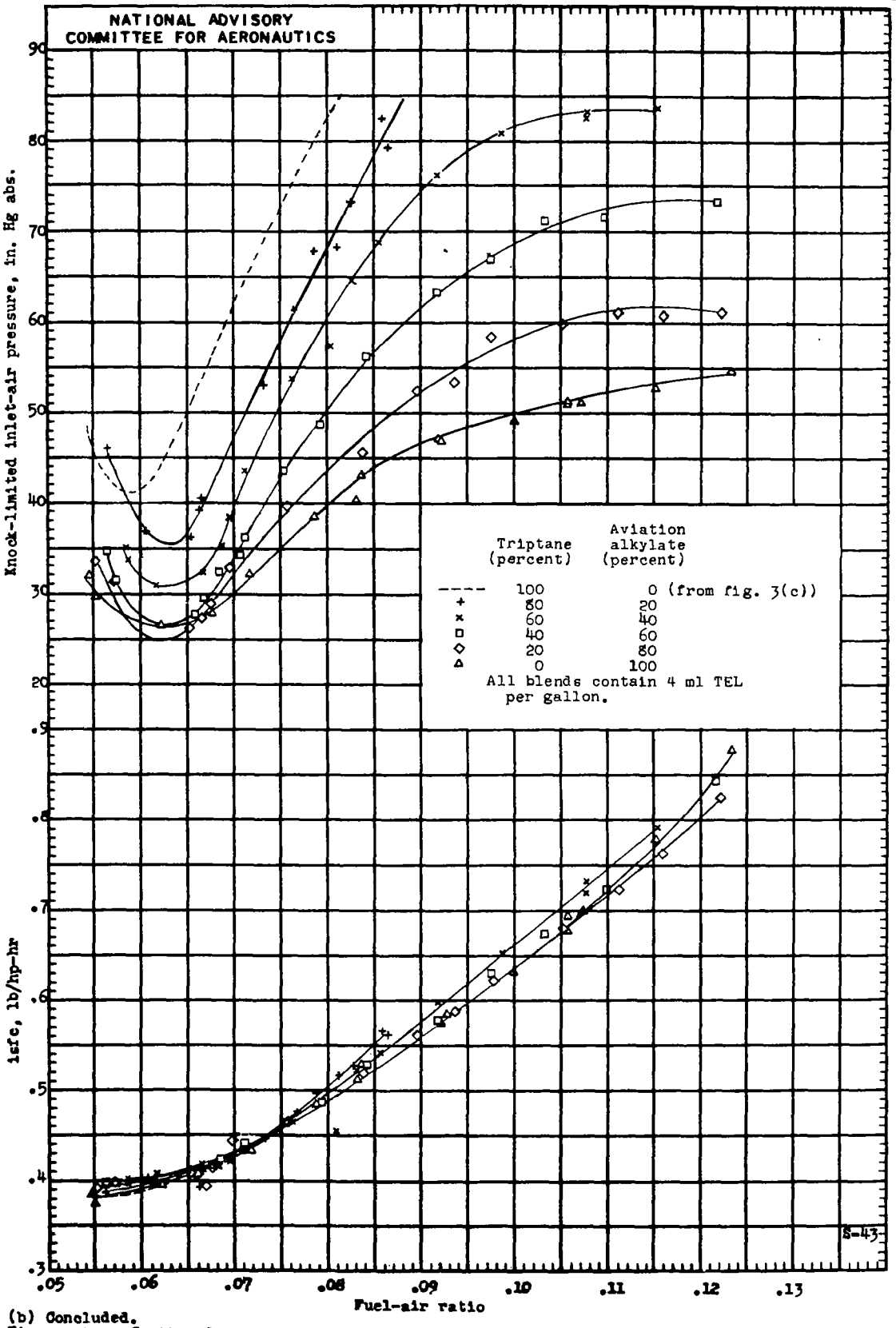
Figure 3. - Knock-limited performance of blends of triptane (2,2,3-trimethylbutane) with virgin base stock, aviation alkylate, and one-pass catalytic stock as determined in an F-4 rating engine.



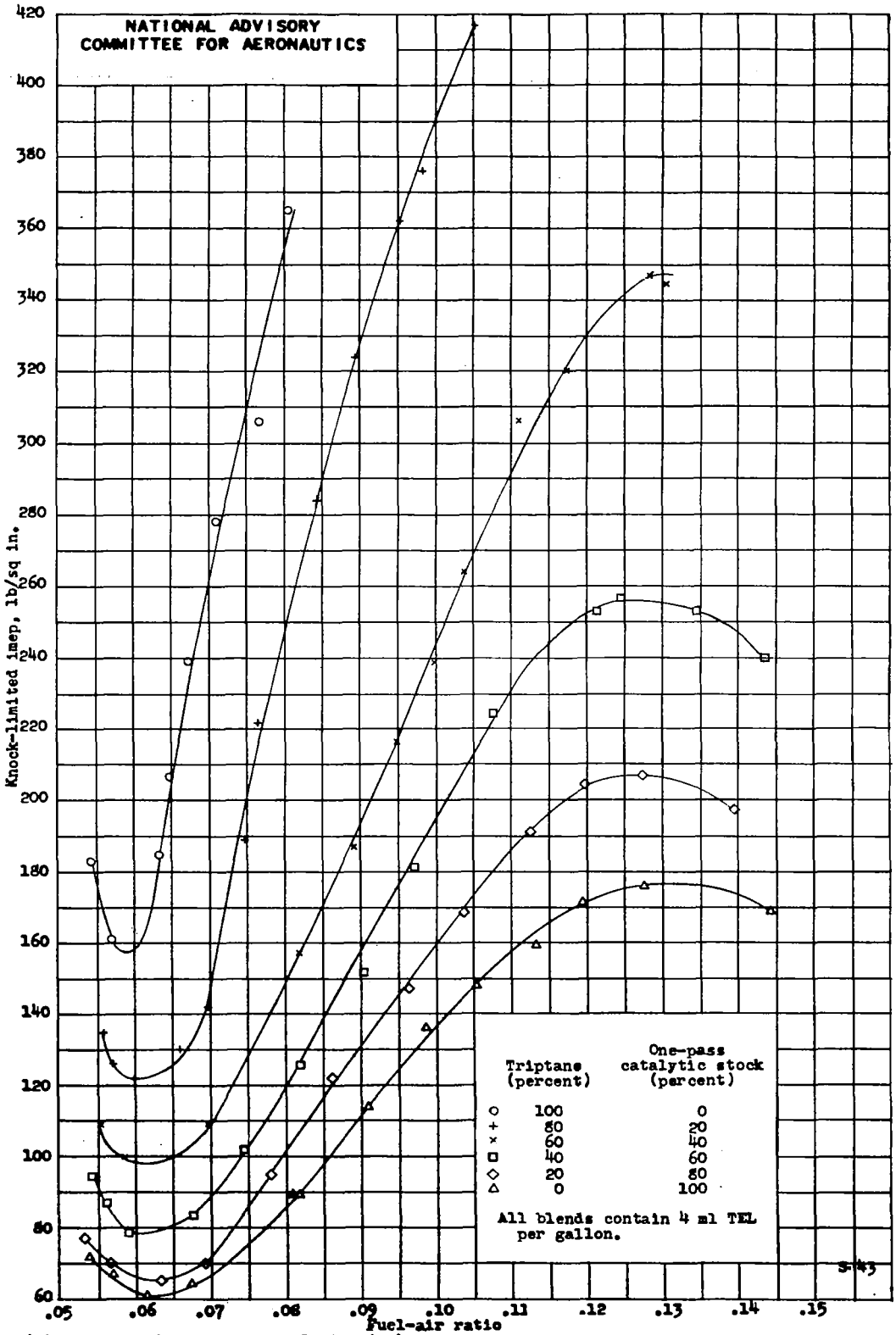
(a) Concluded.
Figure 3. - Continued.



(b) Blends with aviation alkylate.
Figure 3. - Continued.

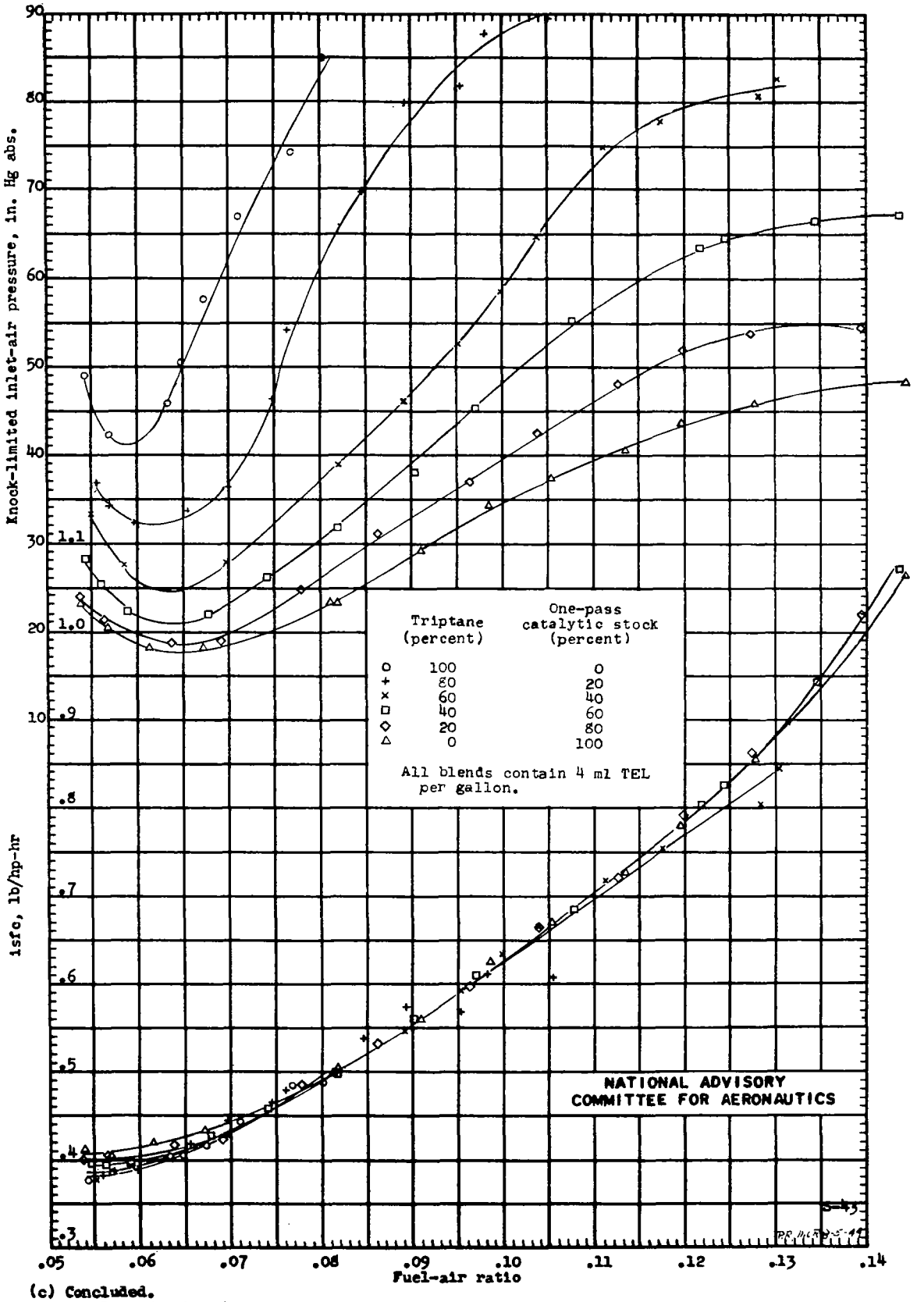


(b) Concluded.
Figure 3. - Continued.



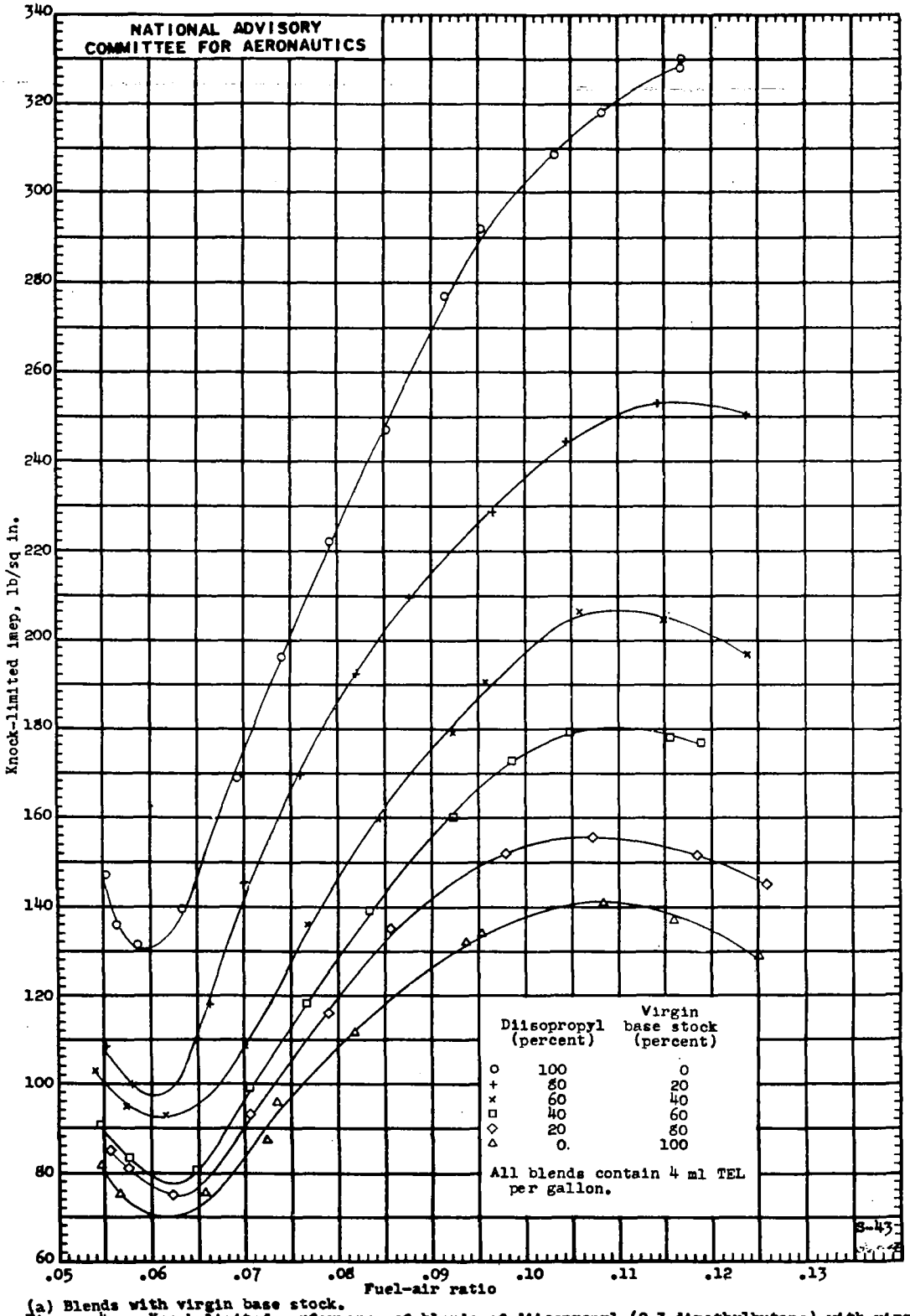
(c) Blends with one-pass catalytic stock.

Figure 3. - Continued.



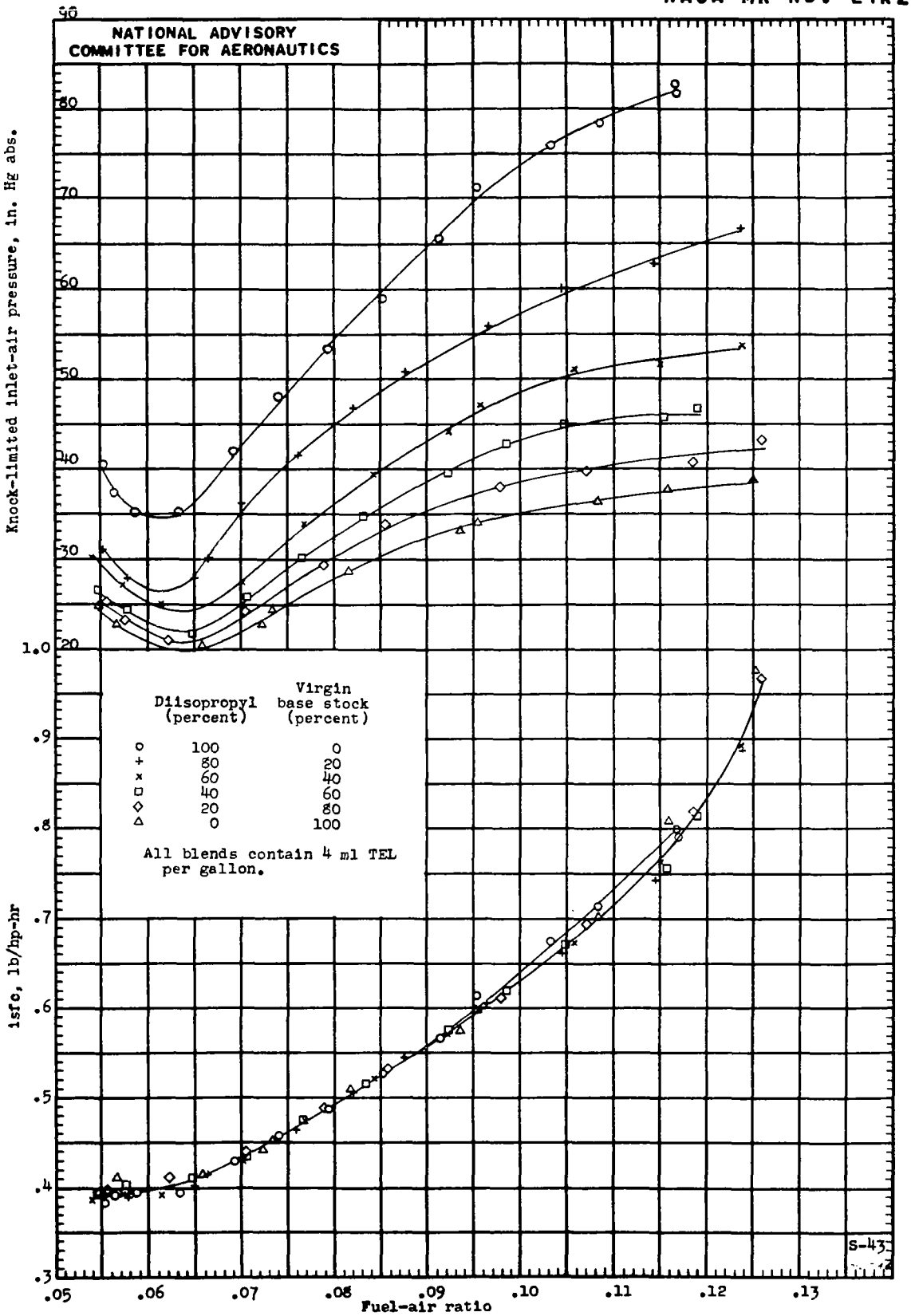
(c) Concluded.

Figure 3. - Concluded.

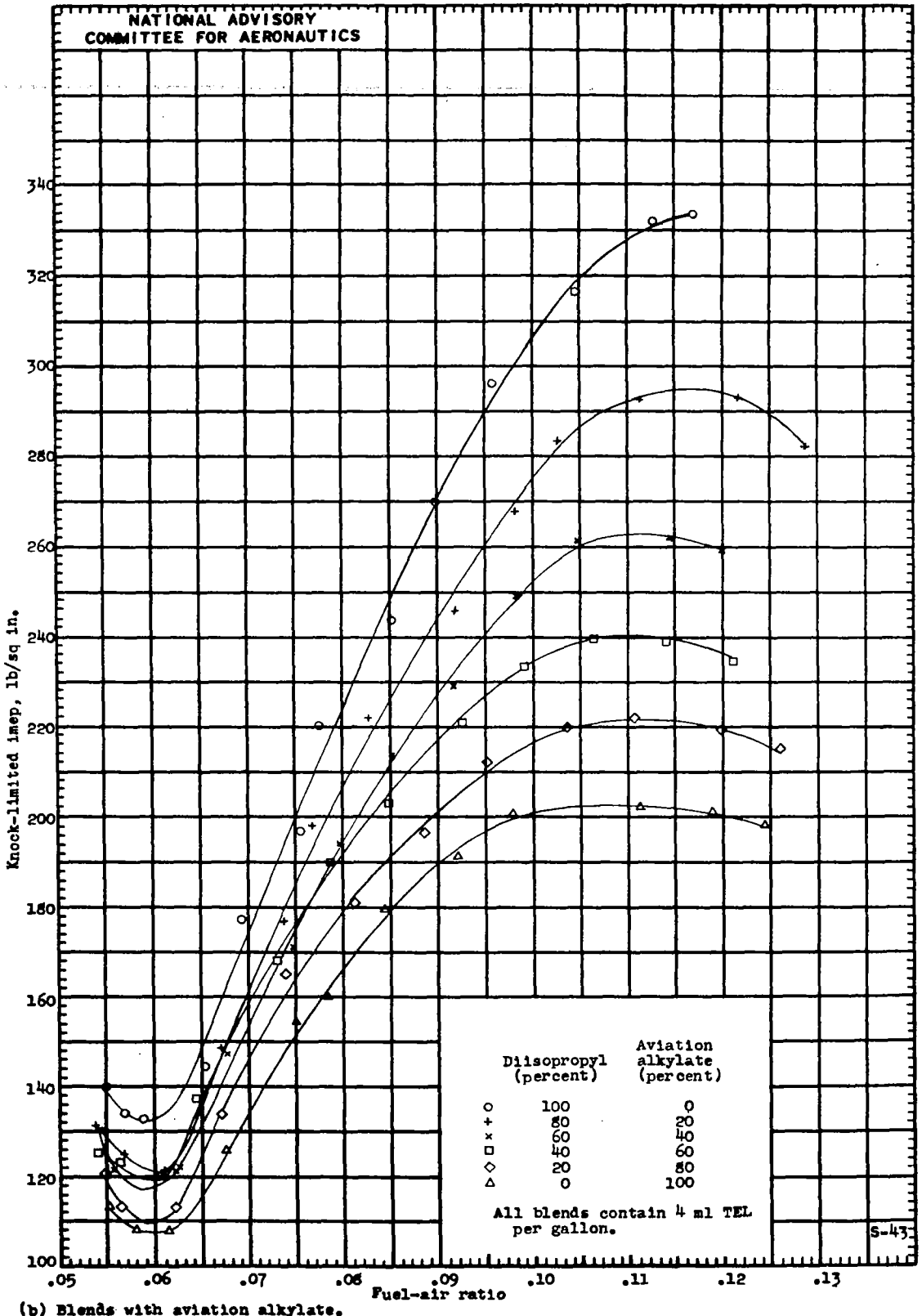


(a) Blends with virgin base stock.

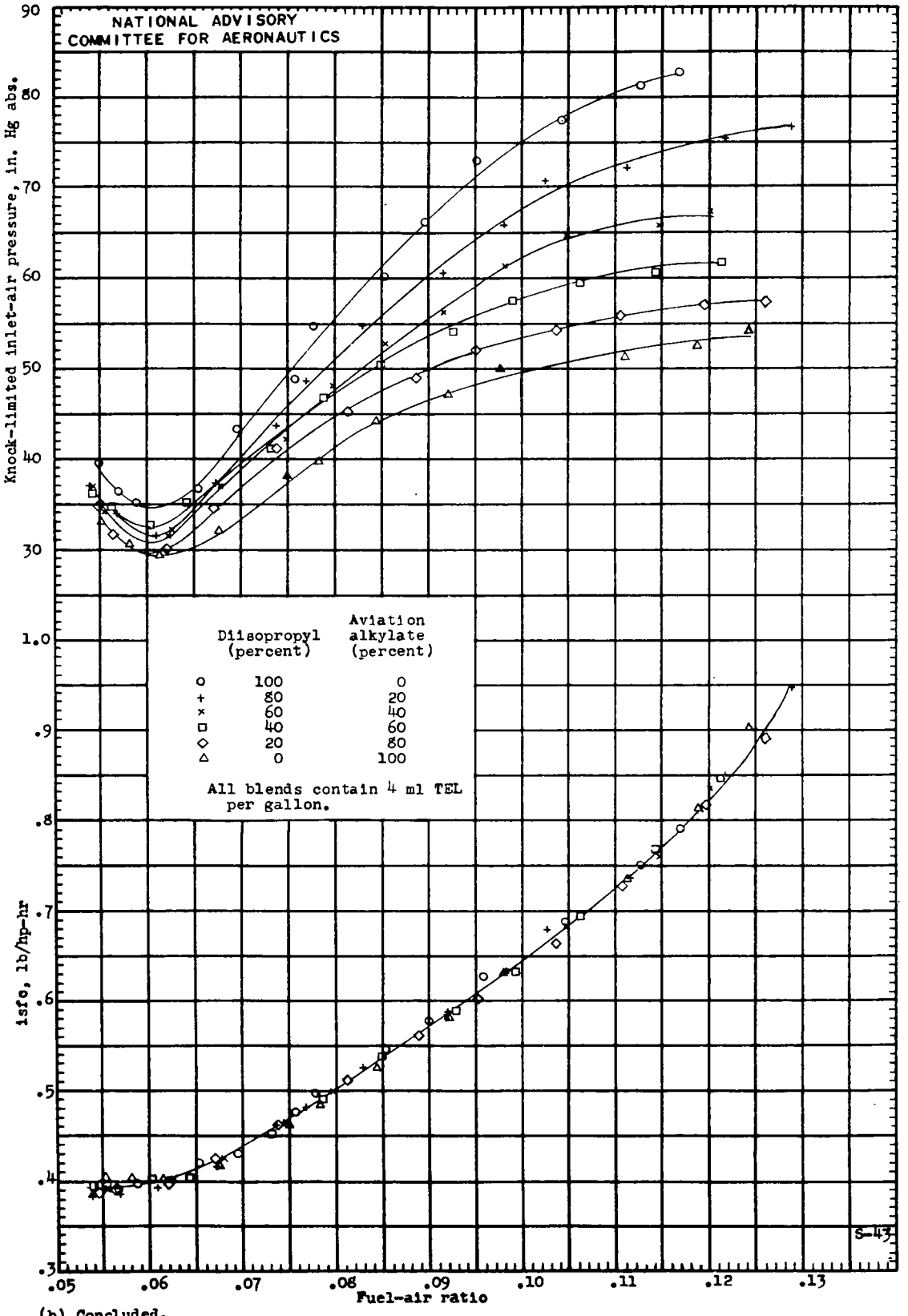
Figure 4. - Knock-limited performance of blends of diisopropyl (2,3-dimethylbutane) with virgin base stock, aviation alkylate, and one-pass catalytic stock as determined in an F-4 rating engine.



