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By Henry E. Alquist and Leonard K. Tower

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WASHINGTON

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MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

THE EFFECT OF COMPRESSION RATIO ON KNOCK LIMITS OF HIGH-PERFORMANCE FUELS IN A CFR ENGINE

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SUMMARY

The knock-limited performance of blends of 0, 50, and 100 percent by volume of triptane (2,2,3-trimethylbutane) in 28-R fuel was determined with a modified F-4 engine at three sets of conditions varying from severe to mild at each of three compression ratios (6.0, 8.0, and 10.0). It was found that the knock limits of the triptane blend were more sensitive to compression ratio than that of 28-R fuel, and the sensitivities of the triptane blends to compression ratio, as measured by knock-limited indicated mean effective pressure, increased as the severity of other engine conditions increased.

INTRODUCTION

At the request of the Army Air Forces, Air Technical Service Command, a general program is being conducted at the NACA laboratory at Cleveland to investigate the knock-limited performance of triptane. Two investigations under this program are reported in references 1 and 2. The tests reported herein were made during July 1944 with a modified F-4 engine at both severe and mild engine conditions with respect to fuel knock; particular emphasis was placed upon determining the effect of compression ratio on the antiknock effectiveness of triptane.

APPARATUS AND TEST PROCEDURE

An F-4 engine, modified as described in reference 3 and coupled to a 100-horsepower, direct-current, cradle-type dynamometer, was used in these tests. At each of three compression ratios, 6.0, 8.0, and 10.0, data were obtained at three sets of operating conditions, varying in severity as follows:

Condition	Inlet-air temperature (°F)	Coolant temperature (°F)	Spark advance (deg B.T.C.)
1	225	375	45
2	250	250	30
3	150	250	30

Except for compression ratio, engine conditions 1, 2, and 3 correspond to the F-4, modified A, and modified B conditions, respectively, used in reference 1. Other engine conditions correspond to specification CRC-F-4-443. At each of these conditions and one of the three compression ratios, blends of 0, 50, and 100 percent triptane (leaded to 4.53 ml TEL/gal) in 28-R fuel were tested on the same day. Data for the standard compression ratio of 7.0, obtained from figures 6, 8, and 11 of reference 1, are included herein to make the data more complete. Inasmuch as the engine installation for the tests reported in reference 1 differed from that for the present tests, direct comparison of the two sets of data may not be justifiable.

The data for 50- and 100-percent blends at high compression ratios and at high power are incomplete because of preignition difficulties. Such difficulties can be associated with the prevailing high power levels and should not be considered as peculiar to the fuel blends tested.

DISCUSSION OF RESULTS

Experimental data for tests at compression ratios of 6.0, 8.0, and 10.0 are given in figures 1 to 3, respectively. The knock-limited performances of the 50- and 100-percent blends of triptane plus 4.53 ml TEL per gallon relative to the 28-R fuel at the four compression ratios are given in table I. Approximately 55-percent improvement in the knock-limited indicated mean effective pressure was recorded for a 50-percent addition of triptane to 28-R fuel over the complete range of fuel-air ratios and at both severe and mild engine conditions for compression ratios of 6.0 and 7.0. At compression ratios of 8.0 and 10.0 the gain varied markedly with engine severity. When the engine operating conditions were moderate, the addition of triptane plus 4.53 ml TEL per gallon to 28-R fuel allowed substantial improvement in the knock-limited performance over the complete range of fuel-air ratios, even at a compression ratio of 10.0.

Table II gives a comparison of the ratio of knock-limited indicated mean effective pressures at an inlet-air temperature of 150° F to that at an inlet-air temperature of 250° F for the three triptane blends tested at the four compression ratios. The difference in the knock-limited indicated mean effective pressure for the corresponding change in inlet-air temperature is also included. With three exceptions the ratio of knock-limited indicated mean effective pressures decreased with an increase of fuel-air ratio. At compression ratios of 6.0 and 7.0 the ratios of knock-limited indicated mean effective pressure were approximately independent of triptane concentration. At compression ratios of 8.0 and 10.0 these ratios increased with increasing percentage of triptane, indicating the higher temperature sensitivity of triptane. The data tabulated in tables I and II indicate that, if triptane blends are used in a high-compression-ratio engine, low inlet-air temperatures are required if the benefits of triptane in increased knock-limited indicated mean effective pressure are to be realized.

The data from figures 1 to 3 were replotted and data at a compression ratio of 7.0 from reference 1 (represented by points) were included in figure 4 to show the effect of compression ratio on the knock limits of 0, 50, and 100 percent triptane in 28-R fuel. As the percentage of triptane was increased, the knock-limited indicated mean effective pressure of the fuel blend became more sensitive to compression ratio. The result of a change in compression ratio was more evident at lean mixtures than at rich mixtures except at severe operating conditions. As the severity of other engine conditions increased, the effect of compression ratio became more pronounced, particularly at low compression ratios.

The graph of the reciprocal of knock-limited indicated mean effective pressure against percentage composition, as applied in reference 4, has been shown to be convenient in predicting blending characteristics of paraffinic fuels. Data from figures 1, 2, and 3 are cross-plotted in figure 5 in this manner at both mild and severe engine conditions and show that a reciprocal relation is approximately satisfied by the blends of triptane and 28-R fuel at all compression ratios tested.

In reference 1 it was estimated that all projected curves of reciprocal knock-limited indicated mean effective pressure against percentage concentration for blends containing triptane and 28-R fuel intersect at infinite indicated mean effective pressure and 137 percent triptane. From the data presented herein, it is apparent that no common intersection of the curves exists when the range of operating conditions is extended over a wider range than that used in tests reported in reference 1. This lack of a common point of intersection, also indicated in table I, shows that the percentage gain in knock-limited indicated mean effective pressure resulting from a given addition of triptane is dependent on engine operating conditions.

SUMMARY OF RESULTS

The results of knock-limited tests of 0, 50, and 100 percent blends of triptane and 28-R fuel in a modified F-4 engine under three operating conditions at compression ratios of 6.0, 8.0, and 10.0 are summarized as follows:

1. The knock limit of the triptane blends was more sensitive to compression ratio than that of 28-R fuel.

2. The sensitivities of triptane blends to compression ratio, as measured by knock-limited indicated mean effective pressure, increased as the severity of other engine conditions increased.

3. At the high compression ratios the triptane blends showed greater temperature sensitivity than 28-R fuel. It is therefore obvious that, if triptane blends are used in a high-compression-ratio engine, low inlet-air temperatures are required if the benefits of triptane in increased knock-limited indicated mean effective pressure are to be realized.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, October 10, 1944.

REFERENCES

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

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

3. Bransetter, J. Robert, and Meyer, Carl L.: Antiknock Effectiveness of Xylidines in Small-Scale Engines. NACA Memo. rep., Aug. 6, 1943.

4. Sanders, Newell D.: A Method of Estimating the Knock Rating of Hydrocarbon Fuel Blends. NACA ARR No. 3H21, 1943.

TABLE I - EFFECT OF COMPRESSION RATIO ON THE KNOCK LIMITS OF BLENDS CONTAINING TRIPTANE AND 28-R FUEL AT THREE SETS OF ENGINE CONDITIONS

Condition 1: Inlet-air temperature, 225° F; coolant temperature, 375° F; spark advance, 45° B.T.C.

Condition 2: Inlet-air temperature, 250° F; coolant temperature, 250° F; spark advance, 30° B.T.C.

Condition 3: Inlet-air temperature, 150° F; coolant temperature, 250° F; spark advance, 30° B.T.C.

Percentage triptane in final blend[a]	imep ratio											
	F/A = 0.0625			F/A = 0.070			F/A = 0.090			F/A = 0.110		
	Condition			Condition			Condition			Condition		
	1	2	3	1	2	3	1	2	3	1	2	3
Compression ratio, 6.0												
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
50	1.45	1.58	1.54	1.46	1.57	1.61	1.56	1.60	1.53	1.57	1.42	----
100	----	2.93	----	----	2.92	----	----	----	----	----	----	----
Compression ratio, 7.0[b]												
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
50	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	----	----
100	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	----	----
Compression ratio, 8.0												
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
50	1.19	1.32	1.57	1.37	1.20	1.60	1.51	1.41	1.56	1.80	1.59	1.46
100	1.76	2.14	3.04	2.10	2.04	3.09	2.78	2.26	----	----	----	----
Compression ratio, 10.0												
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
50	1.07	1.32	1.68	1.09	1.38	1.59	1.26	1.35	1.65	1.30	1.54	1.54
100	1.19	1.70	2.73	1.35	1.60	3.07	1.76	1.97	2.90	2.52	2.67	2.72

[a] Final lead concentration, approximately 4.53 ml TEL per gallon.

[b] Data estimated from figures 6, 8, and 11 of reference 1.

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TABLE II - EFFECT OF INLET-AIR TEMPERATURE ON THE KNOCK LIMITS OF BLENDS CONTAINING TRIPTANE AND 28-R FUEL AT FOUR COMPRESSION RATIOS

[The imep ratio = $\text{imep}_{150}/\text{imep}_{250}$. The imep difference = $\text{imep}_{150} - \text{imep}_{250}$. F-4 engine operating at modified conditions: inlet-air temperatures, 150° and 250° F; coolant temperature, 250° F; spark advance, 30° B.T.C.]

Percentage triptane in final blend[a]	F/A = 0.0625		F/A = 0.070		F/A = 0.080		F/A = 0.090	
	imep ratio	imep difference	imep ratio	imep difference	imep ratio	imep difference	imep ratio	imep difference
Compression ratio, 6.0								
0	1.14	28	1.10	21	1.09	21	1.06	14
50	1.12	38	1.13	44	1.08	30	1.00	2
100	-----	-------	-----	-------	-----	-------	-----	-------
Compression ratio, 7.0[b]								
0	1.24	37	1.16	28	1.09	17	1.05	10
50	1.22	55	1.14	38	1.10	30	1.04	15
100	1.21	120	1.16	100	1.07	50	1.01	10
Compression ratio, 8.0								
0	1.33	40	1.26	36	1.16	28	1.08	15
50	1.56	90	1.70	114	1.56	115	1.20	54
100	1.87	227	1.92	256	-----	-------	-----	-------
Compression ratio, 10.0								
0	1.35	30	1.27	26	1.12	16	1.09	14
50	1.70	78	1.46	62	1.50	86	1.33	68
100	2.20	174	2.42	222	1.99	222	1.60	1.82

[a] Lead concentration, approximately 4.53 ml TEL per gallon.

[b] Data extrapolated from figures 6, 8, and 11 of reference 1.

