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RESEARCH MEMORANDUM

TRANSIENT TEMPERATURE DISTRIBUTION IN AN AERODYNAMICALLY HEATED MULTIWEB WING

By George E. Griffith

Langley Aeronautical Laboratory
Langley Field, Va.

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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RESEARCH MEMORANDUM

TRANSIENT TEMPERATURE DISTRIBUTION IN AN AERODYNAMICALLY HEATED MULTIWEB WING

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SUMMARY

Transient skin and interior temperatures are presented for a multiweb wing tested at Mach number 1.99. Four methods involving various degrees of approximation are used to calculate the temperatures; the results are shown to be in good agreement with the experimental temperatures when the significant types of heat conduction are taken into account.

INTRODUCTION

In order to determine the structural effects of transient aerodynamic heating, the first requisite is a knowledge of the temperature distribution throughout the structure. Methods exist for predicting the temperatures, but there is a lack of test data to check their reliability, particularly in or near internal stiffening where heat conduction effects are important. This paper presents the preliminary results of a study of the transient aerodynamic heating of a model of a multiweb wing, includes a brief discussion of three procedures for calculating the temperatures, and shows the correlation between the experimental and calculated results.

EXPERIMENTAL DATA

The experimental values presented were obtained from the first model (fig. 1) described in reference 1. (A detailed discussion of the testing of this model is also given in ref. 2.) The pertinent test conditions were: Mach number, 1.99; free-stream temperature, 107° F; and free-stream static pressure, 15.0 pounds per square inch absolute.

METHODS FOR CALCULATING TEMPERATURES

In aerodynamically heated structures, heat from the boundary layer is either absorbed by the skin or conducted to other parts of the structure, radiated to the atmosphere, or transferred to the contents by conduction, convection, or radiation. For the problem under consideration only absorption and conduction are of any significance, since, at the low temperatures involved, radiation from the model to the atmosphere is negligible and very little heat is lost to the air contained within the model.

Figure 2 shows a few of the possible methods of calculating the temperatures. As a means of approximating the skin temperature away from any heat sink, consider an element of skin as shown for method I in figure 2. Heat conduction along the skin is assumed to be negligible; hence, all the heat from the boundary layer is used in raising the temperature of the skin element. The simple heat balance at this point is described by an ordinary differential equation. (See, for example, ref. 3.)

In order to find the temperatures through a thin slice of a uniformly heated solid section or through a very thick skin, consider the slab geometry, method II. This geometry is similar to the first except that the thickness has increased considerably. Again the horizontal flow of heat is considered negligible, but now some of the heat entering from the boundary layer is conducted vertically along the material. Addition of the single space dimension leads to a partial differential equation, but the heat-conduction problem is still a simple one (which can be solved as indicated in ref. 4, p. 801).

Consider, as shown in the figure for method III, a piece of skin with a web or stiffener attached. Heat enters from the boundary layer but near the stiffener a considerable amount of heat is conducted along the skin and then down into the stiffener. Because of the change in geometry, this heat-conduction problem is considerably more difficult than the previous ones; again a partial differential equation applies.

For a portion of any solid section, method IV, heat from the boundary layer can be conducted both vertically and horizontally. This two-dimensional flow of heat represents a difficult problem and leads to a more complicated partial differential equation.

Methods I and II denote approximations to the actual conditions, whereas methods III and IV can be considered as representing the true conditions; likewise, although methods I and II are simple to solve, methods III and IV are complex. It is desirable to use the least complicated method whenever the results agree satisfactorily with experiment. Solutions to the partial differential equations, especially of the forms used for methods III and IV, are difficult and tedious to obtain, but other methods - only slightly less exact - yield essentially the same results. As indicated in the key, the same procedure was used for both methods III and IV - in this case, a numerical procedure. (See ref. 4, pp. 806, 807, and 816.)

