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NACA LANGLEY MEMORIAL AERONAUTICAL LABORATORY

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

RESTRICTED MR No. L5L18

GROUND-STAND COOLING INVESTIGATION OF AN R-2600-22 ENGINE IN A PBM-3D NACELLE

By Robert C. Spencer, F. William Petring, and William R. Prince

SUMMARY

This report presents the results of an investigation of the cooling characteristics of an R-2600-22 engine installed in a PBM-3D nacelle. The investigation was divided into two parts; an investigation of the general cooling characteristics of the engine by the NACA cooling-correlation method, and an investigation of the cooling of specific points on the engine cylinder where cooling was critical. Particular effort was directed toward measurements of exhaust-valve-crown temperatures and the investigation of methods of cooling the exhaust-valve crown. Fairly extensive tests were also made in an effort to improve the cooling of the number 8 cylinder.

A comparison with a torque-stand correlation obtained with an engine having a similar cylinder head but different barrel fins indicated very good agreement. A comparison of the cooling-correlation equation determined during these tests with a correlation obtained on an R-2600-22 engine in flight indicated fair agreement between the two.

The data from the exhaust-valve tests show that control of the fuel-air ratio is the most important factor influencing the exhaust-valve-crown temperature. Aside from redesign of the valve and cylinder, it does not appear possible to attain cooling by external means comparable to that attainable by controlling the fuel-air ratio. The ground tests indicate that it is

feasible to operate the engine in flight at 975 horsepower at fuel-air ratios as lean as 0.056.

General engine performance, including brake specific fuel consumption is not adversely affected by very lean mixture operation, although the manifold pressure must be increased by about 10 percent to maintain cruising power.

It is recommended that endurance testing be conducted to determine the effects on the engine of operation at mixture ratios in the neighborhood of 0.056 to 0.058. The service life of the engine might be extended, provided this lean mixture operation does not cause unforeseen deleterious effects.

For this engine installation, removal of the baffles from the number 8 cylinder reduced the temperatures at the rear spark-plug gasket, rear midbarrel, and base of the cylinder, without producing measurable reductions in the temperature of the exhaust valve. It is stressed that, although removal of the baffles from one hard-to-cool cylinder may often prove to be a quick fix, removal of the baffles from all cylinders will be definitely detrimental.

INTRODUCTION

At the request of the Bureau of Aeronautics, Navy Department, the NACA has conducted a cooling investigation of the R-2600-22 engine installation of the PBM-3D airplane, both on a ground-test stand at the Langley full-scale tunnel and in flight. The investigation was requested because the engine cooling of the PBM-3 and PBM-3C airplanes was inadequate at high gross weights. In cruising flight the cylinder-head temperature limit was exceeded, and exhaust valve burning and failures were frequent. When production of the PBM-3D was started, the proto-type airplane and an engine quick-change unit were made available to the NACA for flight and ground-cooling tests, since it was believed that many of the difficulties encountered with the PBM-3 and PBM-3C would also be experienced with the PBM-3D.

The original test programs called for a determination, both in flight and on the ground-stand, of the improvement in cooling possible with redesigned cylinder baffles and with propeller-speed cooling fans. In addition, the ground-test program included some specialized tests, such as measurement of the exhaust-valve-crown temperatures, which required more extensive instrumentation and were difficult to carry out in flight. Because of the results of the baffle revisions and fan installation during the flight tests, some modifications were made in the program for the ground tests. The schedule of baffle tests was greatly rduced, testing of the fan as such was eliminated, greater effort was directed toward an investigation of exhaust-valve cooling, and specific tests were conducted for improving the cooling of number 8 cylinder.

This report presents the general cooling characteristics of the engine by the NACA cooling-correlation method, and the results of the investigation of the effects on the exhaust-valve-crown temperature of several methods of cooling. A brief description of the series of tests for improving the cooling of the number 8 cylinder is also included.

APPARATUS AND INSTRUMENTATION

Engine installation.- The R-2600-22 engine is a 14-cylinder two-row radial air-cooled engine, rated at 1900 horsepower at 2800 rpm for take-off and 1600 horsepower at 2400 rpm for maximum continuous power from sea-level to 5300 feet. The propeller gear ratio is 16:7, the impeller diameter is 11 inches, and the impeller gear ratios are 7.06:1 and 10.06:1. The R-2600-22 engine is of the R-2600 BB series and differs in several respects from the engines of the R-2600 B series used in the PBM-3 and PBM-3C airplanes. Aluminum barrel fins are used instead of steel, nichrome-faced exhaust valves instead of stellite-faced, buttress-threaded exhaust-valve seats instead of seats shrunk into the cylinder head, and two oil sumps instead of one. The aluminum barrel fins are fabricated in the form of 180° arcs which are fastened by rolling them into grooves machined on the cylinder barrels.

The standard PBM-3D quick-change engine unit was installed on an outdoor ground-test setup (fig. 1). This unit, which included those parts of the nacelle ahead of the rear of the engine mount, was supported on a stub wing. Engine controls and instruments were located in a test house about 20 feet from the wing, and engine control was by electric actuators in the wing. Hydraulic pressures and air pressures were read in the control house from direct-actuated instruments.

The engine power was absorbed by a 15-foot 2-inch diameter Curtiss Electric 4-blade propeller. A propeller-speed fan of a Curtiss preliminary design was installed to augment the cooling-air flow.

The engine charge air was measured by a calibrated venturi and was brought to the carburetor through an external duct. The fuel flow was measured by "Stablvis" rotameter, and the engine torque was measured with a standard Wright hydraulic torquemeter supplied with the engine.

The engine was equipped with a Stromberg PR-48A1 carburetor, with Wright Aeronautical Corporation carburetor setting No. 68973N31. The fuel system was modified somewhat to permit greater flexibility in fuel-air ratio control by installing an auxiliary fuel line from the control house to the fuel transfer pipe of the carburetor and by installing special mixture-control plates in the carburetor. The auxiliary fuel line was connected downstream from the rotameter so that the additional fuel flow was read on the rotameter. Control of the auxiliary flow was by a hand needle valve. The special mixture-control plates permitted fine adjustment of the manual mixture control at stations between "automatic rich" and "automatic lean," and between "automatic lean" and "idle cut-off."

The fuel used throughout the tests was specification AN-F-28, grade 100/130.

Instrumentation.- Total-pressure tubes were installed on all front-row (even numbered) cylinder heads and on the number 1 cylinder head. Static-pressure tubes were installed on all rear-row (odd numbered) cylinders. The locations of the total-pressure and the static-pressure tubes are shown in figure 2.

Prior to installation of pressure tubes over the entire engine, a brief investigation was conducted to determine the fore-and-aft location most suitable for these tests. It was found that the smoothest and most reproducible readings were obtained by locating the tube ends 3/16 inch aft of the baffle curl. That location was chosen for these tests.

Embedded iron-constantan thermocouples were installed in the rear-spark-plug boss of each cylinder. The embedded thermocouple consisted of one iron and one constantan number 28 glass-covered wire silver soldered into a 0.018-inch diameter soft brass pellet, which was driven into a hole drilled into the spark-plug boss (fig. 3). The number 28 wires were silver soldered to heavier leads which were held rigidly to the cylinder by a small brass clip.

A few preliminary tests were made to compare the temperature measured by the embedded thermocouple with that measured by two spark-plug gasket-type thermocouples. Both of the gasket-type thermocouples were attached to the same gasket, one pair of leads being embedded in the body and the other pair in the tab projecting from the gasket. The three test thermocouples were installed on the number 3 cylinder of the engine. Army-Navy standard gasket-type thermocouples were installed at the rear spark plugs of cylinders 2 and 4 to obtain reference temperatures.

Three series of thermocouple tests were run. The first series was run with the normal flow of air over the engine, and the second and third series with 167- and 139-mile-per-hour blasts of air from a 3/4-inch tube directed on the thermocouples. Each series of tests was run at several different power conditions selected to give a range of cylinder-head temperatures. The test results (fig. 4) show that the thermocouple embedded in the spark-plug boss was affected least by stray blasts of air, while the thermocouple in the tab projecting from the gasket was affected most. In view of this fact, the embedded type was chosen for the correlation work.

Each cylinder was also equipped with a conventional gasket-type thermocouple at the rear spark plug and thermocouples were installed at the cylinder flanges. During the exhaust-valve work, thermocouples were installed in the exhaust-valve crown of the number 2 cylinder, in the exhaust-valve guide, and in the metal immediately adjacent to the exhaust-valve seat.

The exhaust-valve thermocouple installation is similar to that described by Sanders and others in reference 1, with the exception that provision was made for installing all contacts underneath the rocker-box cover. The general arrangement of the installation is shown schematically in figures 5 and 6. The thermocouple is formed by the junction of the single constantan wire and the stainless steel tube shown in figure 5. The single-wire thermocouple permits a more rugged construction than does the two-wire thermocouple; however, due to the fact that the temperatures encountered are near the upper limit for an iron-constantan thermocouple, the calibration is somewhat uncertain and apparently changes slightly with use. The thermocouple is considered satisfactory for comparative tests, although the absolute values may be in error by as much as 50° or 60° F. The thermocouple emf is transferred to the external leads through the contacts on the long steel springs (fig. 6). These contacts are arranged to touch the contacts on the valve during only about 1/32 inch of valve travel. Movement of the springs is thereby held to a minimum. Inasmuch as the valve remains closed approximately three-fourths of the time, no difficulty has been experienced in obtaining good null balance readings on a potentiometer with a reasonably sensitive galvanometer.

This thermocouple is characterized by both compactness and ruggedness. The complete installation can be made beneath the rocker-box cover, and the present installation has been operated a total of more than 65 hours. The only maintenance required has been replacement of the contacts on one occasion, and minor adjustments of the tension of the contact springs.

NOTATION

rpm	engine crankshaft speed, revolutions per minute
ihp	indicated horsepower
bhp	brake horsepower
P_m	engine manifold pressure measured at the blower rim, inches of mercury absolute

p_a	outside air pressure, inches of mercury absolute
ρ	mass density of cooling air, slugs per cubic foot
σ	relative density of cooling air (ρ/0.002378)
Δp	cooling-air pressure drop across engine, inches of water
W_a	engine cooling air, pounds per hour
W_e	engine charge air, pounds per hour
x,y,z,	exponents applying to W_a, W_e, and $\sigma\Delta p$, respectively
C_1 and C_2	constants
t_h	average temperature of all cylinders, measured by thermocouples embedded in the spark-plug boss, $^{\circ}F$
t_a	cooling-air temperature, $^{\circ}F$
t_c	carburetor-air temperature, $^{\circ}F$
t_g	mean effective gas temperature, $^{\circ}F$
t_{g_o}	reference mean effective gas temperature at carburetor-air temperature of 0° F, $^{\circ}F$
Δt_g	increment of effective gas temperature
g	acceleration of gravity, feet per second^2
c_p	specific heat of air at constant pressure, Btu per pound $^{\circ}F$

COOLING CORRELATION

Establishment of the Cooling Correlation

The fundamental principles of the NACA engine-cooling correlation method have been expressed in references 2, 3, and 4, and detailed descriptions of the application of the method are given in reference 5. The fundamental equation for the cooling of an air-cooled engine is expressed as follows:

$$\frac{t_h - t_a}{t_g - t_h} = C_1 \frac{W_e^{\,y}}{W_a^{\,x}} \qquad (1)$$

or

$$\frac{t_h - t_a}{t_g - t_h} = C_2 \frac{W_e^{\,y}}{(\sigma \Delta p)^z} \qquad (2)$$

Equation (2) is approximate, and is generally used in applying the correlation method at low and medium altitudes. At high altitude the more exact equation (1) is used.

Throughout this report the reference mean effective gas temperature t_{g_o} is used instead of $t_{g_{80}}$, in conformance with current practice. The mean effective gas temperature t_g is determined from the equation:

$$t_g = t_{g_o} + 0.8\ (t_c + \Delta t),$$

where the blower rise Δt is determined from the equation:

$$\Delta t = \frac{(\text{Impeller tip speed})^2}{778\ g\ C_p} \qquad \text{(reference 5)}$$

For this engine, the equation reduces to:

$$\Delta t = 19.1 \left(\frac{\text{rpm}}{1000}\right)^2 \qquad \text{(low blower)},$$

and:

$$\Delta t = 38.8\left(\frac{rpm}{1000}\right)^2 \qquad \text{(high blower)}$$

For low blower, then, the correction Δt_{ε} is determined from the expression

$$\Delta t_{\varepsilon} = 0.8\left[t_c + 19.1\left(\frac{rpm}{1000}\right)^2\right] \tag{3}$$

$$t_{\varepsilon} = t_{\varepsilon_o} + 0.8\left[t_c + 19.1\left(\frac{rpm}{1000}\right)^2\right] \tag{4}$$

The correlation was run in accordance with standard practice, then random points were taken to verify the correlation. All runs were made with the engine in low blower.

Power-Charge-Air Correlation

Generally, the solution of the cooling problems requires a knowledge of the charge-air flow, W_e. The following method of estimating the charge-air flow (see reference 5) is based upon the assumption that the indicated specific air consumption $\left(\frac{W_e}{ihp}\right.$, pounds of air per indicated horsepower hour) is fixed at any one fuel-air ratio. A curve of specific air consumption against fuel-air ratio is plotted from the data taken during the correlation runs, and the charge-air flow is estimated by use of the following equation:

$$ihp = bhp + \left[21.8 + 2.13\left(\frac{W_e}{1000}\right)\right]\left(\frac{rpm}{1000}\right)^2 - 1.61\left(P_m - P_a\right)\frac{rpm}{1000} \tag{5}$$

which may be put into the following form:

$$W_e = \frac{bhp + 21.8\left(\frac{rpm}{1000}\right)^2 - 1.61\left(P_m - P_a\right)\frac{rpm}{1000}}{\frac{1}{W_e/ihp} - 0.00213\left(\frac{rpm}{1000}\right)^2} \tag{6}$$

where W_e/ihp is determined from the plot of specific air consumption against fuel-air ratio.

The equation with the above constants applies only to the R-2600 engine with 11-inch diameter impeller, and with an impeller gear ratio of 7.06:1 (low blower). The corresponding equation for high blower operation is

$$W_e = \frac{\text{bhp} + 21.8 \left(\frac{\text{rpm}}{1000}\right)^2 - 1.61 (P_m - P_a) \frac{\text{rpm}}{1000}}{\frac{1}{W_e/\text{ihp}} - 0.00431 \left(\frac{\text{rpm}}{1000}\right)^2} \qquad (7)$$

Relation of Engine Temperature Limits to t_h

The value of t_h is determined from the engine-temperature limits as set by the manufacturer, given in terms of hottest rear-spark-plug-gasket temperature. The correlation presented in this report is based upon the average temperature of all cylinders (as indicated by thermocouples embedded in the spark-plug bosses), therefore the relationship between hottest rear-spark-plug-gasket temperature and average embedded temperature of all cylinders is needed. This relationship is determined from a plot of hottest rear-spark-plug-gasket temperature against average embedded-thermocouple temperature, from data obtained during the correlation runs.

Cooling-Correlation Results

A general summary of the correlation data is given in table I, and the individual cylinder temperatures are listed in table II.

The variation of t_{g_o} with fuel-air ratio is shown in figure 7. It is seen that the points all fall fairly near the curve, regardless of whether the engine was operated at constant charge-air flow, constant power, or constant manifold pressure.

The value of the exponent z (equation (2)), as determined by the construction curve, is 0.36. The exponent y is 0.59, and C_2 is 0.00420. The complete cooling-correlation equation for this engine is then

$$\frac{t_h - t_a}{t_g - t_h} = 0.00420 \frac{{W_e}^{0.59}}{(\sigma \Delta p)^{0.36}} \qquad (8)$$

The cooling correlation for the engine, with

$$\frac{t_h - t_a}{t_g - t_h} \frac{1}{W_e^{0.59}}$$

plotted against $\sigma\Delta p$, is given in figure 8.

Application

An example of the use of the correlation curves follows. The conditions are assumed for a standard cruise setting.

Conditions:

Navy summer atmosphere

Pressure altitude, feet	5000
Atmospheric pressure, inches of mercury	24.9
Atmospheric temperature °F	71
σ	0.8120
Engine speed, rpm	1975
Engine manifold pressure, inches of mercury	31.5
Brake horsepower	975
Fuel-air ratio	0.065
Assume carburetor air temperature, °F	75

The normal cruising speed of the PBM airplane is somewhere in the neighborhood of 140 miles per hour at the power condition assumed. Corrections for compressibility effects have been applied and the following corrected values are used:

t_a, °F	75
σ	0.82

First, W_e, t_g, and t_h must be determined. From figure 9, $\frac{W_e}{ihp}$ at 0.065 fuel-air ratio is 5.95 pounds of air per indicated horsepower-hour, and from equation 6, W_e = 6500 pounds per hour.

From figure 7, t_{g_o} at 0.065 fuel-air ratio is 1170° F. Then (equation (4))

$$t_g = t_{g_o} + 0.8\left[75 + 19.1\ (1.975)^2\right] = 1170 + 120 = 1290^\circ\ F$$

The manufacturer lists 401° F as the temperature limit for the hottest head (rear-spark-plug-gasket thermocouple) for continuous operation, and figure 10 shows that t_h (embedded thermocouple) at a hottest rear-spark-plug-gasket temperature of 401° F is 410° F.

Then,

$$\frac{t_h - t_a}{t_g - t_h}\ \frac{1}{W_e^{0.59}} = \frac{410 - 75}{1290 - 410}\ \frac{1}{6500^{0.59}} = 0.00214$$

and from figure 8, $\sigma\Delta p$ = 6.9

Supplementary Considerations

The curve of indicated specific fuel consumption (fig. 11) is an index of the general engine performance. The consistency of the fuel and air measurements is illustrated by the fact that the data of both figures 9 and 11 fall reasonably near the curves.

Comparison with Other Correlations

A cooling correlation for the C14B engine is presented by the Wright Aeronautical Corporation in reference 6. The cylinder head of the C14B engine is similar to that of the C14BB (2600-22) engine, and the cooling correlation for the cylinder heads should therefore be similar. A comparison of the two correlations is shown in figure 12. The Wright Aeronautical Corporation data are presented with $\frac{t_h - t_a}{t_g - t_h}$ plotted against $\frac{W_e^{1.66}}{\sigma\Delta p}$, and for comparison the NACA data are plotted on the same basis. The exponent, 1.66, used in the W.A.C. correlation, is obtained by dividing the exponent y by the exponent z, from equation (2). The corresponding exponent from the NACA data is 1.64. The agreement between the two sets of data is very close and indicates the probability of good instrumentation.

The usefulness of any cooling-correlation data is largely dependent upon whether or not the cooling requirements of the engine, as predicted from the curves, agree with actual flight-test data. There have been frequent discrepancies between some wind-tunnel and flight cooling correlations of engines other than the R-2600. For this reason it may be of particular interest to compare the cooling correlation obtained during the flight tests with the cooling-correlation data of this report. The flight tests were carried out at an altitude of 5000 feet, so the question of corrections for high altitude does not enter into the comparison. The flight tests selected for comparison were made with a Curtiss fan installed on the engine.

In figures 13 and 14 are shown comparisons of the cooling-air pressure drops and rear-spark-plug gasket temperatures for somewhat similar conditions, for the flight tests and ground-stand tests.

Figure 15 is a direct comparison of the cooling-correlation curves obtained during the flight tests and during the ground tests. The indicated horsepower is used instead of the charge-air flow because the results of the flight tests were available in that form. The exponent of the indicated horsepower determined during the flight tests was 0.60. In computing the flight-test points for figure 15, however, the same value as determined from the ground tests, 0.59, was used in order that direct comparison of the correlations can be made without resort to computations. Use of the same value of the exponent for indicated horsepower as is used for W_e is legitimate. Both the ground-test and flight-test correlations of figure 15 are based upon the average rear-spark-plug gasket temperatures rather than upon the average of embedded thermocouples. Figure 16, showing hottest rear-spark-plug-gasket temperature plotted against average rear-spark-plug-gasket temperature from the ground-stand test data, is included for convenience in making calculations. A check of similar data from the flight tests shows very good agreement with the ground-test data of figure 16.

It is seen from figure 15 that at the higher values of $\sigma\Delta p$ the difference between the two correlations amounts to about two inches of water pressure drop. At lower values of $\sigma\Delta p$ the difference between the correlations is less, and the two lines would intersect in the neighborhood of 3 inches of water pressure drop.

