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RESEARCH MEMORANDUM

OPERATING TEMPERATURES OF I-40-5 TURBOJET ENGINE BURNER LINERS AND THE EFFECT OF TEMPERATURE VARIATION ON BURNER-LINER SERVICE LIFE

By H. D. Wilsted, Robert T. Duffy
and Ralph E. Grey

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RESEARCH MEMORANDUM

OPERATING TEMPERATURES OF I-40-5 TURBOJET ENGINE BURNER LINERS AND THE EFFECT OF TEMPERATURE VARIATION ON BURNER-LINER SERVICE LIFE

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SUMMARY

Investigations of burner liners were conducted in a 4000-pound-thrust turbojet engine to determine, if possible, the principal factors limiting the burner-liner service life. The investigations covered a range of engine speeds from 3500 to 11,500 rpm. Chromel-alumel thermocouples were welded to the burner liner and tests were run to determine whether bare, ceramic-coated, or shielded thermocouples would give the most nearly correct temperature readings.

The ceramic-coated thermocouple was found to be least affected by cool combustion air flowing over the leads and was used throughout the runs. Burner-liner temperatures were found to rise at an increasing rate with engine speed and to have the same characteristics as the indicated burner-exit gas temperature. The maximum indicated burner-liner temperature and the maximum indicated burner-exit gas temperature recorded were 1590° and 1690° F, respectively. The liner circumferential temperature, besides varying greatly from point to point, was definitely highest at the bottom section as installed in the burner. Temperature gradients as great as 700° F per inch were measured in the liner. It is believed that the high local temperature gradients in the liner are the cause of the short service life.

INTRODUCTION

One of the factors that limit the use of the gas-turbine engine by the armed forces and in commercial transport service is its very short service life as compared with the reciprocating engine. The burner liners, which are directly exposed to the gases undergoing combustion, are subject to high thermal loads, intensive thermal shock during engine starting and accelerating, and the corrosive action of the combustibles. These factors result in a short burner-liner service life and, in turn, reduce the service life of many turbojet engines so that frequent inspection and replacement of liners are required.

As part of the program to improve the service life of the gas-turbine engine, a study of improved materials and improved cooling of engine critical parts has been undertaken at the NACA Cleveland laboratory. The operating temperatures and temperature distribution of the burner liners were obtained from an I-40-5 turbojet engine.

APPARATUS

The I-40-5 turbojet engine used in this investigation was equipped with a 19-inch-diameter jet nozzle. A sketch of an I-40 engine showing a burner-liner installation is presented in figure 1 and a photograph of a burner liner before thermocouples were attached for testing is shown in figure 2. The liner material for the two liners investigated was 0.031-inch Inconel sheet. Each liner was investigated separately in burner 12. (See fig. 1.)

All burner-liner temperatures were measured by chromel-alumel thermocouples spot-welded to the burner liners and coated with ceramic cement, as shown in figure 3(b). The test runs were made using a different thermocouple arrangement on each of the two burner liners. The bayonet-type thermocouple used to indicate burner-exit gas temperatures is shown in figure 4. A chronometric tachometer was used to measure engine speed.

PROCEDURE AND RESULTS

Tests were run with three different methods of mounting thermocouples on the burner liner to determine the effect of the comparatively cool combustion air passing over the thermocouple: bare, ceramic-coated, and shielded (fig. 3). The data presented in figure 5 show that the ceramic-coated thermocouple is least affected, the bare thermocouple only slightly more affected, and the shielded thermocouple most affected by the cool-air flow over the thermocouples. Apparently care must be taken to keep small the area of the liner covered by the ceramic in order that normal cooling of the burner liner adjacent to the thermocouple be maintained. At the time of application, the significance of the amount of ceramic coating used was not fully realized and some variation in temperature readings probably occurred because varying amounts of ceramic coating were used.

As a further check on the correctness of temperature measurement, ceramic-coated thermocouples were placed on the outer and inner surfaces of the burner liner at the same position, as indicated by thermocouples 6 and 7, 8 and 9, 26 and 27 (fig. 6). One thermocouple of each pair was then exposed to the hot combustion gases and the other to the cooler entering combustion air. The maximum variation was found to be 85° F between any pair of thermocouples. This variation is less than 7 percent or a probable error due to cooling of the outside ceramic-coated thermocouple leads of less than 3.5 percent.

The thermocouple locations on the first burner liner investigated (designated liner A) are shown in figure 6. The results of the investigations of liner A over a complete range of engine speed are shown in figures 7, 8, and 9. Figure 7 shows the temperature variation along the top row of cooling louvers. At maximum engine speed a variation of the order of 600° F in a length of 3 inches is shown. The maximum indicated temperature along the row of louvers is of the order of 1300° F.

The temperature variation along the center line of a section containing air-intake holes is shown in figure 8. This section is on the bottom of the liner, as shown in figure 6. With one exception, the maximum indicated temperature was only of the order of 1000° F if the noncritical liner-exit section is not considered. As can be seen from figure 9, these values are probably peculiar to the particular sections and no general conclusions comparing the louver and air-intake sections can be drawn. The wide circumferential temperature variations shown in figure 9 indicate no definite trend. An irregularity exists, however, in the pattern with the highest temperature region located at the lowest portion of the burner liner as installed in burner 12.

The thermocouple locations on burner liner B are shown in figure 10. In this case, it was felt that temperatures taken between the rows of holes and louvers would be more indicative of the effective liner temperature because less variation would result from cooling effects of the incoming air.

The thermocouples on burner liner B are located in circumferential belts; therefore the average circumferential temperature for each position along the length of the liner can be plotted as in figure 11. The average values show the following trend: a peak in temperature about one-third the length downstream on the liner with a greater peak occurring at the liner exit. It is in the region of the first-mentioned peak temperature that liners have failed in NACA investigations. These failures occur in the form of fractures and severe warping extending from the louvers to the air-intake holes at a section approximately 8 inches from the inlet end of the liner. This failure belt will hereinafter be referred to as the "critical section." Inspection of service liners has also shown failures at other locations between air-intake holes and louvers but in every case of this type there was a more serious failure at the critical section.

A replot of the data used in figure 11 is presented for each temperature belt in figure 12 to show the temperature variations with speed. The trend of rising burner-liner temperature with increasing speed or power in figure 12 is reasonably uniform. The irregularity of temperature belt 2 is attributed to the disturbance of the interconnector fittings on air flow. Also shown is the indicated burner-exit gas temperature, which reached a maximum of 1690° F at an engine speed of 11,500 rpm. In general, all the curves are reasonably smooth with temperatures rising at an increasing rate with engine speed.

The circumferential temperature variation nearest the critical section is presented in figure 13. An appreciable temperature variation occurs with a decidedly high-temperature region located at the lowest portion of the burner liner as installed in burner 12. This peak agrees with that of figure 9. The high-temperature region is behind the right-hand interconnector fitting. The axial temperature distribution along this section is shown in figure 14 and the temperature behind the left-hand interconnector fitting in figure 15. These figures also show the maldistribution indicated in figure 13. The peak temperatures behind the right-hand interconnector fitting at the higher speeds are of the order of 500° F greater than the corresponding section behind the left-hand interconnector fitting. Inasmuch as air-flow patterns approaching the burner have not yet been obtained, it is not known whether this shift is a result of air-flow variations or maldistribution of fuel.

The temperature variations along the top of burner liner B, between the louvers and air-intake holes, are shown in figure 16. Except for the rapid variation in temperature at the section between the series of small and large air-intake holes, a relatively small temperature variation exists as contrasted by the variations in figures 7 and 8 for the axial distribution along the center line of the sections containing the louvers and air-intake holes, respectively. An examination of the data shows that the highest indicated burner-liner temperature recorded in these investigations was 1590° F, as shown in figure 9 at an engine speed of 11,500 rpm. This peak temperature occurred in the thermocouple belt $9\frac{1}{2}$ inches from the inlet end of the liner near the critical section.

Temperature gradients as great as 700° F per inch of circumference are shown in figure 9 (point A). The high-temperature gradients from point to point in the burner liner are probably the cause of failure, the principal factor at the present time limiting the service life of the gas-turbine engine. Any process or method that will remove heat from the hot spots or give a more even temperature distribution such as the use of heavier gage metal for the liners to more rapidly conduct heat away from the hot spots or the use of cooling fins to remove heat from the high temperature areas should add materially to the burner-liner service life.

A liner failure typical of 14 liners removed from a service engine after 36 hours and 10 minutes operation is shown in figure 17. The severe warping and fractures are clearly shown in the photograph. The most severe warping and fractures occur in the belt of louvers marked "critical section."

Because of the comparatively short service life as limited by warping and fracturing, liner corrosion is not a problem at the present time.

SUMMARY OF RESULTS

The operating indicated temperatures and temperature distribution obtained over a complete range of engine speeds for two turbojet engine burner liners investigated separately in burner 12 of the engine showed that:

1. Temperature variations from point to point on the burner liner were extreme. The measured local temperature gradients were as large as 700° F per inch. The warping and fractures, occurring principally between the louvers and adjoining intake-air holes, are attributed to these extreme temperature gradients.

2. The maximum burner-liner indicated temperature (1590° F) occurred at a point about $9\frac{1}{2}$ inches from the inlet end of the liner.

This thermocouple was one of the belt nearest the critical section, which is located about 8 inches downstream of the burner-liner inlet. Most of the buckling and fracturing of burner liners investigated occurred in the critical section.