As a first step in calculating the temperature distribution throughout the multiweb wing, the wing cross section was subdivided into the two regions shown in figure 3, one for the leading or trailing edge, the other for any skin and web combination. This simplification in geometry assumes that there is zero rate of change of temperature across the boundaries - along the center line and at the skin extremities located halfway between the web rivet lines or approximately halfway between the first (or last) web rivet line and the solid leading-edge (or trailing-edge) section; hence, no heat enters or leaves at these points. (The results indicate that this is a valid assumption for this type of structure.) Complete temperature distributions, using methods III and IV, were found for each of the two geometries shown. In addition, skin temperatures and temperatures in the webs and at some points in the interior of the solid leading-edge section were approximated, as indicated in figure 2, by using methods I and II.

The heat-transfer coefficients used in the calculations were obtained by using turbulent flow, flat-plate theory based on local flow conditions just outside the boundary layer of the circular-arc airfoil. (See ref. 5.) The adiabatic wall temperature was obtained by extrapolating the experimental skin temperature histories. (See ref. 2.)

RESULTS

Shown in figure 4 are typical temperature histories of two points, one on the skin removed from the heat sink afforded by the web, and one at the web center line. Experimental and calculated temperatures T are plotted against the time. The experimental skin temperature - represented by the circles - rises rapidly to a final value of about 305° F in 8 seconds, considerably less than the adiabatic wall temperature T_{aw} of 446° F. On the other hand, the web temperature is lower and lags considerably behind the skin temperature; this condition illustrates that some time elapses before heat can be conducted down into the web and that, since the web temperature at the end of the test is still much lower than the skin temperature, an appreciable additional time would be needed to reach the steady-state condition.

Results predicted by both methods I and III agree well with the measured skin temperature, but method III overestimates the true web temperature, possibly because the riveted joint between skin and web offers some resistance to the flow of heat not taken into account in the analysis. Method II underestimates the web temperature because it does not account for the horizontal flow of heat along the skin and into the web.

Figure 5 shows temperature distributions at both 4 and 8 seconds for a skin and web combination. Skin temperatures are plotted vertically above the skin and the web temperatures horizontally to the right. Experimental skin temperatures are shown as circles, experimental web temperatures as squares. Method III, which gives the complete temperature distribution, agrees well with the skin temperatures; because of the conduction of some of the heat into the web these temperatures are somewhat lower where the web flange joins the skin. Method I, using the combined thickness of skin and web flange where they are in contact, gives almost as good agreement but certainly overestimates the temperature of the skin alone close to the web. Method III predicts temperatures in the web generally higher than the experimental values, as was also illustrated in figure 4. The temperatures at both 4 and 8 seconds are shown to illustrate that even at the lower temperatures appreciable differences exist between the skin and interior temperatures. Perhaps it is well to recall that the magnitudes of any induced thermal stresses depend upon such differences.

Similar temperature distributions for both 4 and 8 seconds are shown in figure 6 for the leading-edge section. Center-line temperatures for the solid section and skin temperatures are plotted above the surface. Because of the difficulty in thermocouple installation, only two thermocouples (located as shown in fig. 6) give a basis for comparison with the calculations. Method III is in fairly good agreement with the experimental values for both the solid section and the skin. Method I agrees well with the experimental skin temperature but overestimates the skin temperature near the solid section. Method II shows good agreement with the experimental temperature in the solid section. This agreement indicates that in this section heat from the boundary layer is conducted generally downward into the interior with little heat conducted sidewise; this effect is also substantiated in that the variation through the thickness (not shown) is quite small - a maximum of approximately 15°. The temperatures at different times have been shown in order to give an indication of how the temperature distribution changes with time.

Shown in figures 7 and 8 are the chordwise temperature distributions at both 4 and 8 seconds, respectively, across the entire model, including center-line temperatures for the solid leading and trailing edges, skin temperatures, and temperatures at the center line of the webs. Calculated temperatures were obtained by using method III. Experimental skin temperatures appear as circles and interior center-line temperatures as squares. Generally good agreement exists between the calculated and measured temperatures. Note the sink effects of the webs and solid sections. Although the temperatures shown are not very high, differences in excess of 200° F occur between the surface and interior, sufficient to produce substantial thermal stresses.

