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RELATIVE EFFECTS OF CYLINDER-HEAD AND INLET-MIXTURE TEMPERATURES UPON KNOCK LIMITS OF FUELS

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SUMMARY

Object. - To investigate the relation between the effects of cylinder-head temperature and inlet-mixture temperature upon the knock limits of fuels.

Scope. - Tests were run at a constant fuel-air ratio in which the decrease in cylinder-head temperature required to offset the effect of increasing the inlet-mixture temperature on knock-limited power was determined. The position of the knocking zone in the cylinder was varied by cutting out one or the other of the two spark plugs. All tests were conducted on a Pratt & Whitney R-2800 single cylinder.

Summary of results. - The following results were observed in these tests:

1. The decrease in cylinder-head temperature required to maintain incipient knock at constant power when the inlet-mixture temperature was increased was directly proportional to the increase in inlet-mixture temperature. The data are not sufficient to draw the conclusion that such a linear relation always exists.

2. The temperatures of portions of the inner cylinder wall adjacent to the knocking zone had a predominant effect upon knock.

INTRODUCTION

The relative effects of cylinder-head temperature and inlet-mixture, or charge, temperature on the knock-limited power of a fuel is important from two considerations:

(1) Engine-temperature control required to obtain the same results in knock tests of a series of fuels on the same engine model in different laboratories

(2) The relative value of decreasing the inlet-mixture temperature in relation to decreasing the cylinder temperature as a means of increasing knock-limited power

A complete knowledge of the effect of cylinder-head temperature on knock includes heat transfer during the intake stroke, during the compression stroke, and during the combustion period, as well as localized heat transfer between the knocking zone and the cylinder walls. In addition to cylinder-head temperatures, piston and valve temperatures influence knock. Reference 1 presents data showing the effects of piston temperature on the knock limit of a fuel.

Tests were made of the effect of inlet-mixture temperature and cylinder displacement on the charge temperature at the end of the induction stroke by the NACA and were reported in reference 2. Data on the effects of cylinder temperature on knock-limited power have been recently reported by Pratt & Whitney Aircraft and by the Standard Oil Development Company in reports to the Coordinating Research Council. The relations of cylinder temperatures to various methods of increasing knock-limited power have been investigated at the NACA Cleveland laboratory and the results are presented in reference 3.

The purpose of the investigation reported herein was to determine the relative effects of cylinder-head temperature and inlet-mixture temperature upon knock at constant knock-limited power in an air-cooled cylinder and to obtain data showing the extent to which the distribution of cylinder-head temperatures controls knock. No effort has been made toward evaluating heat transfer, but a direct comparison of the effects of cylinder-head and inlet-mixture temperatures upon knock has been made and the results are compared with the results presented in reference 2. The data were obtained at the Aircraft Engine Research Laboratory of the NACA, Cleveland, Ohio, during February 1944.

APPARATUS

Tests were conducted on a Pratt & Whitney R-2800 cylinder. In an effort to simulate the cylinder temperature distribution expected in flight, the cylinder was mounted with its standard baffles on a CUE crankcase and with cooling-air directing vanes in front of the cowling.

Combustion-air flow to the engine was measured by a thin-plate orifice. The air passed through a vaporization tank where fuel and air were mixed and vaporized. The vaporization tank has a volume of approximately 30 times the cylinder displacement (155.6 cu in.) and was connected to the cylinder by an intake pipe, the inside diameter of which was $2\frac{5}{16}$ inches and the length 24 inches. The inlet-mixture temperature was measured by a thermocouple located in the intake pipe at a point 15 inches from the intake port of the cylinder. Fuel was delivered from a Bosch injection pump to a fuel-spray nozzle located at the upstream end of the vaporization tank. Fuel flow was measured by a calibrated rotameter.

The fuel used in the tests was a blend consisting of 52 percent of AN-F-28, Amendment-2, fuel (130 grade) and 48 percent of AN-F-22 fuel (62-octane grade). It was impossible to use AN-F-28, Amendment-2, fuel alone because the available cooling-air pressure drop was insufficient to lower the cylinder-head temperatures to the desired values during operation at the high power levels permitted by AN-F-28, Amendment-2, fuel. The method of tests used in this investigation, however, gives results that are independent of the fuel inasmuch as the inlet-mixture density and the fuel-air ratio were maintained constant.

Knock was detected with a magnetostriction pickup unit and a cathode-ray oscilloscope.

TEST PROCEDURE

A first series of tests was run to determine the relative effects of variations of inlet-mixture and rear spark-plug-bushing temperatures upon knock for normal operating conditions. In order to find the decrease in cylinder-head temperature required to offset the effect of increasing the inlet-mixture temperature on knock intensity, the tests were run at constant fuel-air ratio and constant weight of air inducted.