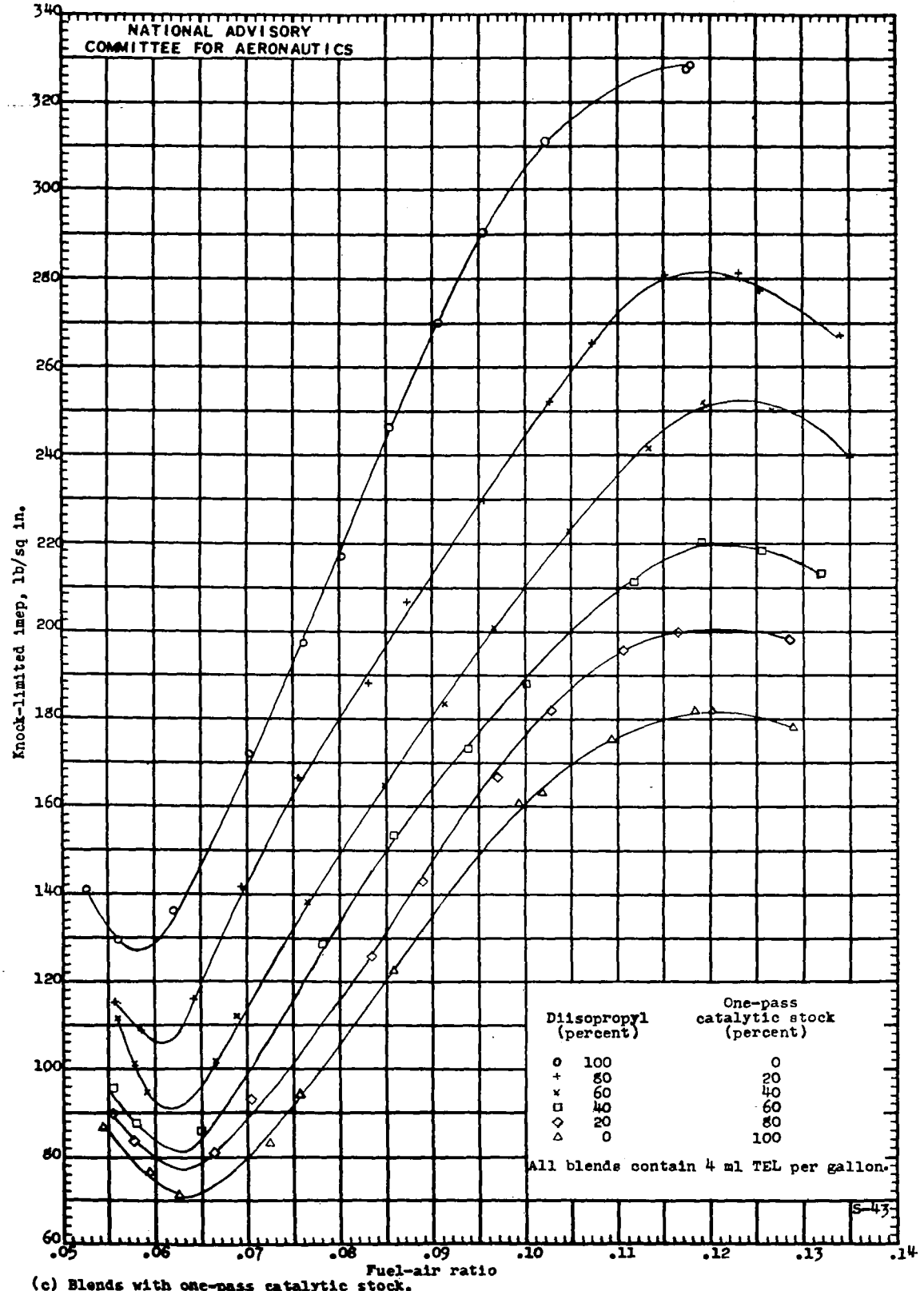
(a) Concluded.
Figure 4. - Continued.



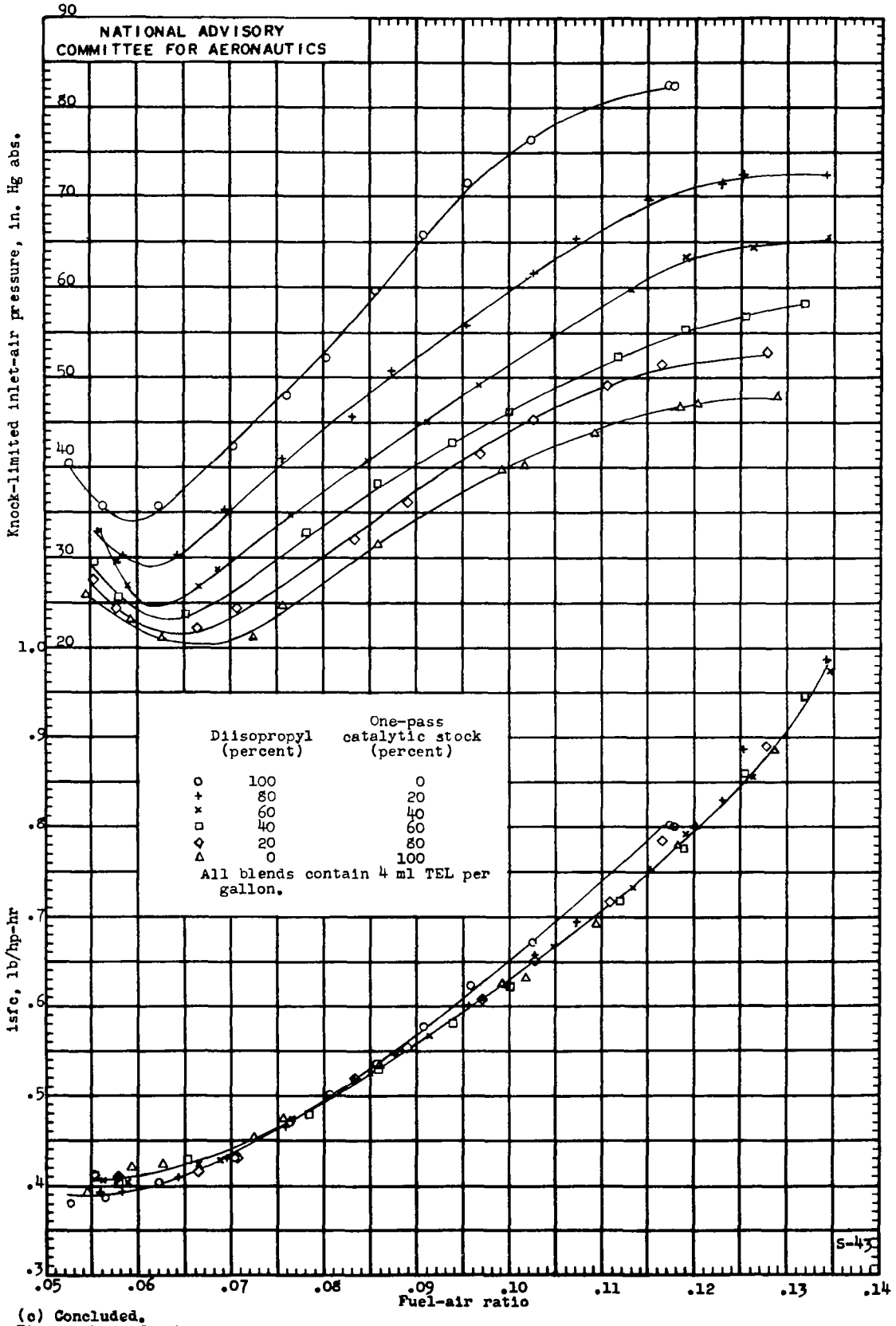
(b) Blends with aviation alkylate.
Figure 4. - Continued.



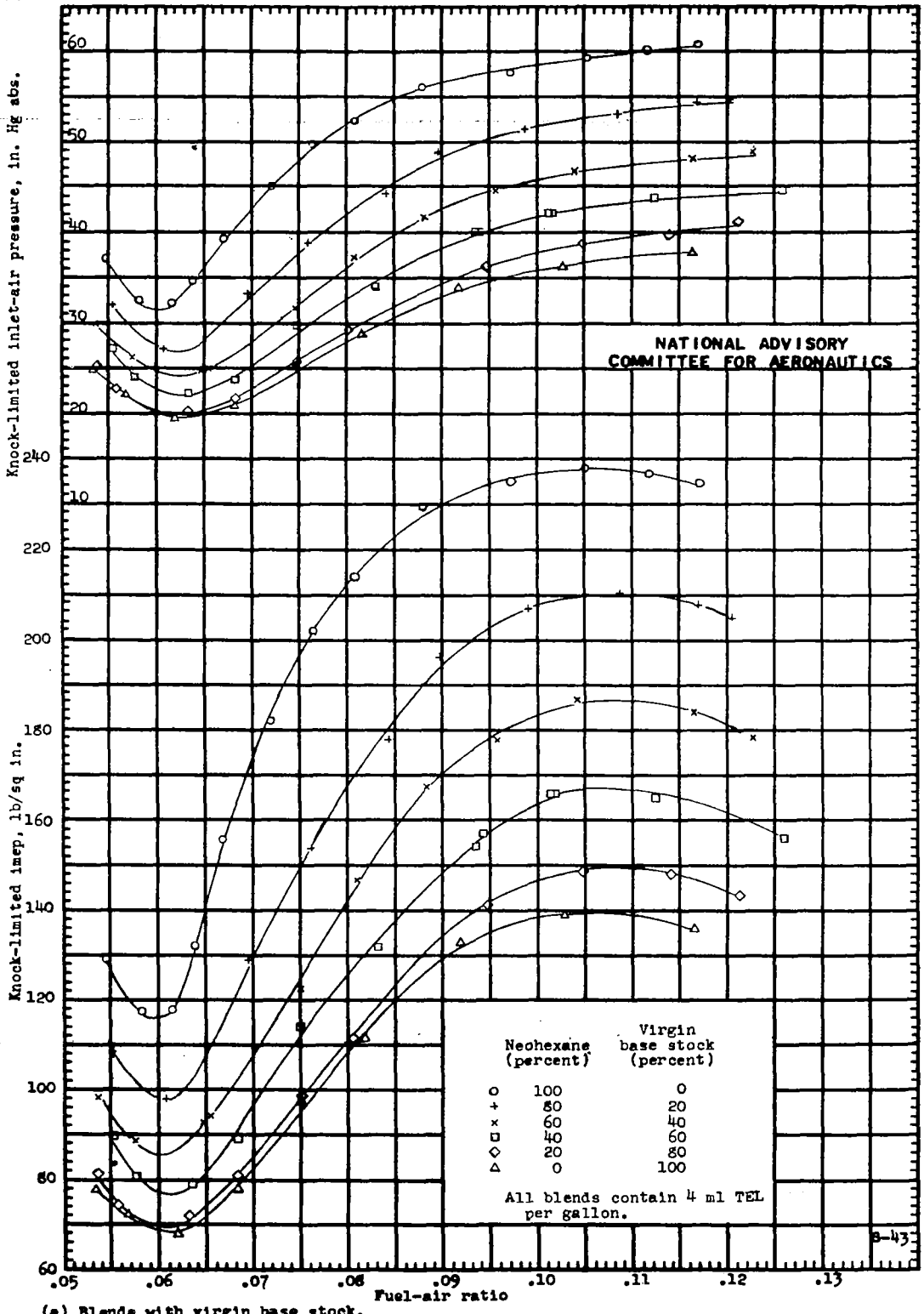
(b) Concluded.
Figure 4. - Continued.



(c) Blends with one-pass catalytic stock.
Figure 4. - Continued.

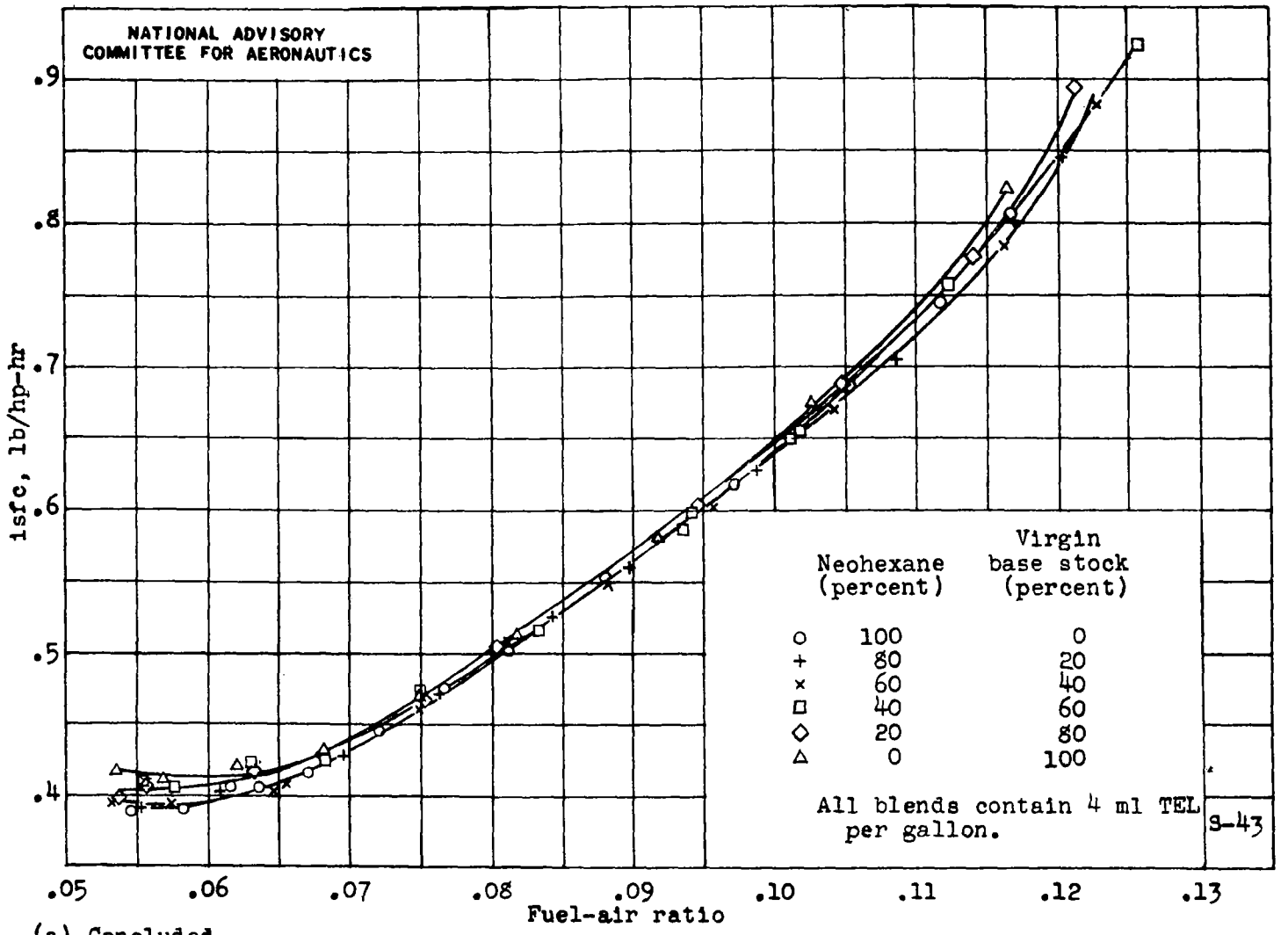


(c) Concluded.
Figure 4. - Concluded.

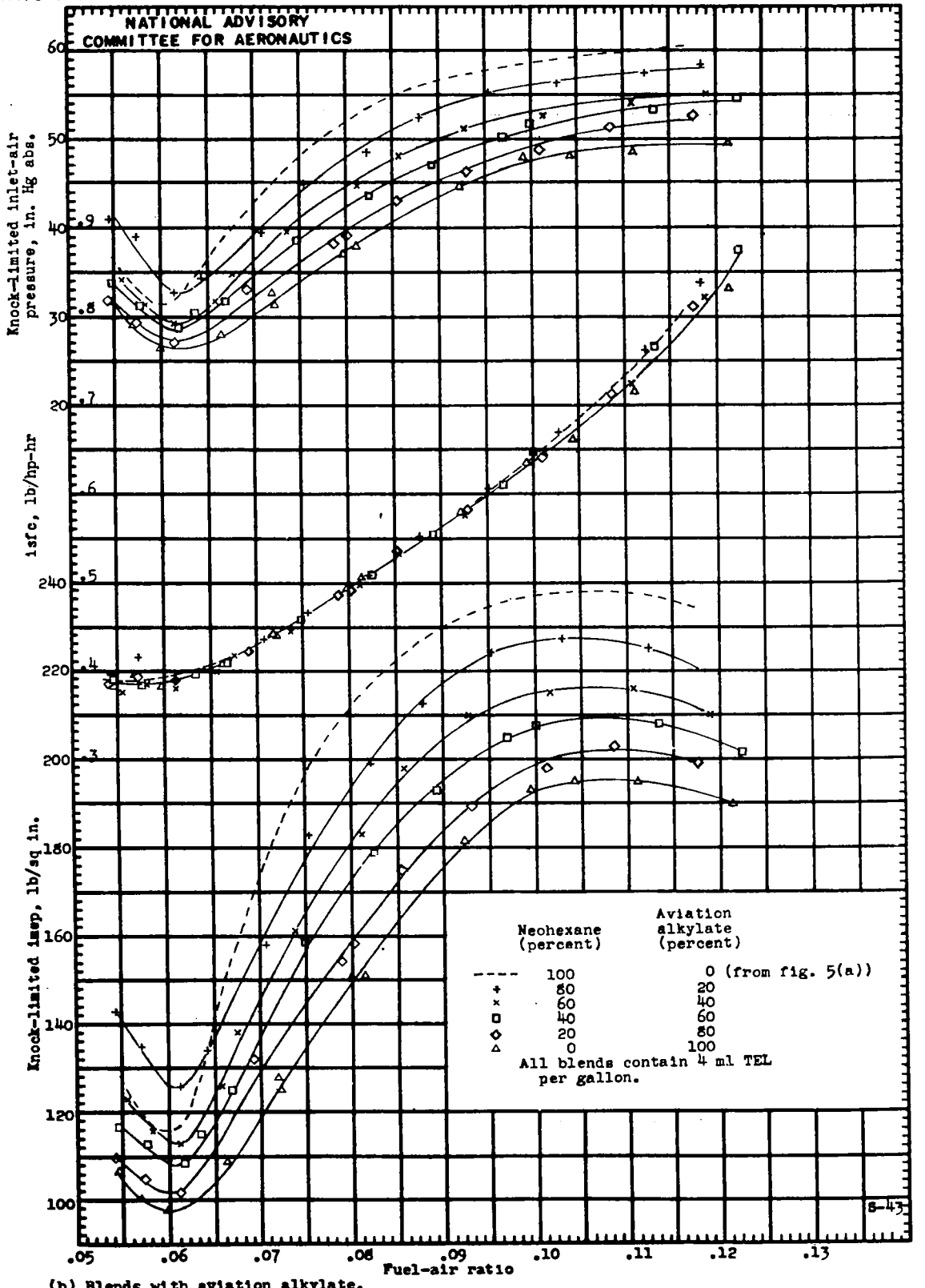


(a) Blends with virgin base stock.

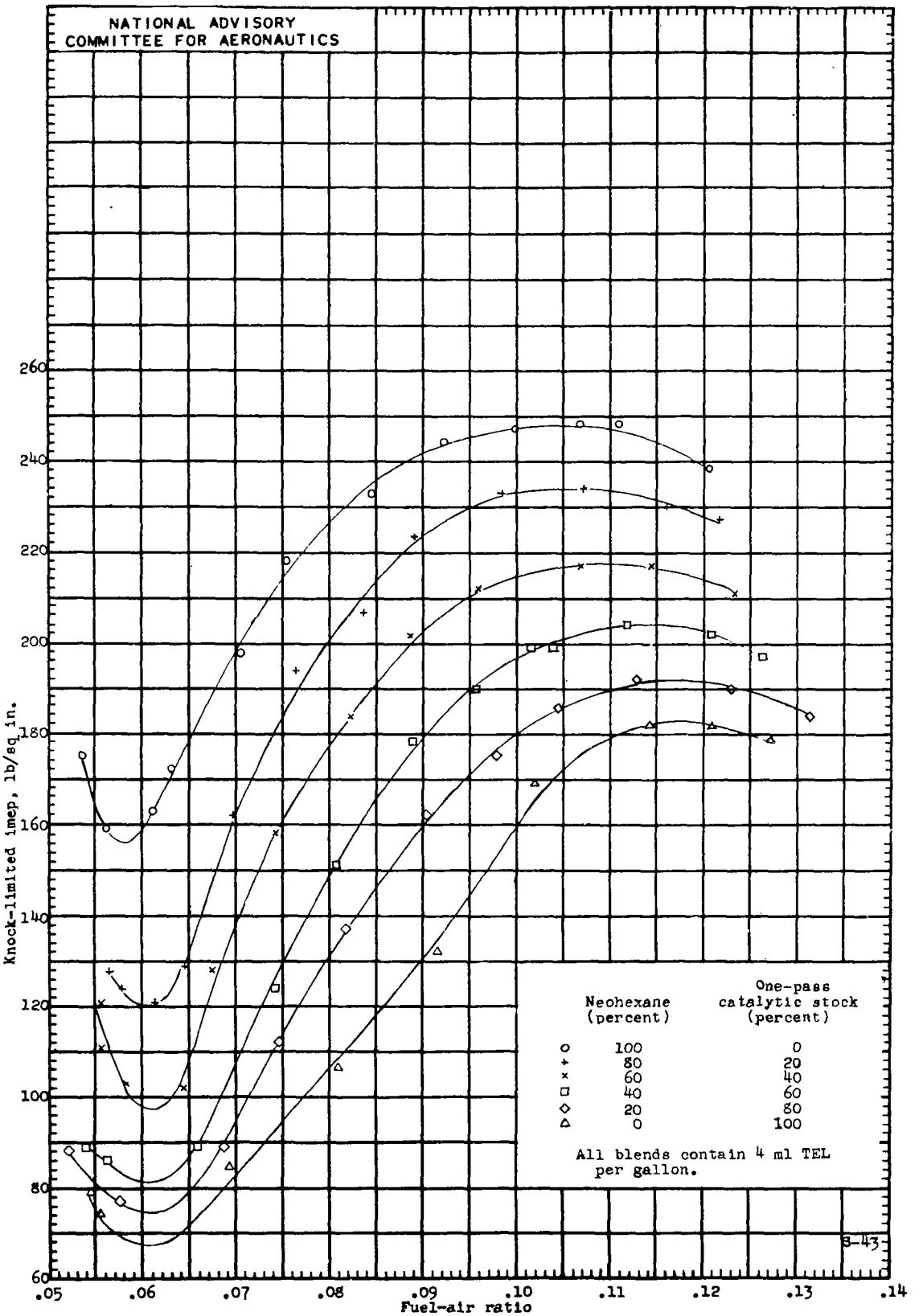
Figure 5. - Knock-limited performance of blends of neohexane (2,2-dimethylbutane) with virgin base stock, aviation alkylate, and one-pass catalytic stock as determined in an F-4 rating engine.



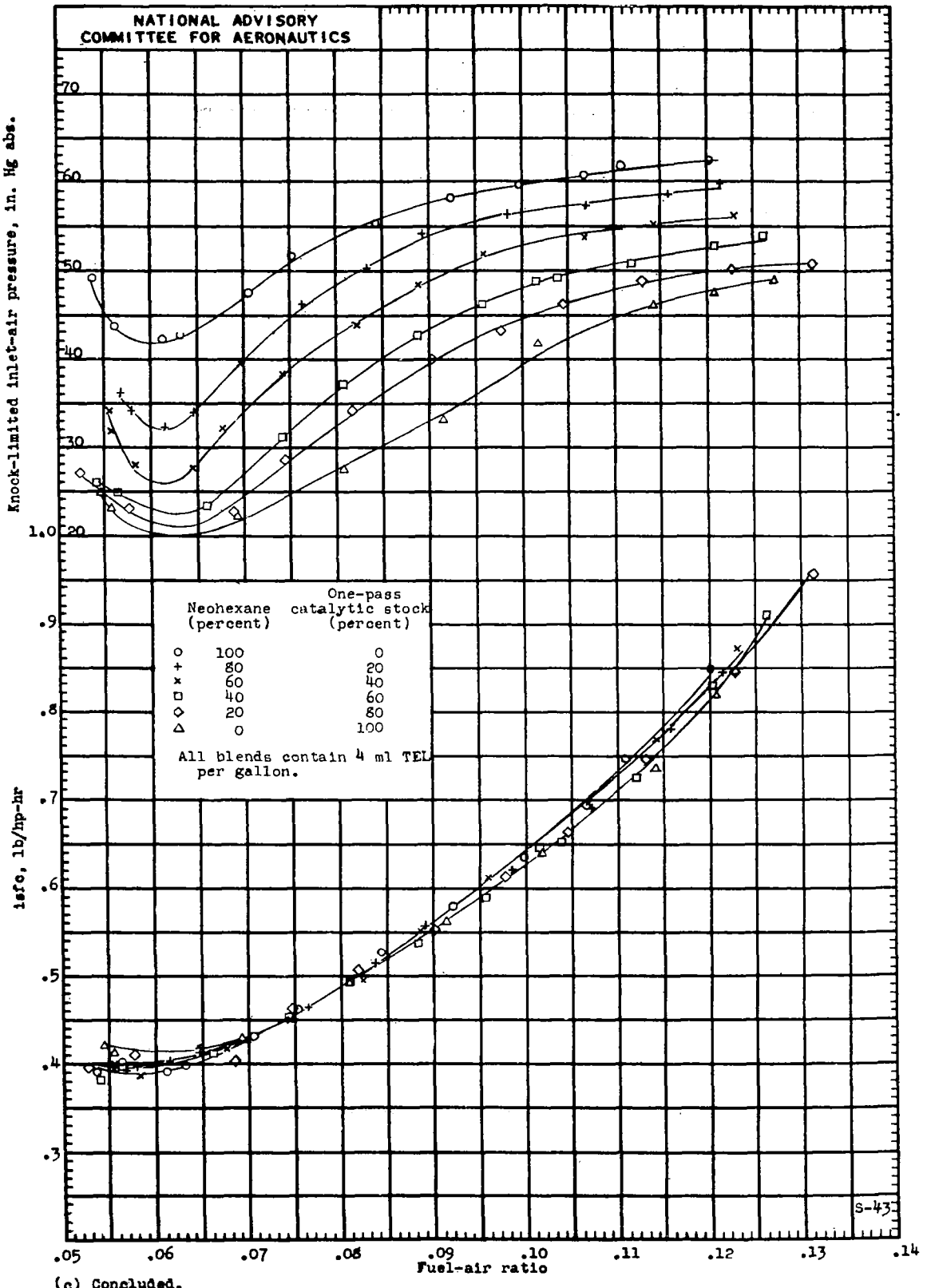
(a) Concluded.
Figure 5. - Continued.