This discussion has been limited to only the first of several models tested and described in reference 1. The data shown are fairly representative of the results obtained for the other models, although the agreement in some cases was not as good as for the model illustrated. No pronounced effects were observed with small changes in angle of attack; as the angle of attack increased the lower surface became hotter slightly faster than the upper surface, as predicted by the local heat-transfer coefficients.

CONCLUDING REMARKS

In conclusion, comparisons of measured and calculated temperatures in a multiweb wing show good agreement when the significant types of heat conduction are taken into consideration. Approximate methods, when used with care, may also give satisfactory results, as, for example, in using method I to predict the skin temperature some distance from a web or stiffener, or in using method II (a slab method) for the interior of solid sections. Approximate methods are less satisfactory in the vicinity of a web or stiffener because the web can drain a large amount of heat from the skin. Since the magnitude of heat drained by such a heat sink is a function of the geometry and materials, substantially smaller or larger discrepancies might be obtained for different structures. Approximate methods, then, are advisable in some cases, but judgment - based upon a physical understanding of the possible heat flow - should be exercised in using them.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 20, 1953.

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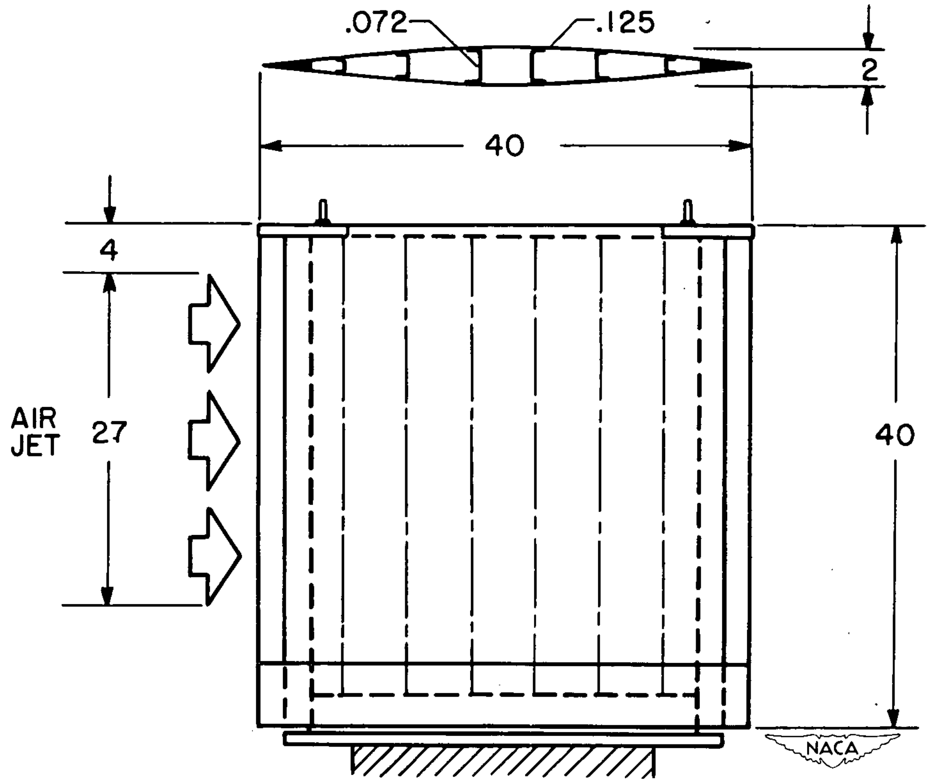

Figure 1.- Configuration of model tested.