The comparisons of data in figures 12 and 15 indicate that, although good agreement may be reached between different ground-stand correlations of similar engines, disagreement still exists between ground-test and flight-test data. Although the flight and ground-test pressure drops are of the same order of magnitude, the 20-percent difference is enough to account for failure of ground-stand correlations to predict flight performance. It has been suggested that differences in instrumentation are responsible for the disagreement, since good instrumentation for flight testing is more difficult than for ground testing. It appears more probable, however, that other factors, such as large differences in inflow pattern, may be contributory.

EXHAUST-VALVE COOLING TESTS

Since one of the chief difficulties encountered with this engine installation in service had been failure of the exhaust valves, a rather extensive investigation was made of the cooling of the exhaust-valve crown and the region in the vicinity of the exhaust valve.

Methods

Cylinder number 2 was chosen for the exhaust-valve tests because of its accessibility. Two different general methods of cooling the valve were tried, namely, internal cooling by varying the fuel-air ratio, and external cooling by means of directed air flow. In order to get some idea of how much valve cooling was possible by external cooling, one series of tests was made with a water spray directed over the cylinder. The water spray was considered to be a more drastic method of external cooling than any method which could be used in practice.

Because of the known behavior of the engine temperatures when the fuel-air ratio is varied (shown in fig. 7, and demonstrated in detail in references 7 and 8), it was believed that leaning of the mixture beyond the stoichiometric might afford an easy method of cooling the valve without recourse to redesign of the cylinder or valve. Accordingly, tests were made to determine the valve temperatures throughout a wide range of fuel-air ratios and to see if the engine could be operated satisfactorily at cruise power at the mixtures necessary to cool the valve.

The tests were conducted at a standard cruise power for the engine (1975 rpm, 150 bmep). The torquemeter reading at the normal cruise setting was first established, then the fuel-air ratio was varied from rich to lean. The torque was maintained at the standard cruise value by varying the manifold pressure. A later series of tests was made, using first standard baffles and then a set of ducted baffles on the cylinder with the thermocouple valve installation.

The ducted baffles that were used were similar to the baffles that were adopted during the flight tests with the exception that only the side baffles were used, in conjunction with the standard top baffle.

The water spray nozzle at the front of the cylinder was made of 1/4-inch-diameter copper tubing with fine holes drilled along its length. An effort was made, in the design, to obtain a spray that would direct a larger proportion of the water to the exhaust side.

Exhaust-Valve-Cooling Results

Results of the fuel-air ratio tests with standard baffles, and the results of the water-spray tests, are shown in figures 17 and 18. Figure 17 shows the exhaust-valve crown temperature for cylinder 2, and the engine brake specific fuel consumption and manifold pressure, plotted against engine fuel-air ratio. The temperatures of the exhaust-valve seat, exhaust-valve guide, and rear-spark-plug gasket on cylinder 2 are shown in figure 18. The data for the water-spray tests were obtained by turning on the spray immediately after obtaining the data for the points on the curve at the same fuel-air ratio.

It is seen from inspection of figure 17 that the exhaust-valve temperature was lowered about 85° F when the engine fuel-air ratio was leaned from 0.065 to 0.0575. There were no adverse effects on fuel consumption. The manifold pressure had to be raised from about 32 inches of mercury to about 35 inches, in order to maintain cruising power.

The other measured temperatures, shown in figure 18, were also lowered when the fuel-air ratio was leaned. Comparison of the temperature data of figures 17 and 18 provides a good example of the relative values of internal and external cooling. The exhaust valve is inside the cylinder and is therefore affected greatly by internal cooling (in this case, by change of fuel-air ratio and consequent change of t_g). The rear-spark-plug gasket, the exhaust-valve guide, and even the metal near the exhaust-valve seat, on the other hand, are most easily influenced by external cooling. For example, a fuel-air ratio change from 0.065 to 0.0575 (engine) cooled the number 2 cylinder spark-plug gasket only about 25° F and at the same time cooled the exhaust-valve crown 85° F. The external cooling by the water spray, on the other hand, lowered the temperatures of the rear-spark-plug gasket, exhaust-valve guide, and the metal near the seat, about 140° F and at the same time had about the same effect on the exhaust-valve-crown temperature as the fuel-air ratio change above. The conclusion to be drawn, then, was that (barring design changes in the cylinder head and valve) changing the fuel-air ratio is the most effective practical means for controlling the exhaust-valve temperature.

As might be expected after study of the foregoing results, attempts to cool the valve externally by use of the ducted baffles were not encouraging. Although the directed air flow reduced the temperatures at the rear of the cylinder and in the vicinity of the exhaust valve, no appreciable cooling of the exhaust-valve crown resulted. Consequently, no data from the ducted baffles are presented in this report.

Mixture Distribution

The variation of the individual rear-spark-plug-gasket temperatures with engine fuel-air ratio is shown in figure 19, with the test points omitted for the sake of clarity. If the fuel-air distribution were uniform, all the curves should peak at the same point along the abscissa; the variation in the input fuel-air ratio at which peak temperature occurred is an indication of the fuel-air distribution. The curve of average temperature of all 14 cylinders, drawn as the dashed line in the figure, peaks at about 0.067, and it is probable that the fuel-air ratio of each cylinder was in the neighborhood of 0.067 at the point of maximum temperature for that cylinder. Cylinder 2, with the thermocouple valve installed, showed its temperature peak at an engine fuel-air ratio of about 0.066, indicating that the cylinder was running slightly richer than the average; that is, the actual fuel-air ratio for cylinder 2 was 0.067 at the point of peak temperature, whereas the input fuel-air ratio was 0.066.

Operating Considerations

Engine operation at fuel-air ratios as lean as 0.056 was smooth and steady. The engine has been operated at 975 horsepower at fuel-air ratios as lean as 0.053, although there is some unsteadiness at that mixture strength.

Present service carburetor settings for this engine are arranged so that the carburetor will meter between the limits of 0.065 to 0.068 in automatic lean setting. Evidently then, the engines are being operated in a range of fuel-air ratios where maximum exhaust-valve-crown temperatures occur. Assuming, then, that it is desirable for the sake of exhaust-valve cooling to run the engine leaner than present practice permits, the following discussion has been prepared to suggest some changes in operating technique which, although small, are important.

<u>Mixture setting</u>.- The first point to be emphasized is that setting the fuel-air ratio for best operation is an item requiring considerable precision. The procedure should not be condemned upon the basis of manual leaning tests conducted without adequate instrumentation or experience. It is believed that an automatic setting must be provided in the carburetor, so that the "superlean" setting is reached without requiring delicate manipulation of controls. According to the data presented herein, the optimum fuel-air ratio

is somewhere in the neighborhood of 0.056 to 0.058. This value provides a mixture rich enough for steady engine operation, but lean enough for large cooling effects on the exhaust valve.

Changing power.- As shown in figure 17, the manifold pressure must be increased to obtain rated cruise power at the lean mixture setting. Normal procedure, in order to avoid possible detonation while the mixture ratio is being changed through the region of maximum detonating tendency, should be to reduce manifold pressure and rpm to cruise power, set the carburetor to "superlean," then increase manifold pressure until the power loss, due to leaning the mixture, is recovered. The reverse procedure should be followed when changing to the automatic rich setting; that is, first reduce manifold pressure, then set the carburetor in automatic rich, and finally increase manifold pressure and rpm to the desired power.

NUMBER 8 CYLINDER COOLING TESTS

During the flight tests, the baffle revisions and fan installation reduced the temperatures of most of the hot cylinders of the engine. Because of the position of the number 8 cylinder (normally one of the hot cylinders already), it was not possible to accomplish any appreciable improvement in the cooling of that cylinder. The oil sump directly behind the cylinder restricts the cooling-air exit to a very considerable extent. The position of the sump also prevents use of the ducted baffles that were developed during the flight tests. Another contributing cause for the tendency for number 8 cylinder to run hot during cruise conditions may be poor mixture distribution at cruising fuel-air ratio. Because of the fact that the baffle improvements reduced the temperatures of the other cylinders the number 8 cylinder was the hot cylinder when the special baffles were installed. Therefore, the program for the ground tests included attempts to improve the cooling of the number 8 cylinder.

A number of devices were tried in attempts to improve the cooling, including the following: turbulence-creating baffles, elimination of cooling-air-exit restriction by redesign of the exhaust stack to enlarge the space between the stack and the oil sump, installation of a fairing on the upper part of the oil cooler, and removal of the baffles on the cylinder. Use of special ducted baffles was regarded as impracticable because of the cramped space.

Of all the devices that were tried, only the removal of the baffles gave results that were in any way encouraging.

Because of the possibility that some portions of the cylinder might be affected unfavorably by removal of the baffles, thermocouples were installed at the rear midbarrel, exhaust-valve guide, exhaust-valve seat, and exhaust-valve crown, and a series of tests at different powers and fuel-air ratios was carried out. Figure 20 shows typical temperature data from this series of tests. Because of the fact that the test with baffles removed was carried out during the hottest part of the day, the temperatures of the rest of the engine in general were higher than they were with the number 8 baffles in place. The effect of the baffle removal is, however, quite apparent. A striking feature of the data was the reduction of the rear-midbarrel temperature that was produced by the baffle removal. With the baffles in place, the rear midbarrel was running at 331° F. This temperature, though not critically high, is certainly in a range approaching the critical point. Removal of the baffles caused a reduction of 37° F in the temperature, even without correcting for the effect of the higher cooling-air temperature when the baffles were off.

The other temperatures about the cylinder, such as exhaust-valve crown, exhaust-valve seat, and exhaust-valve guide, showed minor reductions in temperature, but the effects were not considered important. In no case were any of the temperatures increased by removal of the baffles.

It should be pointed out that, although removal of the baffles from the one cylinder proved to be a quick fix, removal of the baffles from all cylinders would be definitely detrimental.

CONCLUSIONS

1. The cooling characteristics of the engine determined during these tests showed very good agreement with the Wright Aeronautical Corporation correlation of an older model R-2600 engine installed in a torque stand. Cooling requirements in the cruise range as predicted from the ground tests were about 20 percent less than that determined from flight tests.

2. At cruising-power conditions, when the fuel-air ratio of the R-2600-22 engine was changed from 0.065 to between 0.056 and 0.058:

a. The temperature of the number 2 exhaust-valve crown was lowered 85° F. All other engine temperatures that were measured were also reduced.

b. The brake specific fuel consumption was unchanged or slightly reduced, and the general engine performance was not affected.

c. The manifold pressure had to be increased by about 10 percent to maintain cruising power.

d. This conclusion should apply equally well in principle to any other engine that is operated at lean mixtures for long-range cruising, provided that the mixture-distribution characteristics of the engine are good enough for satisfactory operation at the lean mixtures recommended.

3. Endurance testing should be carried out to determine the effects on the physical condition of the engine of operating at cruise power using a fuel-air ratio of 0.056 for an extended period of time.

4. In instances where redesign of the cylinder and valve is not practicable, exhaust-valve cooling troubles can be more readily relieved by means of internal cooling than by external cooling.

5. For this installation, the removal of the baffles from the number 8 cylinder reduced the temperatures at the rear-spark-plug gasket, at the rear midbarrel,

and at the base of the cylinder. None of the measured temperatures were adversely affected.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Table I Master Data

Engine make Wright Aero. Corp.
Model R-2600-22
Mfg. No. 426724
Prop. red. ratio 16:7
Comp. ratio 6.9:1

Blower imp. dia. 11 in.
Gear ratio, 7.06:1
10.06:1
Master rod cylinders Nos. 1 and 12
Spark advance 20°

Prop. make Curtiss
Type Electric
No. of blades 4
Cuffs Removed
Fan Curtiss No. 1

Carb. model PR48A1
Make Stromberg
Serial No. 343544

Fuel Spec. No. ANF-28
Grade 130

Oil-Grade 1120

Magneto make American Bosch
Serial Nos. R.H., S-1998
L.H., T-1644
Model SF14LU-10
Plugs LS-87

Sheet 1 of 3

Test of Wright R-2600-22 Cooling Correlation

1	Test Identification	Series number	——	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2		Run number	——	301	302	303	304	305	306	307	308	309	310	311	312	313	314
3		Date	——	6-23-44	6-23-44	6-23-44	6-23-44	6-23-44	6-23-44	6-23-44	6-23-44	6-23-44	6-23-44	6-23-44	6-23-44	6-24-44	6-24-44
4		Time	E.W.T	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	AM	AM
5	Engine Operation	Engine speed	rpm	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2200	2200
6		Torque pressure	lb/in²	270	287	287	287	287	290	283	283	278	270	240	205	310	332
7		Brake power	hp.	664	706	706	706	706	713	696	696	684	664	590	504	838	896
8		Friction power	hp.	141	140	139	139	138	139	139	138	138	138	138	138	174	174
9		Indicated power	hp	805	846	845	845	844	852	835	834	822	802	728	642	1012	1070
10		Blower position	——	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW
11		Mixture control	——	FR+	FR+	FR	FR-	FR-	AR-	AR-	AR-	AR-	AL+	AL-	AL-	FR+	FR+
12		Cowling flap position	——	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
13		Blower rim pressure	in. hg.-abs.	27.1	27.2	27.0	27.0	27.1	27.1	26.9	27.0	27.0	27.0	27.0	27.0	30.0	30.0
14	Engine Charge	Comp. metering suction	in. H_2O	7.4	7.2	6.7	6.3	6.1	6.1	5.3	5.6	5.4	5.5	5.6	5.4	12.4	12.3
15		Uncomp. " "	in. H_2O	7.8	7.6	7.1	7.1	7.0	7.0	6.5	6.7	6.7	6.7	6.7	6.7	13.1	12.9
16		Venturi suction	in. CCl_4	9.9	9.5	9.0	8.9	8.7	8.7	8.7	8.5	8.4	8.4	8.4	8.4	16.3	16.3
17		Carburetor air temp.	°F	80	82	82	83	83	82	82	82	83	82	84	83	85	85
18		Charge air flow	lb./hr.	5300	5180	5040	5015	4950	4970	4970	4895	4880	4880	4860	4865	6620	6625
19		Fuel flow	lb./hr.	565	491	445	428	395	381	350	343	324	310	280	259	745	680
20		Fuel-air ratio	lb./hr.	.1066	.0946	.0884	.0854	.0798	.0766	.0704	.0701	.0664	.0636	.0576	.0532	.1125	.1026
21	Cooling Air	Indicated specific air cons.	lb/ihp/hr.	6.58	6.13	5.97	5.93	5.86	5.83	5.95	5.87	5.94	6.08	6.67	7.58	6.62	6.19
22		" " fuel "	lb/ihp/hr.	.702	.580	.526	.507	.468	.446	.420	.411	.394	.387	.385	.404	.736	.635
23		Barometric pressure	in. hg.-abs	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.6	29.6
24		Atmospheric temperature	°F	84	84	84	85	84	83	82	83	83	83	85	84	87	86
25		Relative density of air, σ	——	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26		Average front-of-head press	in. H_2O	—	—	—	—	—	—	—	—	—	—	—	—	—	—
27		" rear-of-head press	in. H_2O	—	—	—	—	—	—	—	—	—	—	—	—	—	—
28		" head ΔP	in. H_2O	—	—	—	—	—	—	—	—	—	—	—	—	—	—
29	Cylinder temperature	" head, embedded temp.	°F	346	374	387	394	407	412	419	425	429	428	403	384	362	381
30		" " spk. plug gas. "	°F	316	341	353	360	372	376	381	386	389	387	364	348	327	346
31		Hottest emb. head T & cyl. no.	°F	371-13	404-1	419-1	428-1	443-1	451-1	458-1	461-1	465-1	461-1	437-3	417-3	383-13	402-1
32		" spk. plug gas. T & cyl. no.	°F.	337-1 / 337-13	368-1	382-1	391-1	404-1	410-1	418-1	420-1	423-1	417-1	390-1	371-5	345-1 / 345-13	366-1
33	Computation of tg from tg0	Temp. corr. Δtg	°F	126	127	127	128	128	127	127	127	128	127	129	128	142	142
34		t_{g0}	°F	876	972	1018	1038	1086	1107	1134	1152	1165	1163	1069	1006	839	903
35		$t_g = t_{g0} + \Delta t_g$	°F	1002	1099	1145	1166	1214	1234	1261	1279	1293	1290	1198	1134	981	1045
36		$(t_h - t_a)/(t_g - t_h)$	——	—	—	—	—	—	—	—	—	—	—	—	—	—	—
37																	
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1	Series number	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Run number	315	316	317	318	319	320	321	322	323	418	419	420	421
3	Date	6-24-44	6-24-44	6-24-44	6-24-44	6-24-44	6-24-44	6-24-44	6-24-44	6-24-44	7-18-44	7-18-44	7-18-44	7-18-44
4	Time	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
5	Engine speed	2200	2200	2200	2200	2200	2200	2200	2200	2200	2000	2000	2000	2000
6	Torque pressure	347	347	351	349	347	335	320	310	280	285	285	285	285
7	Brake power	939	939	949	944	939	906	866	838	758	701	701	701	701
8	Friction power	173	172	172	171	171	170	170	171	171	141	139	138	138
9	Indicated power	1112	1111	1120	1114	1109	1076	1036	1008	928	842	840	839	838
10	Blower position	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW
11	Mixture control	FR	FR-	AR+	AR	AR-	AL+	AL-	AL-	AL-	FR+	FR+	FR+	FR+
12	Cowling flap position	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
13	Blower rim pressure	30.0	30.0	30.1	30.0	30.1	30.0	30.0	30.0	30.0	28.0	27.5	27.3	27.0
14	Comp. metering suction	12.1	10.8	9.5	9.2	9.1	8.8	8.8	9.1	9.1	8.1	7.4	7.1	7.0
15	Uncomp. " "	12.9	12.4	12.3	12.0	11.8	11.5	11.5	11.8	11.8	8.4	7.9	7.4	7.3
16	Venturi suction	16.1	15.5	15.3	14.8	14.7	14.3	14.3	14.6	14.6	10.2	9.5	9.2	8.8
17	Carburetor air temp.	85	86	86	85	86	87	87	87	87	79	78	77	78
18	Charge air flow	6595	6480	6420	6340	6310	6240	6240	6300	6300	5420	5250	5175	5040
19	Fuel flow	610	570	522	475	450	413	390	379	355	595	545	515	476
20	Fuel-air ratio	.0926	.088	.0814	.0749	.0713	.0662	.0625	.0602	.0564	.1100	.1038	.0996	.0945
21	Indicated specific air cons.	5.92	5.83	5.73	5.69	5.69	5.80	6.02	6.25	6.79	6.04	6.25	6.17	6.01
22	" " fuel "	.549	.513	.466	.426	.406	.384	.376	.376	.383	.707	.649	.613	.568
23	Barometric pressure	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	30.14	30.14	30.14	30.14
24	Atmospheric temperature	86	87	88	88	88	88	88	88	88	81	81	78	78
25	Relative density of air, σ	—	—	—	—	—	—	—	—	—	—	—	—	—
26	Average front-of-head press	—	—	—	—	—	—	—	—	—	2.20	—	2.72	—
27	" rear-of-head press	—	—	—	—	—	—	—	—	—	-.68	—	-.72	—
28	" head ΔP	—	—	—	—	—	—	—	—	—	2.88	—	3.44	—
29	" head, embedded temp.	405	415	436	446	457	466	461	449	429	353	368	370	384
30	" " spk. plug gas. "	370	377	394	407	415	424	417	406	388	327	337	338	352
31	Hottest emb. head T & cyl. no.	428-13	440-1	459-11	467-1	478-1	488-1	483-1	469-1	447-1	385-11	404-11	403-13	424-11
32	" spk. plug gas. T & cyl. no.	391-8	400-1	416-8	430-8	437-8	452-8	451-8	444-8	424-8	359-13	368-11	366-11	385-11
33	Temp. corr. Δtg	142	143	143	142	143	143	143	143	143	125	124	123	124
34	t_{g0}	981	1010	1075	1109	1144	1173	1157	1118	1053	869	920	935	981
35	$t_g = t_{g0} + \Delta t_g$	1123	1153	1218	1251	1287	1316	1300	1261	1196	994	1044	1058	1105
36	$(t_h - t_a)/(t_g - t_h)$	—	—	—	—	—	—	—	—	—	—	—	—	—

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Table 1 Master Data

MR No. L5L18

Engine make Wright Aero. Corp. Model R-2600-22 Mfg. No. 426724 Prop. red. ratio 16:7 Comp. ratio 6.9:1	Blower imp. dia. 11 in. Gear ratio, 7.06:1 10.06:1 Master rod cylinders Nos. 1 and 12 Spark advance 20°	Prop. make Curtiss Type Electric No. of blades 4 Cuffs Removed Fan Curtiss No. 1	Carb. model PR48A1 Make Stromberg Serial No. 343544	Fuel Spec. No. ANF-28 Grade 130 Oil-Grade 1120	Magneto make American Bosch Serial Nos. RH, S-1998 LH, T-1644 Model SF14LU-10 Plugs LS-87		Sheet 2 of 3 Test of Wright R-2600-22 Cooling Correlation