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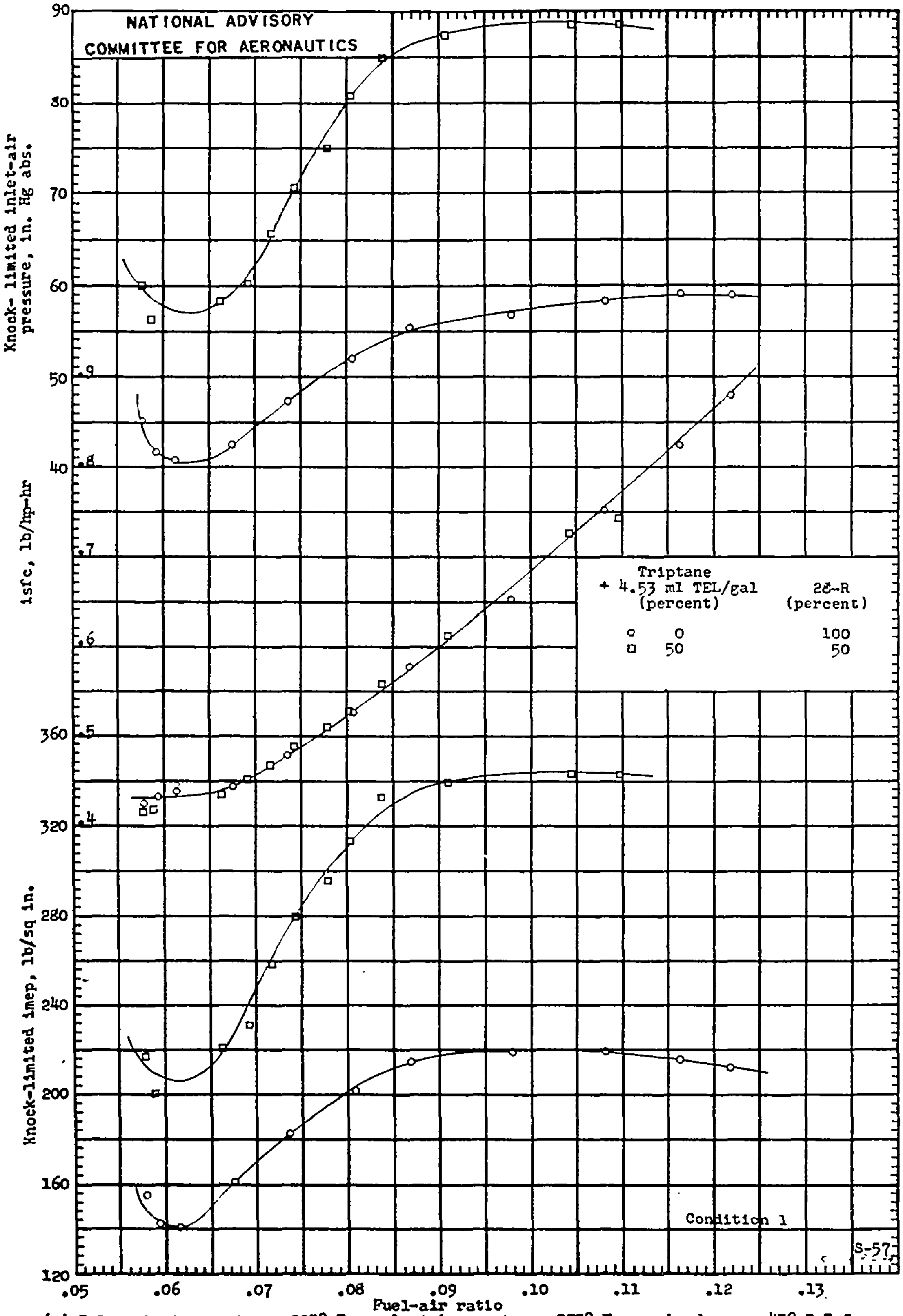
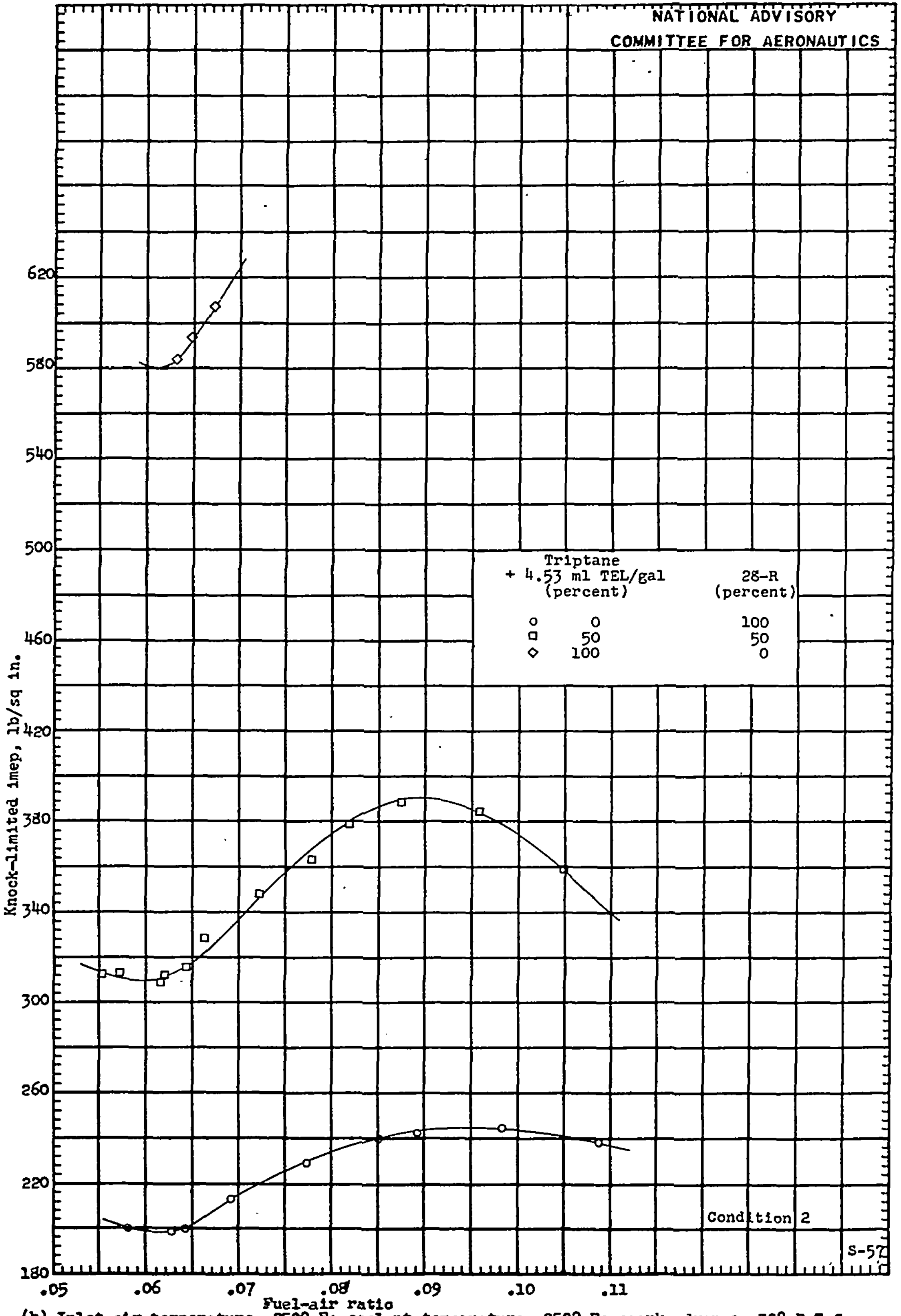
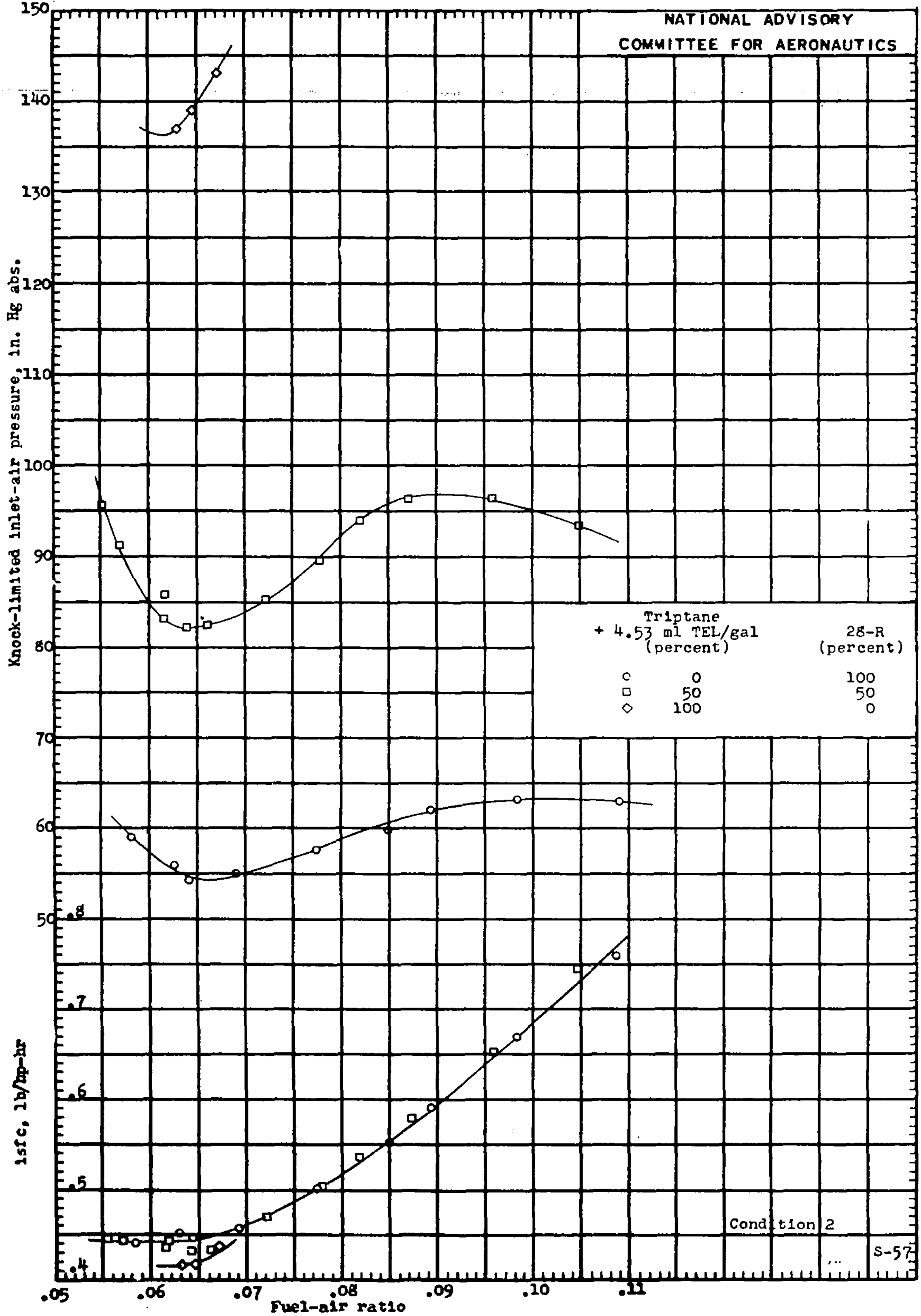


(a) Inlet-air temperature, 225° F; coolant temperature, 375° F; spark advance, 45° B.T.C.