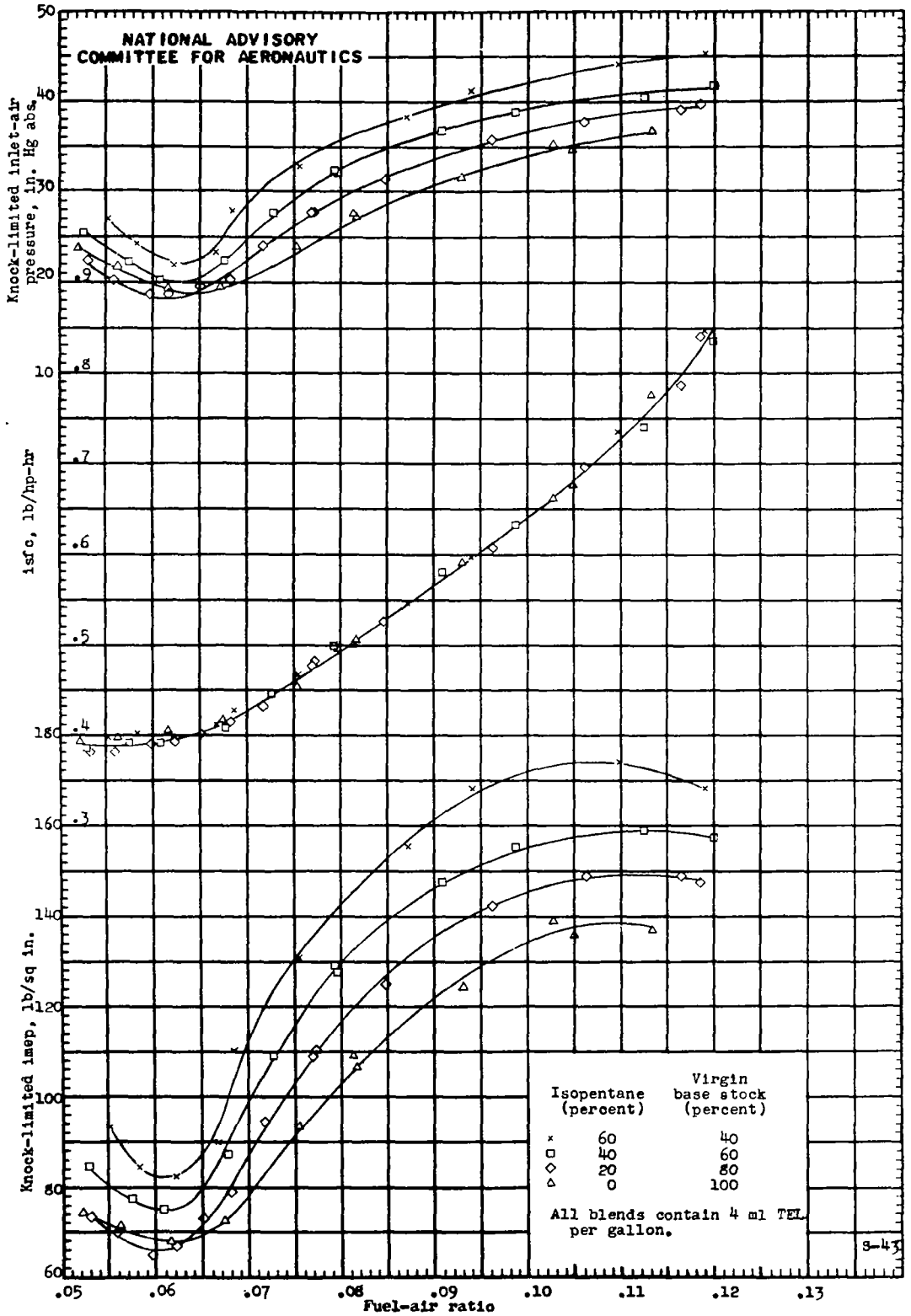
(b) Blends with aviation alkylate.
Figure 5. - Continued.



(c) Blends with one-pass catalytic stock.
Figure 5. - Continued.

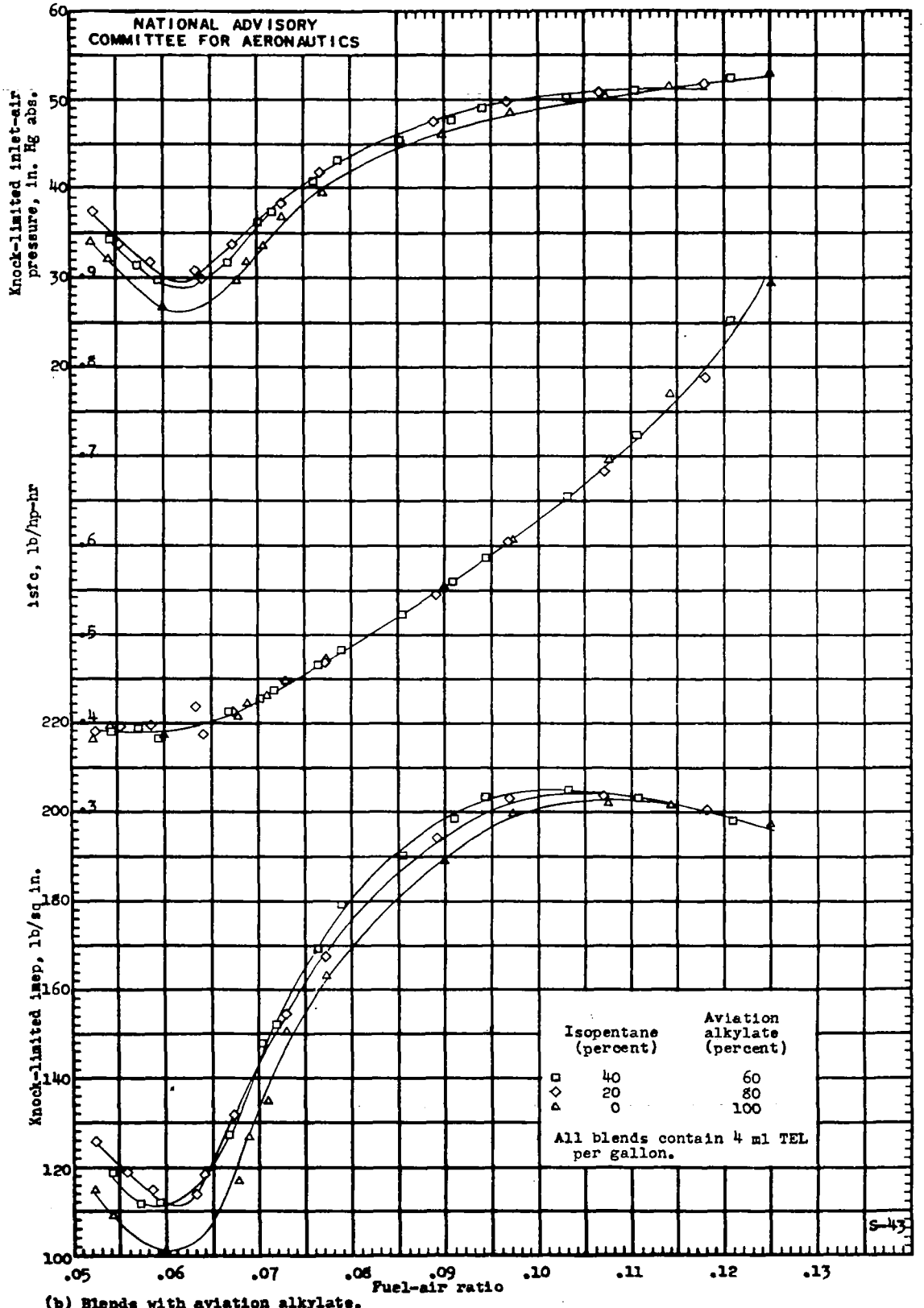


(c) Concluded.
Figure 5. - Concluded.

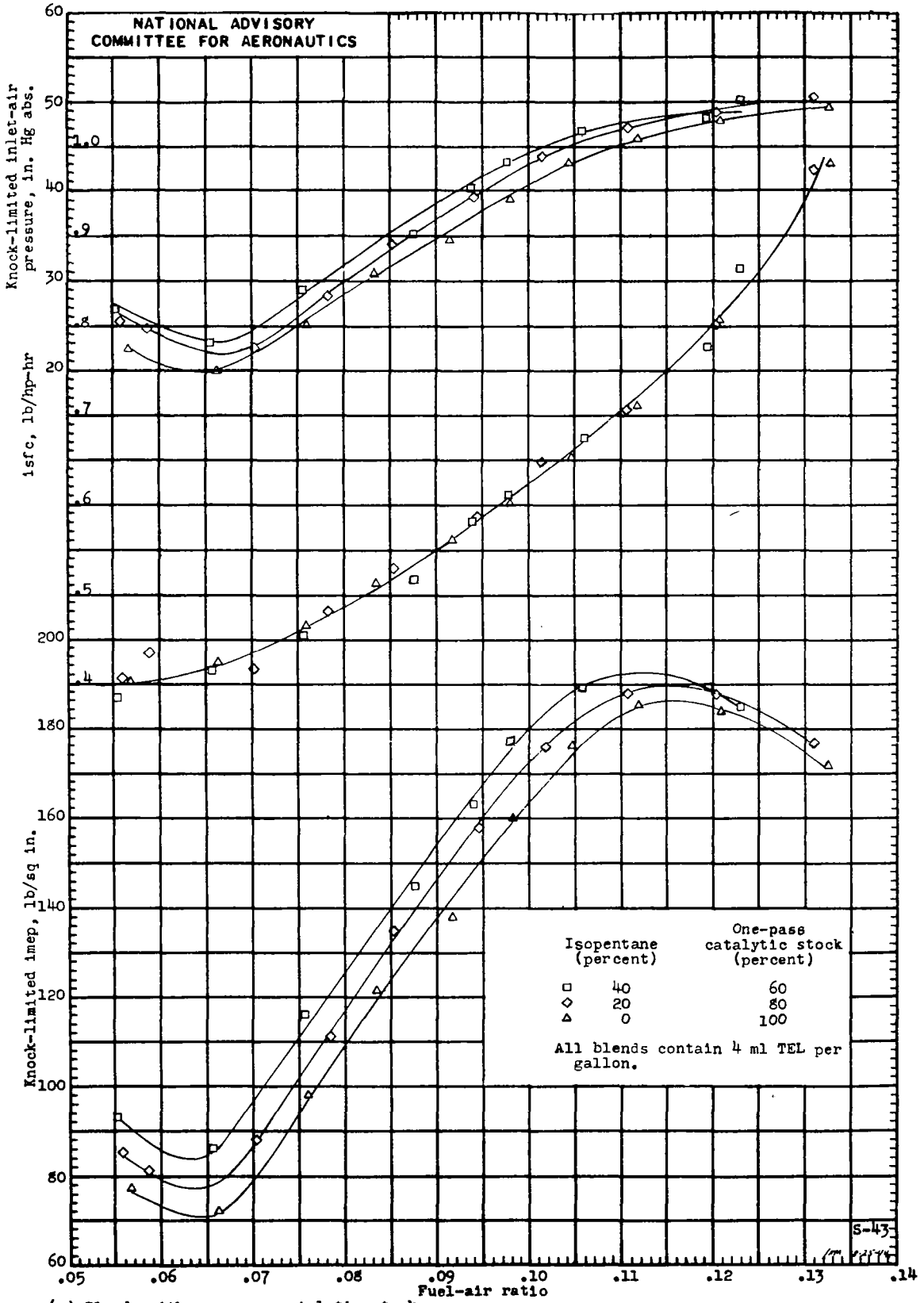


(a) Blends with virgin base stock.

Figure 6. - Knock-limited performance of blends of isopentane (2-methylbutane) with virgin base stock, aviation alkylate, and one-pass catalytic stock as determined in an F-4 rating engine.

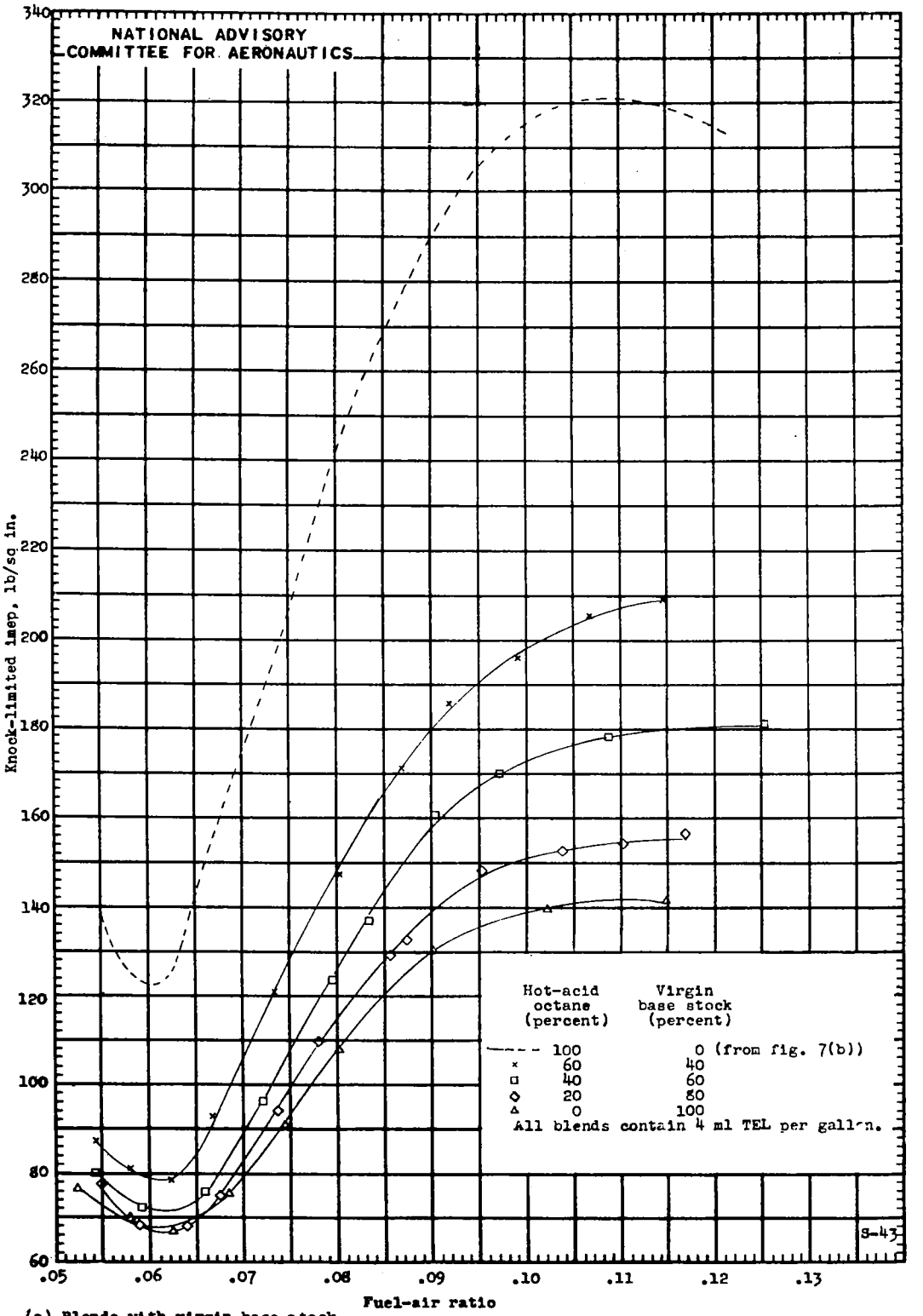


(b) Blends with aviation alkylate.
Figure 6. - Continued.



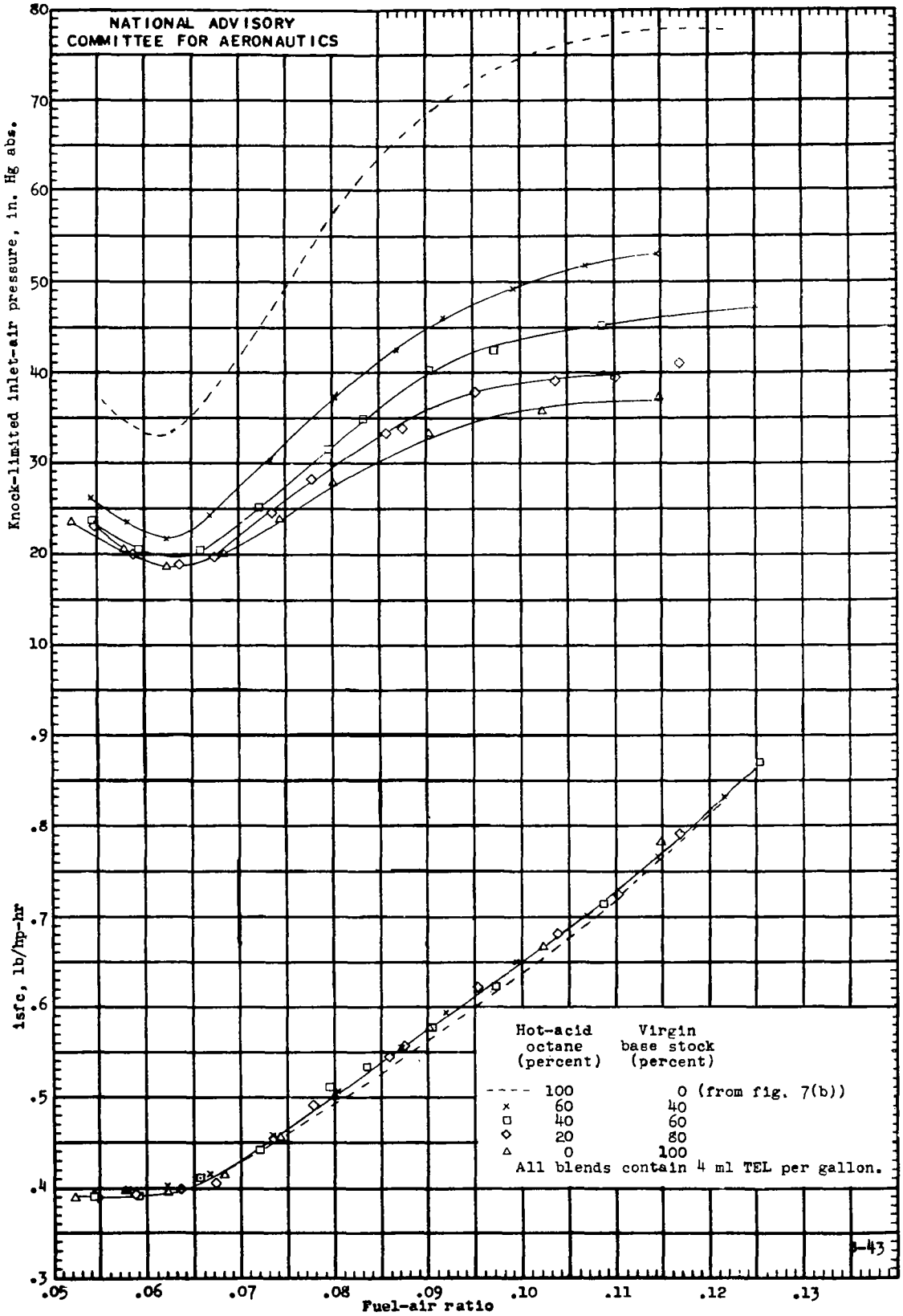
(c) Blends with one-pass catalytic stock.

Figure 6. - Concluded.

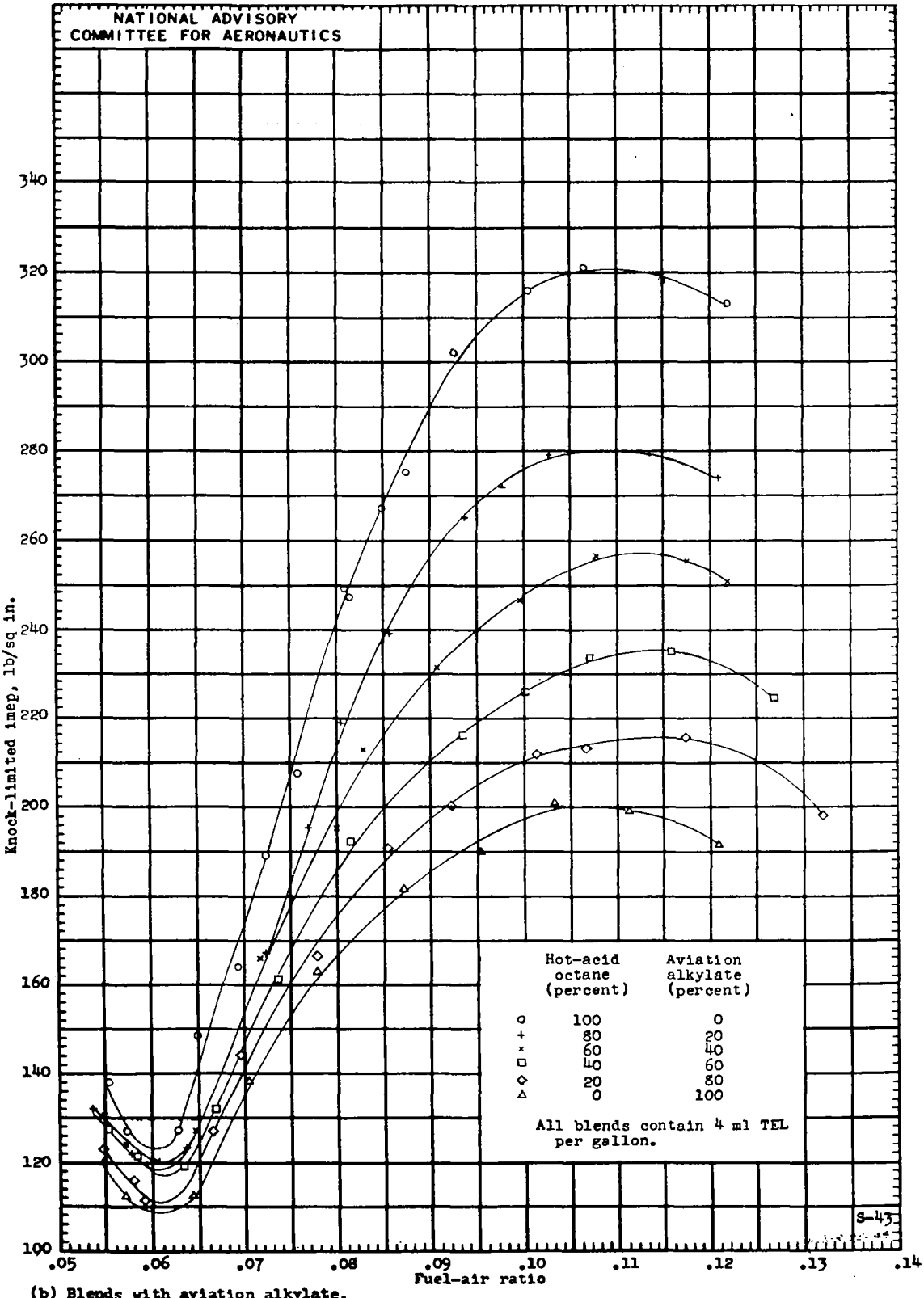


(a) Blends with virgin base stock.

