NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1131

THE EFFECT OF ENGINE VARIABLES ON THE PREIGNITION-LIMITED PERFORMANCE OF THREE FUELS

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SUMMARY

Preignition-limited performance data for S reference fuel, diisobutylene, and benzene were obtained with an engine-heated hot spot on a supercharged CFR engine at 11 sets of engine operating conditions. Increases in compression ratio, spark advance, coolant temperature, or inlet-air temperature decreased the preignition-limited indicated mean effective pressure of all three fuels. Changes in the engine speed either raised or lowered the preignition-limited indicated mean effective pressure depending on the range of speed and the mixture strength. At nearly all of the operating conditions investigated, the order of the fuels according to increasing preignition-limited performance was the same, that is, diisobutylene, benzene, and S reference fuel.

INTRODUCTION

In order to enhance the value of preignition data obtained on small-scale engines, it is desirable to know how the preignition-limited performances of several fuels vary (1) with different engine conditions, (2) with different types of hot spot, and (3) with engine design. The investigations conducted on laboratory engines reported in references 1 to 3 deal with the fundamental relations that govern preignition. Other experiments have been conducted with the aim of predicting the preignition-limited performance of various fuel components in the service engine. The Shell Oil Company Wood River Laboratories (unpublished tests) have obtained preignition-limited performance data on a full-scale single-cylinder Lycoming engine; satisfactory preignition-limited performance tests have been conducted on a 17.6 engine by the Ethyl Corporation; preignition tests have been made at Cleveland on a CFR engine.

In the present investigation preignition-limited performance data were obtained for three fuels under several engine conditions attained by varying individually compression ratio, spark advance, coolant temperature, inlet-air temperature, and engine speed. The purpose of the tests, which were conducted at the NACA Cleveland laboratory from August to November 1944, was to determine whether the three fuels exhibit preignition tendencies in the same order over a wide range of engine conditions and, at the same time, to indicate the effects of engine conditions on preignition tendencies. Because of the number of tests involved, the investigation was limited to the testing of S (S-3 and S-4) reference fuel, diisobutylene, and benzene, which represent, respectively, the paraffinic, the olefinic, and the aromatic groups of compounds.

APPARATUS AND TEST PROCEDURE

The tests were performed on a high-speed supercharged CFR engine coupled to a 25-horsepower, alternating-current, cradle-type induction dynamometer. The engine was equipped with an aluminum piston, a sodium-cooled exhaust valve, and a cylinder head with four 18-millimeter spark-plug holes. Data obtained at Cleveland on a similar setup have shown that the use of a shrouded intake valve decreases the sensitivity of hot-spot temperatures to knock for hot spots installed in the same cylinder-head location as those in the subject tests. A 180° shrouded intake valve (position of shroud shown in fig. 1) was therefore installed to aid in isolating the effects of preignition from the effects of knock. A magnetostriction pickup unit installed in the top spark-plug hole was used in conjunction with a cathode-ray oscilloscope to follow the changing pressure diagram during advancing preignition and to detect knock. The fuel flow was determined with a rotameter and the air flow was metered through standard orifices. All operating temperatures were measured with iron-constantan thermocouples and a self-balancing potentiometer.

In the tests presented, each of the engine variables listed except oil temperature was individually varied from the following reference engine conditions:

Compression ratio	7.0
Engine speed, rpm	1800
Spark advance, degrees B.T.C.	20
Inlet-air temperature, °F	225
Coolant temperature, °F	250
Oil temperature, °F	138 to 144

The coolant temperature was varied by using three different coolants in the evaporative cooling system: water, a mixture of water and ethylene glycol, and ethylene glycol.

The data were obtained with three nearly identical hot spots (fig. 2) designated in the data plots J-1, J-3, and J-4. Hot spot J-1 was used to obtain the data in figure 3 and was damaged before more tests were run. Hot spot J-3 was therefore used to obtain the data in figures 4 and 5. The engine was then overhauled (Oct. 18, 1944) and a worn exhaust-valve guide replaced. This change apparently affected the preignition-limited performance of the engine and hot spot J-4 was therefore installed to correct for the shift in the data indicated by tests with S-3 reference fuel. This hot spot was used to complete the program. The date of each test and the hot spot used are indicated on the figures.

The hot-spot design (fig. 2) provides for a short piece of Inconel tubing open to the cylinder and silver-soldered to the center electrode of a spark plug. The outside diameter of the tube is 0.10 inch and the wall thickness is 0.010 inch. Experience has shown that a hot spot of this type can be used as a preignition source for a large number of engine hours without noticeable deterioration and without a significant change in the heat range of the hot spot. Furthermore, the hot spots can be easily constructed and the desired heat range can be readily attained by adjusting the length of the tube. The hot spot under test was installed in the cylinder as indicated in figure 1.

Under some conditions knock was encountered before preignition. The data taken at these conditions were nevertheless preignition-limited even though light, medium, or heavy knock was encountered. These concurrently knocking preignition-limited data are marked on the figures with a letter K.

An attempt was made to test all three fuels at any given set of engine conditions on the same day; this procedure was not always possible. When 2 days were required to obtain the data for a given set of conditions, either a complete curve or check points for S-3 reference fuel were determined on each day.

RESULTS AND DISCUSSION

The values of preignition-limited indicated mean effective pressure, preignition-limited inlet-air pressure, and indicated specific fuel consumption for S-3 reference fuel, benzene, and diisobutylene obtained under the 11 sets of engine conditions are shown

in figures 3 to 7 as functions of percentage of stoichiometric mixture ratio. Figure 3 presents data for three compression ratios (5.0, 7.0, and 9.0); figure 4, data for three values of spark advance (0°, 10°, and 20° B.T.C.); figure 5, data for three inlet-air temperatures (150°, 225°, and 300° F); figure 6, data for three coolant temperatures (208°, 250°, and 368° F); and figure 7, data for three engine speeds (1200, 1800, and 2400 rpm). Engine conditions for all tests are listed in table I together with corresponding figure numbers.

In figures 3(b) and 5(c) different S-3 reference-fuel curves are presented for benzene and diisobutylene because in these instances the fuels were tested on 2 days and the two S-3 reference curves did not coincide.

For the range of fuel-air ratios from 90 to 145 percent of the stoichiometric mixture ratio, the three fuels rated in the same order of increasing preignition-limited indicated mean effective pressure, (diisobutylene, benzene, and S-3 reference fuel) for all of the engine conditions except with the spark timing at top center (fig. 4(a)), where benzene and S-3 reference fuel rated about equally.

The data in figures 3 to 7 indicate also the effects of varying the five engine test variables on the preignition-limited performance of the three fuels. In order to check these trends, repeat runs on S-4 reference fuel are presented in figures 8 to 12. (Because the supply of S-3 reference fuel was depleted, it was necessary to use S-4 reference fuel for these tests.) The tests with S-4 reference fuel made at the reference engine conditions are replotted together in figure 13 to indicate the reproducibility of preignition-limited performance from day to day. The spread of the data of the several tests is of the same magnitude as the spread of knock-limited performance checks.

In order to show more clearly the effects of different engine conditions on the preignition-limited performance of the three fuels, cross plots of preignition-limited indicated mean effective pressure against each engine variable are presented in figures 14 to 18. The percentage of stoichiometric mixture ratio is shown parametrically on the figures and the lean-mixture curves are dashed for clarity. In each cross plot the curves for benzene and diisobutylene (from figs. 3 to 7) compare data from 3 days' engine operation while the curves for S-4 reference fuel (from figs. 8 to 12) compare data from 1 day's operation.

The curves in figure 14 indicate that an increase in compression ratio caused a decrease in the preignition-limited indicated mean effective pressures for the three fuels of approximately 7 to 12 pounds per square inch per unit change in compression ratio for stoichiometric mixtures.

Figure 15 shows that advancing the spark timing lowered the preignition-limited indicated mean effective pressures for the fuels approximately 0.5 pound to 4 pounds per square inch per degree of spark advance for stoichiometric mixtures. The large spread of values is due to the behavior of diisobutylene, especially at or near the stoichiometric mixture ratio.

An increase in the inlet-air temperature (fig. 16) lowered the preignition-limited indicated mean effective pressure for the fuels approximately 0.1 to 0.3 pound per square inch per °F.

Figure 17 presents cross plots of coolant temperature with the preignition-limited indicated mean effective pressures for the three fuels. Because the three coolants used have different thermal properties, the effect on the preignition-limited performances of the fuels was not entirely due to differences in coolant temperature; water is known to have a higher over-all heat-transfer coefficient than ethylene glycol-water mixtures. The curves indicate that an increase in the coolant temperature was accompanied by a decrease in the preignition-limited indicated mean effective pressures for the three fuels.

The data indicate that any change in engine conditions that increases the compression gas temperature or the hot-spot temperature will lower the preignition-limited performance. For example, an increase in the inlet-air temperature is accompanied by increases in both the compression gas temperature and the hot-spot temperature. In a similar manner, increases in compression ratio, spark advance, or coolant temperature cause the preignition-limited performance of a fuel to decrease as a result of increased compression gas temperature, increased hot-spot temperature, or both.

The effect of engine speed on the preignition-limited indicated mean effective pressures of the three fuels is shown in figure 18. The curves are all concave upward and for the stoichiometric mixtures have minimum points between 1500 and 2100 rpm. The trends due to changes of engine speed that are reported herein may not be representative of trends for engines of different design.

Because the sets of engine conditions used in these tests are broad in scope, the conclusion is suggested that the rating order of different fuels is not, in general, altered by moderate changes in engine conditions. It must be remembered, however, that the three fuels tested may represent extremes of preignition-limited performance with respect to fuel composition. The task remains of correlating small-scale engine data with full-scale and service-engine data before a valid preignition rating method can be established for small-scale engines.

The experience of the NACA Cleveland laboratory has been that preignition-limited performance is affected to a much larger extent by changes in engine and hot-spot design with regard to cooling than by changes in fuel composition. Most fuels can be made to preignite by using a suitable hot spot, but surface ignition does not occur in an engine whose component parts are sufficiently cooled. The task of eliminating preignition difficulties in service engines, therefore, will probably be accomplished by improved engine design rather than by controlled fuel composition. Compounds causing low preignition-limited performances should, however, be avoided in fuel manufacture.

SUMMARY OF RESULTS

The following results were obtained from preignition tests on three fuels with a supercharged CFR engine under 11 sets of operating conditions attained by varying individually compression ratio, spark advance, coolant temperature, inlet-air temperature, and engine speed:

1. The order of the fuels, according to increasing preignition-limited indicated mean effective pressure, at nearly all operating conditions investigated was the same, that is, diisobutylene, benzene, and S reference fuel.

2. Increases in compression ratio, spark advance, coolant temperature, or inlet-air temperature decreased the preignition-limited indicated mean effective pressure of all three fuels. Changes in engine speed either raised or lowered the preignition-limited indicated mean effective pressure depending on the range of speed and the mixture strength.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, February 3, 1945.

REFERENCES

1. Serruys, Max: Experimental Study of Ignition by Hot Spot in Internal Combustion Engines. NACA TM No. 873, 1938.

2. Spencer, R. C.: Preignition Characteristics of Several Fuels under Simulated Engine Conditions. NACA Rep. No. 710, 1941.

3. Alquist, Henry E., and Male, Donald W.: Trends in Surface-Ignition Temperatures. NACA ARR No. E4I25, 1944.

TABLE I - ENGINE CONDITIONS AND CORRESPONDING FIGURE NUMBERS

Engine conditions					Figures			
Compression ratio	Spark advance (deg B.T.C.)	Inlet-air temperature (°F)	Coolant temperature (°F)	Engine speed (rpm)	S-3, benzene, and diisobutylene	S-4	Reproducibility of data	Cross plots of S-4, benzene, and diisobutylene
5	20	225	250	1800	3(a)	8		14
7					(b)	8	13	14
9					(c)	8		14
7	0	225	250	1800	4(a)	9		15
	10				(b)	9		15
	20				(c)	9	13	15
7	20	150	250	1800	5(a)	10		16
		225			(b)	10	13	16
		300			(c)	10		16
7	20	225	208	1800	6(a)	11		17
			250		(b)	11	13	17
			368		(c)	11		17
7	20	225	250	1200	7(a)	12		18
				1300	(b)	12	13	18
				2400	(c)	12		18

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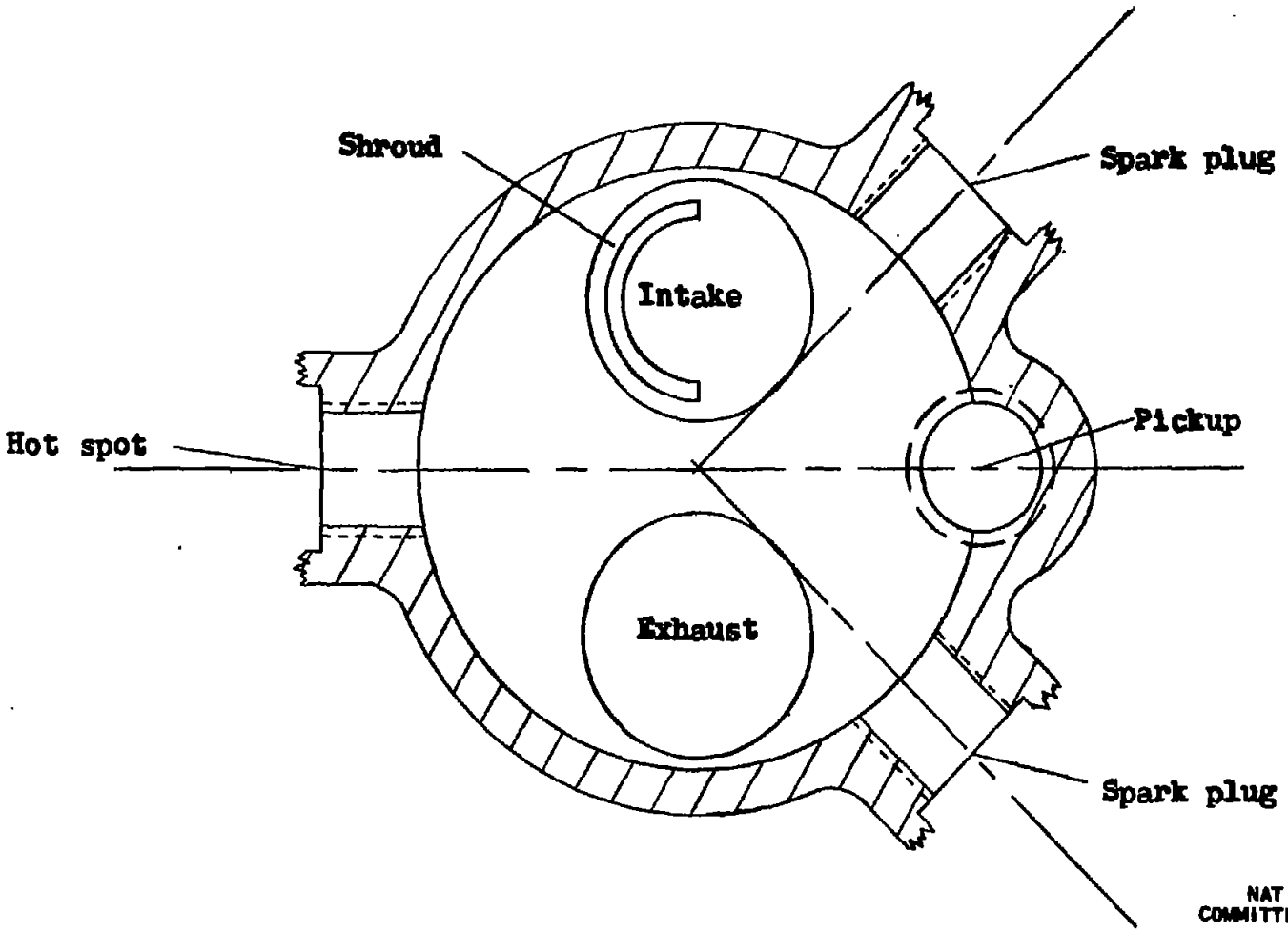

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Figure 1. - Schematic diagram of CFR cylinder showing position of spark plugs, hot spot, pickup, and shrouded intake valve.

