NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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OF A TWO-ROW RADIAL ENGINE INSTALLATION

III - ENGINE TEMPERATURE DISTRIBUTION

By Robert M. Rennak, Wesley E. Messing, and James E. Morgan
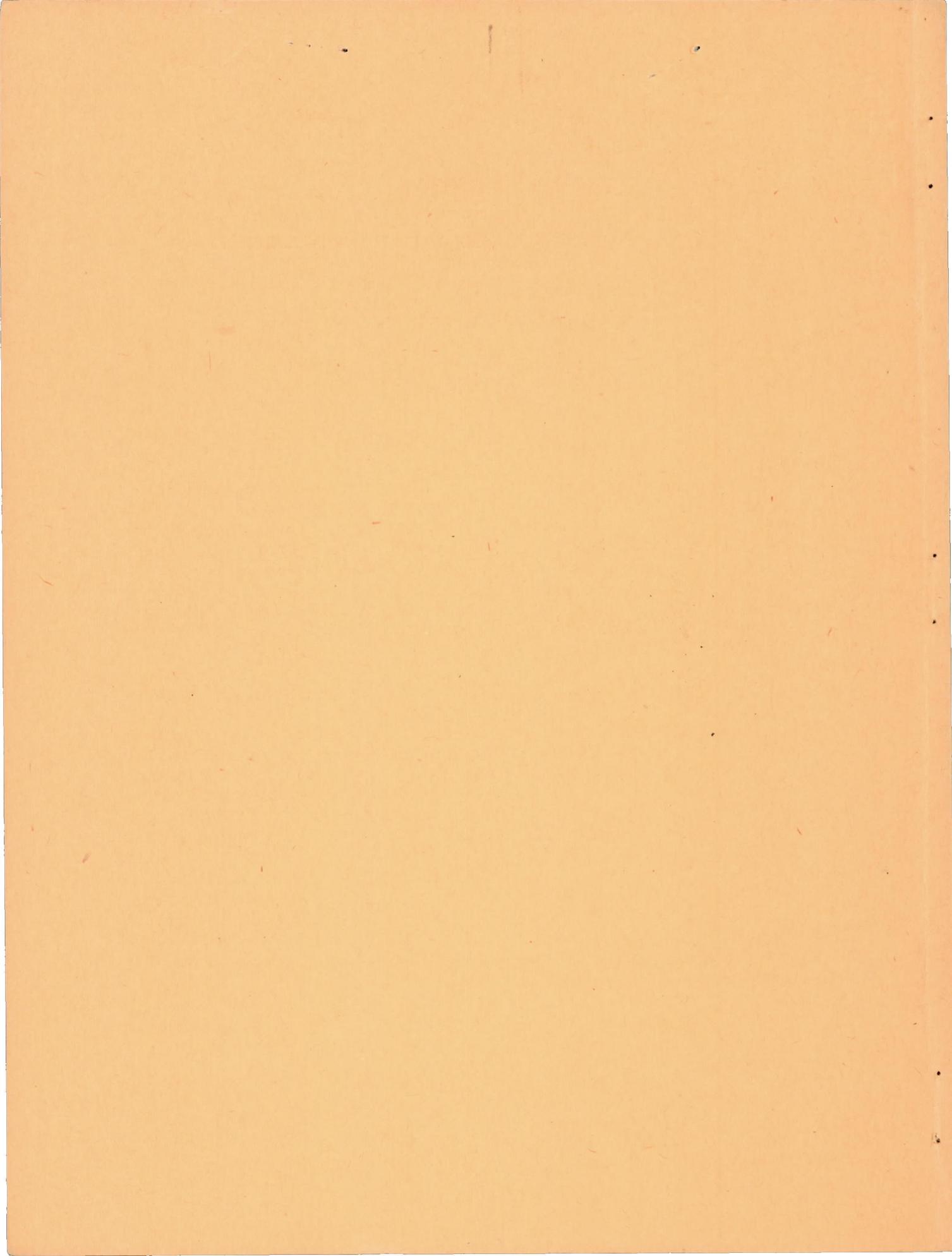
Aircraft Engine Research Laboratory
Cleveland, Ohio

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FLIGHT INVESTIGATION OF THE COOLING CHARACTERISTICS

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SUMMARY

The temperature distribution of a two-row radial engine in a
twin-engine airplane has been investigated in a series of flight
tests. The test engine was operated over a wide range of conditions
at density altitudes of 5000 and 20,000 feet; quantitative results
are presented showing the effects of flight and engine variables
upon average engine temperature and over-all temperature spread.
Discussions of the effect of the variables on the shape of the tem-
perature patterns and on the temperature distribution of individual
cylinders are also included.

The results indicate that, for the tests conducted, the temper-
ature distribution patterns were chiefly determined by the fuel-air
ratio and cooling-air distributions. It was possible to calculate
individual cylinder temperature, on the assumption of equal power
distribution among cylinders, to within an average of ±14° F of the
actual temperature. A considerable change occurred in either the
spread or the shape of the temperature patterns with a variation
in the angle of attack of the thrust axis, the average engine fuel-
air ratio, the engine speed, the power, or the blower ratio. Smaller
effects on the temperature pattern were noticed with a change in
cowl-flap opening and altitude. In most of the tests, a change in
conditions affected the temperature of the barrels less than that of
the heads. The variation of flight and engine variables had a negli-
gible effect on the temperature distributions of the individual
cylinders.

INTRODUCTION

Flight tests have been conducted by the NACA Cleveland laboratory to investigate the cooling characteristics of a two-row radial engine in a twin-engine airplane. A series of three reports present the results of the investigation. The first report (reference 1) presents a correlation of the engine-cooling variables and the application of this correlation for the determination of general cooling performance of the engine installation; the second report presents an analysis of the cooling-air pressure recovery and distribution within the engine cowling (reference 2). In the present report a temperature-distribution study is presented for the overall engine and the individual cylinders and the factors that affect the distribution are discussed.

The temperature distribution among the cylinders of an aircraft engine is an important factor that governs its performance and cooling requirements. The engine power output is frequently limited by the maximum temperature at which the hottest cylinder may operate and the excessive cooling air or the high fuel-air ratios required in many installations because of poor temperature distribution result in high fuel consumption or in excess cooling drag of the airplane. In order to obtain more information on the flight and the engine variables that affect the temperature distribution the present study was undertaken. The flight variables studied are as follows: the cowl-flap opening, which partly regulates the cooling-air pressure behind the engine and the cooling-air flow; the angle of attack of the thrust axis, which influences the streamline pattern of air flow into the cowling; and the altitude at which the airplane is flown, which affects the density and the temperature of the cooling air. The engine variables studied are average engine fuel-air ratio, engine speed, power, and blower ratio, any of which may influence the distribution of charge and of fuel-air ratio to the cylinders. Many of the variables affect the distribution of the cooling-air pressure drop across the engine, which in turn affects the temperature pattern. In this report, however, only the final effect of the variables on the temperature distribution will be presented, the cooling-air pressure distribution having been discussed in reference 2.

DESCRIPTION OF EQUIPMENT

Airplane and Engine

The tests were conducted with an airplane (fig. 1) powered with two 18-cylinder double-row radial air-cooled engines, each having a normal rating of 1500 brake horsepower at 2400 rpm and a take-off

rating of 1850 brake horsepower at 2600 rpm. The engines were
equipped with gear-driven single-stage two-speed superchargers having
a low blower ratio of 7.6:1 and a high blower ratio of 9.45:1. In
order to measure the power output of the test engine the conventional
reduction gear of 2:1 ratio was replaced by a torquemeter having the
same gear ratio. An injection carburetor that was standard for the
engine was used throughout the tests. The engine uses an impeller
slinger ring, which injects fuel centrifugally into the combustion
air stream at the inlet to the supercharger impeller. (See fig. 2.)
Each engine was equipped with a four-blade constant-speed propeller
$13\frac{1}{2}$ feet in diameter and having cuffs and spinner. The engine cowl-
ings were of the low-inlet-velocity type with the cowl flap opening
on both sides of the lower half of the cowl. (See reference 2.)

The fuel used throughout the tests conformed to specification
AN-F-28.

Instrumentation

The complete instrumentation installed in the airplane is com-
pletely described in references 1 and 2 and a detailed description
will be given of only the particular instrumentation involved in
obtaining engine-temperature data.

The right engine of the airplane was instrumented and tested.
All cylinder temperatures were measured by iron-constantan thermo-
couples and recorded by two automatic-recording potentiometers.
Three automatic selector switch-boxes were so connected that all
temperatures could be recorded within 3 minutes.

Five thermocouples were attached to each of the 18 cylinders,
three on the head and two on the barrel. (See fig. 3.) The thermo-
couples on the head were located on the rear spark-plug gasket (T12),
on the rear spark-plug boss (T35), and on the rear of the head between
the two top circumferential fins (T13). The thermocouples on the
barrel were located on the rear middle of the barrel halfway up the
finning (T6) and at the rear of the cylinder flange (T14). Thirty
additional thermocouples were located (fig. 4) on front-row cylin-
der 18 and on rear-row cylinder 7; all thermocouples were peened
into the cylinder to a depth of one-sixteenth inch except those on
the flange, which were spot-welded to the surface. These thermo-
couples were added to obtain a survey of the temperature distribution
of individual cylinders. The cylinder numbering system used was con-
ventional; that is, the cylinders were numbered clockwise when viewed
from the rear with cylinder 1 at the top.

In addition to standard engine instruments the test engine was provided with means of obtaining values of fuel flow, engine charge-air flow, cooling-air temperature and pressure, and manifold pressure. The angle of attack of the thrust axis was measured by a pendulum-type inclinometer and the cowl-flap positions were measured by an electrical transmitter and indicator. Fuel-air ratios were determined for the individual cylinders by means of Orsat analyses of the exhaust gases. When no exhaust samples were obtained, the average engine fuel-air ratio was calculated from the fuel flow and the charge-air flow (reference 1). Continuous records of airspeed, altitude, engine speed, and torque were obtained by the use of standard NACA recording instruments.

All cooling-air pressures were recorded either by means of an NACA 30-cell recording manometer or by a multiple-tube liquid-manometer board that was photographed during flight.

TESTS AND PROCEDURE

The data were obtained from flights in which the effect of any one variable on the temperature pattern could be isolated. Tests were conducted at density altitudes of 5000 and 20,000 feet, 800 to 1500 brake horsepower, engine speeds from 1800 to 2600 rpm, and at high and low blower ratio. During the tests, all of which were made at level flight, the cowl-flap opening, the airspeed, the angle of attack of the thrust axis, and the fuel-air ratio were varied independently, which sometimes necessitated lowering the landing flaps and the landing gear. Although it was impossible to maintain precisely the desired conditions at all times, the variations that occurred were slight. Conditions were set, held constant for approximately 4 minutes to allow for stabilization, and then all measurements were recorded.

The temperature distribution among cylinders was determined by using thermocouple T13 at the rear of the head between the two top circumferential fins for the heads and thermocouple T6 at the rear middle of the barrel for the barrels. Thermocouple T13 gave temperature readings that were proportional to the average head temperature T_h that was determined from the average temperature of 21 head thermocouples (fig. 4). The relation of T13 and T_h is presented in figure 5 for cylinders 7 and 18 for altitudes of 5000 and 20,000 feet.

In order to show the variation in temperature distribution with operating conditions, the temperatures T13 and T6 were plotted for the various cylinders. Because of the difference in the average

cylinder temperature of the front and the rear rows, they were plotted
separately to make the trend resulting from a change of one of the
variables more evident. The omission of any point on the distribution
curves indicates a thermocouple failure. The temperature readings of
the head on cylinder 10 and of the barrel on cylinder 18 were unreli-
able throughout most of the tests.

All temperatures were corrected by the method given in refer-
ence 3 for the difference between the free-air temperature and the
Army summer air for the nominal altitude at which the flights were
made.

RESULTS AND DISCUSSION

General Characteristics of Temperature Patterns and Correlation

with Fuel-Air Ratio and Pressure-Drop Distribution

Before the effects of various flight and engine variables upon
temperature distribution are determined, some general characteristics
of the patterns will be noted and the chief factors contributing to the
patterns discussed. For the average of all tests the temperature
spread between the hottest and the coldest cylinder heads of the
entire engine was 101° F, whereas the corresponding spread for the
barrels was approximately half as great. The average temperature
spread of the rear row was considerably less than that of the front
row for both the heads and the barrels and the front-row cylinders
were appreciably hotter than those of the rear row. Although some
variables had a definite effect on the temperature pattern, the
general shape of the pattern of each row remained substantially
the same throughout the tests. Cylinder head 18 was predominately
the hottest for all tests, whereas no particular barrel was con-
sistently hot.

In order to investigate the extent to which individual cylinder
fuel-air ratio and pressure drop control cylinder temperature, the
distribution of these variables, together with actual and computed
head temperatures, is plotted in figure 6. The pressure drops shown
were measured by total-head tubes at the baffle entrance and static-
pressure tubes located on a rake behind each cylinder (reference 2).
The computed head temperatures were obtained by use of the cooling-
correlation equation presented in reference 1; the values of pressure
drop were modified according to the relation between the pressure-
drop method used herein and the method on which the correlation
equation is based (reference 2). The charge weight to each cylinder
was assumed to be equal because no method was available for
determining the charge distribution. Fairly good agreement exists

between the actual and calculated temperatures; the average difference
for the individual cylinders was 14° F and the difference between the
average of the patterns only 3° F. This agreement indicates that, at
the conditions tested, the characteristics of the temperature patterns
are determined chiefly by fuel-air ratio and cooling-air distribution
rather than from charge distribution or some other unaccounted-for
variable and that the maldistribution of temperature could be largely
overcome by obtaining even distributions of fuel-air ratio and cooling
air.

The computed values of head temperature are usually somewhat
higher than the actual value for the rear row and lower for the front
row (fig. 6). This difference can probably be explained by the
distribution of power between the two rows. Unpublished data on a
similar engine showed that the front row developed approximately
53 percent of the total engine power, whereas the rear row developed
47 percent. If a similar distribution is assumed for the present
tests, the agreement between the actual and computed temperatures
for individual cylinders is in the order of 10° F in contrast to the
value of 14° F obtained when the uneven distribution of power was
not considered.

Effect of Flight Variables on Temperature Pattern

Cowl-flap opening. - The effect of cowl-flap opening on temper-
ature distribution is shown in figures 7 and 8 for density altitudes
of 5000 and 20,000 feet, respectively. Little change was observed
in the general shape of the temperature patterns for either altitude
when the cowl-flap positions were changed from closed to full open
although in all cases the temperature of the bottom cylinders
decreased slightly more than the top cylinders, especially at
20,000 feet. This decrease in temperature indicates that the cowl
flaps, which extend only around the lower half of the cowling, are
more effective in cooling the bottom cylinders than the top cylinders.
Although this effect on temperature is small, it is of approximately
the magnitude that would be expected from the change in pressure
distribution shown in reference 2.

The average temperature reduction for the entire engine that
resulted from opening the cowl flaps was approximately 30° F at
5000 feet and 20° F at 20,000 feet.

Angle of attack of the thrust axis. - A variation of the angle
of attack of the thrust axis over a wide range has a decided effect
on the temperature distribution, as shown in figure 9. Although an
increase in angle of attack from 1.6° to 3.2° showed only little

change a further increase to 6.6° greatly increased the temperatures of the top cylinders and the temperature spread of both the heads and the barrels, particularly on the front row. The greater spread at the high angle of attack is due to increased spillage of cooling air over the top section of the cowling, resulting in low pressures in front of the top cylinders (reference 2) and reduced cooling-air flows to these cylinders. The general effect is an increase in the temperature of the top cylinders. The spillage of cooling air was verified by the action of tufts that were placed around the cowling and photographed in flight.

The large difference between the temperature level of the patterns in figure 9 is caused by the fact that two of the flights were made at an impact pressure of 22.0 inches of water and the third flight at 12.0 inches of water.

Altitude. - Comparisons of temperature patterns obtained at density altitudes of 5000 and 20,000 feet are presented in figure 10. All engine conditions were held constant except manifold pressure, which was decreased slightly at 20,000 feet in order to maintain constant brake horsepower. The temperatures of each pattern have been corrected to standard Army summer air for the altitude at which the tests were made.

The change of altitude from 5000 to 20,000 feet resulted in no appreciable change in either the temperature patterns or the average temperature of the heads or barrels. It is to be emphasized, however, that this very small change in average temperature is for only one specific set of operating conditions and may not be indicative of the variation in engine temperature with altitude at all operating conditions.

Effect of Engine Variables on Temperature Patterns

The effects of engine variables on temperature pattern that are discussed herein may not be applicable to all types of air-cooled engines; they should be representative, however, of engines similar to the test engine and using the same method of introducing fuel to the engine, that is, by means of an impeller slinger ring (fig. 2). During the tests made at varying fuel-air ratio, engine speed, and blower ratio, it was necessary to vary the throttle angle slightly; because this variation never exceeded 5° or one-sixteenth of the entire throttle angle, the temperature patterns should not be appreciably affected as can be determined from figure 13 of reference 4.

Fuel-air ratio. - The temperature patterns for the heads and the barrels at various average engine fuel-air ratios from 0.059 to 0.104 are compared in figure 11. The temperature distribution remains practically the same for the three highest values of fuel-air ratio, but at 0.059 the pattern changes noticeably. When the average fuel-air ratio is decreased from 0.104 to 0.083, all the cylinder-head temperatures rise but, as it is further decreased to 0.059, seven of the cylinders show a drop in temperature. Because cylinder temperatures decrease when fuel-air ratios are decreased below a value of approximately 0.067, the cylinders that became colder were the leanest ones; the other cylinders did not become sufficiently lean to drop in temperature. The patterns of the barrels show characteristics similar to those of the heads but not so pronounced. When the average engine fuel-air ratio was reduced from 0.104 to 0.059, the spread between the temperatures of the hottest and the coldest cylinder heads increased 23° F.

Engine speed. - A change in engine speed from 1800 to 2600 rpm while other conditions were held constant is shown by figure 12 to have caused a considerable increase in the spread of the temperature patterns although the characteristic shape of the patterns remained similar. The increase in engine speed resulted in a rise of 30° F in the average head and barrel temperatures and a much greater rise in the hottest head temperature. Increased temperatures are to be expected, however, because a change in engine speed, when other conditions are held constant, will cause an increase of approximately 200 indicated horsepower as shown by engine-performance curves. The observed increase of 30° F in average cylinder temperature agrees very closely with the calculated increase based on the cooling correlation equation given in reference 1.

