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TRENDS IN SURFACE-IGNITION TEMPERATURES

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ADVANCE RESTRICTED REPORT

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SUMMARY

Object. - To evaluate the variation of surface-ignition temperature with charge density, fuel-air ratio, and surface-ignition advance.

Scope. - Tests were made on a supercharged CFR engine to determine surface-ignition temperature as a function of each of three variables - fuel-air ratio, intake-manifold pressure, and surface-ignition advance - for S-3 reference fuel, benzene, methanol, and AN-F-28, Amendment-2, fuel. Surface ignition was induced by a platinum to platinum-10 percent rhodium thermocouple hot spot made of 0.040-inch wire and projecting 3/16 inch into the combustion chamber. The hot-spot temperature was controlled by heating the hot spot with an audio-frequency current.

Summary of results. - The following results were obtained from tests of the four fuels:

1. The range of the surface-ignition temperatures was between 1900° F and 2600° F. Although the absolute temperatures measured were not always reproducible, the trends and the absolute values of the slopes of the curves representing the data were.

2. Surface-ignition temperature increased approximately linearly with surface-ignition advance in degrees before top center, and the rate of increase was about the same for the four fuels.

3. At constant fuel-air ratio and surface-ignition advance, the temperatures required for surface ignition decreased about 70° F when the intake-manifold pressure was increased from 30 to 45 inches of mercury absolute.

4. Surface-ignition temperatures reached minimum values at fuel-air ratios within 10 percent of the theoretical mixtures.

5. At similar conditions, surface-ignition temperatures for the four fuels were within about 150° F of each other and, under certain conditions, fuels of presumably different preignition characteristics, such as S-3 and benzene, had the same surface-ignition temperatures.

Conclusion. - Because not much difference was observed between the surface-ignition temperatures of the several fuels tested, it is concluded that surface-ignition temperature is not a satisfactory criterion for differentiating between the preignition characteristics of different fuels in internal-combustion engines.

INTRODUCTION

As part of a research program to determine the preignition characteristics of aviation-fuel components, this laboratory has conducted tests on a supercharged CFR engine to determine the relationships between a hot-spot temperature required for surface ignition and other engine variables with four different fuels. Previous work conducted on preignition by the NACA is presented in reference 1. The data presented in this report were obtained from tests made at the Aircraft Engine Research Laboratory at Cleveland, Ohio, from October 1, 1943 to February 1, 1944.

APPARATUS

The tests were performed on a high-speed, supercharged CFR engine coupled to a 25-horsepower, alternating-current, cradle-type 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. Knock, when it occurred, was detected by a cathode-ray oscilloscope in conjunction with a magnetostriction pickup unit. Data taken under knocking conditions are so indicated on the figures. All operating temperatures were measured by iron-constantan thermocouples and a self-balancing potentiometer. Champion RJ-11 spark plugs were used throughout the tests. The fuels used in these tests were: (1) S-3 reference fuel, (2) benzene, (3) methanol, and (4) AN-F-28, Amendment-2, fuel.

An electrically heated thermocouple (Pt to Pt-10 percent Rh) hot spot was the source of surface ignition. It was mounted symmetrically with an ionization-gap-flame-front indicator in a steel plug (fig. 1), designed to be installed in a spark-plug-hole. The

ionization gap coupled to an electronic circuit activated the spark-timing indicator plate on the engine. The wires were sealed into the plug with powdered talc (see fig. 1); the thermocouple extended beyond the plug body 3/16 inch. The diameter of the thermocouple wires was 0.040 inch except at the junction where it was reduced, thus insuring the junction as the hottest point. The wire electrode of the ionization gap was not allowed to extend more than 1/32 inch into the combustion chamber because it might otherwise act as a source of surface ignition. Because the platinum occasionally melted during advanced preignition, four hot-spot units were required to obtain the data for the report. The unit used for each test is indicated on the figures.

Platinum and platinum-10 percent rhodium were chosen as thermocouple materials because of their high melting points and their resistance to oxidation. The use of platinum as a source of surface ignition has the disadvantage that the metal is catalytic; it is believed, however, that the effect is not large enough to subtract materially from the significance of the results presented in this report. Data indicating the catalytic effect of platinum on surface-ignition temperatures are given in the appendix. A similar unit using chromel and alumel as thermocouple materials, when employed in preliminary tests, indicated surface-ignition temperatures of the same order of magnitude as did the unit using the platinum to platinum-rhodium thermocouple.

The heating current to the hot spot was supplied by an audio-frequency oscillator (fig. 2). A blocking condenser was required in the circuit to keep out direct current from the thermocouple. The thermal electromotive force was measured with a self-balancing potentiometer connected in series with a choke coil, which was installed to prevent the heating current from affecting the measurements of the thermal electromotive force. The reliability of the circuit for measuring electromotive forces was checked by simultaneously measuring the hot-spot temperature with the test thermocouple and with a thermocouple in an independent external circuit. Both thermocouples indicated the same temperature.

The tests were made with the unit in spark-plug hole 3 (fig. 2) in order to place the hot spot in the end zone and hence allow surface-ignition data to be recorded at the latest possible crank-angle position in relation to the ignition timing. The unit was mounted in the cylinder with the ionization gap on the intake-valve side and at the same level as the thermocouple. The unit was installed in such a way that its inner surface was flush with the cylinder wall, within the limits of one revolution.

PROCEDURE

Under normal operating conditions the flame front arrived at the ionization gap 45° to 55° (crank angle) after the excitation of the spark plug. When the hot-spot temperature was high enough to ignite the charge ahead of the normal flame front, the ionization gap indicated this ignition. Surface-ignition advance (the time at which surface ignition occurred, measured in degrees of crank angle) depended upon the hot-spot temperature, which was externally controlled by changing the output of the power source.

The following engine conditions were maintained constant:

Engine speed, rpm	1800
Compression ratio	7.0
Coolant temperature, °F	250
Inlet-air temperature, °F	100
Spark advance, degrees B.T.C.	35
Oil temperature, °F	150

Data were obtained to show the variation of required surface-ignition temperature for the four fuels with each of three variables: surface-ignition advance (time), charge density, and fuel-air ratio. Test points were taken when the hot-spot temperature was adjusted to give the desired surface-ignition advance. Some points were stable, that is, for a given power input both the temperature and the surface-ignition advance remained constant. At other points, however, combustion caused the temperature to rise without additional heating current, which resulted in a corresponding advance of surface ignition. It was necessary to make instantaneous temperature readings for the desired advances in recording these unstable points. Because of the "run-away" tendency of most fuels, it was rarely possible to obtain data for early advances.

The cycle-to-cycle variation of the surface-ignition advance, as determined with the ionization gap, varied from 2° at late advances to 10° at early advances. For very advanced preignition, the cycle-to-cycle variation was often as high as 40°, but no data were recorded for these conditions. The lengths of the arrows on the curve of S-3 reference fuel (fig. 3) graphically illustrate these variations. The temperature measurement on any one datum point is believed to be accurate to ±10° F. The data were not sufficiently reproducible, however, to warrant extensive comparison of the absolute temperatures of one curve with those of another, except when they were obtained on the same day. Day-to-day variation may be due to slight changes in the thermocouple geometry,

surface condition, and activity of the platinum. When a fuel-air-ratio test was made for a fuel, a similar test was made on the same day with S-3 reference fuel using the same unit; thus, a basis for comparison between fuels was established. Trends and slopes of curves were quite reproducible.

DISCUSSION

The curves of surface-ignition temperature plotted against surface-ignition advance for the four fuels are approximately linear with positive slopes (fig. 3). It is evident by comparing the curves that the differences in either the absolute temperature values or the slopes are too small to be a significant indication of any variation in preignition characteristics of these four fuels. The data for methanol were taken at a lower percentage theoretical fuel-air ratio than the other fuels, but it will be shown later (fig. 6(b)) that this difference does not materially alter the comparison. It was possible to obtain data for methanol for advances earlier than 40° B.T.C. because run-away preignition did not occur. Significantly enough, methanol surface-ignited for these engine conditions at about 10° B.T.C. with no external heat, which limited the extent of the curve. The curve for AN-F-28 fuel containing 4.53 milliliters tetraethyl lead per gallon is essentially the same as the curves for the other fuels.

Curves of surface-ignition advance at different fuel-air ratios were determined for S-3 reference fuel. As can be seen from figure 4, the slopes of these curves are the same as and check reasonably well with the curves in figure 3.