The following conditions were fixed for all tests:

Compression ratio	6.7
Spark advance (both plugs), degrees B.T.C.	20
Engine speed, rpm	2000
Fuel-air ratio	0.075

The initial conditions of the primary variables were as follows:

Inlet-mixture temperature, °F	125
Rear spark-plug-bushing temperature, °F	450

At the initial conditions, the engine was adjusted to give incipient knock and the rate of air consumption of the engine was observed. The inlet-mixture temperature was then increased in successive increments of about 20° F over a range from 125° F to 190° F and the head temperature was reduced to the point of incipient knock at each increment by increasing the cooling-air flow. The inlet-air pressure was adjusted to give the same rate of air consumption as was observed at the initial condition.

A second series of tests was run to find the effect of the distribution of cylinder temperatures on knock. Tests similar to the ones just described were run with only the front or the rear spark plugs firing. This procedure shifted the location of the knocking zone and permitted comparison of results obtained when the knocking zone was near the hot portions of the cylinder with results obtained when the knocking zone was near the cool portions of the cylinder.

RESULTS

Figure 1 shows the required rear spark-plug-bushing temperature at different inlet-mixture temperatures for constant knock-limited cylinder-charge density or approximately constant indicated mean effective pressure. The relation under the given conditions is linear.

Figure 2, as well as showing the data presented in figure 1, shows similar results for the front and the rear spark-plug bushing with only the front or the rear spark plug firing. Again, straight lines represent the data reasonably well. The corresponding cooling-air pressure drops across the cowling are presented in figure 3. The indicated horsepower was 71 ±3 for all tests.

ANALYSIS

In the analysis of the results it is assumed that, if the knock-limited charge density were held constant, an increase in the inlet-air temperature would raise the temperature of the gases in the knocking zone but the decrease in cylinder-head temperature would lower the temperature of the gases in the knocking zone to its initial value. No net change in the temperature of the knocking zone would therefore result.

Reference 4 gives a simple equation relating inlet-mixture temperature and cylinder-charge temperature at the instant of inlet-valve closure. This equation can be put into the form

$$T_c = T_a B + \bar{T}_w (1 - B) \qquad (1)$$

where

T_c temperature of cylinder charge at instant of inlet-valve closure

T_a temperature of inlet mixture

$\bar{T}_w$ mean temperature of cylinder walls

B constant, involving heat transfer, which is related to cylinder displacement

Equation (1) will be applied to temperatures of the knocking zone instead of to temperatures of the charge at the instant of inlet-valve closure.

If the knocking-zone temperature T_c is assumed to be constant, then

$$\frac{\Delta T_a}{\Delta \bar{T}_w} = \frac{1 - B}{B} \qquad (2)$$

Equation (2) gives a linear relation between cylinder-wall temperature and inlet-mixture temperature that agrees well with the data in figures 1 and 2. In figure 1, a change in temperature of the rear spark-plug bushing of 100° F is equivalent to a change in inlet-mixture temperature of 42° F and the value of B is therefore 0.70. This value is somewhat higher than the value of 0.65 predicted in reference 2 for cylinders of 155-cubic-inch displacement. The disagreement is probably caused in part by the fact that the temperature of the rear spark-plug bushing is not a representative temperature of the inner cylinder wall.

The variation in the inlet-air pressure required to maintain a constant rate of air consumption by the engine is an indication of the degree to which the charge temperature was maintained constant at the instant of inlet-valve closure. The inlet-air pressure rose about 3 percent over the range of inlet-mixture temperatures tested, which indicated that the cylinder head cooled the gases in the knocking zone more effectively than it cooled the entire charge. This result is to be expected because the end zone was in contact with the cylinder walls in all cases.

The variation in knock-limited inlet-mixture temperature at a given cylinder-head temperature was less when the point of measurement of the cylinder-head control temperature was located near the knocking zone (curves A and B, fig. 2) than when the point of measurement of the cylinder-head control temperature was located away from the knocking zone (curves C and D, fig. 2). It is concluded that the reproducibility of the knock-test data between different setups for the same cylinder will be less affected by differences in external cooling of the cylinder if the control point of the cylinder-head temperature is located at or near the knocking zone.

DISCUSSION OF RESULTS

The effect of changes in cylinder-head temperature upon the knock limit of any fuel can be found with the aid of a curve of the type shown in figure 1 if the variation of the knock limit with inlet-air or inlet-mixture temperature is known. The variation of cylinder-head temperature can be converted to an equivalent variation of inlet-air temperature and the variation of the knock limit can be read from the curves showing the effect of inlet-air temperature on knock limit. The relation shown in figure 1 applies, of course, only to tests with the engine and under the conditions that were used in getting the data for this figure.