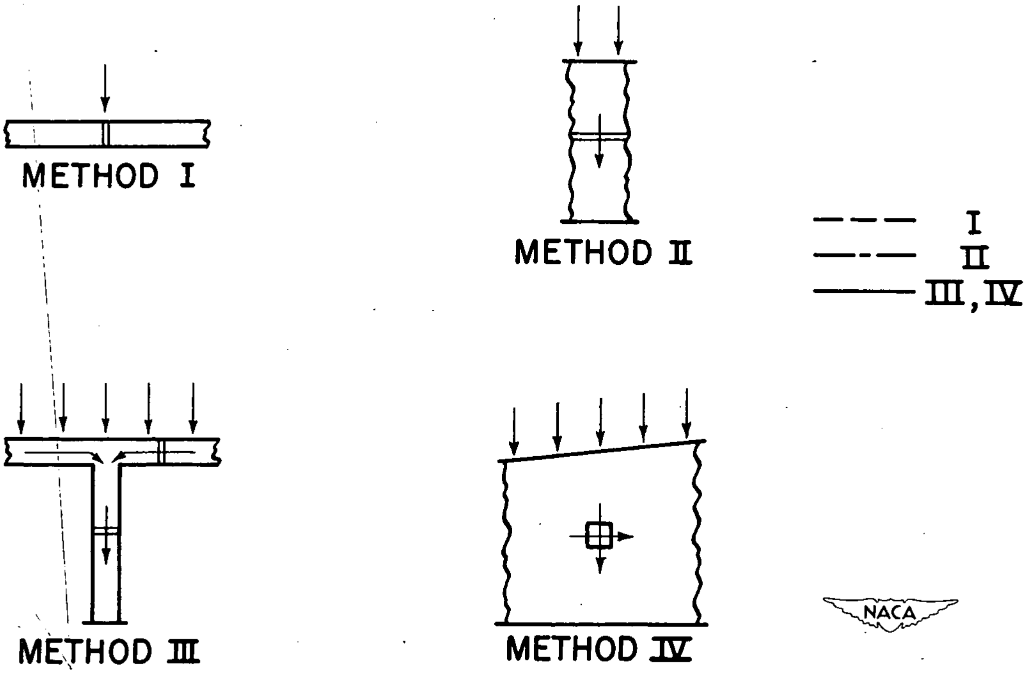

Figure 2.- Heat-flow calculating methods.

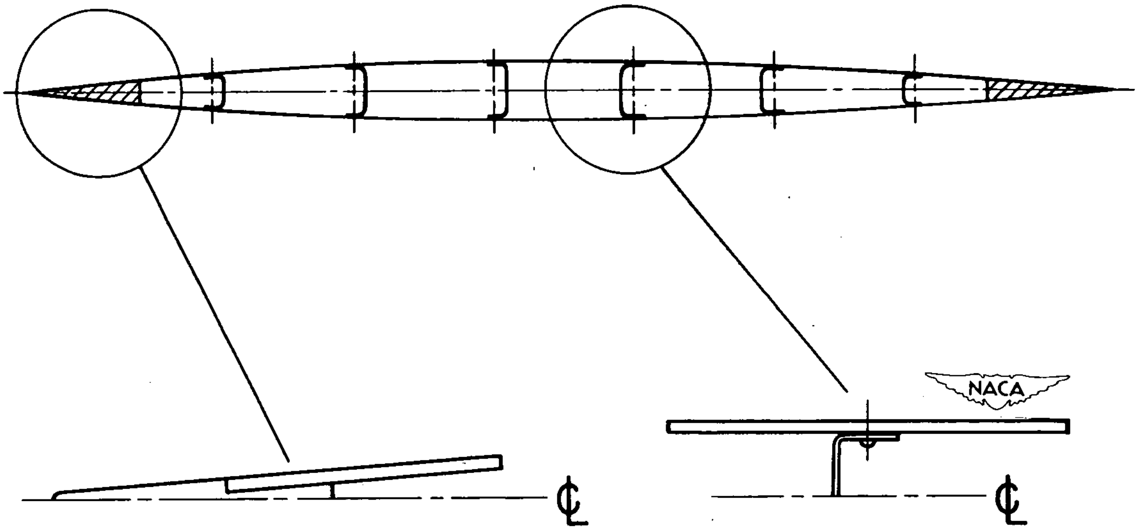

Figure 3.- Subdivision of wing cross section.