Brake horsepower. - Figure 13 shows the effect of changes in brake horsepower on head and barrel temperature distribution. Similar patterns are observed for the heads at 800 and 1000 horsepower, whereas the patterns show a noticeable variation between 1250 and 1500 horsepower. The greater part of this difference probably results from variations in the mixture distribution that were caused by the changes of power and of throttle setting.

The temperature spread between the hottest and the coldest cylinder heads remained essentially unchanged for 800, 1000, and 1250 brake horsepower but decreased somewhat at 1500 horsepower. The general shape and spread of the barrel patterns did not change significantly at any of the four power conditions. The temperature levels increased progressively as the power was increased although they may have been slightly affected due to the small variations of impact pressure.

Blower ratio. - The cylinder temperature patterns with the engine in high and low blower ratios are compared in figure 14. The pattern of the head temperature varied considerably, probably owing to a change in fuel-air-ratio distribution effected by change in blower ratio (reference 4), whereas the barrel temperature pattern showed only a slight variation. When the engine was operated in high blower ratio, the average temperature was slightly higher for the heads and the barrels than when in low blower ratio owing to the increase in temperature rise across the supercharger and the increase in indicated horsepower. The change from low to high blower ratio had only a slight effect on the over-all spread of the head and the barrel temperatures.

Temperature Distribution of Individual Cylinders

A study was made of the temperature distribution of front-row cylinder 18 and rear-row cylinder 7 and of the effect of flight and engine variables upon the distribution. It was noted that none of the variables had an appreciable effect on the temperature distribution of the two cylinders and therefore only a comparison of the distribution at two widely different operating conditions is presented. All temperatures measured on cylinders 7 and 18 at these two conditions are listed in table I.

The longitudinal temperature distribution of cylinders 18 and 7 giving temperatures on two planes 90° apart through the center of the cylinder are shown in figure 15. Both operating conditions result in temperature-distribution patterns that are consistent in shape and similar for both cylinders. The high-power run resulted in lower cylinder temperature than the low-power run because of the rich fuel-air ratio, the open cowl flaps, and the high impact pressure. For both conditions and for both cylinders the temperatures increase progressively from the middle barrel upward toward the top of the cylinder and downward to the cylinder flange. The temperatures increase progressively directly across the top of the head from the intake to the exhaust side of the cylinder. Likewise, the temperatures increase from the top center of the head rearwardly to the spark-plug boss.

A comparison of the circumferential cylinder temperature distribution as indicated by temperatures from thermocouples evenly spaced around the head and the barrel for the two operating conditions is shown in figure 16. In all cases the temperature distribution is quite consistent for both operating conditions although the shape of the patterns is somewhat different for the two cylinders. The highest temperatures are at the rear of the cylinder being approximately 50° F hotter than the front for the heads and 35° F and 75° F hotter for the barrels of cylinders 18 and 7, respectively. The greater

temperature differential that exists between the front and rear of cylinder 7 is probably caused by the fact that the pressure drop across the rear row is appreciably higher than that across the front row, as discussed in reference 2.

SUMMARY OF RESULTS

From flight tests of a two-row radial engine enclosed in a low-inlet-velocity cowling, the following results were obtained:

1. When individual cylinder temperatures were calculated on the basis of known fuel-air ratio and pressure drop and on the assumption that power distribution was equal among the cylinders, the calculated values were, on the average, within $\pm 14^\circ$ F of the actual temperatures; this close agreement indicates that for the conditions at which the tests were conducted the engine temperature distribution was determined chiefly by fuel-air ratio and cooling-air distribution.

2. Changing the cowl flaps from full open to the closed position caused only small changes in the shape of the temperature patterns for density altitudes of 5000 and 20,000 feet.

3. Varying the angle of attack of the thrust axis from 1.6° to 6.6° increased the temperature spread for both the heads and the barrels, especially on the front-row cylinders.

4. An increase in density altitude from 5000 to 20,000 feet had no appreciable effect on the shape of the temperature patterns.

5. The spread or the shape of the temperature pattern changed considerably with a variation of the average engine fuel-air ratio, the engine speed, the power, or the blower ratio.

6. The variation of flight and engine variables had a negligible effect on the temperature distribution of individual cylinders.

Aircraft Engine Research Laboratory,
        National Advisory Committee for Aeronautics,
                Cleveland, Ohio, January 17, 1946.

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1. Bell, E. Barton, Morgan, James E., Disher, John H., and Mercer, Jack R.: Flight Investigation of the Cooling Characteristics of a Two-Row Radial Engine Installation. I - Cooling Correlation. NACA TN No. 1092, 1946.

2. Hill, E. John, Blackman, Calvin C., and Morgan, James E.: Flight Investigation of the Cooling Characteristics of a Two-Row Radial Engine Installation. II - Cooling-Air Pressure Recovery and Pressure Distribution. NACA TN No. 1109, 1946.

3. Schey, Oscar W., Pinkel, Benjamin, and Ellerbrock, Herman H., Jr.: Correction of Temperatures of Air-Cooled Engine Cylinders for Variation in Engine and Cooling Conditions. NACA Rep. No. 645, 1938.

4. Marble, Frank E., Butze, Helmut F., and Hickel, Robert O.: Study of the Mixture Distribution of a Double-Row Radial Aircraft Engine. NACA ARR No. E5I05, 1945.

TABLE I - TEMPERATURE SURVEY OF A FRONT- AND A REAR-ROW CYLINDER

Thermocouple designation	Temperature, °F			
	Run 1[a]		Run 2[b]	
	Front-row cylinder 18	Rear-row cylinder 7	Front-row cylinder 18	Rear-row cylinder 7
T1	292	263	300	273
T2	224	181	211	174
T3	230	202	223	192
T4	244	220	233	203
T5	250	245	230	226
T6	263	266	245	245
T7	225	236	200	223
T8	246	215	227	205
T9	231	194	223	191
T10	264	230	255	223
T11	258	226	238	214
T12	386	340	343	305
T13	412	350	374	311
T14	291	272	290	275
T15	322	270	296	262
T16	311	274	287	254
T17	323	254	293	220
T18	330	295	296	264
T19	373	329	343	303
T20	343	307	308	277
T21	317	262	283	237
T22	300	255	274	231
T23	330	296	301	263
T24	322	270	287	255
T25	364	318	326	287
T26	218	215	184	182
T27	349	281	318	261
T28	350	280	313	251
T29	455	384	414	343
T30	387	335	355	299
T31	(c)	(c)	(c)	(c)
T32	431	319	405	288
T33	400	337	363	301
T34	356	305	325	278
T35	425	358	386	318

[a]Brake horsepower, 820; engine speed, 2030 rpm; density altitude, 5000 feet; cowl flaps closed; low blower ratio; fuel-air ratio, 0.077; impact pressure, 18.9 inches of water; angle of attack of thrust axis, 5°.

[b]Brake horsepower, 1545; engine speed, 2415 rpm; density altitude, 5000 feet; cowl flaps open; low blower ratio; fuel-air ratio, 0.111; impact pressure, 29.0 inches of water; angle of attack of thrust axis, 2°.

[c]Faulty thermocouple.

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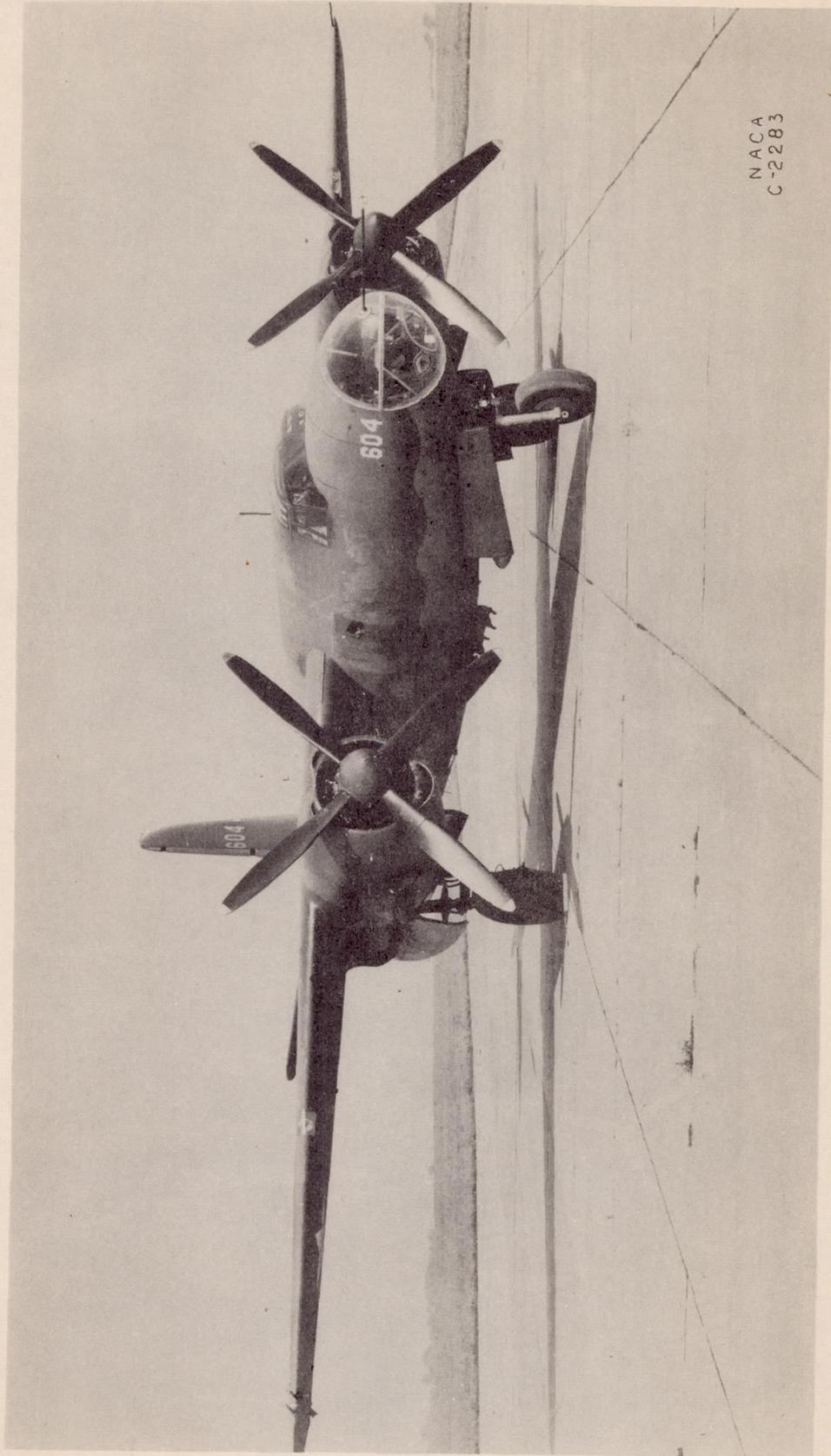
Figure 1. – Three-quarter front view of test airplane.
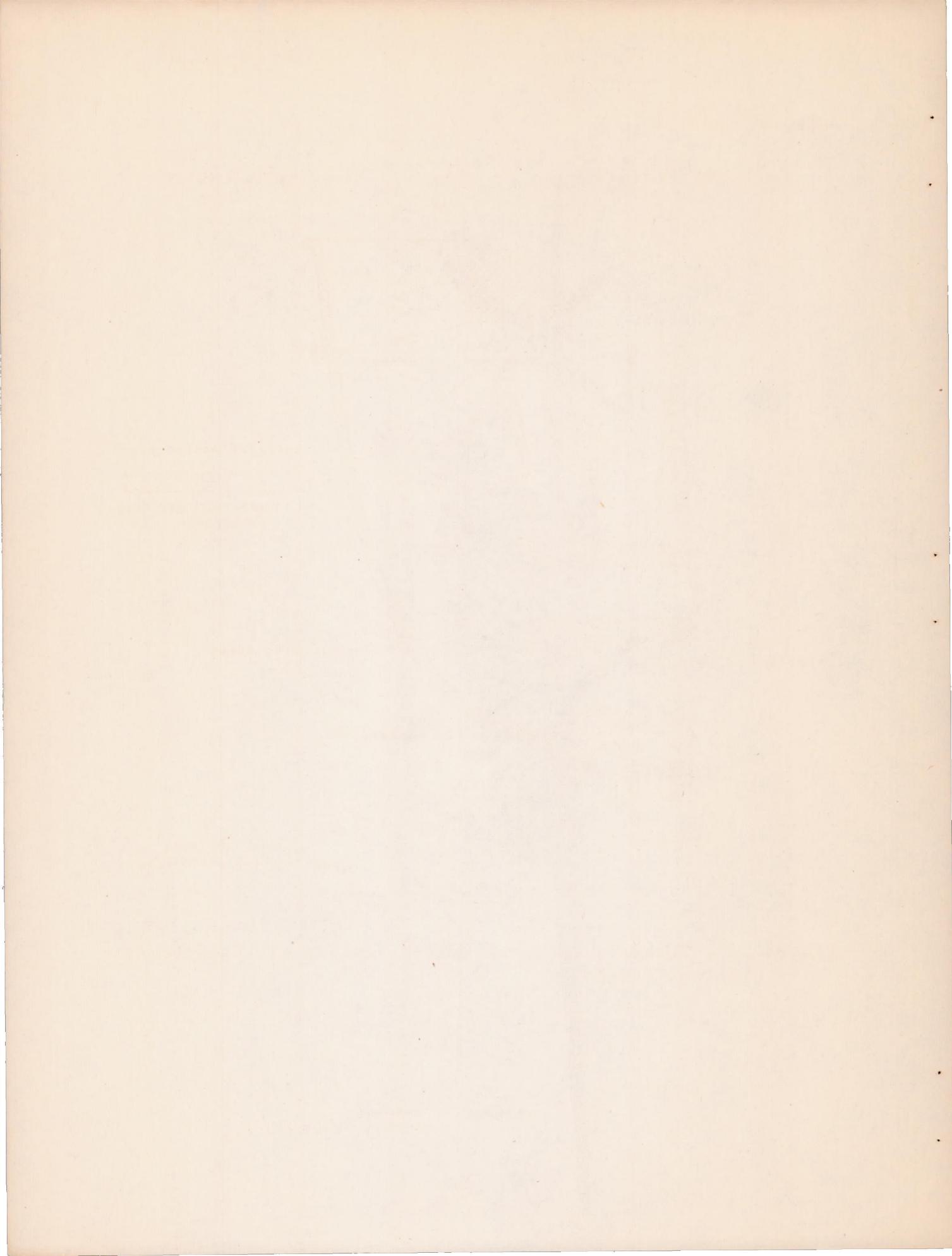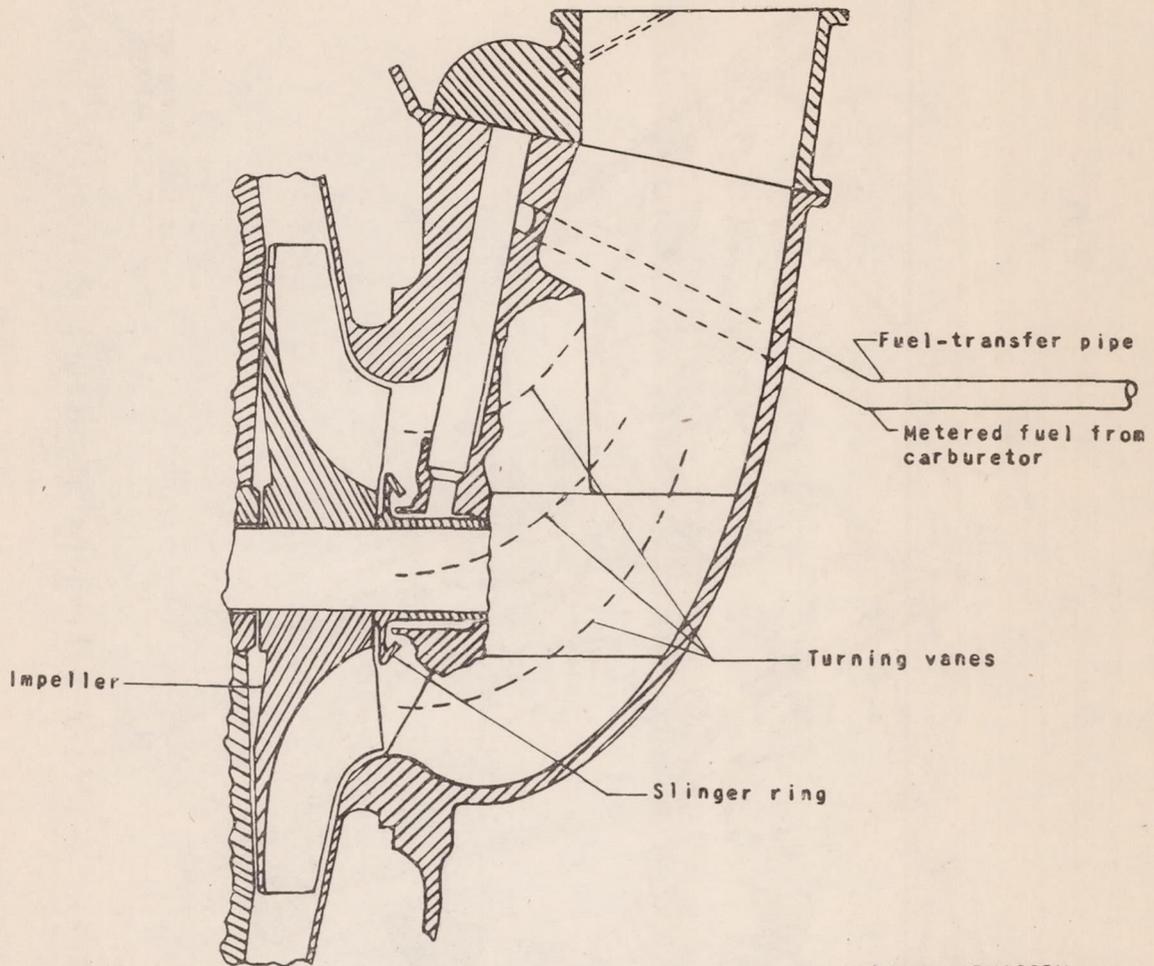
Figure 2. - Schematic diagram showing method of introducing
fuel to test engine.