From the tests run at a constant fuel-air ratio to determine the relative effects of cylinder-head temperature and inlet-mixture temperature upon the knock limits of fuels, the following results were obtained:

1. The decrease in cylinder-head temperature required to maintain incipient knock at constant power when the inlet-mixture temperature was increased was directly proportional to the increase in inlet-mixture temperature. The data are not sufficient to draw the conclusion that such a linear relation always exists.

2. The temperatures of portions of the inner cylinder wall adjacent to the knocking zone had a predominant effect upon knock.

If it is desired to compare knock-test data from two engine cylinders of the same model, the data will not be directly comparable unless:

(a) Rear spark-plug-bushing temperatures are the same and both cylinders have cooling-air supply systems and cylinder baffles to give the same temperature distributions over the cylinder heads; or

(b) The temperatures of the inner cylinder-head walls near the knocking zone are the same for both cylinders and the mean value of all cylinder temperatures for both cylinders is equal.

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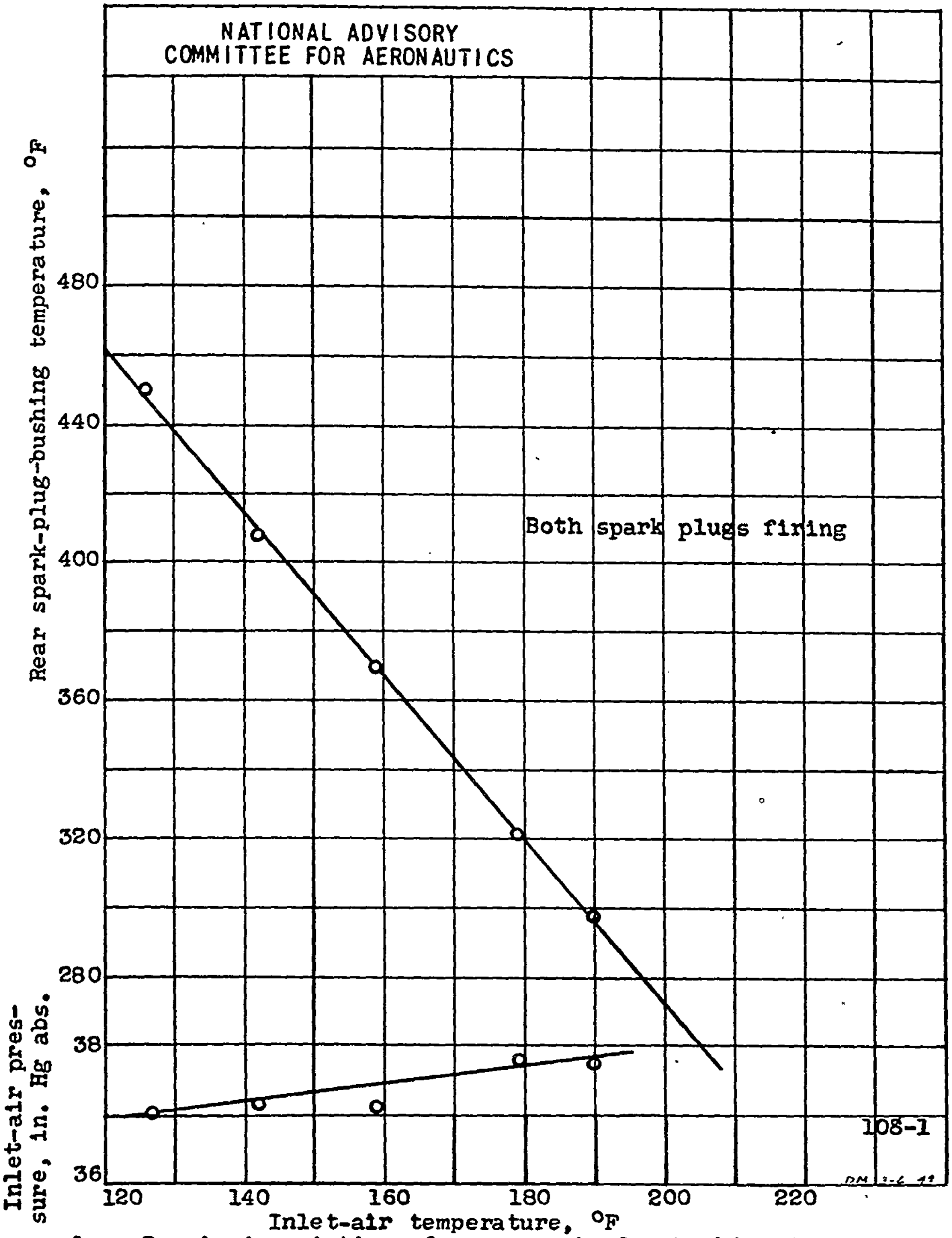