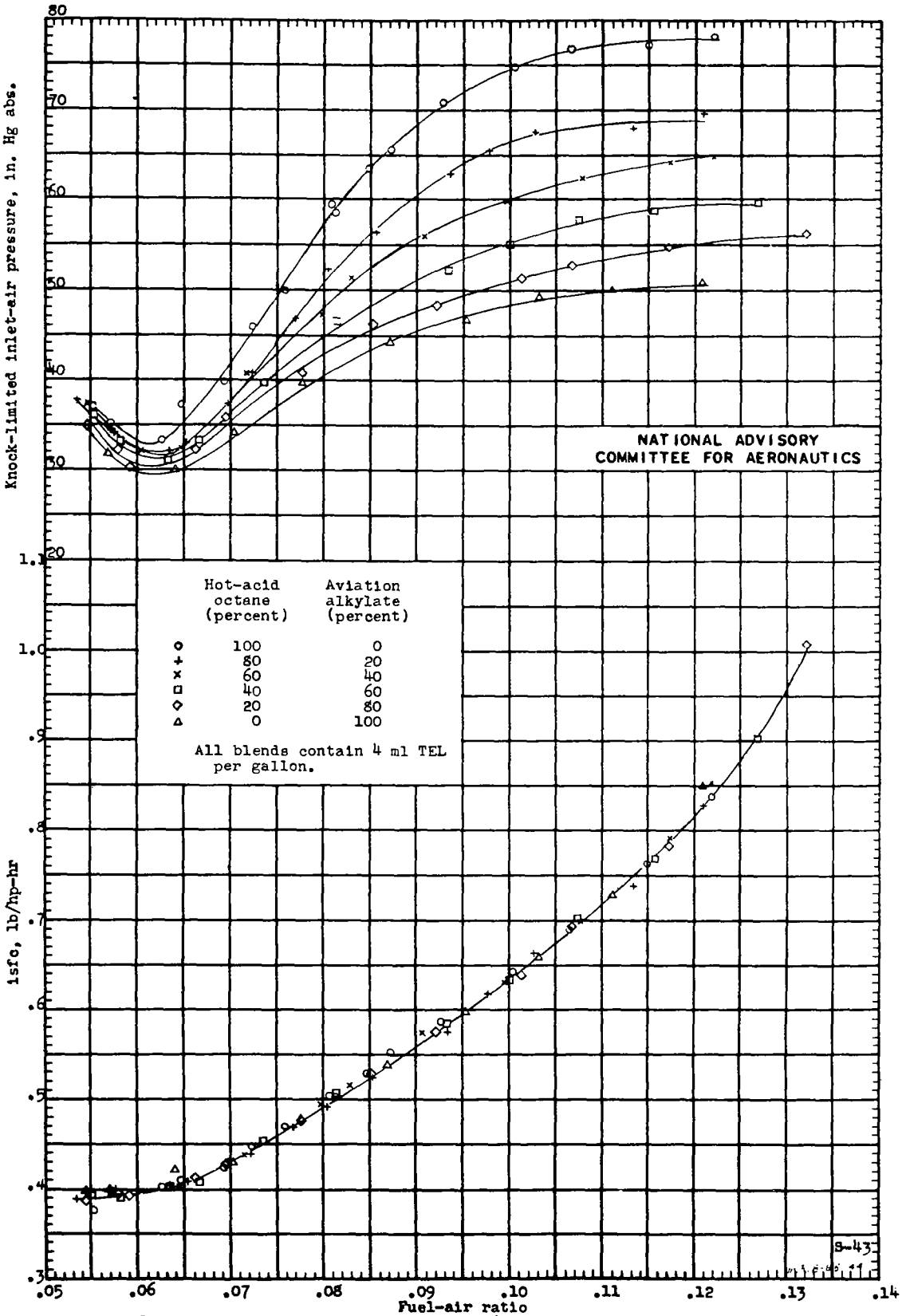
Figure 7. - Knock-limited performance of blends of hot-acid octane with virgin base stock, aviation alkylate, and one-pass catalytic stock as determined in an F-4 rating engine.



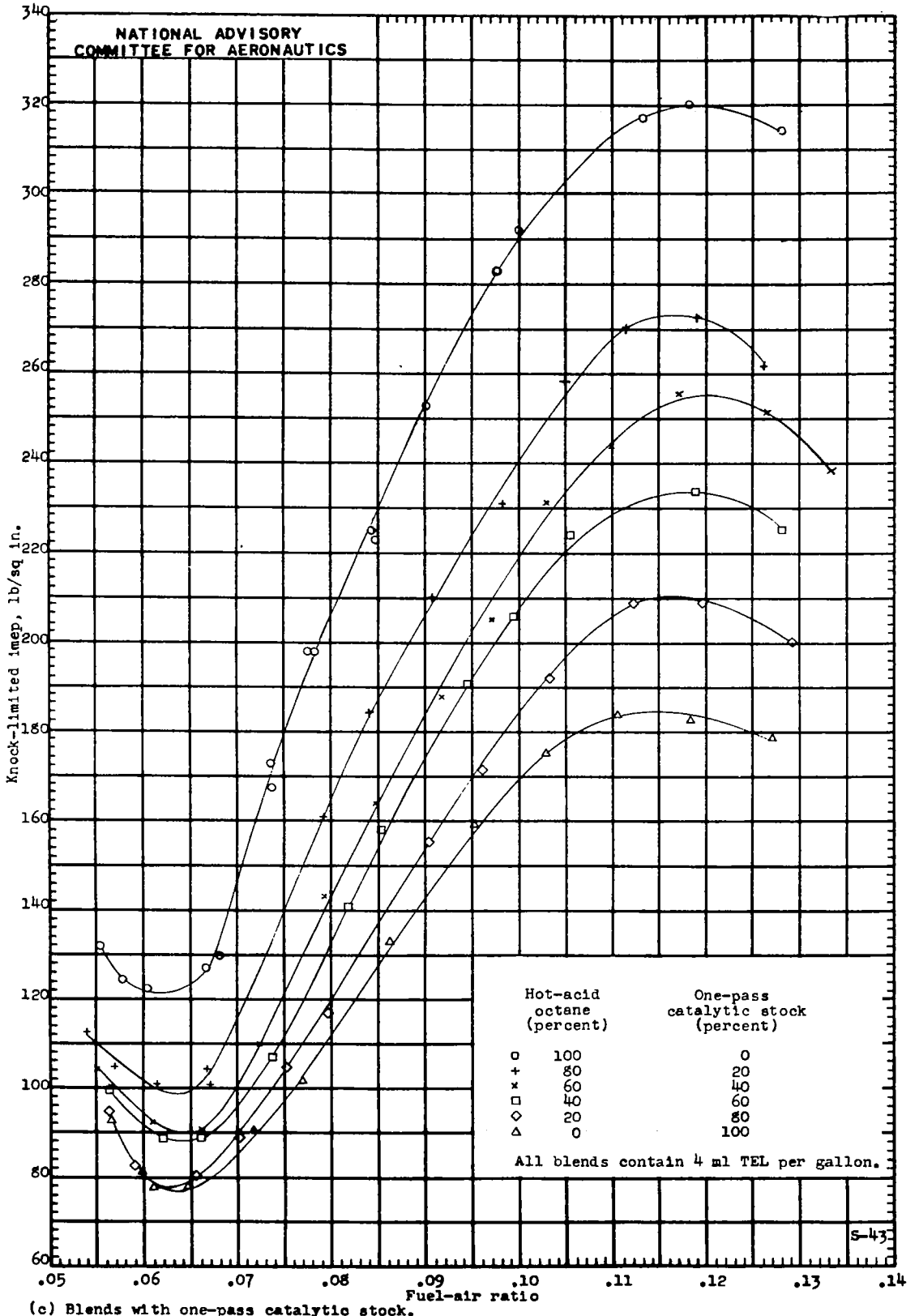
(a) Concluded.
Figure 7. - Continued.



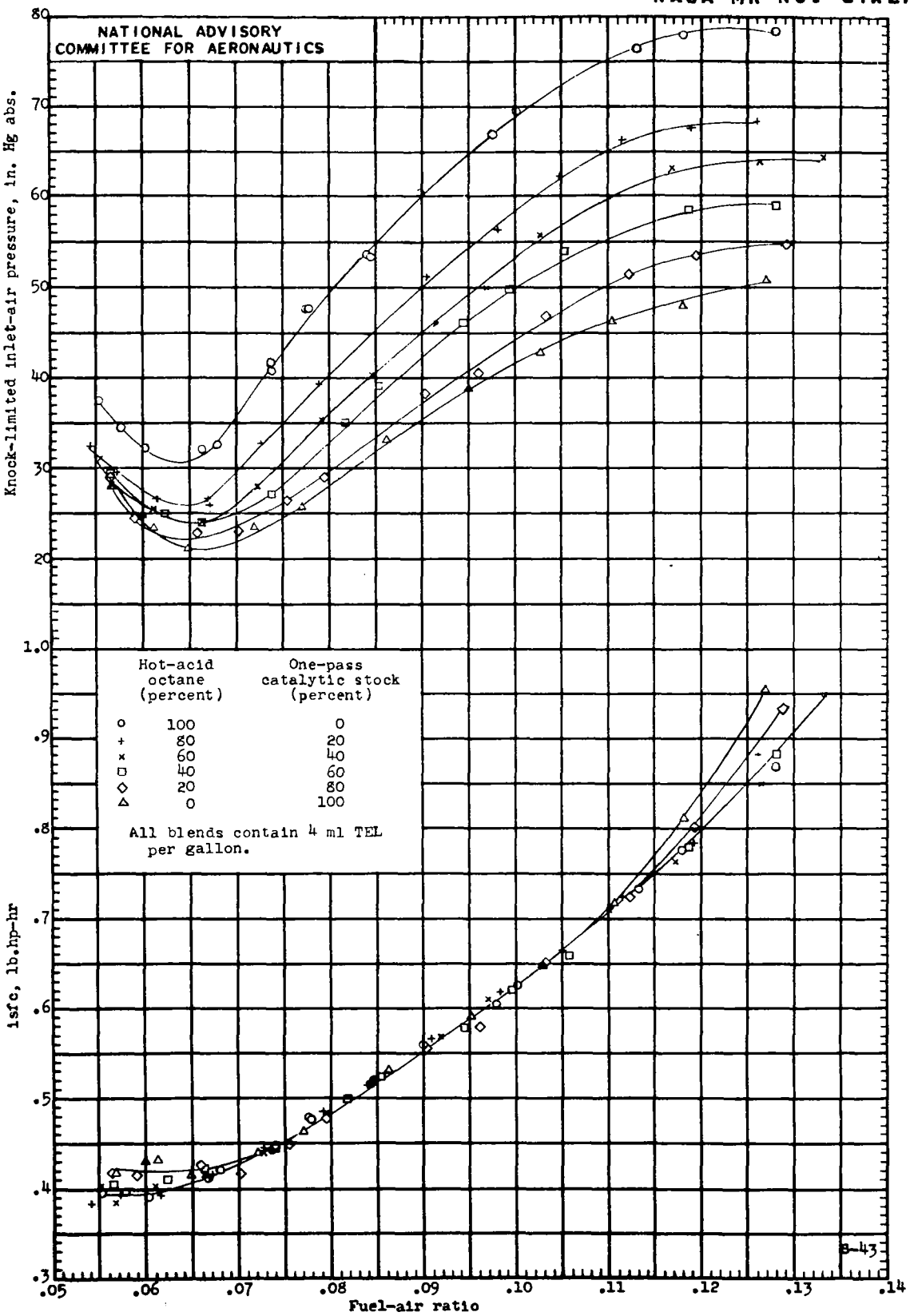
(b) Blends with aviation alkylate.
Figure 7. - Continued.



(b) Concluded.
Figure 7. - Continued.

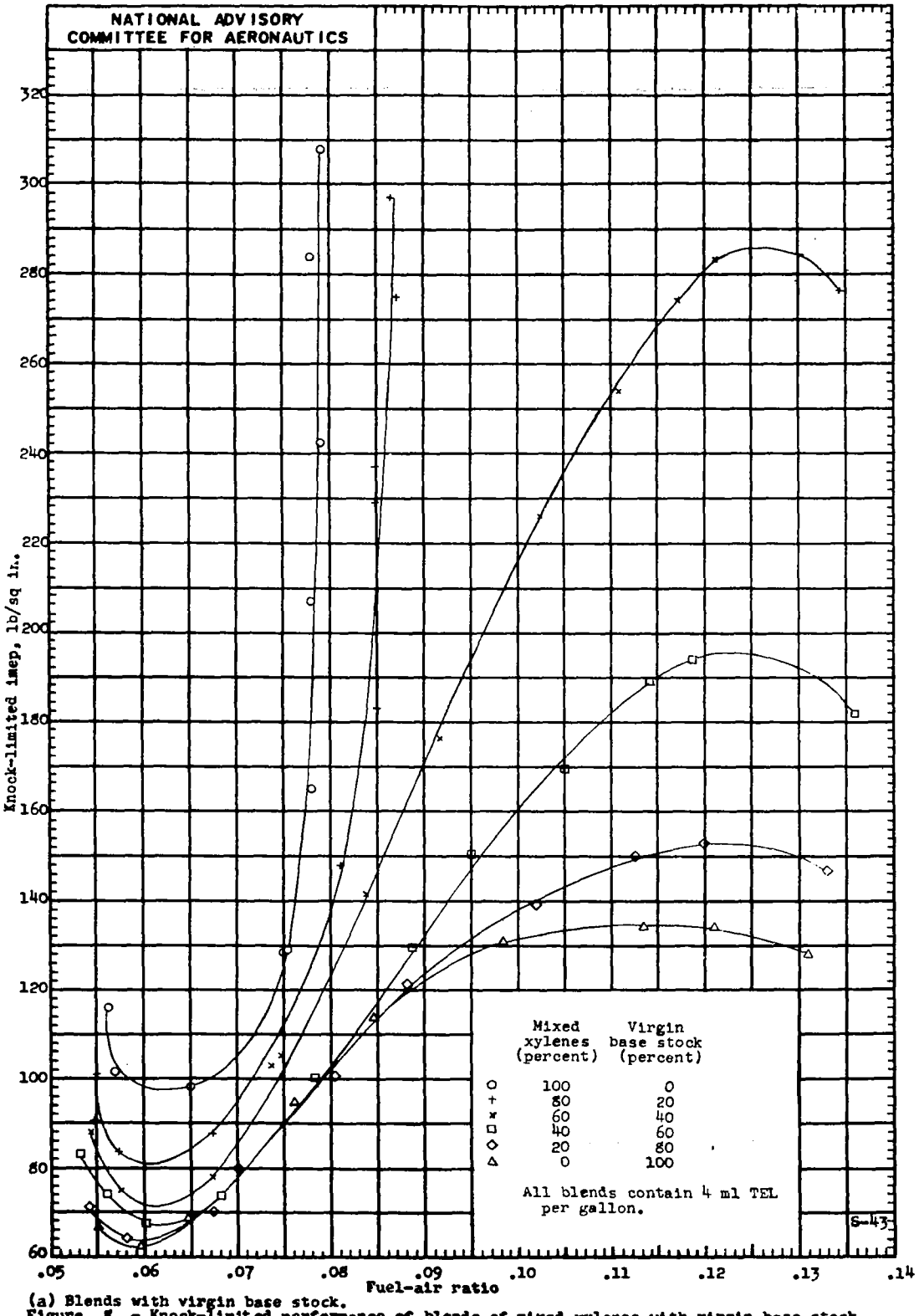


(c) Blends with one-pass catalytic stock.
Figure 7. - Continued.



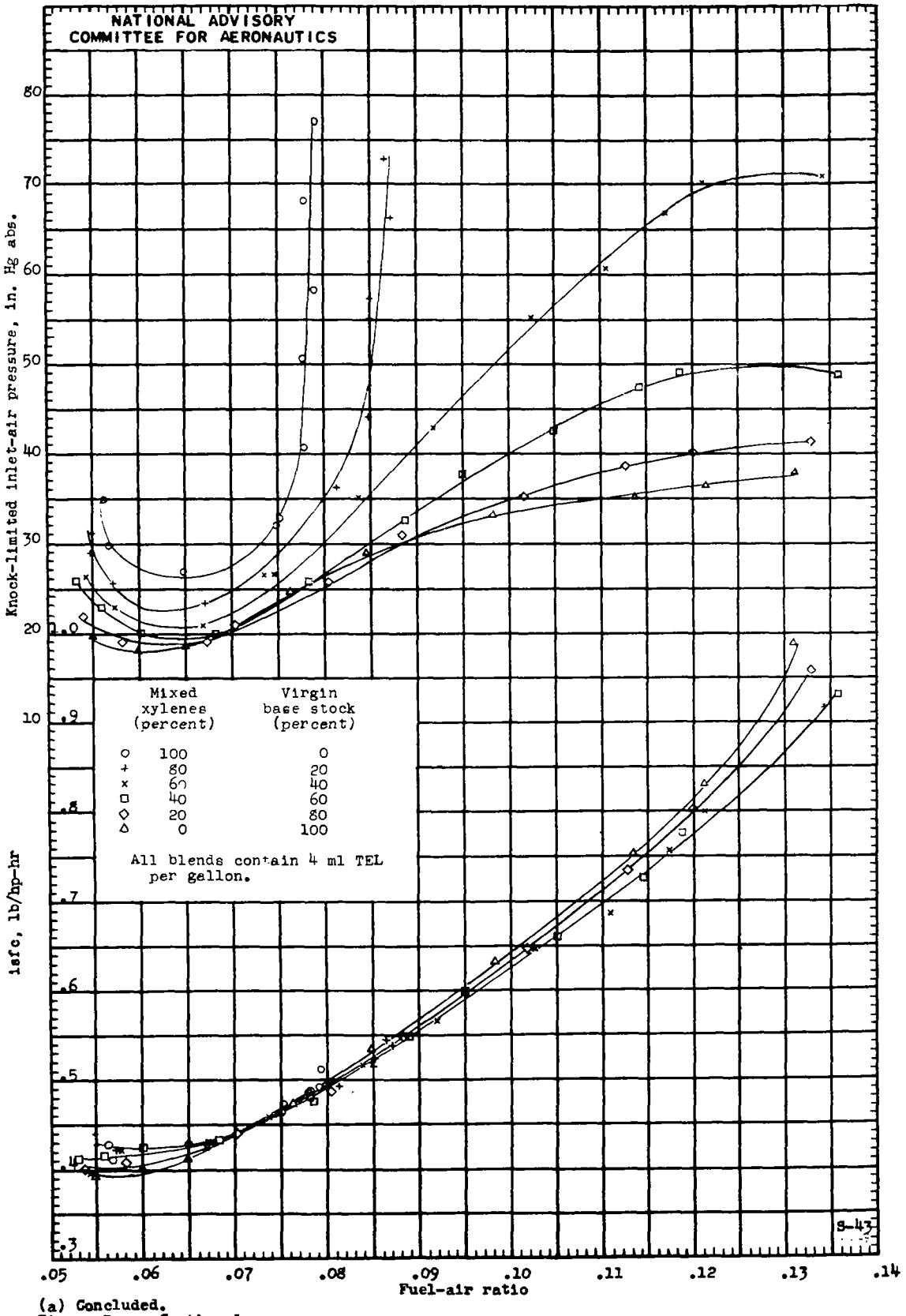
(c) Concluded.

Figure 7. - Concluded.

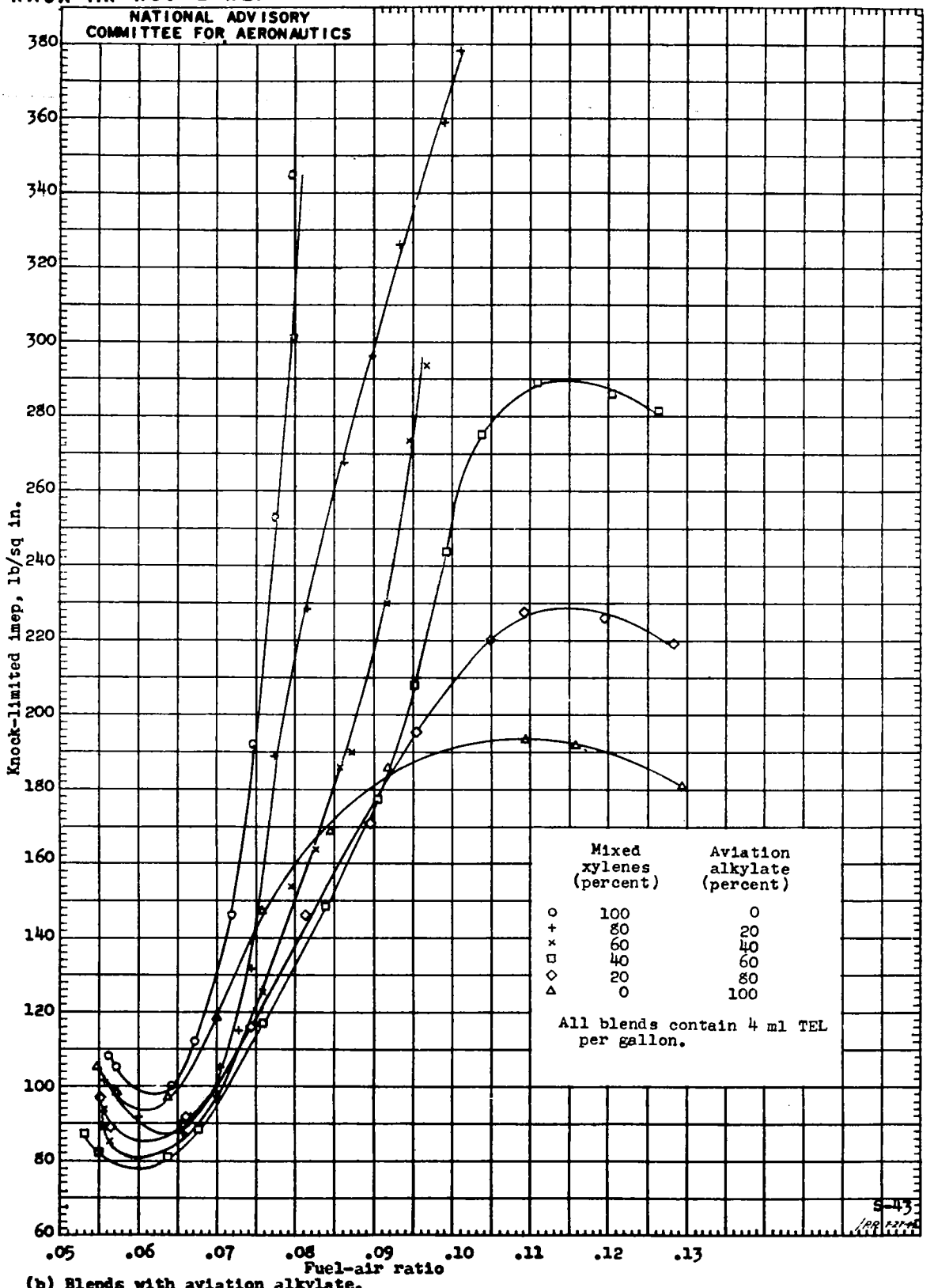


(a) Blends with virgin base stock.

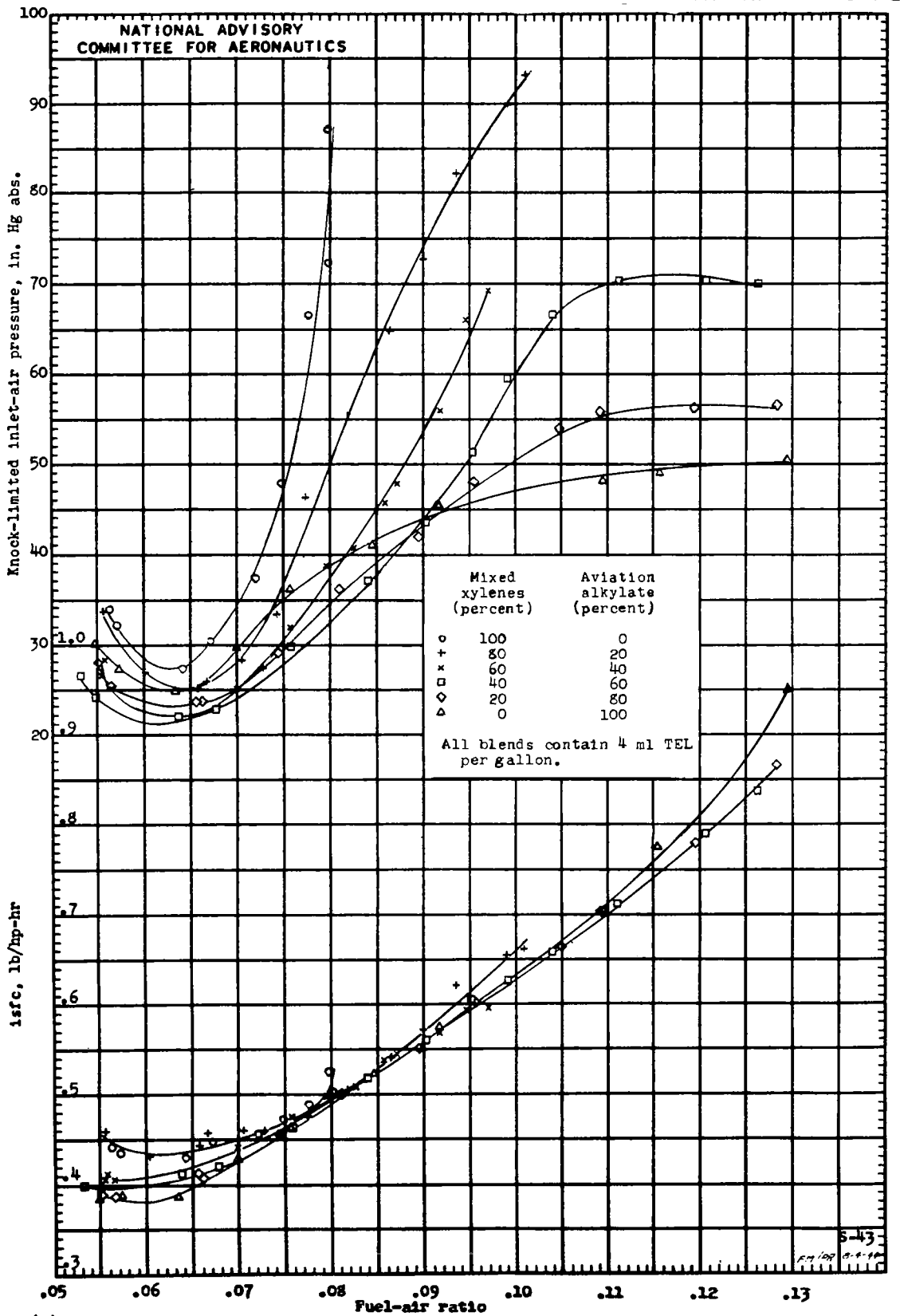
Figure 8. - Knock-limited performance of blends of mixed xylenes with virgin base stock, aviation alkylate, and one-pass catalytic stock as determined in an F-4 rating engine.