The surface-ignition temperatures at a constant surface-ignition advance of 20° B.T.C. are plotted in figure 5 as a function of fuel-air ratio on a percentage theoretical-mixture basis for benzene, methanol, and AN-F-28 fuel. For comparison, each is presented with its own S-3 reference curve. The trends are the same for the four fuels, and the temperature differences are, in general, small; the greatest difference is about 160° F. The temperature increases in both the lean and the rich regions from a minimum at about 110 percent of the theoretical mixture except for benzene, which has a minimum at about 95 percent of the theoretical mixture.

For the plots in figure 6, data were taken first for successively richer and then for successively leaner mixtures throughout the operating range. These results eliminate the possiblity of confusing other trends with the actual trends caused by fuel-air ratio.

The effect of intake-manifold pressure on surface-ignition temperatures at an advance of 20° B.T.C. and at constant fuel-air ratio is shown in figure 7 for the four fuels. Data were taken first for progressively higher and then for progressively lower intake-manifold pressures. Inasmuch as charge density varies directly with intake-manifold pressure, the curves represent the effect of charge density on surface-ignition temperature. The temperatures are lower for the high charge densities than for the low, but the difference is small.

It is evident from the tests conducted and the results presented that surface-ignition temperature, as measured by the hot-spot thermocouple, will not suffice to indicate the preignition tendencies of engine fuels. The heating current to the hot spot required for a given surface-ignition advance, however, varies considerably for various fuels and engine conditions. Further work is being conducted at this laboratory to determine the preignition characteristics of fuel components.

CONCLUSION

Because not much difference was observed between the surface-ignition temperatures of the several fuels tested, it is concluded that surface-ignition temperature is not a satisfactory criterion for differentiating between the preignition characteristics of different fuels in internal-combustion engines.

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APPENDIX - CATALYTIC EFFECT OF PLATINUM ON SURFACE-IGNITION TEMPERATURES

When a platinum to platinum-rhodium thermocouple was used as an engine-heated hot spot with S reference fuel, temperatures of about 1900° F were reached without signs of surface ignition. The hot-spot temperature dropped to approximately 1400° F when S + 1 ml TEL per gallon was tested at the same fuel flow, air flow, and engine conditions. These data indicate that tetraethyl lead will poison a platinum catalyst. When S reference fuel was again used, the temperature remained at about 1400° F. After the platinum was reactivated by additional heat and advanced preignition, the temperature recorded with S reference fuel was again 1900° F. The temperatures required to cause run-away preignition were measured in each of the foregoing tests and were found to be very nearly the same, that is, about 2200±50° F, although the required inlet-air pressures were quite different even for the same fuel.

As a further test, the hot spot was removed, dipped in commercial tetraethyl lead, and reinstalled in the engine. This time, the catalytic deactivation of the hot spot seemed to be complete and permanent; even extremely high powers, heavy knock, and advanced preignition failed to reactivate the platinum. Although the preignition-limited indicated mean effective pressures had increased greatly with S reference fuel, the temperature required to cause preignition after deactivation was lowered only about 50° F. (See fig. 7.)

The deactivation of platinum by tetraethyl lead seems to be simple and effective. Concentrations as low as 1 ml TEL per gallon in the gasoline will achieve the result. Similar tests of tetraethyl lead and Inconel hot spots showed no corresponding effects.

REFERENCES

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

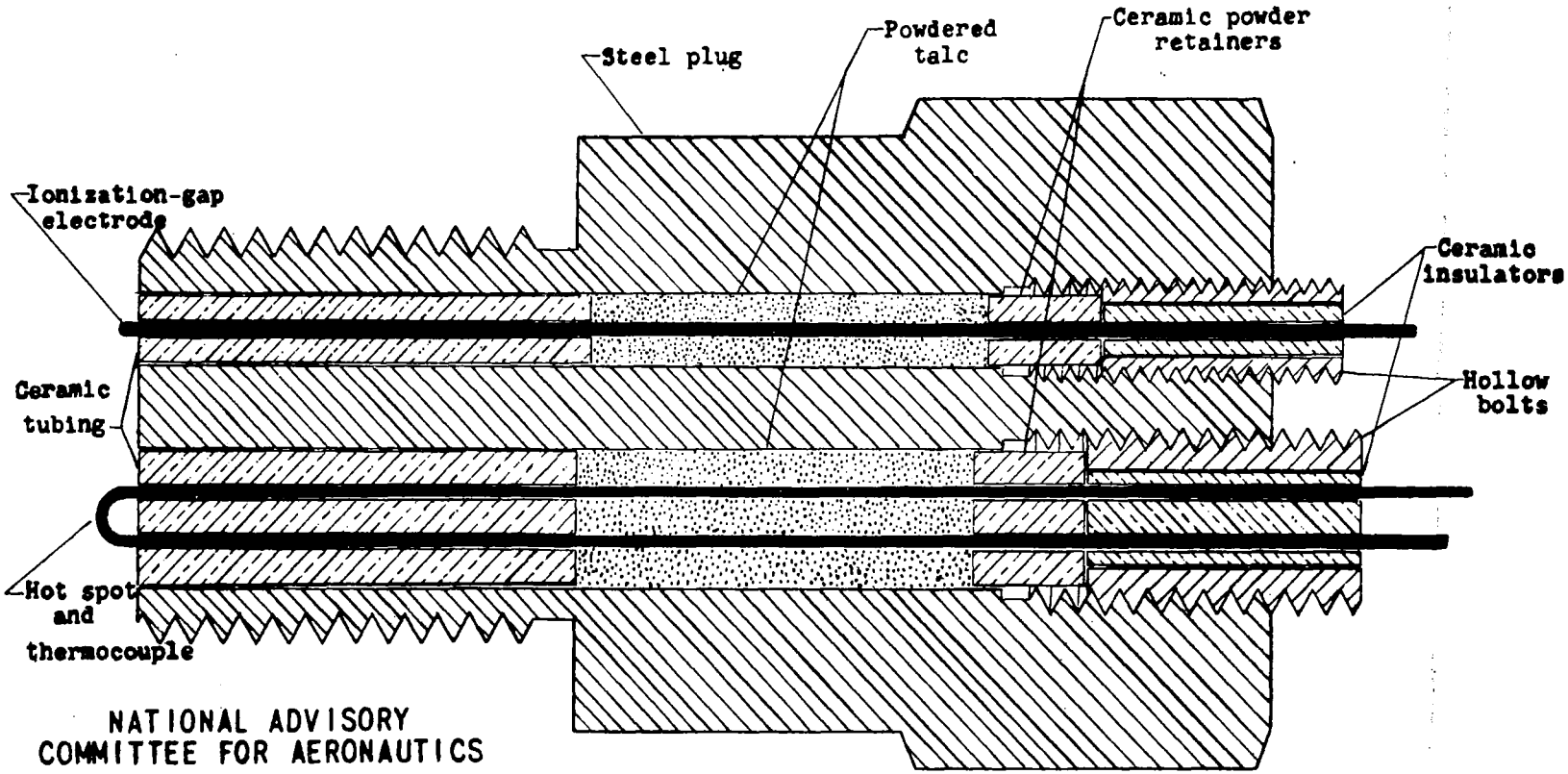

Figure 1. - Combination hot spot - thermocouple and ionization gap.