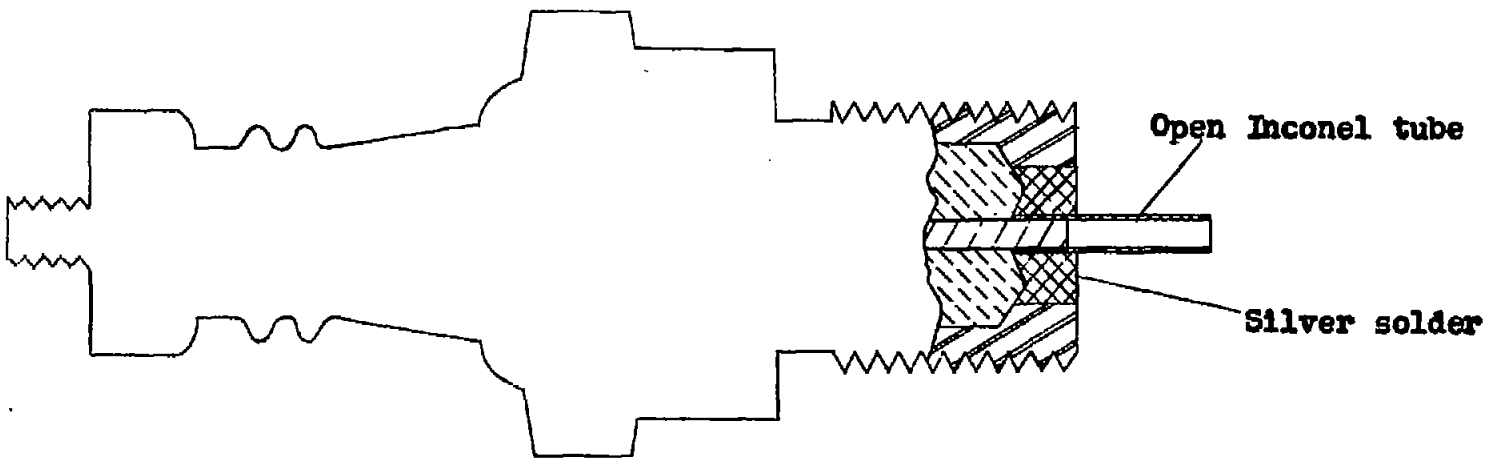

Figure 2. - Sketch of open-tube hot spot used in tests.

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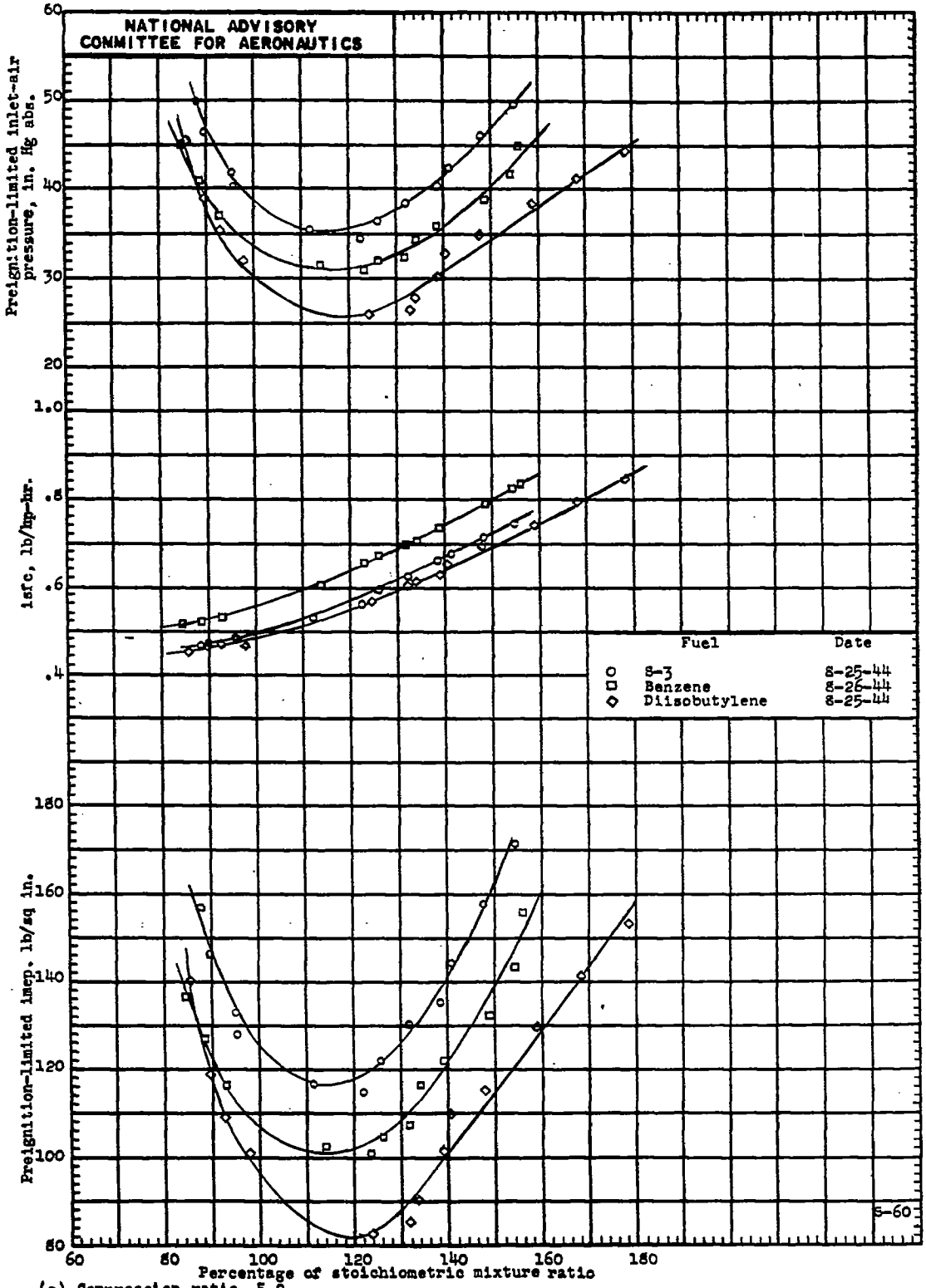
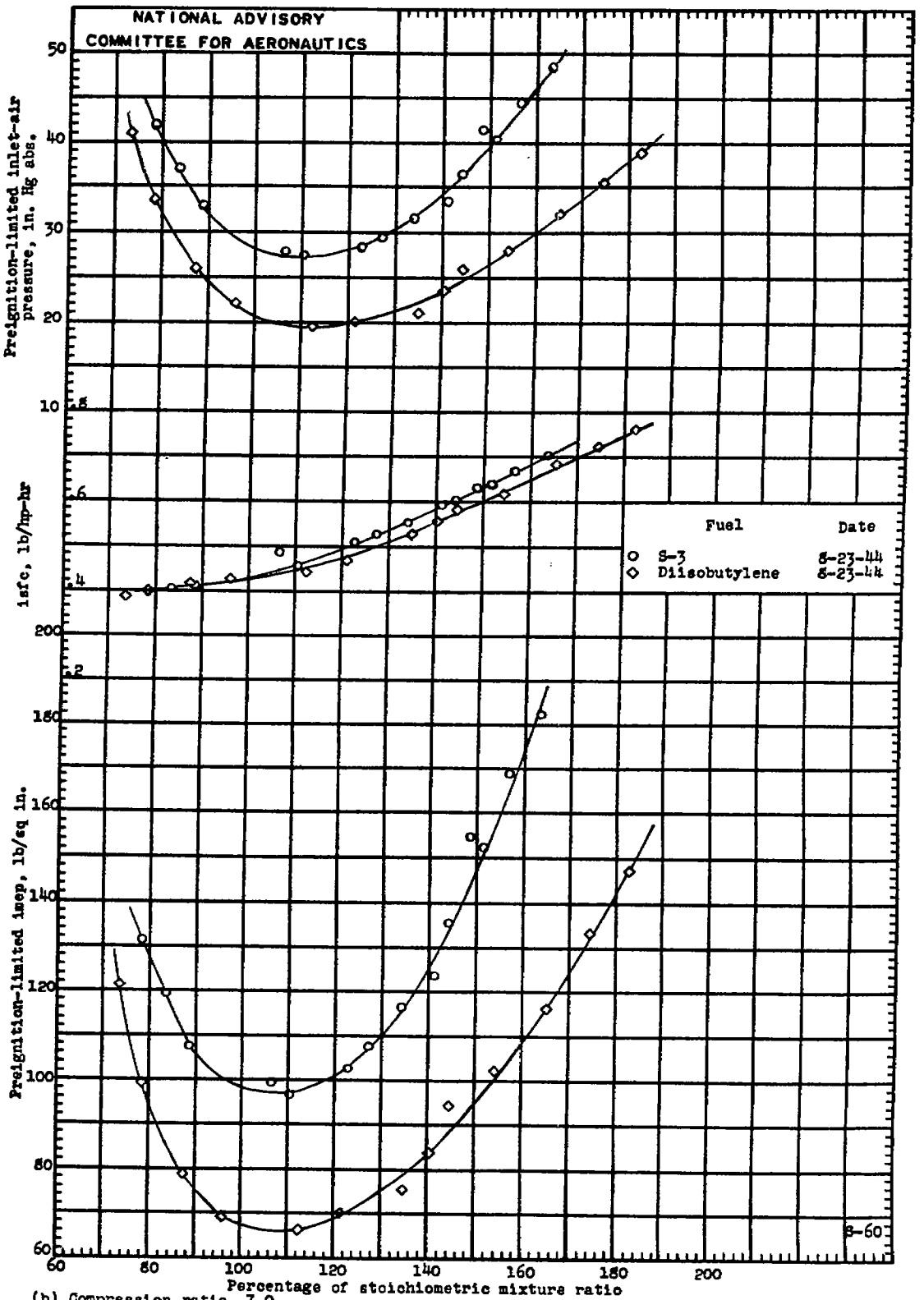
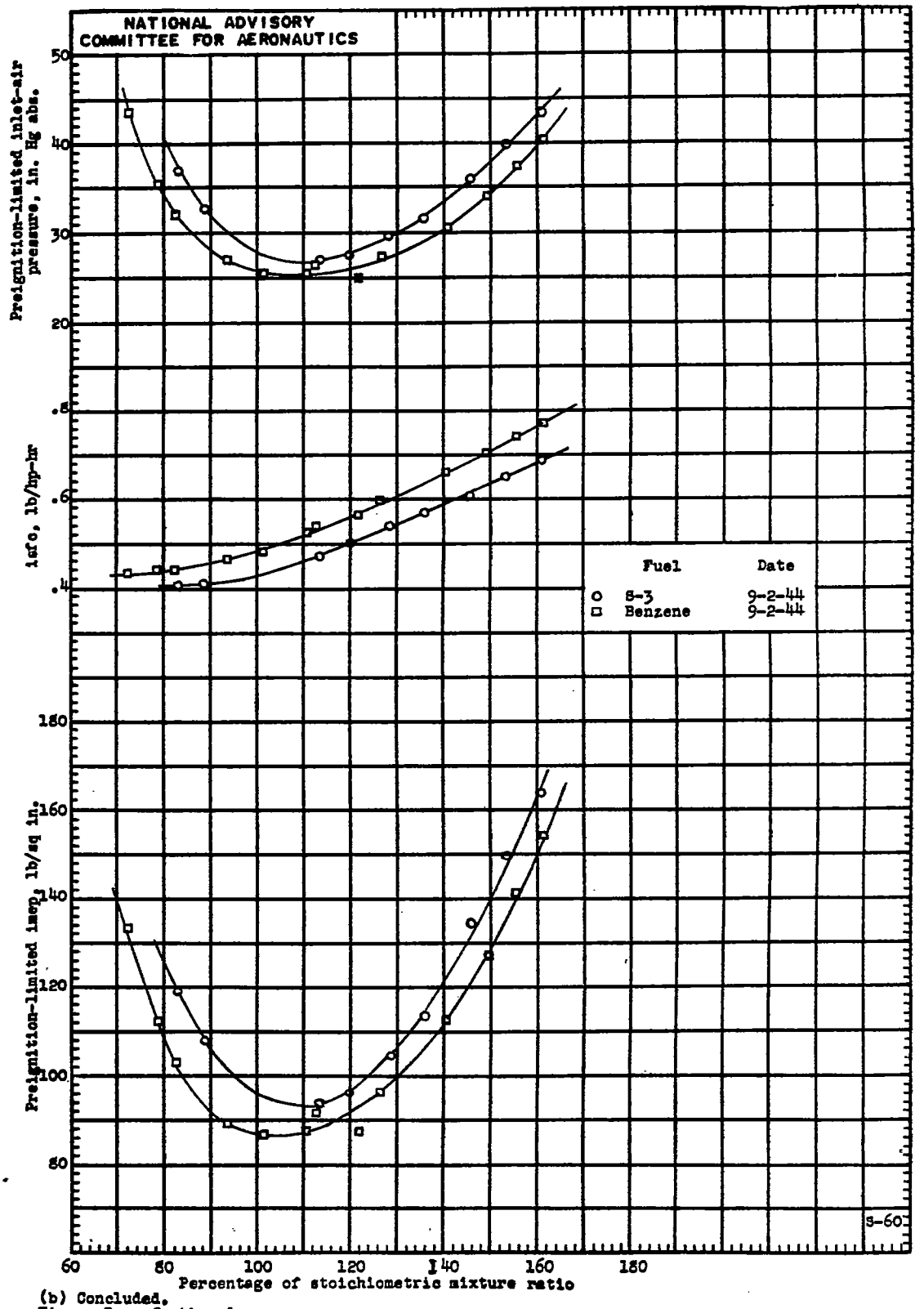


(a) Compression ratio, 5.0.

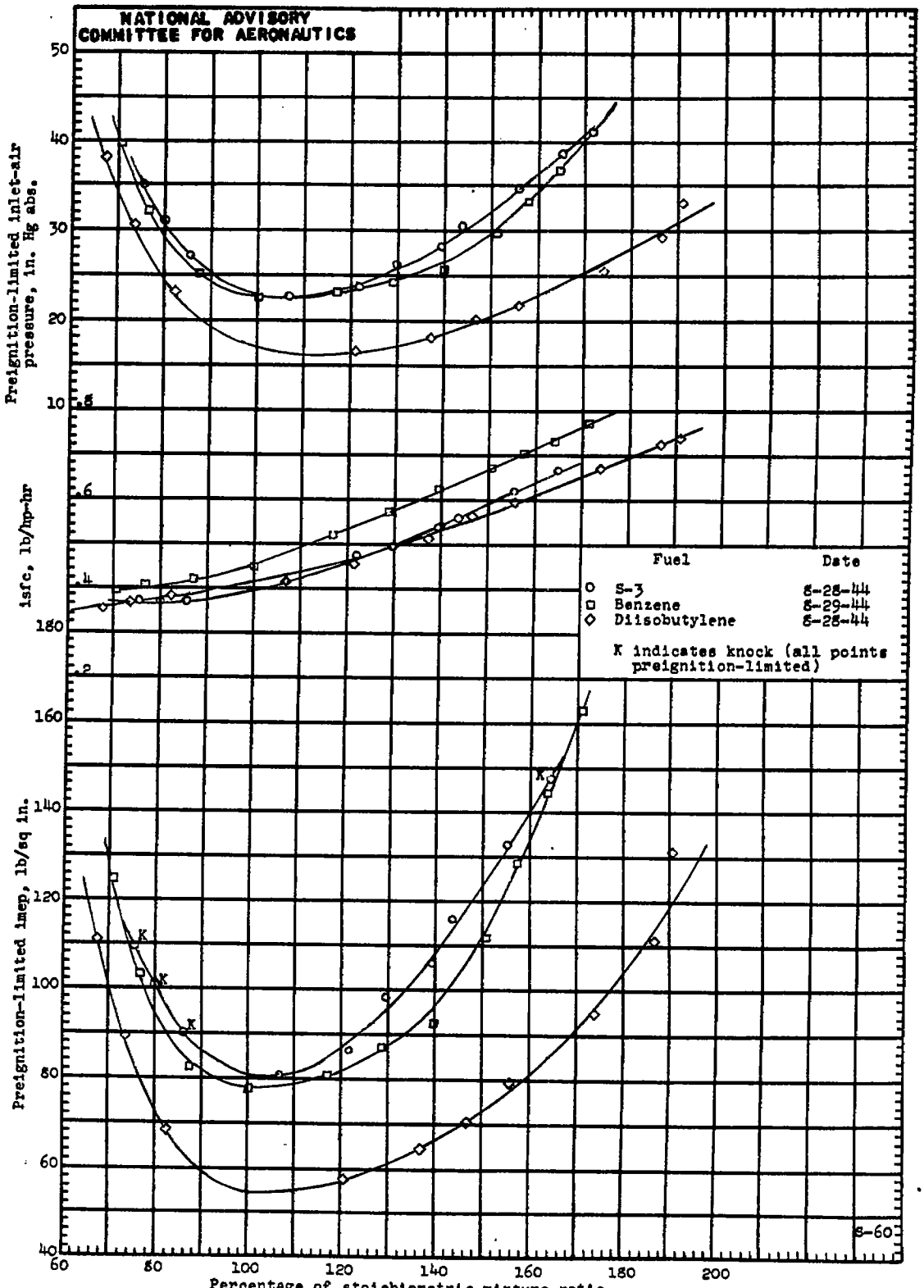
Figure 3. - Preignition-limited performance of S-3 reference fuel, benzene, and diisobutylene at three compression ratios. CFR engine; hot spot, J-1; engine speed, 1800 rpm; spark advance, 20° B.T.C.; inlet-air temperature, 225° F; coolant temperature, 250° F.