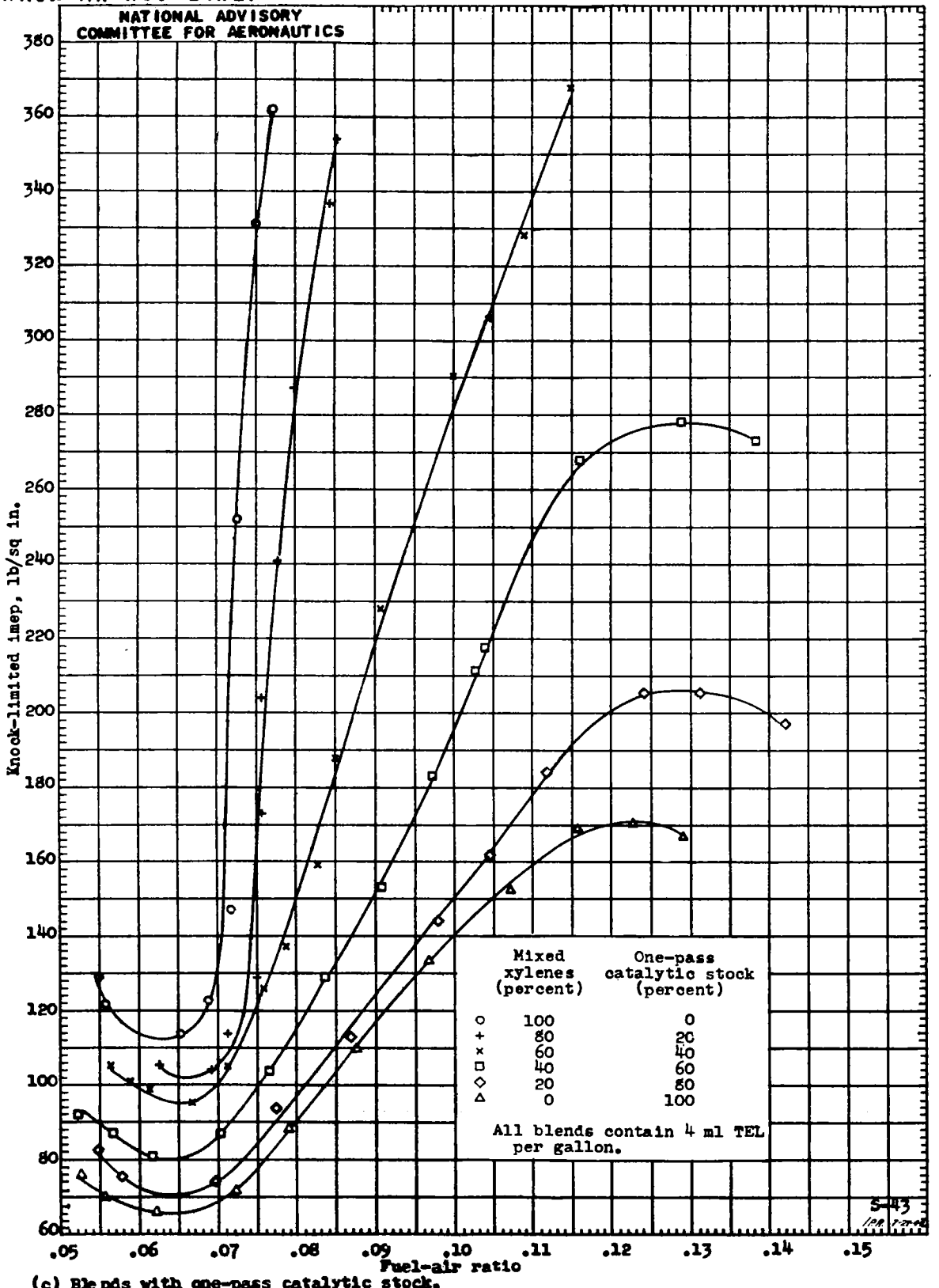
(a) Concluded.
Figure 8 . - Continued.



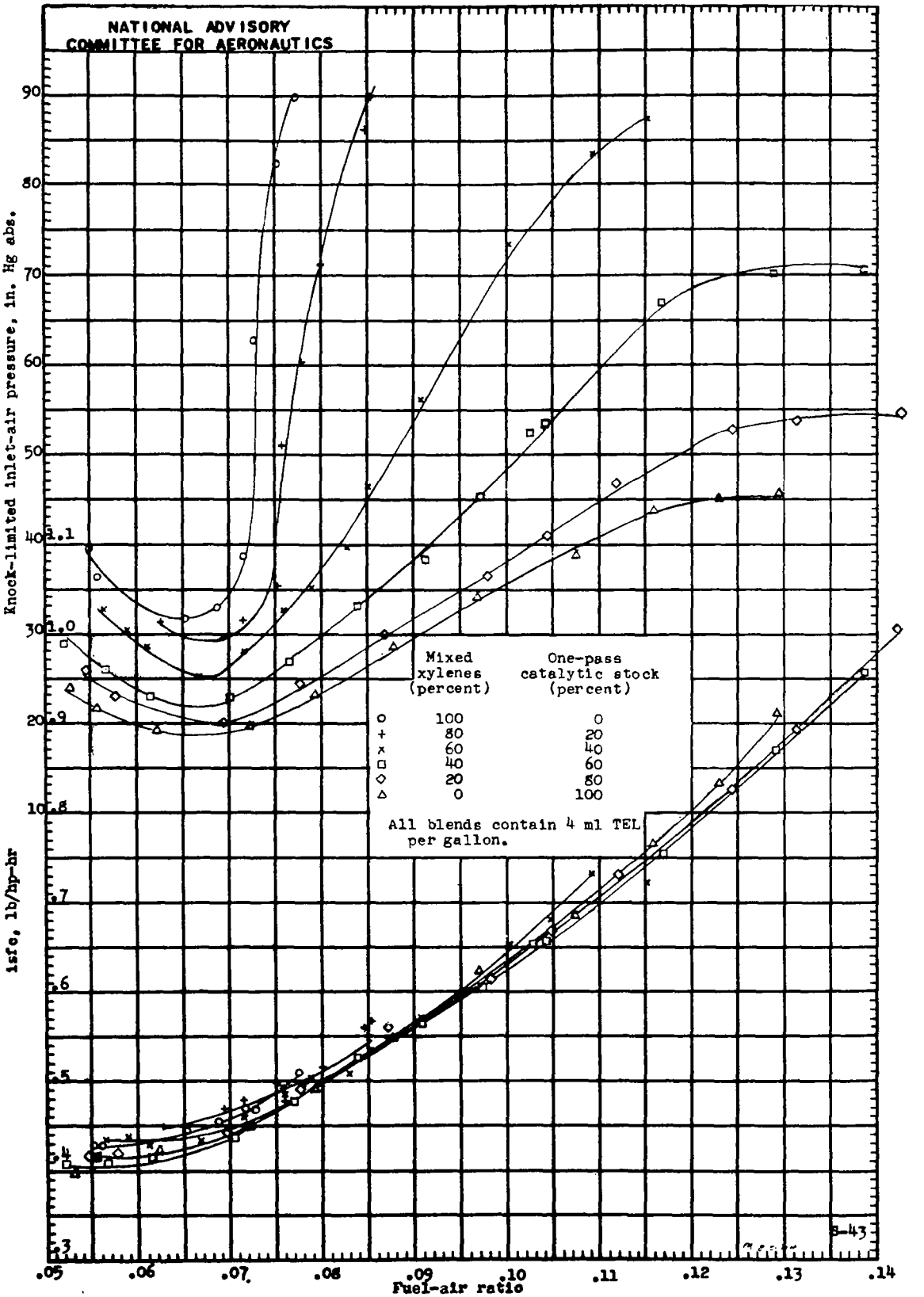
(b) Blends with aviation alkylate.
Figure 8. - Continued.



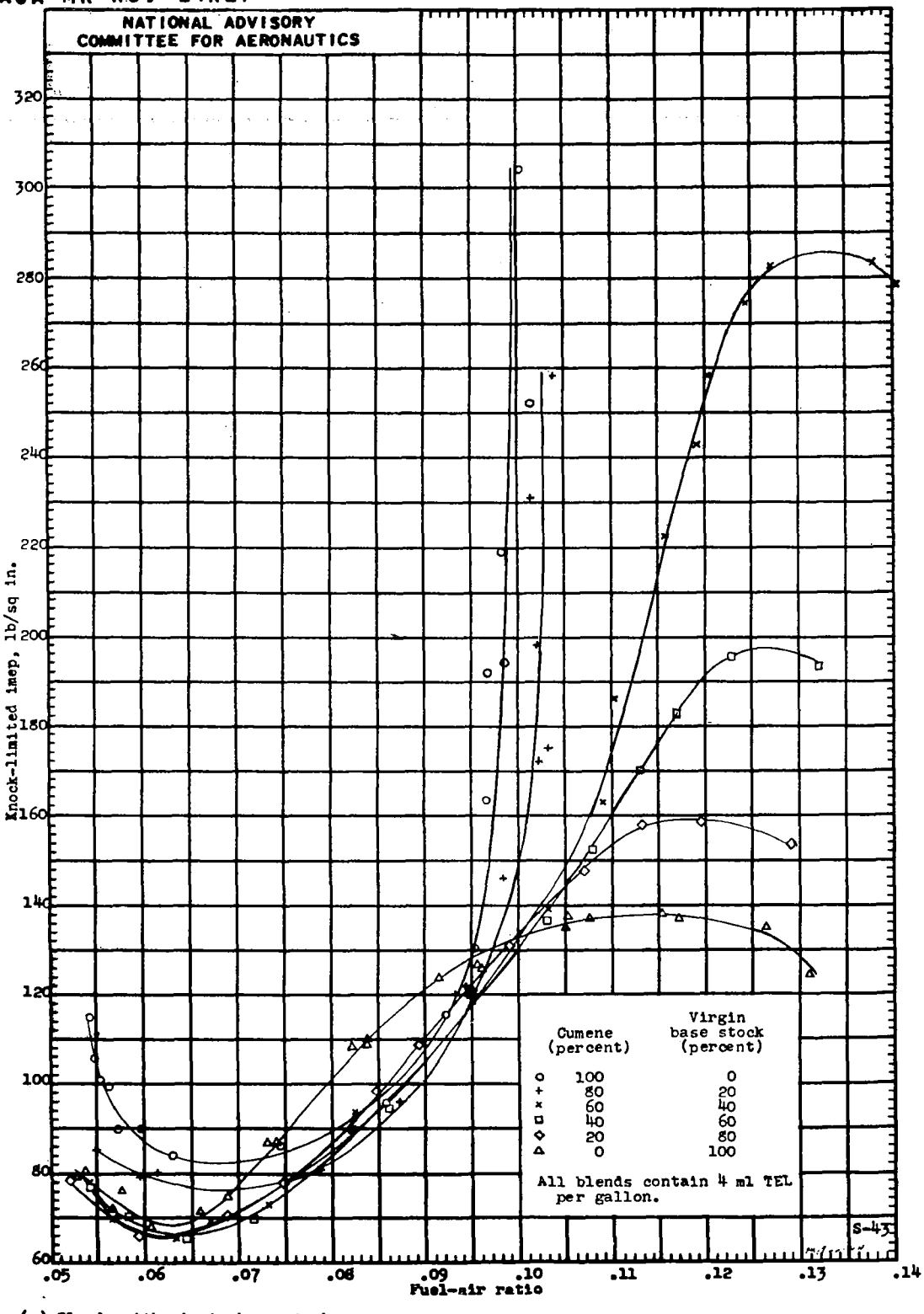
(b) Concluded.
Figure 8. - Continued.



(c) Blends with one-pass catalytic stock.
Figure 8. - Continued.

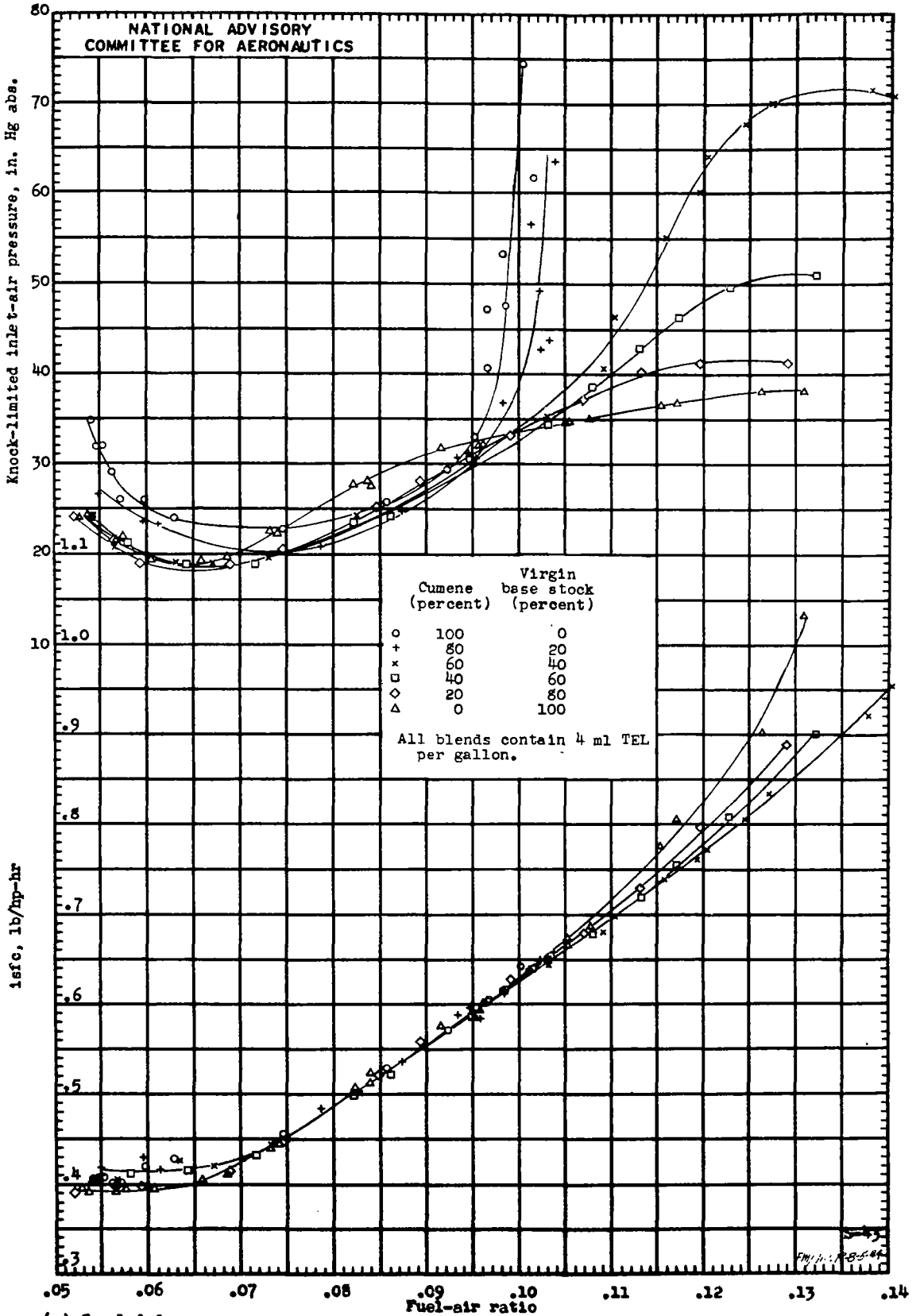


(c) Concluded.
Figure 8. - Concluded.

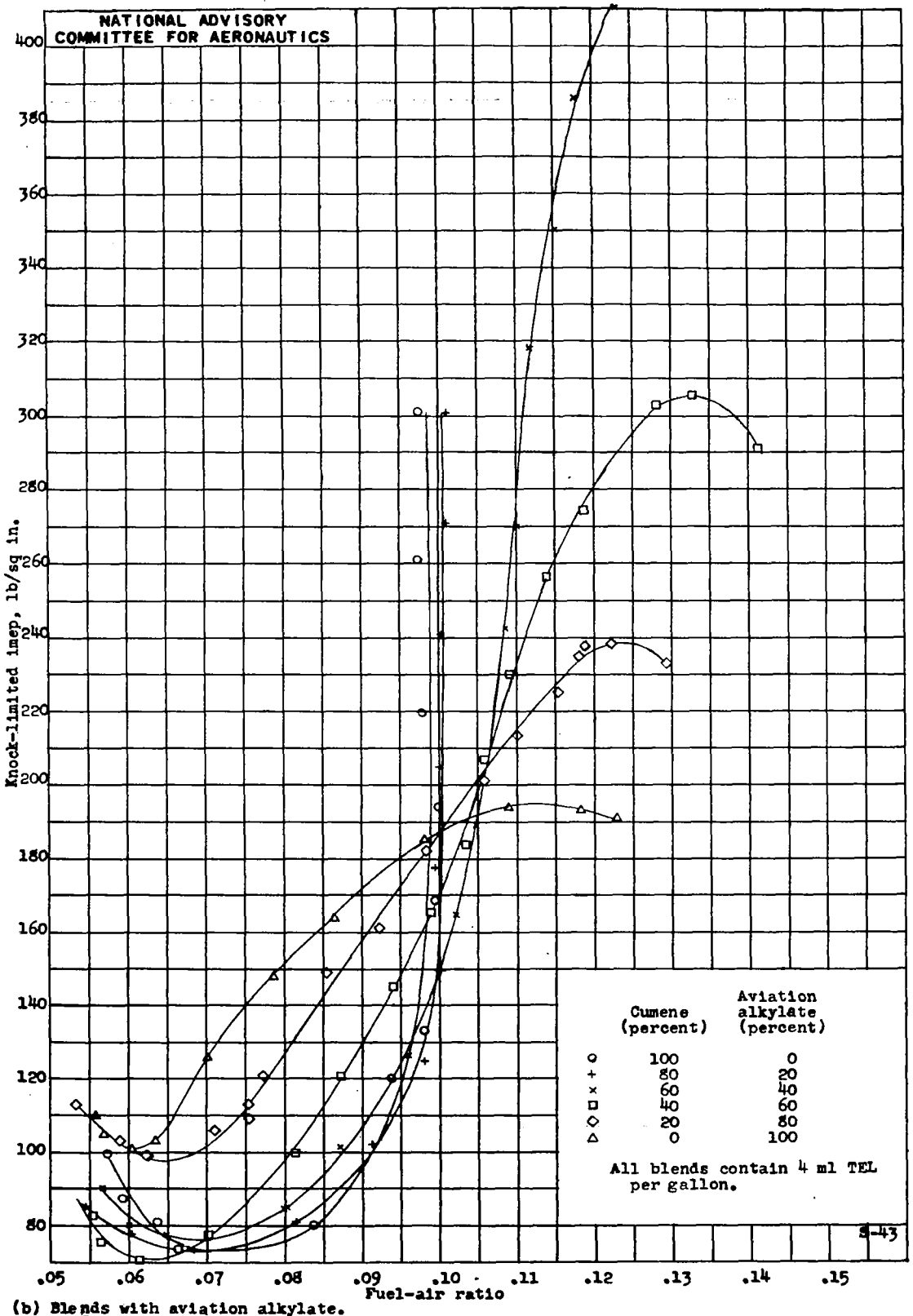


(a) Blends with virgin base stock.

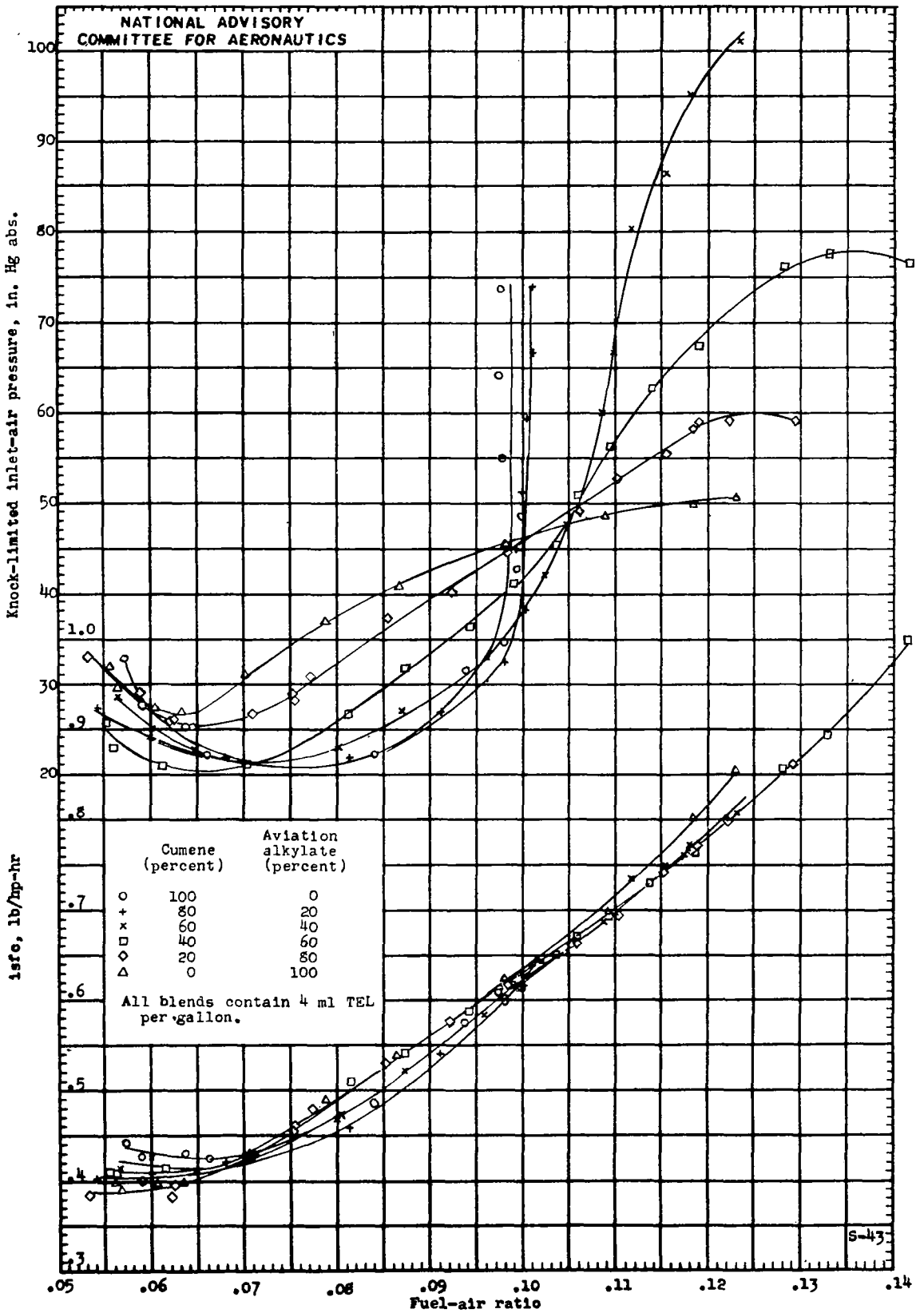
Figure 9. - Knock-limited performance of blends of cumene (isopropylbenzene) with virgin base stock, aviation alkylate, and one-pass catalytic stock as determined in an F-4 rating engine.



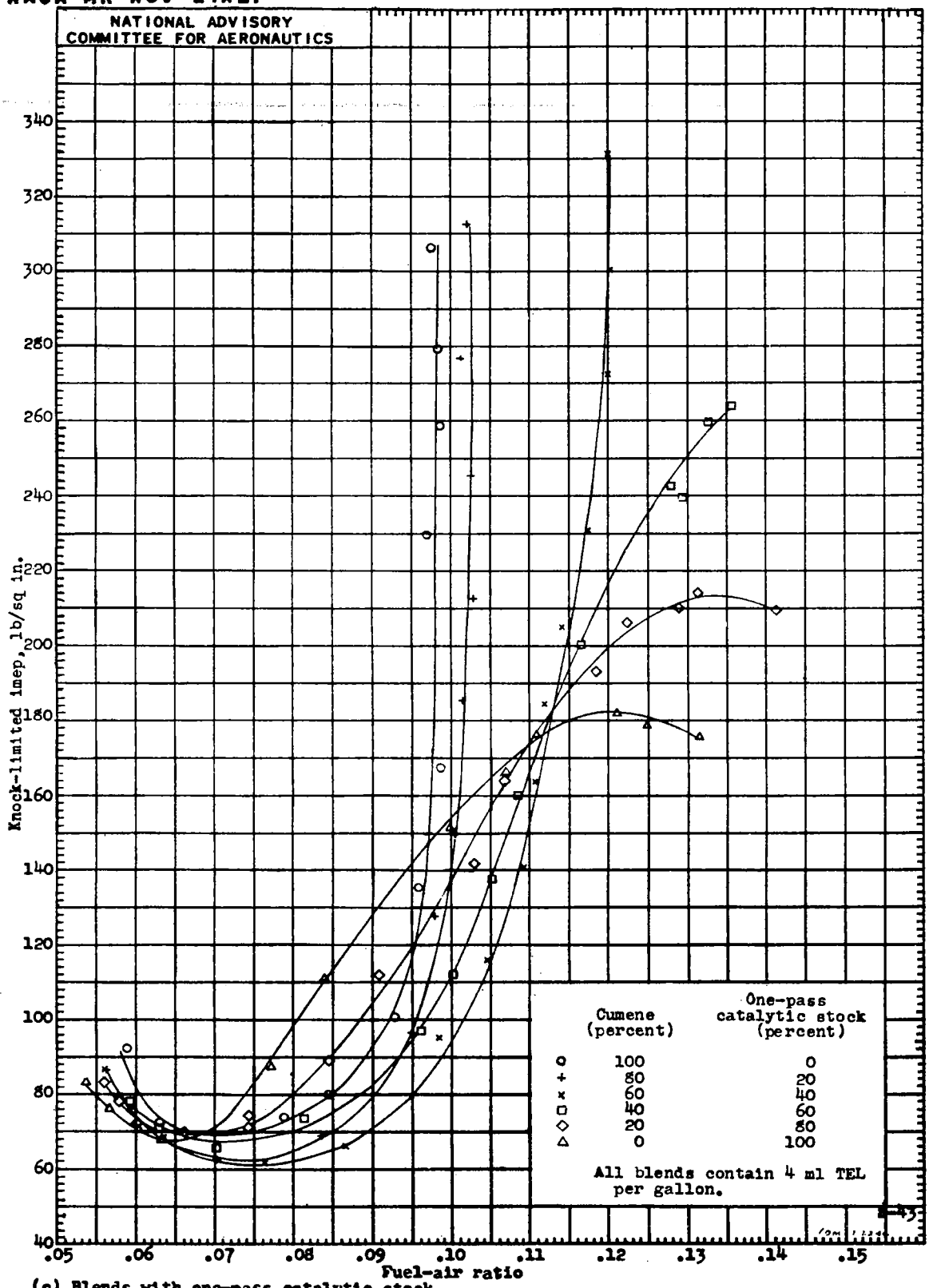
(a) Concluded.
Figure 9. - Continued.