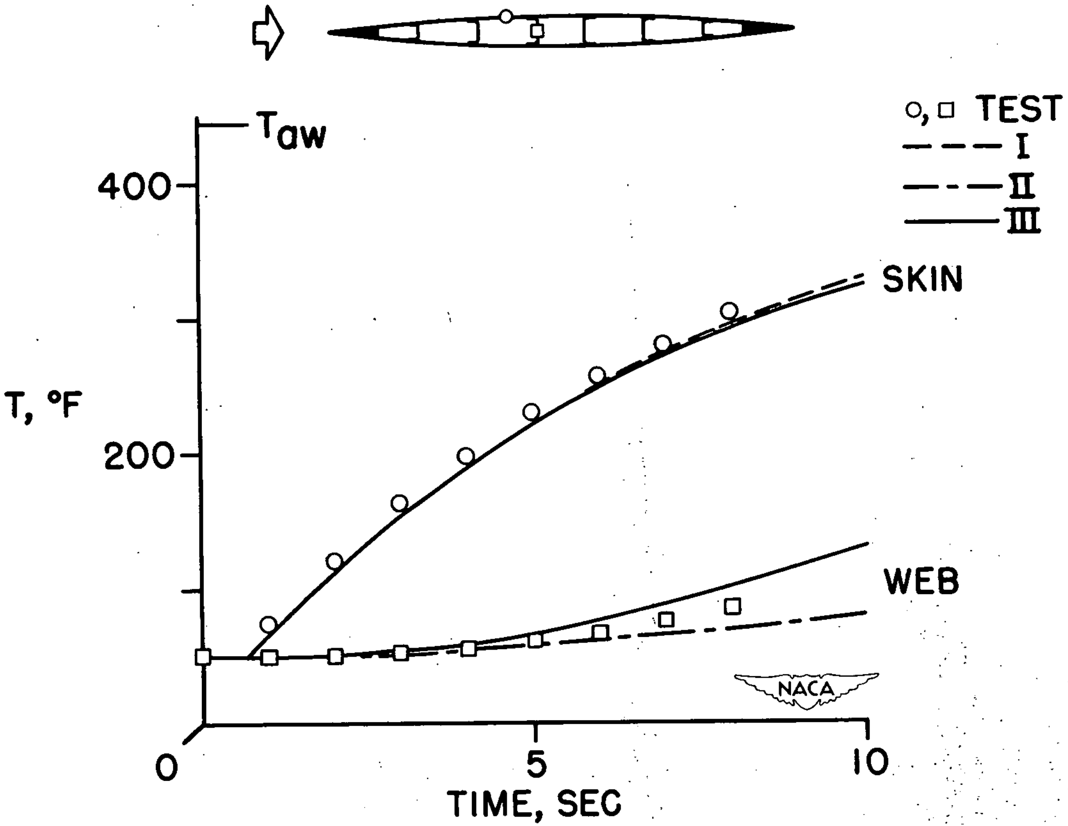

Figure 4.- Typical skin and web temperature histories.