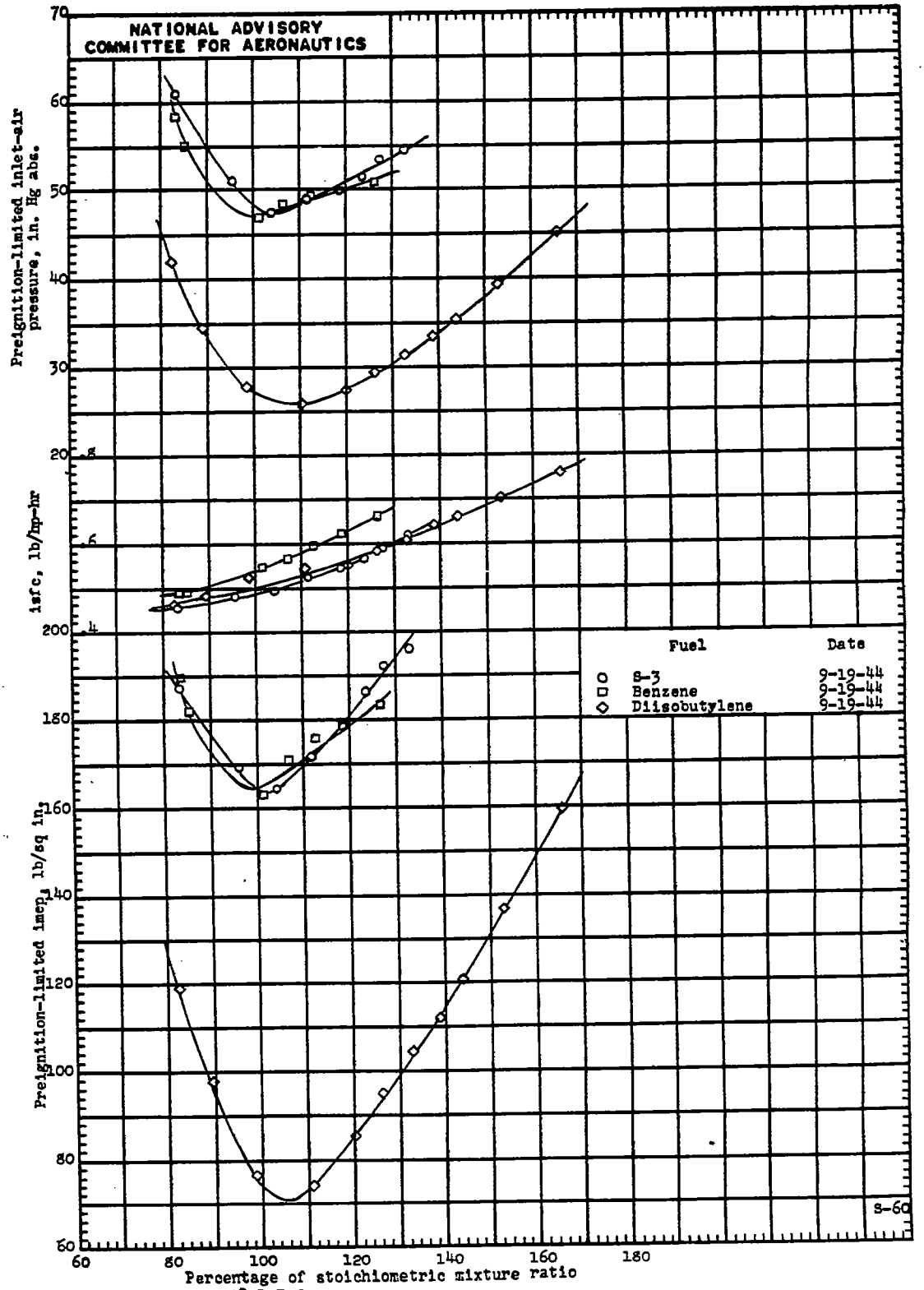
(b) Compression ratio, 7.0.
Figure 3. - Continued.



(b) Concluded.
Figure 3. - Continued.

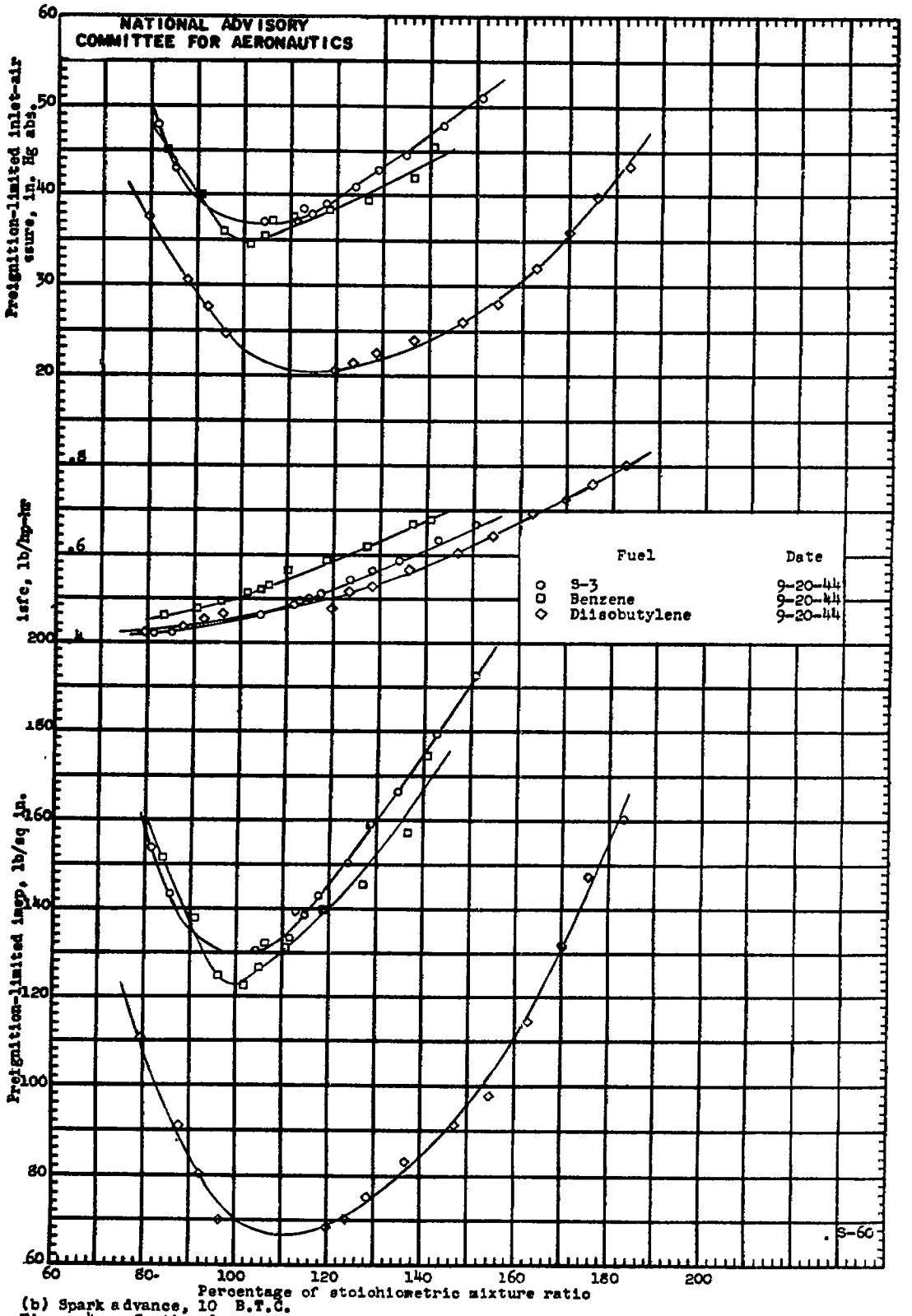


(c) Compression ratio, 9.0.
Figure 3. - Concluded.

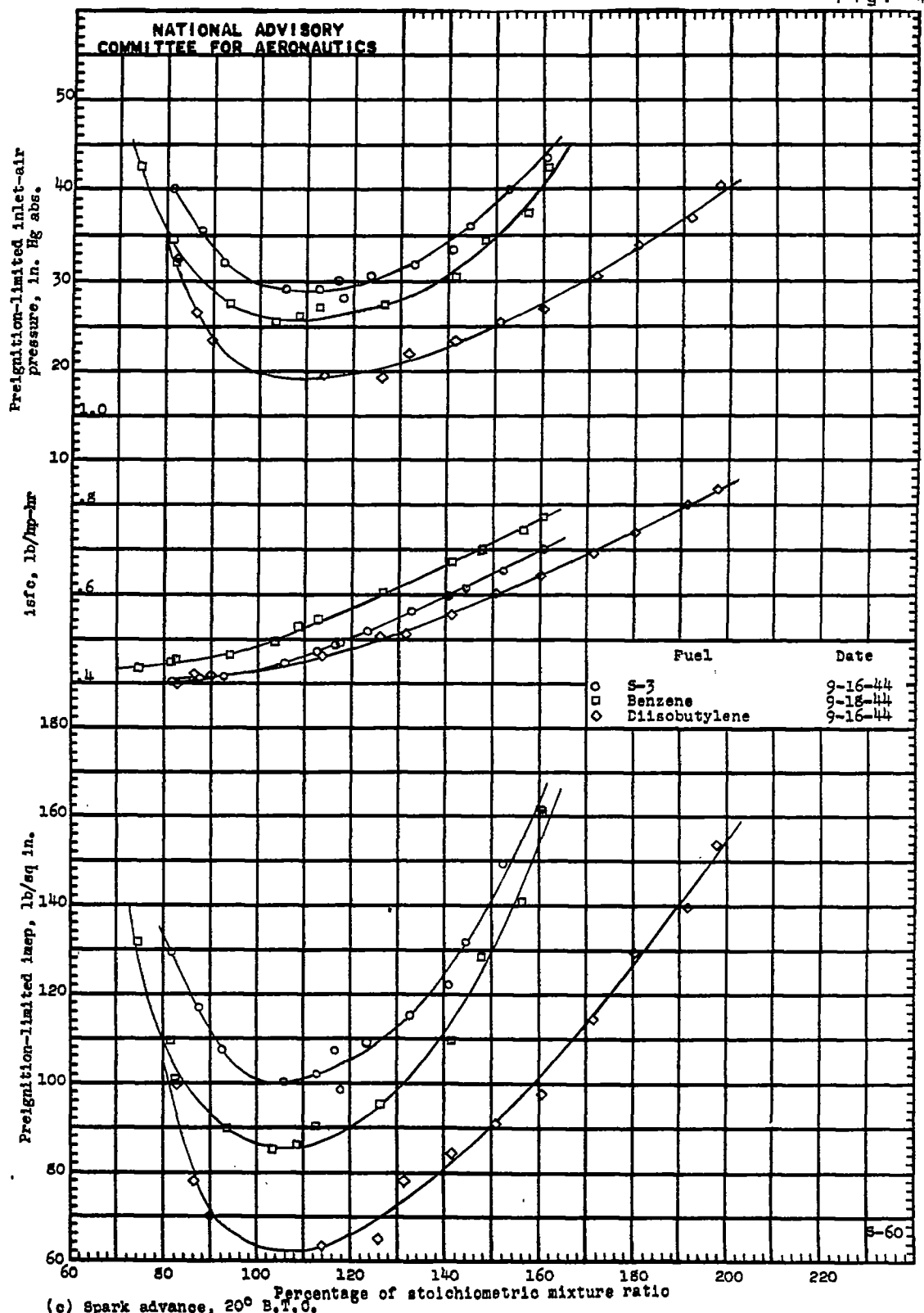


(a) Spark advance, 0° B.T.C.

Figure 4. - Preignition-limited performance of S-3 reference fuel, benzene, and diisobutylene with three spark advances. CFR engine; hot spot, J-3; compression ratio, 7.0; engine speed, 1800 rpm; inlet-air temperature, 225° F; coolant temperature, 250° F.

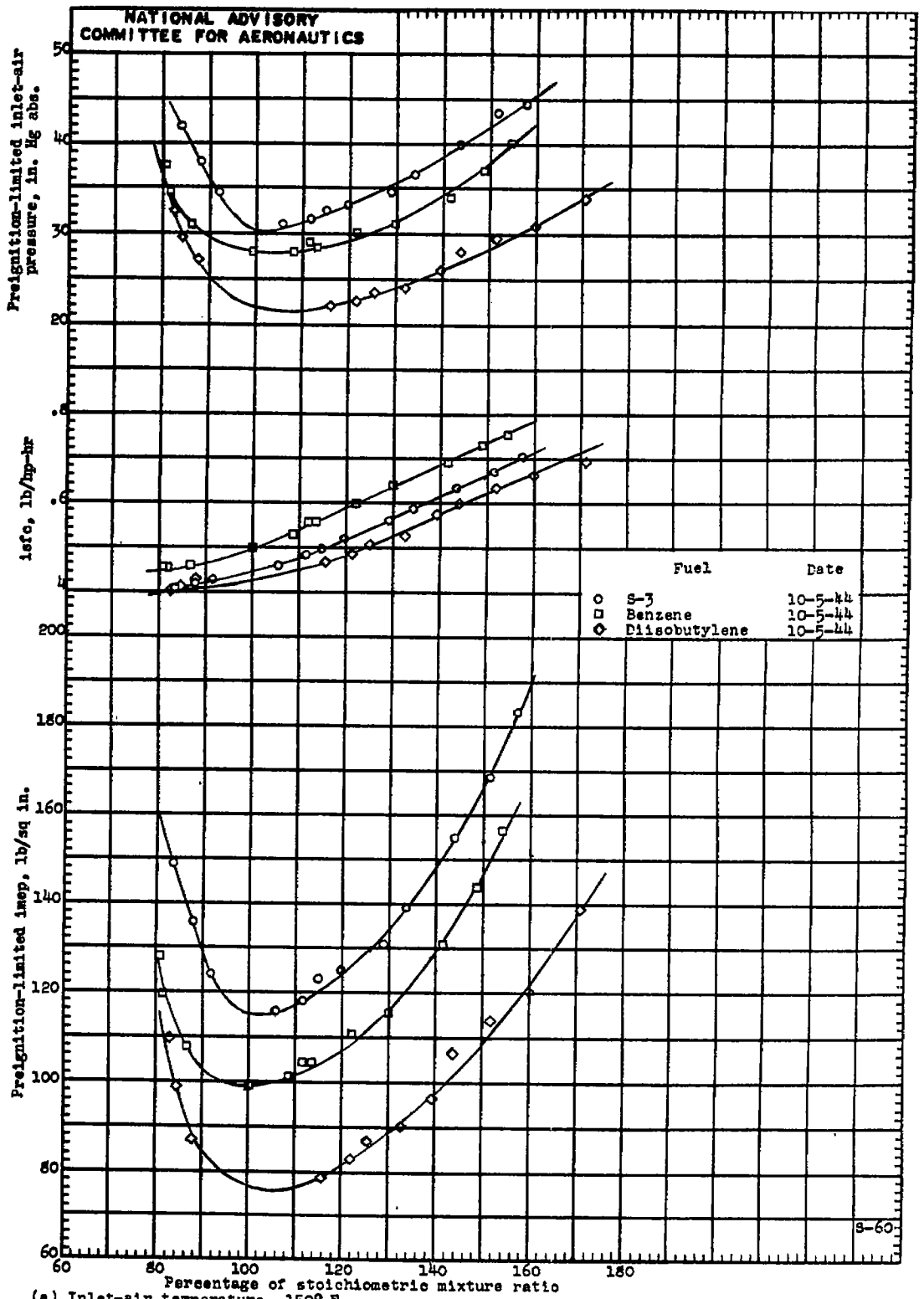


(b) Spark advance, 10° B.T.C.
Figure 4. - Continued.