Fig. 3

T35

T12

T35

T12

T13

T6

T14

T13   T6   T14

Air flow
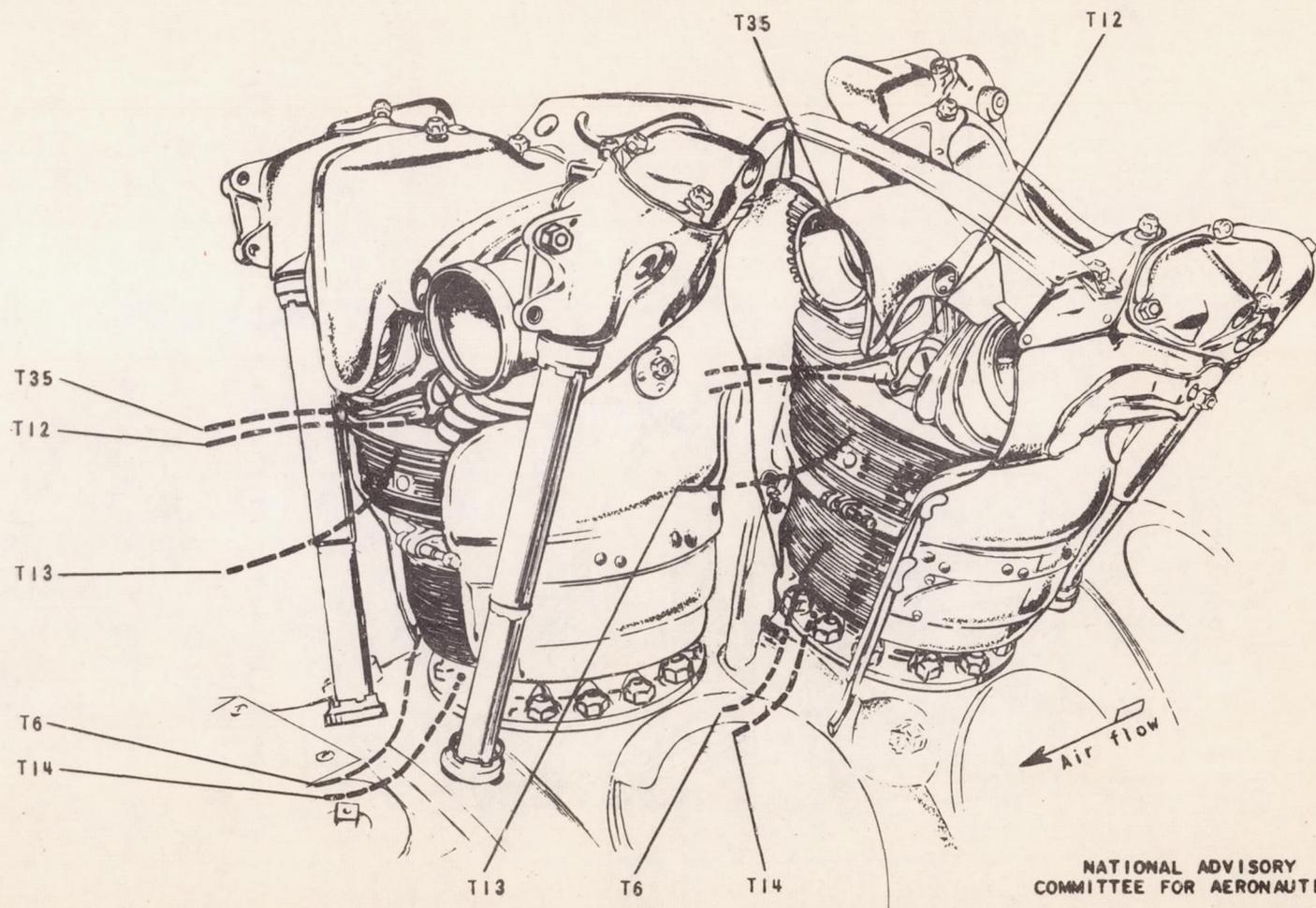
NATIONAL ADVISORY
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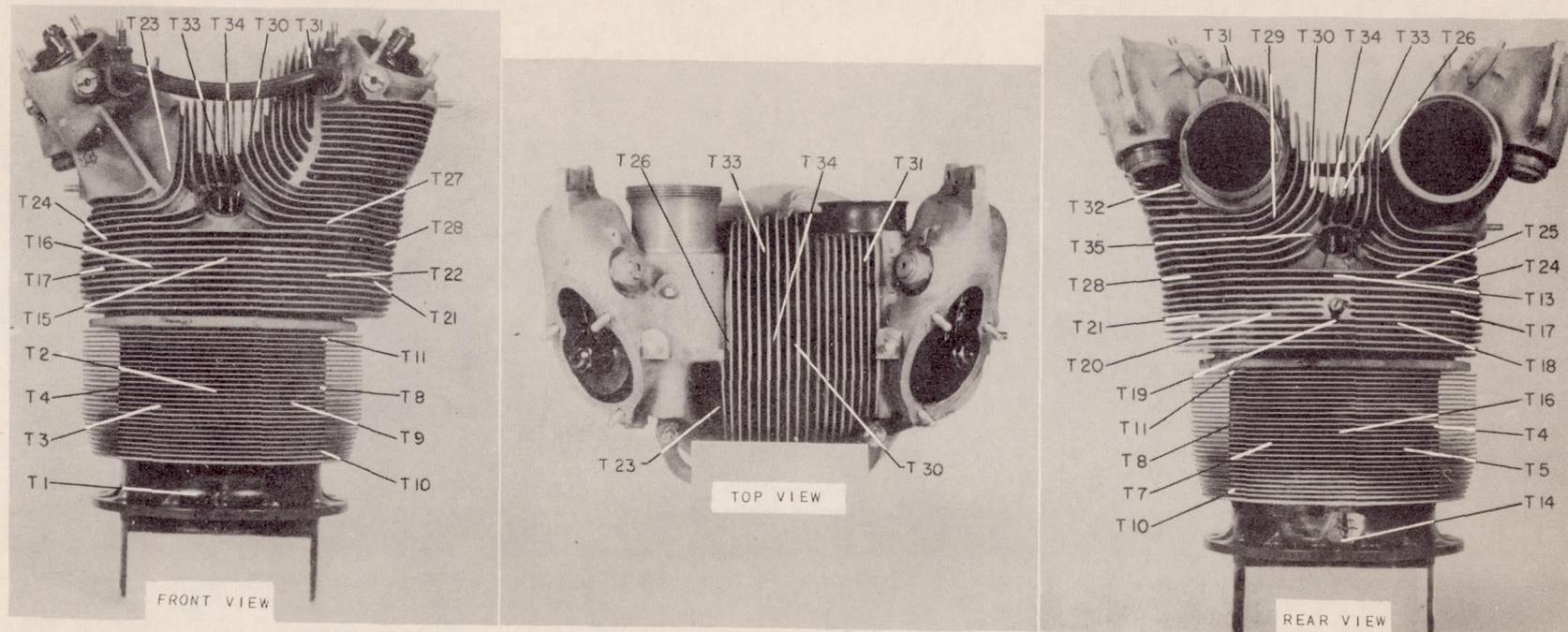Figure 3. - Rear view of front and rear cylinders showing thermocouple locations.
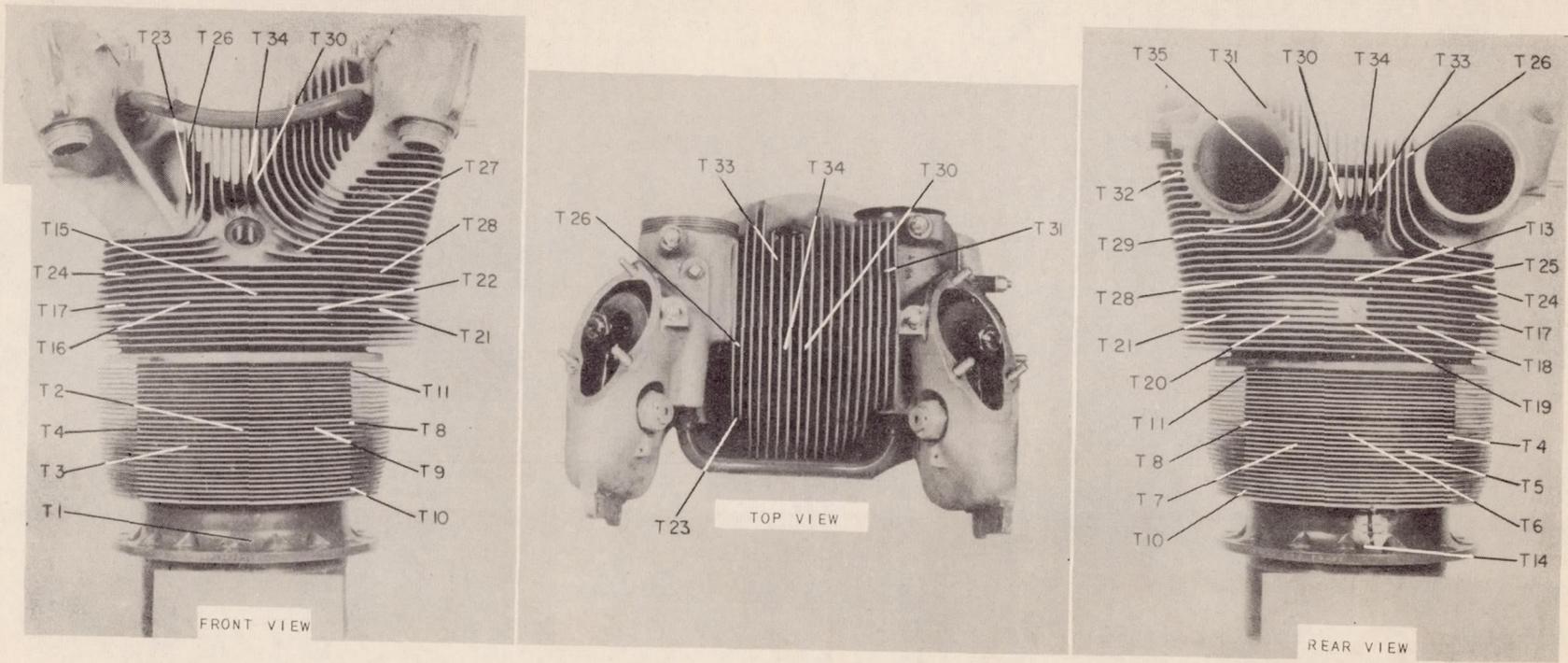
(a)   Front-row cylinder 18.
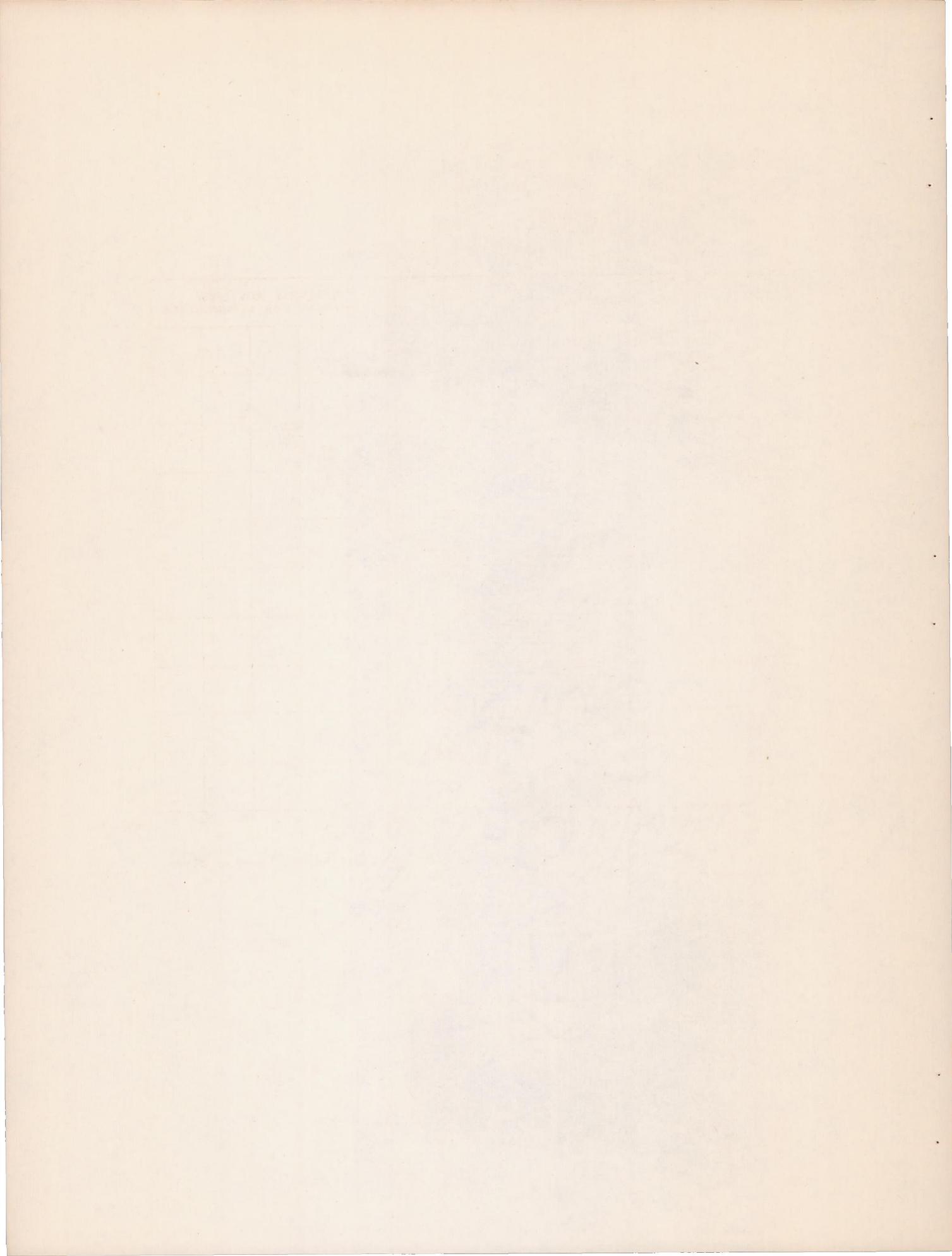
Figure 4. - Location of cylinder thermocouples.

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FRONT VIEW

T 23 T 33 T 34 T 30 T 31

T 24
T 16
T 17
T 15
T 2
T 4
T 3
T 1

T 27
T 28
T 22
T 21
T 11
T 8
T 9
T 10

TOP VIEW

T 26   T 33   T 34   T 31

T 23   T 30

REAR VIEW

T 31 T 29 T 30 T 34 T 33 T 26

T 32
T 35
T 28
T 21
T 20
T 19
T 11
T 8
T 7
T 10

T 25
T 24
T 13
T 17
T 18
T 16
T 4
T 5
T 14
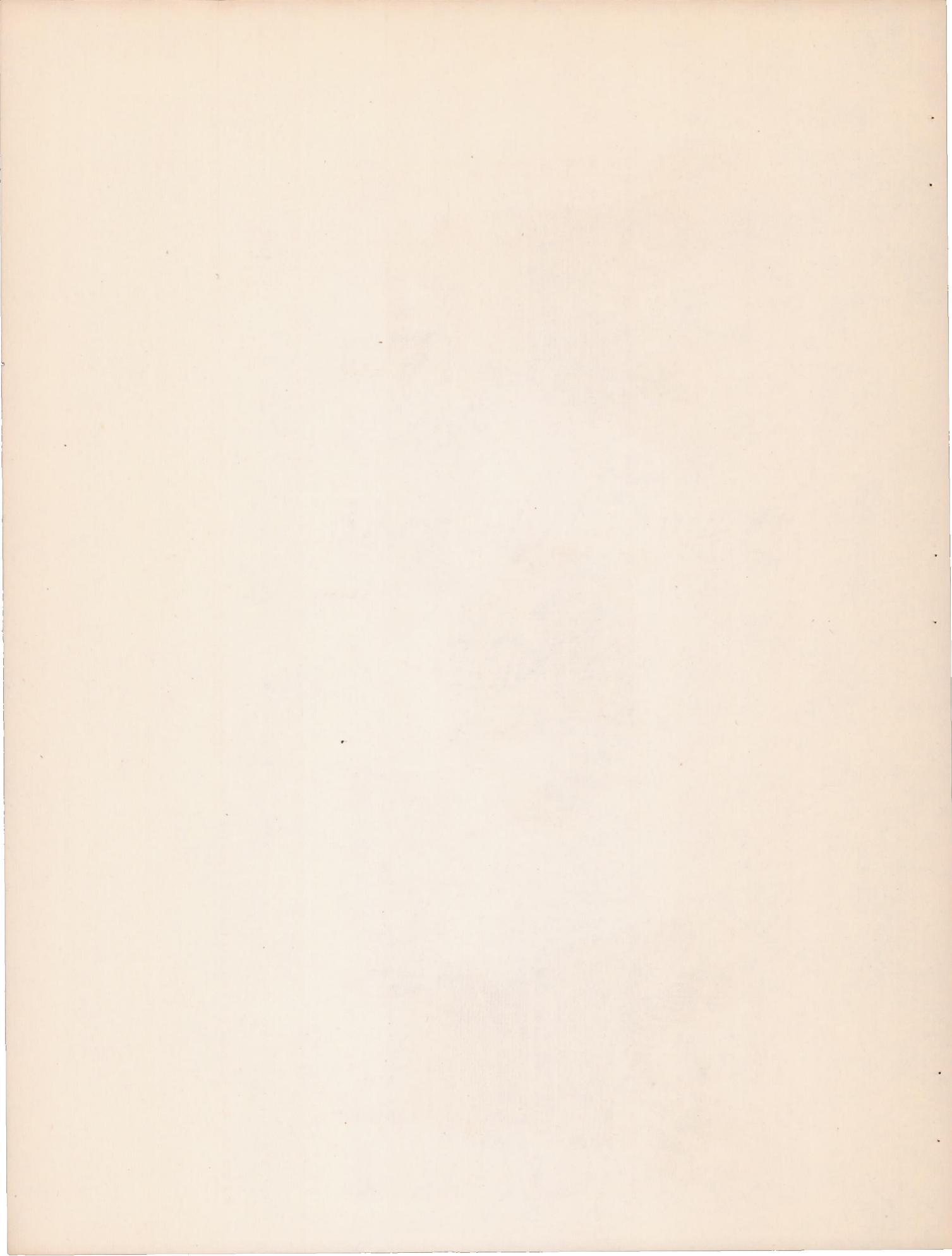
(b)   Rear-row cylinder 7.