3. Indicated burner-liner temperatures were found to rise at an increasing rate with engine speed, having the same characteristics as the indicated burner-exit gas temperature. The maximum indicated burner-liner and maximum indicated burner-exit gas temperatures were 1590° and 1690° F, respectively. The liner circumferential temperature distribution, besides varying greatly from point to point, was definitely higher at the bottom section as installed in the burner.

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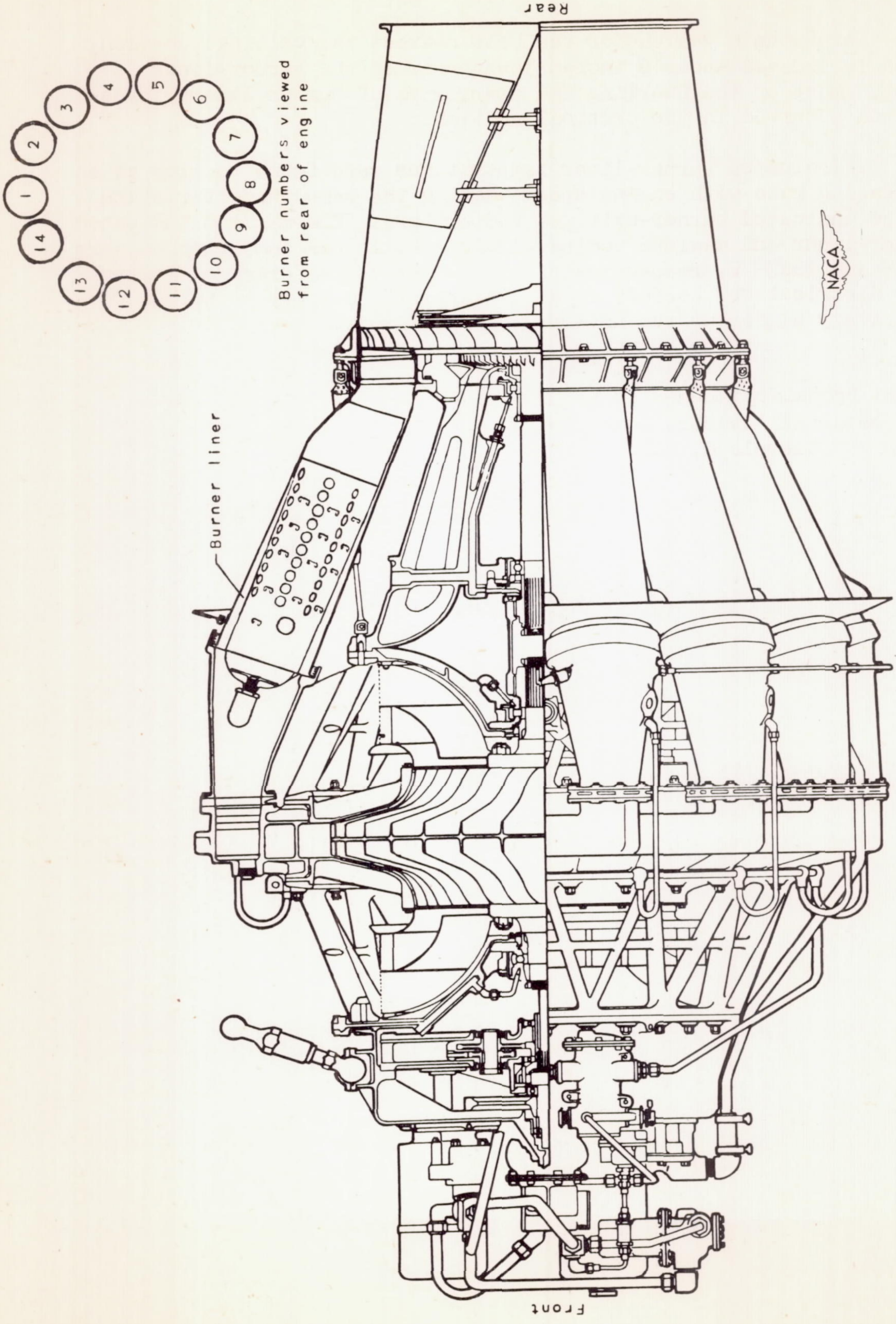

Figure 1. - The I-40 turbojet engine showing typical burner-liner installation.