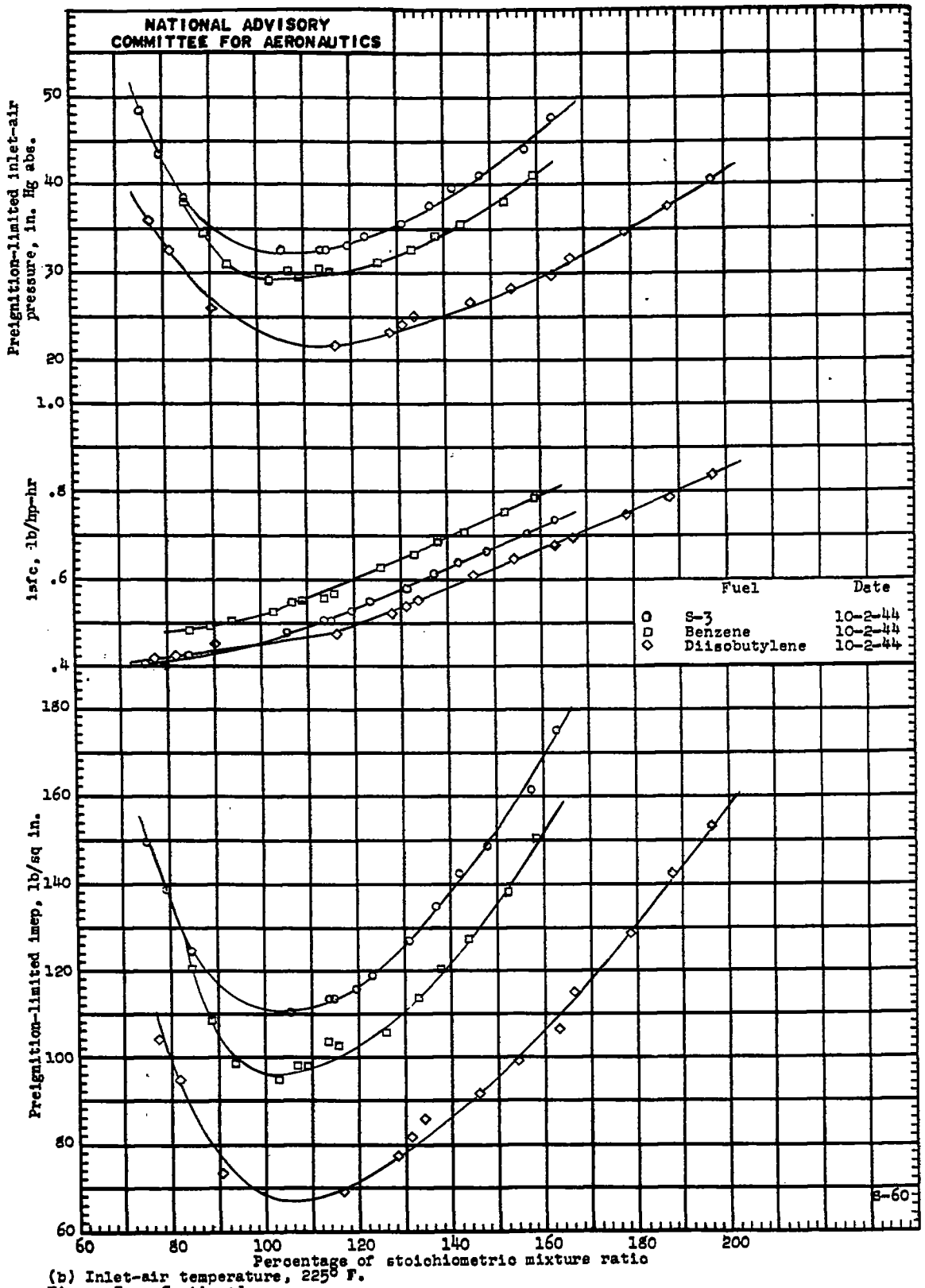
(c) Spark advance, 20° B.T.C.

Figure 4. - Concluded.

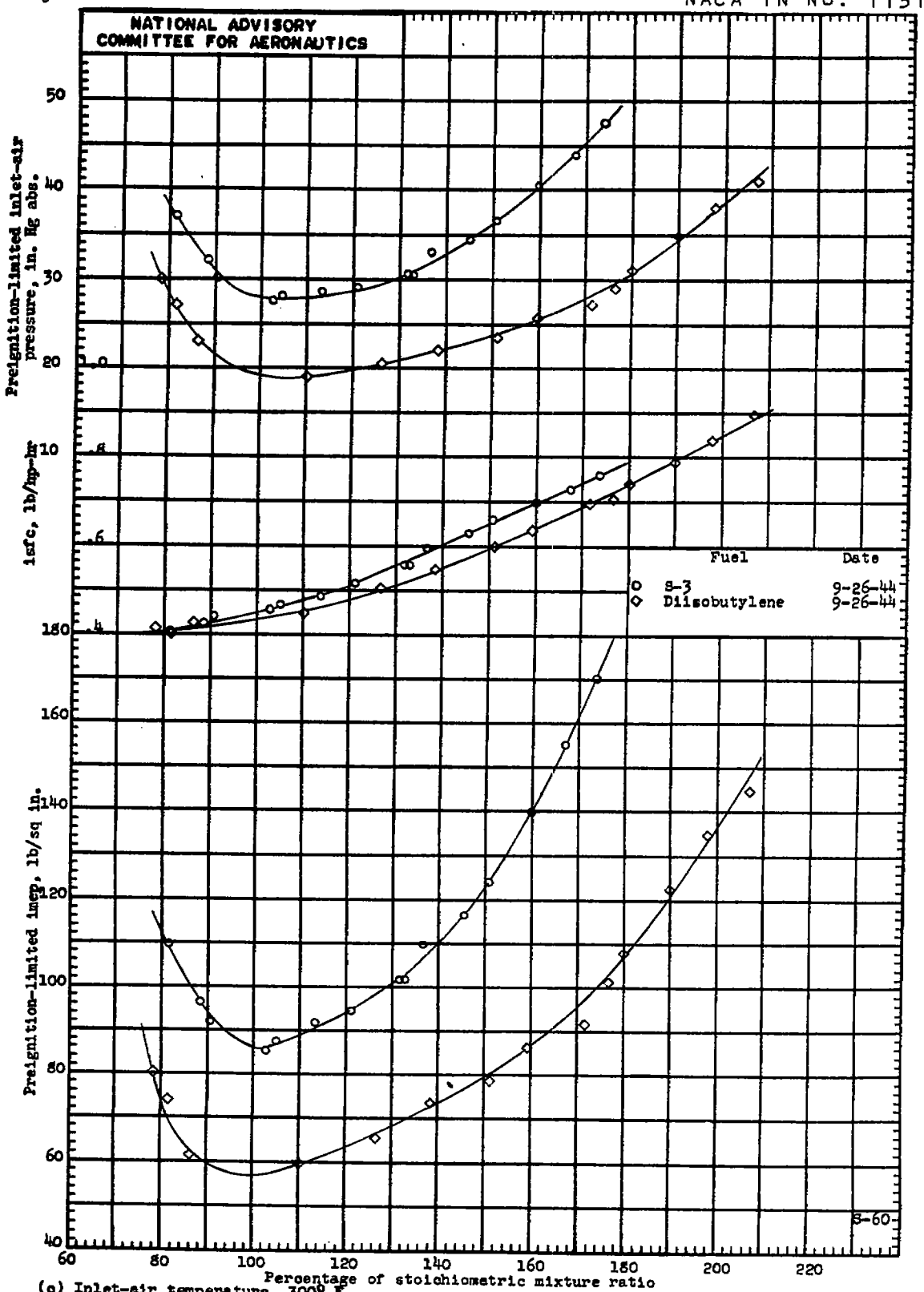


(a) Inlet-air temperature, 150° F.

Figure 5. - Preignition-limited performance of S-3 reference fuel, benzene, and diisobutylene at three inlet-air temperatures. CFR engine; hot spot, J-3; compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant temperature, 250° F.

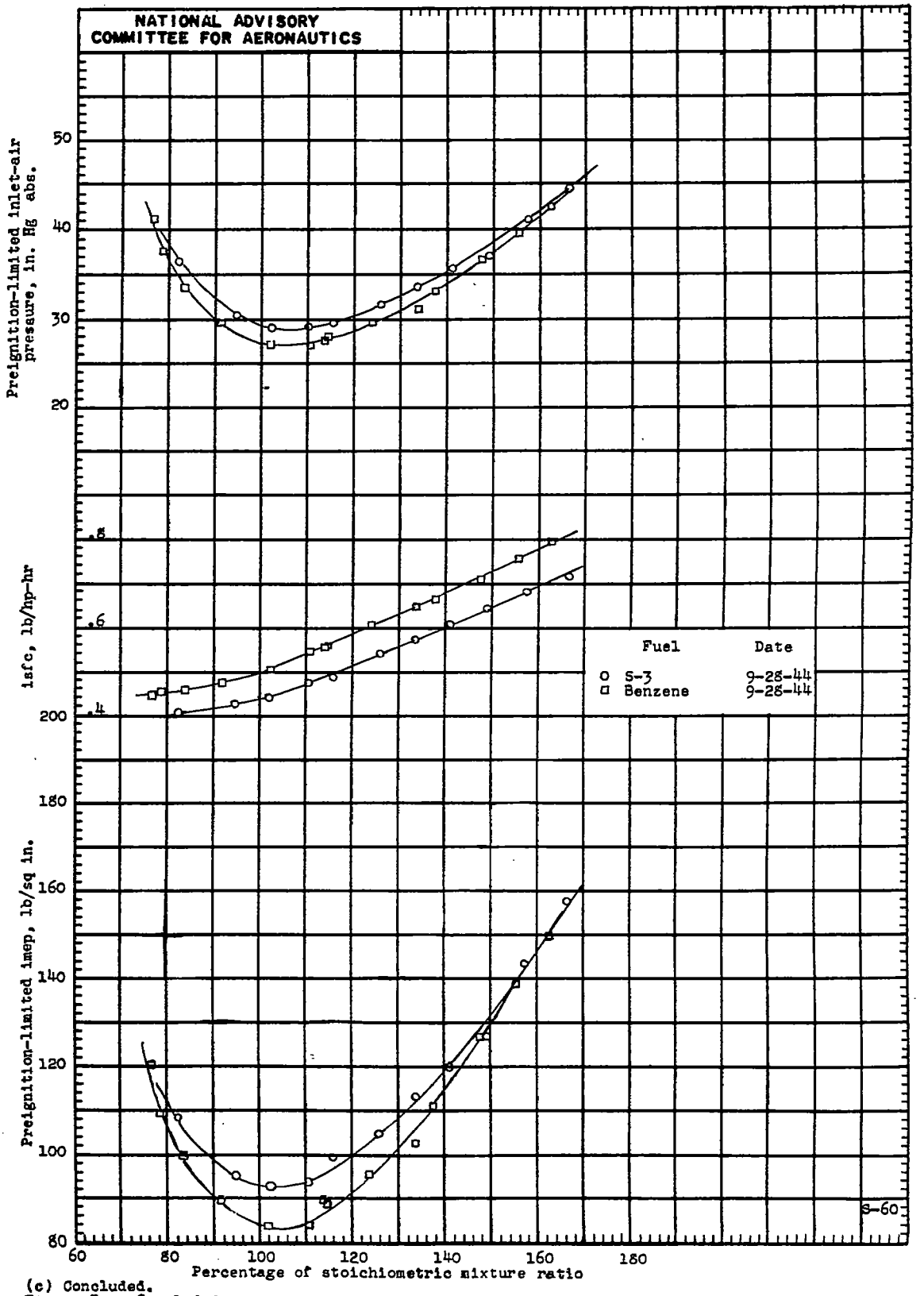


(b) Inlet-air temperature, 225° F.
Figure 5. - Continued.

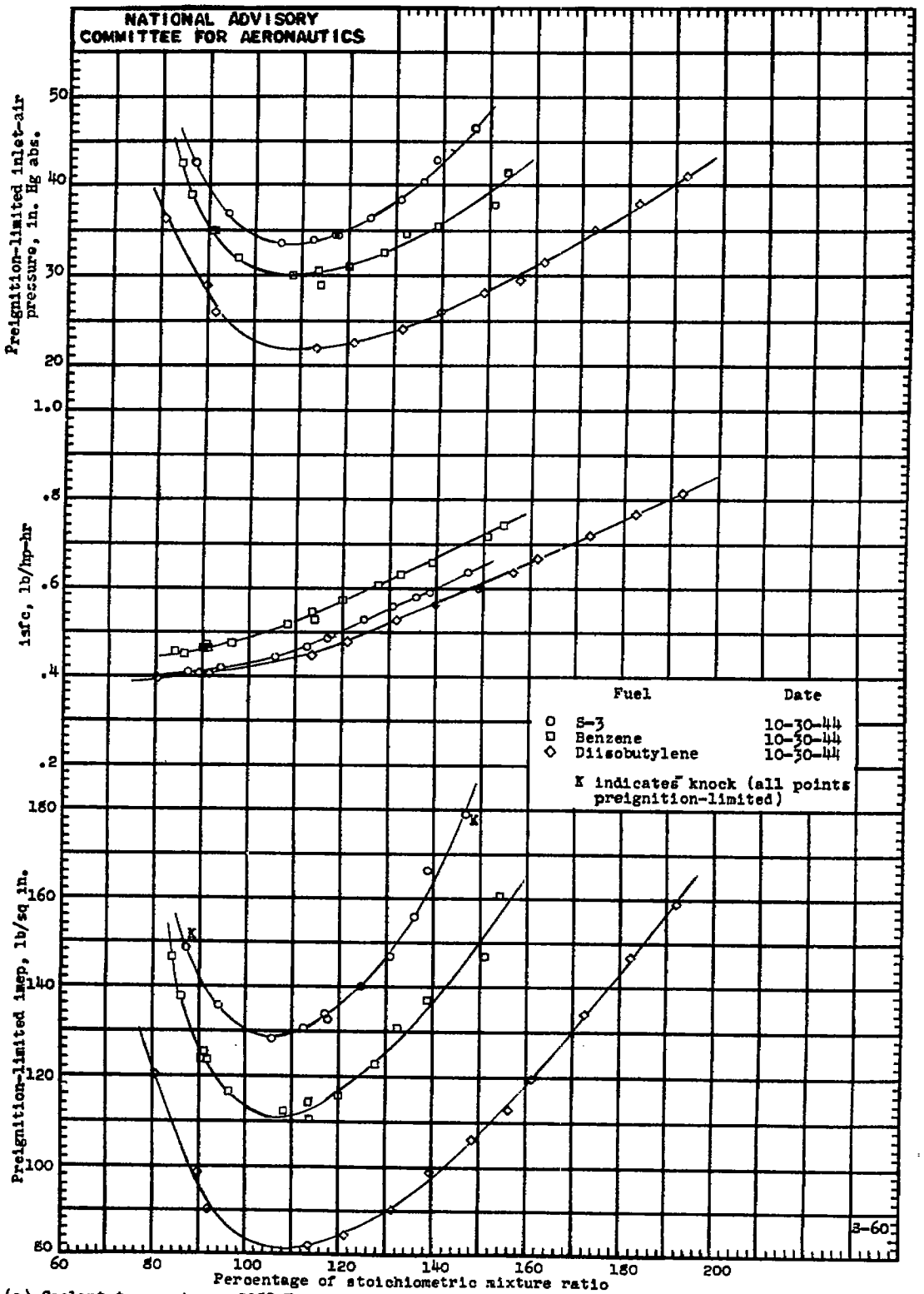


(c) Inlet-air temperature, 300° F.