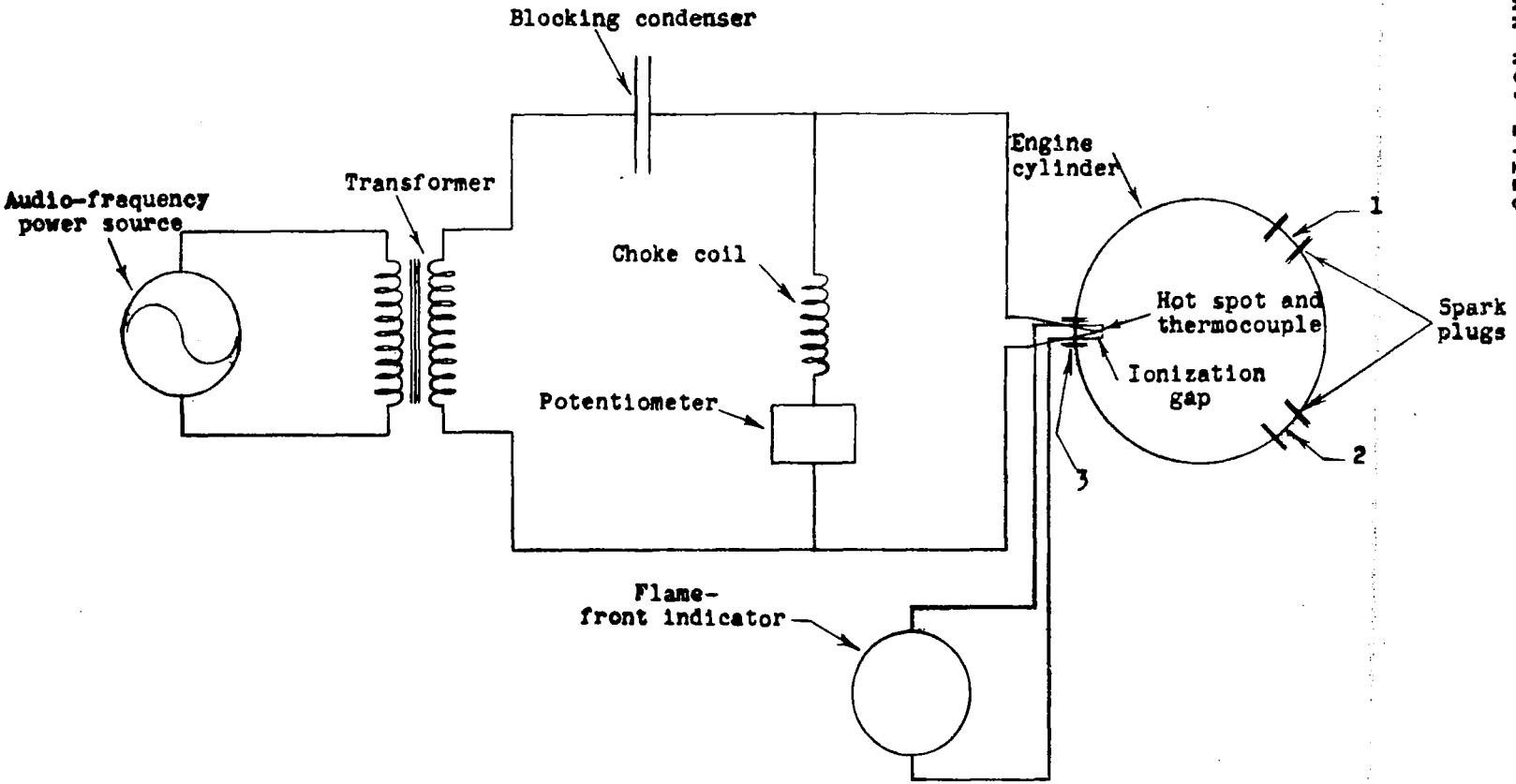

Figure 2. - Circuit diagram.

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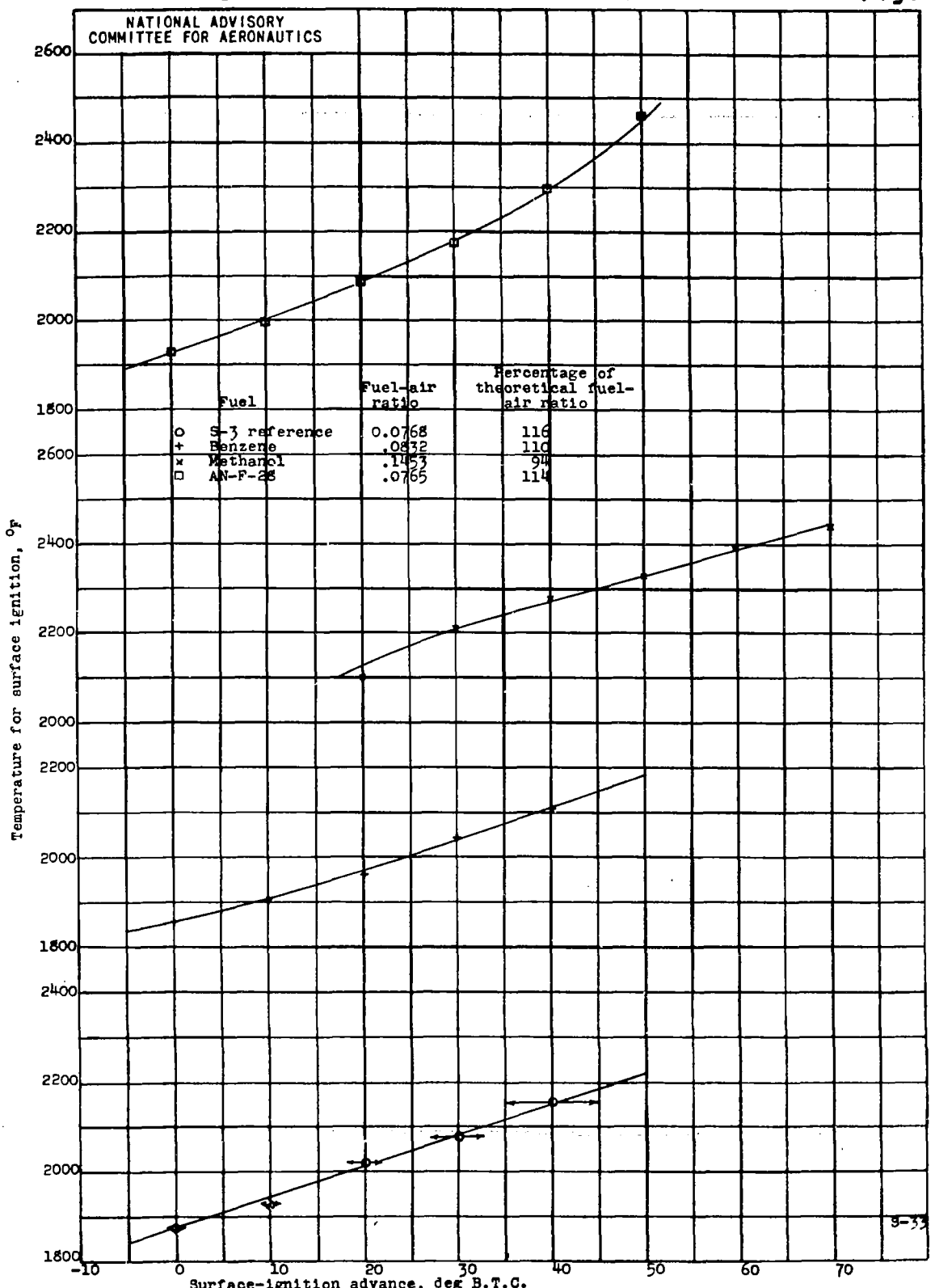


Figure 3. - Correlation of temperature required for surface ignition with surface-ignition advance, Intake-manifold pressure, 35 inches of mercury absolute (32.5 in. Hg absolute for methanol); spark advance, 35° B.T.C.; inlet-air temperature, 100° F; engine speed, 1800 rpm; coolant temperature, 250° F; compression ratio, 7.0; thermocouple, F-3.