	Group	Item	Units											
1	Test Identification	Series number	——	1	1	1	1	1	1	1	1	1	1	1
2		Run number	——	422	423	424	425	426	427	428	429	442	443	444
3		Date	——	7-18-44	7-18-44	7-18-44	7-18-44	7-18-44	7-18-44	7-18-44	7-18-44	7-22-44	7-22-44	7-22-44
4		Time	E.W.T	AM	AM	AM	PM	PM	PM	PM	PM	AM	AM	AM
5	Engine Operation	Engine speed	r.p.m.	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
6		Torque pressure	lb./in.²	285	285	285	285	285	285	285	285	250	267	275
7		Brake power	h.p.	701	701	701	701	701	701	701	701	616	658	676
8		Friction power	h.p.	136.3	135.5	135.6	135.5	135.5	136.3	139.9	144.8	142	142	142
9		Indicated power	hp	837.3	836.5	836.6	836.5	836.5	836.3	840.9	845.8	758	800	818
10		Blower position	——	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW
11		Mixture control	——	FR	AR+	AR+	AL+	AL+	AL	AL-	AL-	FR+	FR+	FR+
12		Cowling flap position	——	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
13		Blower rim pressure	in.hg.-abs.	27.0	26.8	27.0	27.0	27.1	27.8	29.3	31.3	26.0	26.2	26.2
14	Engine Charge	Comp. metering suction	in. H_2O	6.6	5.7	6.0	5.4	5.3	5.7	6.6	8.2	6.7	6.6	6.6
15		Uncomp " "	in. H_2O	7.0	6.7	6.8	6.7	6.7	7.1	8.3	10.2	7.1	7.0	7.0
16		Venturi suction	in. CCL_4	8.5	8.2	8.3	8.2	8.2	8.6	10.0	12.4	8.4	8.3	8.3
17		Carburetor air temp.	°F	78	79	78	79	80	80	80	79	78	79	78
18		Charge air flow	lb./hr.	4950	4865	4880	4870	4870	4960	5370	5960	4940	4910	4910
19		Fuel flow	lb./hr.	440	404	387	359	335	319	316	322	550	505	478
20		Fuel-air ratio	lb./hr.	.0889	.0831	.0793	.0737	.0689	.0643	.0589	.0540	.112	.103	.0974
21	Cooling Air	Indicated specific air cons.	lb/ihp/hr	5.91	5.82	5.84	5.82	5.82	5.93	6.39	7.05	6.43	6.14	6.00
22		" " fuel "	lb/ihp/hr	.526	.483	.462	.429	.400	.377	.376	.381	.726	.632	.584
23		Barometric pressure	in.hg.-abs.	30.14	30.14	30.14	30.14	30.14	30.14	30.14	30.14	30.18	30.18	30.18
24		Atmospheric temperature	°F	78	79	78	77	78	78	78	78	76	77	77
25		Relative density of air, σ	——	——	——	——	——	——	——	——	——	——	——	——
26		Average front-of-head press.	in. H_2O	——	2.12	——	2.32	——	2.16	——	2.60	2.48	2.32	2.32
27		" rear-of-head press	in. H_2O	——	-.72	——	-.72	——	-.68	——	-.96	-.60	-.68	-.68
28		" head ΔP	in. H_2O	——	2.84	——	3.04	——	2.84	——	3.56	3.08	3.00	3.00
29	Cylinder temperature	" head, embedded temp.	°F	394	406	417	431	439	443	426	403	352	368	377
30		" " spk. plug gas. "	°F	361	373	384	395	400	407	386	364	323	337	347
31		Hottest emb. head T.+cyl. no.	°F	429-11	443-1	458-13	459-1	468-1	473-1	452-1	438-3	380-11	397-13	404-1
32		" spk. plug gas T+cyl. no.	°F	393-1	407-1	419-1	427-1	429-1	437-1	420-8	392-8	345-8/345-11	361-11	373-1
33	Computation of tg from tgo	Temp. corr. Δtg	°F.	124	125	124	125	126	126	126	125	124	125	124
34		t_{g_o}	°F	1014	1051	1091	1139	1163	1176	1119	1043	856	905	936
35		$t_g = t_{g_o} + \Delta t_g$	°F	1138	1176	1215	1264	1289	1302	1245	1168	980	1030	1060
36		$(t_h - t_a)/(t_g - t_h)$	——	——	——	——	——	——	——	——	——	.442	.442	.442
37														
38														
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	Item																
1	Series number	1	1	1	1	1	1	1	1	2	2	2	2	2	3	3	3
2	Run number	445	446	448	449	450	451	452	453	401	402	403	404	405	454	455	456
3	Date	7-22-44	7-22-44	7-22-44	7-22-44	7-22-44	7-22-44	7-22-44	7-22-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	7-25-44	7-25-44	7-25-44
4	Time	AM	AM	PM	PM	PM	PM	PM	PM	AM	AM	AM	AM	AM	AM	AM	AM
5	Engine speed	2000	2000	2000	2000	2000	2000	2000	2000	2600	2600	2600	2600	2600	2400	2400	2400
6	Torque pressure	285	290	295	305	295	285	260	220	235	235	233	233	232	500	475	430
7	Brake power	702	714	727	751	727	702	640	542	751	751	745	745	742	1475	1402	1269
8	Friction power	141	141	139	138	139	139	138	139	253	254	252	252	252	207	207	207
9	Indicated power	843	855	866	889	866	841	778	681	1004	1005	997	997	994	1682	1609	1476
10	Blower position	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW
11	Mixture control	FR+	FR+	AR+	AR-	AL+	AL+	AL-	AL-	FR+	FR+	FR+	FR+	FR+	AR+	AR+	AR+
12	Cowling flap position	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED	Intermediate Steps			OPEN	OPEN	OPEN	OPEN
13	Blower rim pressure	26.7	26.8	27.0	27.7	27.5	27.5	27.6	27.4	26	26	26	26	26	42	40	37
14	Comp. metering suction	6.5	6.6	5.6	5.7	5.5	5.6	5.6	5.6	10.3	10.4	10.3	10.4	10.3	28.0	25.2	22.1
15	Uncomp " "	6.8	7.0	7.0	7.1	6.8	7.0	7.0	7.0	10.8	10.9	10.8	10.9	10.8	31.5	28.6	22.8
16	Venturi suction	8.5	8.5	8.4	8.8	8.5	8.6	8.5	8.5	13.1	13.5	12.8	12.6	12.7	44.9	38.9	30.7
17	Carburetor air temp.	78	79	80	80	87	81	81	80	74	73	73	75	76	82	82	82
18	Charge air flow	4975	4975	4940	5060	4975	5010	4975	4975	6150	6185	6080	6030	6030	10,370	9,820	8,890
19	Fuel flow	455	445	392	373	344	320	292	266	595	595	585	582	580	1040	975	890
20	Fuel-air ratio	.0915	.0894	.0794	.0736	.0691	.0636	.0586	.0535	.0968	.0962	.0946	.0965	.0962	.1003	.0994	.1001
21	Indicated specific air cons.	5.90	5.82	5.70	5.70	5.75	5.96	6.40	7.31	6.12	6.16	6.10	6.05	6.07	6.17	6.10	6.02
22	" " fuel "	.540	.520	.453	.420	.397	.381	.375	.391	.592	.592	.587	.584	.584	.620	.606	.603
23	Barometric pressure	30.18	30.18	30.18	30.18	30.18	30.18	30.18	30.18	30.11	30.11	30.11	30.11	30.11	30.00	30.00	30.00
24	Atmospheric temperature	77	77	80	80	78	78	78	78	72	72	72	73	75	81	81	82
25	Relative density of air, σ	——	——	——	——	——	——	——	——	.9742	.9742	.9742	.9750	.9732	.953	.953	.950
26	Average front-of-head press.	2.28	2.28	2.48	2.28	2.60	2.52	2.44	2.28	4.48	4.74	4.86	4.96	4.88	3.32	3.92	3.64
27	" rear-of-head press	-.68	-.68	-.72	-.68	-.72	-.64	-.60	-.64	+.92	+.36	-.44	-.84	-1.24	-2.40	-2.04	-2.12
28	" head ΔP	2.96	2.96	3.20	2.96	3.32	3.16	3.04	2.92	3.56	4.38	5.30	5.80	6.12	5.72	5.90	5.76
29	" head, embedded temp.	390	393	427	439	447	447	418	386	400	387	374	364	360	427	422	410
30	" " spk. plug gas. "	358	364	390	400	408	410	384	354	363	350	338	329	324	385	380	370
31	Hottest emb. head T.+cyl. no.	418-1	423-1/11	458-1	467-1	481-1	476-1	442-1	407-1	424-1	415-1	401-1	391-1	388-1	453-12	451-1	435-1
32	" spk. plug gas T+cyl. no.	385-1	390-1	420-1	430-1	440-1	449-8	423-8	390-8	384-1	375-1	362-1	355-1	350-1	406-12	409-1	394-1
33	Temp. corr. Δtg	124	125	126	126	126	126	126	126	163	162	162	163	163	154	154	154
34	t_{g_o}	978	987	1090	1129	1160	1160	1065	961	953	958	971	956	958	927	934	929
35	$t_g = t_{g_o} + \Delta t_g$	1102	1112	1216	1255	1286	1286	1191	1087	1116	1120	1133	1119	1121	1081	1088	1083
36	$(t_h - t_a)/(t_g - t_h)$	.442	.442	.442	.442	.442	.442	.442	.442	.477	.447	.414	.398	.387	.552	.534	.507

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Table I Master Data

Engine make Wright Aero. Corp.
Model R-2600-22
Mfg. No. 426724
Prop. red. ratio 16:7
Comp. ratio 6.9:1

Blower imp. dia. 11in.
Gear ratio 7.06:1, 10.06:1
Master rod cylinders Nos. 1 and 12
Spark advance 20°

Prop. make Curtiss
Type Electric
No. of blades 4
Cuffs Removed
Fan Curtiss No. 1

Carb. model PR48A1
Make Stromberg
Serial No. 343544

Fuel Spec. No. ANF-28
Grade 130
Oil-Grade 1120

Magneto make American Bosch
Serial Nos. RH, S-1998; LH, T-1644
Model SF14LU-10
Plugs LS-87

Sheet 3 of 3
Test of Wright R-2600-22
Cooling Correlation

1	Test Identification	Series number	——	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4
2		Run number	——	457	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	477	478	479	480	481
3		Date	——	7-25-44	7-25-44	7-25-44	7-25-44	7-25-44	7-25-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	8-23-44	8-23-44	8-23-44	8-23-44	8-23-44
4		Time	E.W.T.	AM	AM	PM	PM	PM	PM	AM	AM	AM	AM	AM	AM	AM	PM	PM	PM	PM	PM	AM	AM	AM	AM	AM
5	Engine Operation	Engine speed	r.p.m.	2400	2400	2400	2400	2400	2400	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	2200	2000	1800	1600	2000
6		Torque pressure	lb./in.²	400	313	278	220	180	147	462	417	402	382	375	345	300	272	250	215	165	102	380	280	225	140	203
7		Brake power	hp	1181	924	821	650	532	434	1476	1280	1187	1082	1015	892	738	636	554	450	325	188	1028	689	498	276	500
8		Friction power	hp	208	209	210	210	213	213	257	231	209	189	171	155	139	123	110	100	91	83	175	138	114	94	138
9		Indicated power	hp	1389	1133	1031	860	745	647	1733	1511	1396	1271	1186	1047	877	759	664	550	416	320	1203	827	612	370	638
10		Blower position	——	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW
11		Mixture control	——	FR+	FR+	FR+	FR+	FR+	FR	FR	FR	FR+	FR+	FR+	FR+	FR+	FR+	FR+	FR+	FR+	FR+	AR	AL	AL	AL	AL-
12		Cowling flap position	——	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
13		Blower rim pressure	in. hg-abs	35	30	28	25	22	20	42.3	38.3	35.0	33.0	32.0	30.0	28.0	27.0	26.0	24.0	22.0	20.0	32	27	24	20	27
14	Engine Charge	Comp. metering suction	in. H_2O	19.7	13.2	11.4	8.3	6.3	4.9	35.3	26.7	19.7	16.1	13.9	10.8	7.7	5.7	4.6	3.4	2.1	1.3	11.1	5.3	3.2	1.3	5.2
15		Uncomp. " "	in. H_2O	19.7	13.9	11.8	8.5	6.6	5.1	35.8	27.4	19.7	16.6	14.5	11.4	8.1	6.0	4.8	3.5	2.3	1.3	13.9	6.6	4.1	1.7	6.5
16		Venturi suction	in. CCl_4	26.7	17.0	14.2	10.1	7.4	5.6	54.1	37.5	26.6	21.1	18.4	14.1	9.9	7.5	5.9	4.1	2.4	1.5	16.8	8.1	4.7	1.75	7.9
17		Carburetor air temp.	°F	82	85	87	87	89	92	83	83	83	84	85	85	87	87	88	88	89	89	79	80	80	81	81
18		Charge air flow	lb./hr	8370	6315	6270	5370	4570	3950	11120	9640	8330	7520	7060	6260	5210	4590	4100	3430	2626	2100	6820	4815	3690	2270	4750
19		Fuel flow	lb./hr.	830	680	630	532	450	400	1248	1062	828	745	708	628	525	458	414	344	262	210	563	317	242	161	256
20		Fuel-air ratio	lb/hr	.0992	.0997	.1004	.0992	.0985	.0987	.1120	.1100	.0994	.0991	.100	.100	.100	.0998	.101	.100	.100	.100	.0826	.0659	.0656	.0709	.0539
21	Cooling Air	Indicated specific air cons.	lb/ihp/hr	6.02	6.02	6.02	6.25	6.13	6.10	6.42	6.38	5.97	5.92	5.95	5.89	5.94	6.05	6.08	6.23	6.31	6.56	5.67	5.82	6.03	6.13	7.44
22		" " fuel "	lb/ihp/hr	.598	.600	.611	.618	.604	.618	.720	.703	.593	.586	.597	.600	.599	.603	.624	.626	.630	.656	.468	.383	.395	.435	.401
23		Barometric pressure	in. hg-abs	30.00	30.00	30.00	30.00	30.00	30.00	30.10	30.10	30.10	30.10	30.10	30.10	30.10	30.10	30.10	30.10	30.10	30.10	30.10	30.10	30.10	30.10	30.10
24		Atmospheric temperature	°F	83	85	86	87	89	90	83	84	85	85	86	87	88	88	89	89	88	88	79	79	80	80	81
25		Relative density of air, σ	——	.950	.944	.944	.944	.944	.944	.953	.953	.953	.953	.953	.952	.950	.950	.950	.947	.947	.947	.958	.958	.958	.958	.954
26		Average front-of-head press.	in. H_2O	3.80	4.00	3.88	4.00	4.08	4.12	4.84	4.56	3.80	3.44	2.96	2.80	2.52	2.36	2.12	1.88	1.52	1.36	3.04	2.40	1.88	1.48	2.48
27		" rear-of-head press.	in. H_2O	-1.96	-1.56	-1.48	-1.24	-.96	-.96	-2.28	-2.00	-1.96	-1.88	-1.60	-1.56	-1.28	-1.12	-.96	-.76	-.56	-.52	-1.12	-.72	-.52	-.28	-.60
28		" head ΔP	in. H_2O	5.76	5.56	5.36	5.24	5.04	5.08	7.12	6.56	5.76	5.32	4.56	4.36	3.80	3.48	3.08	2.64	2.08	1.88	4.16	3.12	2.40	1.76	3.08
29	Cylinder temperature	" head, embedded temp.	°F	408	380	369	358	349	339	395	385	401	392	389	380	376	365	356	346	331	313	445	448	425	383	392
30		" " spk. plug gas."	°F	367	347	332	322	318	310	357	348	364	357	354	346	341	333	327	317	304	287	408	401	391	354	357
31		Hottest emb. head T+cyl. no.	°F	430-1	407-1	398-1	385-1	378-1	370-1	420-1	414-1	427-1	417-1	414-1	404-1	402-1	395-1	382-1	373-1	363-1	351-1	473-11	478-1	458-1	429-1	414-1
32		" spk. plug gas T+cyl. no.	°F	389-1	371-1	356-1	349-1	344-1	335-1	379-1	375-1	386-1	379-1	376-1	367-1	365-1	359-1	349-1	341-1	333-1	322-1	433-8	437-8	419-8	393-1	392-8
33	Computation of tg from tg₀	Temp. corr. Δt_g	°F	154	156	158	158	159	162	170	161	154	148	142	136	131	125	120	115	110	106	137	126	114	104	126
34		t_{g_0}	°F	935	932	926	935	940	938	848	859	934	936	930	930	930	932	929	930	930	930	1065	1168	1169	1147	995
35		$t_g = t_{g_0} + \Delta t_g$	°F	1089	1088	1084	1093	1099	1100	1018	1020	1088	1084	1072	1066	1061	1057	1049	1045	1040	1036	1202	1294	1273	1251	1121
36		$(t_h - t_a)/(t_g - t_h)$	——	.496	.434	.413	.384	.360	.340	.523	.494	.478	.462	.461	.445	.438	.417	.401	.381	.355	.323	.486	.438	.408	.350	.429
37																										
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MR No. L5L18

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Table II — Cylinder Temperatures

Engine make Wright Aero. Corp.
Model R-2600-22
Mfg. No. 426724
Prop. red. ratio 16:7
Comp. ratio 6.9:1

Blower imp. dia. 11in.
Gear ratio, 7.06:1 / 10.06:1
Master rod cylinders Nos. 1 and 12
Spark advance, 20°

Prop. make Curtiss
Type Electric
No. of blades 4
Cuffs Removed
Fan Curtiss No. 1

Carb. model PR48A1
Make Stromberg
Serial No. 343544

Fuel Spec. No. ANF-28
Grade 130
Oil-Grade 1120

Magneto make American Bosch
Serial Nos. RH,S-1998 / LH,T-1644
Model SF14LU-10
Plugs LS-87

Equation (2)
$\Delta t_g = .8\left[t_c + 18\left(\frac{rpm}{1000}\right)^2\right]$

Sheet 1 of 3
Test of Wright R-2600-22 Cooling Correlation

No.	Item	Unit														
1	Test identification: Series number	—	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Run number	—	301	302	303	304	305	306	307	308	309	310	311	312	313	314
3	Date	—	6-23-44	6-23-44	6-23-44	6-23-44	6-23-44	6-23-44	6-23-44	6-23-44	6-23-44	6-23-44	6-23-44	6-23-44	6-24-44	6-24-44
4	Time	E.W.T.	PM 1:30	PM 1:42	PM 1:51	PM 2:00	PM 2:15	PM 2:24	PM 2:31	PM 2:43	PM 2:51	PM 3:00	PM 3:10	PM 3:17	AM 9:11	AM 9:21
5	ENGINE TEMPERATURES, Embedded: Cylinder number 1	°F	370	404	420	428	443	451	458	461	465	461	431	407	382	402
6	2	°F	340	374	388	396	410	415	420	424	430	428	408	392	351	374
7	3	°F	357	387	400	409	426	433	441	446	454	454	437	417	367	387
8	4	°F	327	354	366	375	387	393	401	403	412	412	407	397	331	350
9	5	°F	335	367	379	389	403	409	417	422	431	432	414	400	353	371
10	6	°F	327	352	366	374	388	393	400	404	413	414	399	386	336	352
11	7	°F	340	366	379	386	402	406	415	422	428	430	404	392	364	381
12	8	°F	342	369	382	388	401	404	413	419	425	427	399	381	364	385
13	9	°F	353	380	394	398	411	415	423	428	432	432	401	383	380	398
14	10	°F	329	354	366	372	385	387	394	400	404	404	382	363	354	374
15	11	°F	356	384	397	404	415	418	427	431	433	428	392	368	379	399
16	12	°F	352	378	389	397	407	410	419	423	422	412	377	352	363	382
17	13	°F	371	400	410	422	431	436	443	446	446	439	404	378	383	402
18	14	°F	346	372	381	389	400	404	408	413	416	411	388	364	355	376
19	Average	°F	346	374	387	394	407	412	419	425	429	428	403	384	362	381
20		—														
21	Rear spark plug gasket: Cylinder number 1	°F	337	368	382	391	404	410	418	420	423	417	390	370	345	366
22	2	°F	311	340	354	363	374	379	385	386	391	389	371	357	316	339
23	3	°F	—	—	—	—	—	—	—	—	—	—	—	—	—	—
24	4	°F	304	330	340	349	361	366	372	372	381	382	377	369	305	326
25	5	°F	311	340	353	362	376	380	388	392	397	400	382	371	324	345
26	6	°F	293	317	328	336	349	353	359	363	368	372	355	346	219	316
27	7	°F	310	333	345	351	365	370	376	382	386	388	365	355	325	344
28	8	°F	327	352	365	370	385	388	384	401	406	407	382	366	344	364
29	9	°F	316	339	351	355	368	369	376	382	385	384	356	340	336	353
30	10	°F	300	324	335	341	352	354	360	366	369	367	347	327	320	337
31	11	°F	324	349	359	367	377	378	385	390	391	383	352	330	340	360
32	12	°F	321	345	356	362	373	376	381	384	384	374	342	319	327	345
33	13	°F	337	362	372	381	390	394	399	404	403	396	365	340	345	362
34	14	°F	318	340	350	358	367	370	375	379	382	377	355	333	324	343
35	Average	°F	316	341	353	360	372	376	381	386	389	387	364	348	327	346
36		—														
37	Base: Cylinder number 1	°F	—	—	—	—	—	—	—	—	—	—	—	—	—	—
38	2	°F														
39	3	°F														
40	4	°F														
41	5	°F														
42	6	°F														
43	7	°F														
44	8	°F														
45	9	°F														
46	10	°F														
47	11	°F														
48	12	°F														
49	13	°F														
50	14	°F														
51	Average	°F	—	—	—	—	—	—	—	—	—	—	—	—	—	—
52		—														