Figure 5. - Continued.

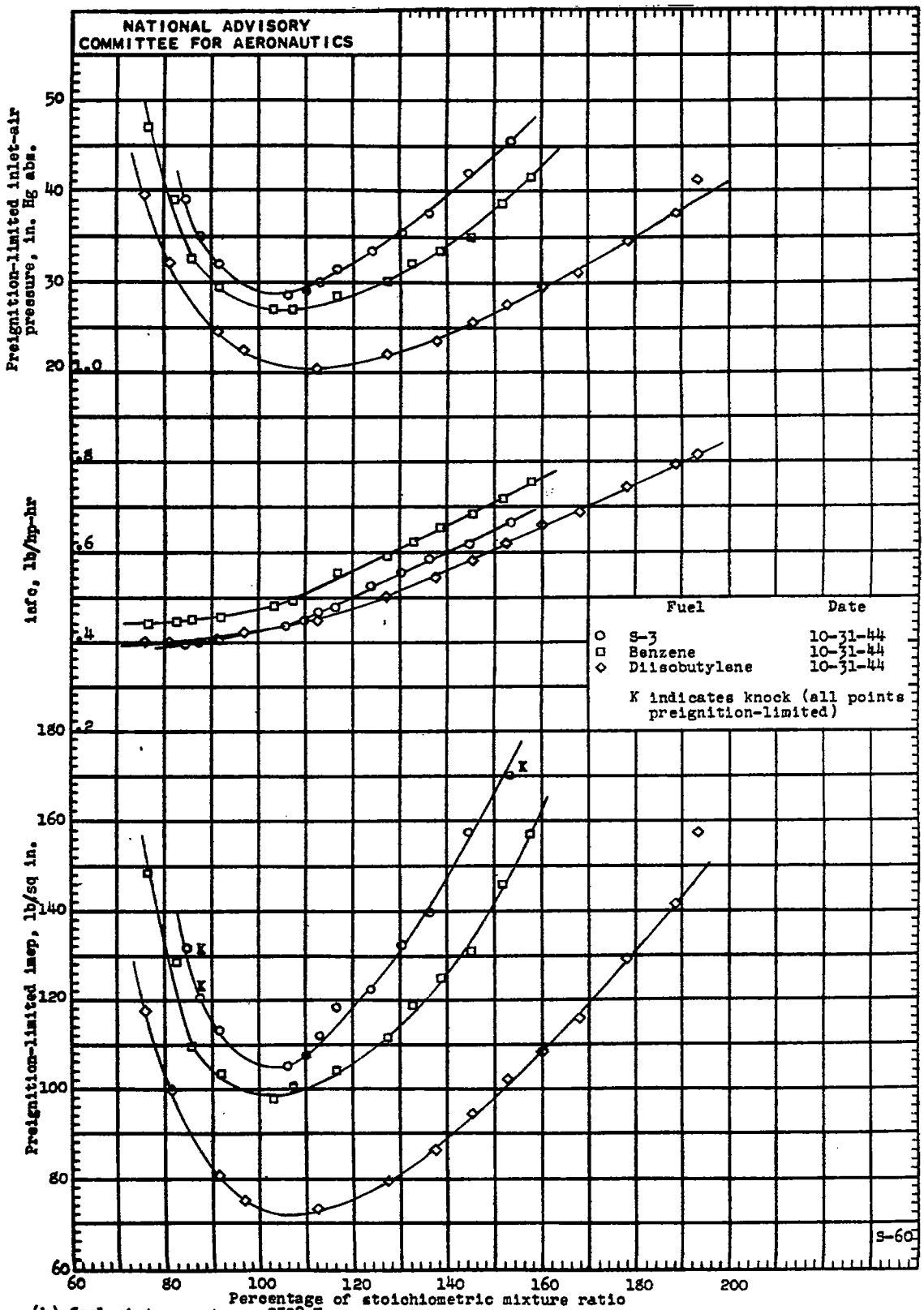


(c) Concluded.
Figure 5. - Concluded.

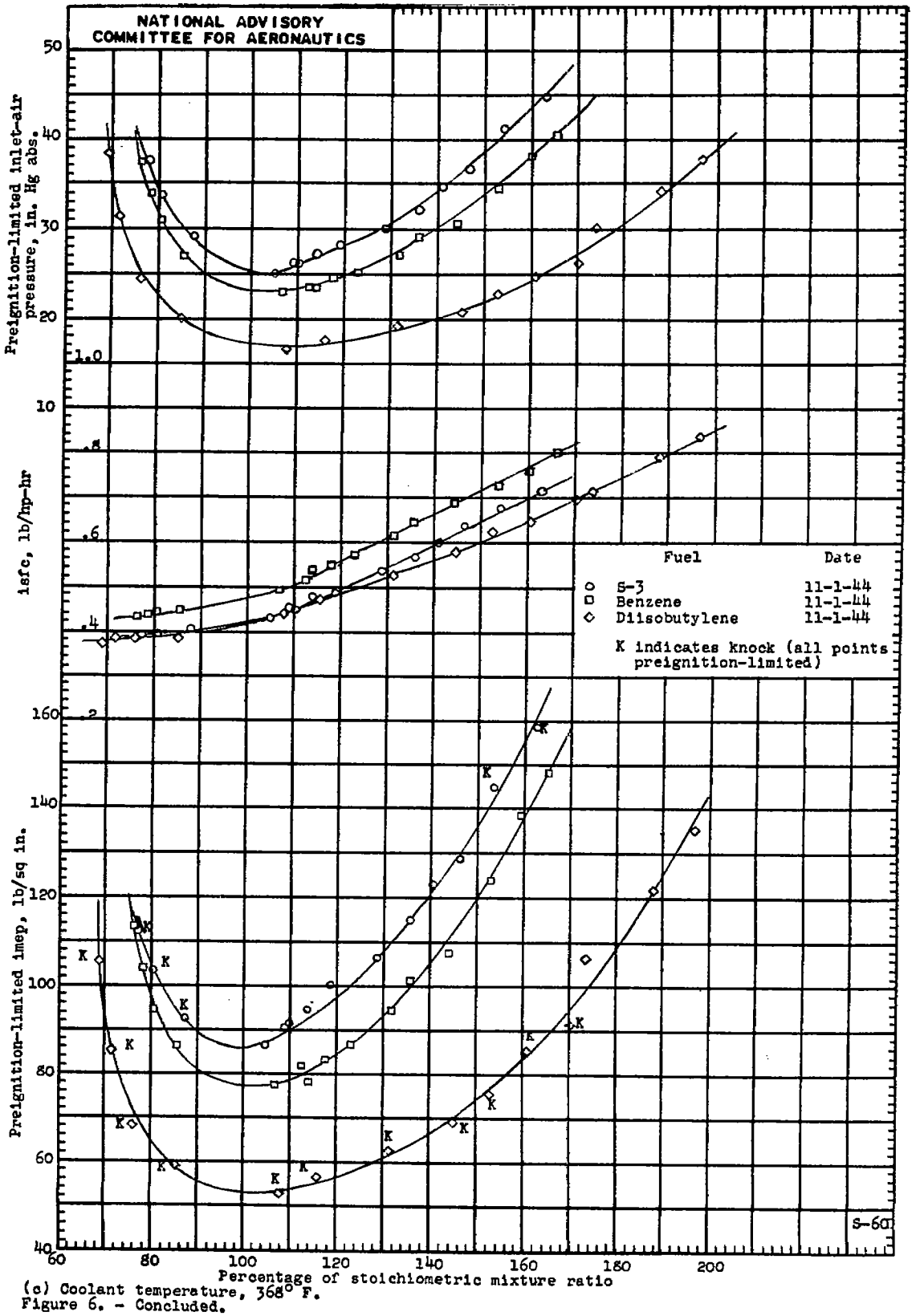


(a) Coolant temperature, 208° F.

Figure 6. - Preignition-limited performance of S-3 reference fuel, benzene, and diisobutylene at three coolant temperatures. CFR engine; hot spot, J-4; compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 20° B.T.C.; inlet-air temperature, 225° F.



(b) Coolant temperature, 250° F.
Figure 6. - Continued.



(c) Coolant temperature, 368° F.
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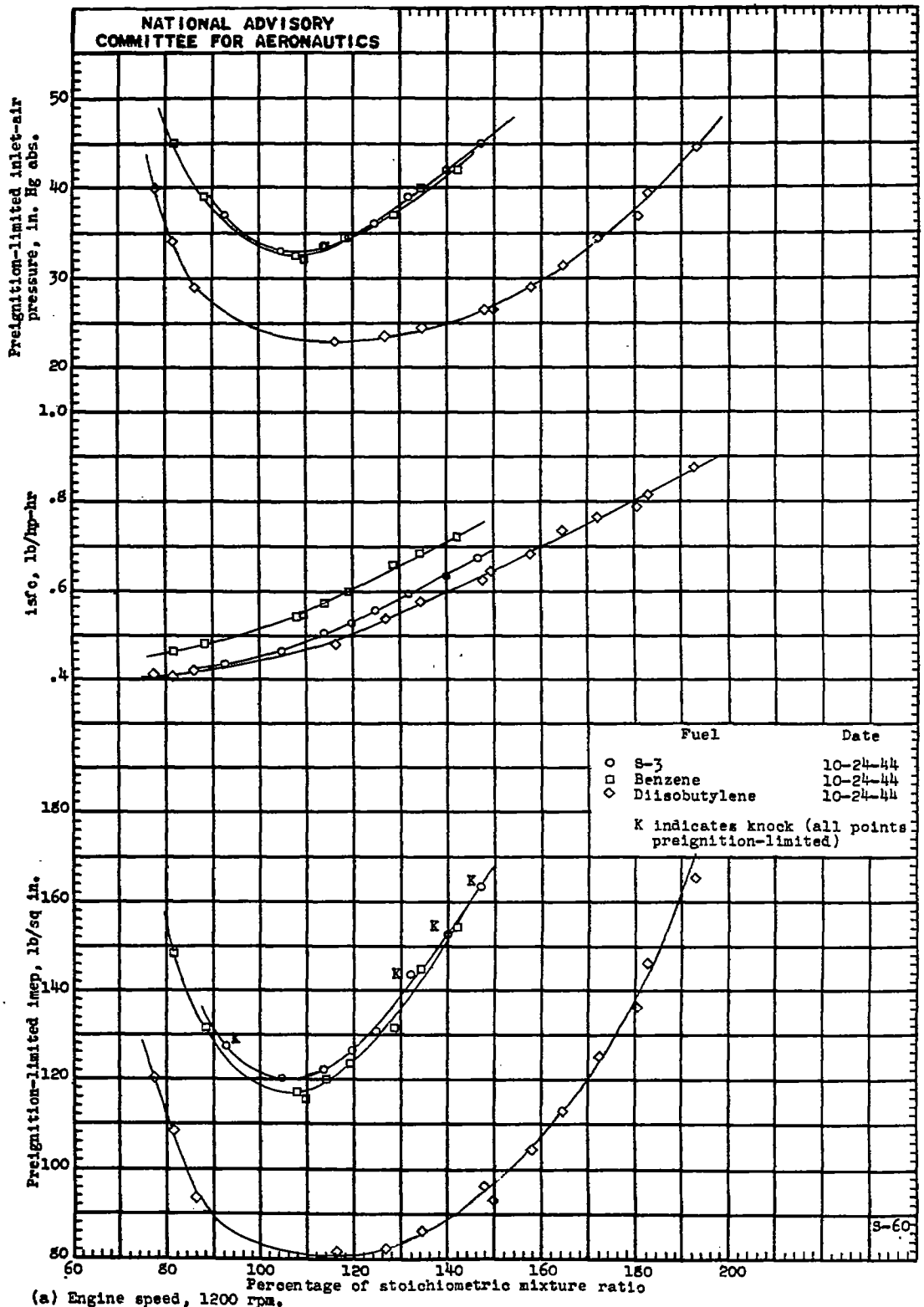
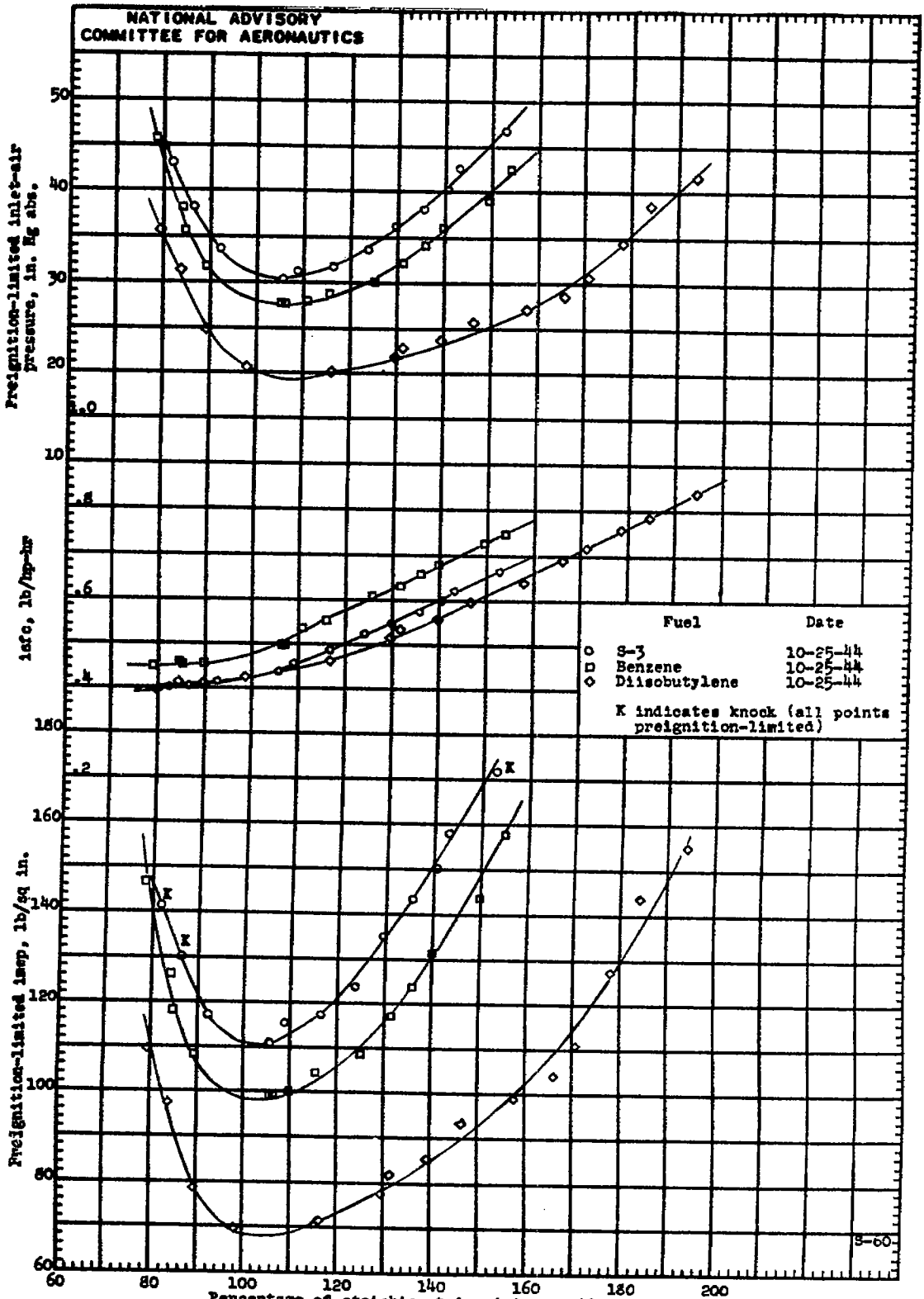
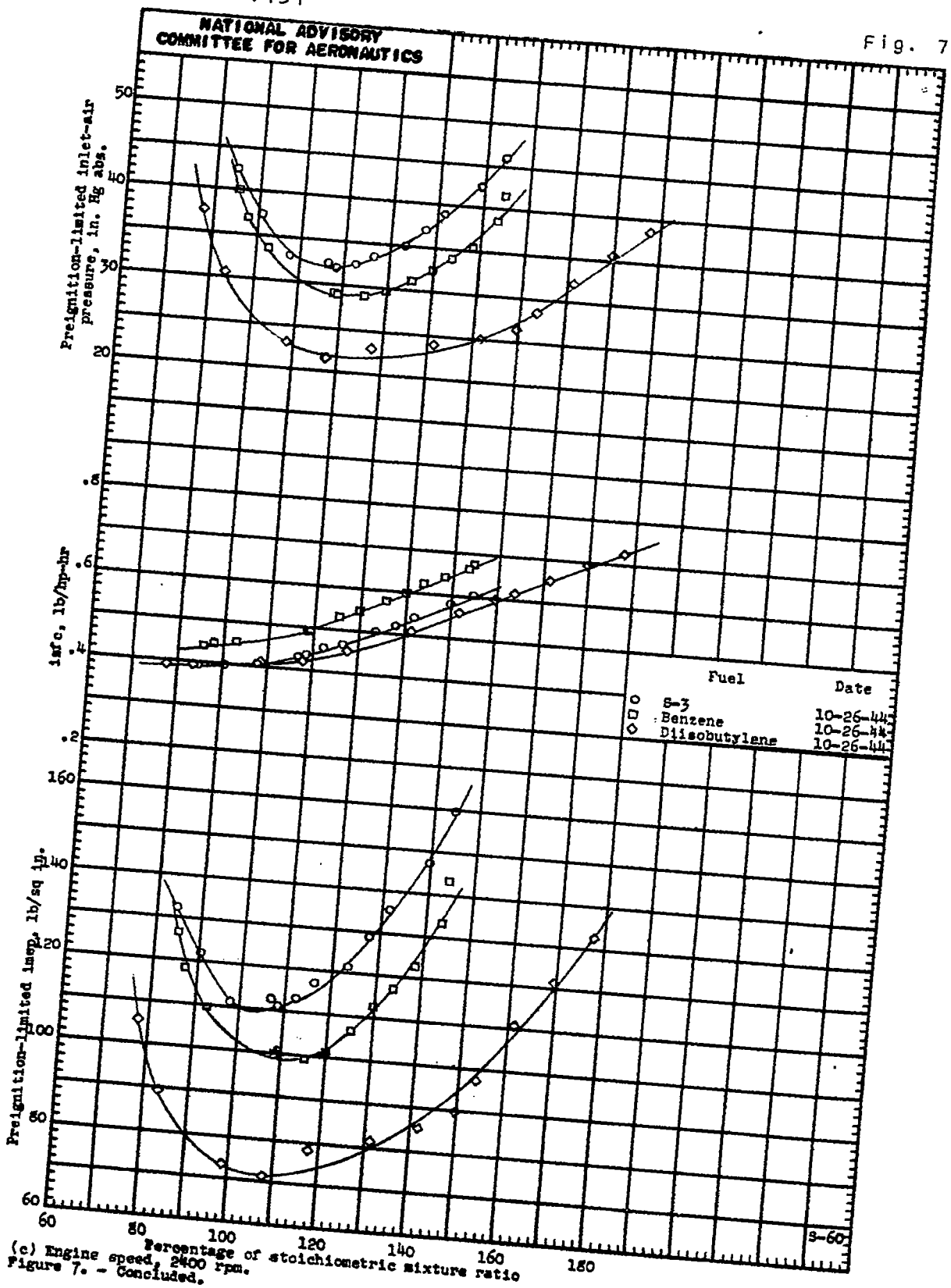