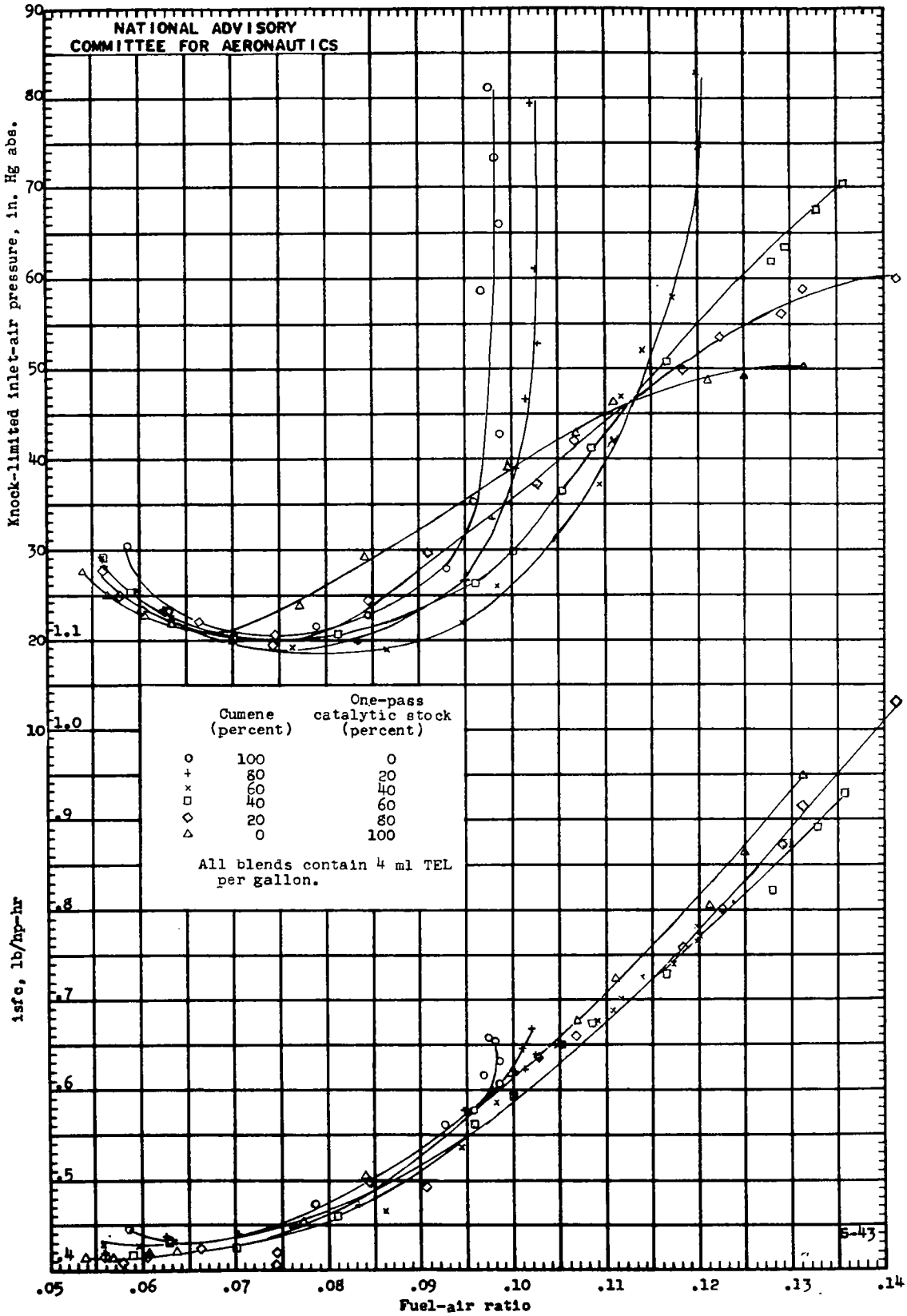
(b) Blends with aviation alkylate.
Figure 9. - Continued.



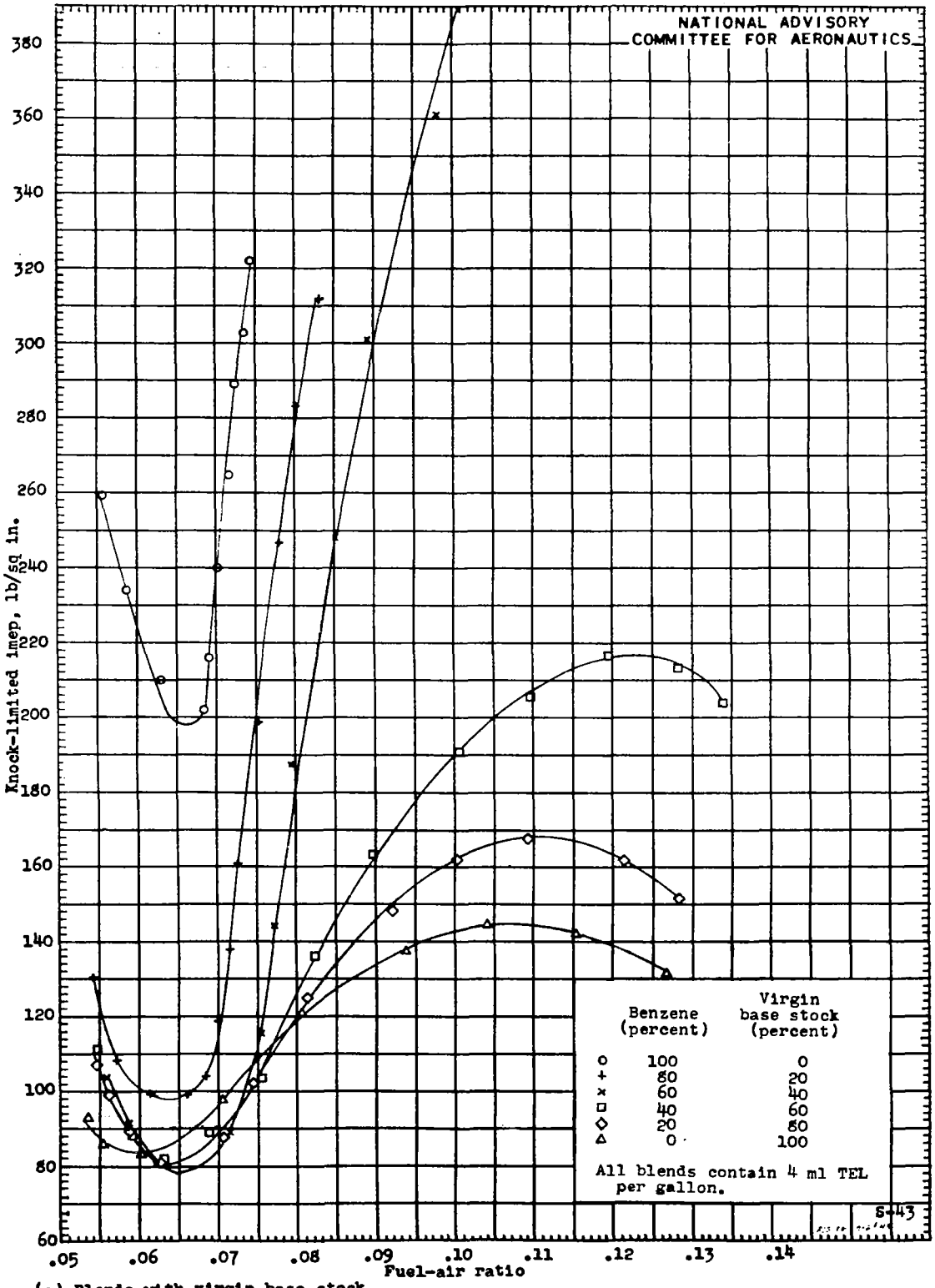
(b) Concluded.
Figure 9. - Continued.



(c) Blends with one-pass catalytic stock.
Figure 9. - Continued.

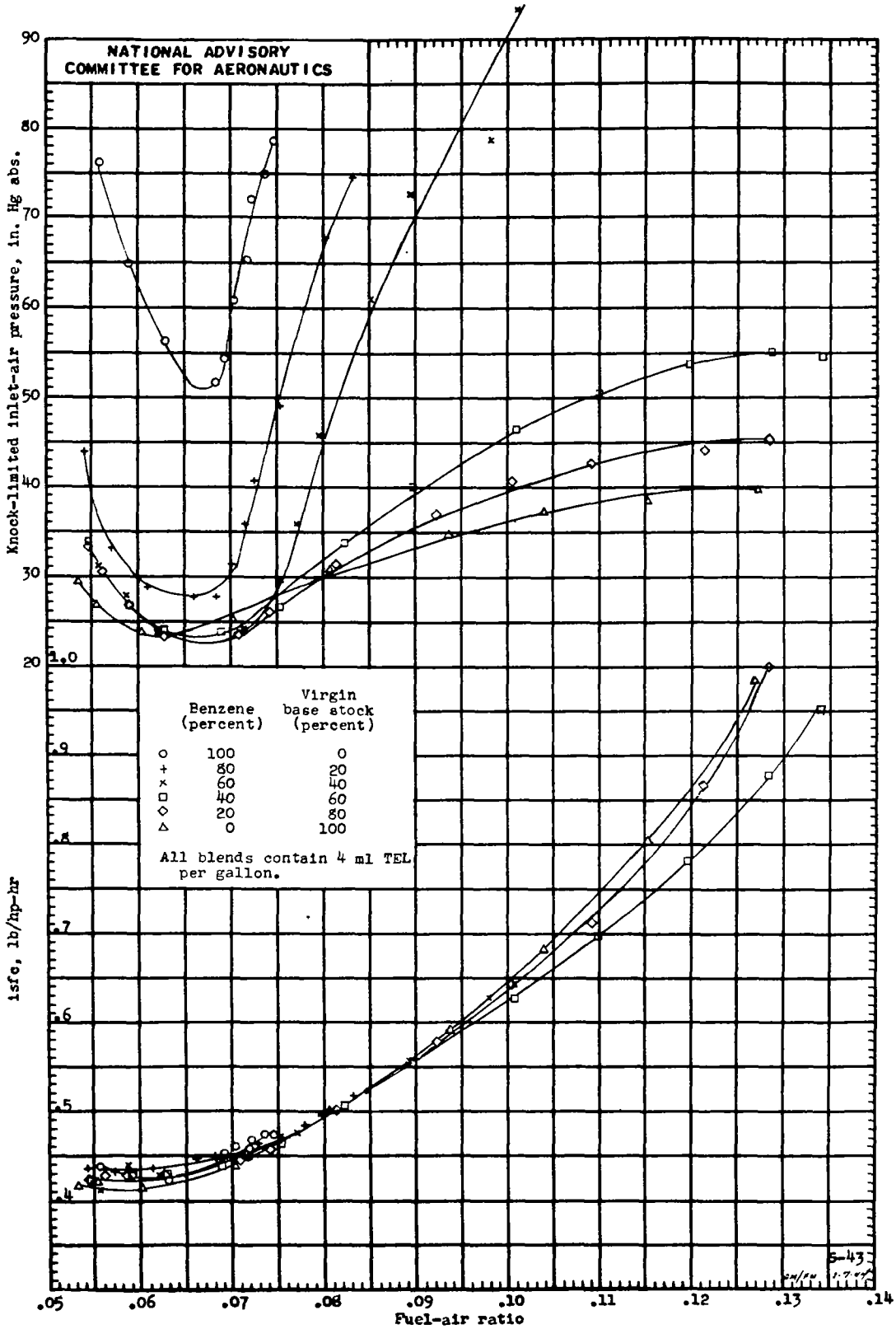


(c) Concluded.
Figure 9. - Concluded.

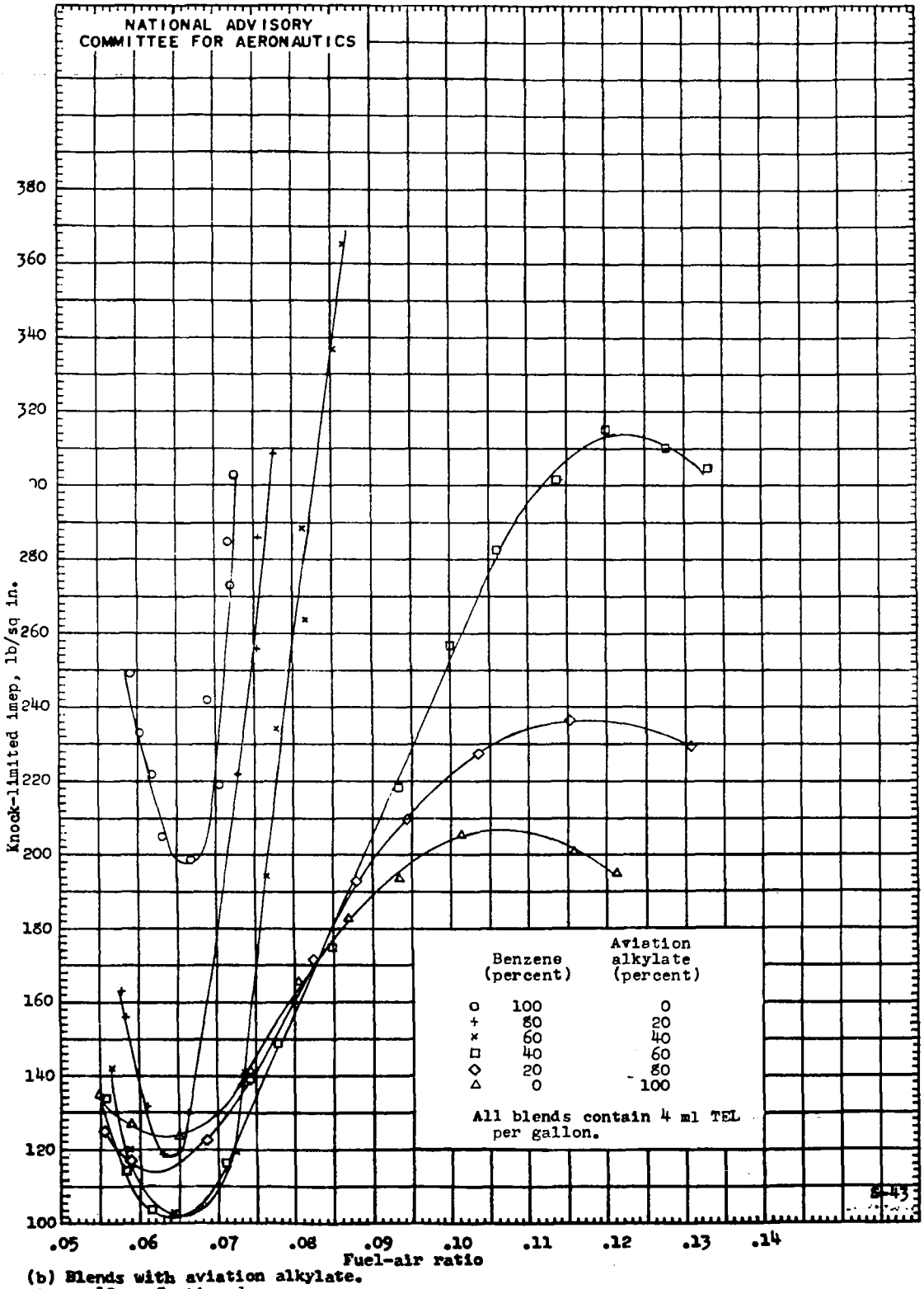


(a) Blends with virgin base stock.

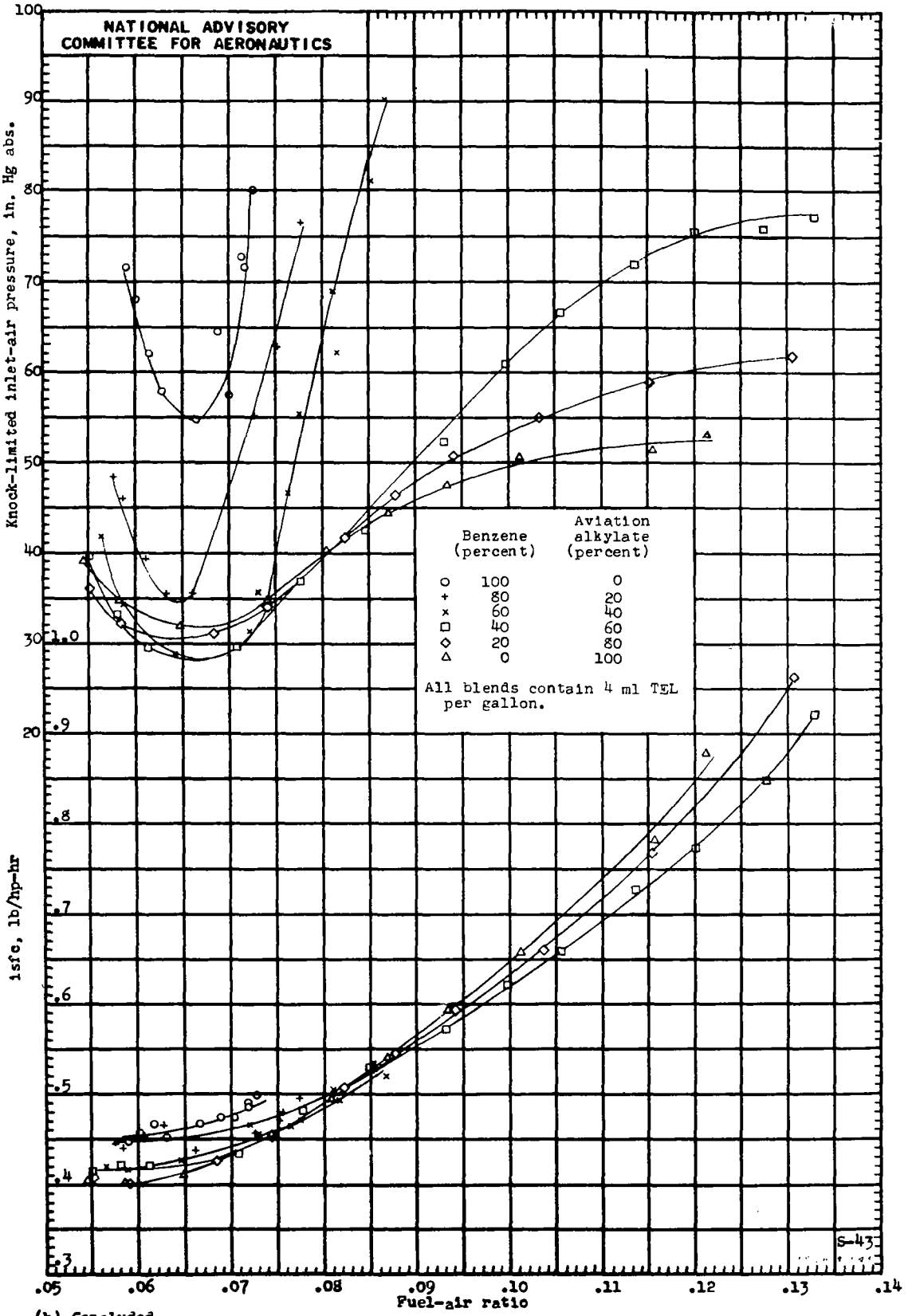
Figure 10. – Knock-limited performance of blends of benzene with virgin base stock, aviation alkylate, and one-pass catalytic stock as determined in an F-4 rating engine.



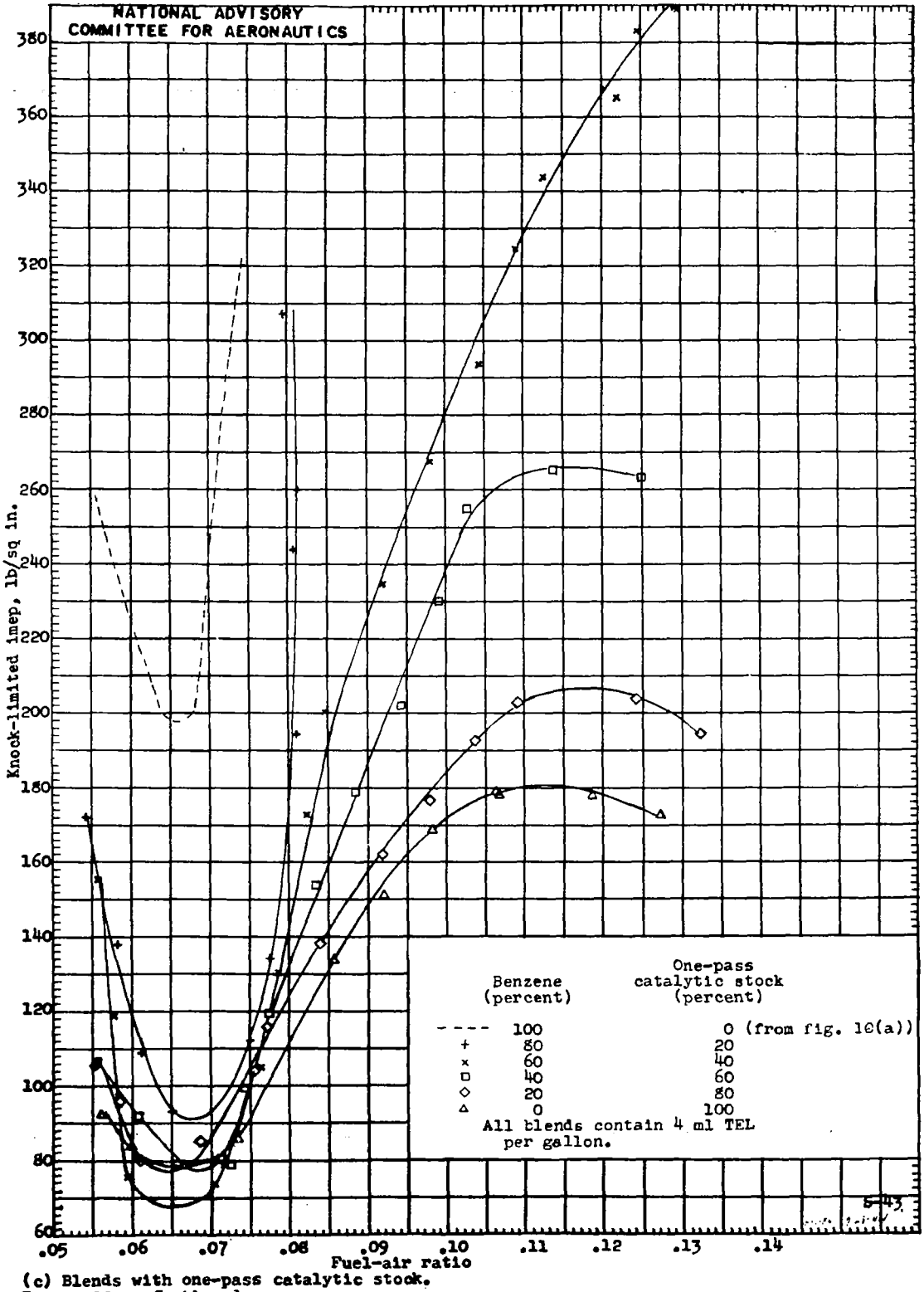
(a) Concluded.
Figure 10. - Continued.



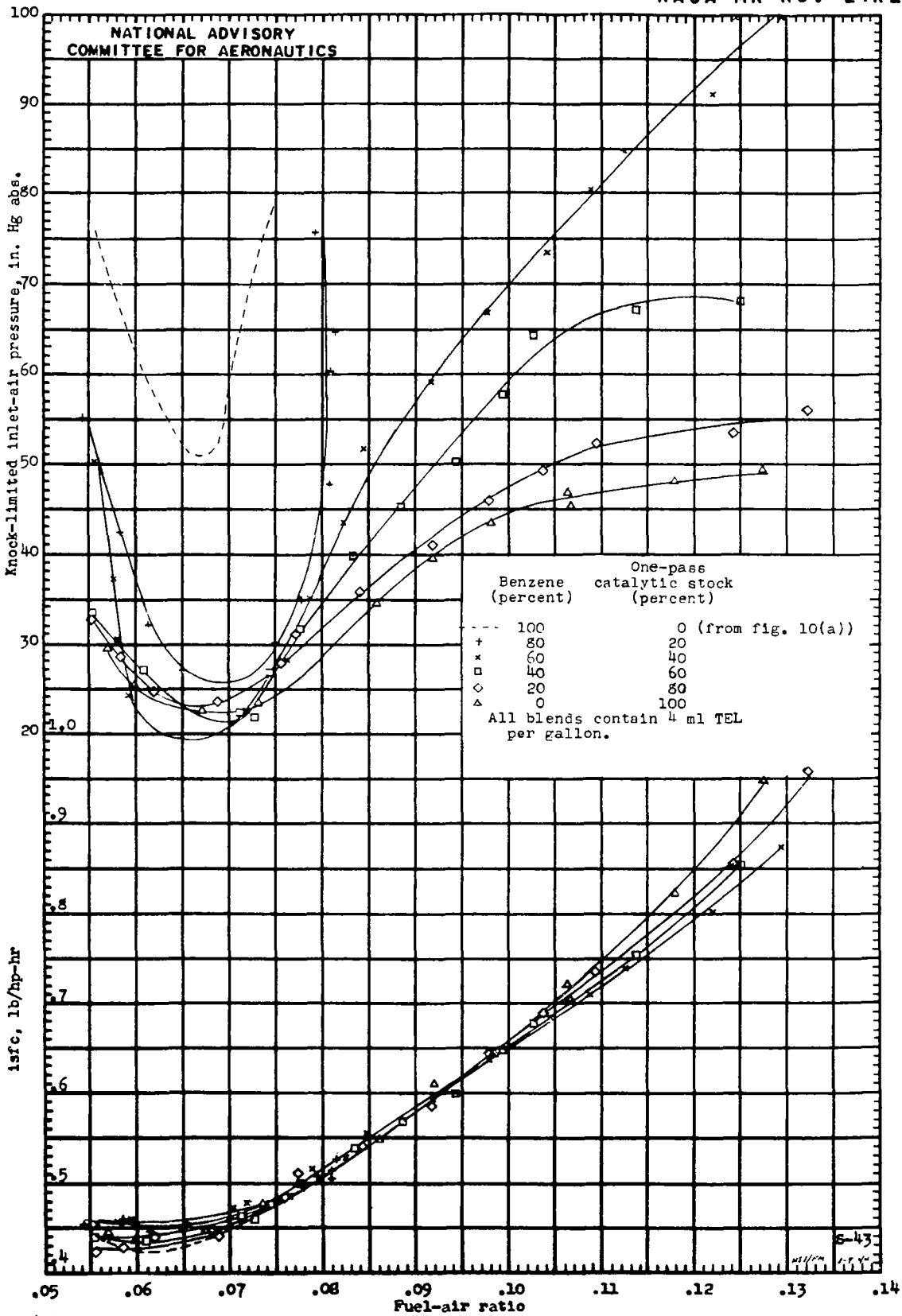
(b) Blends with aviation alkylate.
Figure 10. - Continued.