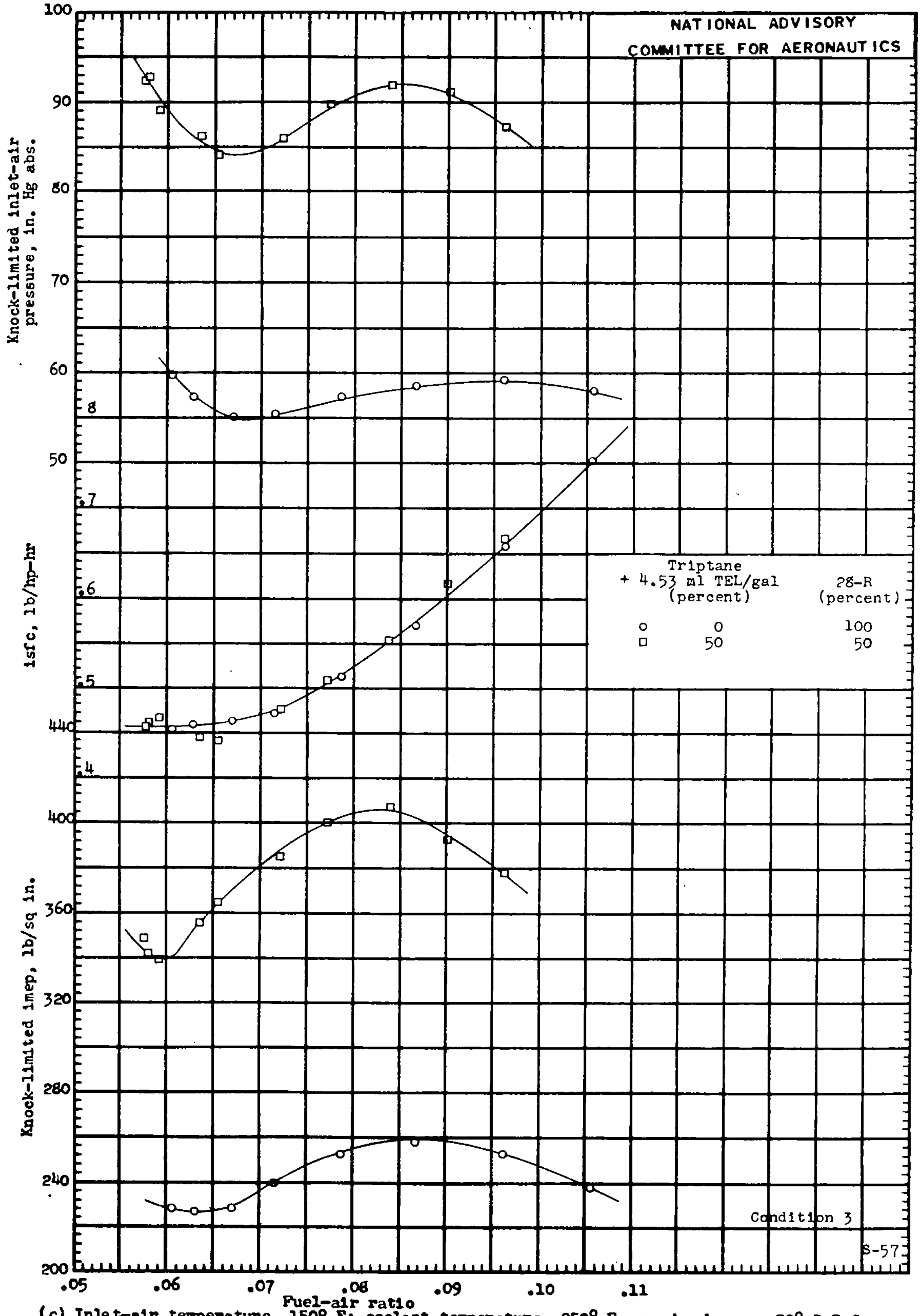
Figure 1. - Knock-limited performance of blends of triptane and 28-R fuel in CFR engine at compression ratio of 6.0. Engine speed, 1800 rpm; oil temperature, 165° F.



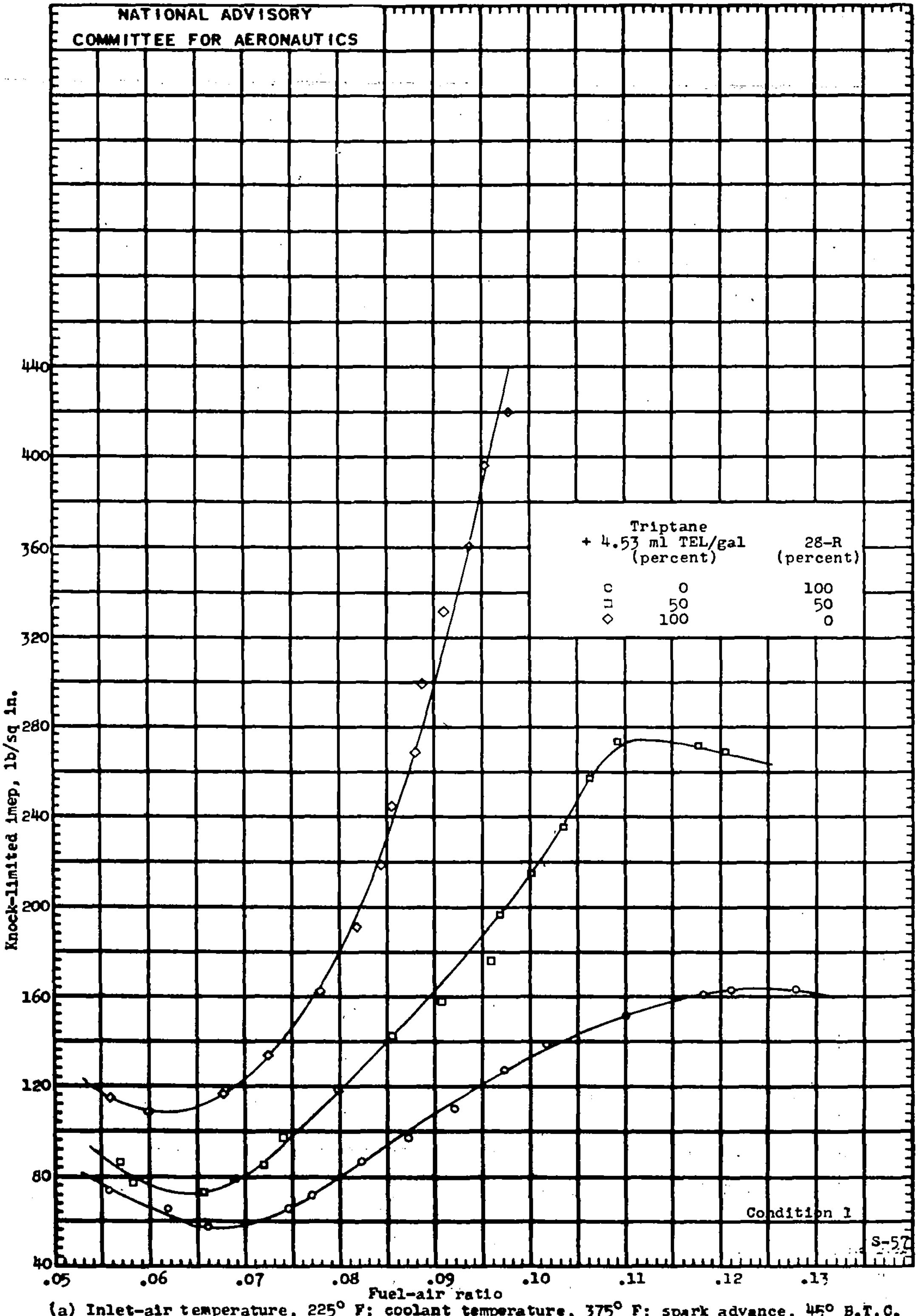
(b) Inlet-air temperature, 250° F; coolant temperature, 250° F; spark advance, 30° B.T.C.
Figure 1. - Continued.



(b) Concluded.
Figure 1. - Continued.

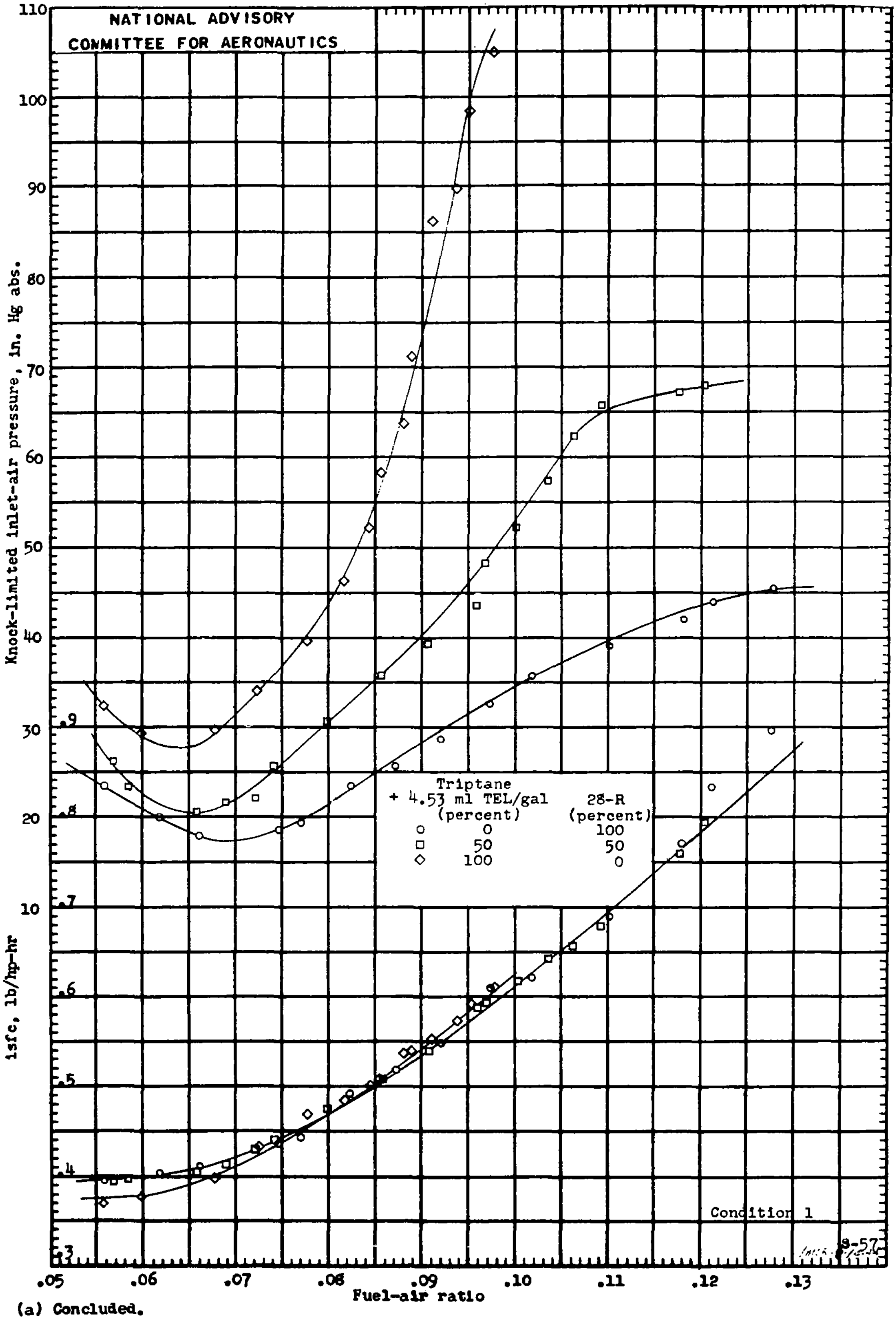


(c) Inlet-air temperature, 150° F; coolant temperature, 250° F; spark advance, 30° B.T.C.
Figure 1. - Concluded.



(a) Inlet-air temperature, 225° F; coolant temperature, 375° F; spark advance, 45° B.T.C.

Figure 2. - Knock-limited performance of blends of triptane and 28-R fuel in CFR engine at compression ratio of 8.0. Engine speed, 1800 rpm; oil temperature, 165° F.