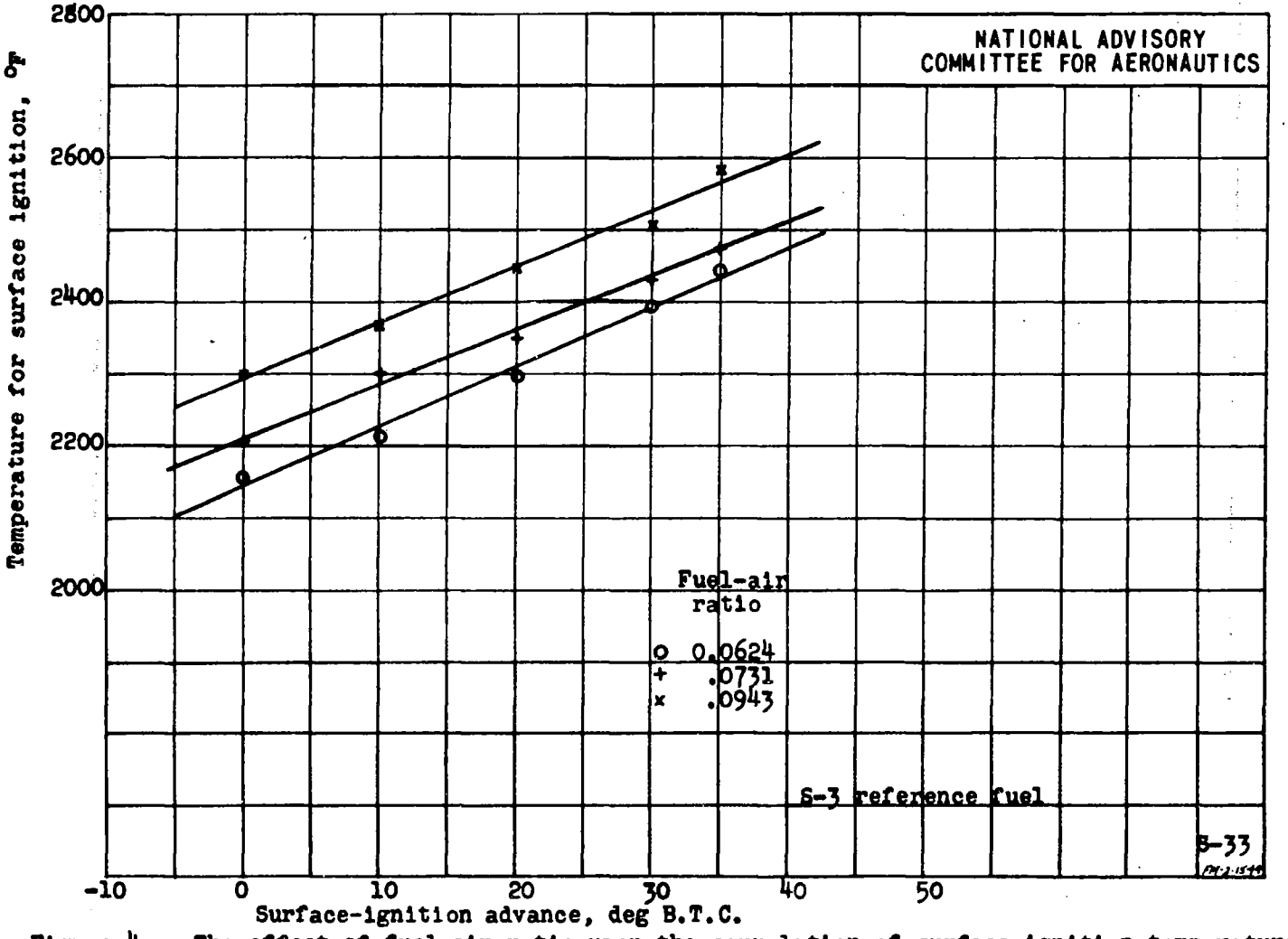
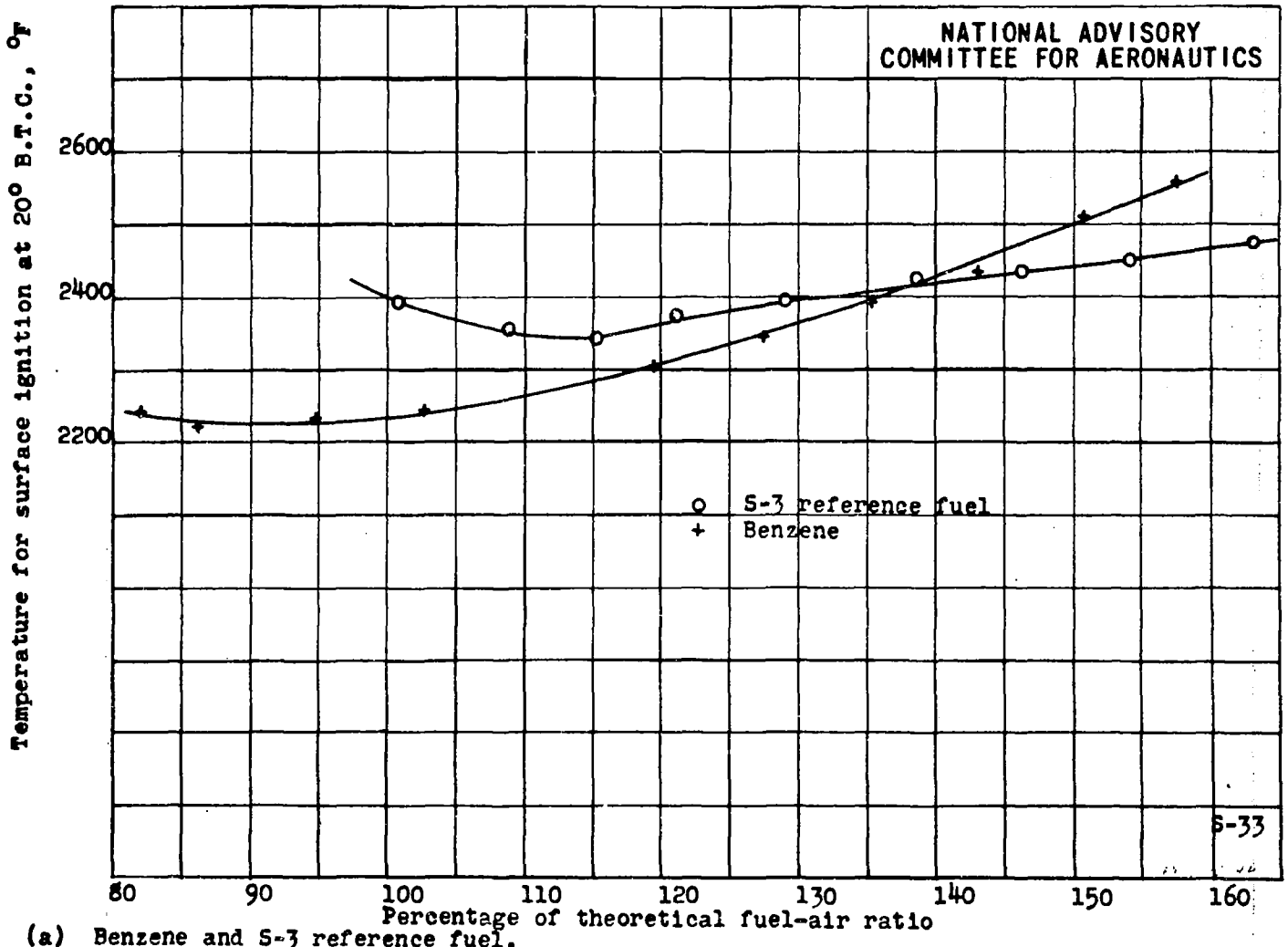
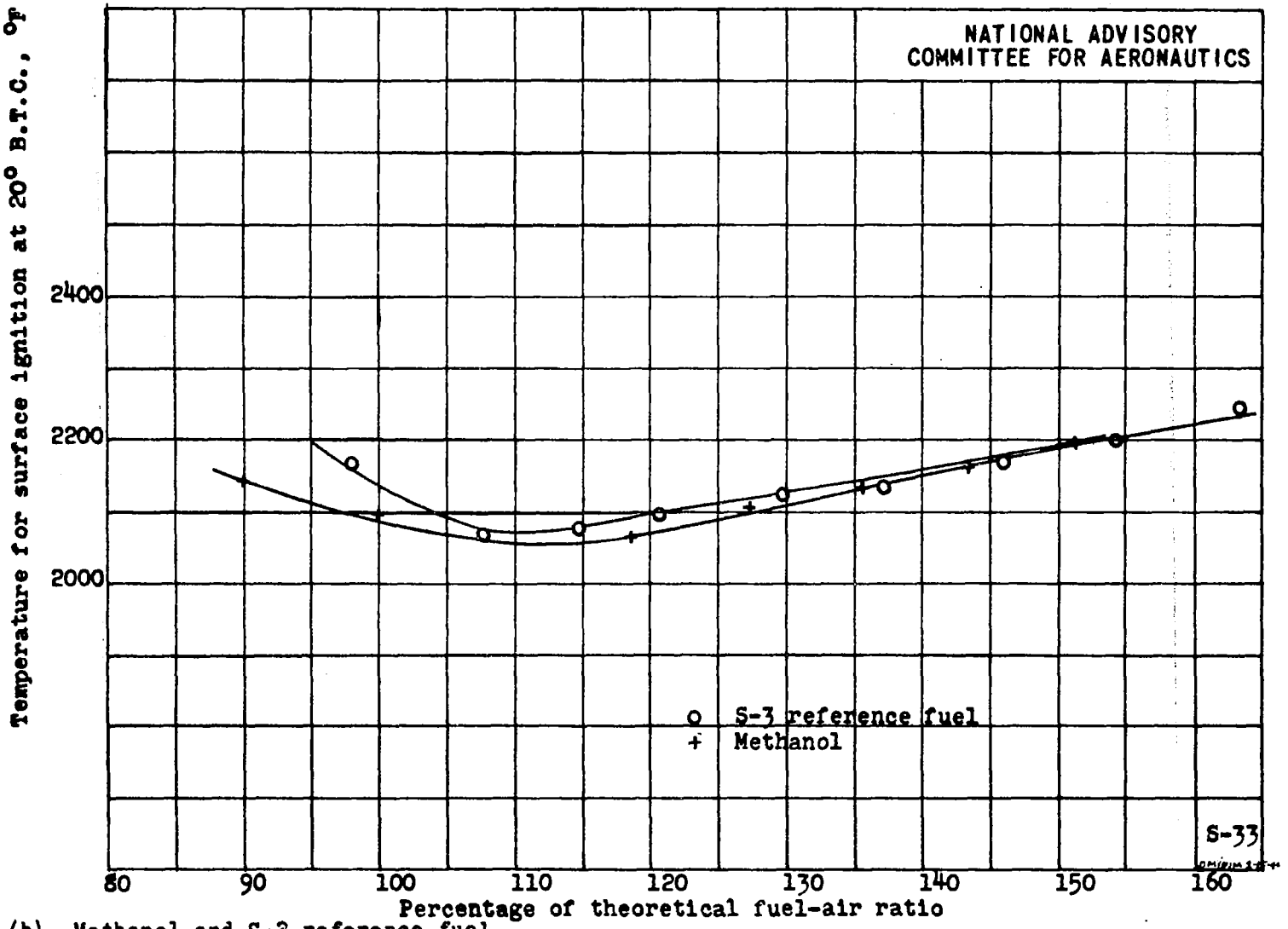


Figure 4. - The effect of fuel-air ratio upon the correlation of surface-ignition temperature and advance. Intake-manifold pressure, 35 inches of mercury absolute; engine speed, 1800 rpm; inlet-air temperature, 100° F; coolant temperature, 250° F; spark advance, 35° B.T.C.; compression ratio, 7.0; thermocouple, F-1.