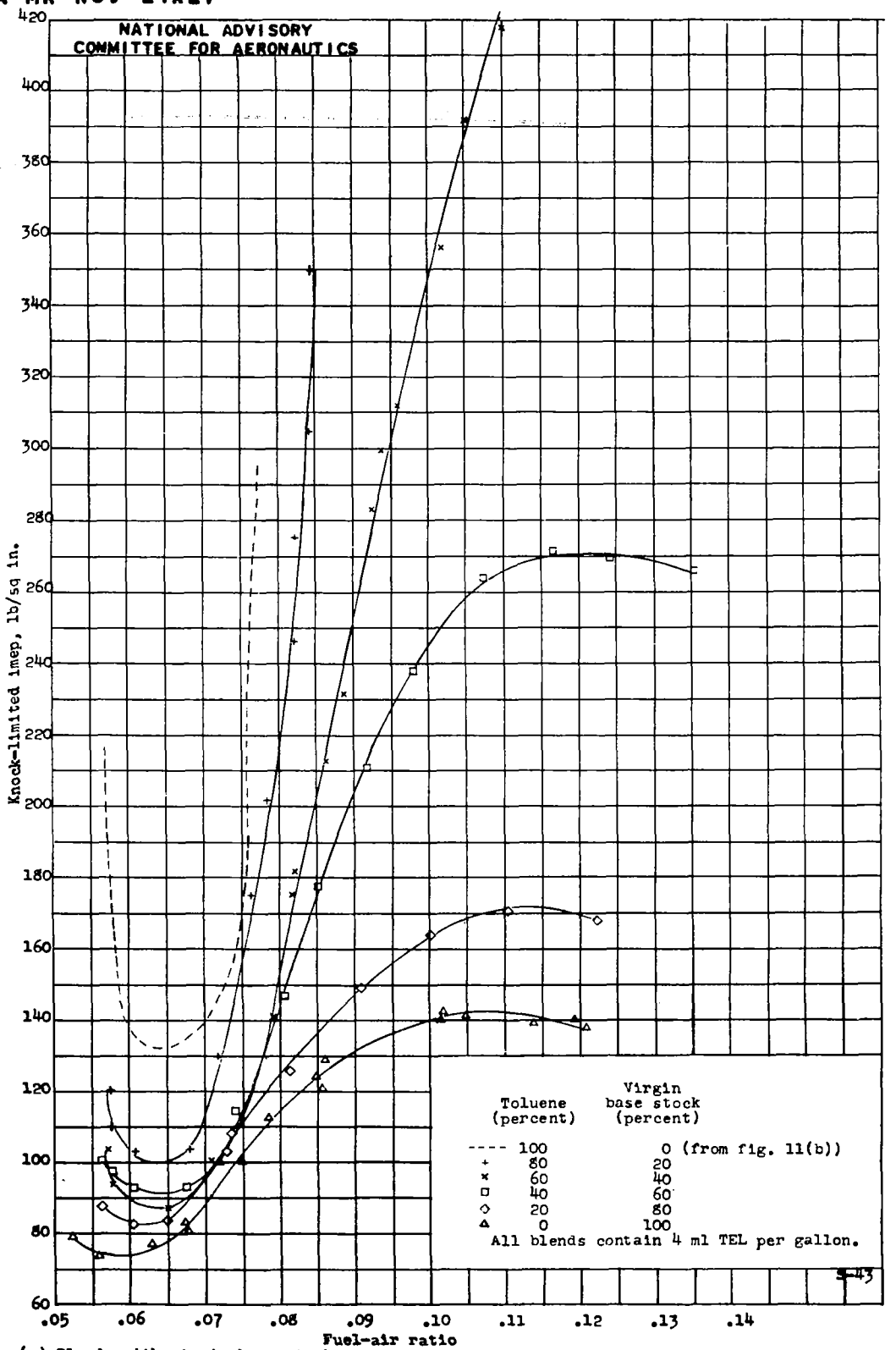
(b) Concluded.
Figure 10. - Continued.



(c) Blends with one-pass catalytic stock.
Figure 10. - Continued.

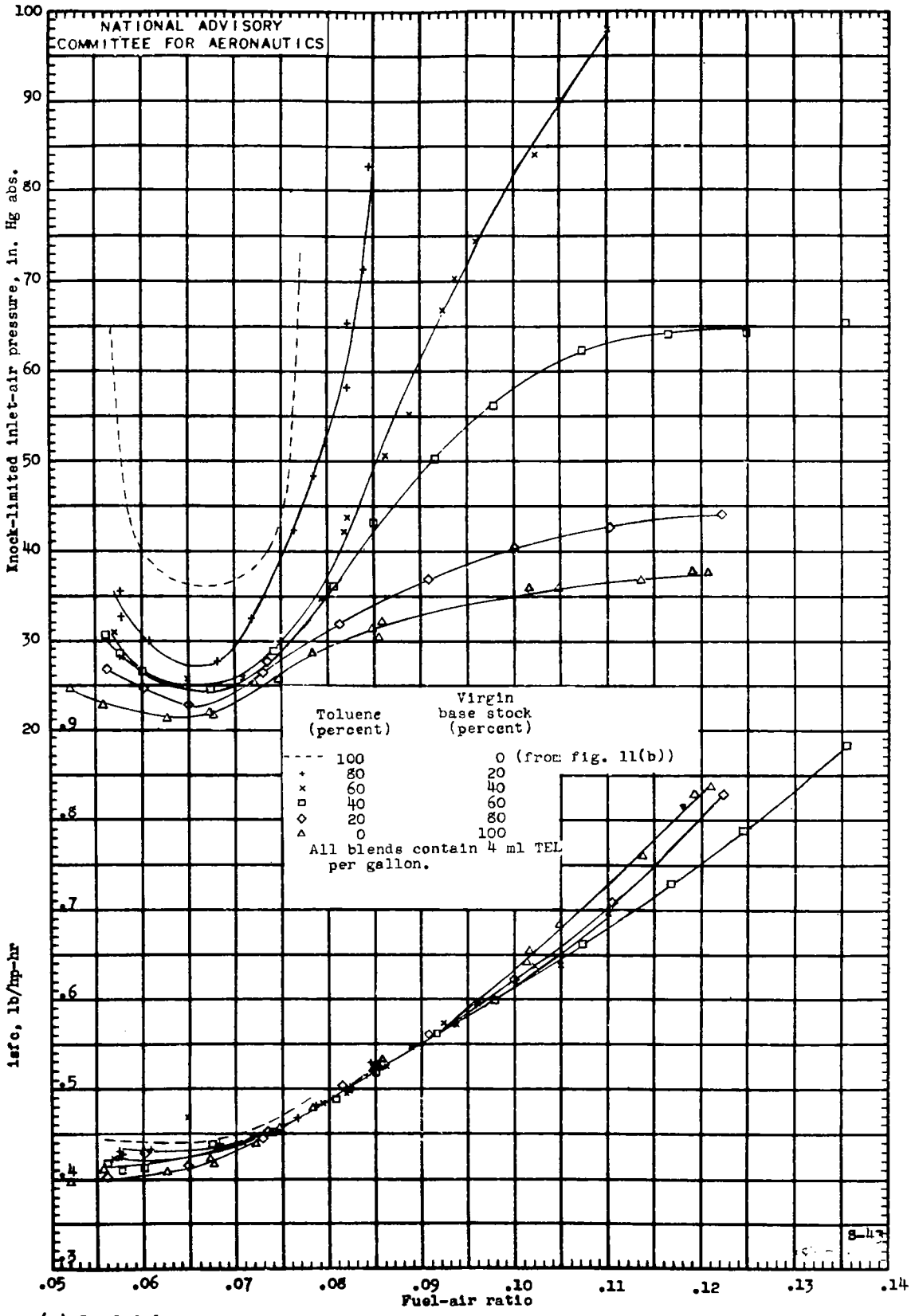


(c) Concluded.
Figure 10. - Concluded.

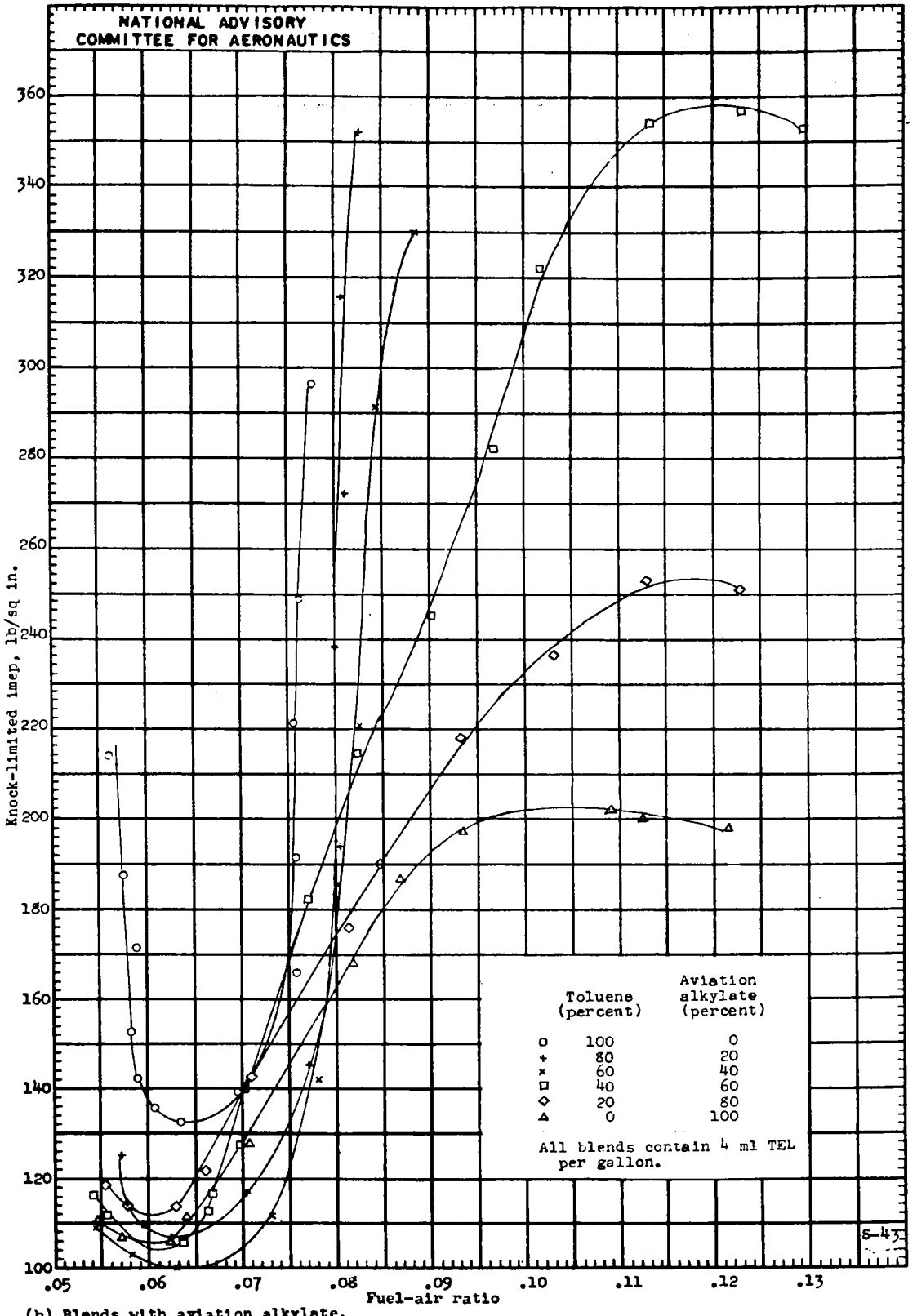


(a) Blends with virgin base stock.

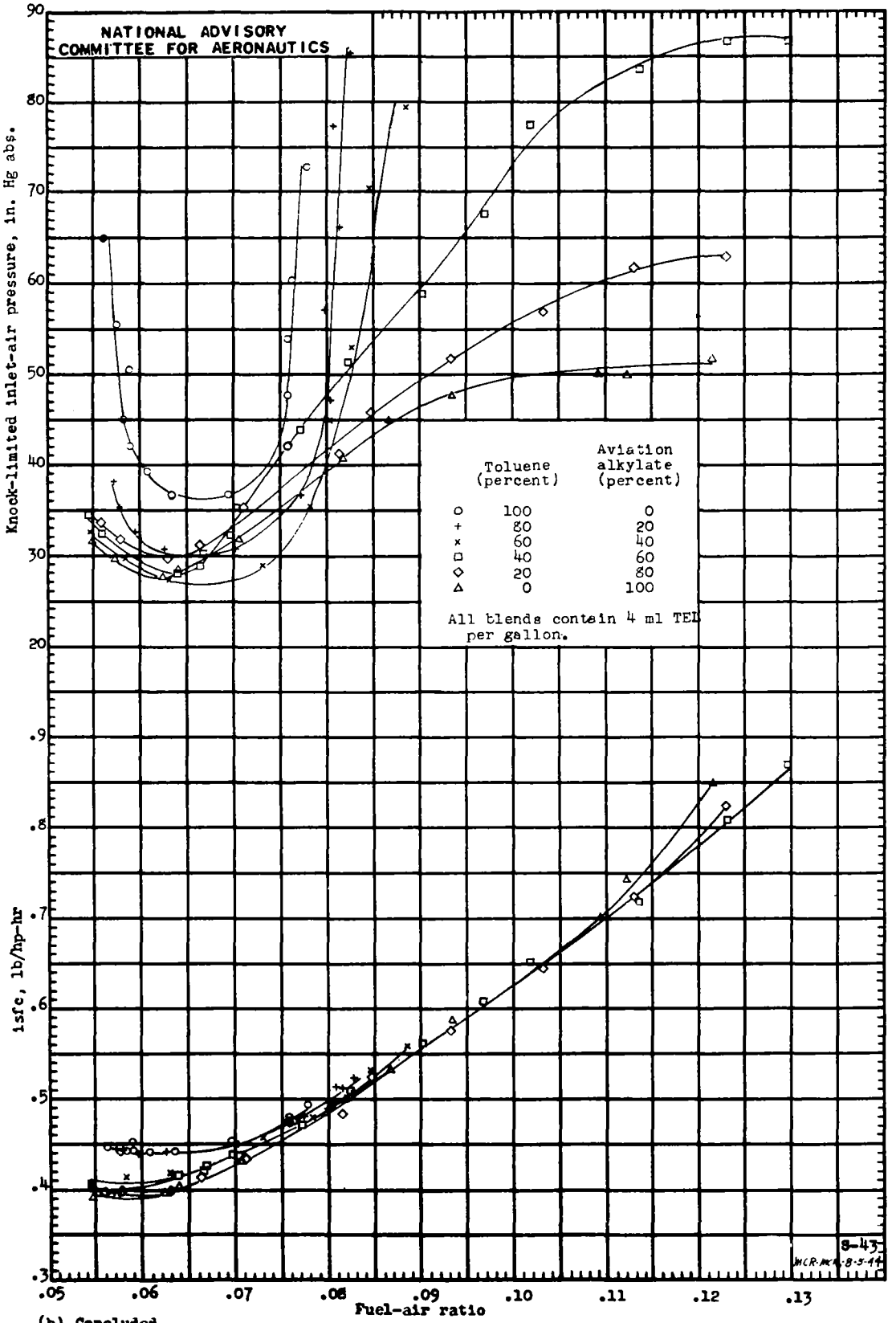
Figure 11. - Knock-limited performance of blends of toluene (methylbenzene) with virgin base stock, aviation alkylate, and one-pass catalytic stock as determined in an F-4 rating engine.



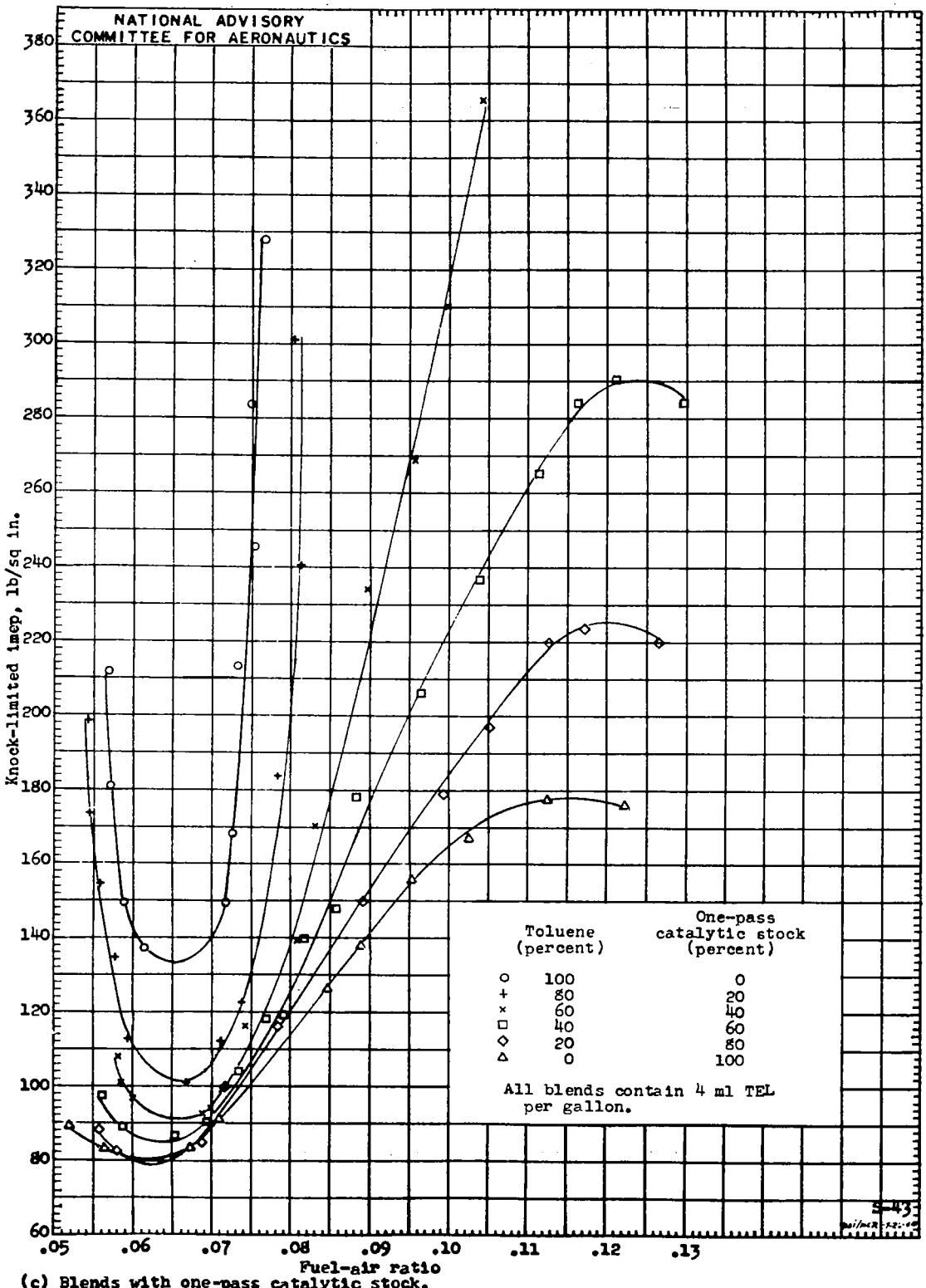
(a) Concluded.
Figure 11. - Continued.



(b) Blends with aviation alkylate.
Figure 11. - Continued.

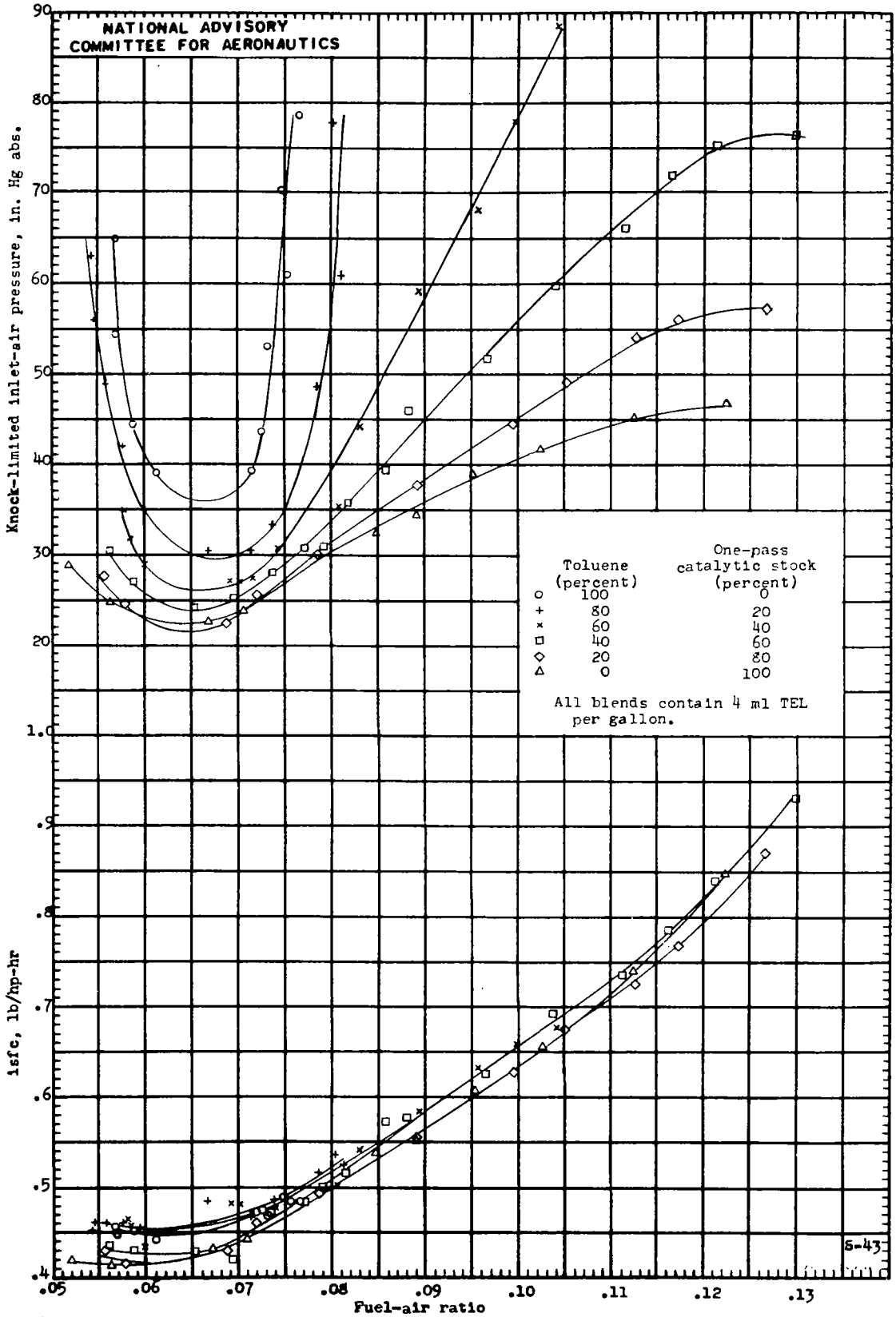


(b) Concluded.
Figure 11. - Continued.