(a) Concluded.
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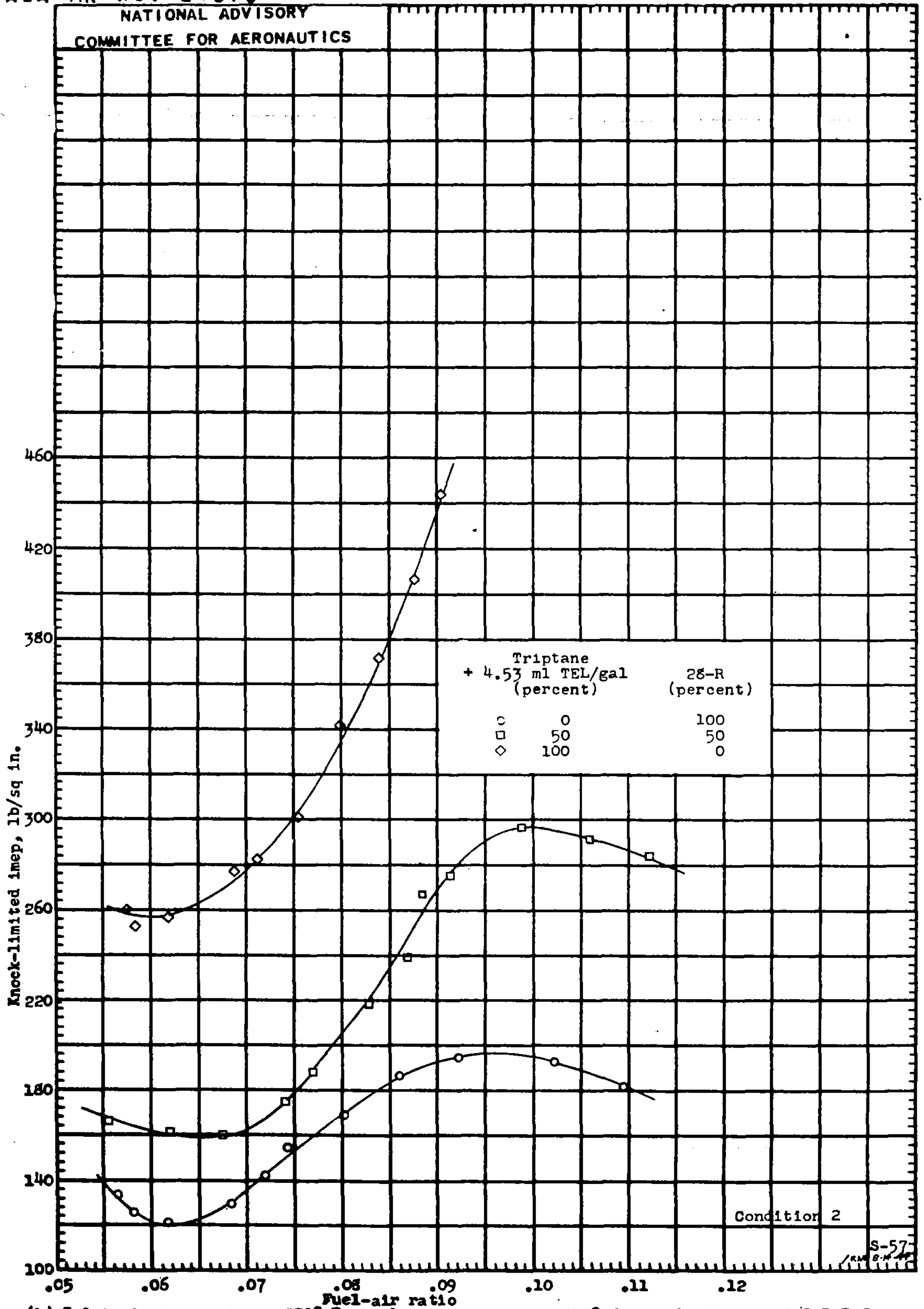
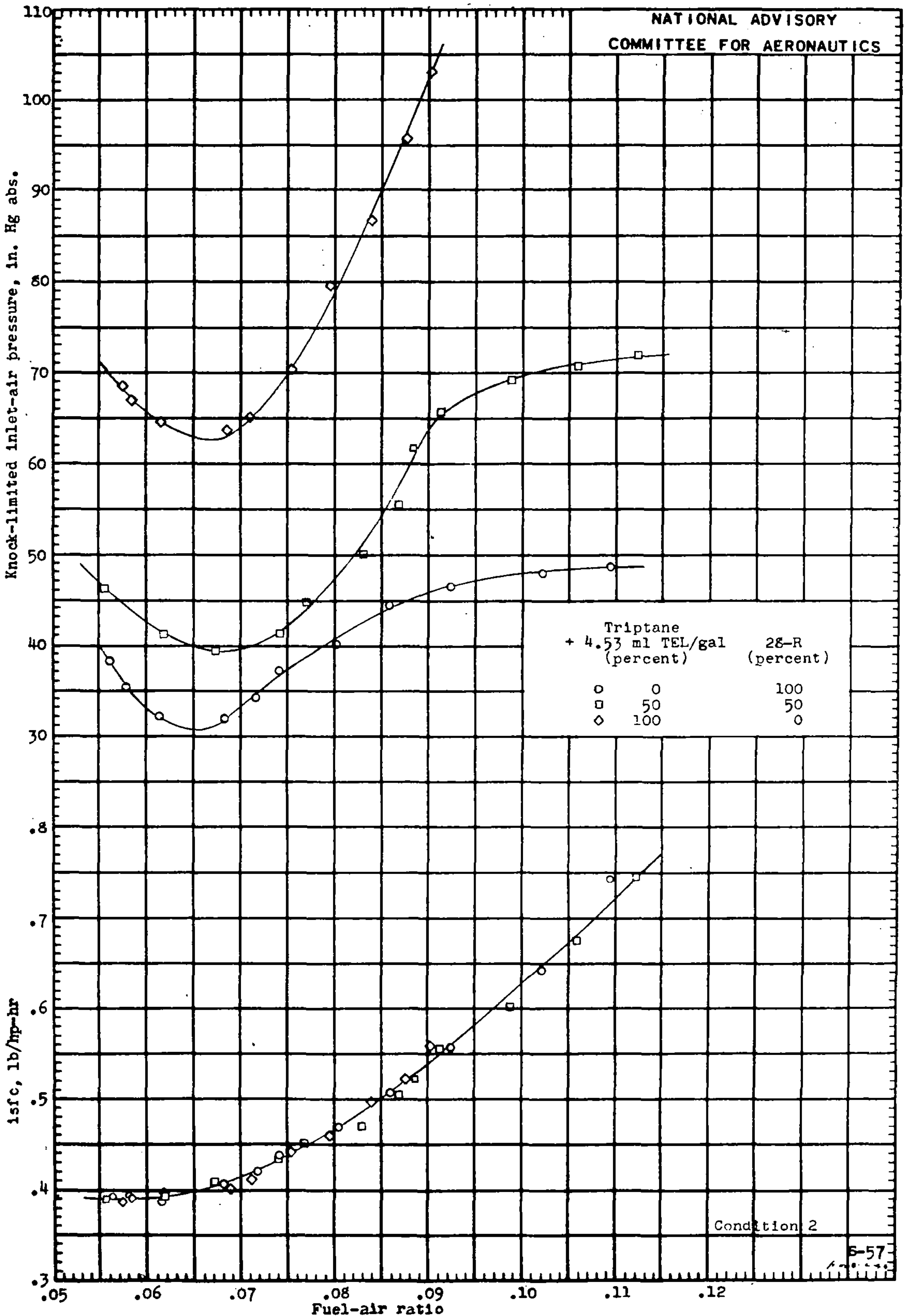
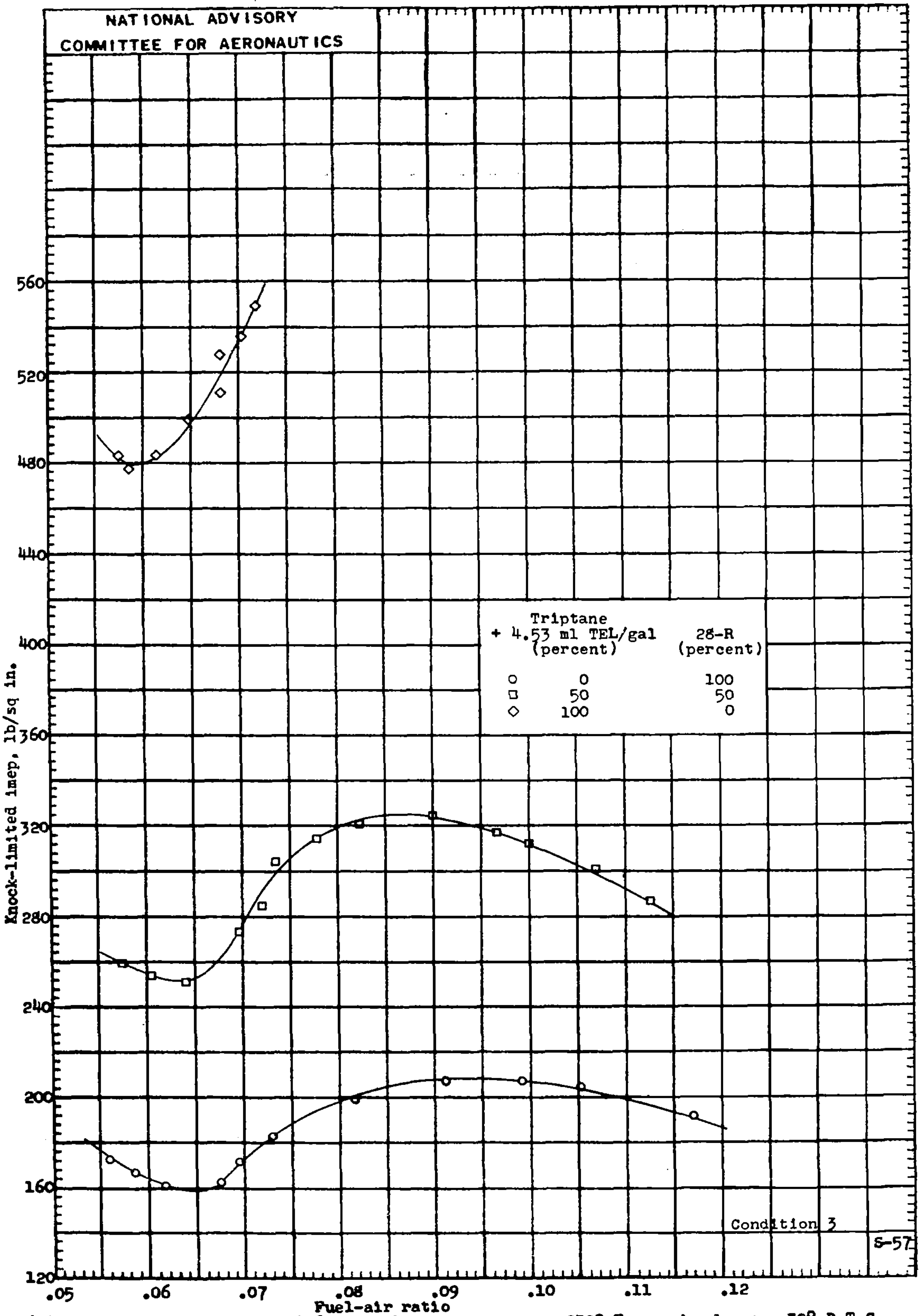


(b) Inlet-air temperature, 250° F; coolant temperature, 250° F; spark advance, 30° B.T.C.
Figure 2. - Continued.



(b) Concluded.
Figure 2. - Continued.



(c) Inlet-air temperature, 150° F; coolant temperature, 250° F; spark advance, 30° B.T.C.
Figure 2. - Continued.