Figure 4. - Concluded.   Location of cylinder thermocouples.

Fig. 4 b
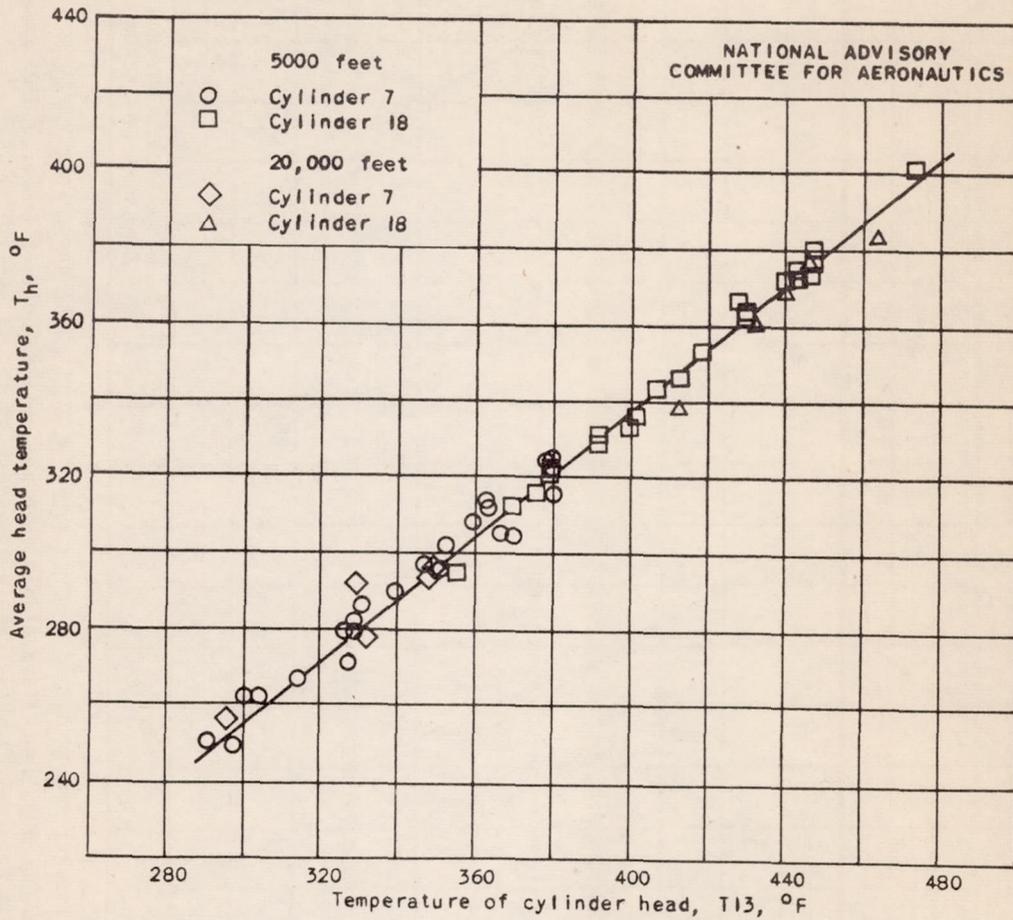
Figure 5. — Variation of average head temperature of cylinders 7 and 18 with cylinder head temperature as measured by thermocouple T13.
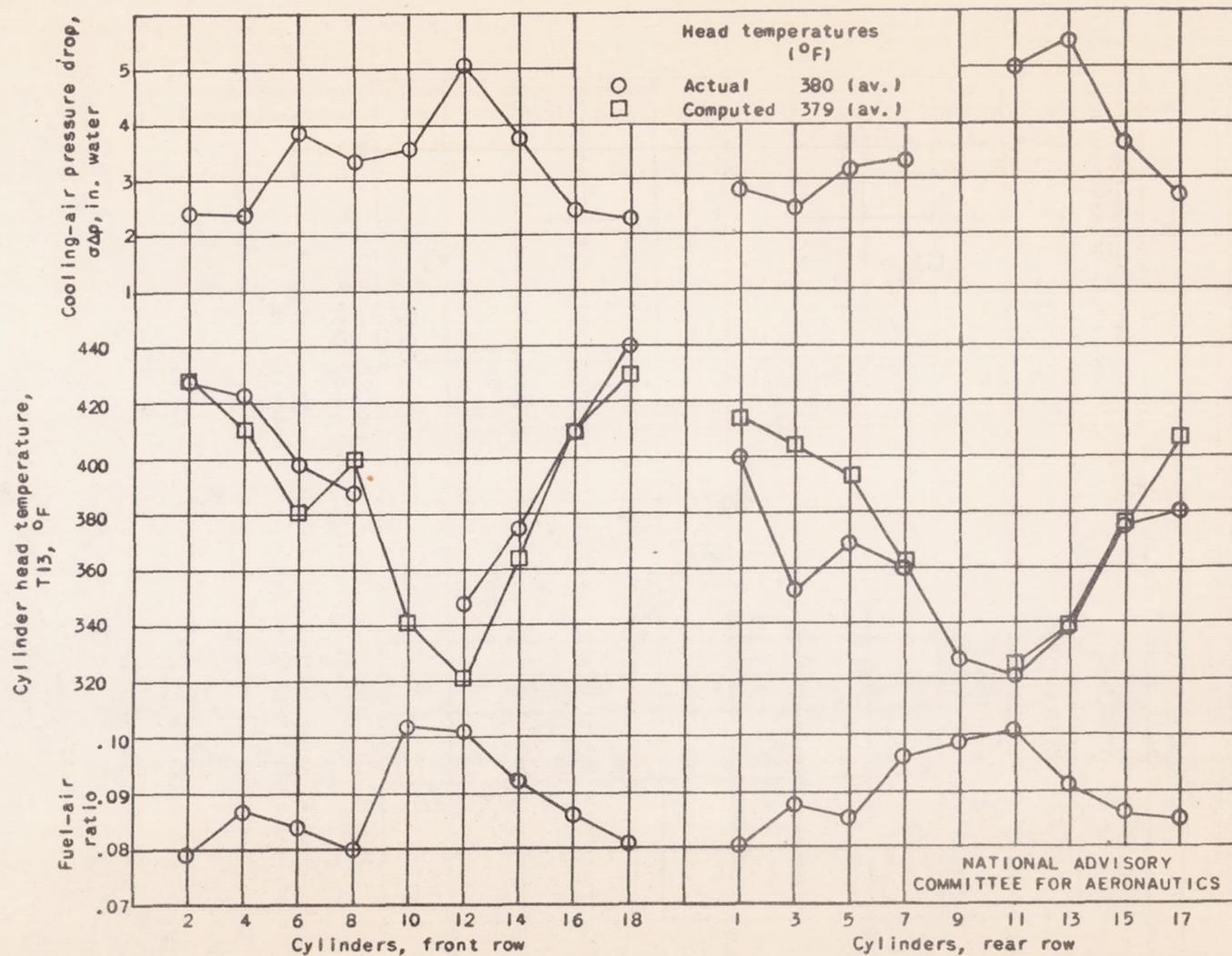
(a) Brake horsepower, 800; cowl flaps closed; average engine fuel–air ratio, 0.082; impact
pressure, 16.6 inches of water; angle of attack of thrust axis, 5°.

Figure 6. – Comparison of actual and calculated values of head temperature at 5000–foot density altitude;
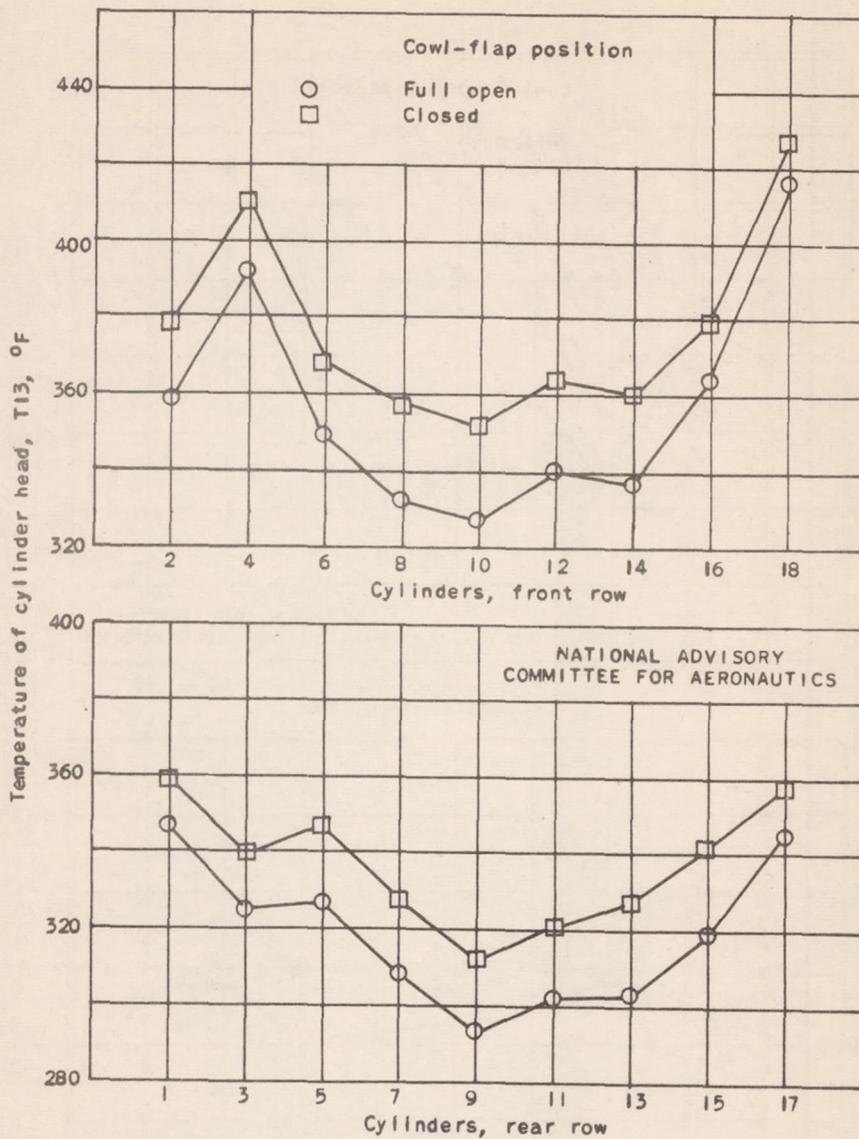engine speed, 2400 rpm; low blower ratio.
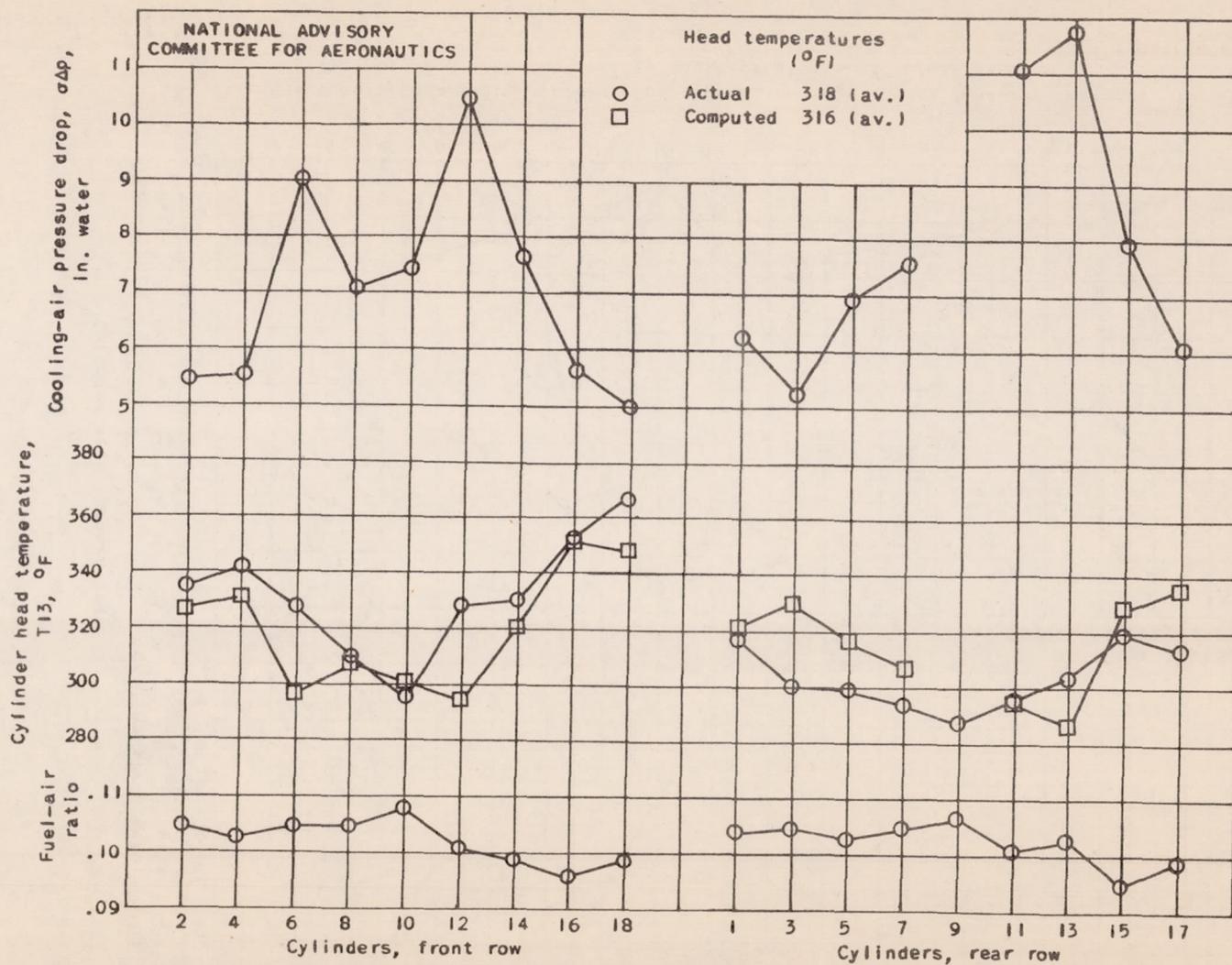
(b) Brake horsepower, 1000; cowl flaps open; average engine fuel-air ratio, 0.101; impact
pressure, 21.9 inches of water; angle of attack of thrust axis, 3°.

Figure 6. - Continued. Comparison of actual and calculated values of head temperature
at 5000-foot density altitude; engine speed, 2400 rpm; low blower ratio.
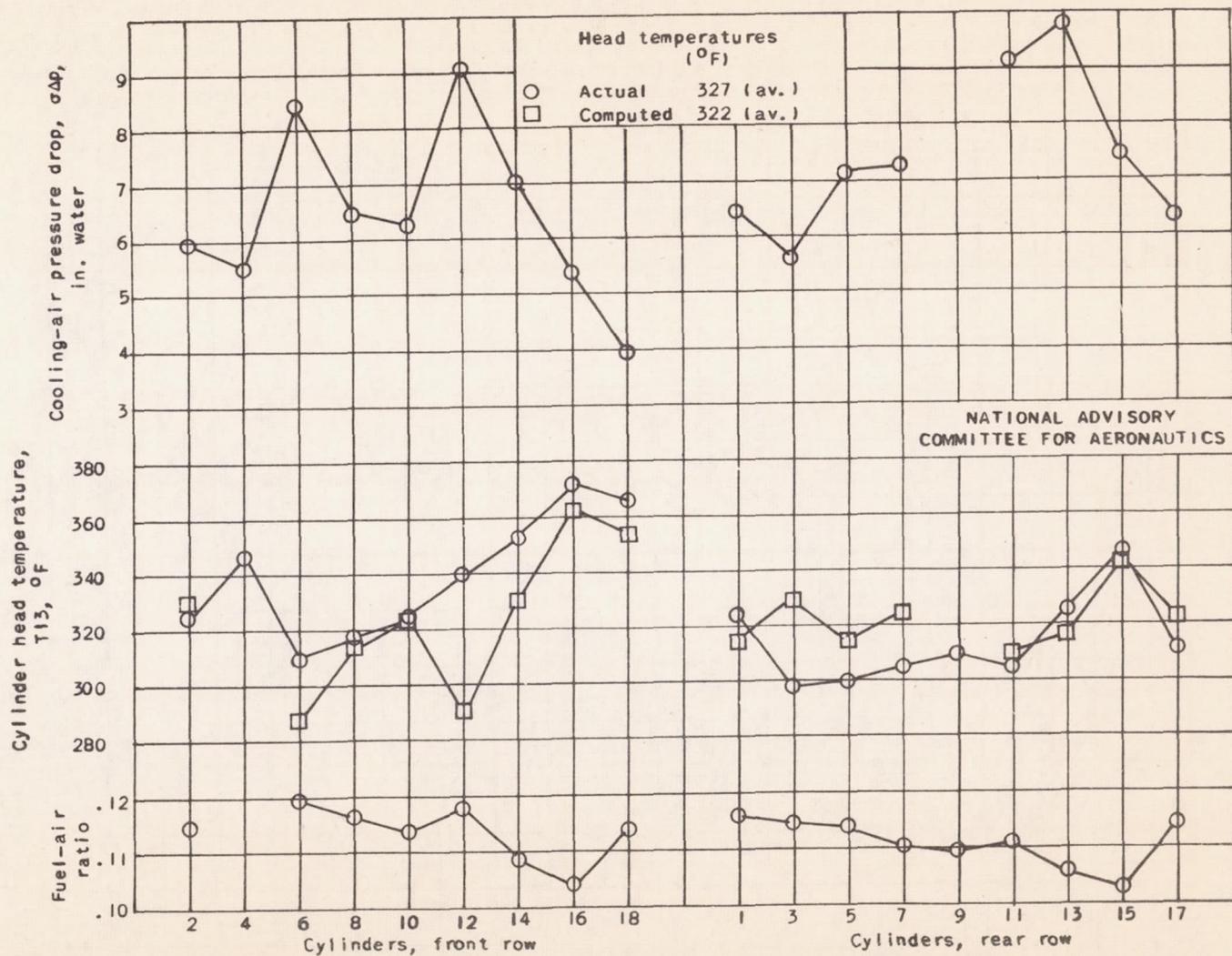
(c) Brake horsepower, 1500; cowl flaps closed; average engine fuel-air ratio, 0.112; impact pressure, 33.0 inches of water; angle of attack of thrust axis, 2°.