No.	Item	Unit														
1	Test identification: Series number	—	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Run number	—	315	316	317	318	319	320	321	322	323	418	419	420	421	422
3	Date	—	6-24-44	6-24-44	6-24-44	6-24-44	6-24-44	6-24-44	6-24-44	6-24-44	6-24-44	7-18-44	7-18-44	7-18-44	7-18-44	7-18-44
4	Time	E.W.T.	AM 9:32	AM 9:40	AM 9:49	AM 10:02	AM 10:13	AM 10:24	AM 10:34	AM 10:46	AM 10:56	AM 8:52	AM 9:07	AM 9:33	AM 9:49	AM 10:07
5	ENGINE TEMPERATURES, Embedded: Cylinder number 1	°F	427	440	457	461	478	488	483	469	447	378	390	402	415	428
6	2	°F	397	410	432	443	454	463	463	450	428	337	353	360	370	386
7	3	°F	410	420	441	453	467	473	478	467	443	353	366	368	380	395
8	4	°F	372	381	402	416	433	440	447	442	427	326	341	342	353	366
9	5	°F	395	402	425	438	450	456	460	448	429	336	346	348	361	374
10	6	°F	377	382	401	413	427	434	437	430	413	321	331	333	345	358
11	7	°F	404	410	431	440	451	459	459	447	430	345	355	354	366	381
12	8	°F	411	416	440	447	462	474	480	467	443	353	365	364	378	391
13	9	°F	422	431	451	460	470	483	472	460	438	370	383	379	395	405
14	10	°F	402	413	437	444	455	466	451	439	413	347	361	356	375	382
15	11	°F	427	439	459	460	469	482	463	449	423	385	404	401	424	429
16	12	°F	407	418	443	450	460	468	447	436	417	370	388	389	409	412
17	13	°F	428	438	458	464	474	483	468	453	430	381	398	403	419	425
18	14	°F	401	413	433	443	457	461	450	438	417	353	369	377	387	392
19	Average	°F	405	415	436	446	457	466	461	441	429	353	368	370	384	394
20		—														
21	Rear spark plug gasket: Cylinder number 1	°F	388	400	414	426	436	444	439	425	406	350	362	363	380	393
22	2	°F	361	372	389	403	412	418	419	406	386	309	322	324	339	351
23	3	°F	—	—	—	—	—	—	—	—	—	—	—	—	—	—
24	4	°F	345	351	372	389	398	406	411	409	392	304	316	319	331	340
25	5	°F	366	373	393	408	416	422	425	412	393	308	317	324	336	345
26	6	°F	399	342	359	373	380	389	390	384	368	287	296	303	313	321
27	7	°F	365	371	389	401	405	414	413	402	386	309	319	324	334	345
28	8	°F	391	397	416	430	437	452	451	444	424	337	348	354	365	375
29	9	°F	377	382	398	413	420	433	420	409	391	328	341	344	357	363
30	10	°F	369	375	393	405	412	422	410	395	377	320	330	331	337	351
31	11	°F	387	393	408	417	424	434	417	402	381	356	368	366	385	392
32	12	°F	372	377	395	407	416	423	403	391	377	349	358	350	370	379
33	13	°F	388	394	410	420	430	436	420	408	389	359	367	362	381	387
34	14	°F	368	376	394	407	417	422	410	398	379	334	340	339	355	359
35	Average	°F	370	377	394	407	415	424	417	406	388	327	337	338	352	361
36		—														
37	Base: Cylinder number 1	°F	—	—	—	—	—	—	—	—	—	253	256	255	260	264
38	2	°F										223	225	221	224	227
39	3	°F										246	249	247	249	253
40	4	°F										222	225	221	221	223
41	5	°F										252	255	253	257	260
42	6	°F										213	216	216	218	219
43	7	°F										247	—	250	254	254
44	8	°F										—	—	—	—	—
45	9	°F										239	244	242	245	246
46	10	°F										229	233	228	234	235
47	11	°F										257	259	254	258	263
48	12	°F										240	241	235	241	245
49	13	°F										242	243	238	243	248
50	14	°F										229	230	221	226	231
51	Average	°F	—	—	—	—	—	—	—	—	—	238	239	237	241	243
52		—														

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Table II Cylinder Temperatures

Engine make Wright Aero Corp. Model R-2600-22 Mfg. No. 426724 Prop. red. ratio 16:7 Comp. ratio 6.9:1	Blower imp. dia 11in. Gear ratio 7.06:1 10.06:1 Master rod cylinders Nos. 1 and 12 Spark advance 20°	Prop. make Curtiss Type Electric No. of blades 4 Cuffs Removed Fan Curtiss No.1	Carb. model PR48A1 Make Stromberg Serial No. 343544	Fuel Spec. No. ANF-28 Grade 130 Oil-Grade 1120	Magneto make American Bosch Serial Nos. R.H.S-1998 L.H.T-1644 Model SF14LU-10 Plugs LS-87	Sheet 2 of 3 Test of Wright R-2600-22 Cooling Correlation

Line	Group	Item	Cyl.	Unit																												
1	Test Identification	Series number		——	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3
2	Test Identification	Run number		——	423	424	425	426	427	428	429	442	443	444	445	446	448	449	450	451	452	453	401	402	403	404	405	454	455	456	457	
3	Test Identification	Date		——	7-18-44	7-18-44	7-18-44	7-18-44	7-18-44	7-18-44	7-18-44	7-22-44	7-22-44	7-22-44	7-22-44	7-22-44	7-22-44	7-22-44	7-22-44	7-22-44	7-22-44	7-22-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	7-25-44	7-25-44	7-25-44	7-25-44	
4	Test Identification	Time		E.W.T	AM 10:32	AM 10:50	PM 2:07	PM 2:21	PM 2:37	PM 2:55	PM 3:12	AM 9:29	AM 9:48	AM 10:11	AM 10:27	AM 10:48	PM 1:30	PM 1:50	PM 2:07	PM 2:25	PM 2:40	PM 2:57	AM 6:33	AM 6:48	AM 7:06	AM 7:25	AM 7:38	AM 9:36	AM 9:51	AM 10:08	AM 10:24	
5	Engine Temperatures – Embedded	Cylinder number	1	°F	443	456	459	468	473	452	423	370	393	404	418	423	458	467	481	476	442	407	424	415	401	391	388	444	451	435	430	
6			2	°F	400	406	416	426	431	414	392	334	355	365	378	380	411	420	429	434	406	377	377	368	356	348	343	415	428	412	402	
7			3	°F	410	418	439	449	459	447	438	349	370	380	392	394	433	451	458	465	438	405	416	404	391	362	376	440	441	428	422	
8			4	°F	380	387	402	412	423	423	404	322	338	347	360	361	391	410	417	426	412	384	386	371	361	350	345	420	431	414	420	
9			5	°F	388	396	420	431	439	429	412	335	351	364	376	380	413	433	438	443	420	390	408	392	382	370	364	404	396	400	398	
10			6	°F	368	377	401	411	420	417	398	321	334	346	358	362	392	410	416	423	404	372	382	367	355	345	340	395	381	378	377	
11			7	°F	392	401	427	435	441	430	410	344	354	365	378	380	415	432	439	444	420	390	401	384	370	360	351	400	382	385	389	
12			8	°F	398	408	435	444	448	439	408	360	369	381	395	400	432	443	455	464	439	401	400	386	372	363	355	425	413	401	401	
13			9	°F	412	422	447	455	457	437	419	370	379	388	402	408	438	448	458	459	425	394	415	402	386	377	371	428	417	410	411	
14			10	°F	390	400	419	428	433	406	379	349	360	369	384	389	419	427	435	435	403	372	376	363	349	342	336	417	410	397	398	
15			11	°F	438	452	455	463	459	426	400	380	394	403	415	423	451	457	468	456	423	387	420	407	390	381	375	448	434	420	418	
16			12	°F	425	443	439	445	443	410	383	368	382	388	402	404	437	443	452	444	406	370	395	382	368	358	353	453	439	420	414	
17			13	°F	441	458	450	457	453	425	396	378	397	402	415	418	452	460	465	452	419	387	423	409	394	380	380	441	436	422	419	
18			14	°F	408	422	419	427	427	407	384	350	371	378	390	390	429	440	447	435	404	371	383	375	364	353	350	440	441	426	411	
19		Average		°F	406	417	431	439	443	426	403	352	368	377	390	393	427	439	447	447	418	386	400	387	374	364	360	427	422	410	408	
20				——																												
21	Engine Temperatures – Rear spark-plug gasket	Cylinder number	1	°F	407	419	427	429	437	412	388	340	358	373	385	390	420	430	440	439	407	373	384	375	362	355	350	402	409	394	389	
22			2	°F	361	371	381	385	395	375	355	305	323	333	344	348	370	384	391	394	371	345	343	331	321	313	307	374	386	369	362	
23			3	°F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
24			4	°F	351	363	375	382	393	390	373	303	316	326	337	339	367	386	392	400	387	360	356	345	334	326	319	389	393	381	374	
25			5	°F	359	371	387	398	403	396	379	313	327	339	349	353	384	403	409	414	392	364	376	363	350	340	335	371	366	366	363	
26			6	°F	331	341	360	370	376	375	356	291	303	315	323	328	353	371	377	385	367	337	338	325	314	306	300	352	340	335	332	
27			7	°F	355	367	387	397	395	387	368	313	323	332	341	347	376	391	400	406	385	358	363	347	334	325	318	361	345	340	349	
28			8	°F	383	395	417	425	430	420	392	345	354	366	379	386	414	425	436	449	423	390	383	369	356	347	341	398	392	382	380	
29			9	°F	371	381	401	406	410	387	371	331	341	350	361	370	392	402	408	411	380	354	367	353	337	329	323	379	370	362	364	
30			10	°F	361	371	385	388	400	368	341	320	331	341	351	360	382	388	395	400	371	341	341	329	317	310	305	375	370	357	357	
31			11	°F	401	411	419	418	425	388	361	345	361	369	380	389	413	415	422	419	385	354	379	365	351	343	337	405	389	379	378	
32			12	°F	392	403	402	401	412	385	342	335	350	357	368	375	401	400	411	408	373	340	357	343	331	323	317	406	393	377	372	
33			13	°F	403	415	410	412	420	385	357	344	361	365	378	384	410	413	421	413	382	353	381	368	354	345	339	394	389	379	377	
34			14	°F	374	383	385	388	397	375	351	323	341	349	357	360	392	397	404	401	372	341	349	341	331	323	321	397	400	386	376	
35		Average		°F	373	384	395	400	407	386	364	323	337	347	358	364	390	400	408	410	384	354	363	350	338	329	324	385	380	370	367	
36				——																												
37	Engine Temperatures – Base	Cylinder number	1	°F	269	273	279	279	279	272	261	249	244	259	263	265	277	282	284	281	267	255	266	261	256	253	252	275	276	272	270	
38			2	°F	231	234	239	237	239	231	223	218	222	226	229	230	239	240	241	241	233	223	233	228	223	221	219	246	246	241	238	
39			3	°F	256	260	267	267	270	264	253	242	247	251	255	256	268	272	273	275	263	249	263	258	254	251	249	275	274	268	266	
40			4	°F	226	230	239	239	240	236	231	217	222	225	230	231	240	243	246	246	239	228	241	236	231	229	225	255	254	249	245	
41			5	°F	263	267	275	279	279	273	265	249	255	259	263	264	276	282	283	284	273	262	278	272	267	263	260	285	282	279	276	
42			6	°F	219	223	233	236	233	233	227	212	215	219	222	223	231	239	239	238	231	220	236	230	225	222	218	243	243	237	235	
43			7	°F	—	259	275	275	255	271	265	244	247	250	251	253	271	275	277	277	267	251	272	265	260	257	254	278	274	267	267	
44			8	°F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
45			9	°F	249	251	266	265	265	257	245	239	243	248	252	255	263	266	270	268	257	245	263	257	253	248	243	271	268	264	263	
46			10	°F	237	239	247	245	249	237	227	225	229	232	236	240	248	246	248	249	240	229	237	231	227	224	221	248	247	242	240	
47			11	°F	265	269	277	274	274	264	254	250	255	259	264	266	275	277	280	278	267	253	269	263	259	256	253	281	277	273	270	
48			12	°F	247	251	256	253	255	243	233	229	234	238	242	244	253	253	254	255	243	222	244	239	233	230	229	257	254	249	247	
49			13	°F	251	254	261	257	258	246	237	236	240	243	247	250	257	260	261	260	249	227	252	247	241	239	238	261	259	254	252	
50			14	°F	233	236	239	237	242	229	219	220	224	227	230	232	240	240	242	241	231	220	233	227	222	219	216	243	243	239	235	
51		Average		°F	245	249	258	257	257	250	241	233	237	241	245	247	257	260	261	261	251	237	253	247	242	239	236	263	261	256	254	
52				——																												

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MR No. L5L18

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Table II Cylinder Temperatures

Engine make Wright Aero. Corp. Model R-2600-22 Mfg. No. 426724 Prop. red ratio 16:7 Comp. ratio 6.9:1	Blower imp. dia. 11in. Gear ratio 7.06:1 10.06:1 Master rod cylinders Nos.1 and 12 Spark advance 20°	Prop. make Curtiss Type Electric No. of blades 4 Cuffs Removed Fan Curtiss No.1	Carb. model PR48A1 Make Stromberg Serial No. 343544	Fuel Spec. No. ANF-28 Grade 130 Oil-Grade 1120	Magneto make American Bosch Serial Nos. RH,S-1998 LH,T-1644 Model SF14LU-10 Plugs LS-87	Equation (2) $\Delta t_g = .8[t_c + 18(\frac{rpm}{1000})^2]$

Sheet 3 of 3

Test of Wright R-2600-22 Cooling Correlation

1	Test identification	Series number		——	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4
2		Run number		——	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	477	478	479	480	481
3		Date		——	7-25-44	7-25-44	7-25-44	7-25-44	7-25-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	7-24-44	8-23-44	8-23-44	8-23-44	8-23-44	8-23-44
4		Time		E.W.T.	AM 11:06	PM 1:04	PM 1:23	PM 1:44	PM 2:04	AM 9:59	AM 10:15	AM 10:33	AM 10:49	AM 11:08	AM 11:24	AM 11:46	PM 12:01	PM 12:16	PM 12:33	PM 12:48	PM 1:00	AM	AM	AM	AM	AM
5	ENGINE TEMPERATURES — Embedded	Cylinder number	1	°F	407	398	386	378	370	420	414	427	417	414	404	402	395	382	373	363	350	468	478	458	429	414
6			2	°F	370	362	350	349	341	394	388	394	385	379	376	364	355	349	342	325	311	433	430	408	363	386
7			3	°F	397	382	371	366	358	418	408	415	408	404	394	388	381	373	366	354	341	452	453	433	396	400
8			4	°F	368	356	343	337	330	383	379	395	380	372	363	377	350	347	343	322	311	419	419	396	341	377
9			5	°F	375	365	353	350	341	389	378	397	390	387	375	369	362	356	349	335	320	429	435	412	374	382
10			6	°F	352	345	334	330	323	370	355	372	366	365	355	349	345	339	332	315	302	409	419	397	342	367
11			7	°F	366	353	344	342	334	367	355	383	380	376	367	362	351	348	341	331	310	431	436	416	376	385
12			8	°F	374	363	350	345	335	392	378	397	389	389	378	373	364	355	347	329	309	450	453	431	376	401
13			9	°F	390	378	361	354	345	402	394	409	402	394	382	376	366	356	347	336	311	460	465	444	411	408
14			10	°F	365	353	335	327	318	380	367	384	370	373	368	357	347	339	325	308	285	443	444	417	364	395
15			11	°F	400	388	370	361	328	415	401	420	415	409	397	394	382	371	355	343	315	472	468	451	424	403
16			12	°F	384	368	351	341	331	399	383	409	393	394	387	380	370	355	337	316	295	464	458	432	378	389
17			13	°F	400	391	375	366	355	405	399	419	413	412	402	397	387	376	360	349	328	461	466	449	418	402
18			14	°F	377	367	352	344	336	403	394	399	387	384	379	370	355	349	331	313	295	445	442	417	368	380
19		Average		°F	380	369	358	349	339	395	385	401	392	389	380	376	365	356	346	331	313	445	448	425	383	392
20				——																						
21	ENGINE TEMPERATURES — Rear spark-plug gasket	Cylinder number	1	°F	371	356	349	344	335	379	375	386	379	376	367	365	359	349	341	333	322	425	430	415	393	371
22			2	°F	336	323	317	317	310	354	349	356	349	344	339	331	323	320	313	299	286	396	393	377	336	351
23			3	°F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
24			4	°F	347	329	320	316	311	356	351	362	350	346	338	333	327	326	321	303	290	391	390	370	323	349
25			5	°F	351	334	326	323	317	357	349	365	361	356	345	342	334	332	323	313	290	402	408	386	355	355
26			6	°F	319	304	298	296	290	327	316	333	327	326	318	315	311	310	301	289	277	363	373	355	313	326
27			7	°F	335	320	312	312	305	330	321	349	343	341	331	328	319	319	309	302	283	387	393	375	343	344
28			8	°F	355	344	333	330	320	370	358	379	369	370	359	355	345	341	331	310	297	433	437	419	368	392
29			9	°F	351	335	323	317	309	353	345	361	359	351	340	336	327	322	311	305	281	415	420	403	375	368
30			10	°F	333	320	306	299	291	345	333	350	338	341	335	327	317	313	299	284	263	413	409	390	344	365
31			11	°F	360	350	335	326	317	375	362	380	377	371	361	358	348	337	324	314	289	431	427	411	389	365
32			12	°F	346	330	319	311	302	362	347	370	359	356	355	345	338	324	311	291	373	429	422	398	352	355
33			13	°F	360	347	336	330	323	362	357	377	373	369	362	358	350	340	327	319	300	424	423	412	387	365
34			14	°F	344	330	320	315	307	369	360	366	357	352	347	340	329	322	307	289	273	397	391	374	332	337
35		Average		°F	347	332	322	318	310	357	348	364	357	354	346	341	333	327	317	304	287	408	401	391	354	357
36				——																						
37	ENGINE TEMPERATURES — Base	Cylinder number	1	°F	263	256	253	251	247	266	263	267	264	264	259	255	251	245	239	233	225	281	277	267	254	253
38			2	°F	230	225	222	222	221	237	234	237	236	234	231	227	221	220	215	209	203	243	238	229	219	225
39			3	°F	260	253	250	248	246	266	263	266	265	265	260	255	248	245	239	233	227	274	265	257	246	246
40			4	°F	238	231	227	227	227	243	239	245	242	242	237	235	231	230	223	217	211	249	241	231	215	225
41			5	°F	270	264	260	258	255	277	273	277	275	274	268	261	256	254	246	239	231	288	280	268	252	259
42			6	°F	231	224	221	221	219	236	232	236	234	233	228	225	222	222	215	209	203	243	238	228	213	219
43			7	°F	250	242	252	252	249	270	263	270	267	265	257	246	240	233	—	—	—	292	—	267	247	257
44			8	°F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
45			9	°F	255	250	245	242	241	263	258	263	260	256	249	244	237	232	225	218	209	279	271	257	240	249
46			10	°F	231	227	223	222	220	241	236	240	237	238	232	227	222	219	213	205	197	255	251	243	230	235
47			11	°F	262	257	252	251	247	272	267	271	268	267	261	255	250	245	239	231	221	285	278	271	260	258
48			12	°F	240	237	233	231	229	246	241	246	246	246	242	235	231	228	220	213	205	261	256	250	237	239
49			13	°F	244	241	237	235	233	255	250	254	252	251	247	240	235	232	225	218	209	268	258	252	240	241
50			14	°F	228	222	220	218	217	236	232	235	233	233	229	225	221	216	209	203	197	245	242	233	220	226
51		Average		°F	246	240	238	237	234	254	250	254	252	251	246	241	236	232	225	219	211	266	258	250	236	241
52				——																						