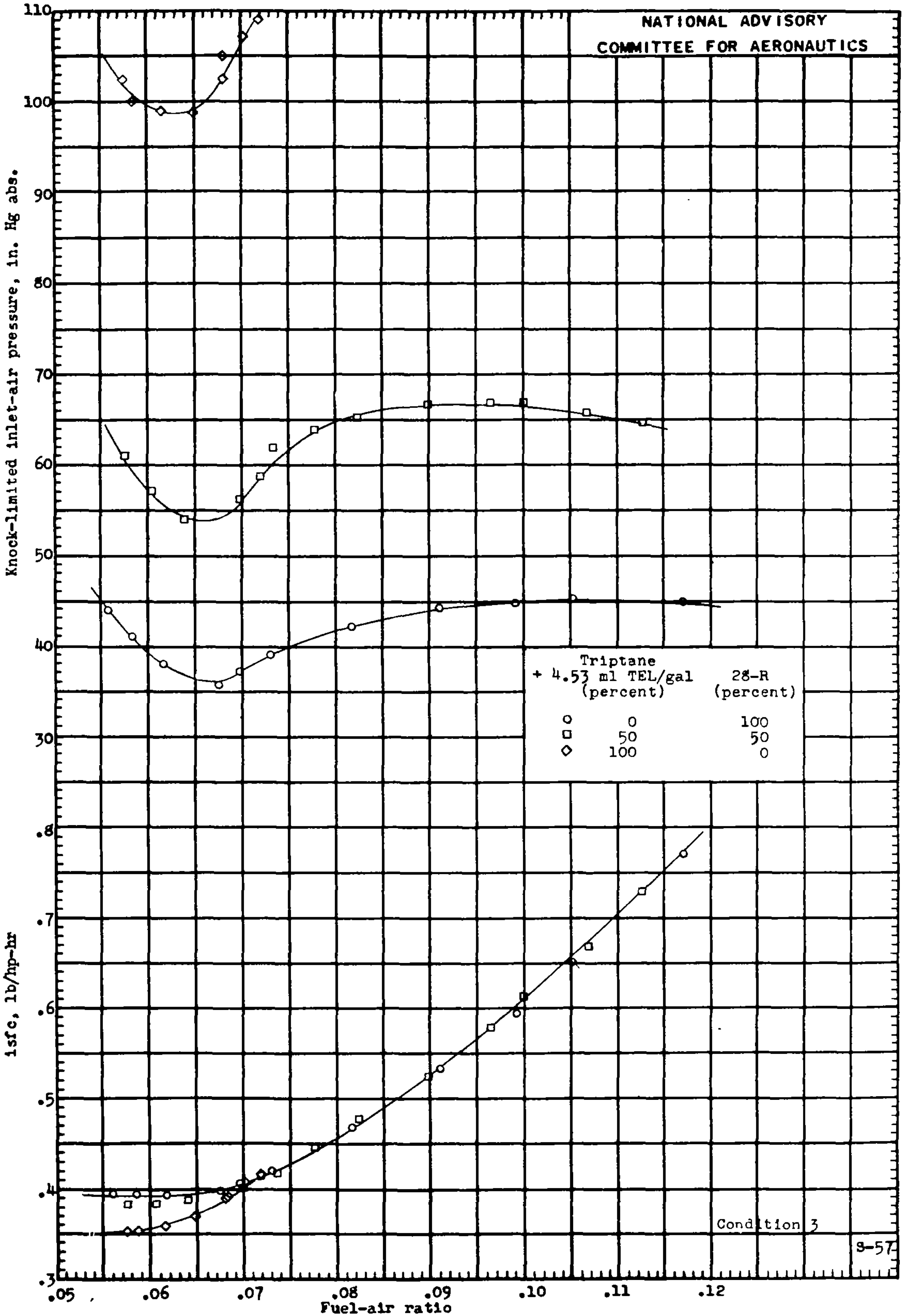


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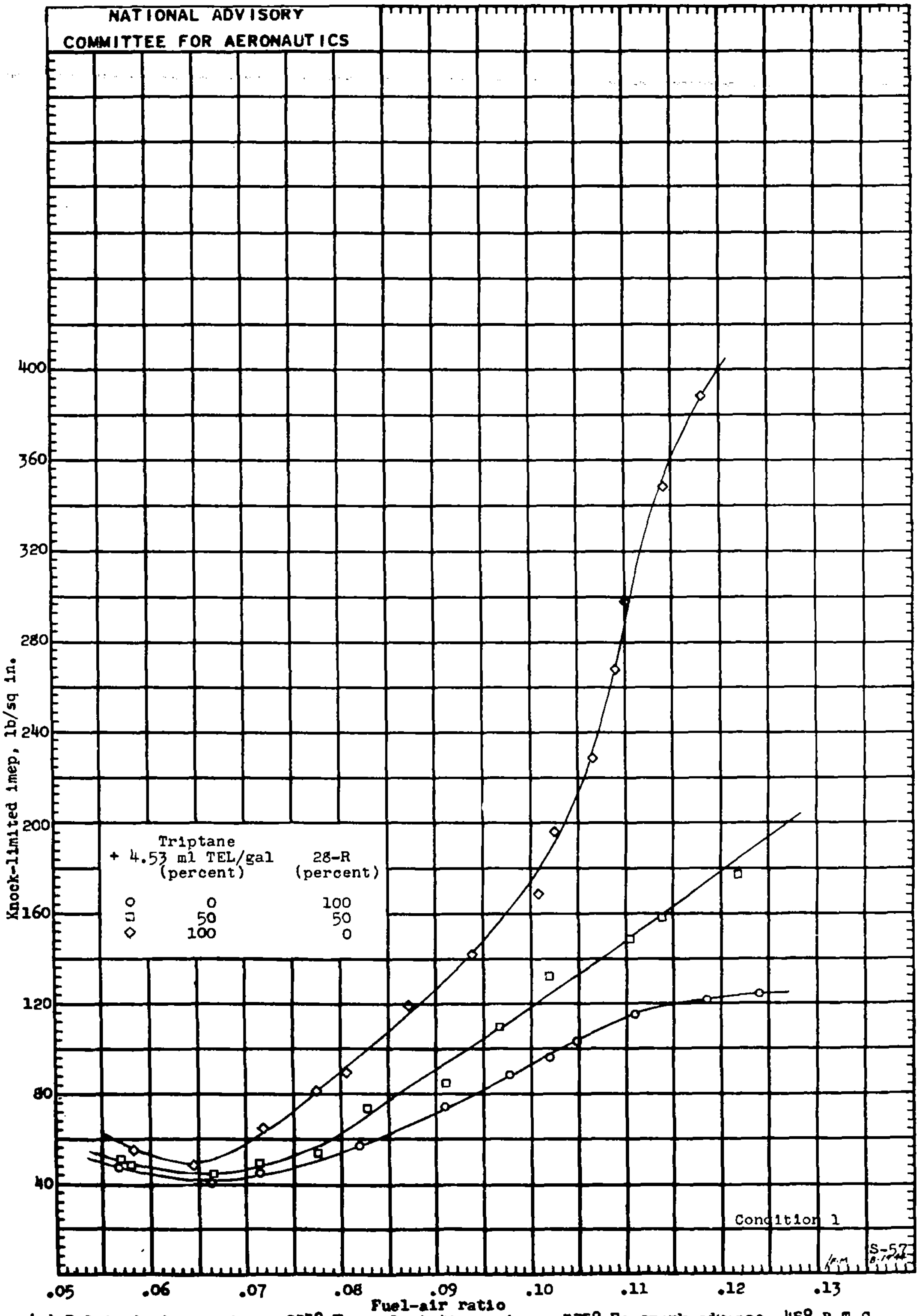
Figure 2. - Concluded.



(a) Inlet-air temperature, 225° F; coolant temperature, 375° F; spark advance, 45° B.T.C.

Figure 3. - Knock-limited performance of blends of triptane and 28-R fuel in CFR engine at compression ratio of 10.0. Engine speed, 1800 rpm; oil temperature, 165° F.