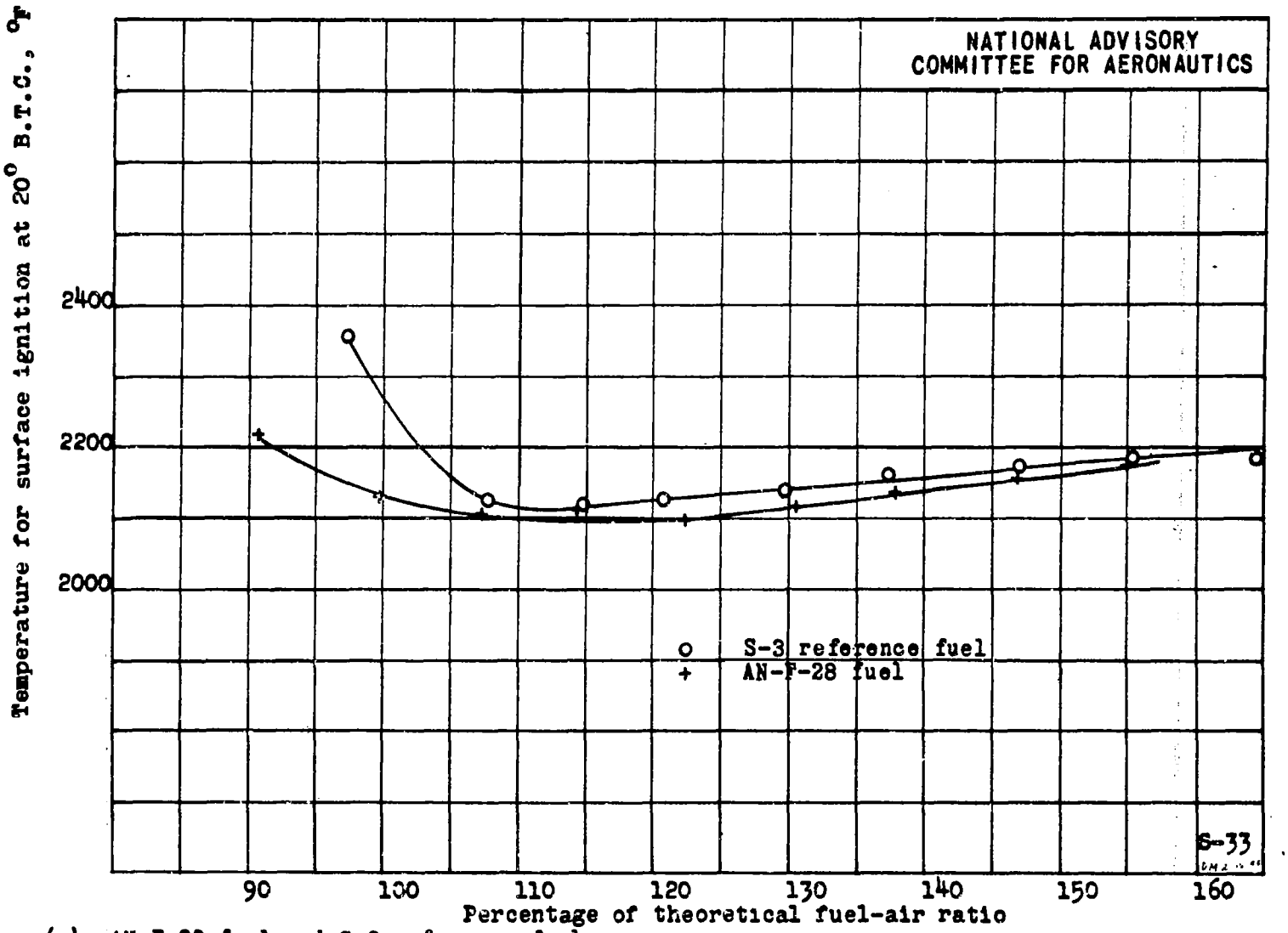
(a) Benzene and S-3 reference fuel.

Figure 5. - The effect of fuel-air ratio upon surface-ignition temperature. Intake-manifold pressure, 35 inches of mercury absolute; coolant temperature, 250° F; inlet-air temperature, 100° F; compression ratio, 7.0; spark advance, 35° B.T.C.; engine speed, 1800 rpm; thermocouple, F-3.



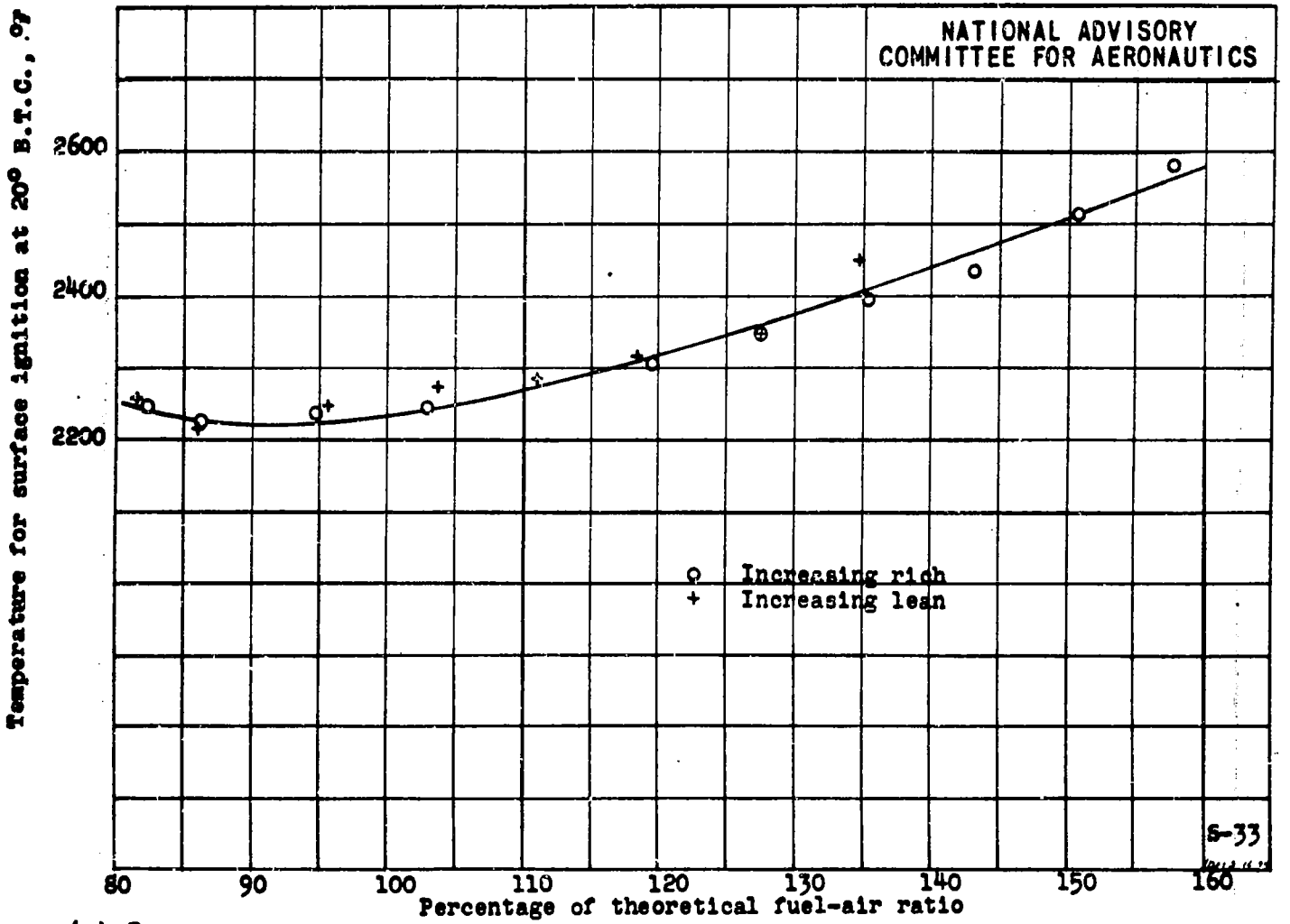
(b) Methanol and S-3 reference fuel.