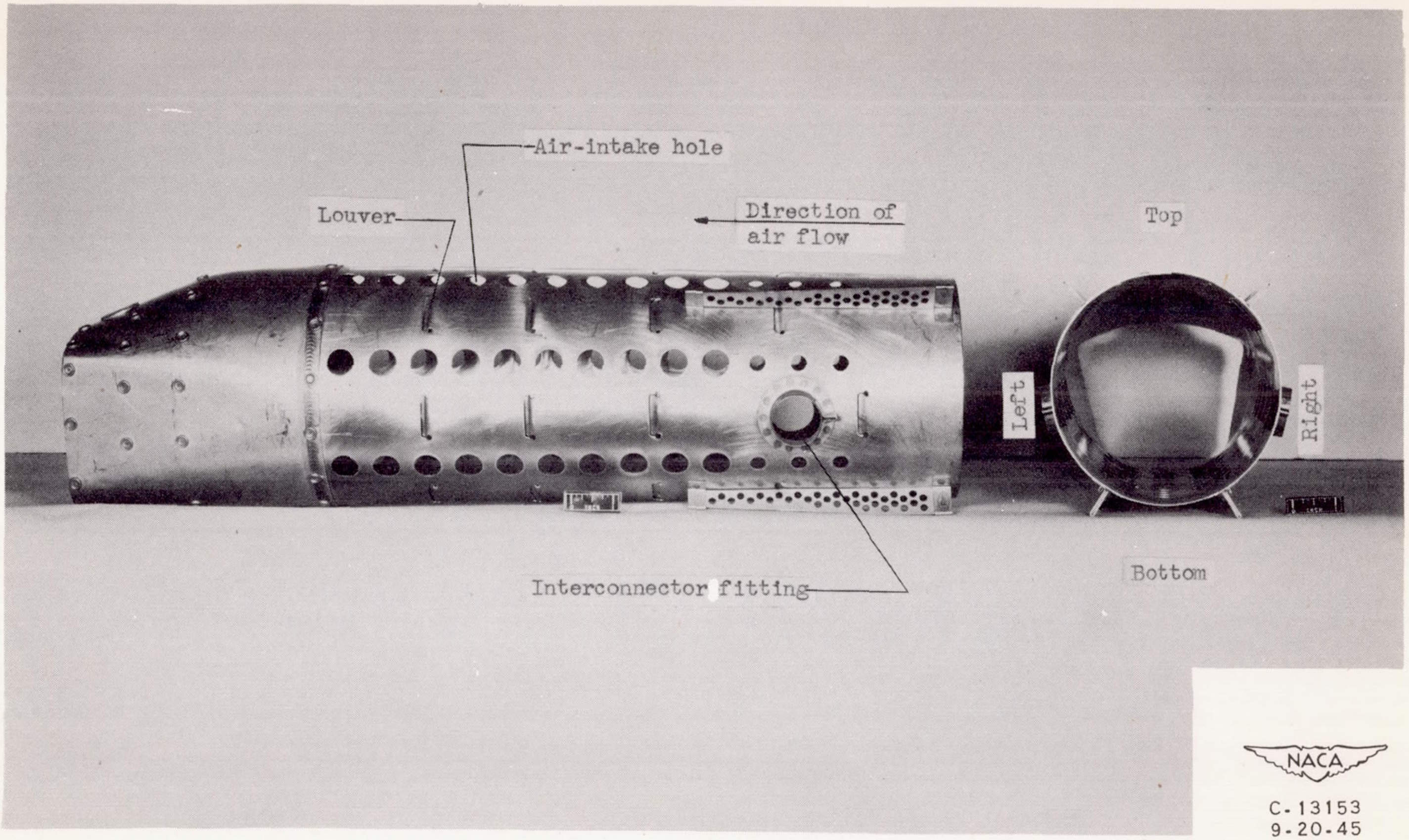

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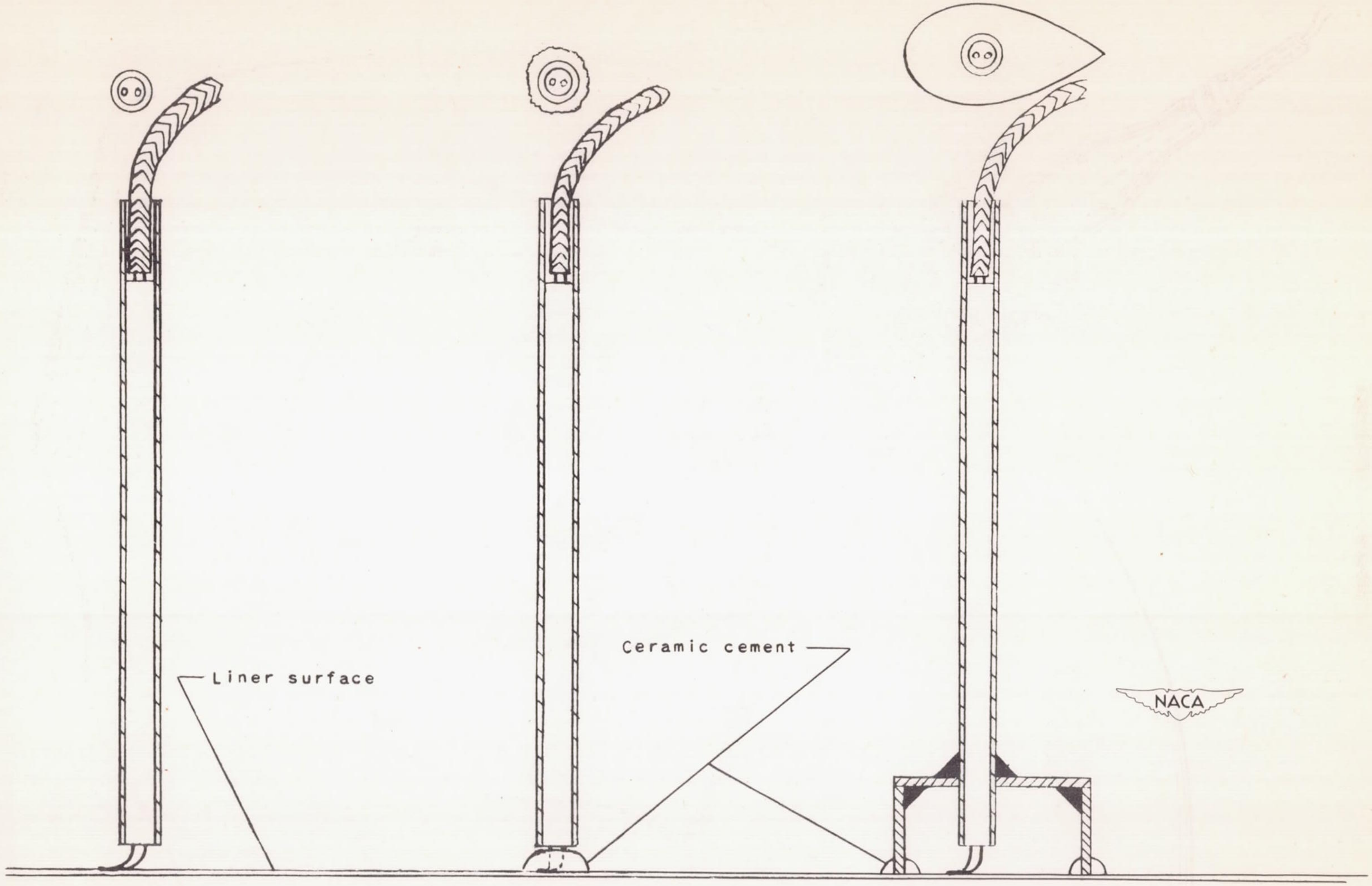
Figure 2. - Turbojet-engine burner liner.



(a) Bare. (b) Ceramic-coated. (c) Shielded.

Figure 3. - Thermocouple installations used to determine most correct method of measuring burner-liner temperatures. Thermocouple wires spot-welded to liner.

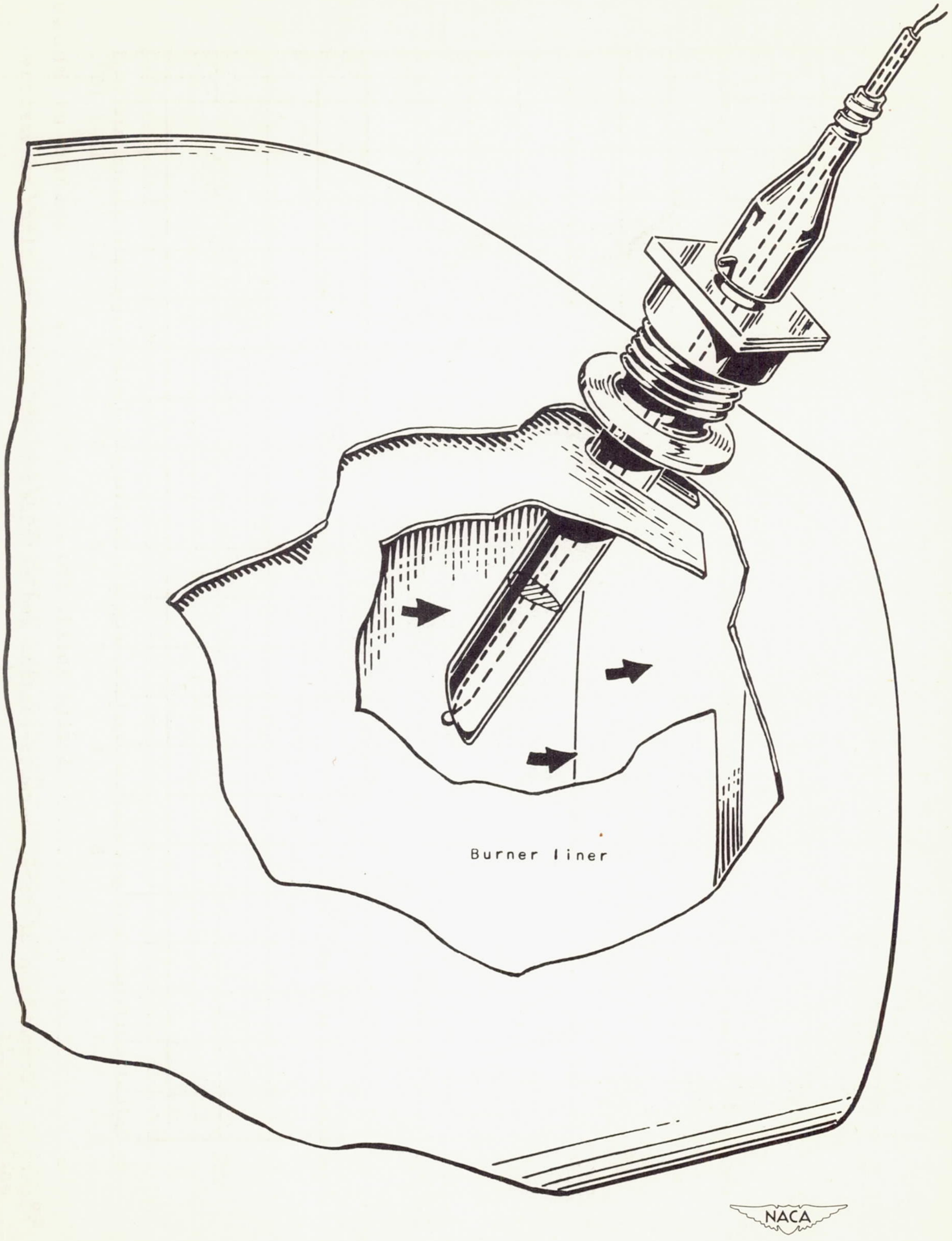


Figure 4. - Bayonet-type thermocouple installed in burner exit to indicate burner-exit gas temperature.

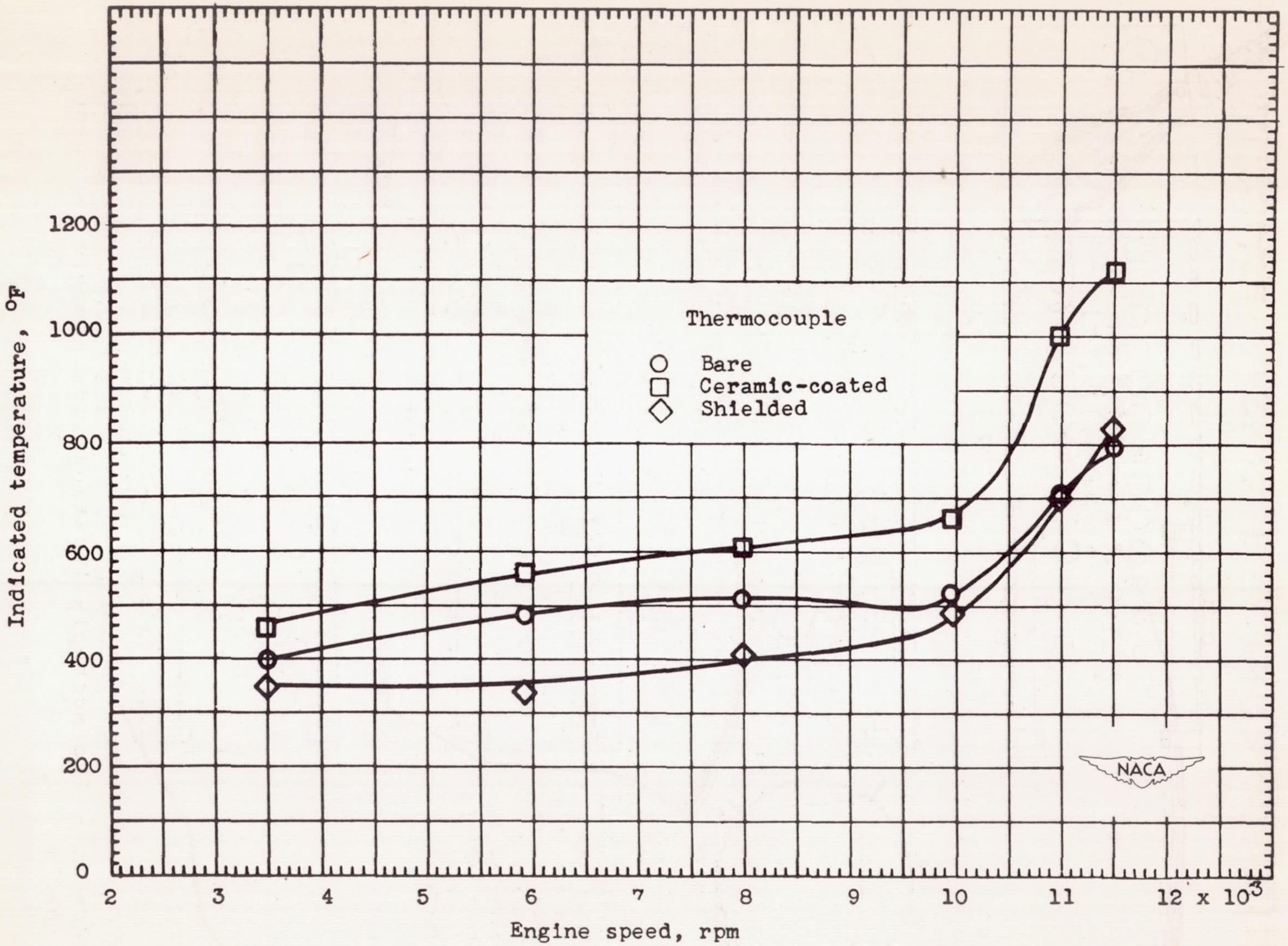


Figure 5 - Comparison of bare, ceramic-coated, and shielded thermocouple readings at various engine speeds.