Figure 1. - Required variation of rear spark-plug-bushing temperature with inlet-air temperature to maintain incipient knock when the cylinder-charge density and fuel-air ratio are held constant. Pratt & Whitney R-2800 cylinder; compression ratio, 6.7; spark advance, 20° B.T.C.; engine speed, 2000 rpm; fuel-air ratio, 0.075.

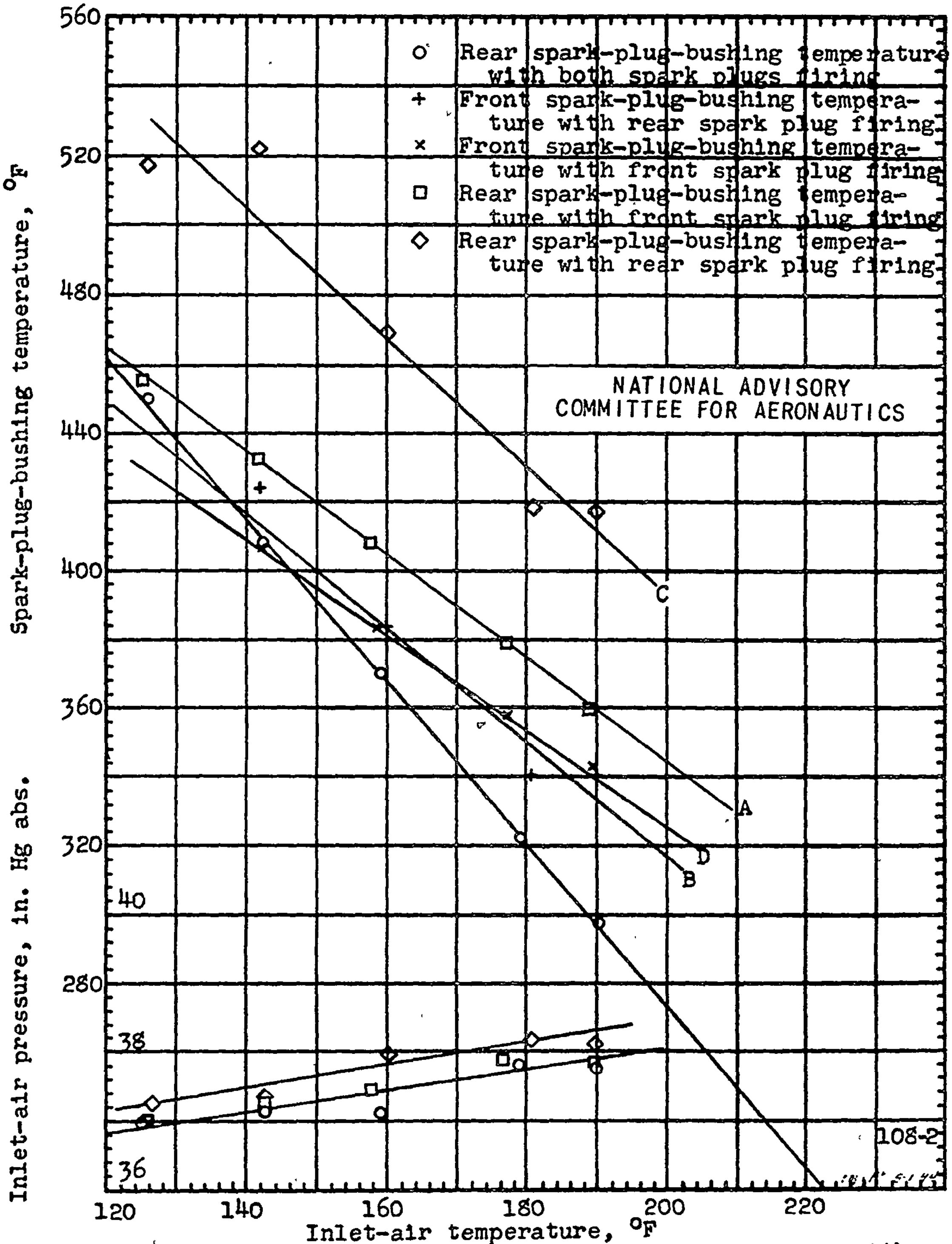

Figure 2. - Required variation of cylinder-head temperatures with inlet-air temperature to maintain incipient knock when the cylinder-charge density and fuel-air ratio are held constant. Pratt & Whitney R-2800 cylinder; compression ratio, 6.7; spark advance, 20° B.T.C.; engine speed, 2000 rpm; fuel-air ratio, 0.075.