Figure 6. - Concluded. Comparison of actual and calculated values of head temperature at 5000-foot density altitude; engine speed, 2400 rpm; low blower ratio.
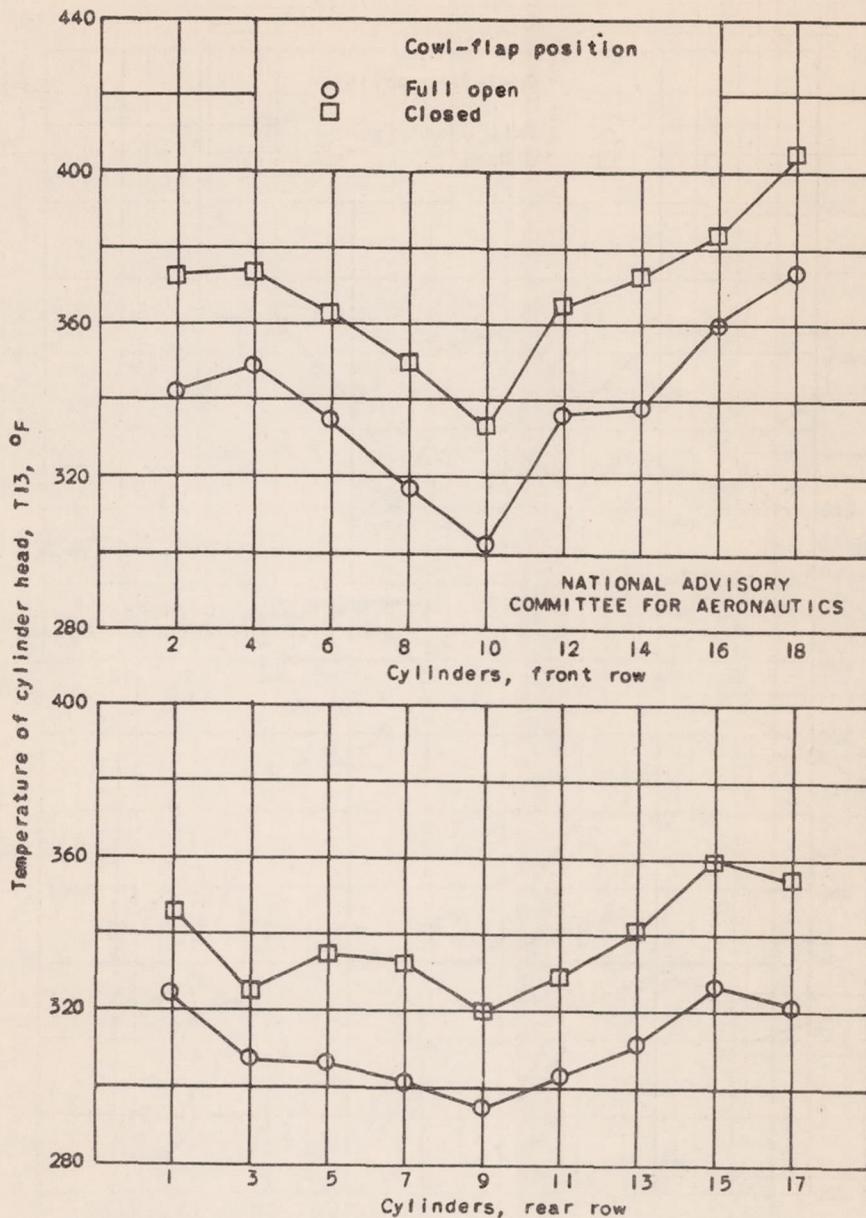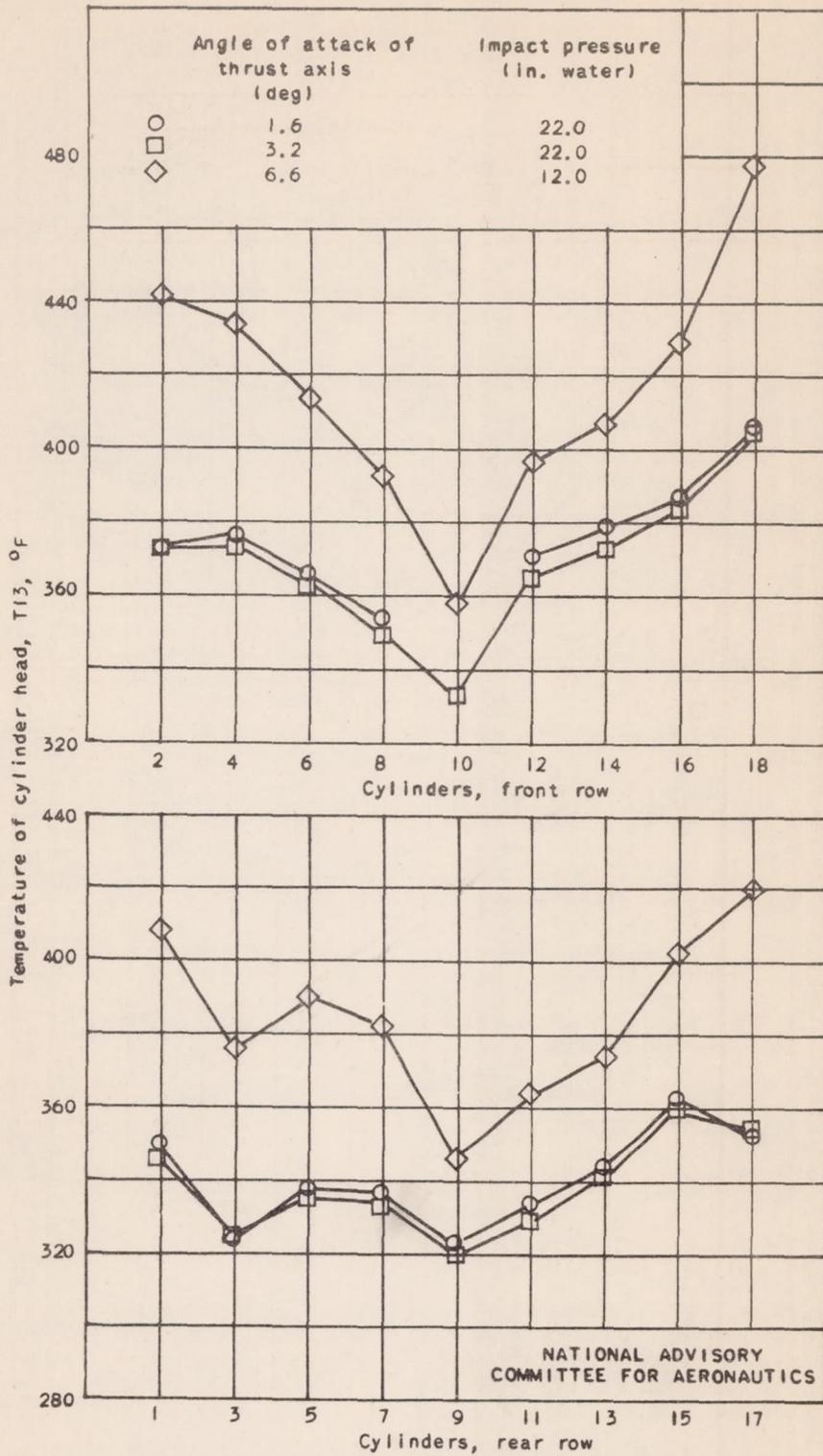
(a) Cylinder-head temperatures.

Figure 7. – Effect of cowl-flap position on temperature distribution
at density altitude of 5000 feet. Brake horsepower, 1000; engine
speed, 2400 rpm; low blower ratio; average engine fuel-air ratio,
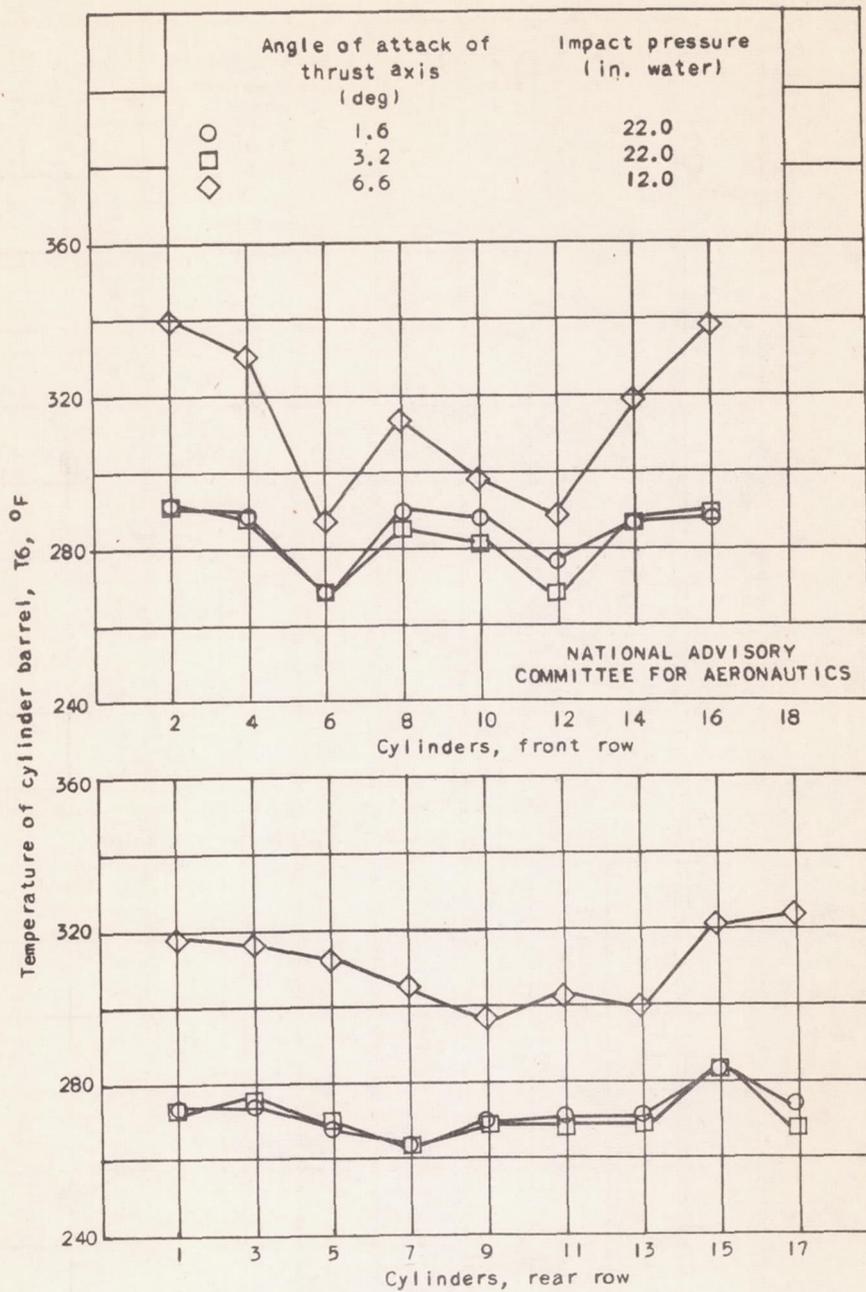0.101; impact pressure, 22 inches of water; angle of attack of
thrust axis, 3°.
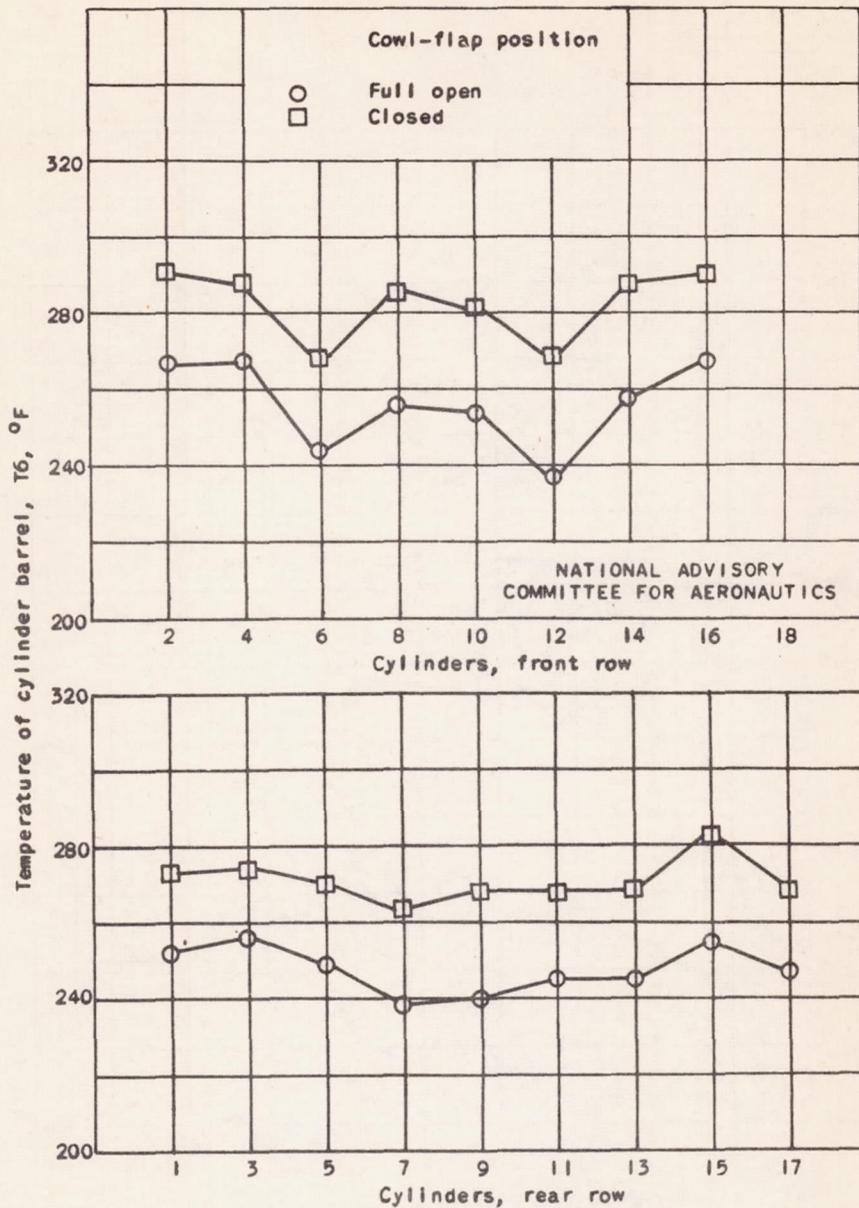
(b) Cylinder-barrel temperatures.

Figure 7. - Concluded. Effect of cowl-flap position on temperature distribution at density altitude of 5000 feet. Brake horsepower, 1000; engine speed, 2400 rpm; low blower ratio; average engine fuel-air ratio, 0.101; impact pressure, 22 inches of water; angle of attack of thrust axis, 3°.

(a) Cylinder-head temperatures.