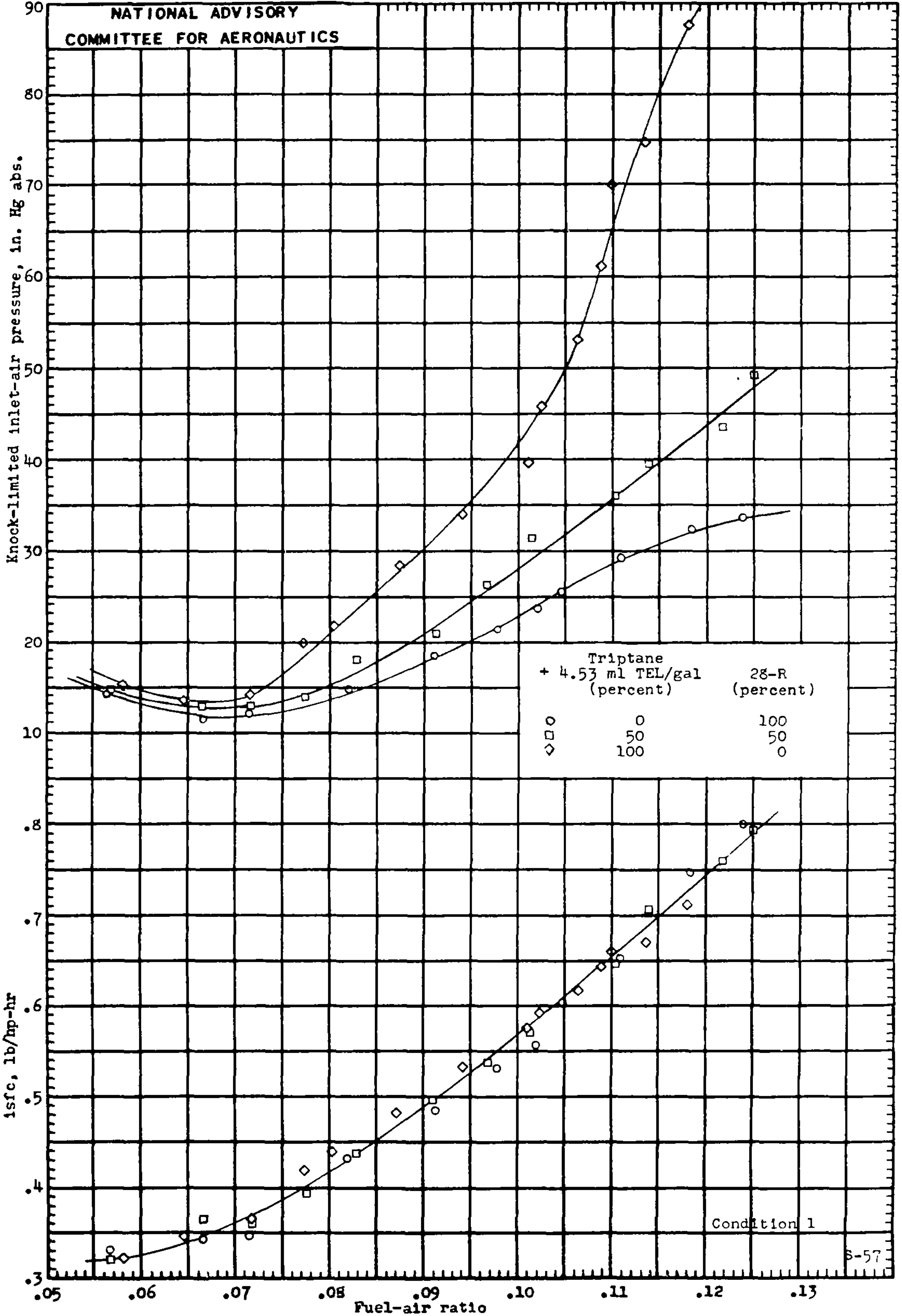


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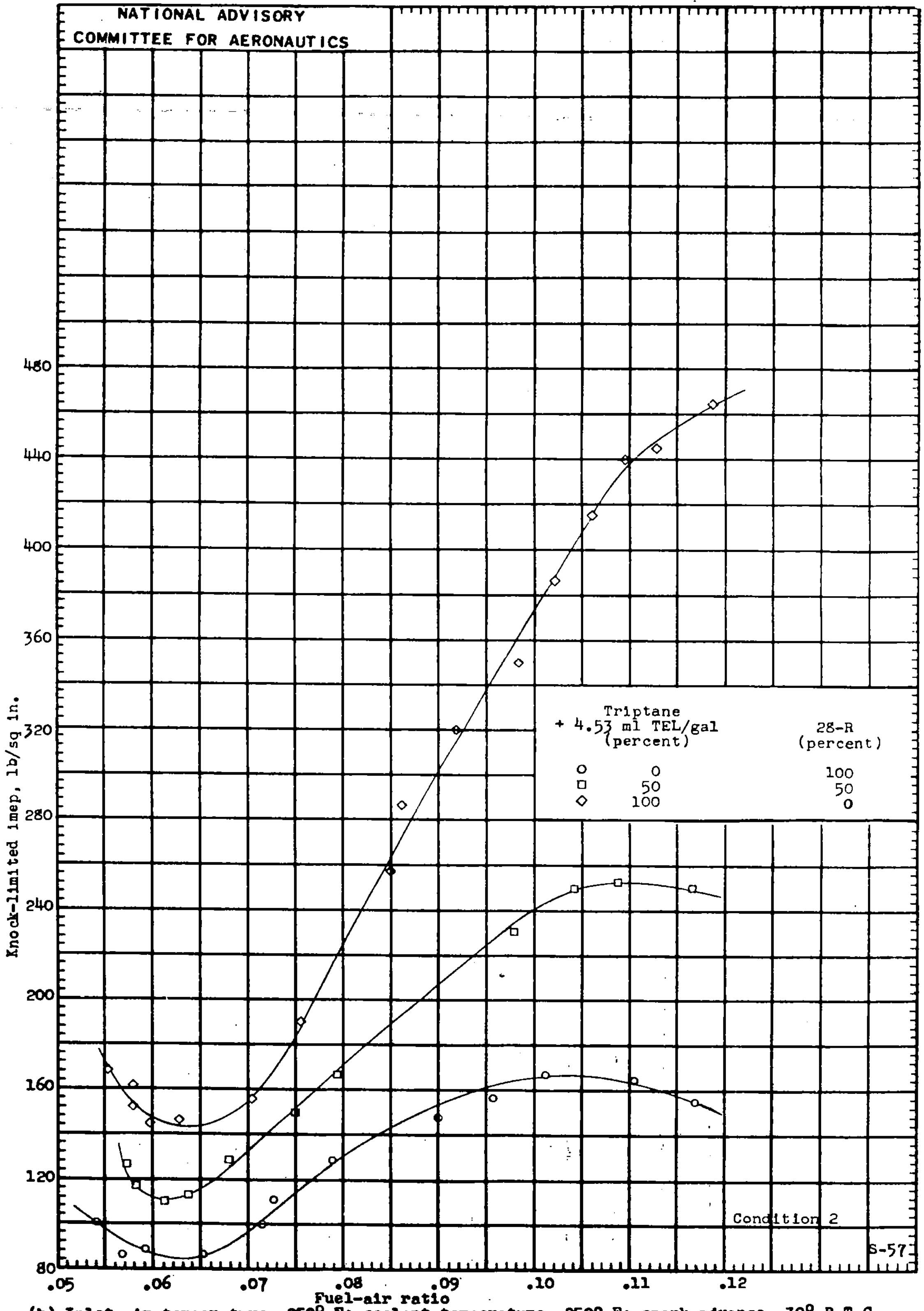
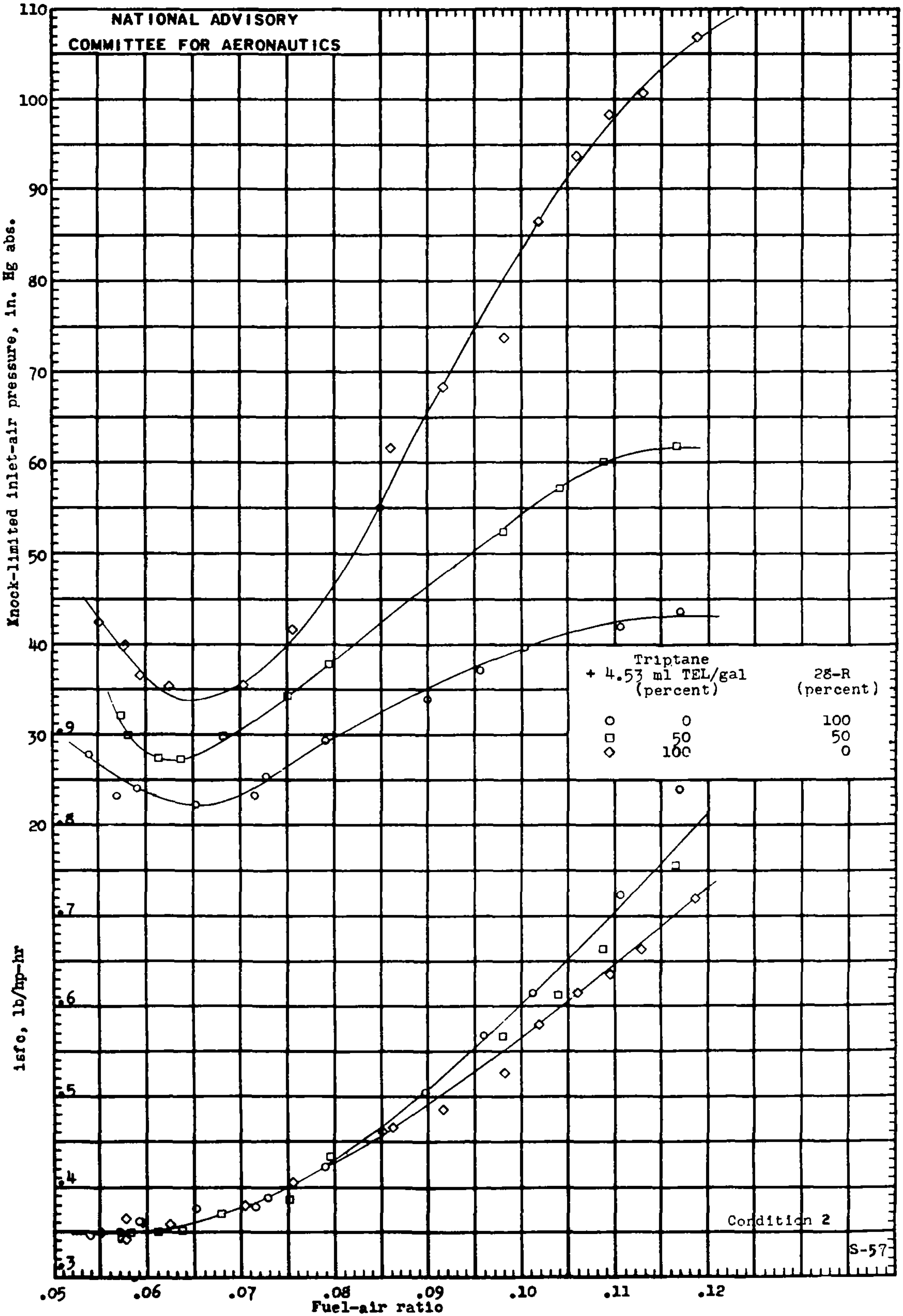
Figure 3. - Continued.



(b) Inlet-air temperature, 250° F; coolant temperature, 250° F; spark advance, 30° B.T.C.
Figure 3. - Continued.



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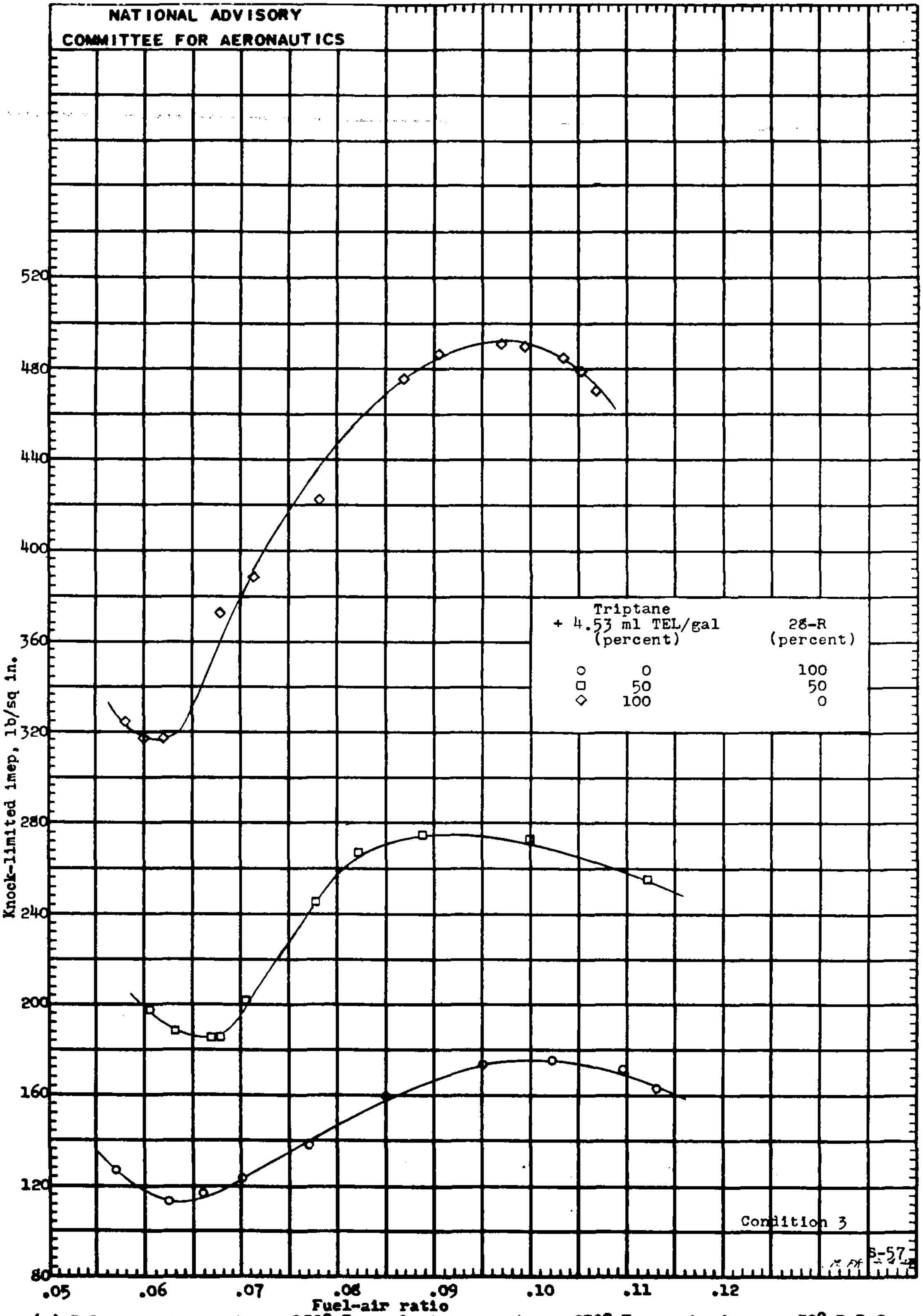

(c) Inlet-air temperature, 150° F; coolant temperature, 250° F; spark advance, 30° B.T.C.
Figure 3. - Continued.