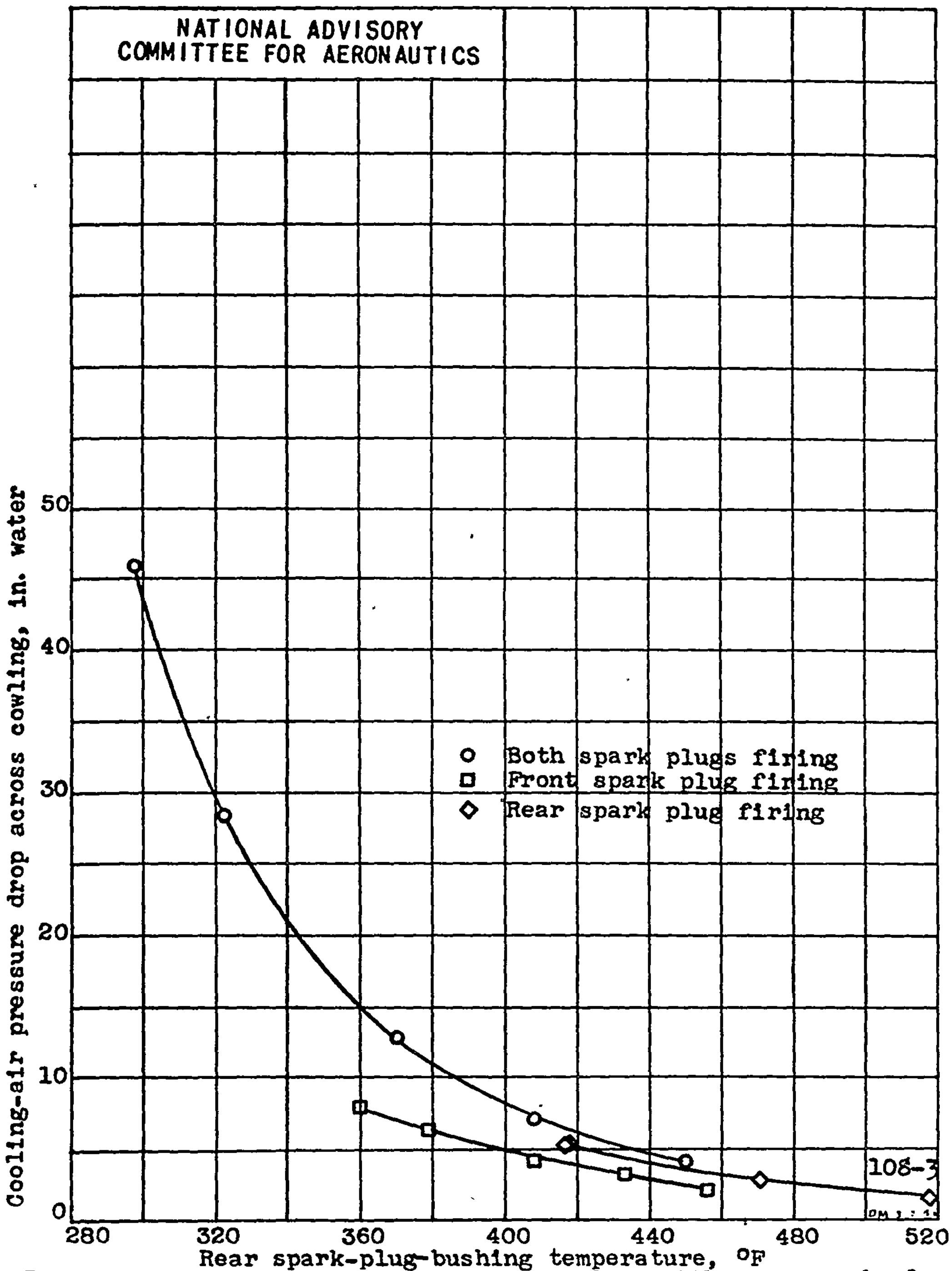

Figure 3. - Variation of cooling-air pressure drop with rear spark-plug-bushing temperature at constant knock-limited charge density when inlet-air temperature is changed. Pratt & Whitney R-2800 cylinder; compression ratio, 6.7; spark advance, 20° B.T.C.; engine speed, 2000 rpm; fuel-air ratio, 0.075.