Figure 8. – Effect of cowl-flap position on temperature distribution
at density altitude of 20,000 feet. Brake horsepower, 1000; engine
speed, 2400 rpm; high blower ratio; average engine fuel-air ratio,
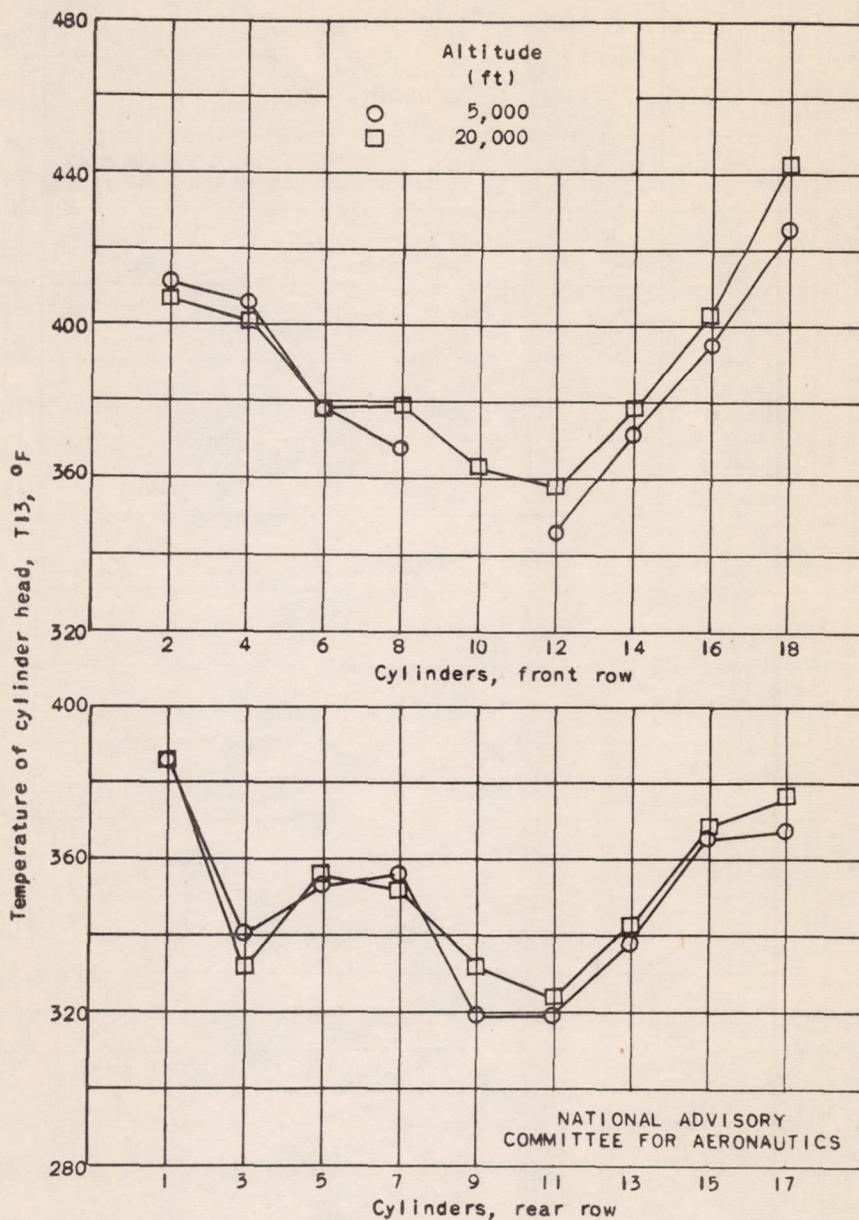0.108; impact pressure, 17 inches of water; angle of attack of thrust
axis, 3°.
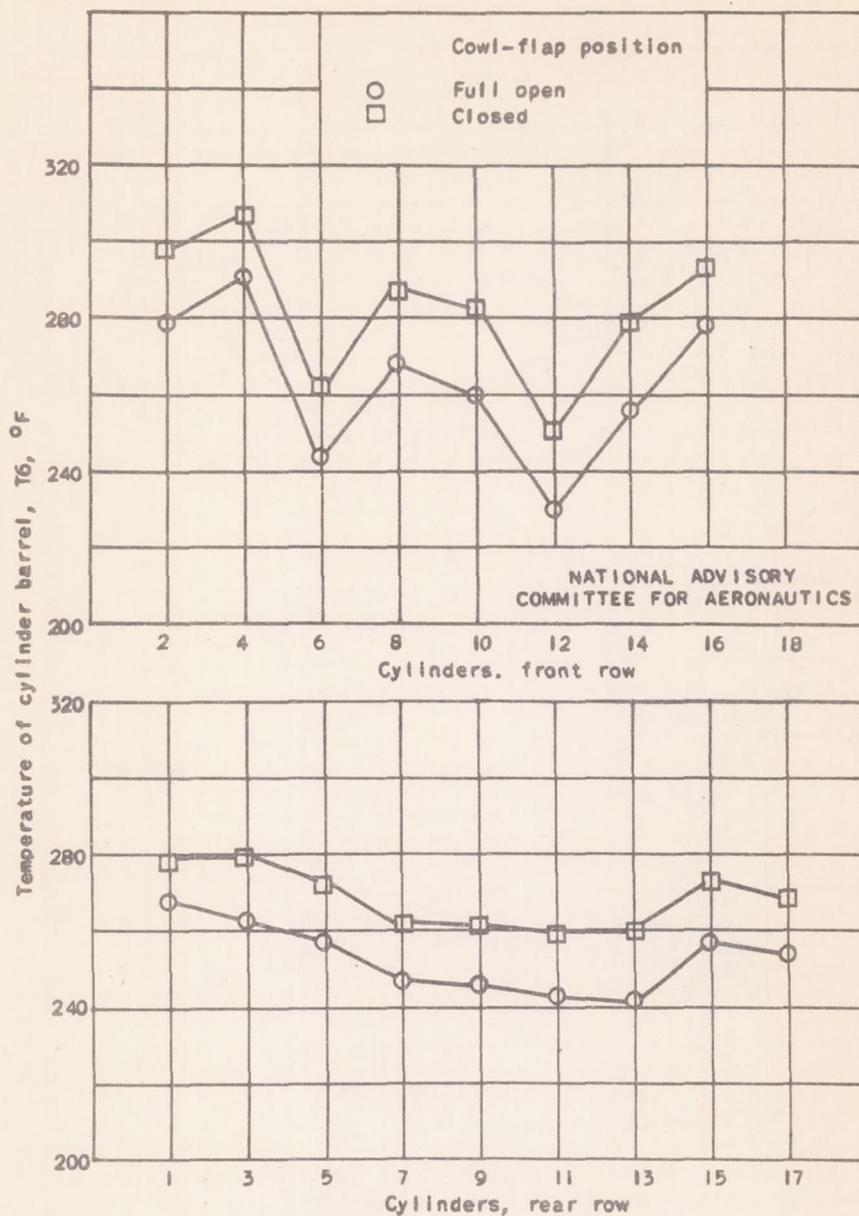
(b) Cylinder-barrel temperatures.

Figure 8. - Concluded. Effect of cowl-flap position on tem-
    perature distribution at density altitude of 20,000 feet.
    Brake horsepower, 1000; engine speed, 2400 rpm; high blower
    ratio; average engine fuel-air ratio, 0.108; impact
    pressure, 17 inches of water; angle of attack of thrust
    axis, 3°.

(a) Cylinder-head temperatures.

Figure 9. - Effect of angle of attack of thrust axis on temperature
distribution. Brake horsepower, 1000; engine speed, 2400 rpm;
density altitude, 5000 feet; cowl flaps closed; low blower ratio;
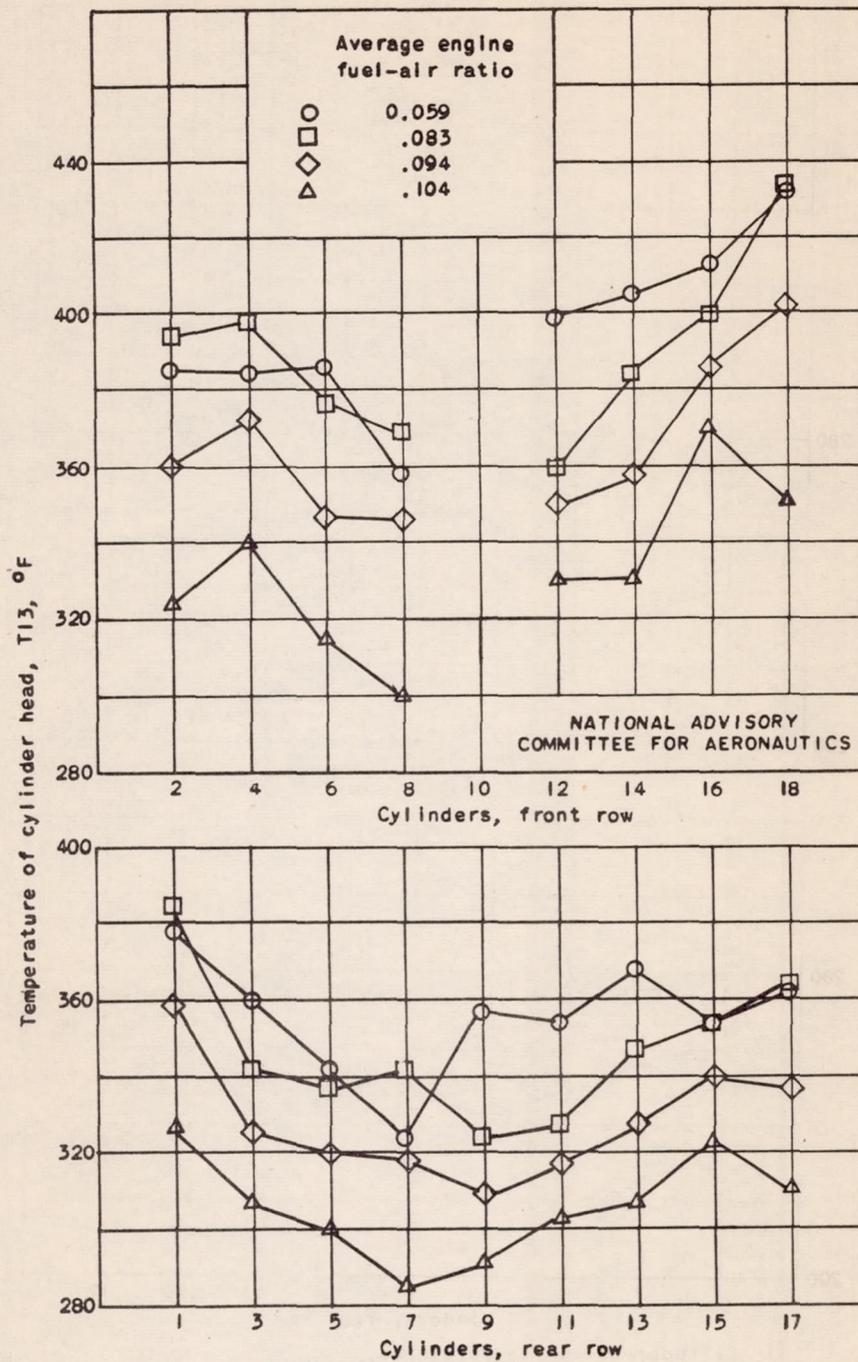average engine fuel-air ratio, 0.101.

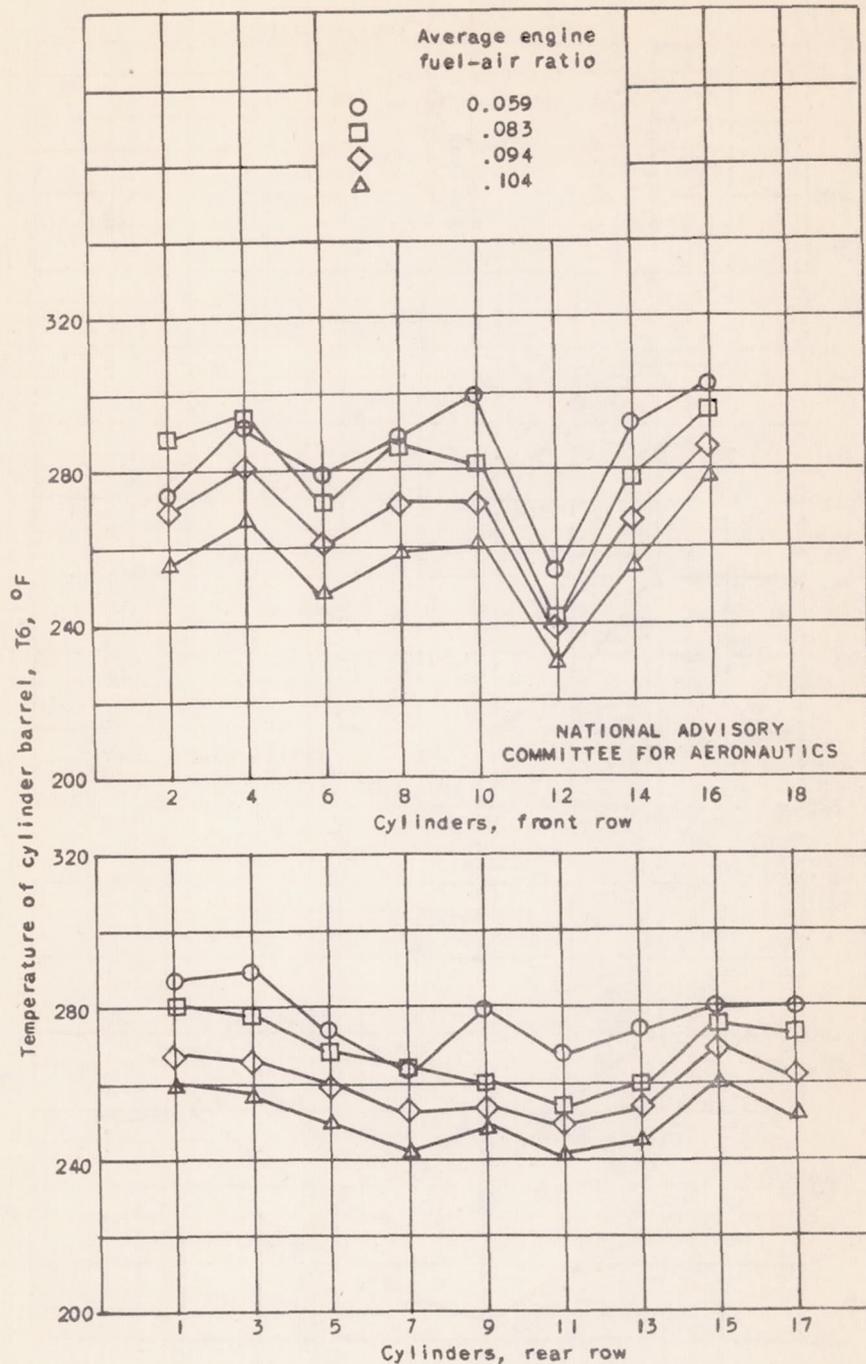(b) Cylinder-barrel temperatures.

Figure 9. - Concluded. Effect of angle of attack of thrust axis on temperature distribution. Brake horsepower, 1000; engine speed, 2400 rpm; density altitude, 5000 feet; cowl flaps closed; low blower ratio; average engine fuel-air ratio, 0.101.

(a) Cylinder-head temperatures.

Figure 10. – Effect of altitude on temperature distribution. Brake
horsepower, 800; engine speed, 2400 rpm; cowl flaps closed; low
blower ratio; average engine fuel-air ratio, 0.092; impact pres-
sure, 16 inches of water; angle of attack of thrust axis, 5°.
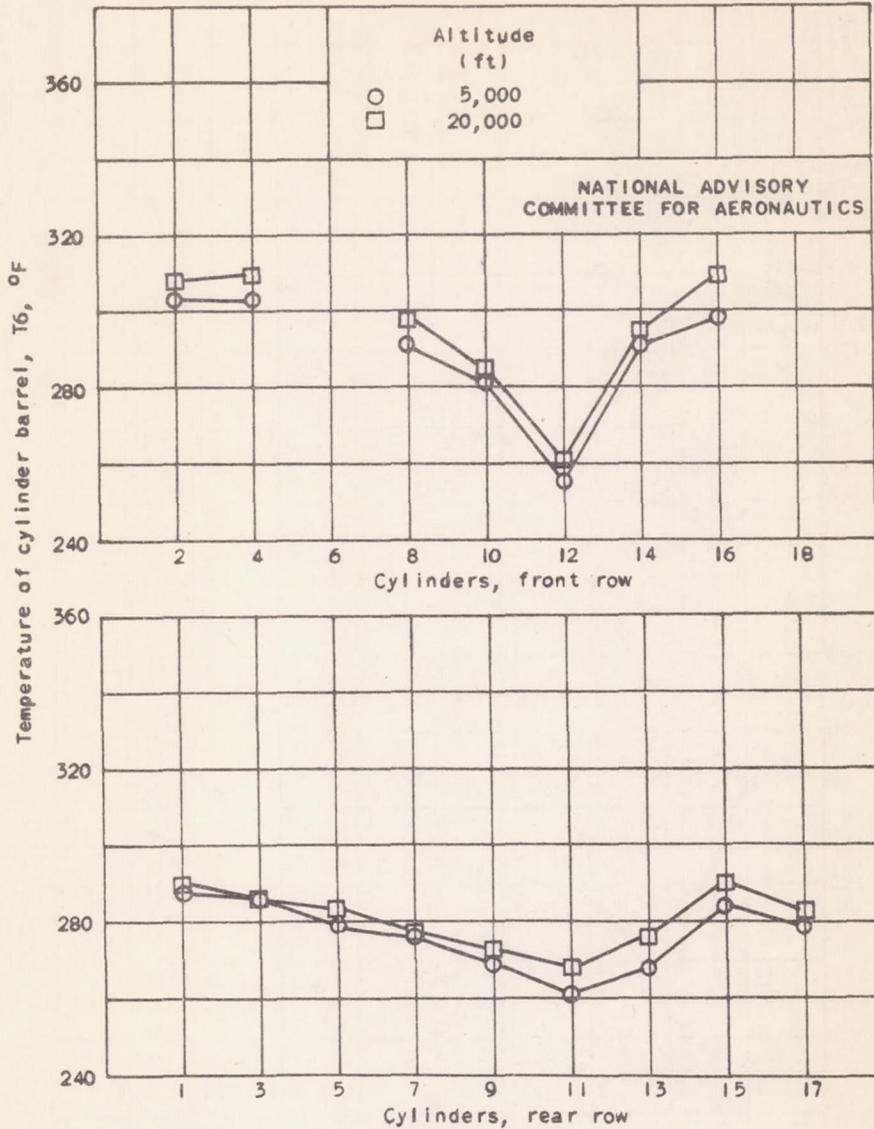
(b) Cylinder-barrel temperatures.

Figure 10. - Concluded. Effect of altitude on temperature
distribution. Brake horsepower, 800; engine speed,
2400 rpm; cowl flaps closed; low blower ratio; average
engine fuel-air ratio, 0.092; impact pressure, 16 inches
of water; angle of attack of thrust axis, 5°.

(a) Cylinder-head temperatures.