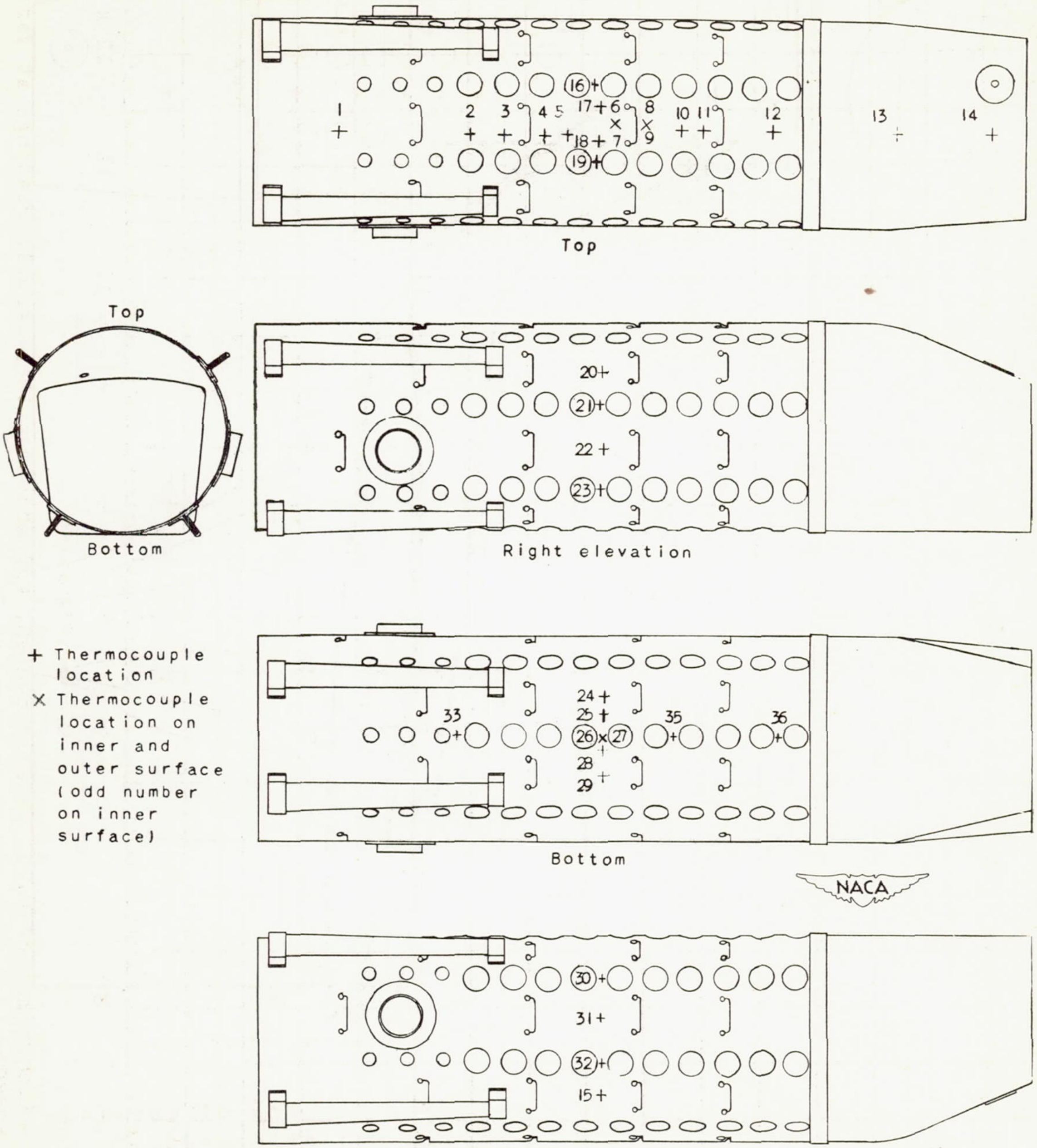


Figure 6. - Thermocouple locations and numbers on burner liner A.

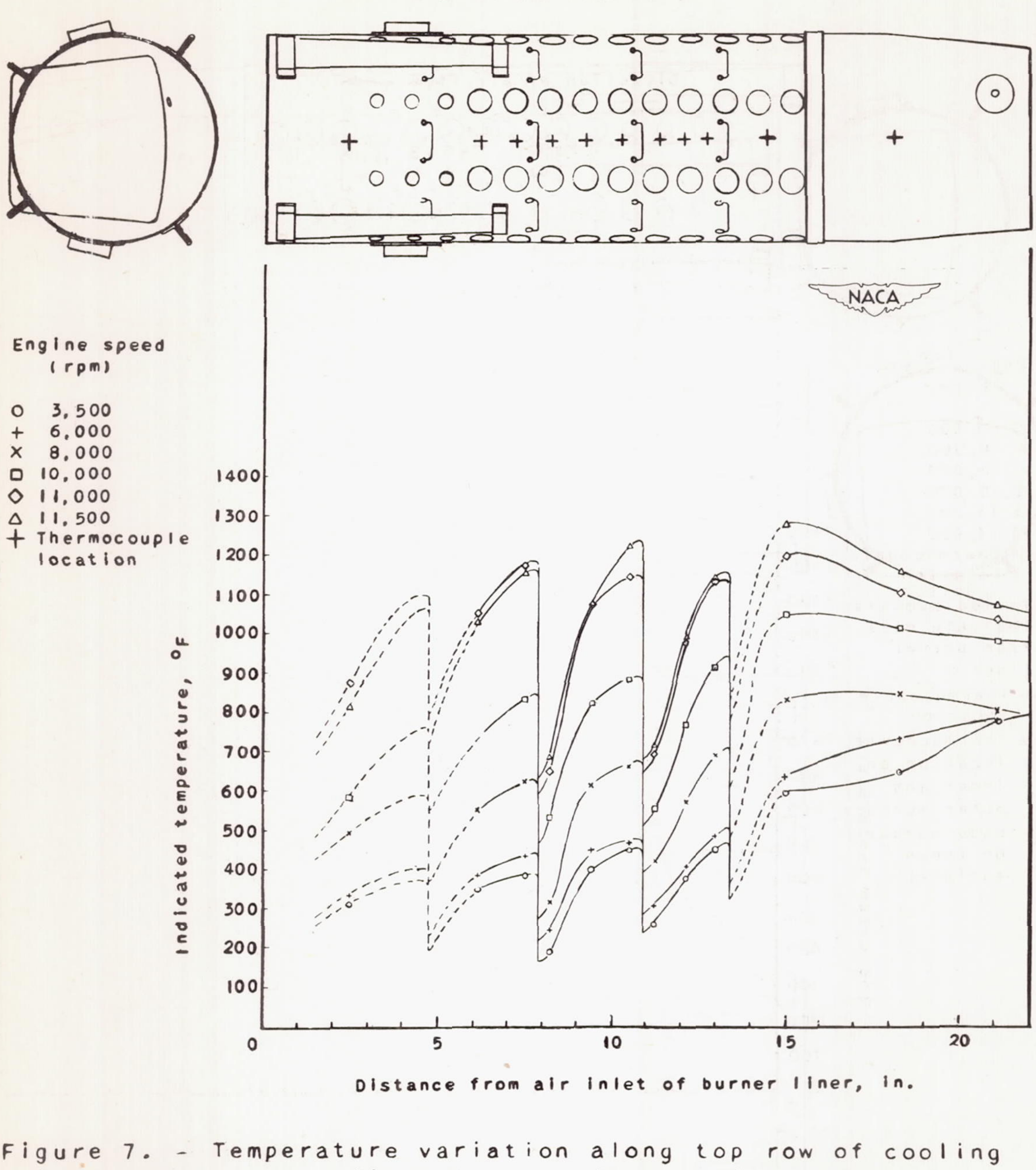


Figure 7. - Temperature variation along top row of cooling louvers on burner liner A at various engine speeds.