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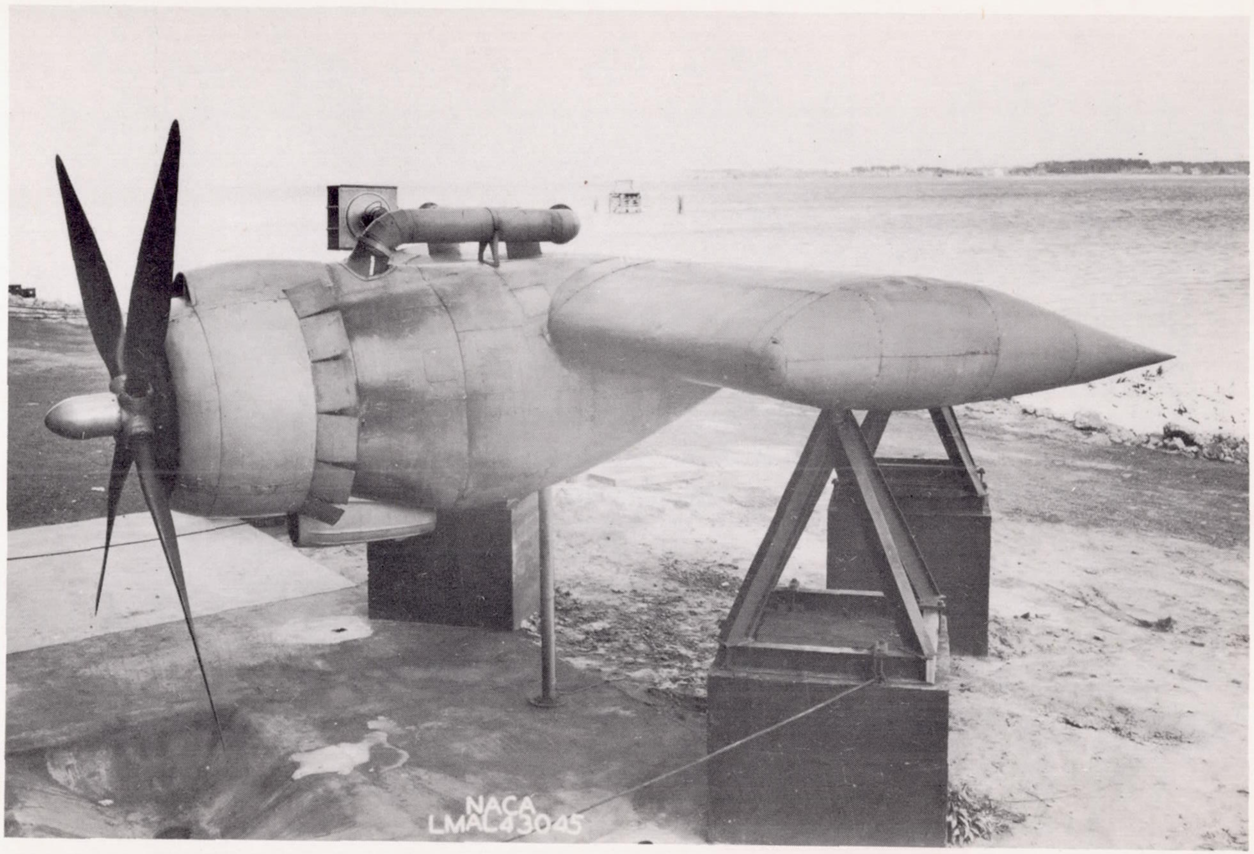
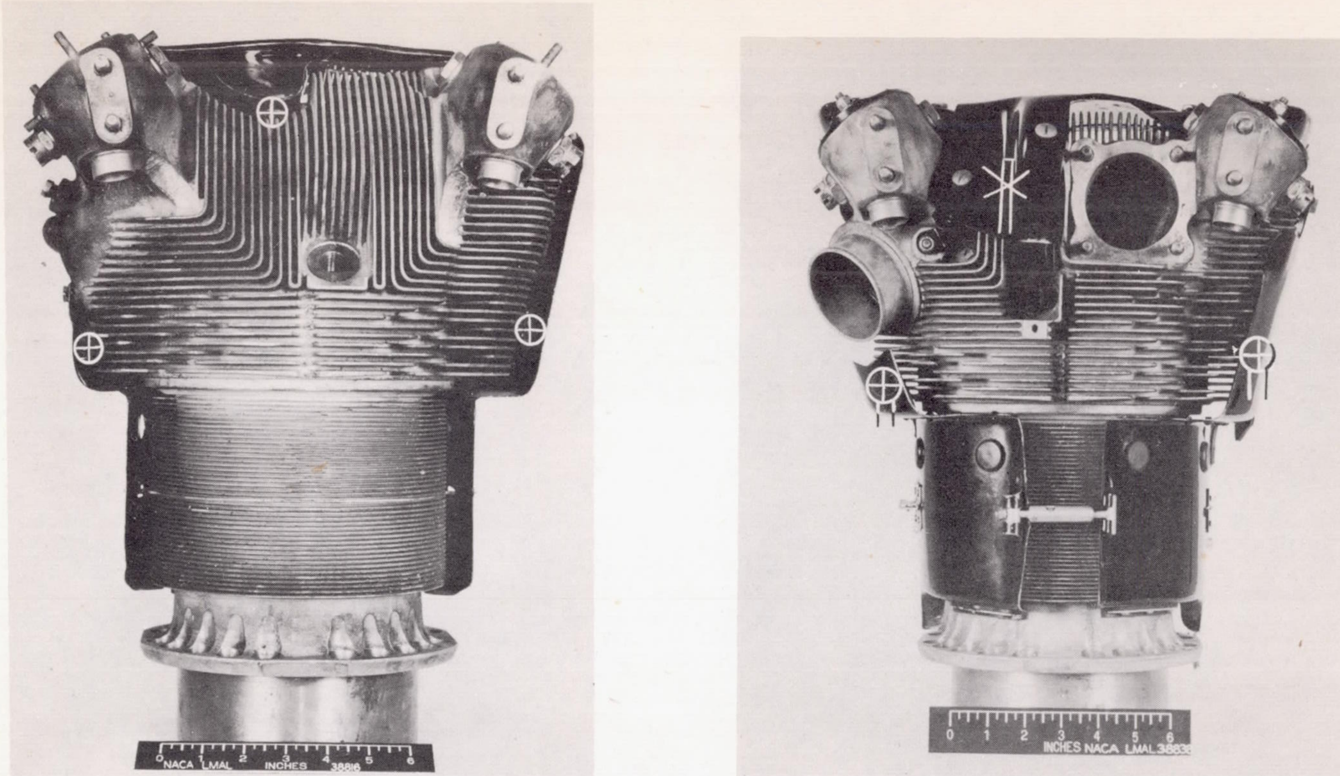


Figure 1.- R-2600-22 engine installation in PBM-3D ground-test setup.



(a) Front of front cylinder (b) Rear of rear cylinder

⊕ total-pressure tube
=⊕ open-end static tube
✳ closed-end static tube

NACA
LMAL 39117.1

Figure 2.- Locations for pressure-tube installation on R-2600 cylinders.

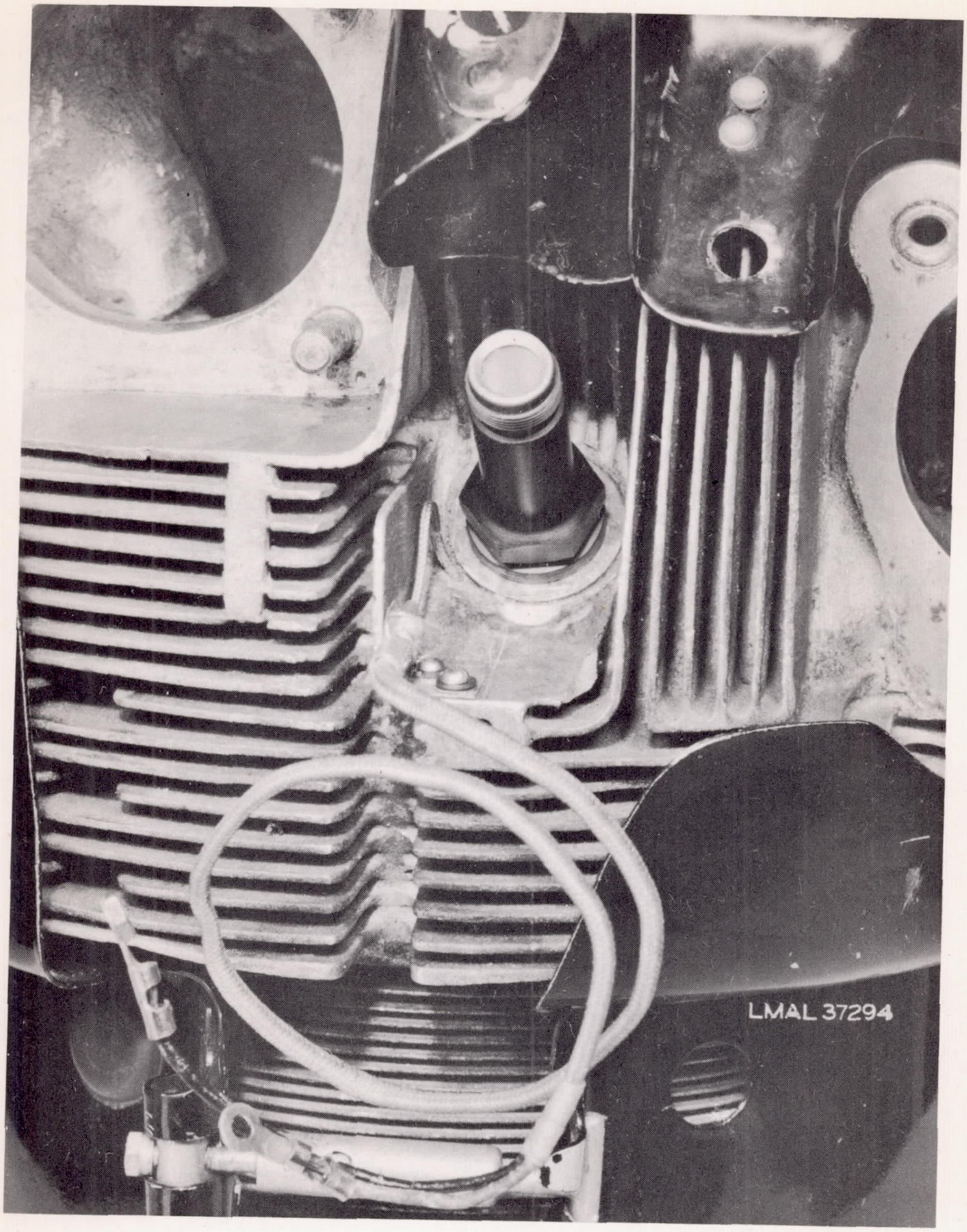


Figure 3.- Embedded thermocouple installed on front cylinder of R-2600 engine.

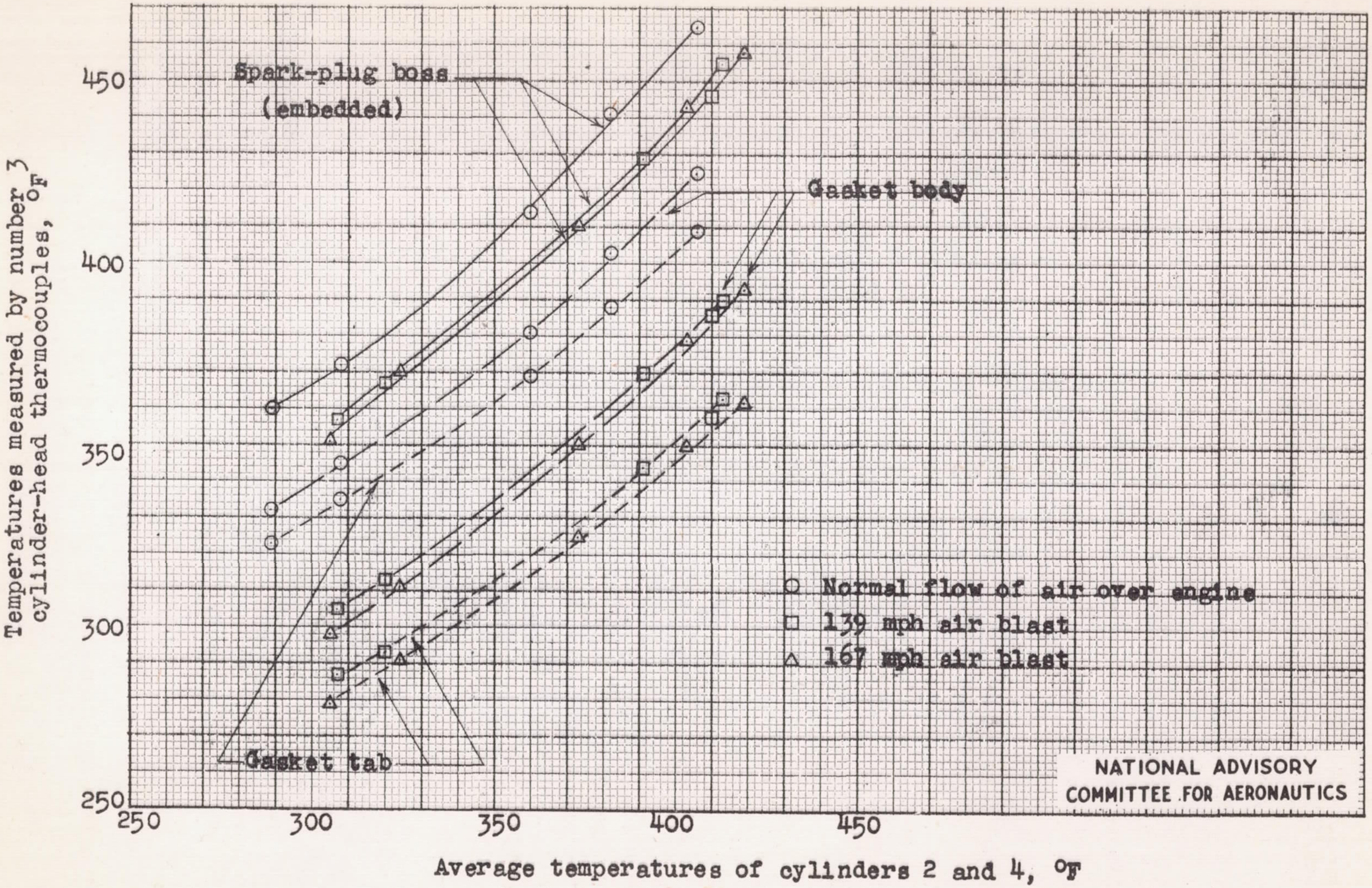


Figure 4.- Comparison of temperatures measured by test thermocouples.

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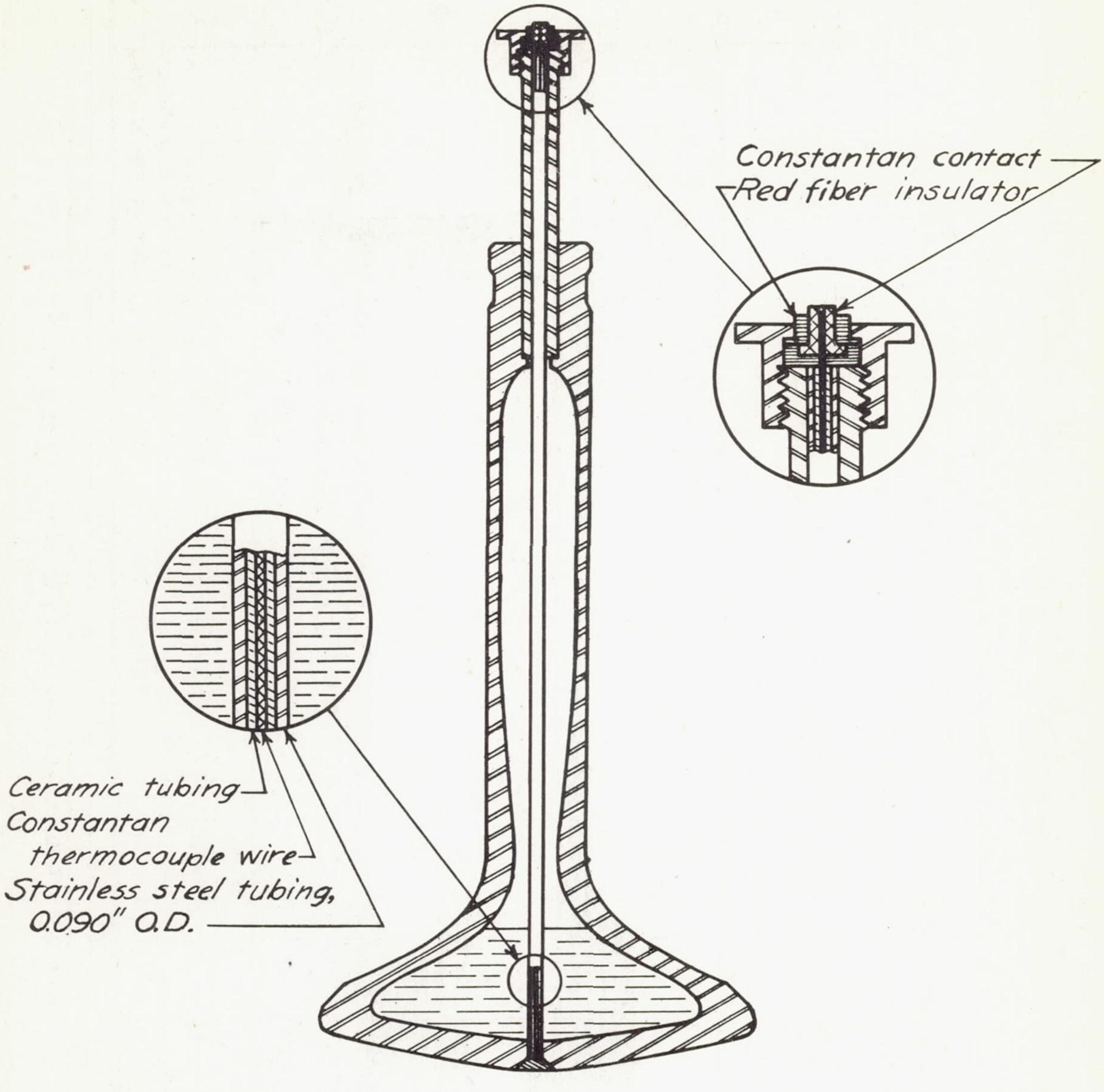

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Figure 5.- Details of sodium-cooled exhaust valve equipped with a thermocouple.