Figure II. - Effect of average engine fuel-air ratio on temperature distribution. Brake horsepower, 1000; engine speed, 2400 rpm; density altitude, 5000 feet; cowl flaps open; low blower ratio; impact pressure, 21 inches of water; angle of attack of thrust axis, 4°.
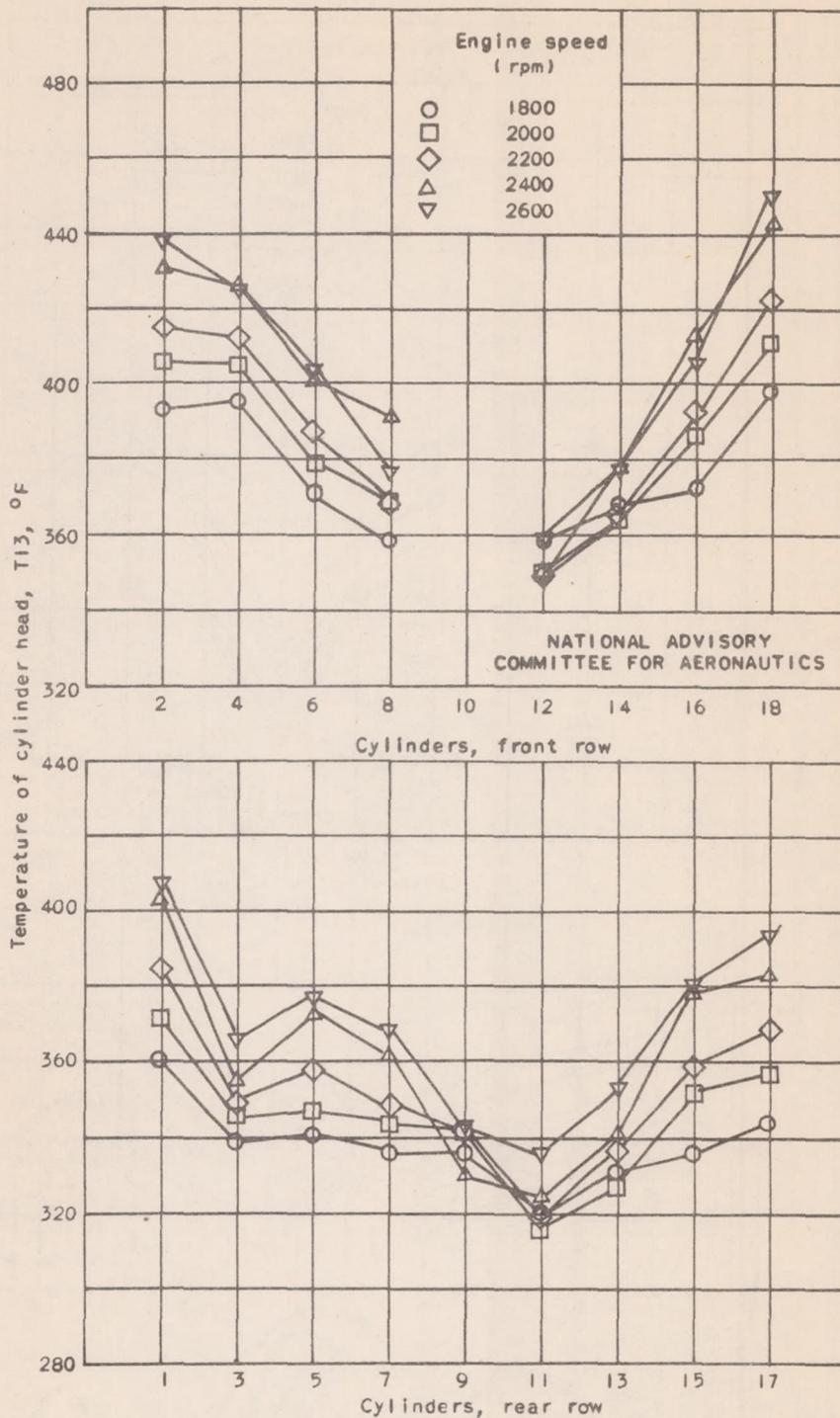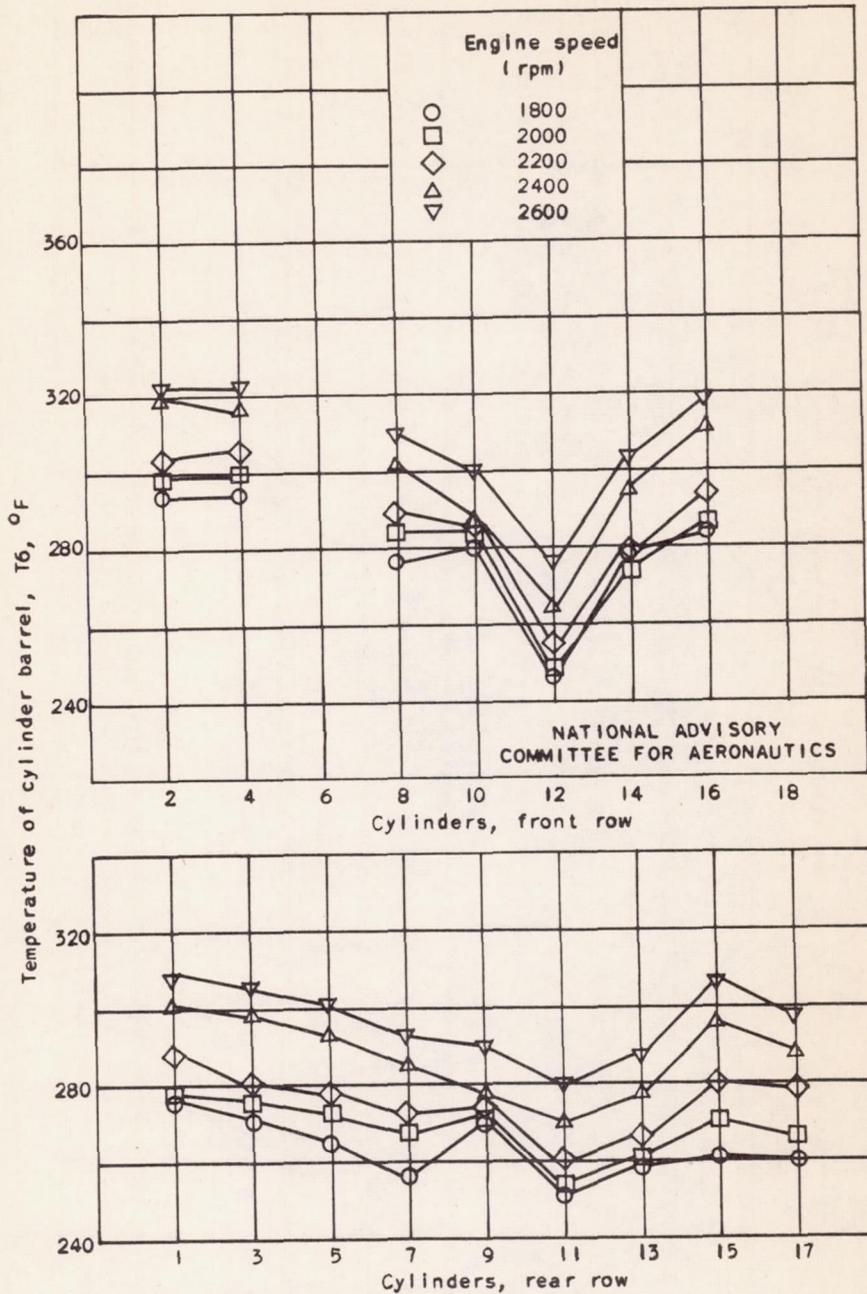
(b) Cylinder-barrel temperatures.

Figure II. – Concluded. Effect of average engine fuel–air
ratio on temperature distribution. Brake horsepower, 1000;
engine speed, 2400 rpm; density altitude, 5000 feet; cowl
flaps open; low blower ratio; impact pressure, 21 inches
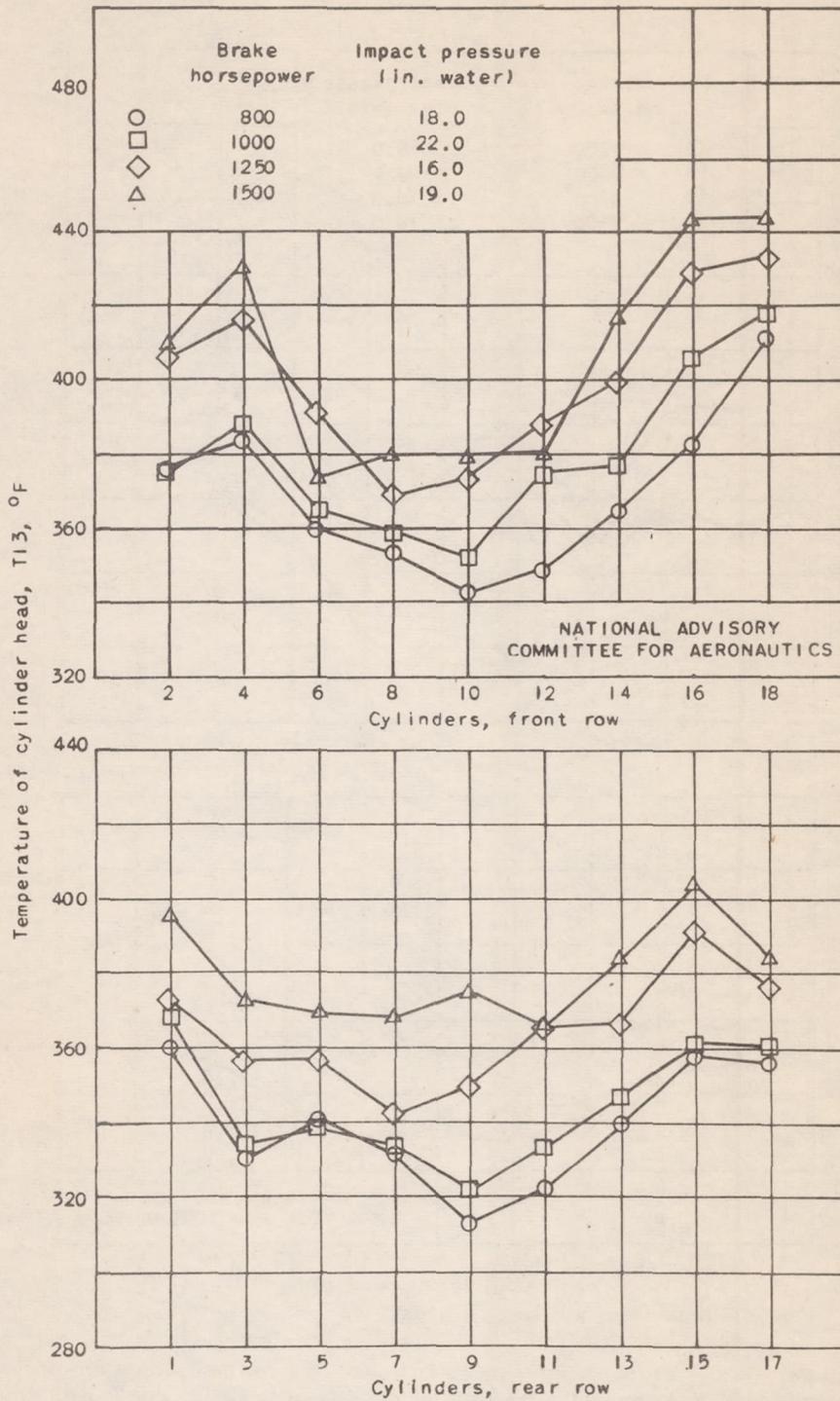of water; angle of attack of thrust axis, 4°.

(a) Cylinder-head temperatures.

Figure 12. - Effect of engine speed on temperature distribution.
Brake horsepower, 800; density altitude, 5000 feet; cowl flaps
closed; low blower ratio; average engine fuel-air ratio, 0.082;
impact pressure, 17 inches of water; angle of attack of thrust
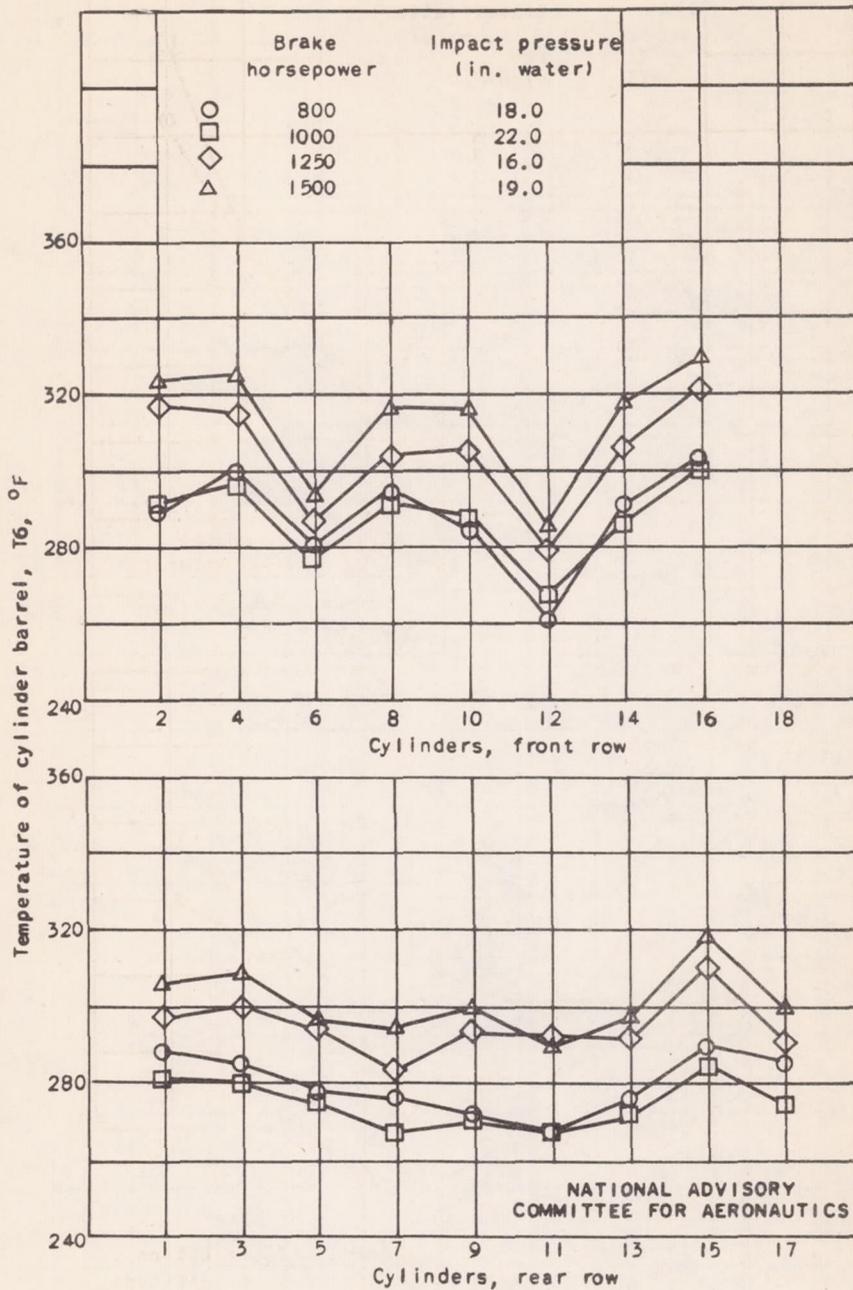axis, 5°.

(b) Cylinder-barrel temperatures.

Figure 12. - Concluded. Effect of engine speed on tempera-
ture distribution. Brake horsepower, 800; density alti-
tude, 5000 feet; cowl flaps closed; low blower ratio;
average engine fuel-air ratio, 0.082; impact pressure, 17
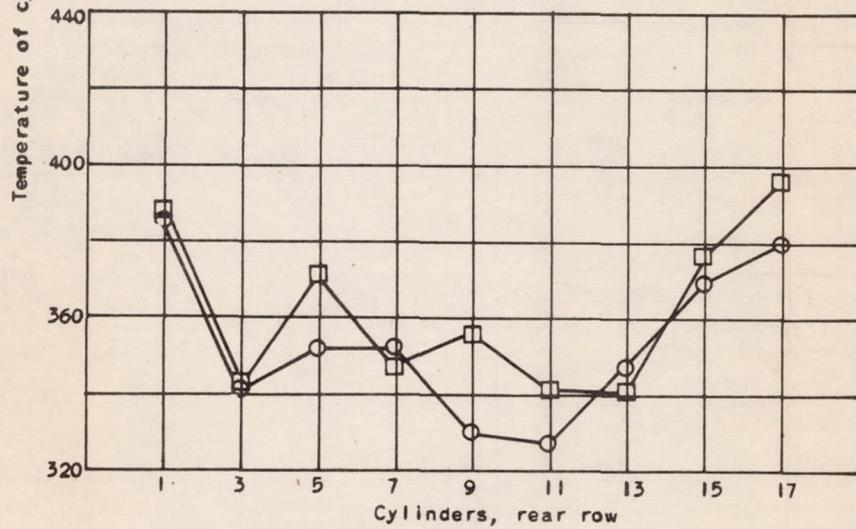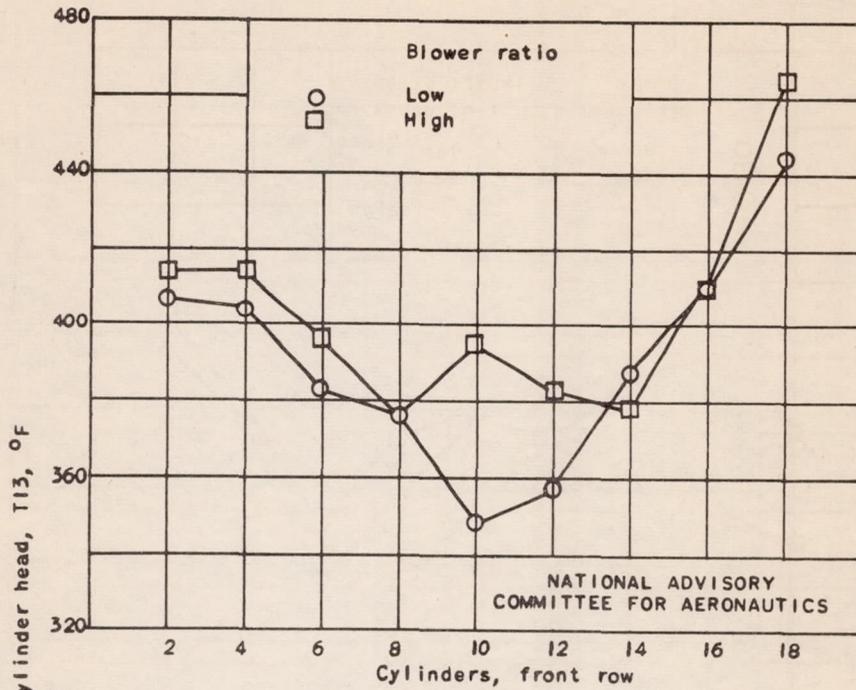inches of water; angle of attack of thrust axis, 5°.

(a) Cylinder-head temperatures.

Figure 13. — Effect of brake horsepower on temperature distribution.
Engine speed, 2400 rpm; density altitude, 5000 feet; cowl flaps
closed; low blower ratio; average engine fuel-air ratio, 0.101;
angle of attack of thrust axis, 3°.

	Brake horsepower	Impact pressure (in. water)
○	800	18.0
□	1000	22.0
◇	1250	16.0
△	1500	19.0

(b) Cylinder-barrel temperatures.