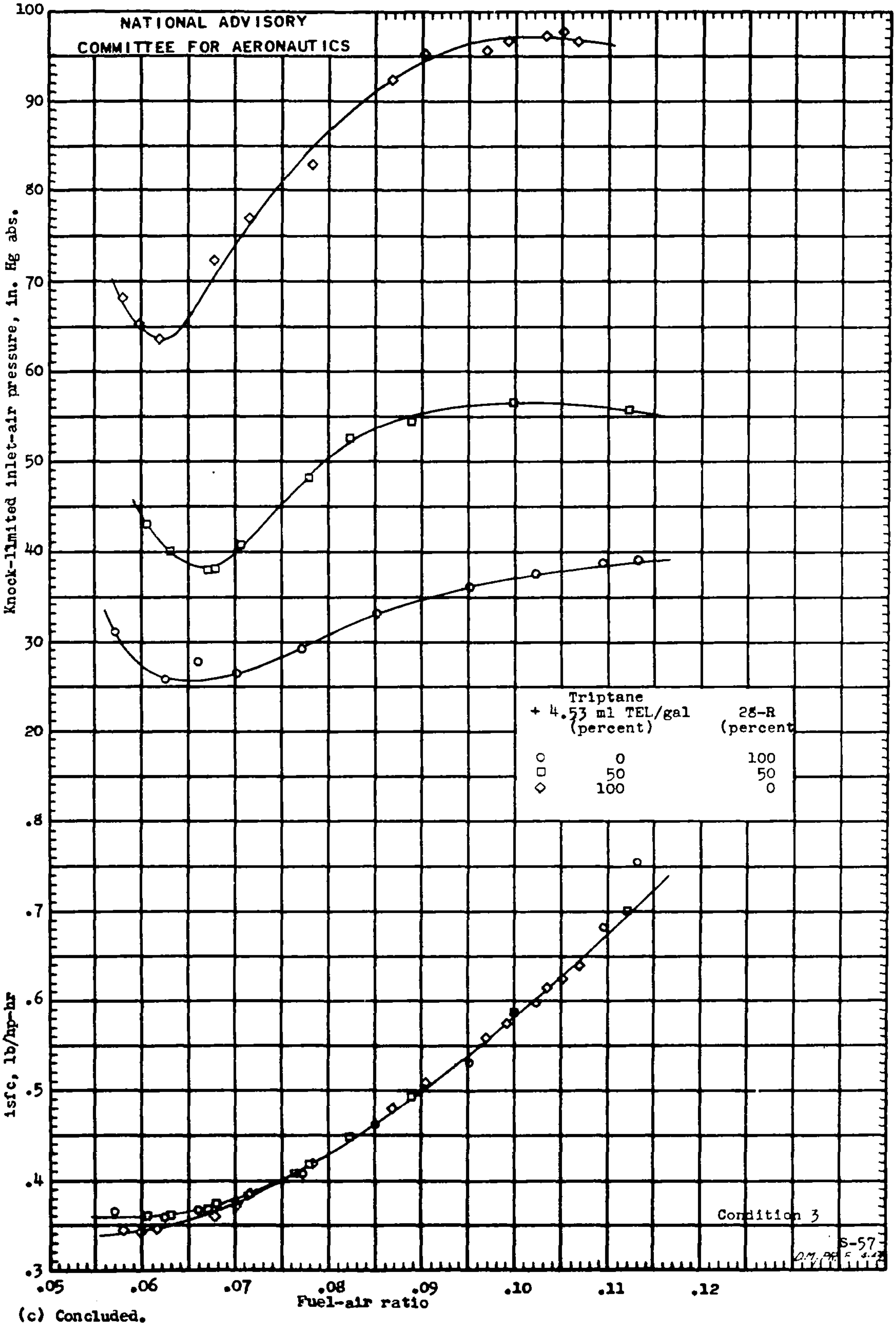

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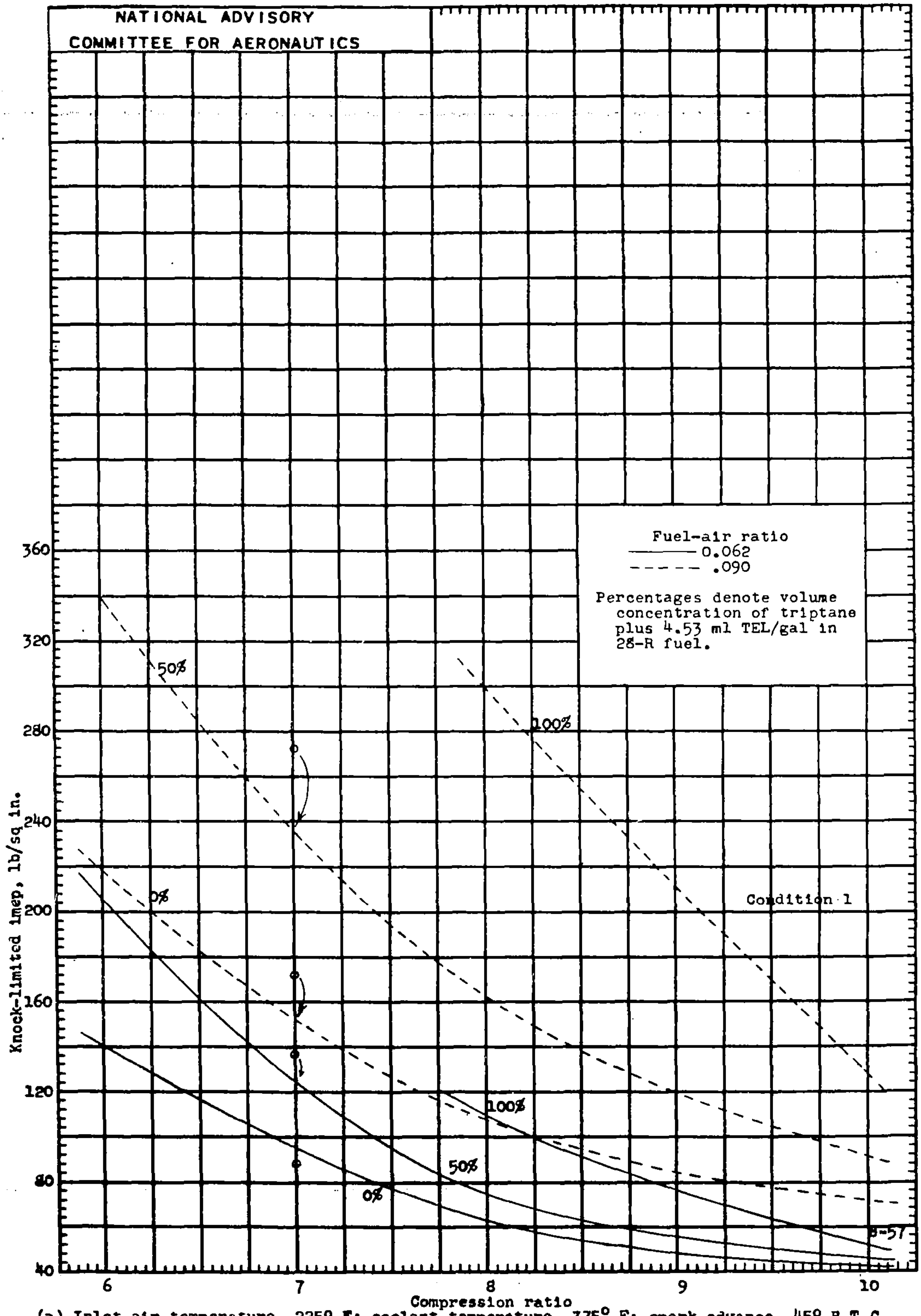
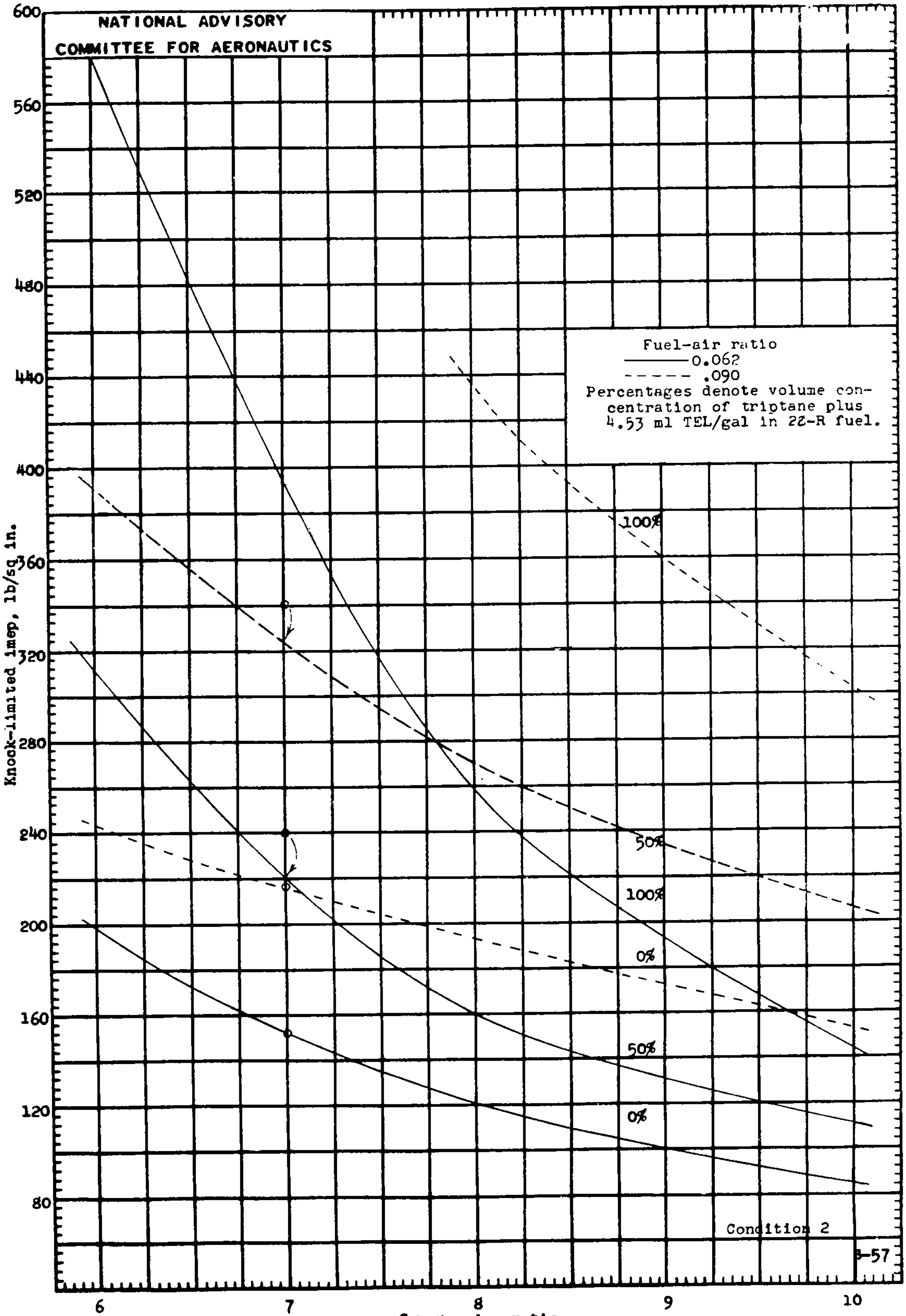
Figure 3. - Concluded.