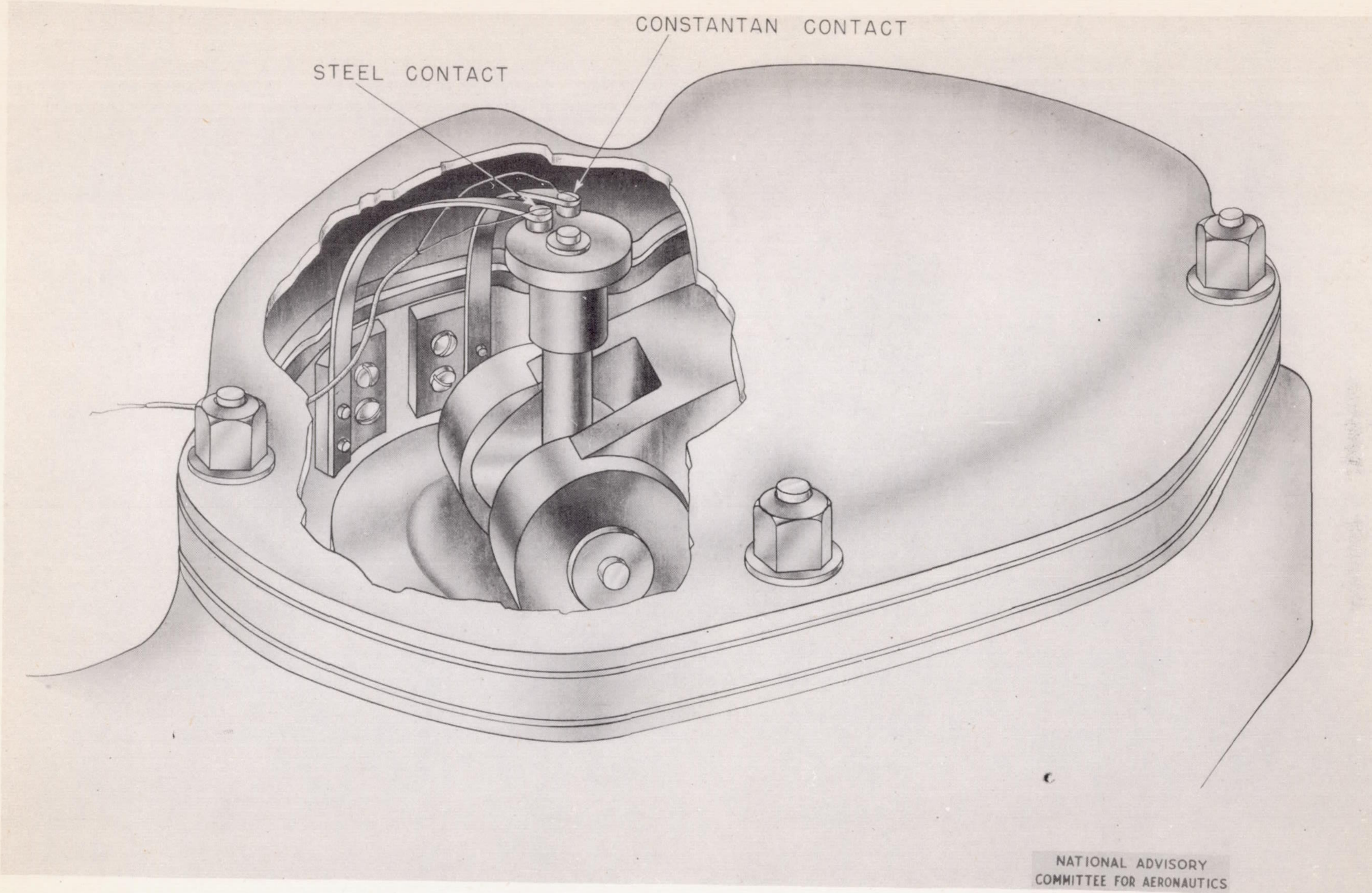

Figure 6. - General arrangement of exhaust-valve thermocouple contacts inside rocker-box of engine cylinder.

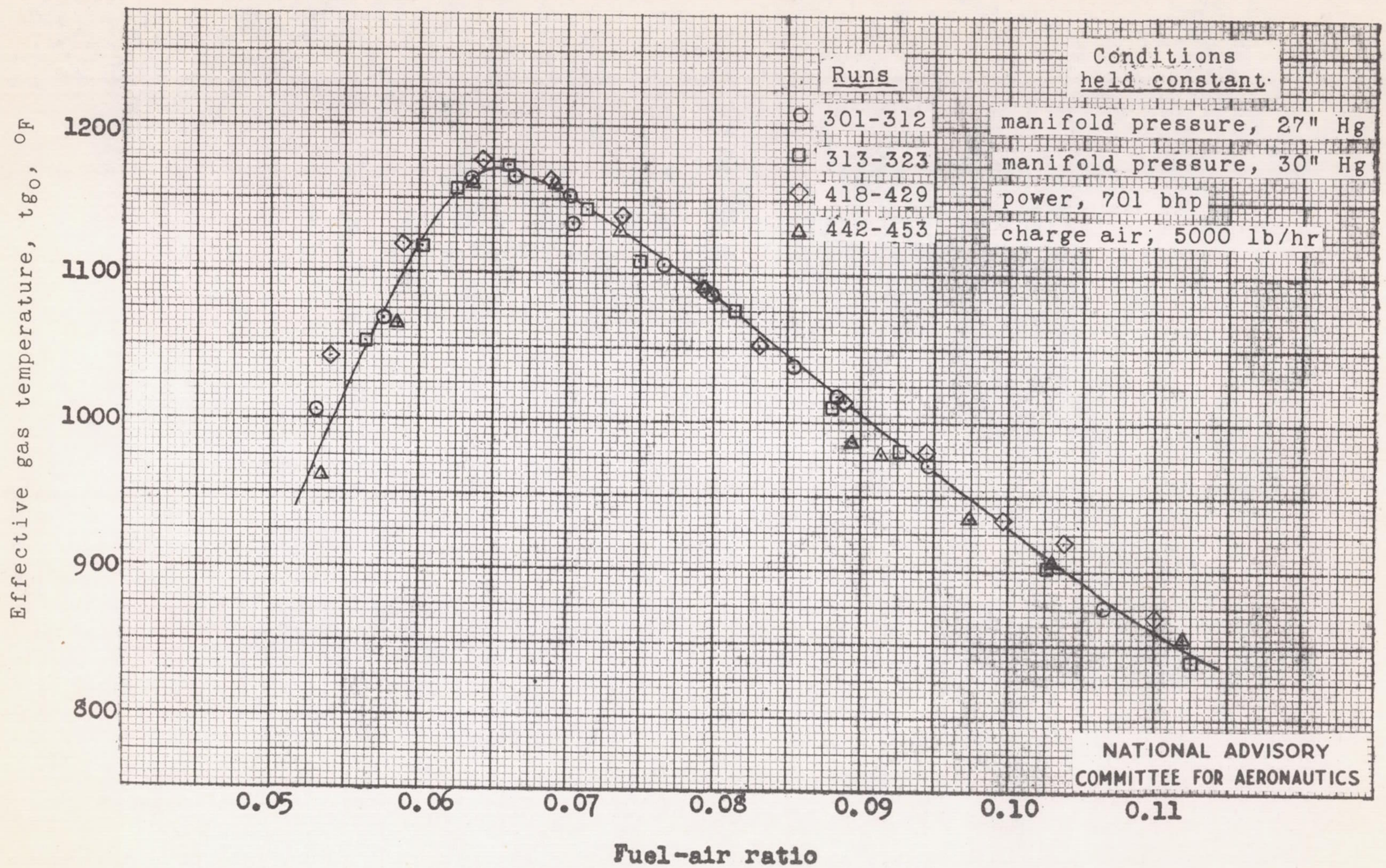

Figure 7.- Variation of effective gas temperature with fuel-air ratio. Cylinder heads; Wright R-2600-22 engine.

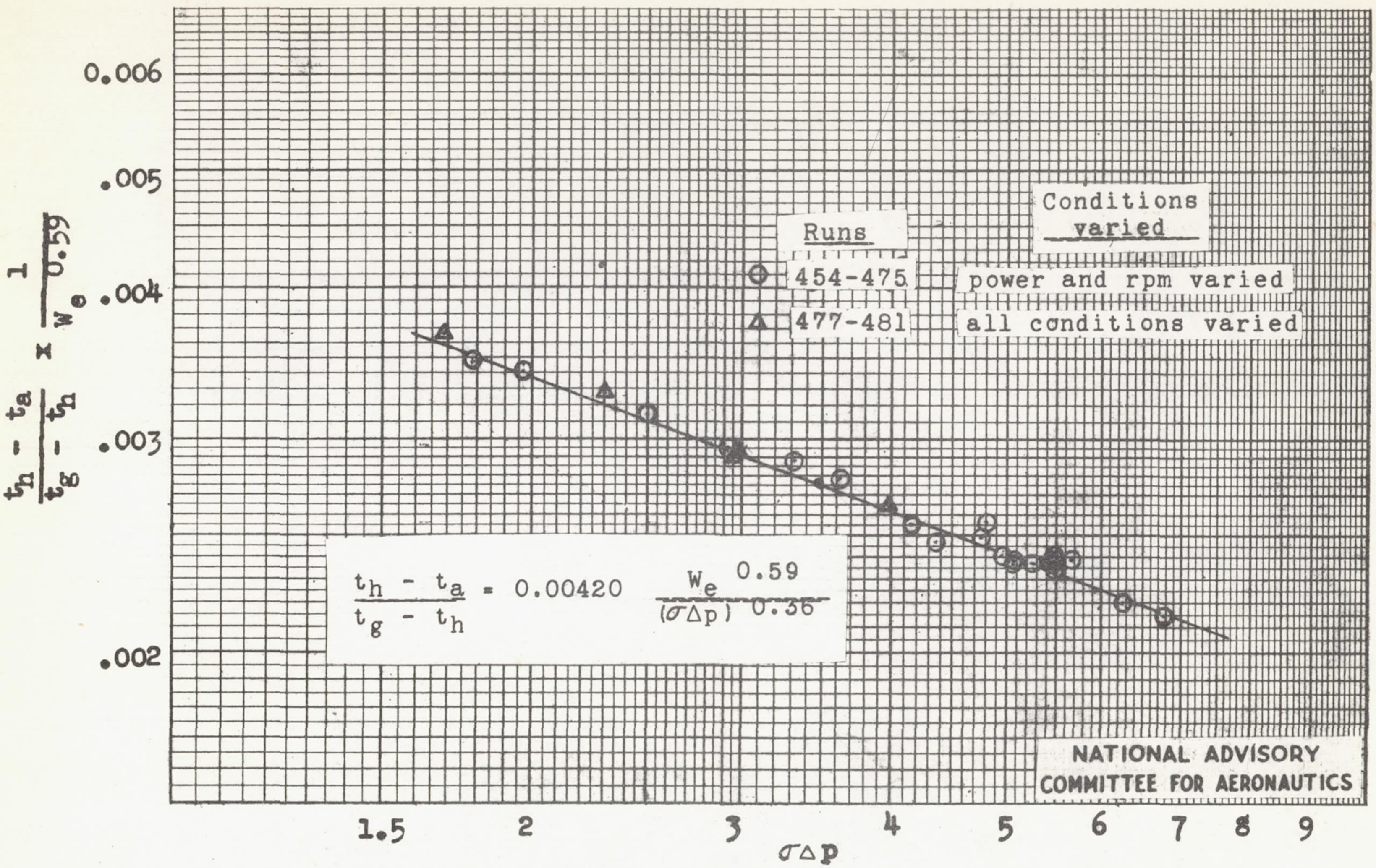

Figure 8.- Cooling characteristics of Wright R-2600-22 engine: Established correlation line referred to $\sigma \Delta p$

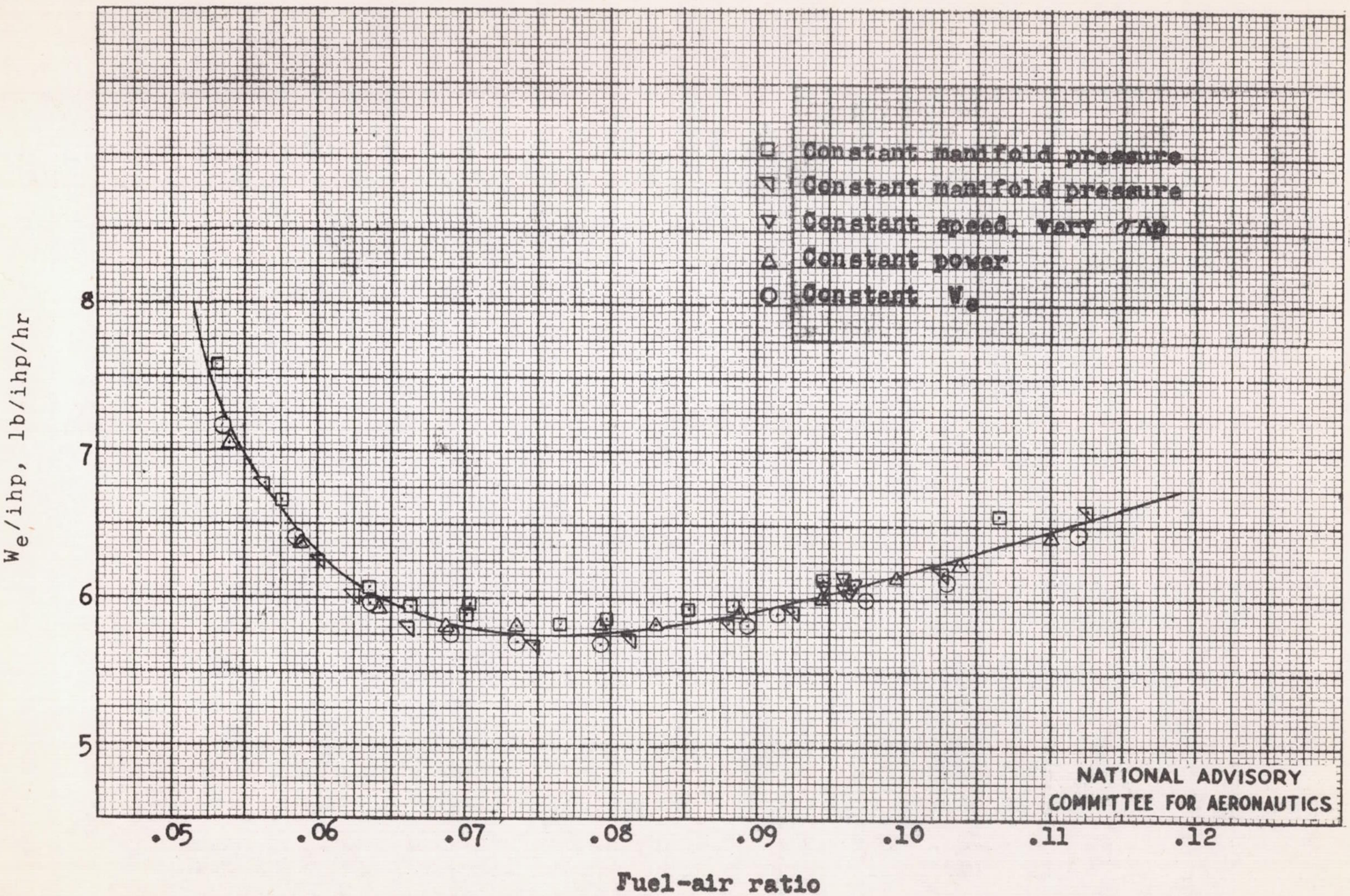

Figure 9.- Indicated specific air consumption; Wright R-2600-22 engine.

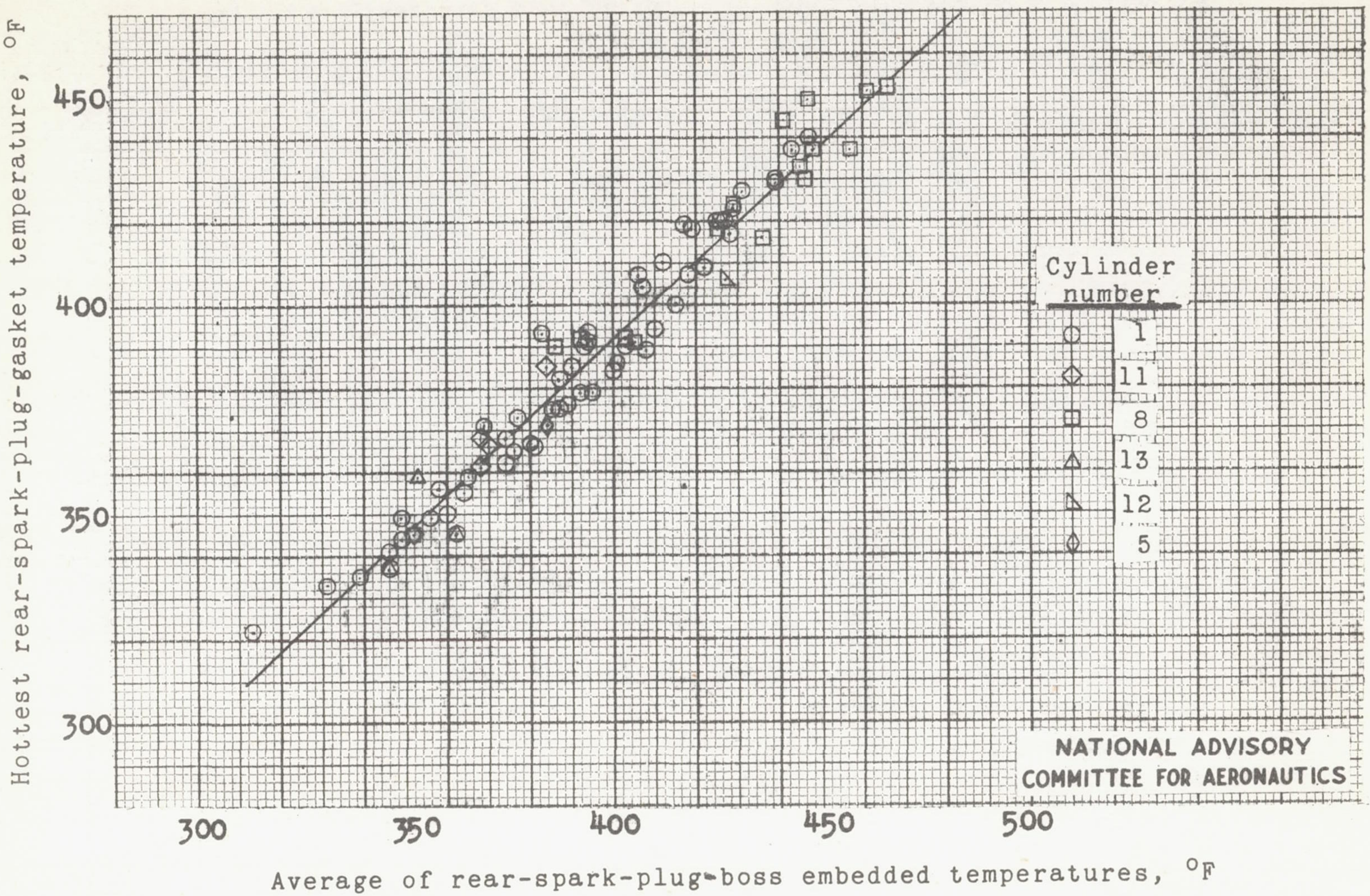

Figure 10.- Relationship of hottest rear-spark-plug-gasket temperature to average embedded head temperatures. Wright R-2600-22 engine.