Figure 5. - Continued. Intake-manifold pressure for methanol, 32.5 inches of mercury absolute.



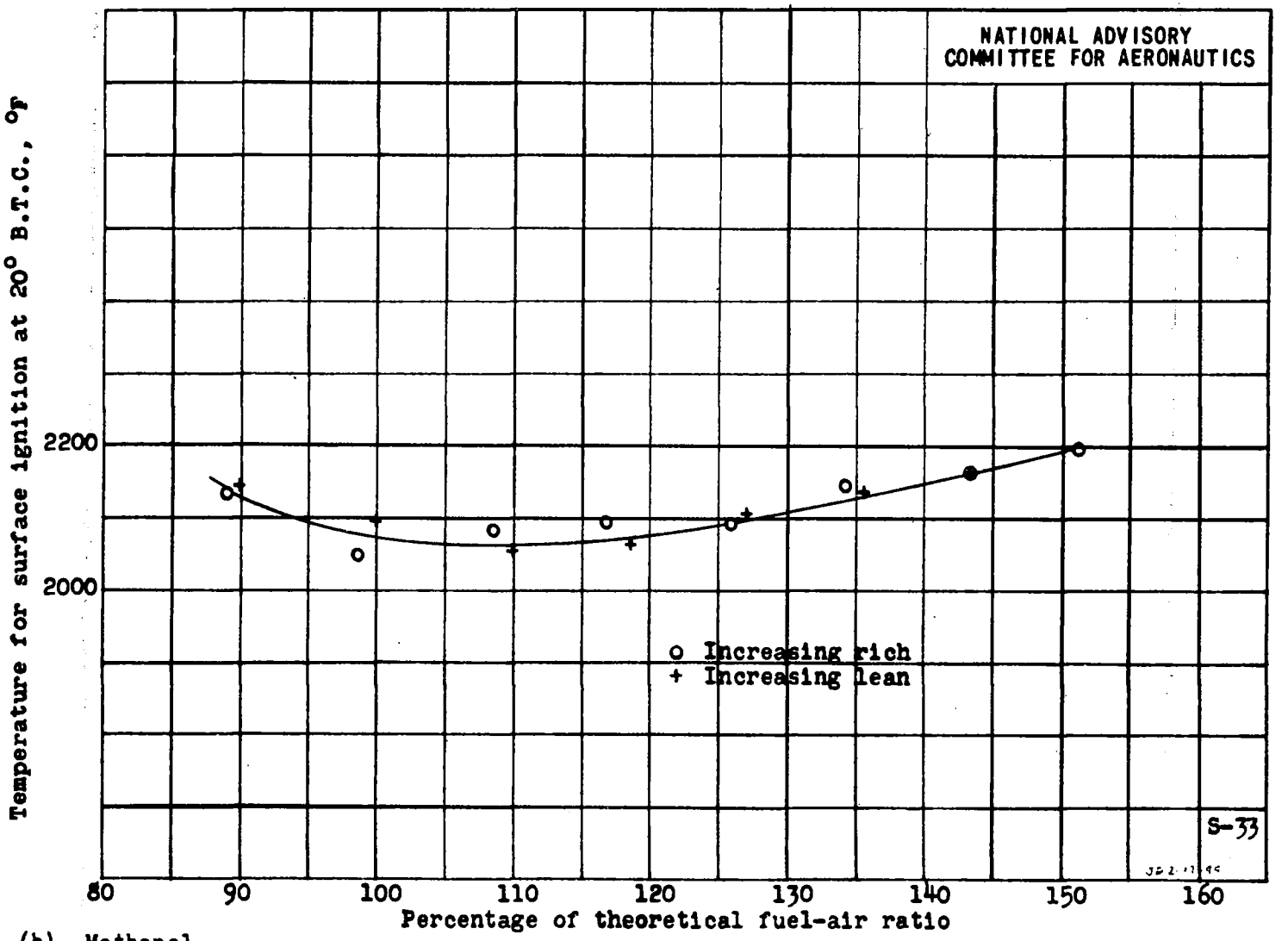
(c) AN-F-28 fuel and S-3 reference fuel.

Figure 5. - Concluded.



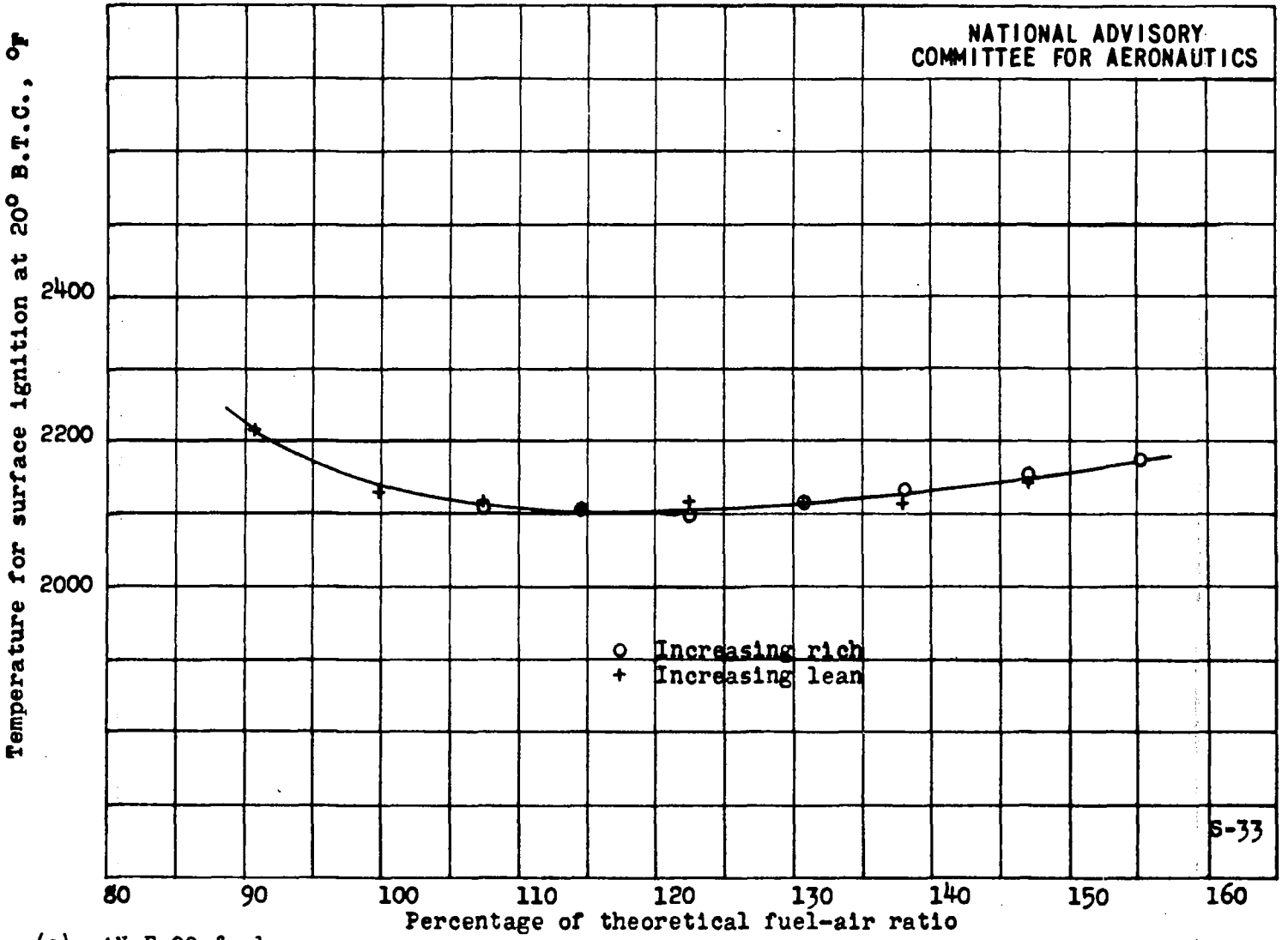
(a) Benzene.