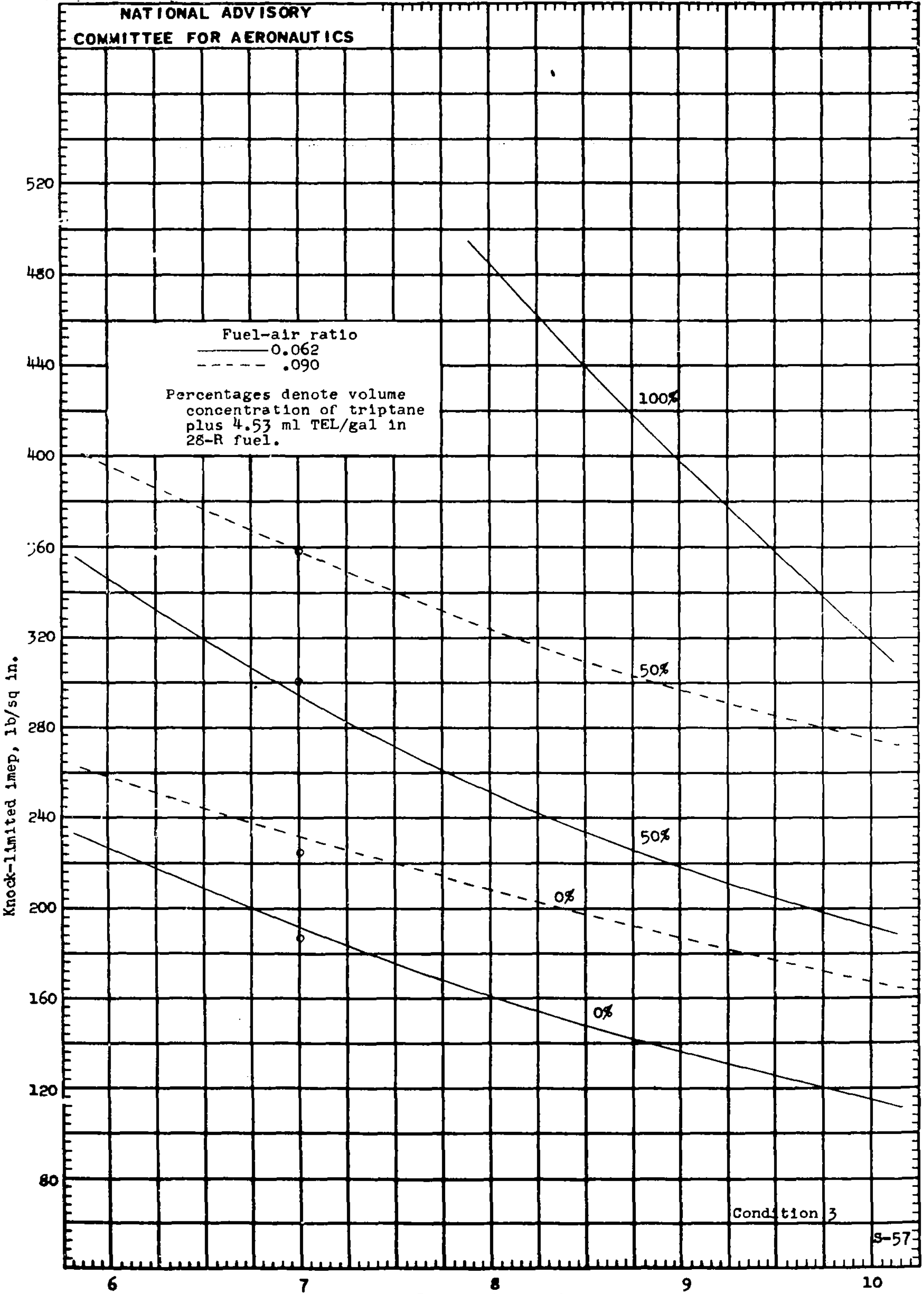


(a) Inlet-air temperature, 225° F; coolant temperature, 375° F; spark advance, 45° B.T.C.

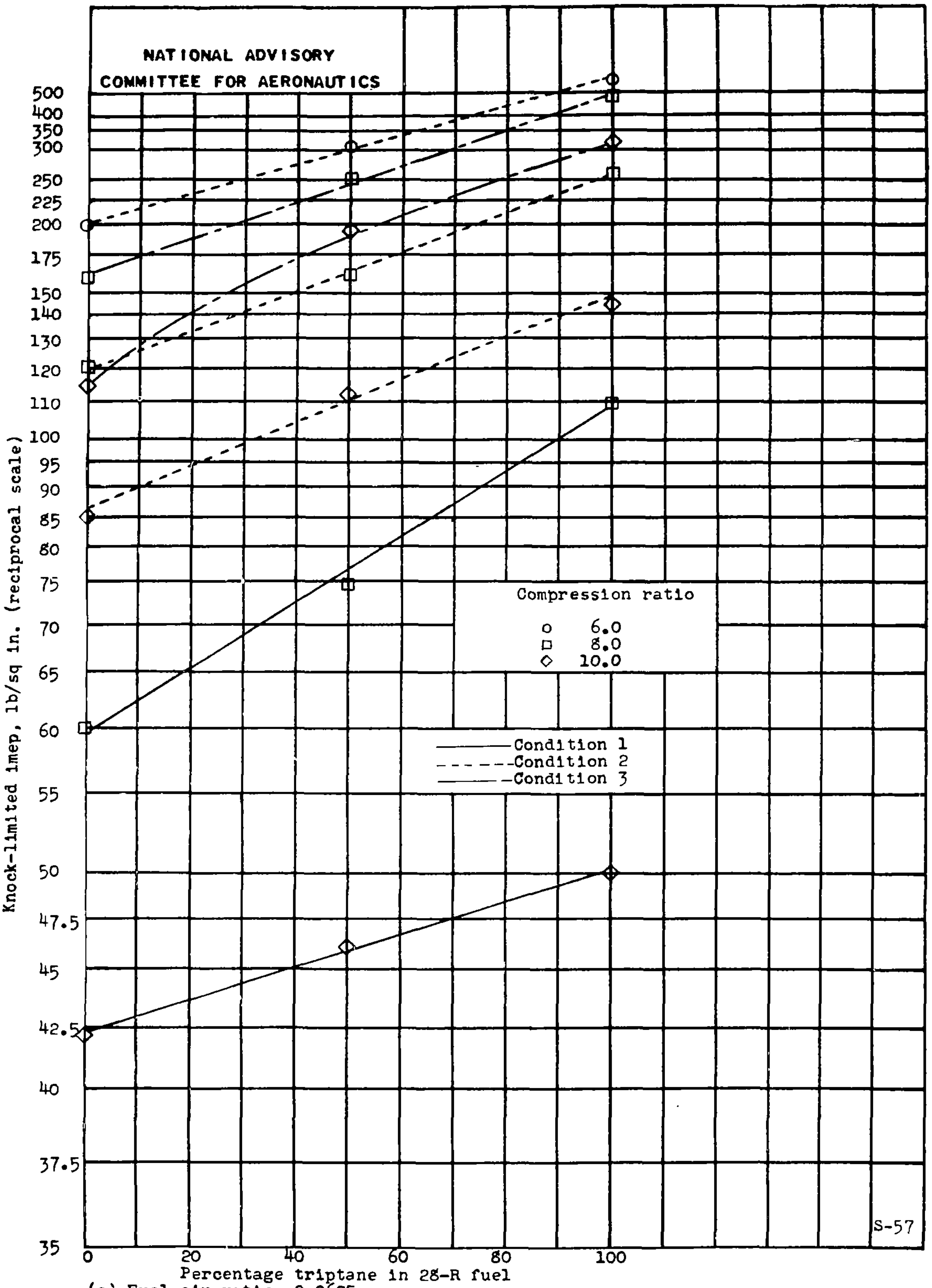
Figure 4. - Effect of compression ratio on knock-limited performance of 0, 50, and 100 percent triptane in 28-R fuel at fuel-air ratios of 0.062 and 0.090. (Points at 7.0 compression ratio taken from data in reference 1.)



(b) Inlet-air temperature, 250° F; coolant temperature, 250° F; spark advance, 30° B.T.C.
Figure 4. - Continued.

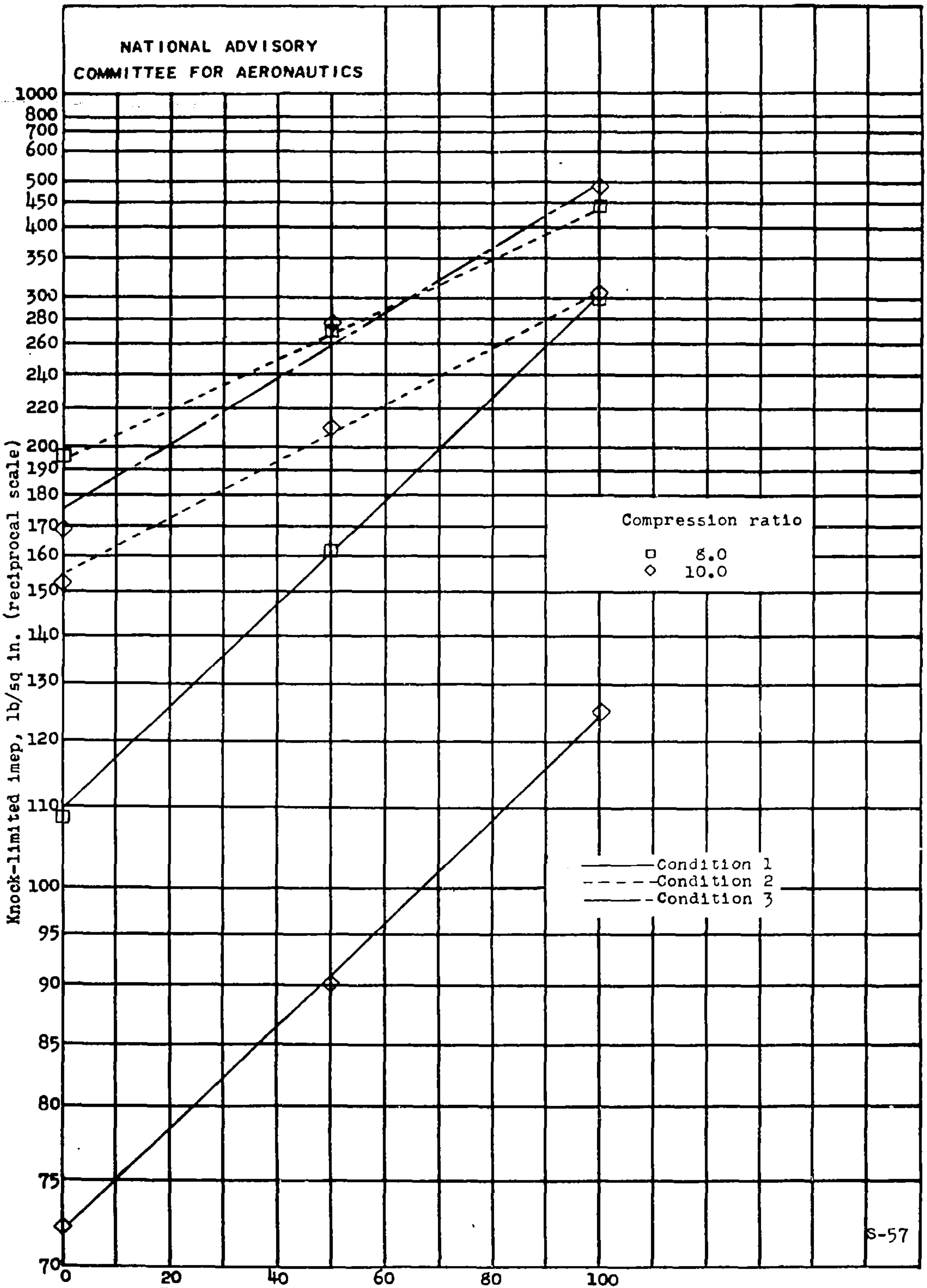


(c) Inlet-air temperature, 150° F; coolant temperature, 250° F; spark advance, 30° B.T.C.
Figure 4. - Concluded.



(a) Fuel-air ratio, 0.0625.

Figure 5. - Blending characteristics of triptane at three compression ratios operating at severe and modified conditions. Lead concentration of final blend, approximately 4.53 ml TEL per gallon.



Percentage triptane in 28-R fuel

(b) Fuel-air ratio, 0.090.

Figure 5. - Concluded.