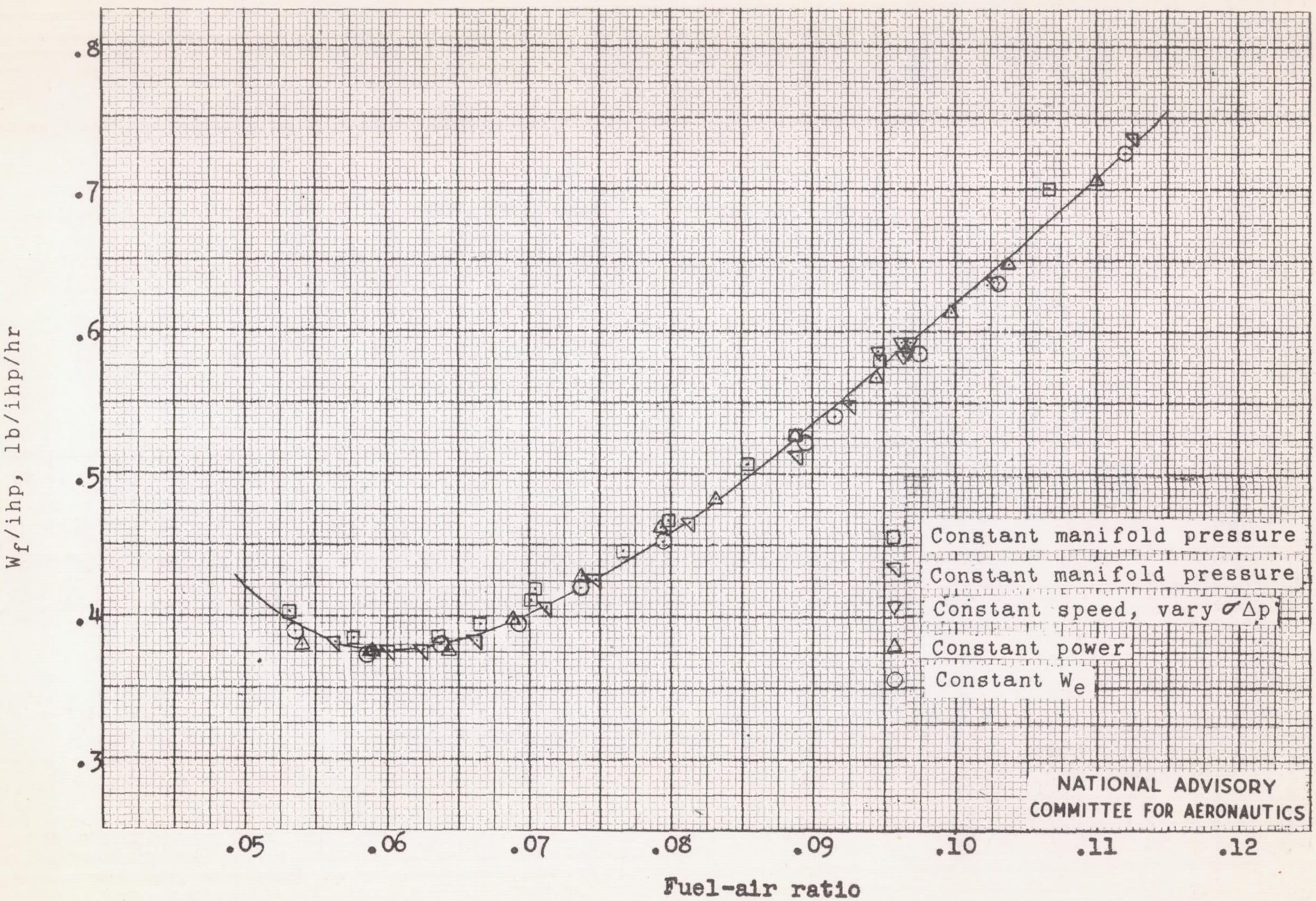

Figure 11.- Indicated specific fuel consumption; Wright R-2600-22 engine.

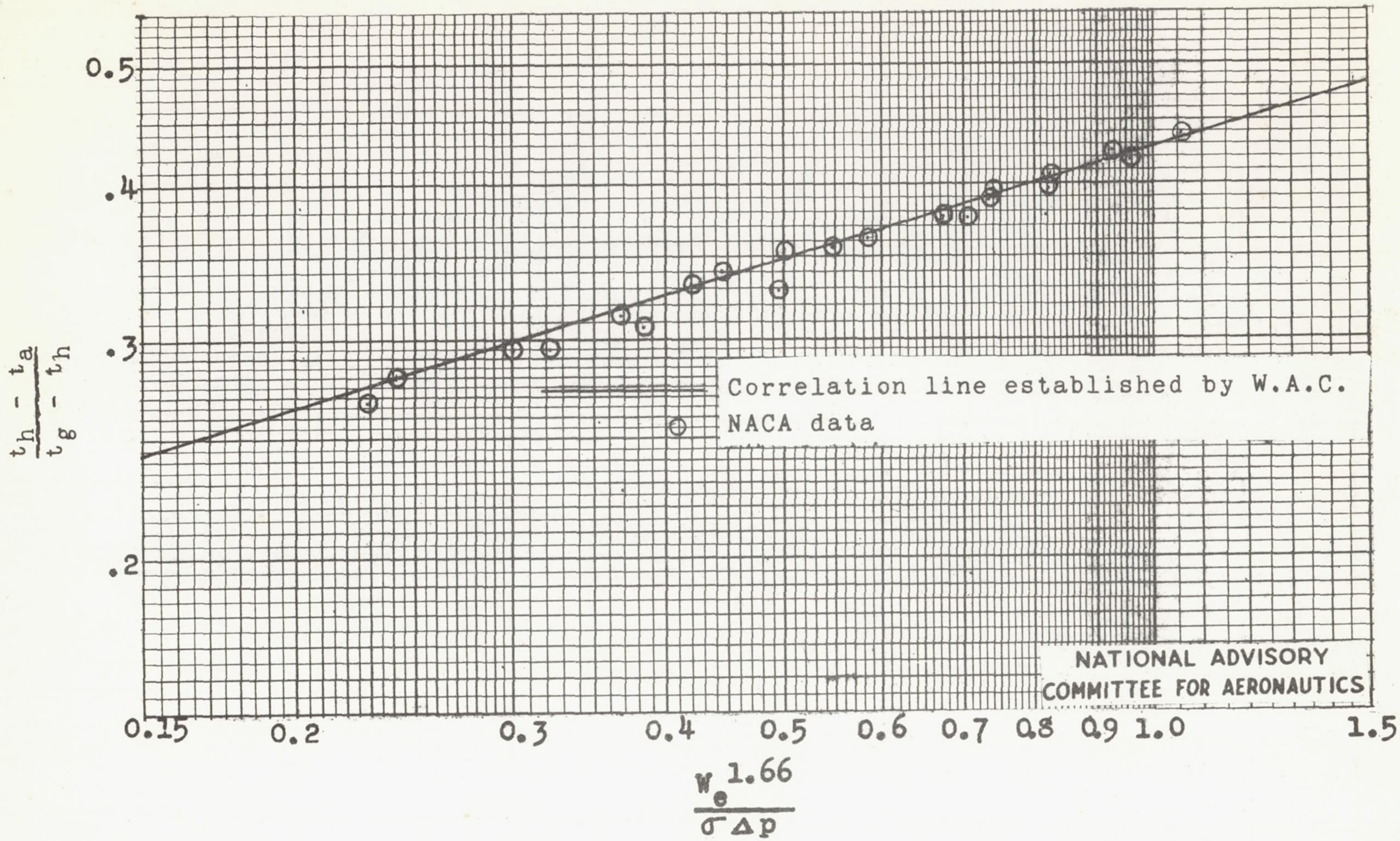

Figure 12.- Comparison of NACA data with Wright Aeronautical Corporation correlation.

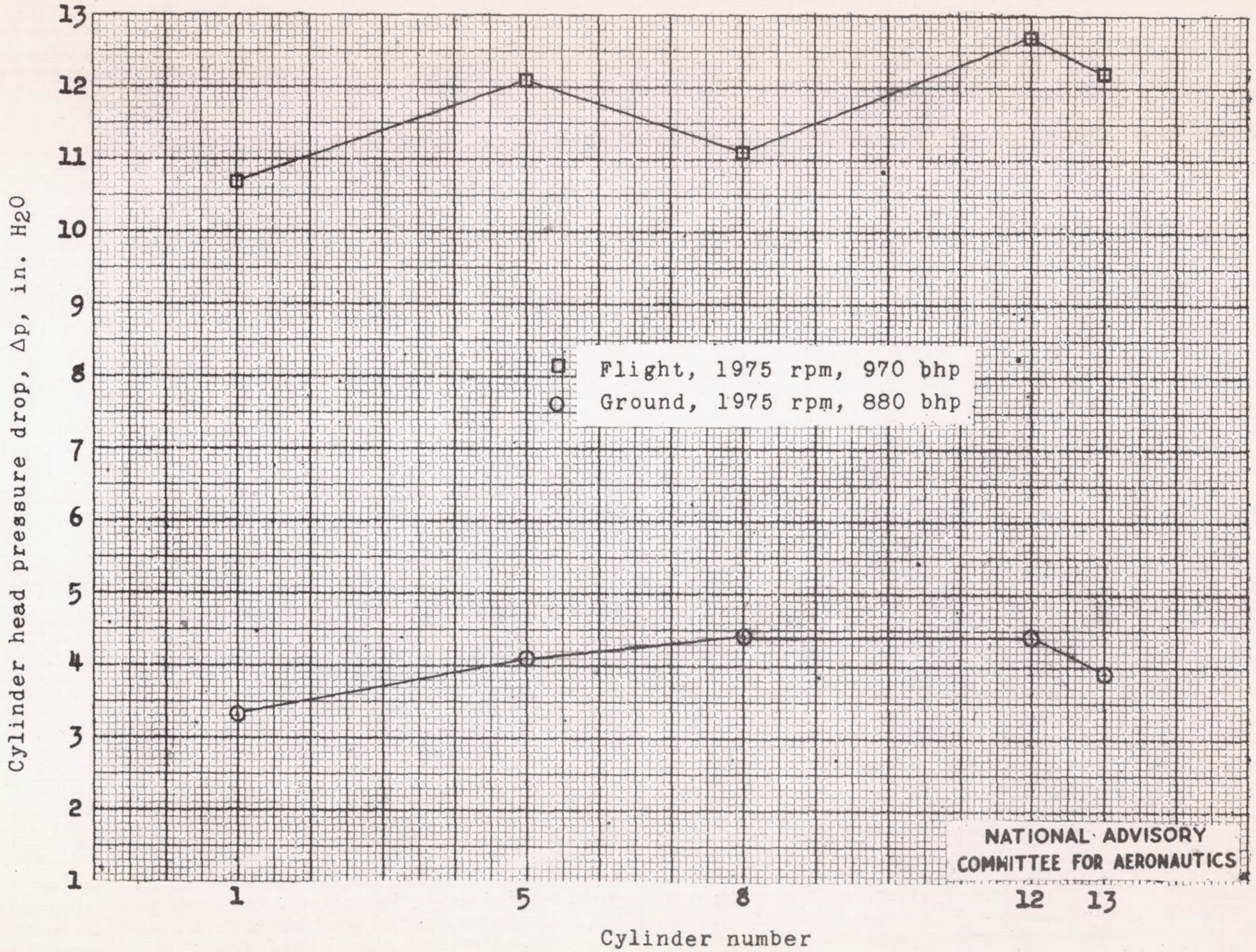

Figure 13.- Comparison of typical pressure-drop patterns for ground test and flight test. Both tests with Curtiss fans and original baffles. Wright R-2600-22 engines.

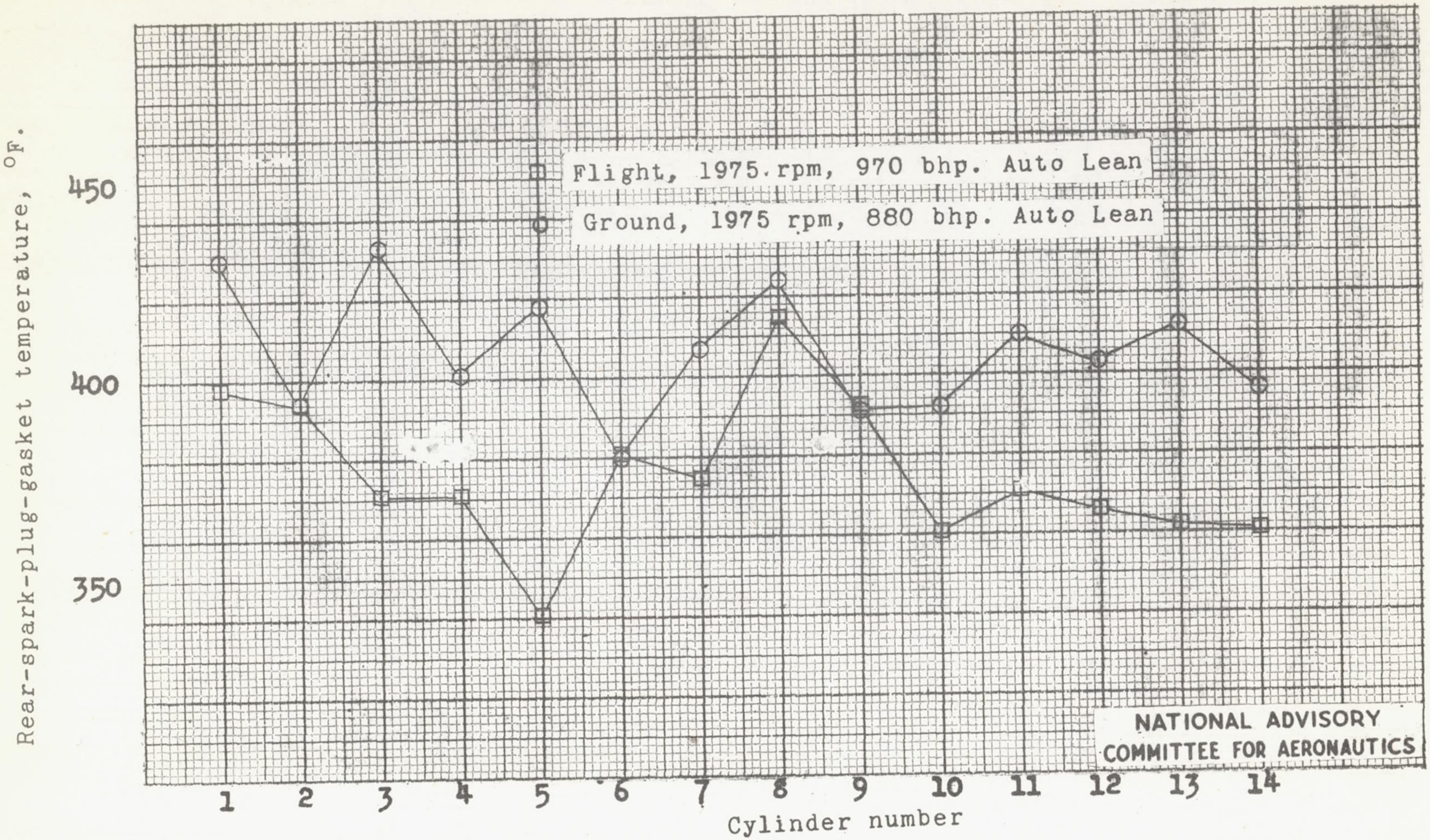

Figure 14.- Comparison of typical temperature patterns for ground test and flight test. Wright R-2600-22 engines.

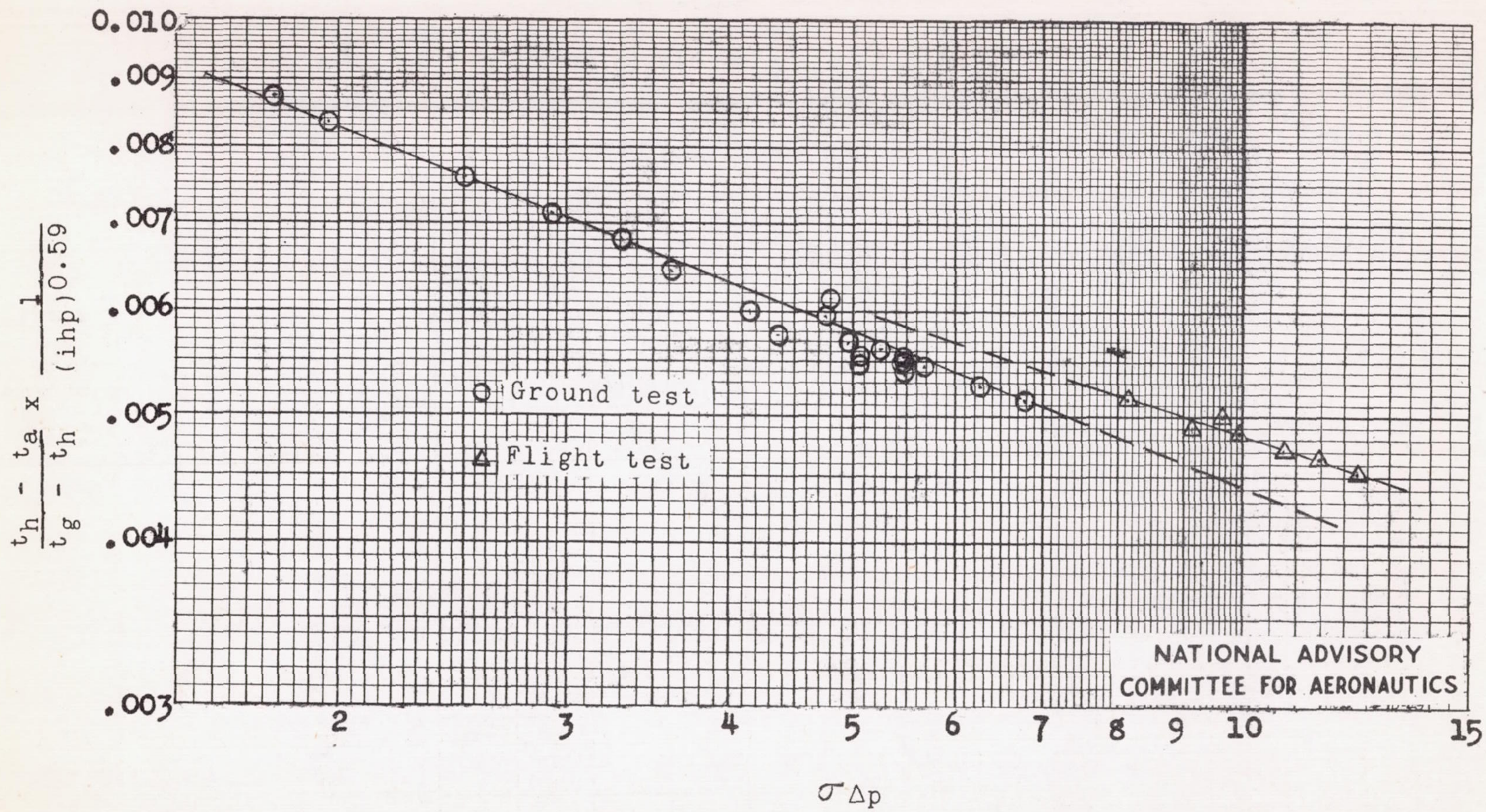

Figure 15.- Comparison of flight-test correlations and ground-test correlations. Wright R-2600-22 engines.

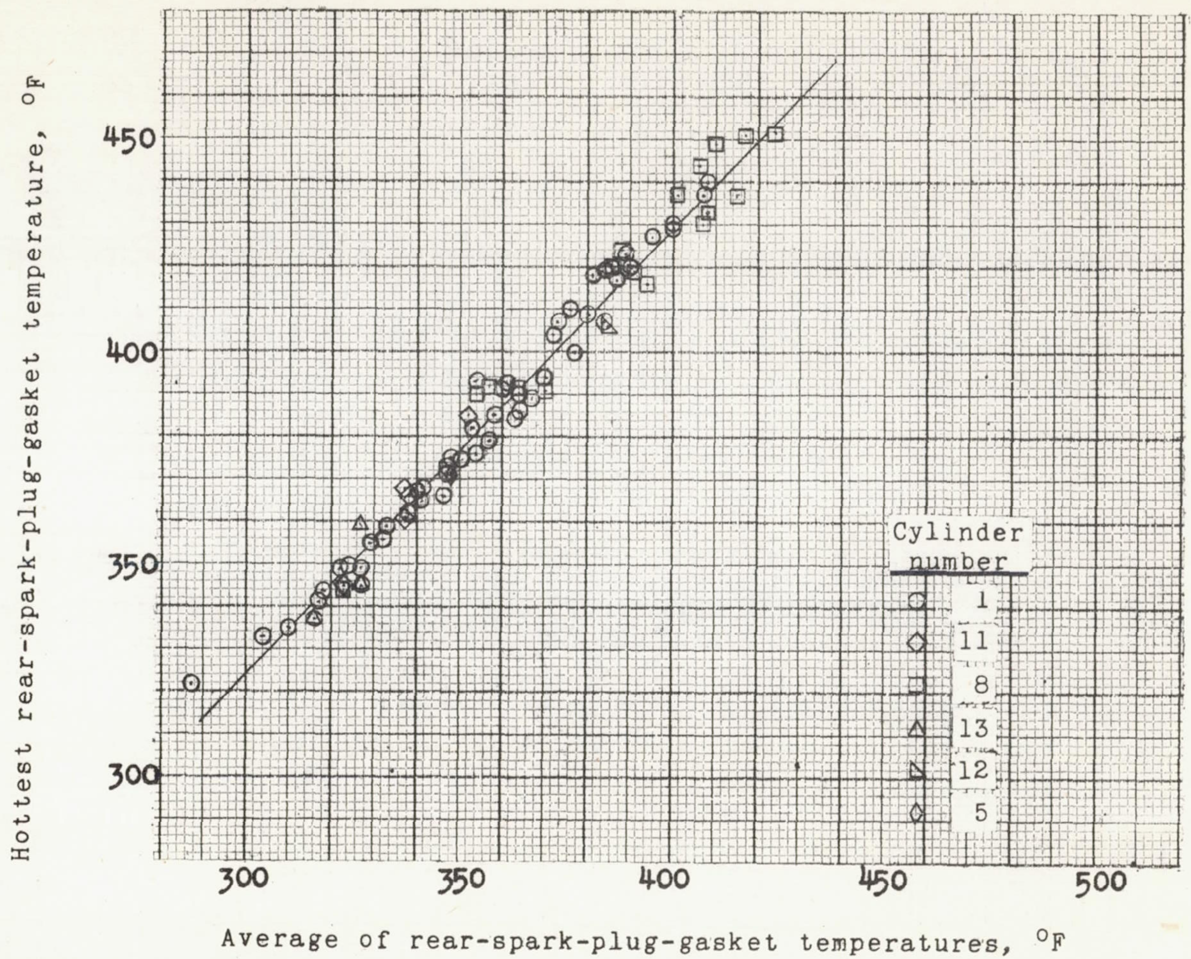

Figure 16.- Relationship of hottest rear-spark-plug-gasket temperatures to average rear-spark-plug-gasket temperatures. Wright R-2600-22 engine.