Figure 13. — Concluded. Effect of brake horsepower on temperature distribution. Engine speed, 2400 rpm; density altitude, 5000 feet; cowl flaps closed; low blower ratio; average engine fuel-air ratio, 0.101; angle of attack of thrust axis, 3°.
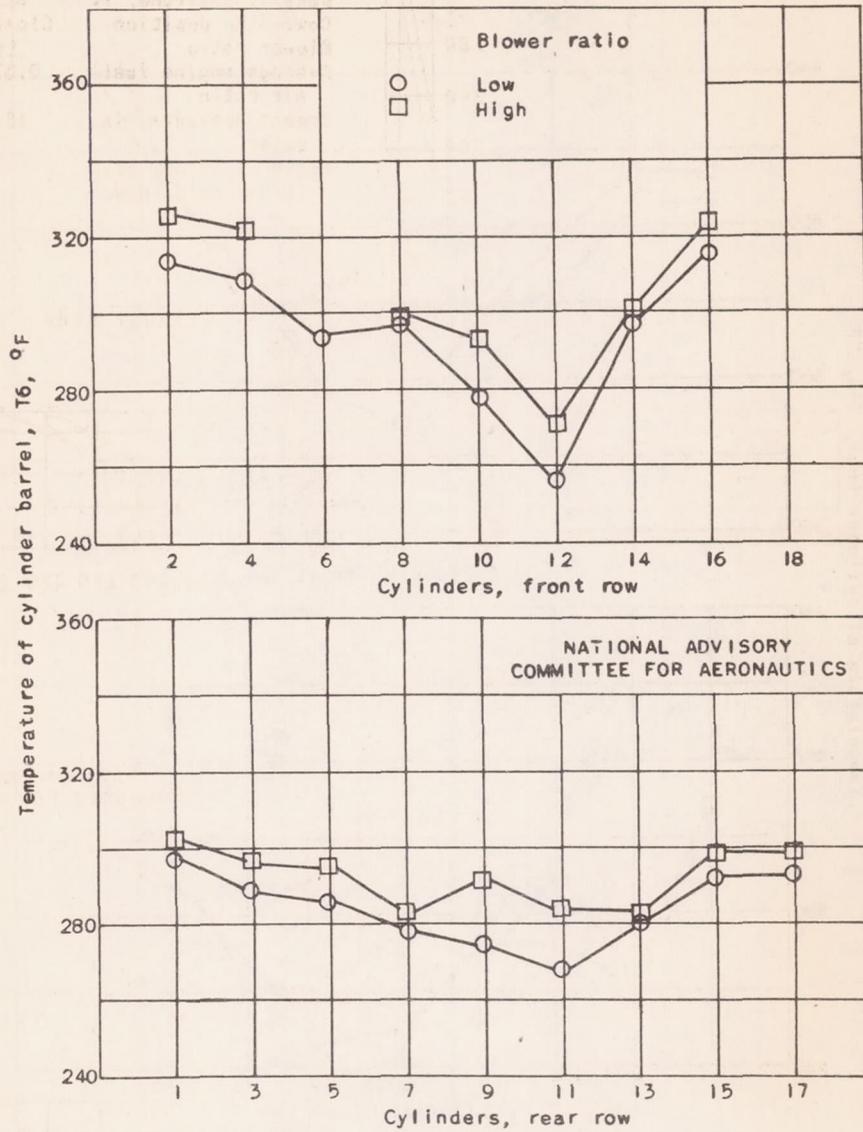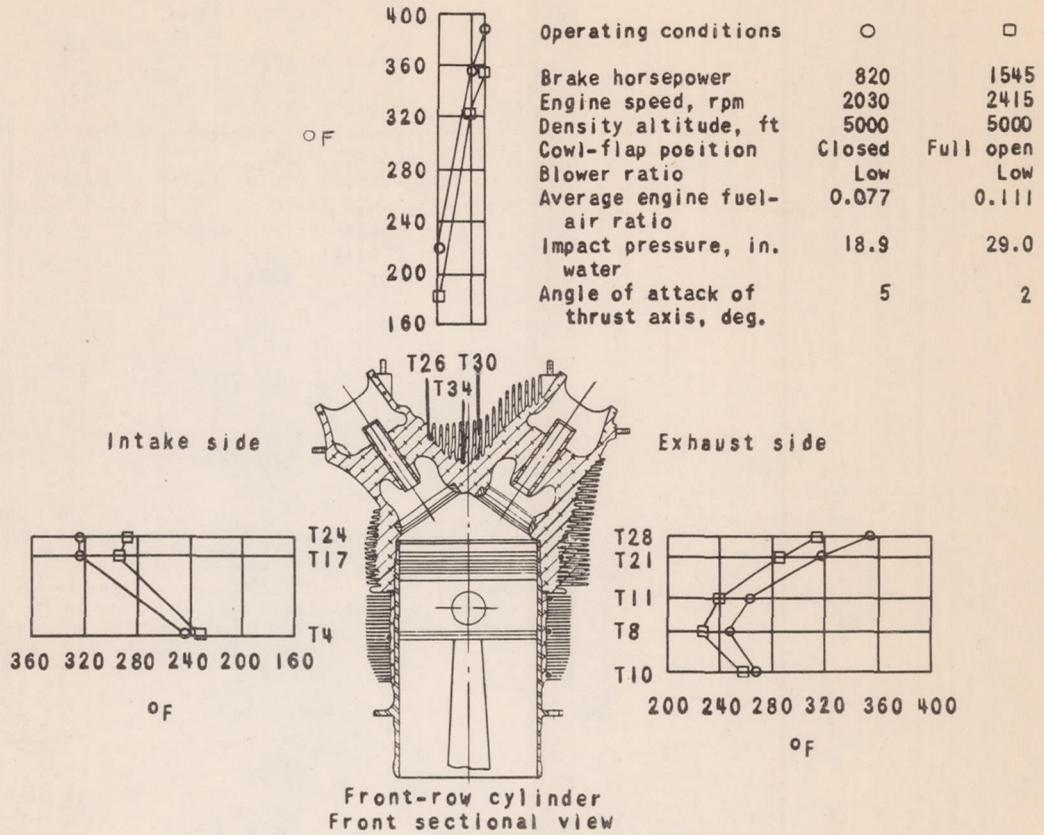
(a) Cylinder-head temperatures.

Figure 14. – Effect of blower ratio on temperature distribution.
Brake horsepower, 800; engine speed, 2400 rpm; density altitude,
20,000 feet; cowl flaps closed; average engine fuel-air ratio,
0.091; impact pressure, 14 inches of water; angle of attack of
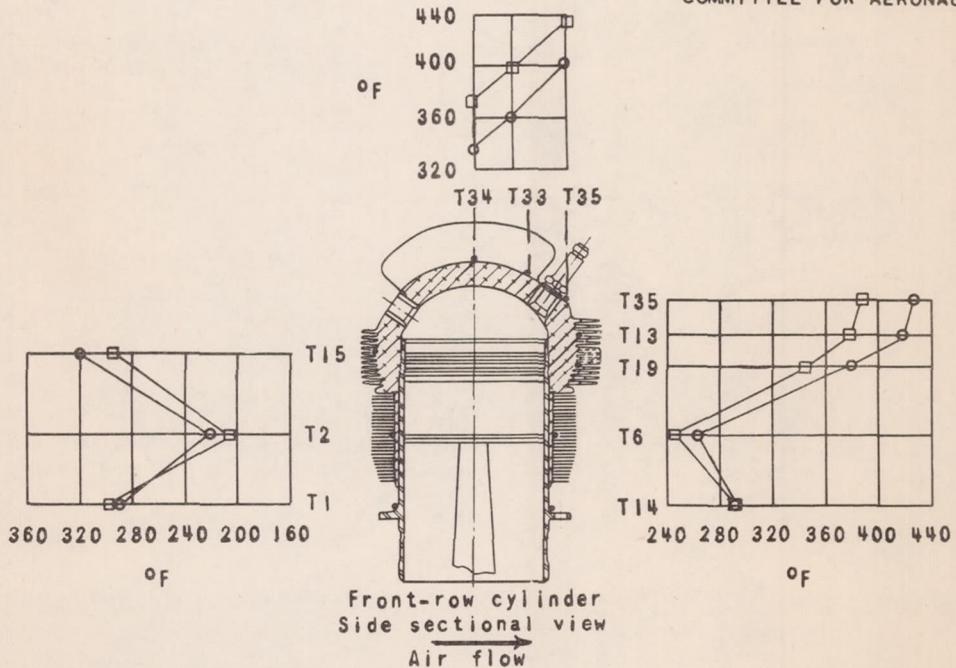thrust axis, 6°.

(b) Cylinder-barrel temperatures.

Figure 14. - Concluded. Effect of blower ratio on tempera-
ture distribution. Brake horsepower, 800; engine speed,
2400 rpm; density altitude, 20,000 feet; cowl flaps
closed; average engine fuel-air ratio, 0.091; impact pres-
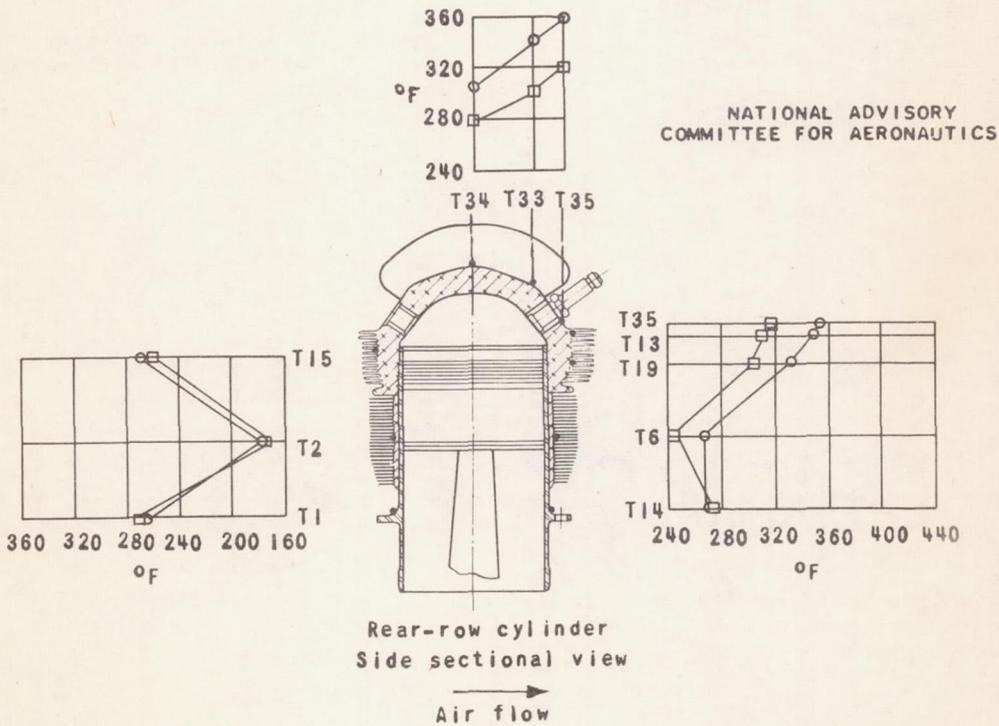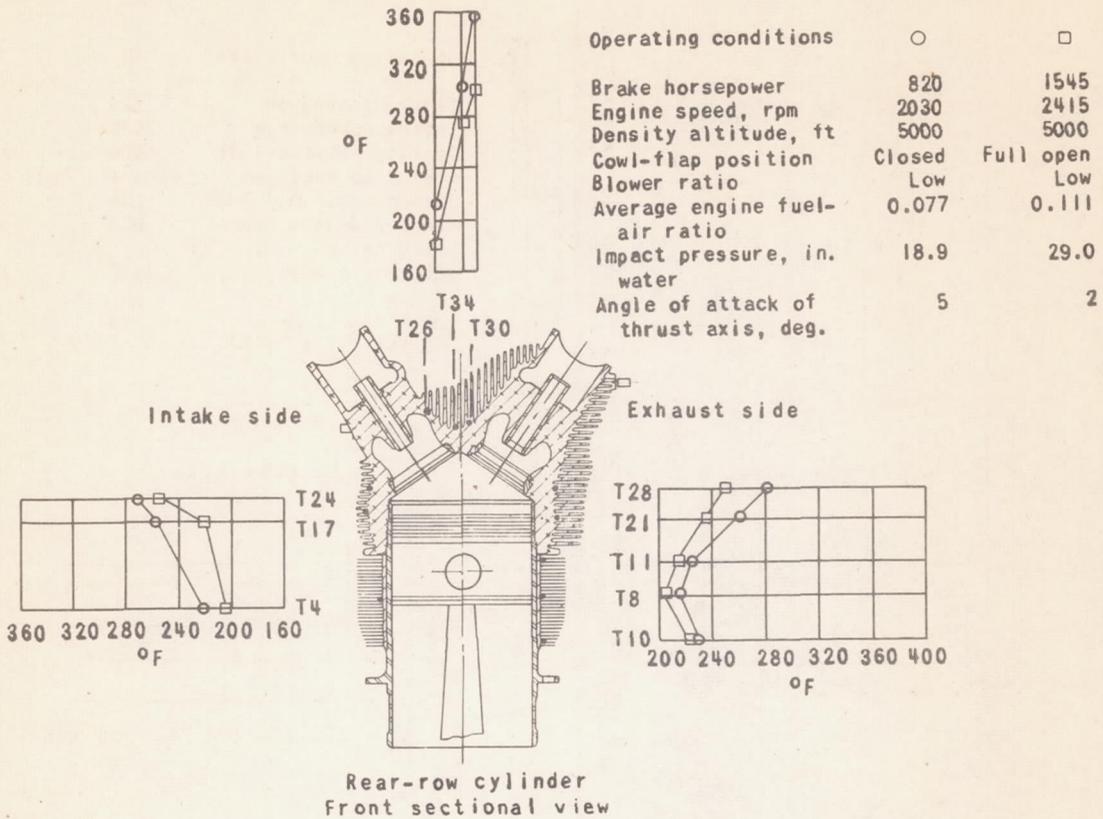sure, 14 inches of water; angle of attack of thrust axis,
6°.

Operating conditions	○	□
Brake horsepower	820	1545
Engine speed, rpm	2030	2415
Density altitude, ft	5000	5000
Cowl-flap position	Closed	Full open
Blower ratio	Low	Low
Average engine fuel-air ratio	0.077	0.111
Impact pressure, in. water	18.9	29.0
Angle of attack of thrust axis, deg.	5	2

Intake side   Exhaust side

Front-row cylinder
Front sectional view

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Front-row cylinder
Side sectional view
Air flow

(a) Cylinder 18.

Figure 15. - Longitudinal temperature distribution of cylinder.

Operating conditions	○	□
Brake horsepower	820	1545
Engine speed, rpm	2030	2415
Density altitude, ft	5000	5000
Cowl-flap position	Closed	Full open
Blower ratio	Low	Low
Average engine fuel-air ratio	0.077	0.111
Impact pressure, in. water	18.9	29.0
Angle of attack of thrust axis, deg.	5	2

Intake side   Exhaust side

Rear-row cylinder
Front sectional view

Rear-row cylinder
Side sectional view

Air flow
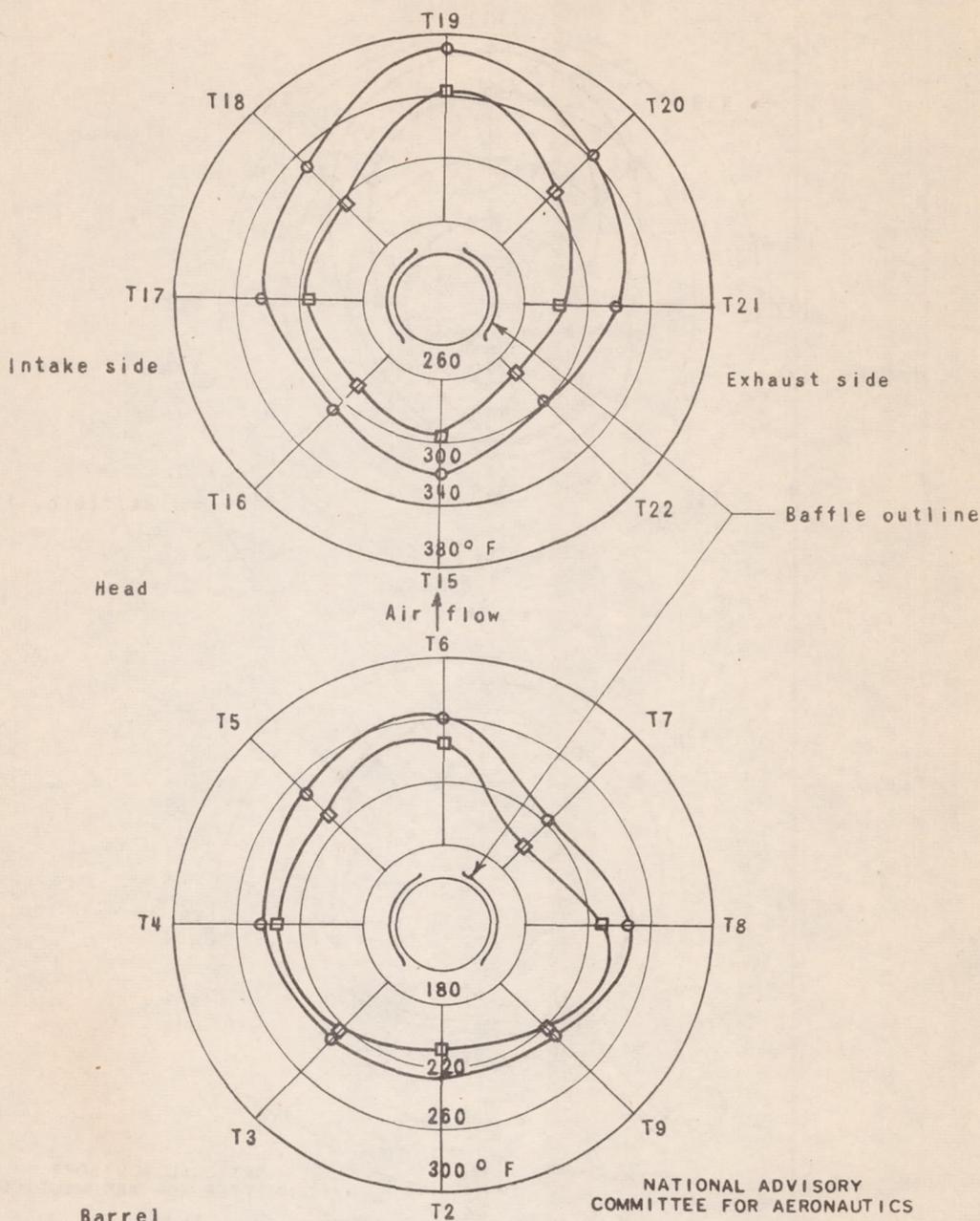
(b) Cylinder 7.

Figure 15. - Concluded. Longitudinal temperature distribution of cylinder.

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(a) Cylinder 18.

Figure 16. – Circumferential temperature distribution of cylinder.

T19
T18   T20
T17   T21
Intake side   Exhaust side
220
260
T16   300   T22   Baffle outline
340° F
Head   T15
Air flow
T6
T5   T7
T4   T8
160
200
T3   240   T9
280° F
Barrel   T2

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Operating conditions	○	□
Brake horsepower	820	1545
Engine speed, rpm	2030	2415
Density altitude, ft	5000	5000
Cowl-flap position	Closed	Full open
Blower ratio	Low	Low
Average engine fuel-air ratio	0.077	0.111
Impact pressure, in. water	18.9	29.0
Angle of attack of thrust axis, deg	5	2

(b) Cylinder 7.

Figure 16. – Concluded.   Circumferential temperature distri-
bution of cylinder.