Figure 6. - Hysteresis effect due to fuel-air ratio variation. Intake-manifold pressure, 35 inches of mercury absolute; inlet-air temperature, 100° F; coolant temperature, 250° F; compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 35° B.T.C.; thermocouple, F-3.

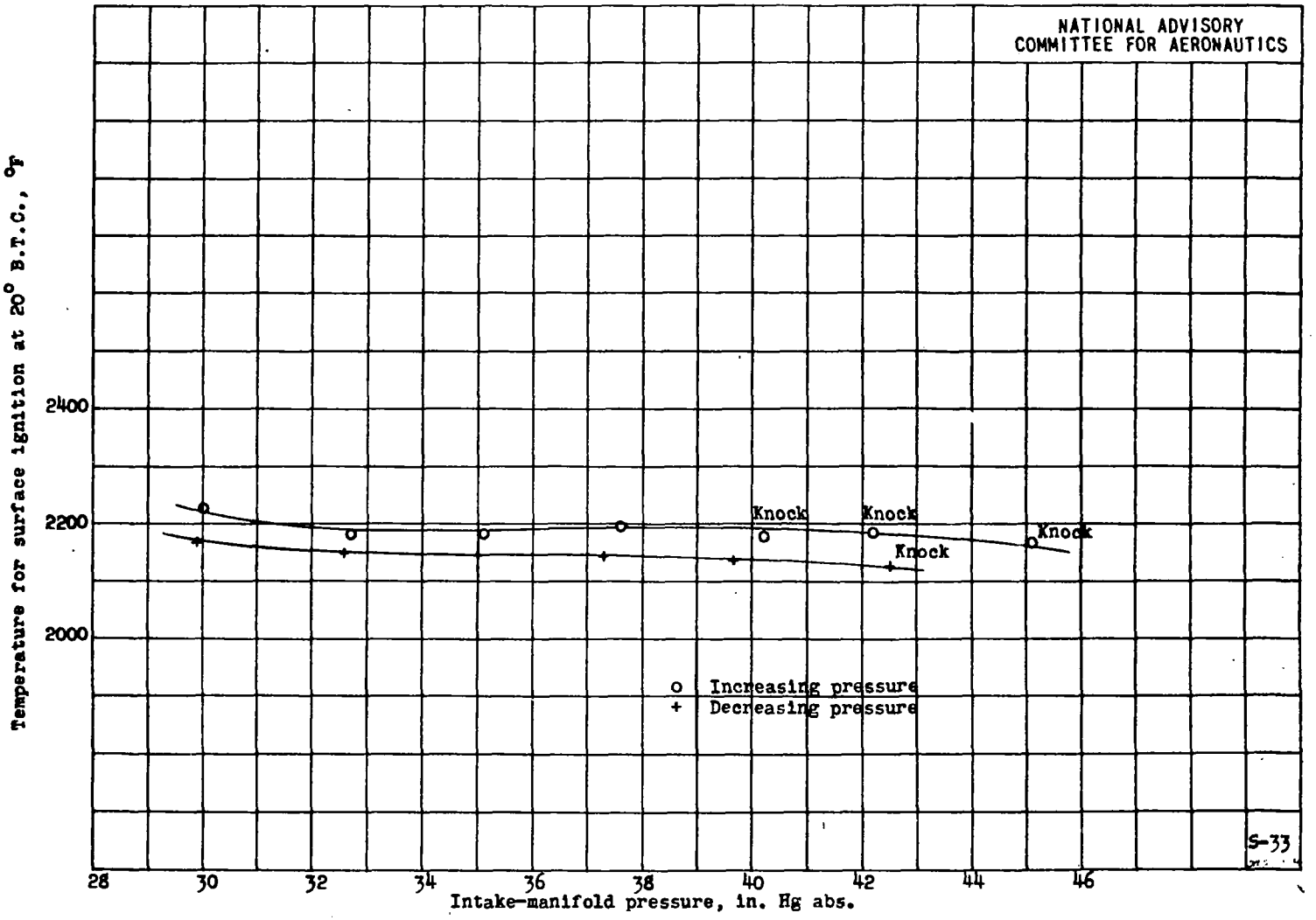


(b) Methanol.

Figure 6. - Continued. Intake-manifold pressure, 32.5 inches of mercury absolute.

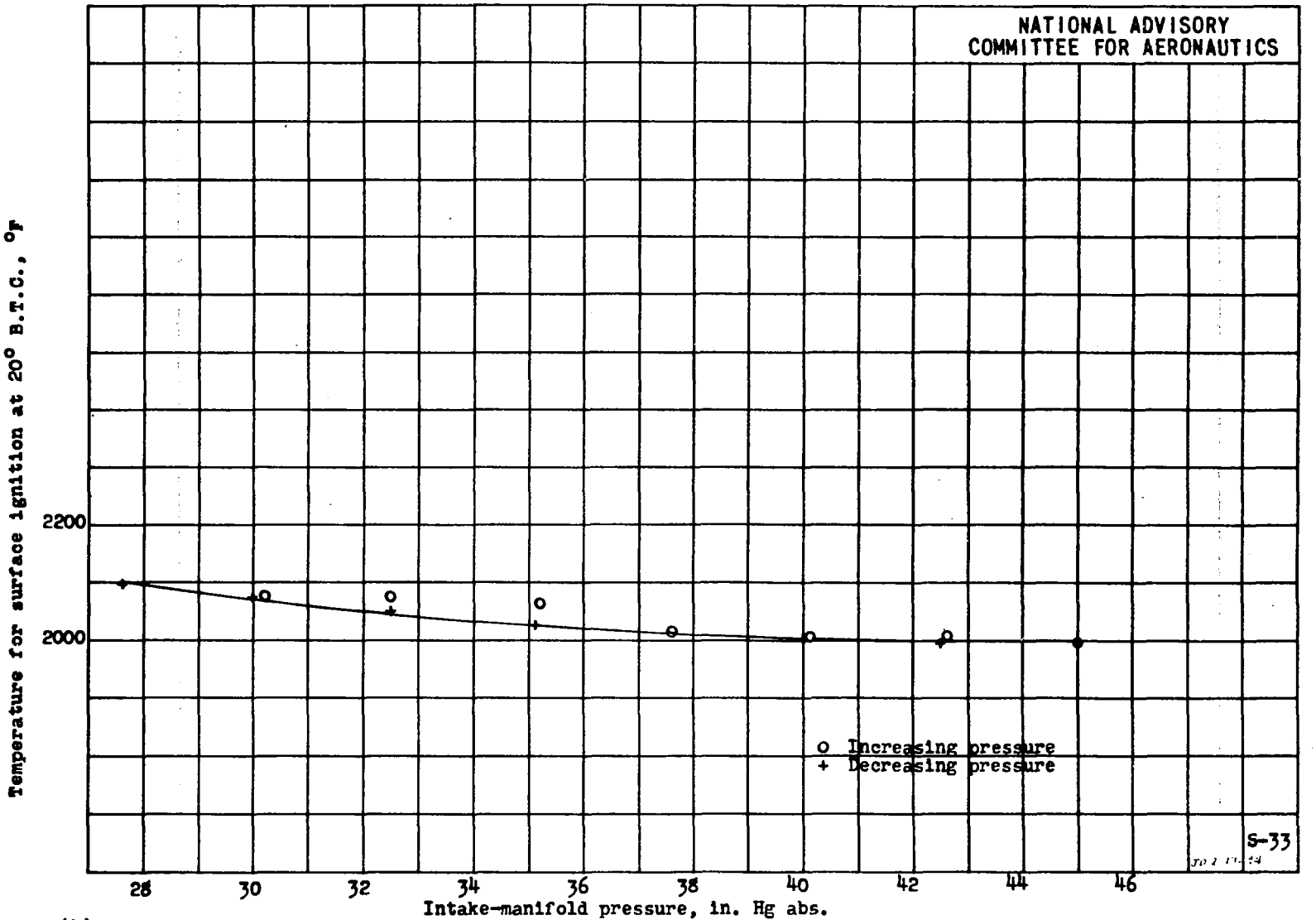


(c) AN-F-28 fuel.
Figure 6. - Concluded.