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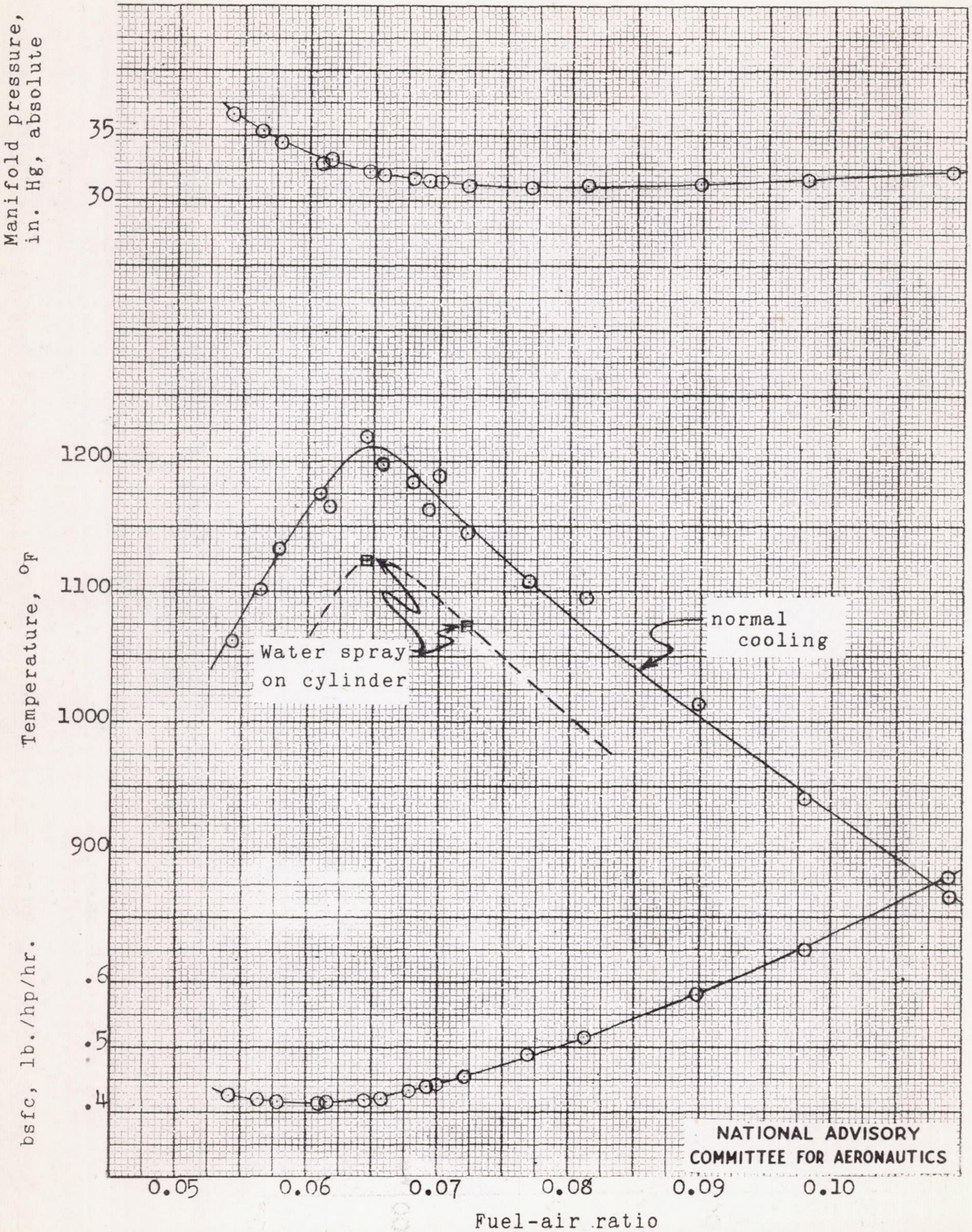

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Figure 17.- Effect of fuel-air ratio on exhaust-valve crown temperature. bsfc, and required manifold pressure. Wright R-2600-22 engine, 1975 rpm, 150 bmep.

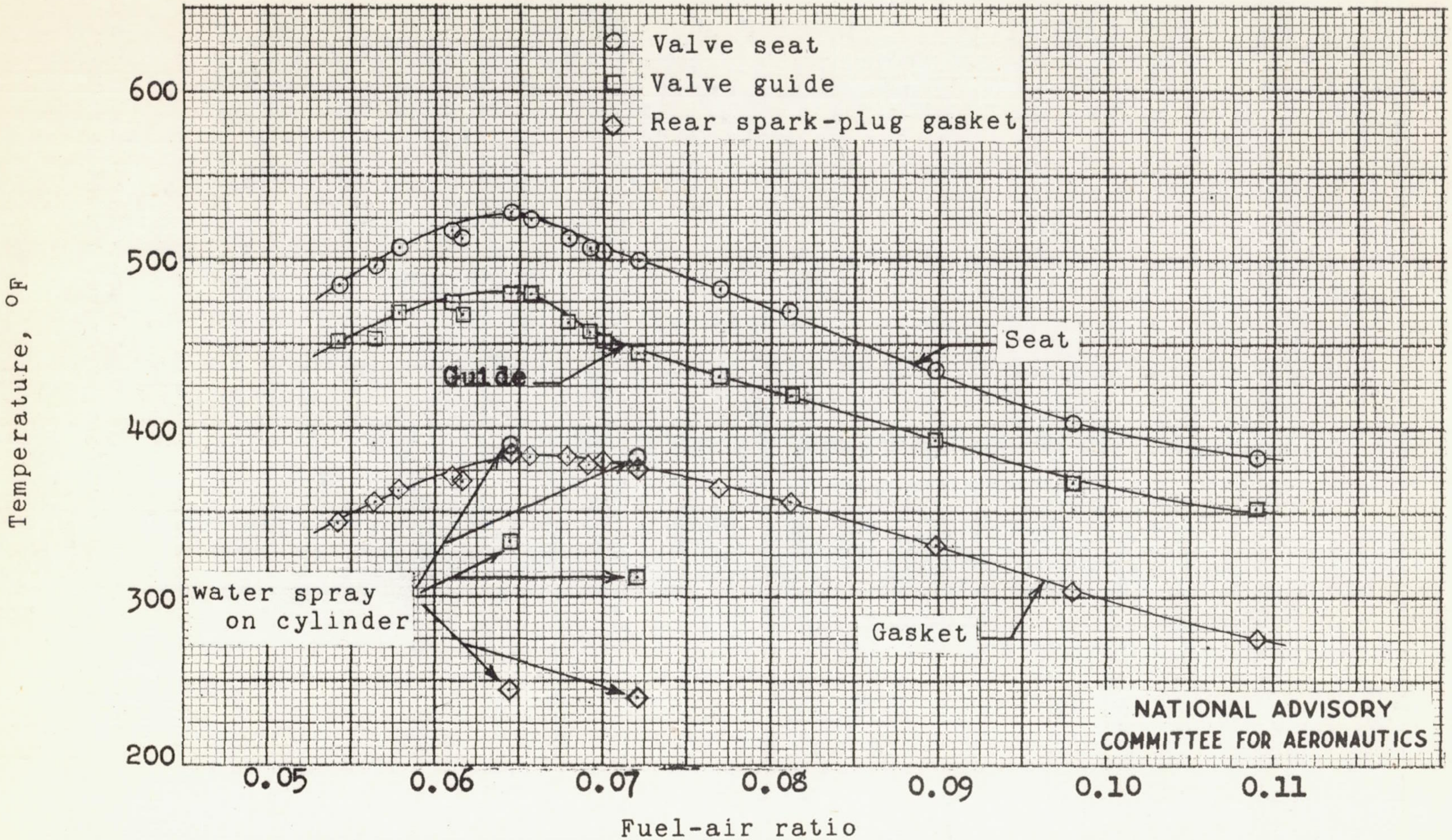

Figure 18.- Effect of fuel-air ratio on temperature of exhaust-valve seat, exhaust-valve guide, and rear spark-plug gasket. Wright R-2600-22 engine, 1975 rpm, 150 bmep.

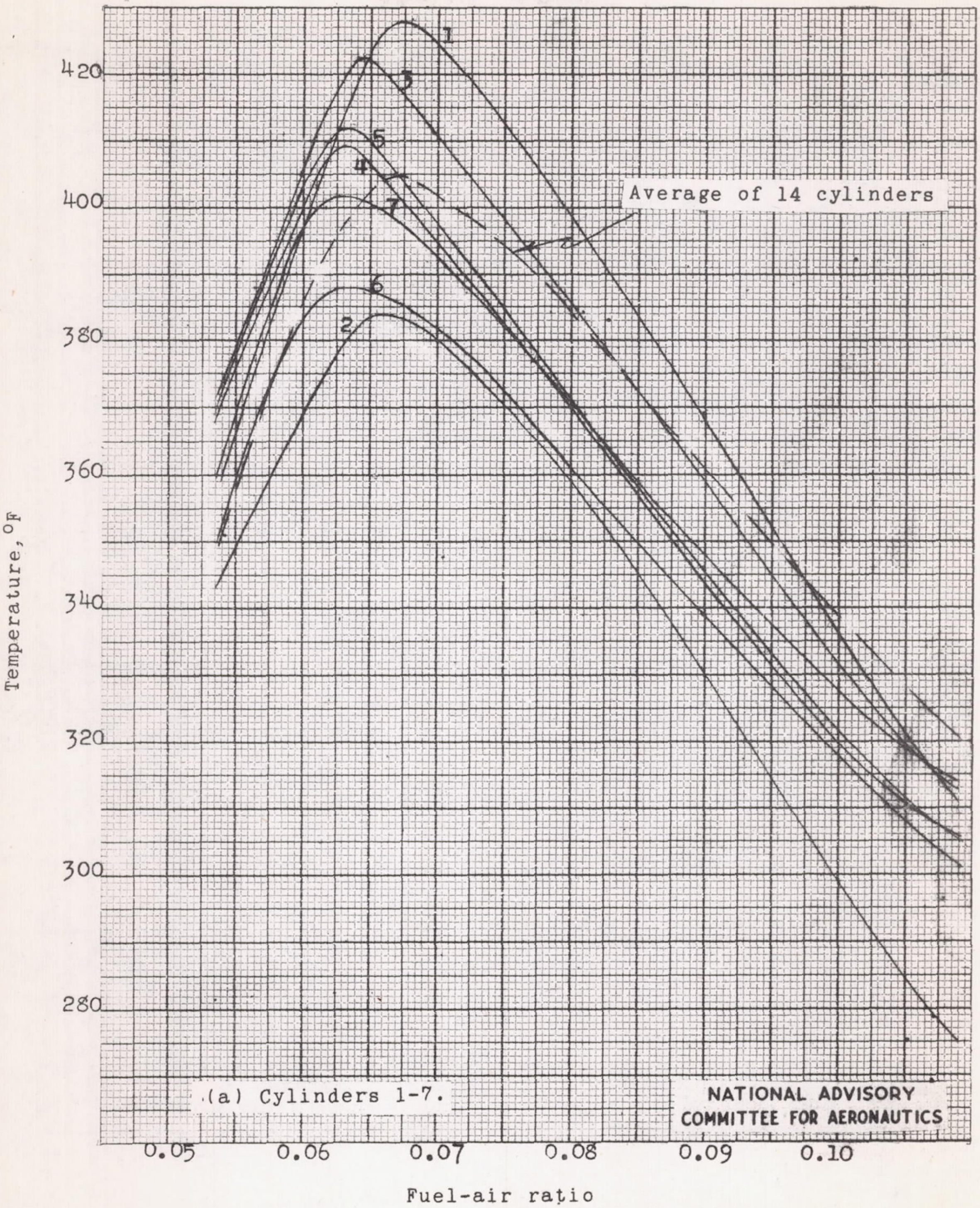

Figure 19.- Effect of changing engine fuel-air ratio on rear spark-plug gasket temperatures of different cylinders. Wright R-2600-22 engine, 1975 rpm, 150 bmep.

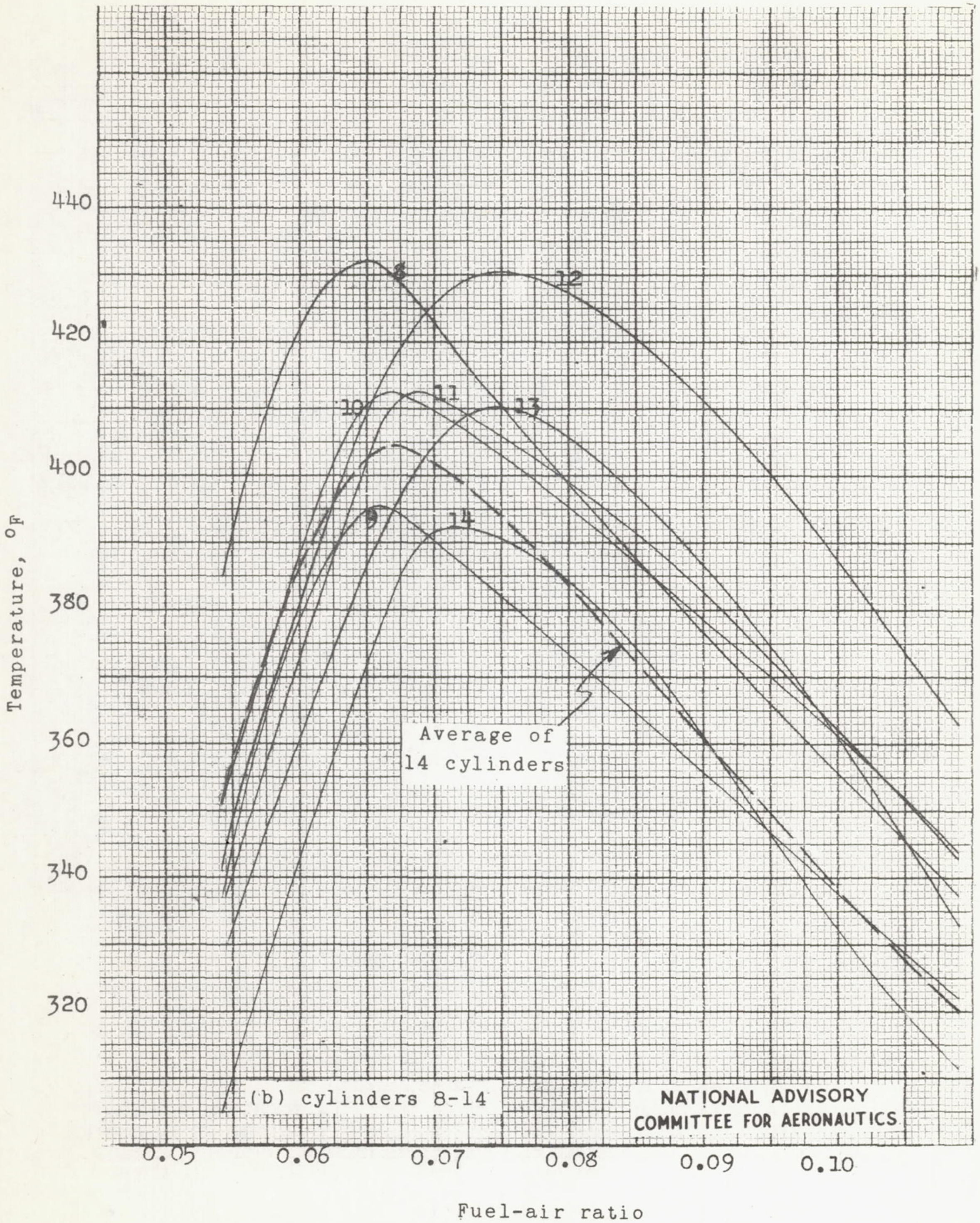

Figure 19.- Concluded.

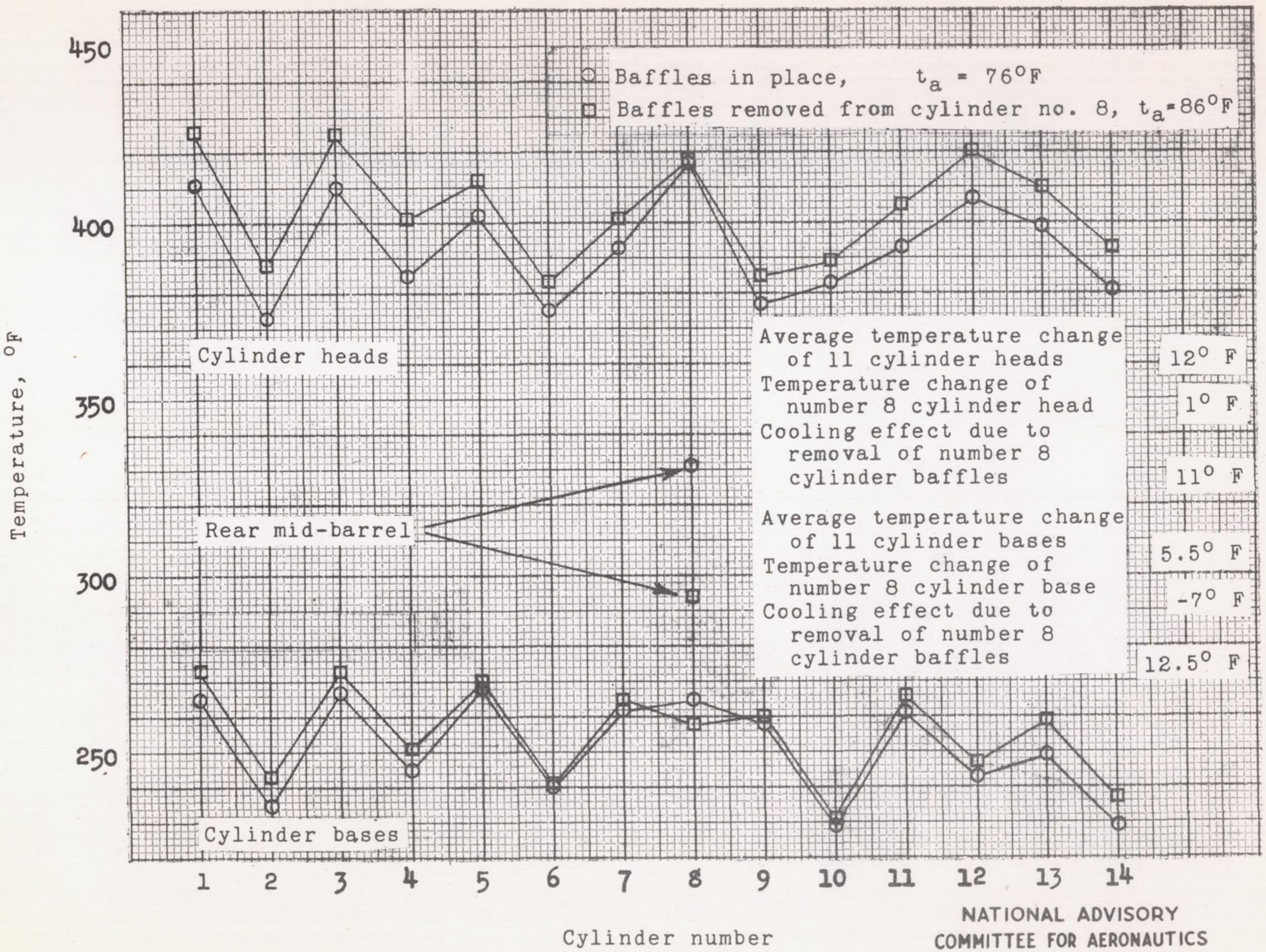

Figure 20.- Comparison of temperature patterns with baffles on and off of cylinder number 8. 1975 rpm, 0.079 F/A. Wright R-2600-22 engine. 880 bhp.