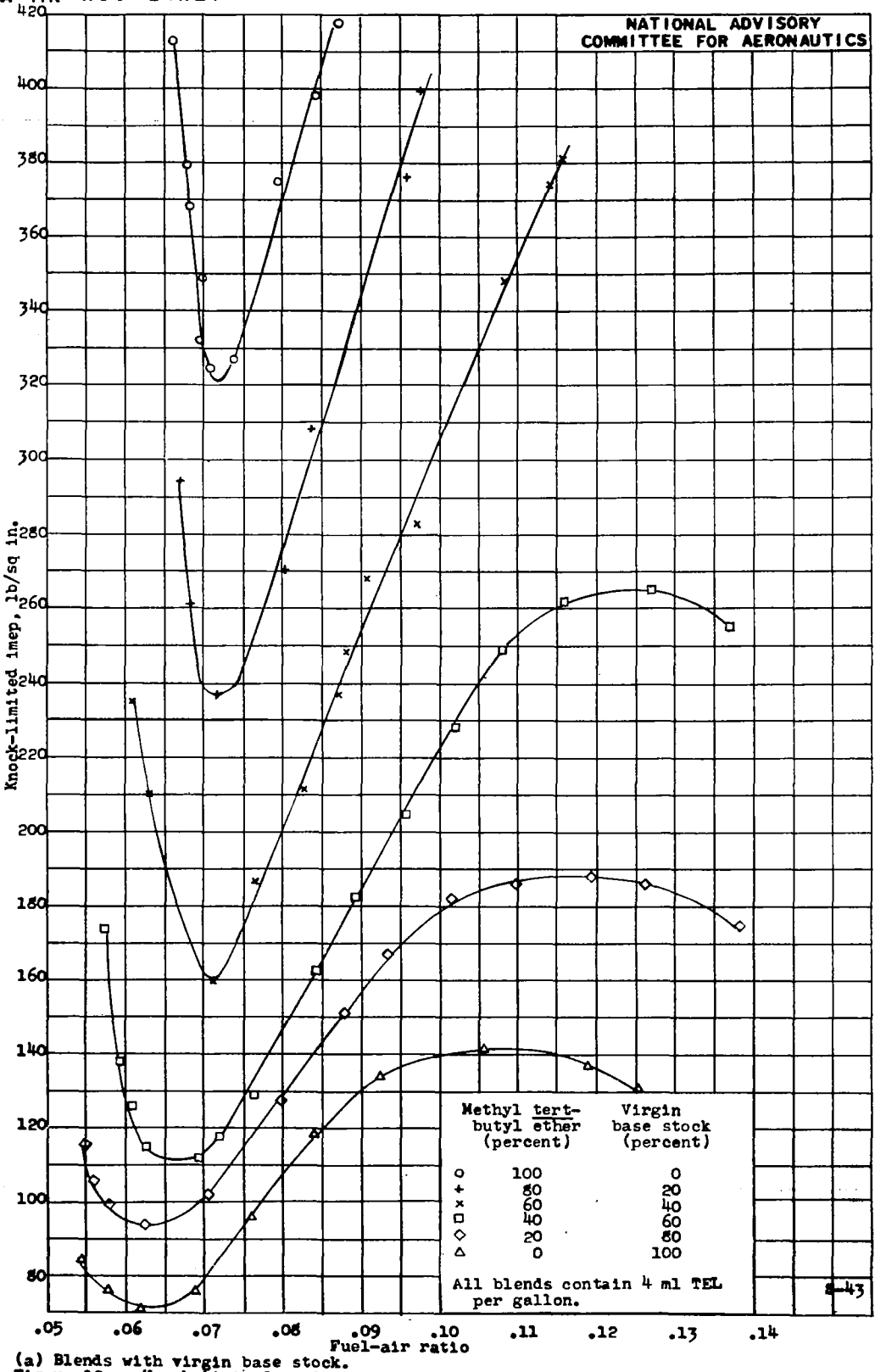


(c) Blends with one-pass catalytic stock.

Figure 11. - Continued.

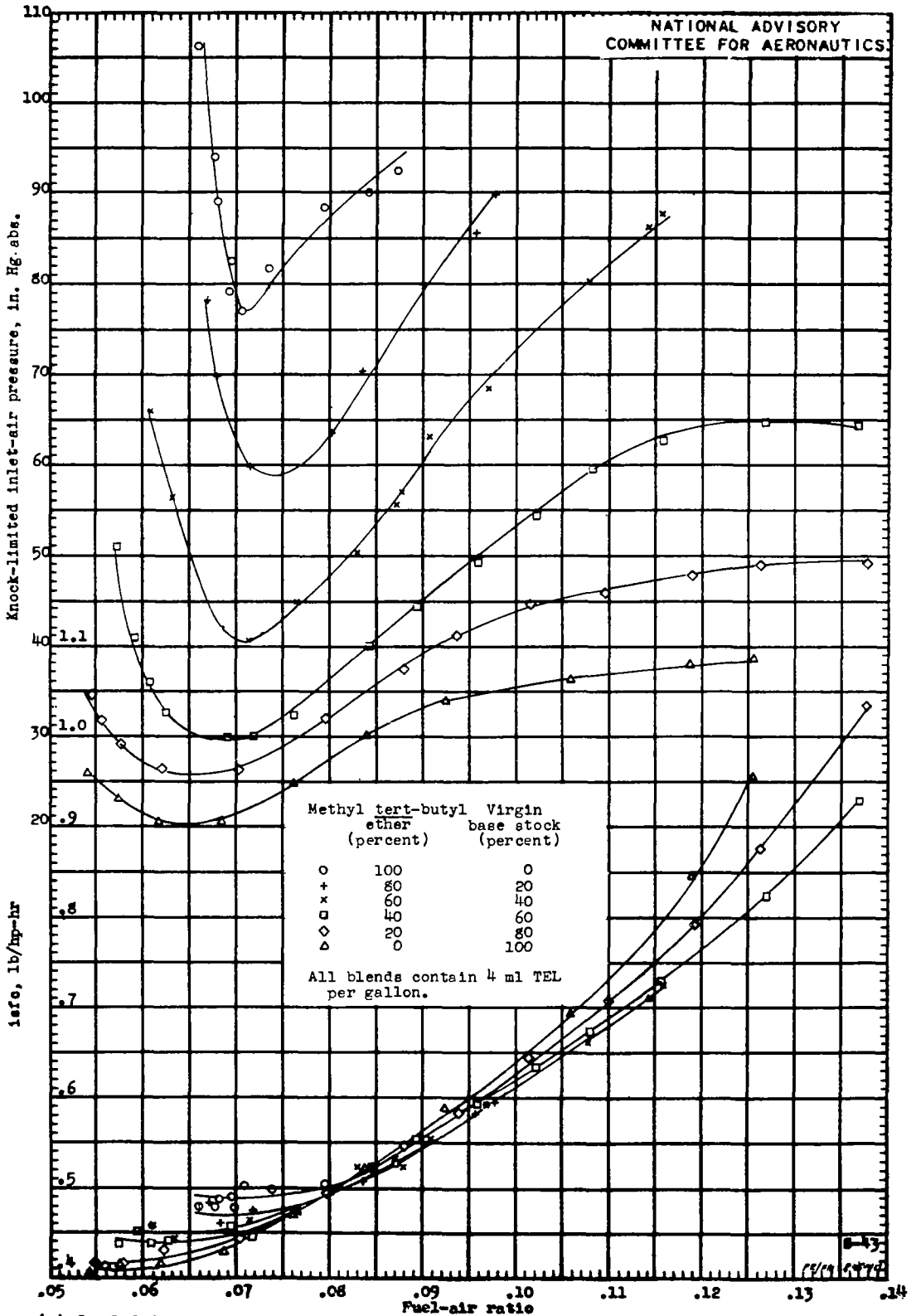


(c) Concluded.
Figure 11. - Concluded.

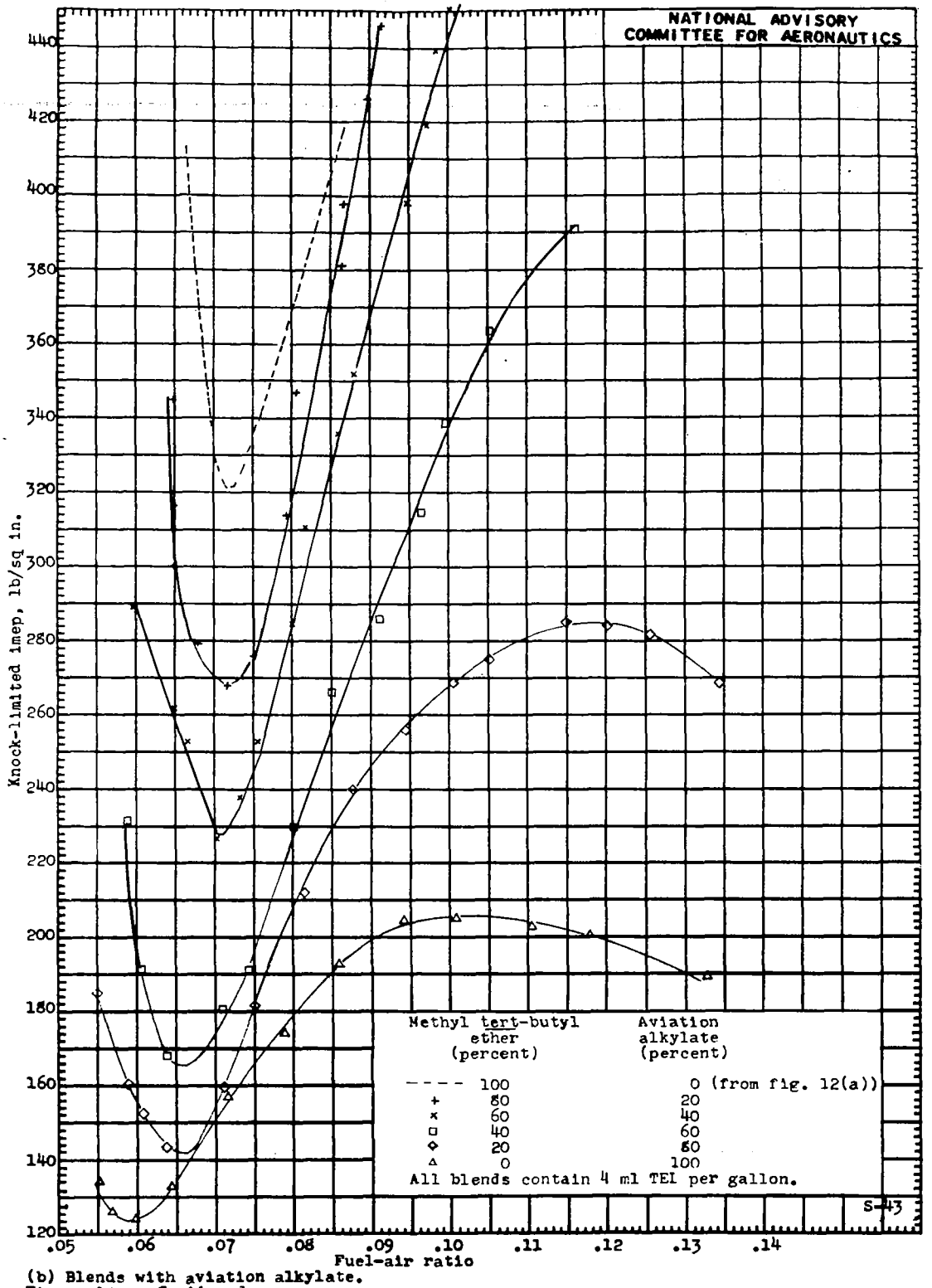


(a) Blends with virgin base stock.

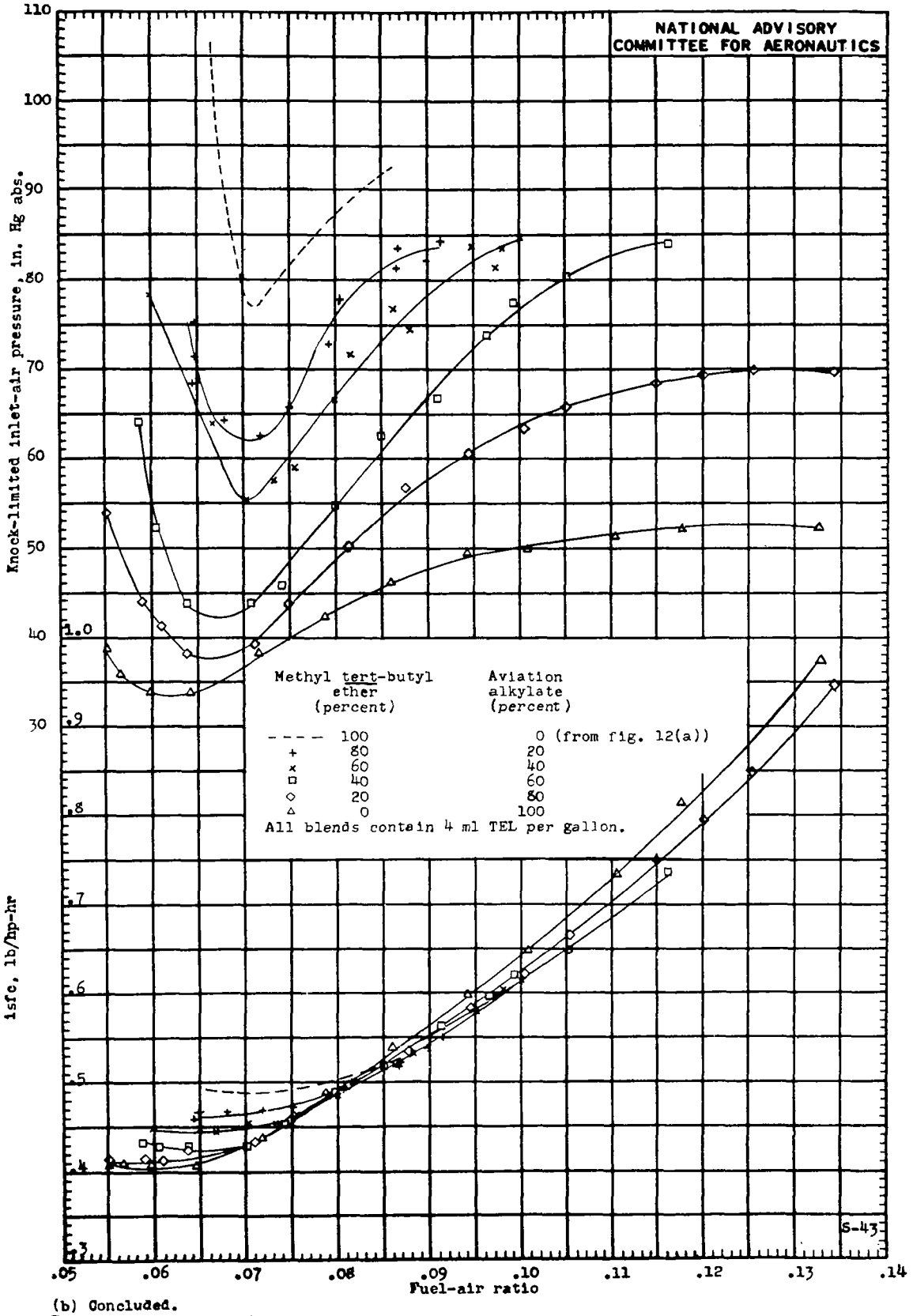
Figure 12. - Knock-limited performance of blends of methyl tert-butyl ether with virgin base stock, aviation alkylate, and one-pass catalytic stock as determined in an F-4 rating engine.



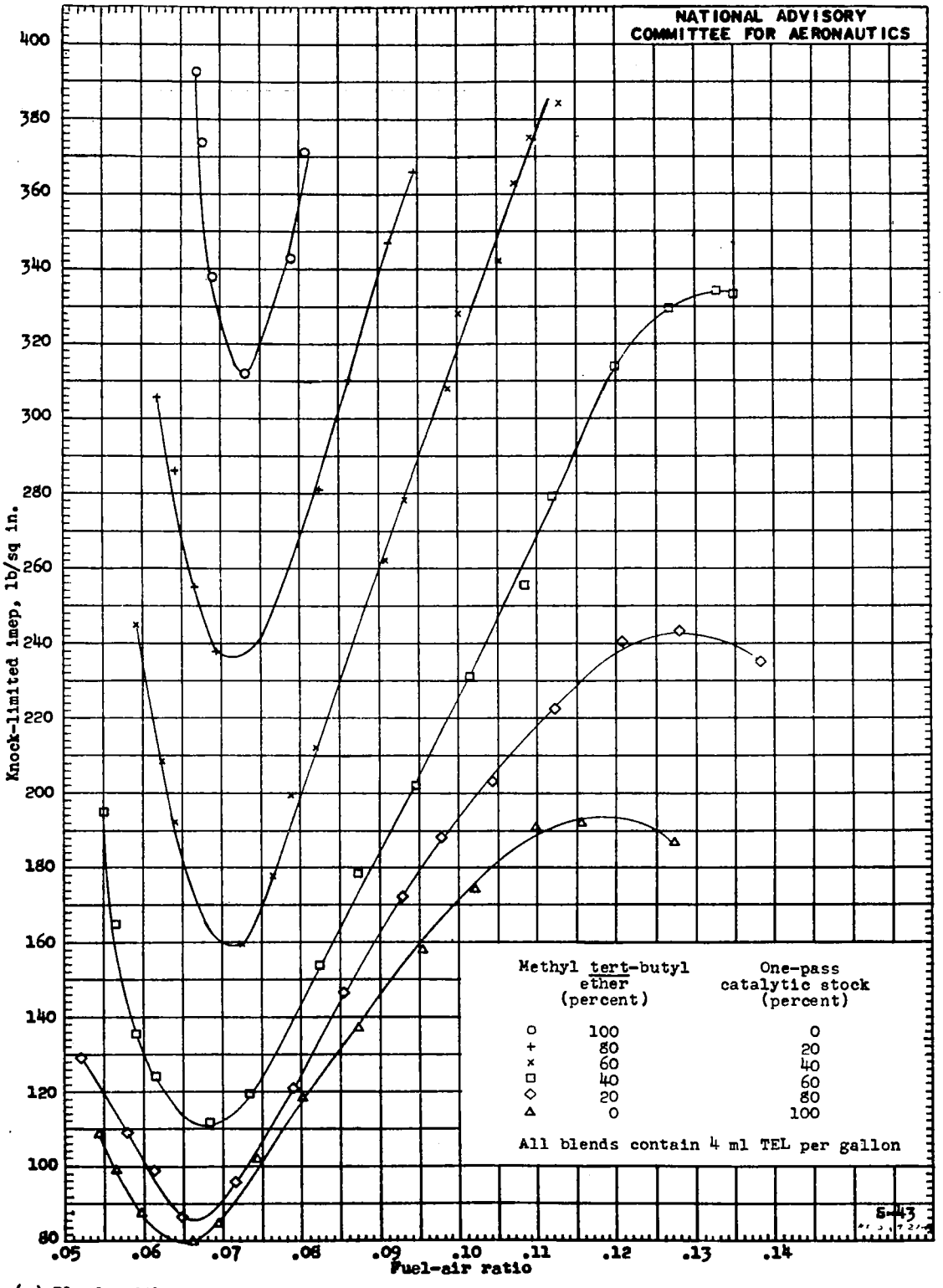
(a) Concluded.
Figure 12. - Continued.



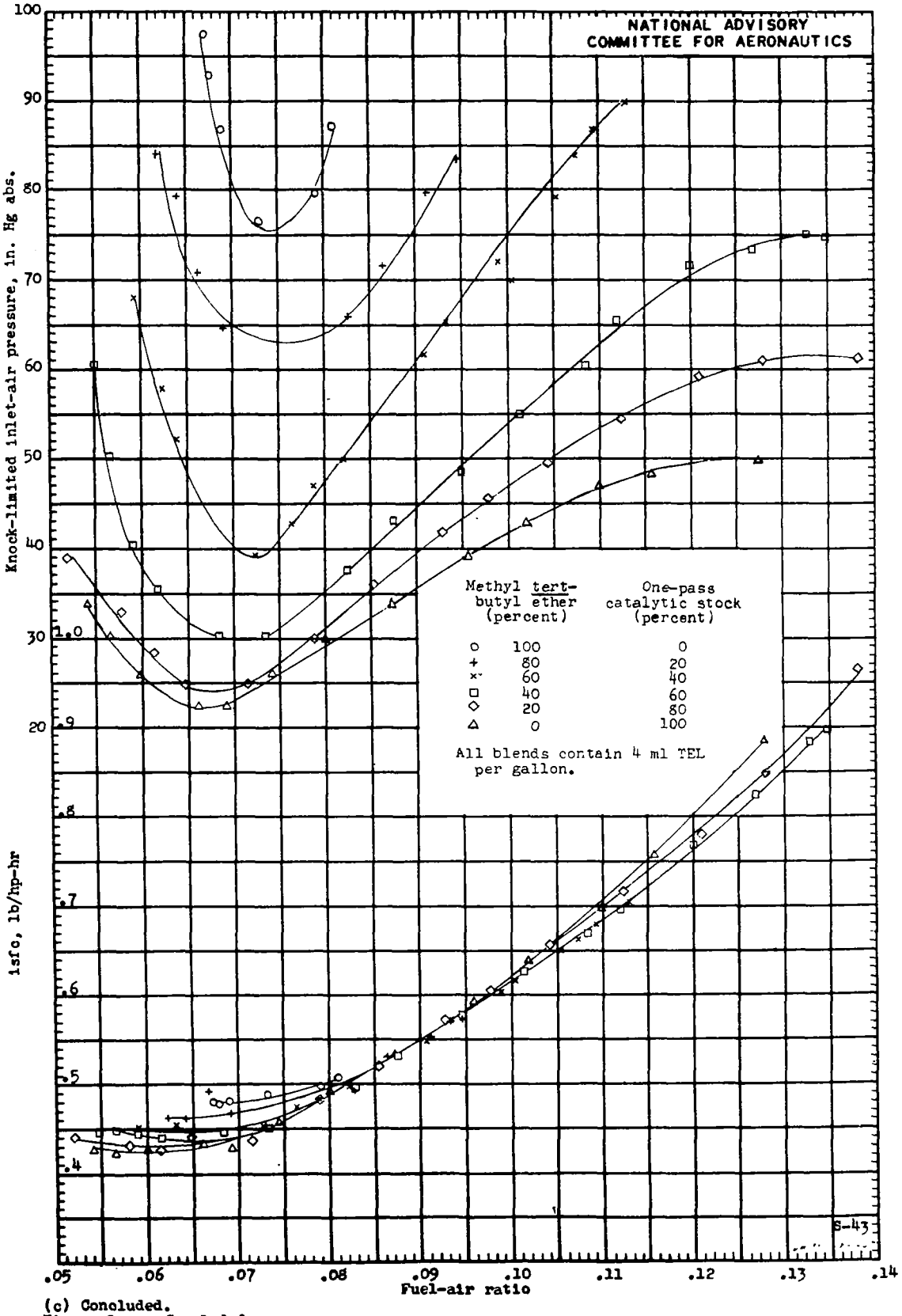
(b) Blends with aviation alkylate.
Figure 12. - Continued.



(b) Concluded.
Figure 12. - Continued.



(c) Blends with one-pass catalytic stock.
Figure 12. - Continued.



(c) Concluded.

Figure 12. - Concluded.

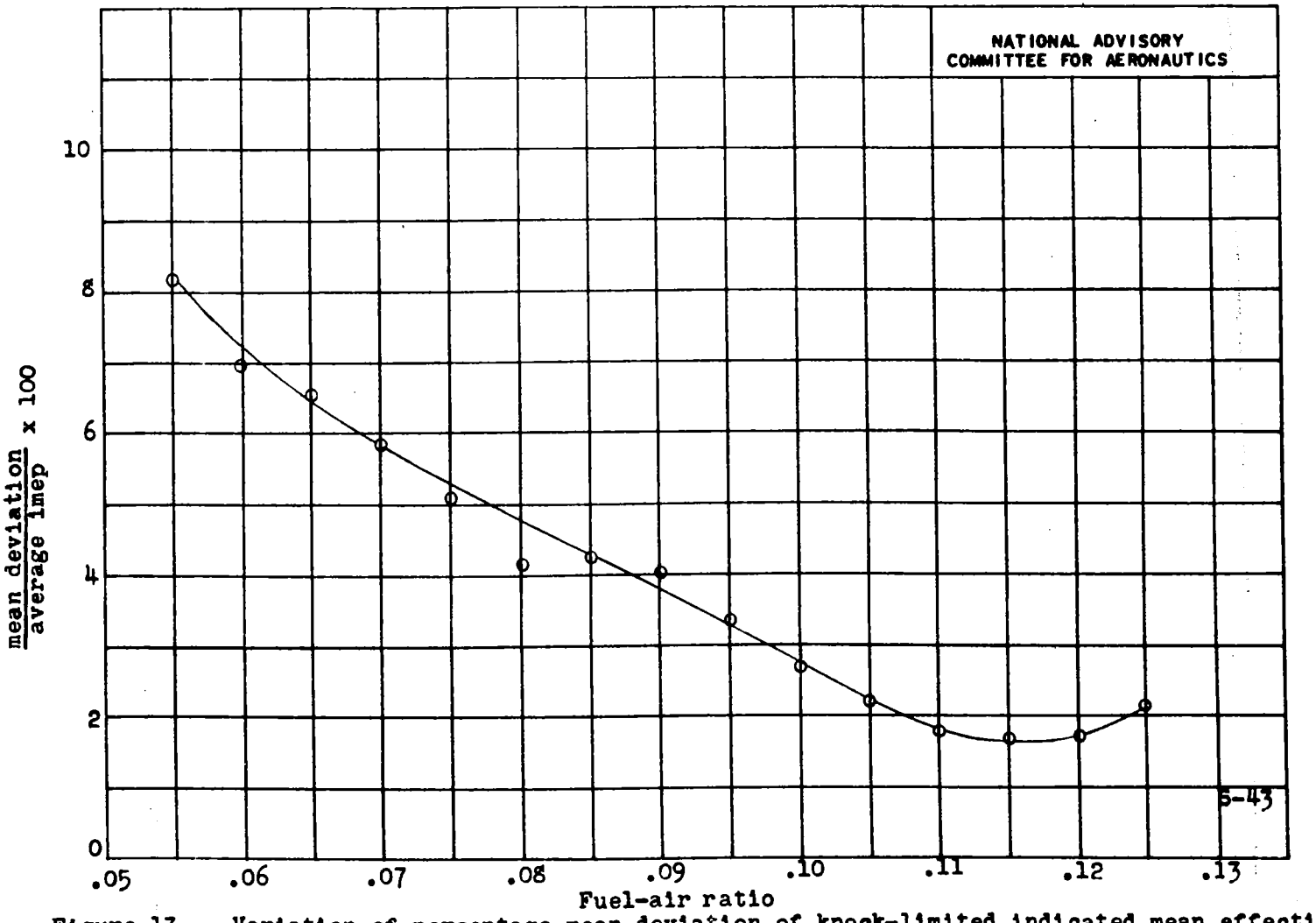


Figure 13. - Variation of percentage-mean deviation of knock-limited indicated mean effective pressure [(mean deviation/average imep) x 100] with fuel-air ratio as determined in an F-4 rating engine. (Calculated from fig. 2.)