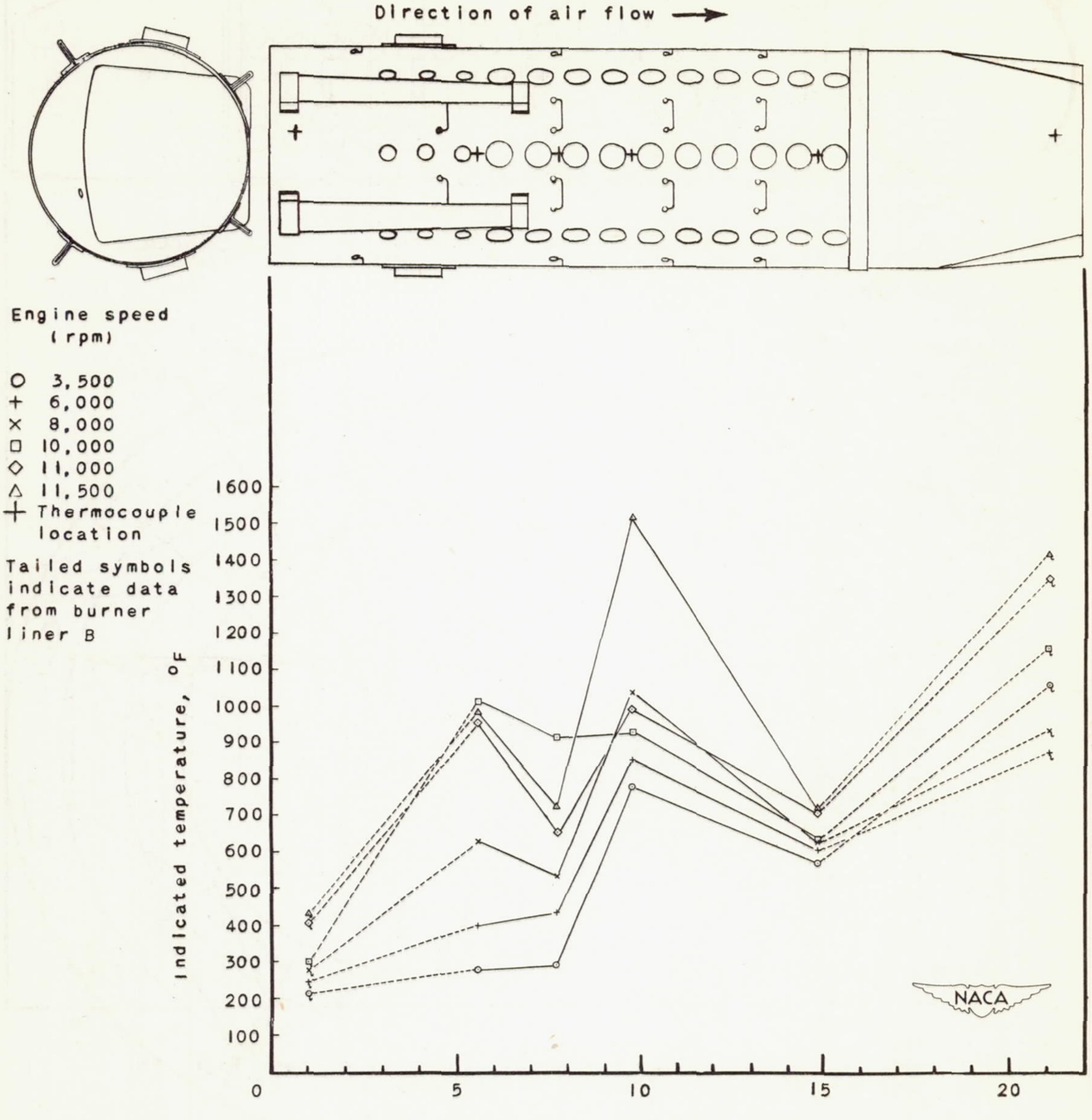


Figure 8. - Temperature variation along bottom row of air intake holes on burner liner A at various engine speeds.

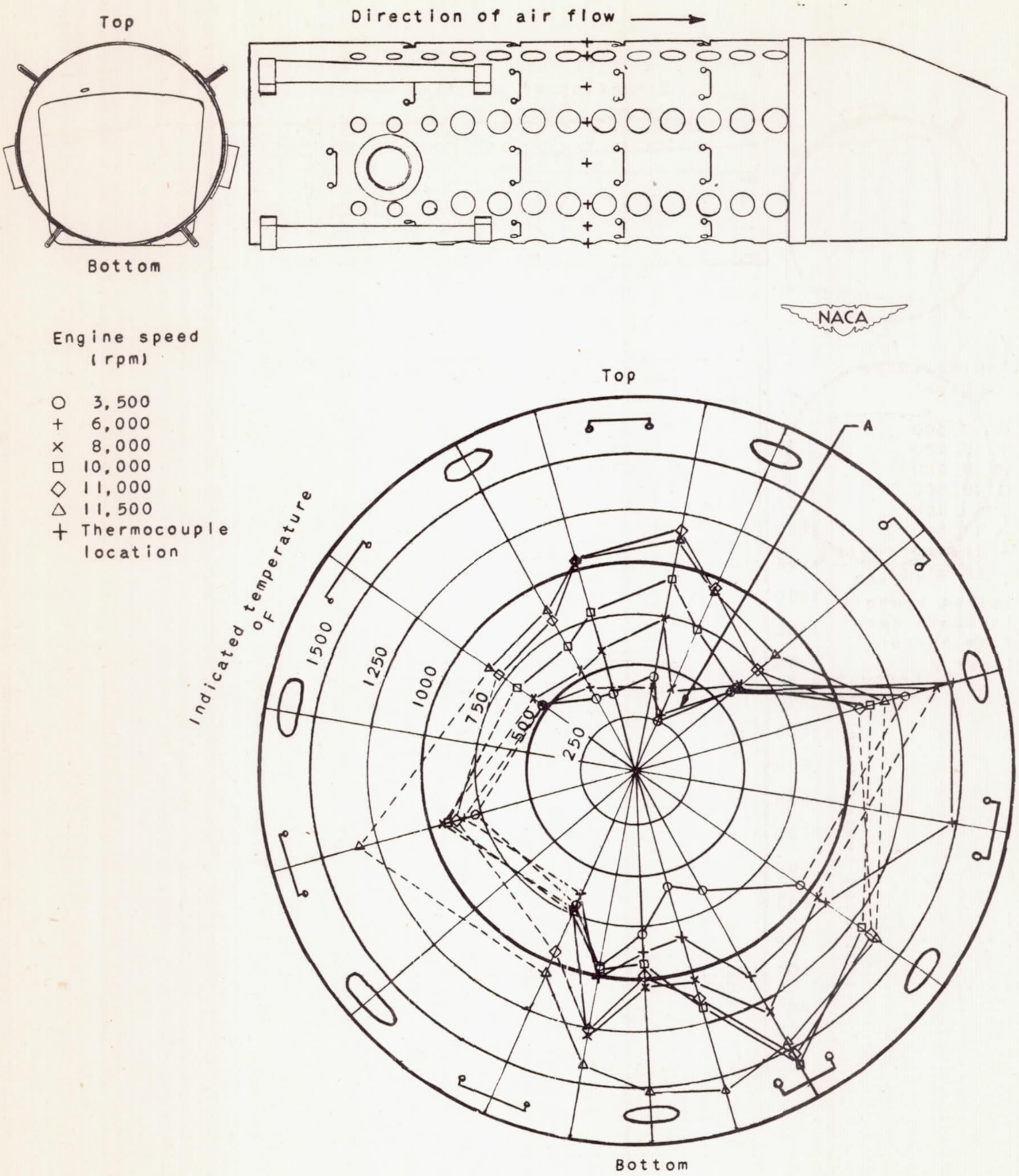


Figure 9. - Circumferential burner-liner temperature distribution near hottest temperature belt on burner liner A at various engine speeds. Average diameter of liner, 5.5 inches. (Dashed lines indicate missing temperature readings as a result of thermocouple failure.)