(a) Engine speed, 1200 rpm.

Figure 7. - Preignition-limited performance of S-3 reference fuel, benzene, and diisobutylene at three engine speeds. CFR engine; hot spot, J-4; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 225° F; coolant temperature, 250° F.



(b) Engine speed, 1800 rpm.
Figure 7. - Continued.



(c) Engine speed, 2400 rpm.

Figure 7. - Concluded.

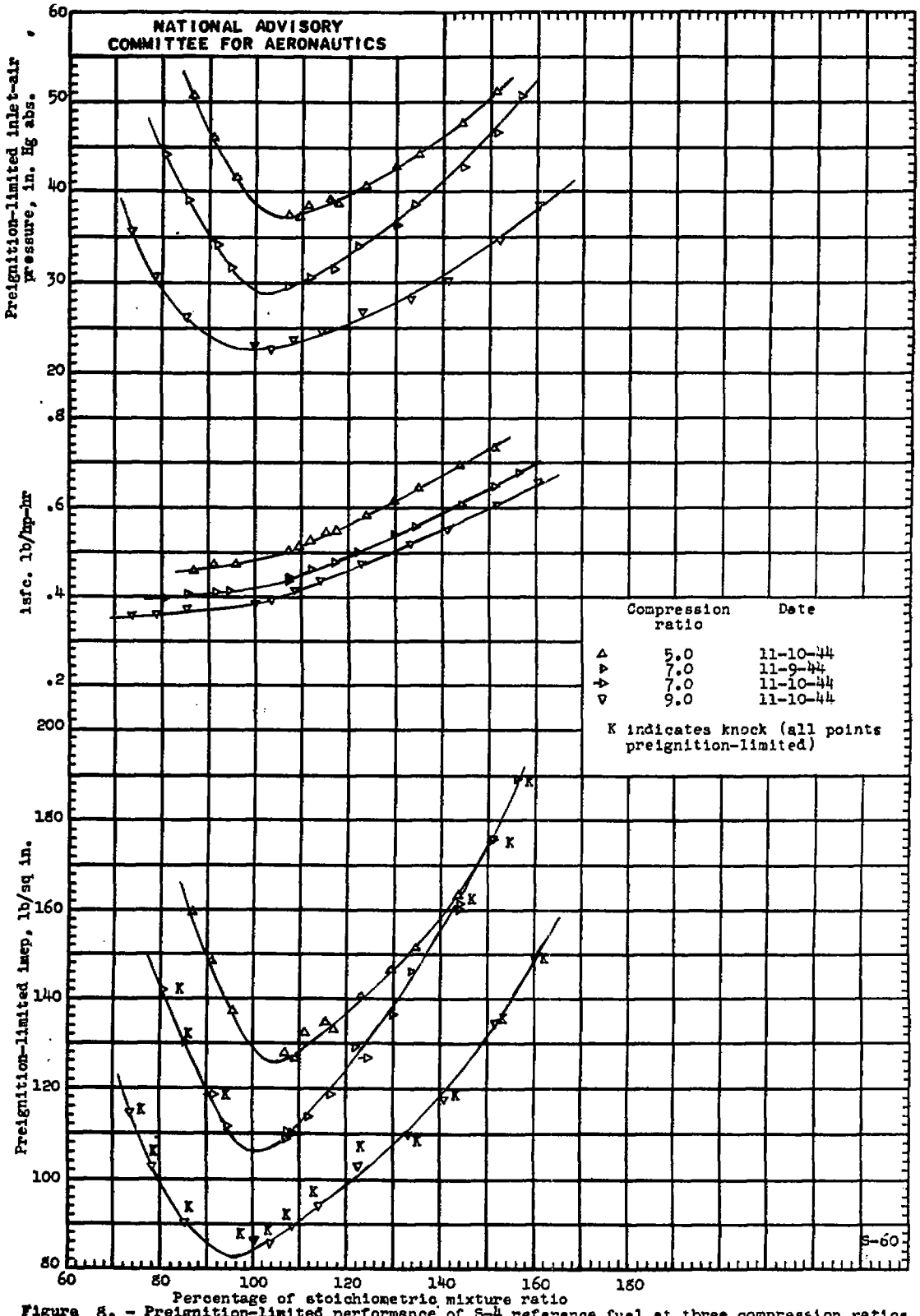


Figure 8. - Preignition-limited performance of S-4 reference fuel at three compression ratios. CFR engine; hot spot, J-4; engine speed, 1800 rpm; spark advance, 20° B.T.C.; inlet-air temperature, 225° F; coolant temperature, 250° F.

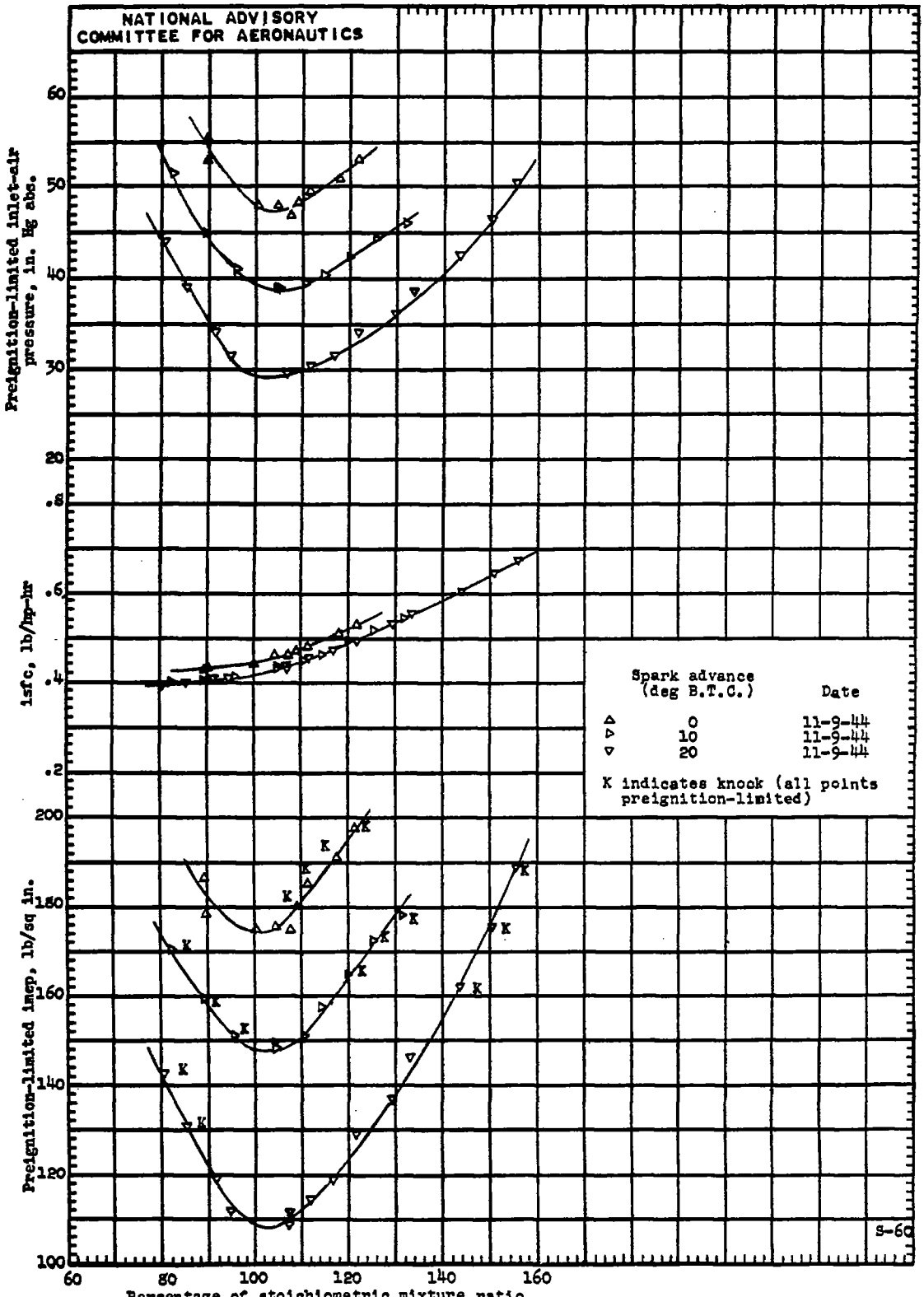


Figure 9. - Preignition-limited performance of S-4 reference fuel with three spark advances. CFR engine; hot spot, J-4; compression ratio, 7.0; engine speed, 1800 rpm; inlet-air temperature, 225° F; coolant temperature, 250° F.

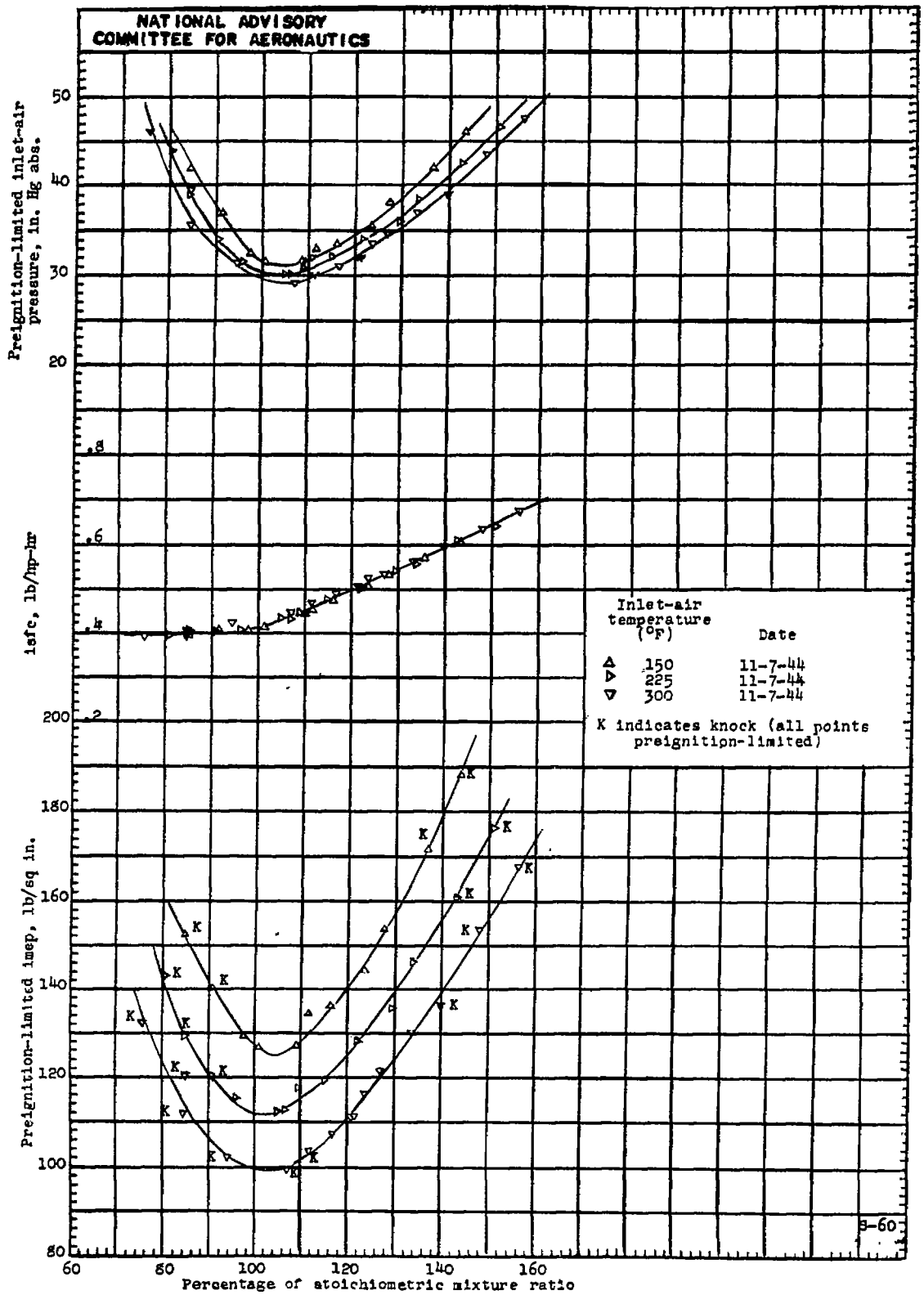


Figure 10. - Preignition-limited performance of S-4 reference fuel at three inlet-air temperatures. CFR engine; hot spot, J-4; compression ratio, 7.0; engine speed, 1800 rpm; spark advance 20° B.T.C.