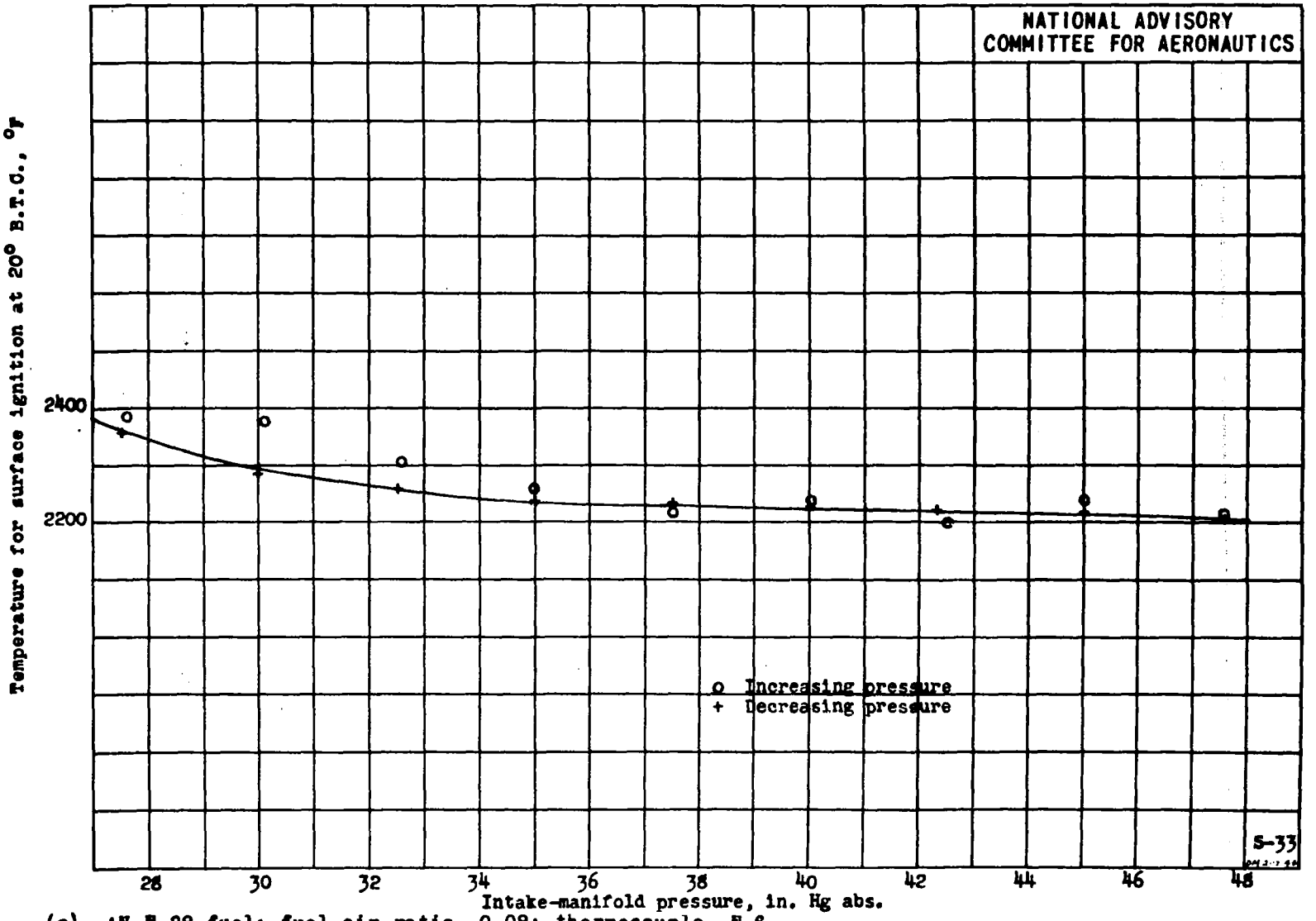
(a) S-3 reference fuel; fuel-air ratio, 0.08; thermocouple, F-3.

Figure 7. - The effect of intake-manifold pressure upon surface-ignition temperature. Inlet-air temperature, 100° F; coolant temperature, 250° F; spark advance, 35° B.T.C.; engine speed, 1800 rpm; compression ratio, 7.0.



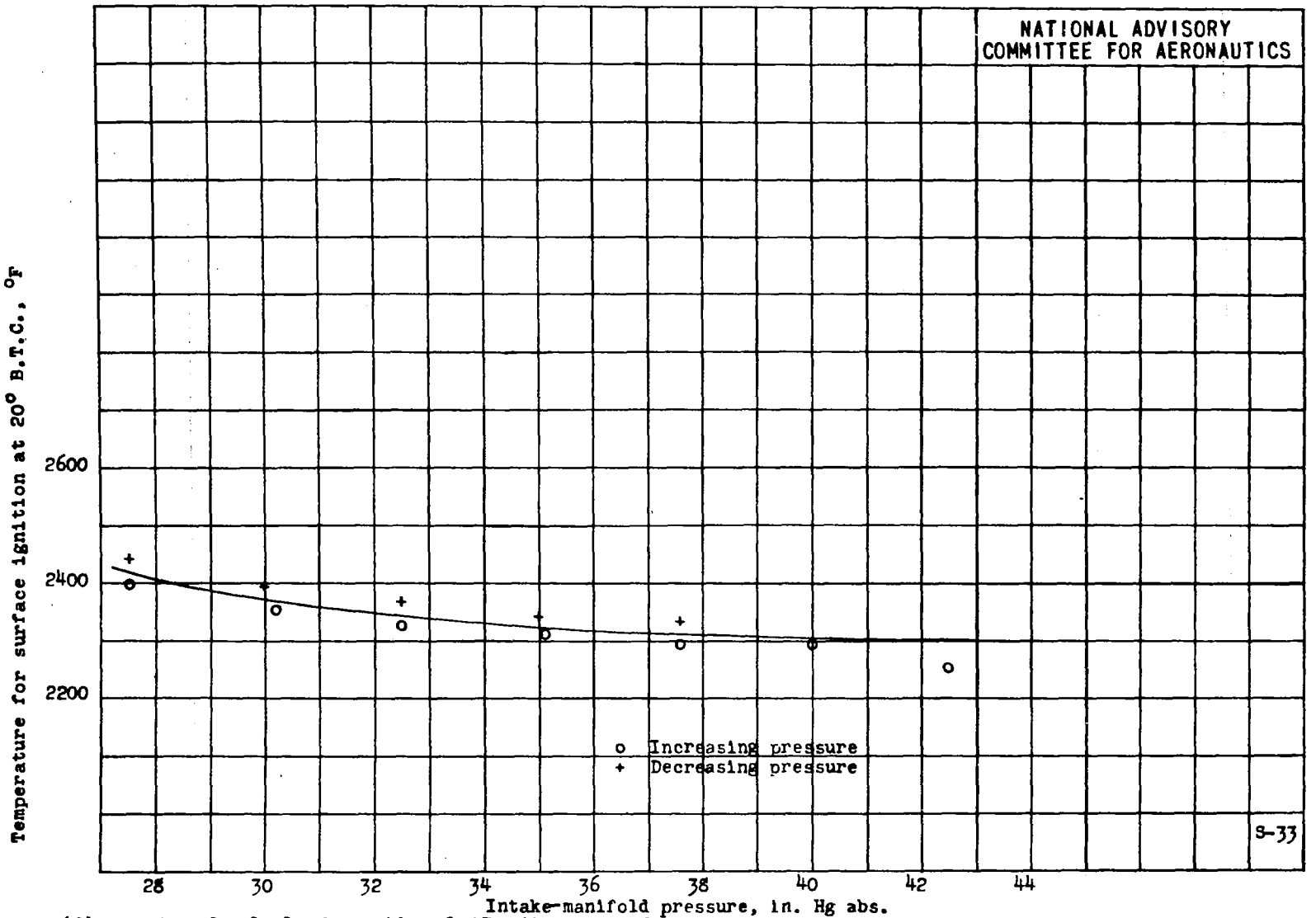
(b) Benzene; fuel-air ratio, 0.08; thermocouple, F-4.

Figure 7. - Continued.



(c) AN-F-28 fuel; fuel-air ratio, 0.08; thermocouple, F-6.

Figure 7. - Continued.



(d) Methanol; fuel-air ratio, 0.17; thermocouple, F-6.

Figure 7. - Concluded.

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ABSTRACT

Tests were made on a supercharged CFR angine to determine surface-ignition temperature as a function of fuel-air ratio, intake-manifold pressure, and surface-ignition advance for four fuels - S-3 reference fuel, benzene, methanol, and AN-F-28, Amendment-2, fuel. Range of surface-ignition temperetures was between 1900° and 2600°F. Because the diffsrence in temperatures wae very small, it wes concluded that surfece-ignition temperature is not a satisfactory criterion for differentiating between preignition characteristics of diffarent fuels in internal-combustion engines.

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