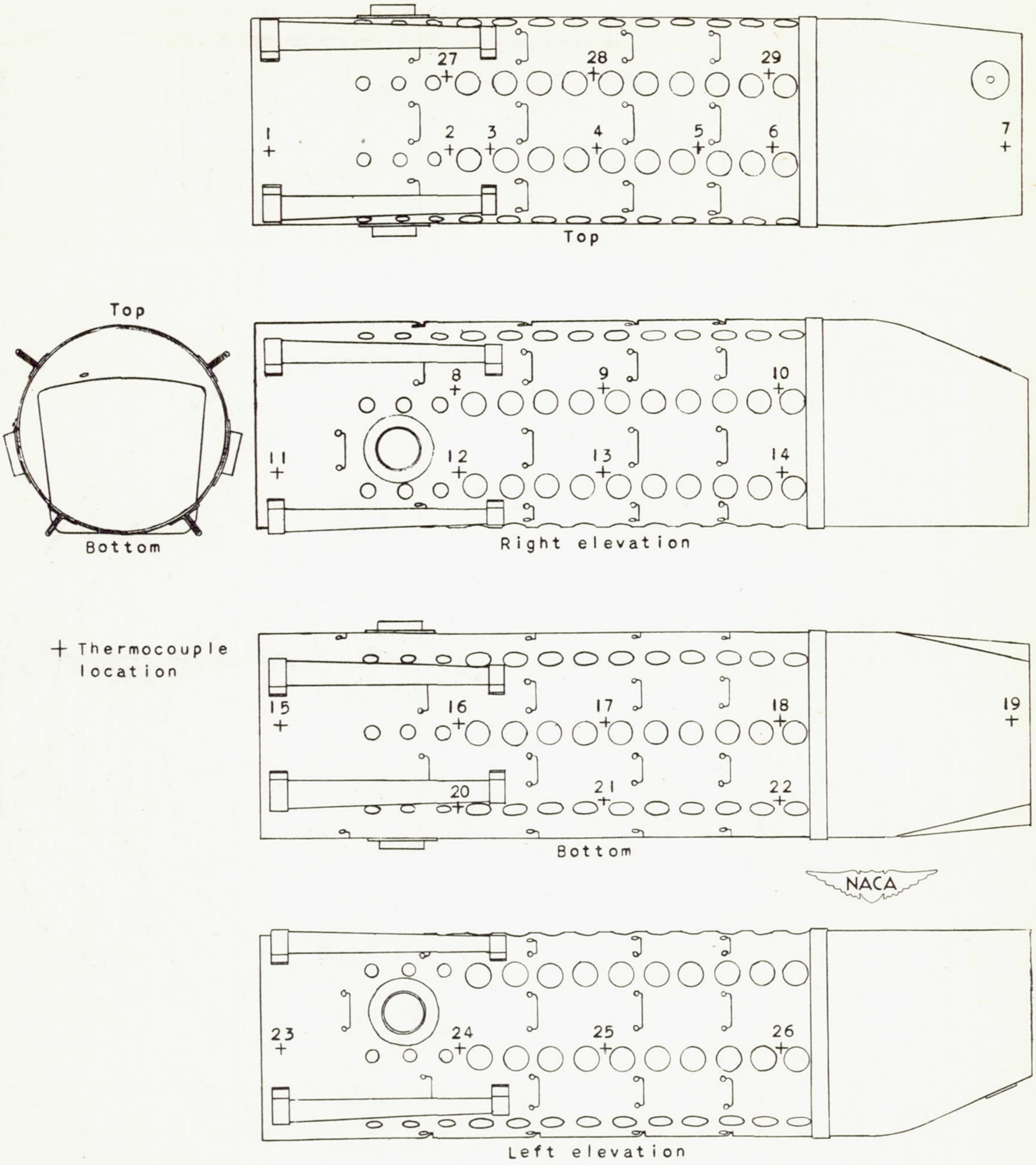


Figure 10. - Thermocouple locations and numbers on burner liner B.

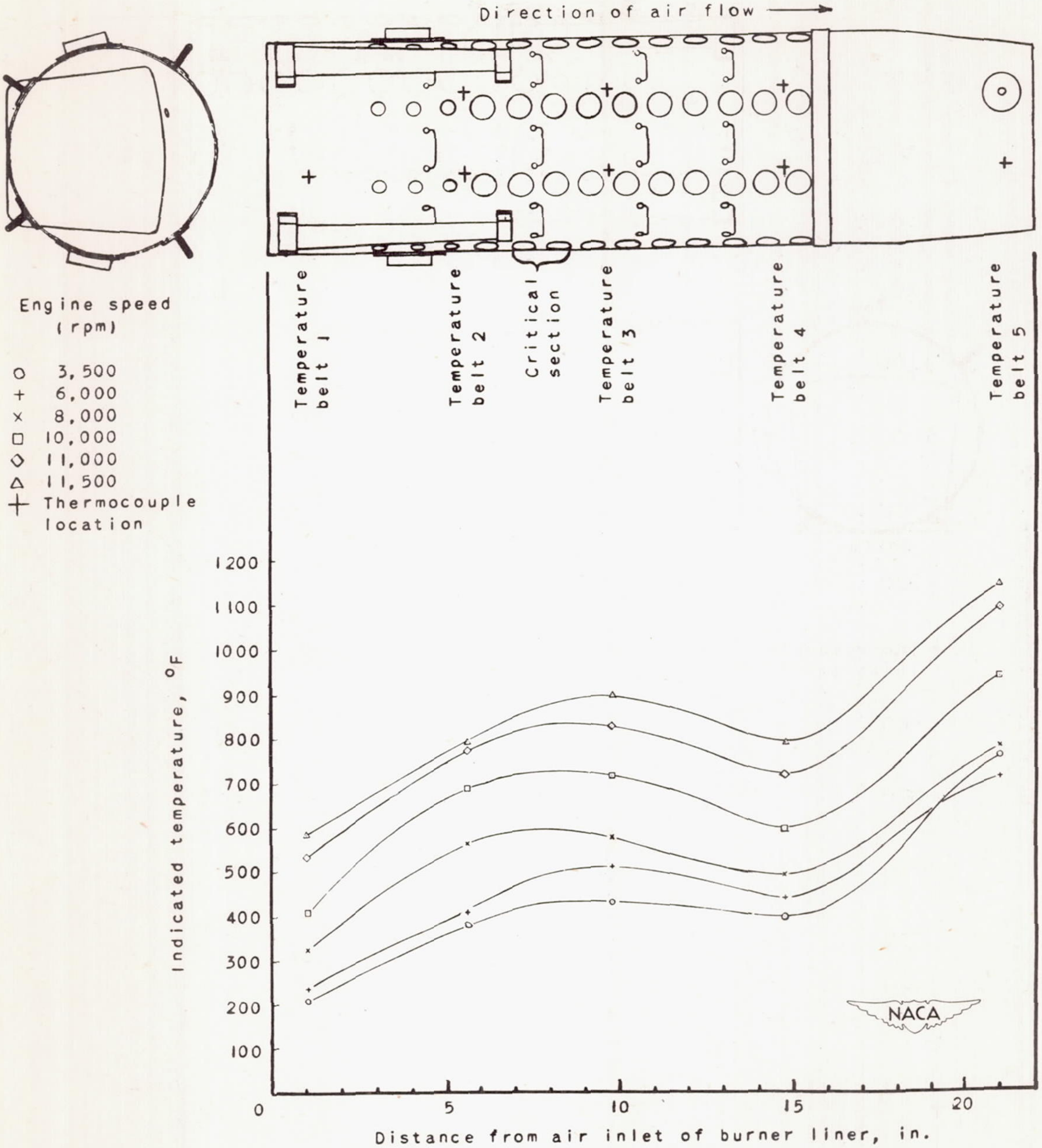


Figure 11. - Temperature variation along length of burner liner B. All points are average of belt temperatures.

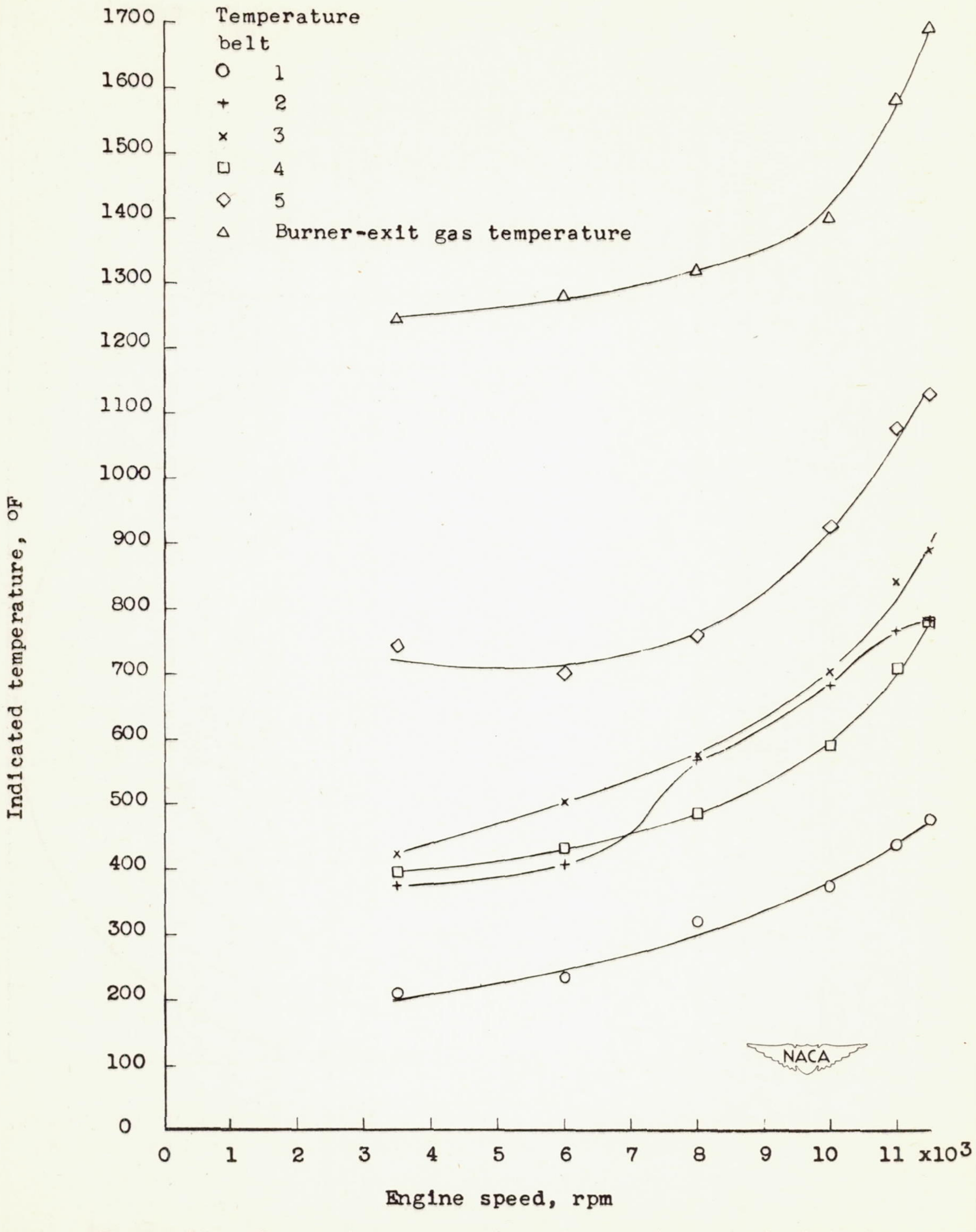


Figure 12. - Temperature variation with engine speed of temperature belts on burner liner B. All points are average belt temperatures. (See fig. 11 for belt location.)