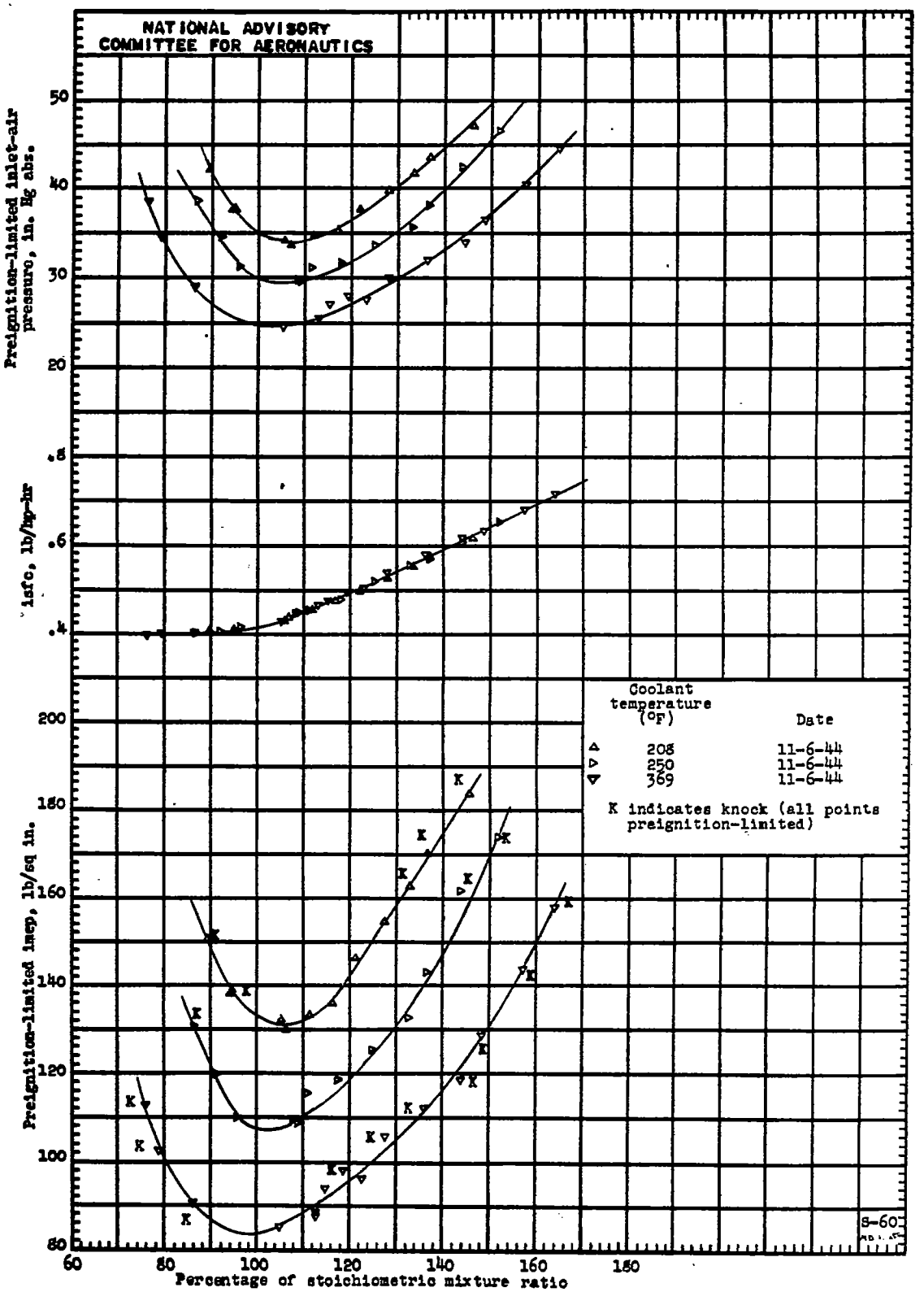


Figure 11. - Preignition-limited performance of S-4 reference fuel at three coolant temperatures. CFR engine; hot spot, J-4; compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 20° B.T.C.; inlet-air temperature, 225° F.

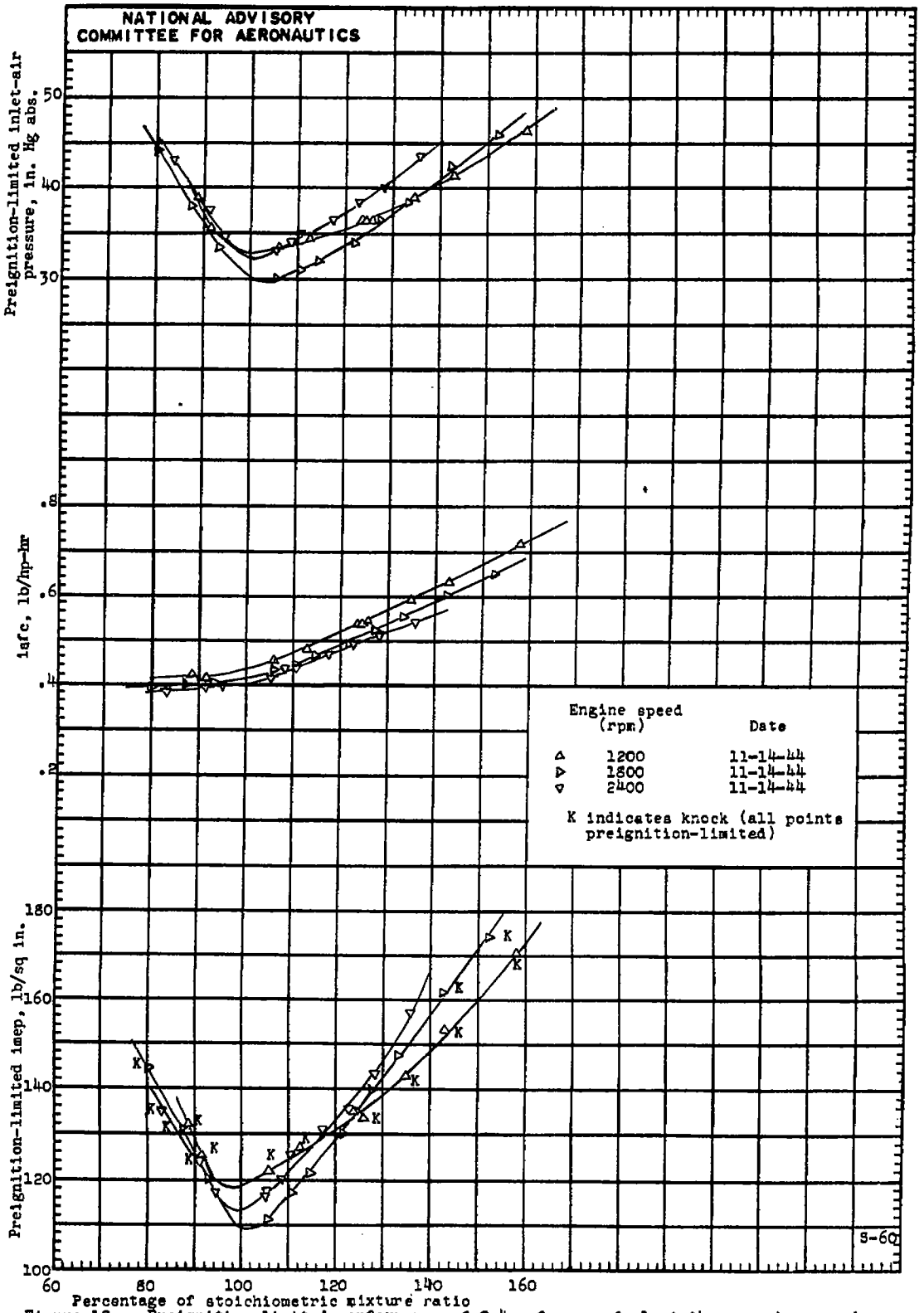


Figure 12. - Preignition-limited performance of S-4 reference fuel at three engine speeds. CFR engine; hot spot, J-4; compression ratio, 7.0; spark advance, 20° B.T.C.; inlet-air temperature, 225° F; coolant temperature, 250° F.

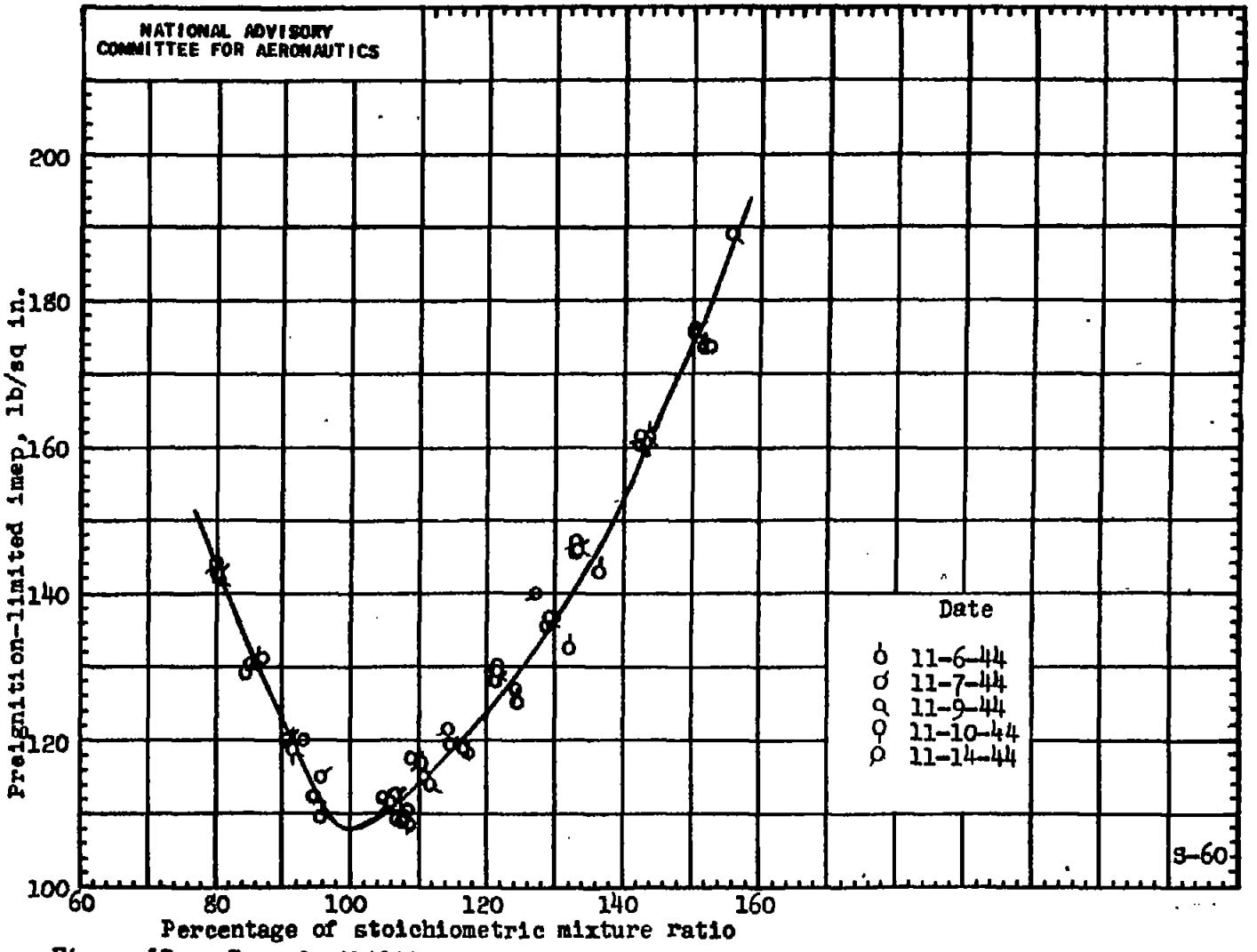


Figure 13. - Reproducibility of preignition-limited indicated mean effective pressure from day to day for S-4 reference fuel at the reference engine conditions. CFR engine; hot spot, J-4; compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 20° B.T.C.; inlet-air temperature, 225° F; coolant temperature, 250° F.

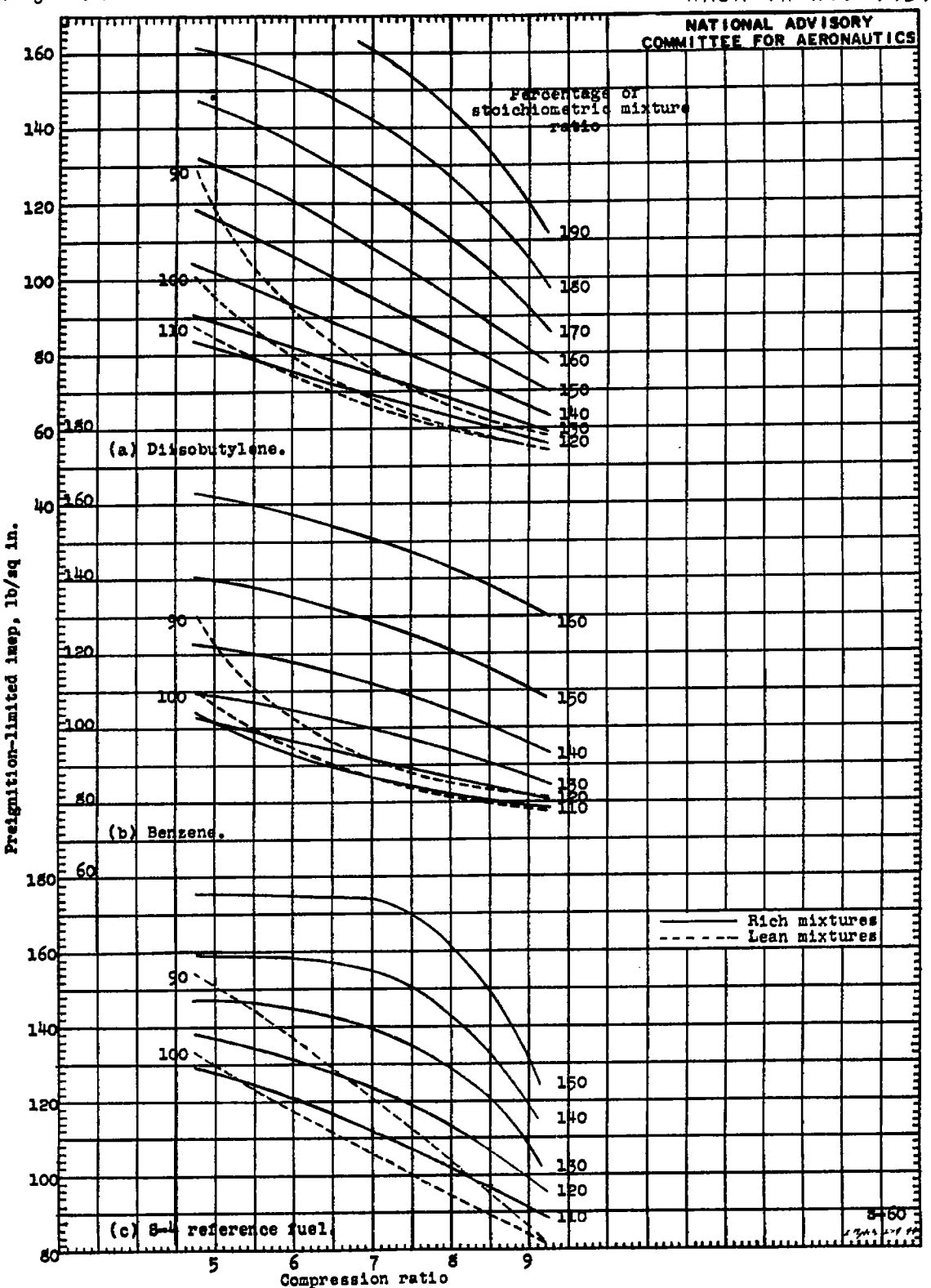


Figure 14. - Effect of compression ratio on the preignition-limited indicated mean effective pressures for diisobutylene, benzene, and S-4 reference fuel. Cross plot from figures 3 and 8.