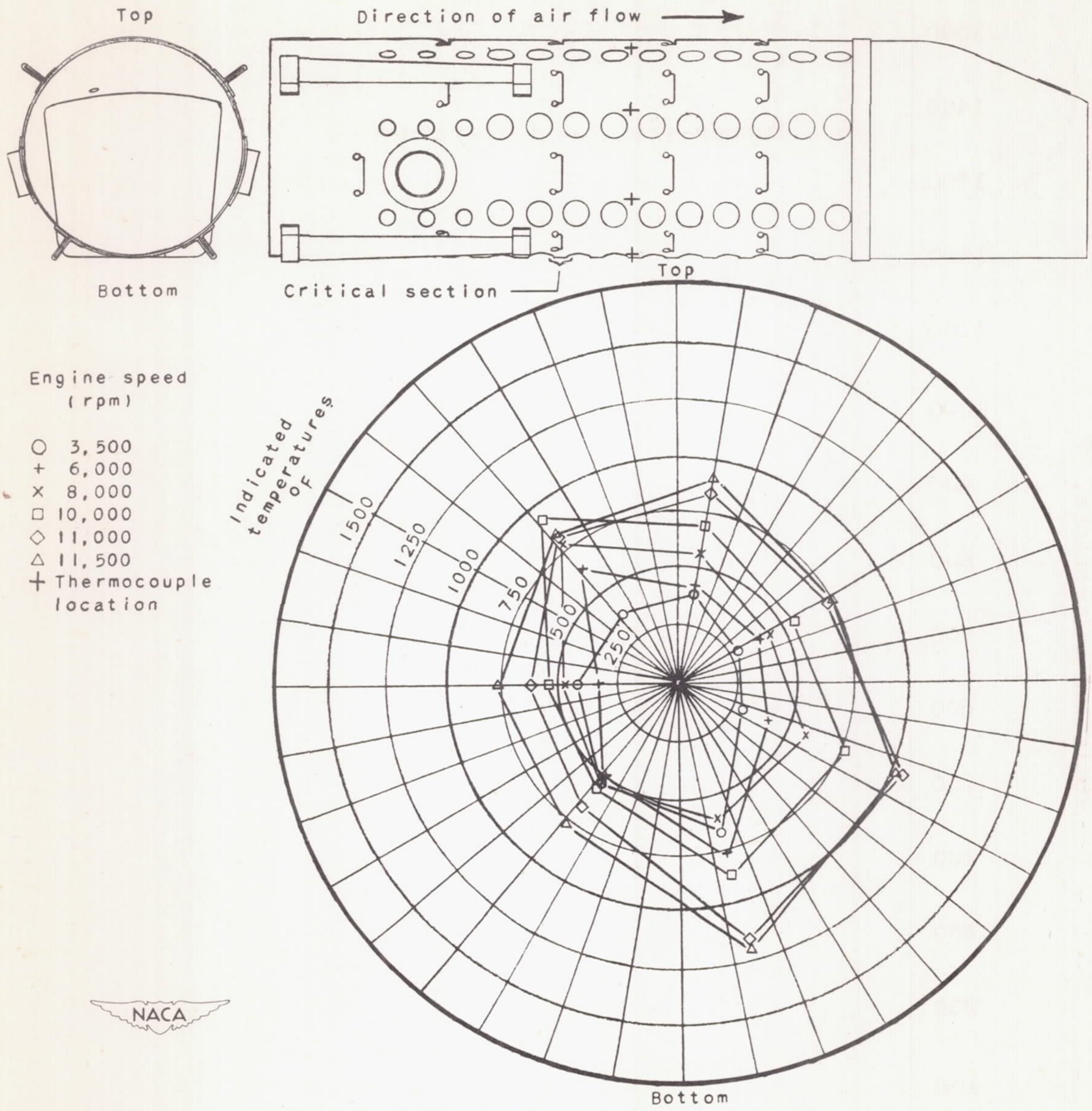


Figure 13. - Circumferential temperature distribution nearest critical section of burner liner B at various engine speeds.

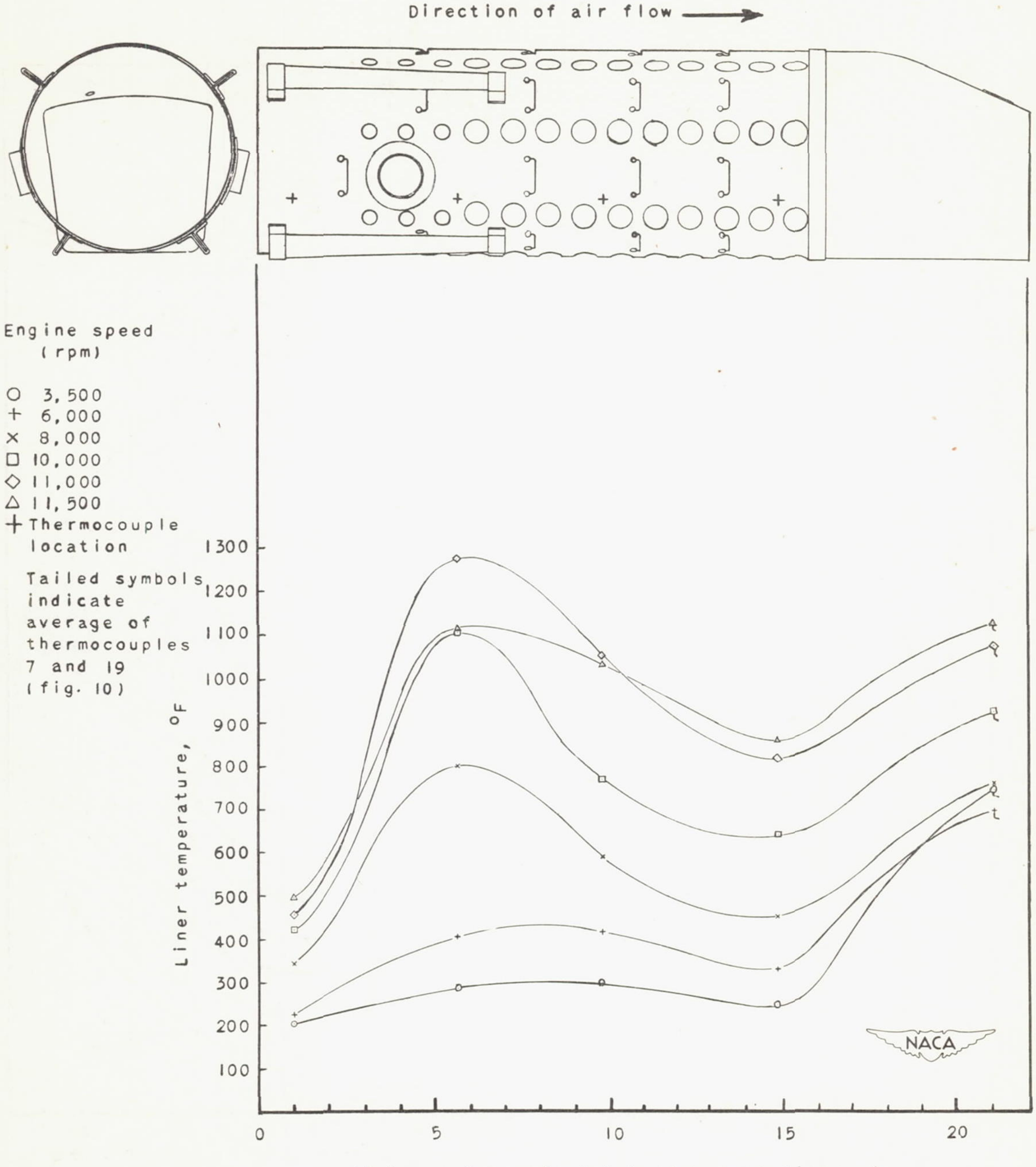


Figure 14. - Temperature variation along right side of burner liner B at various engine speeds.

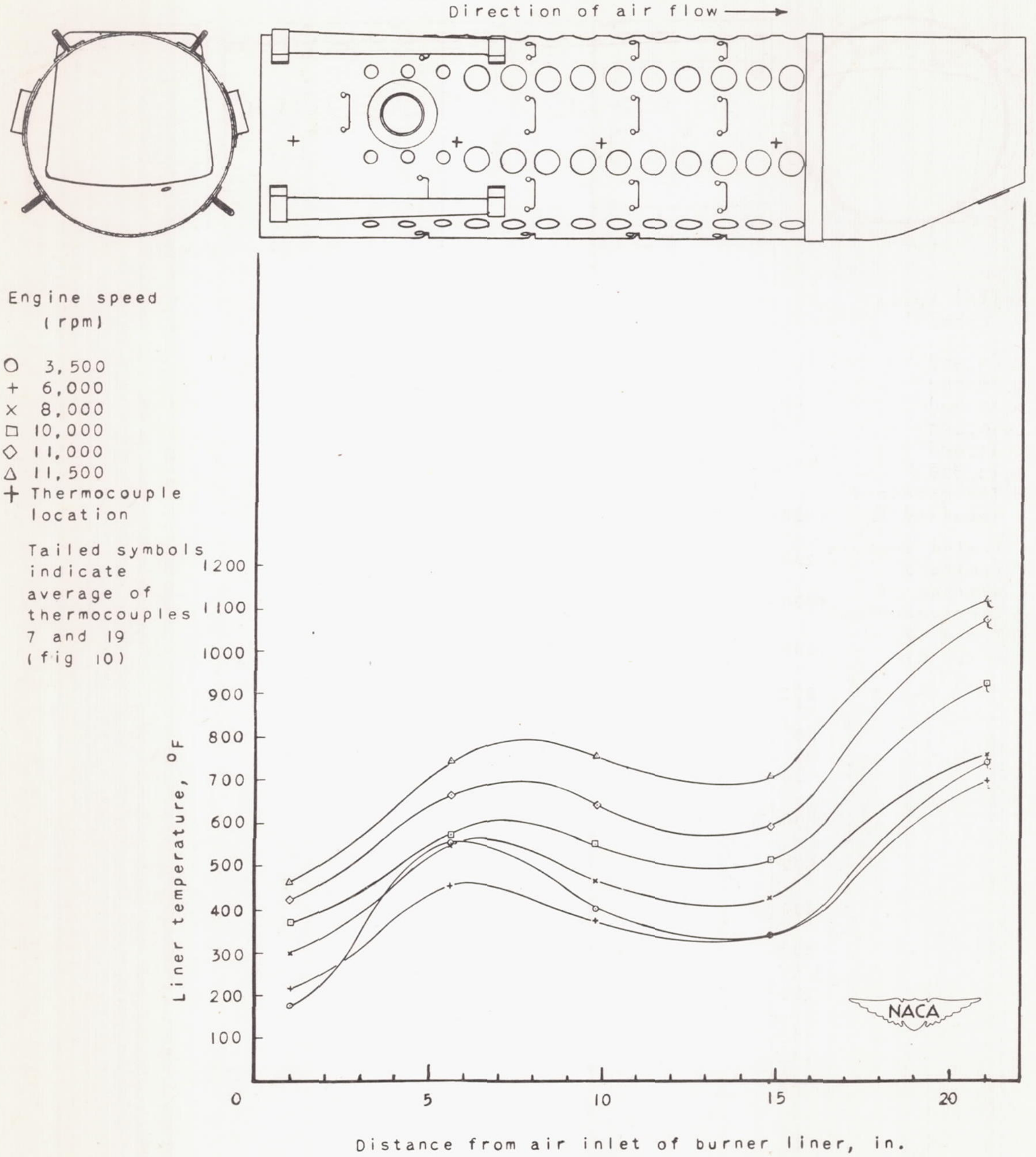


Figure 15. - Temperature variation along left side of burner liner B at various engine speeds.

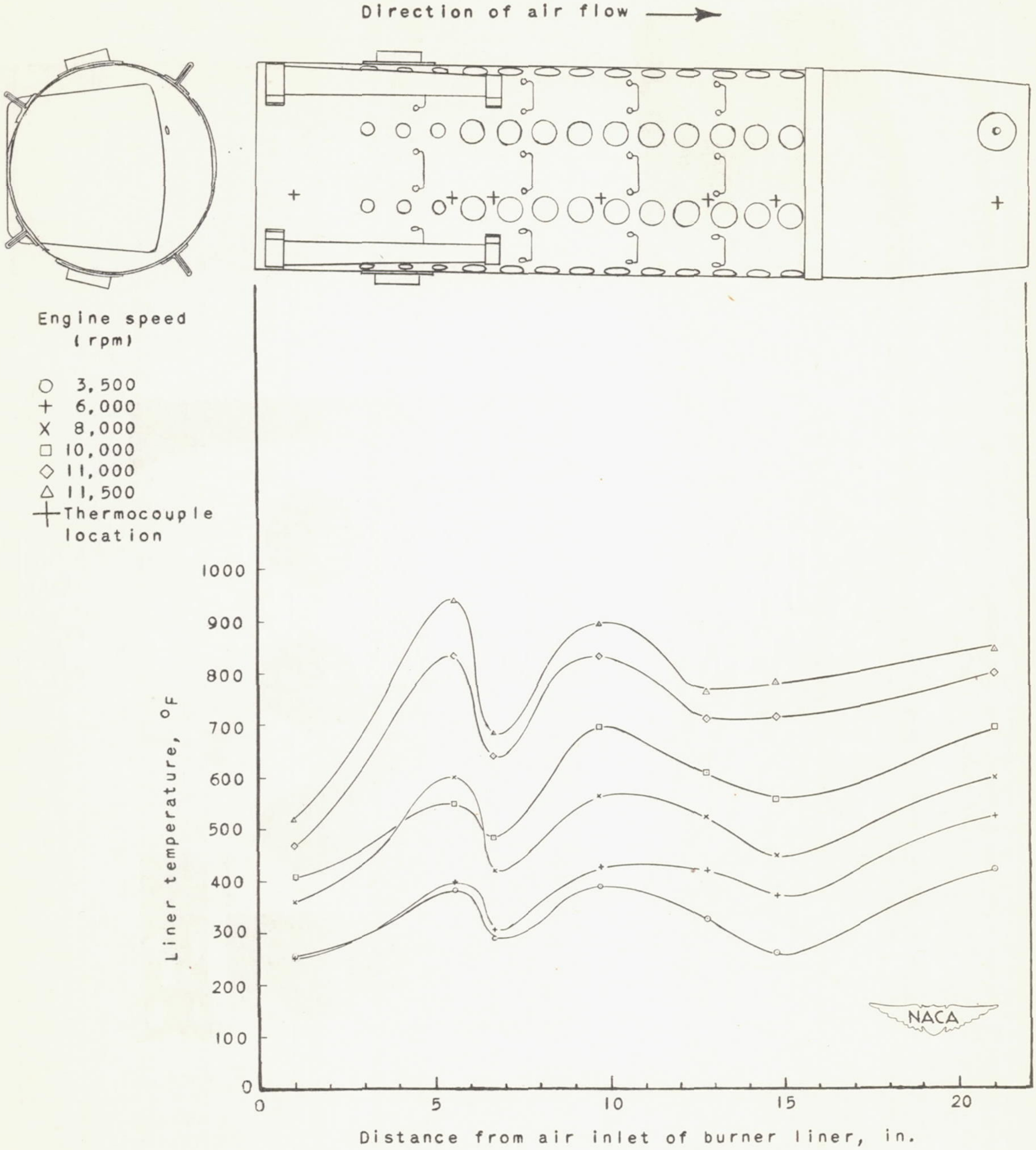


Figure 16. - Temperature variation along top of burner liner B at various engine speeds.

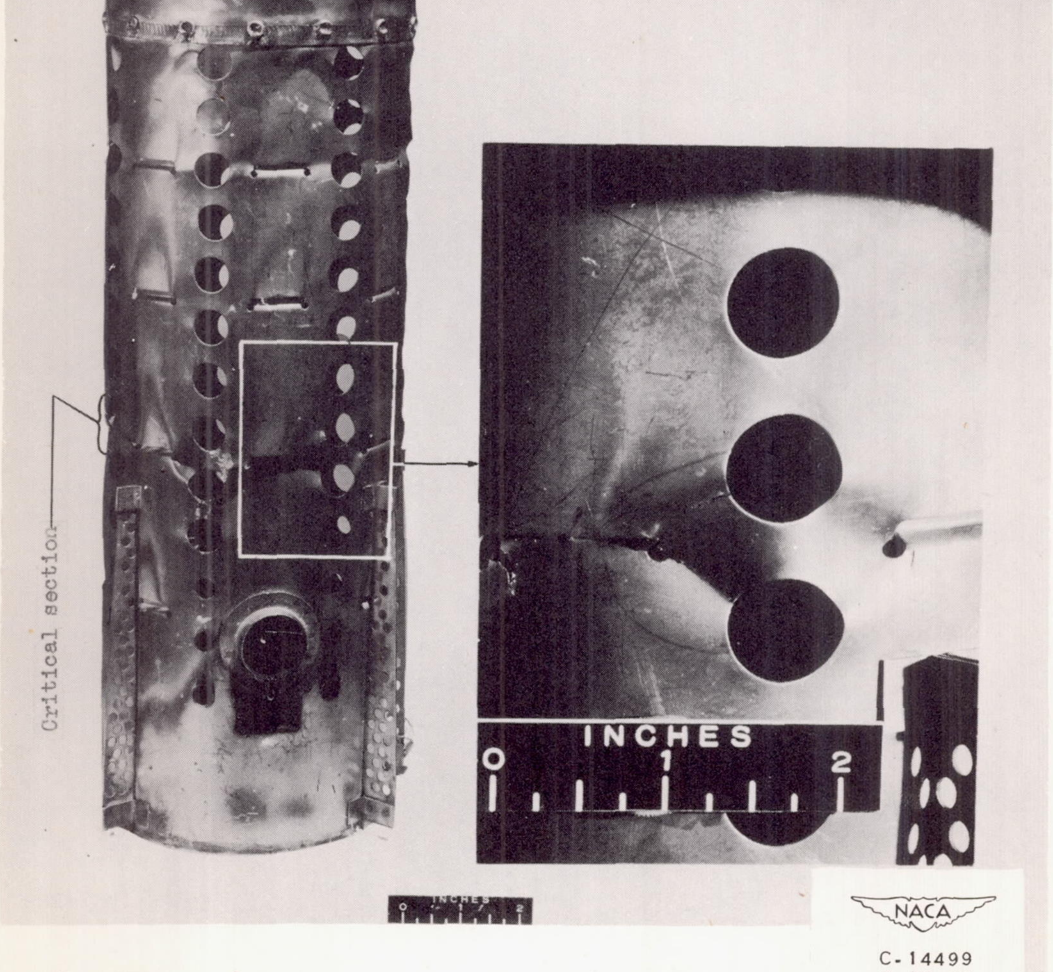


Figure 17. - Typical burner-liner failure. Total operating time, 36 hours and 10 minutes.