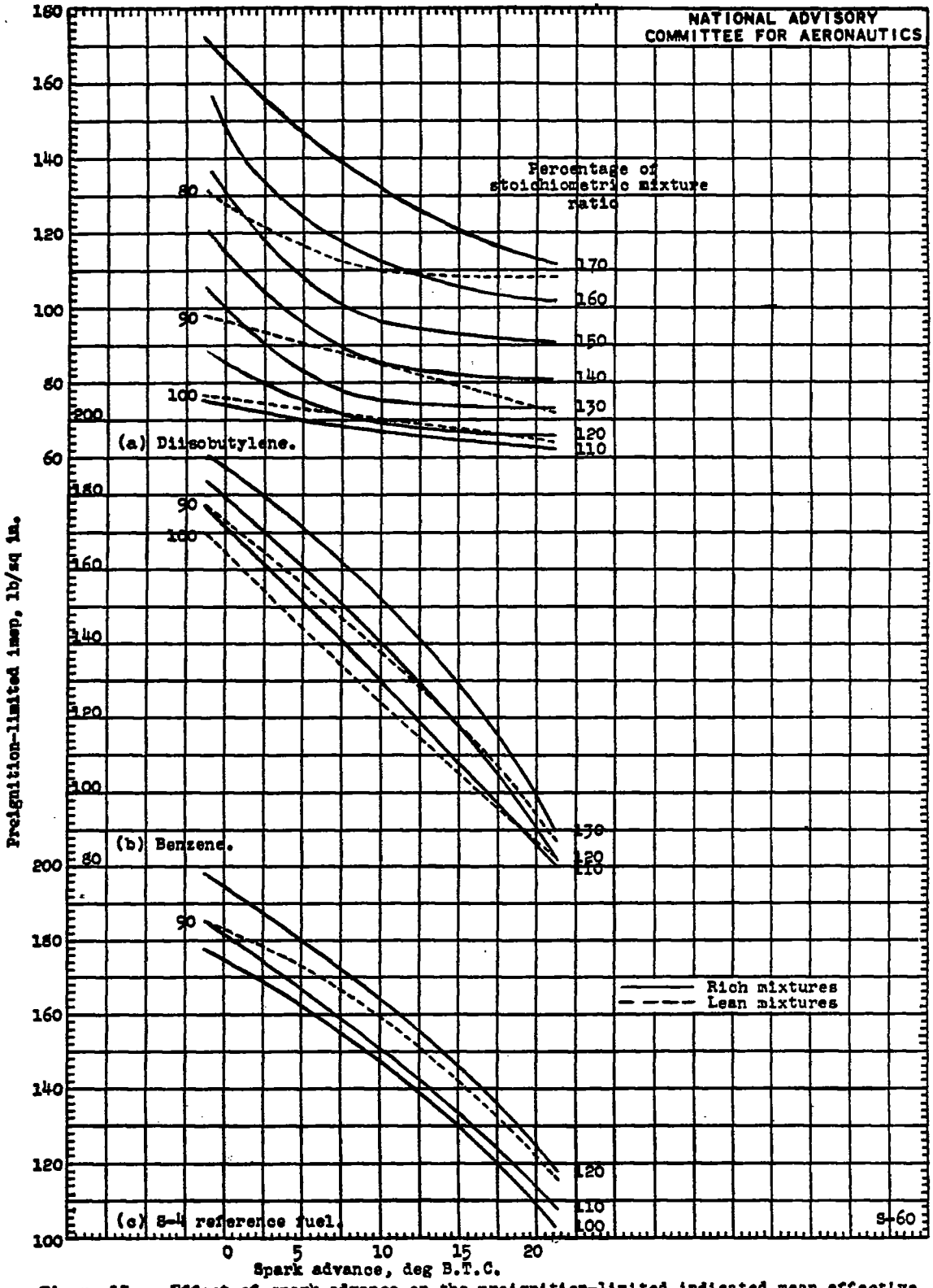


Figure 15. - Effect of spark advance on the preignition-limited indicated mean effective pressures for diisobutylene, benzene, and S-4 reference fuel. Cross plot from figures 4 and 9..

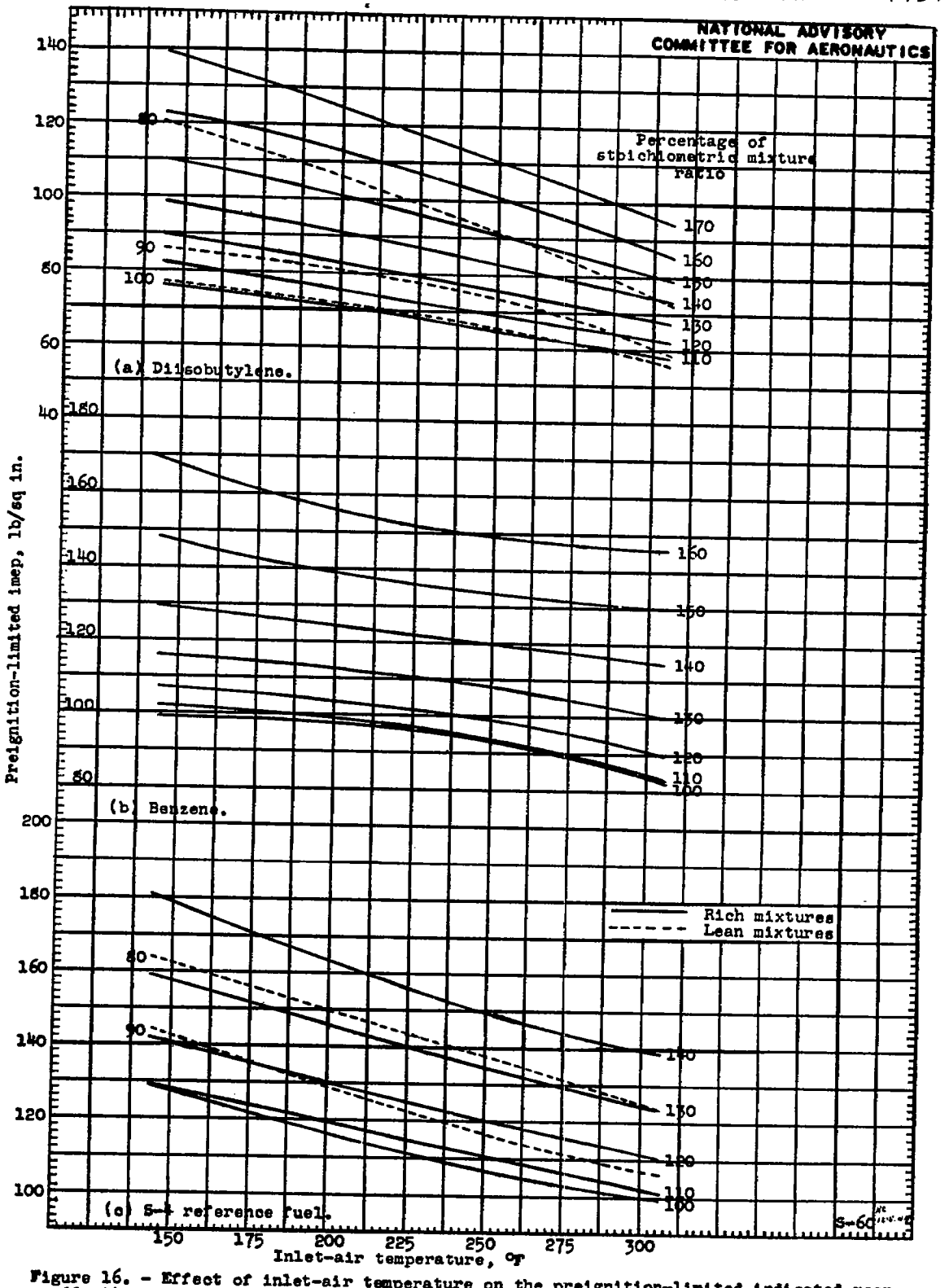


Figure 16. - Effect of inlet-air temperature on the preignition-limited indicated mean effective pressures for diisobutylene, benzene, and S-4 reference fuel. Cross plot from figures 5 and 10.

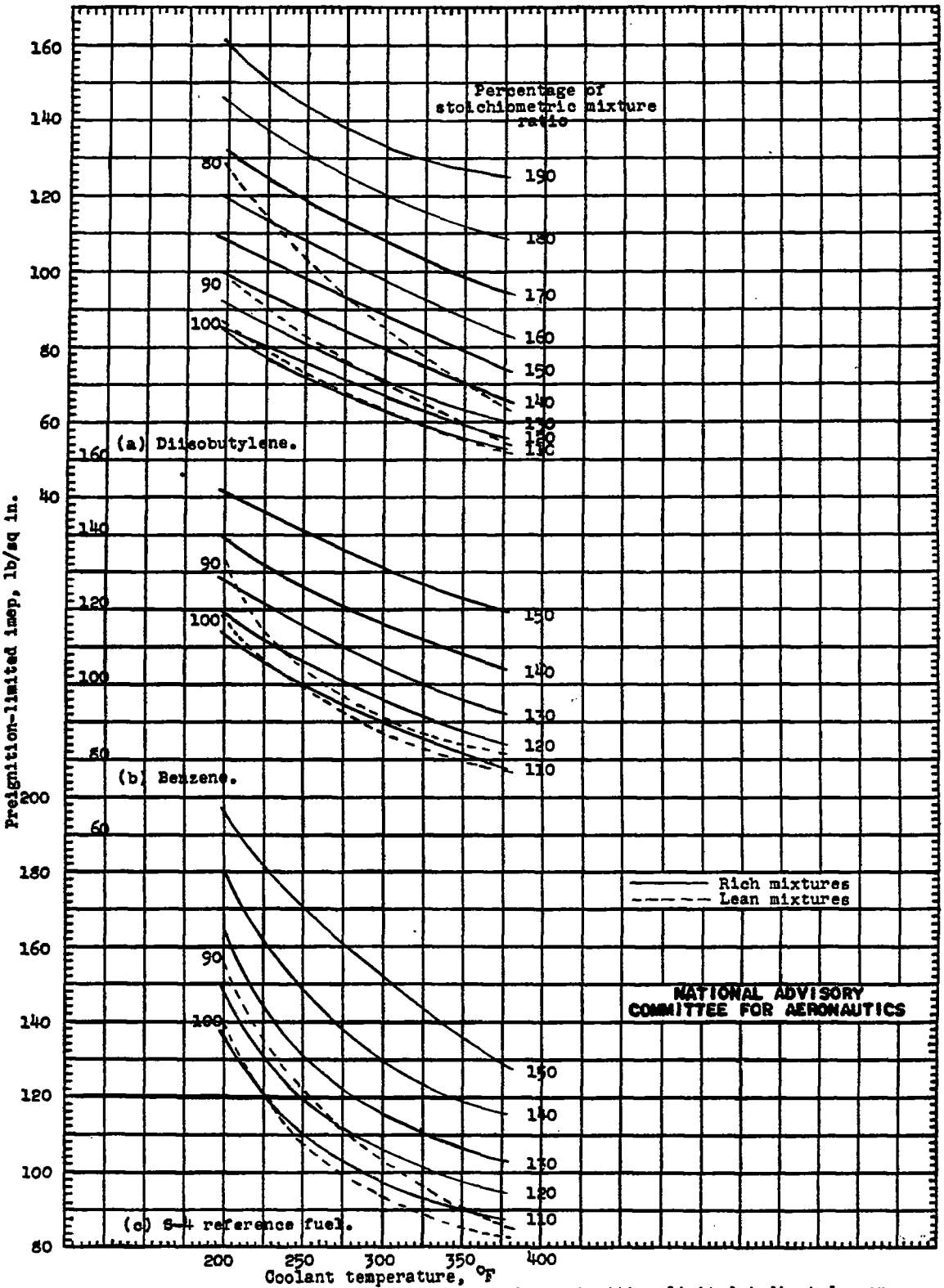


Figure 17. - Effect of coolant temperature on the preignition-limited indicated mean effective pressures for diisobutylene, benzene, and S-4 reference fuel. Cross plot from figures 6 and 11.

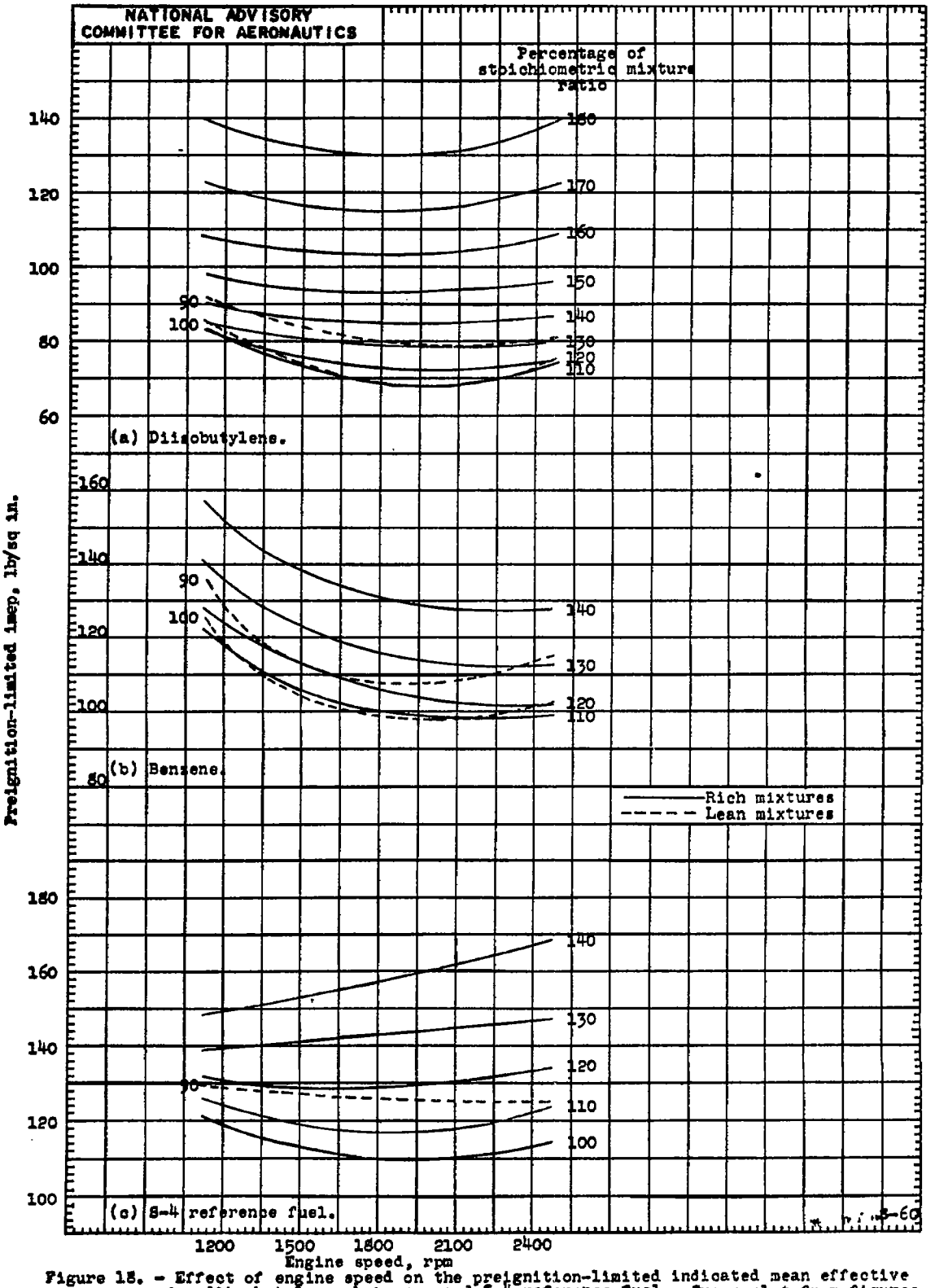


Figure 18. - Effect of engine speed on the preignition-limited indicated mean effective pressures for diisobutylene, benzene, and S-4 reference fuel. Cross plot from figures 7 and 12.