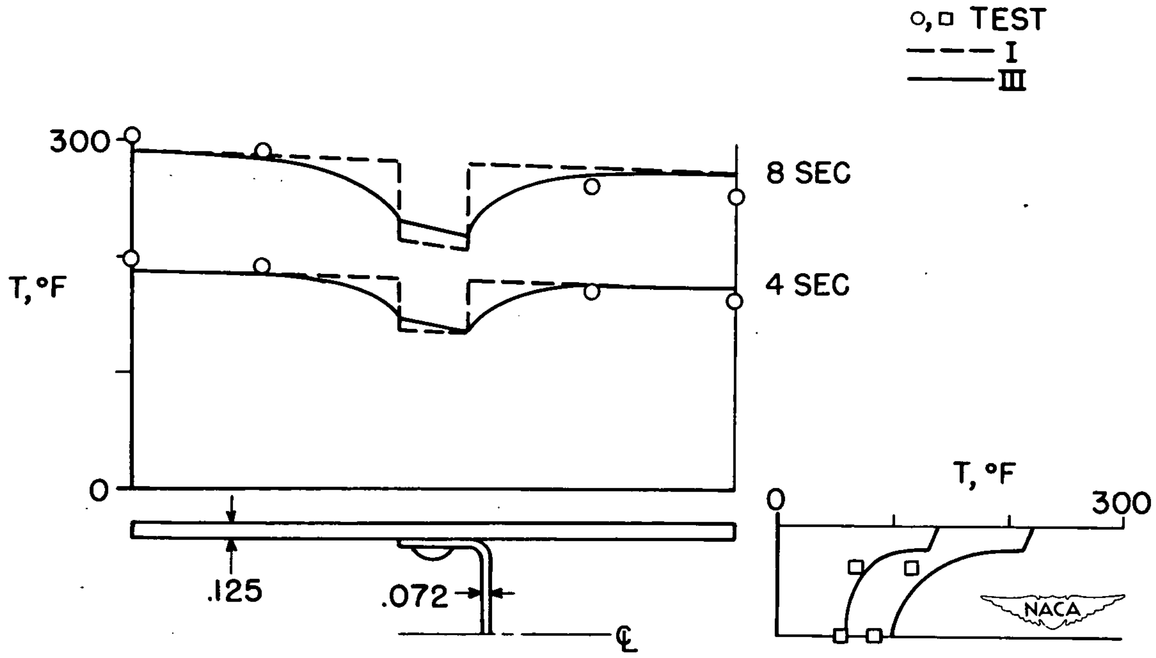

Figure 5.- Skin and web temperature distributions.

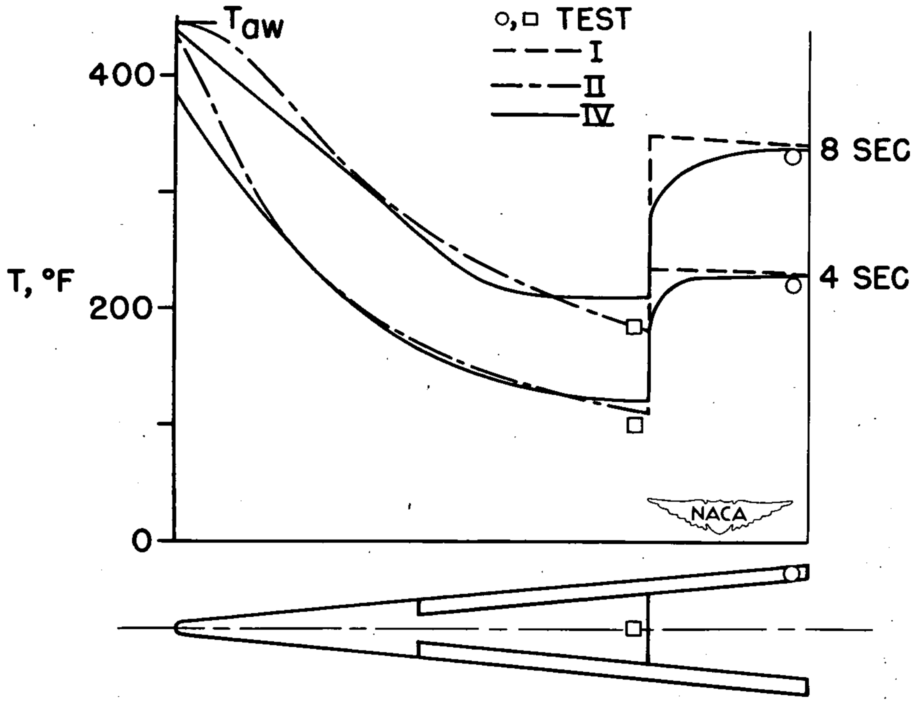

Figure 6.- Temperature distributions in leading-edge section.

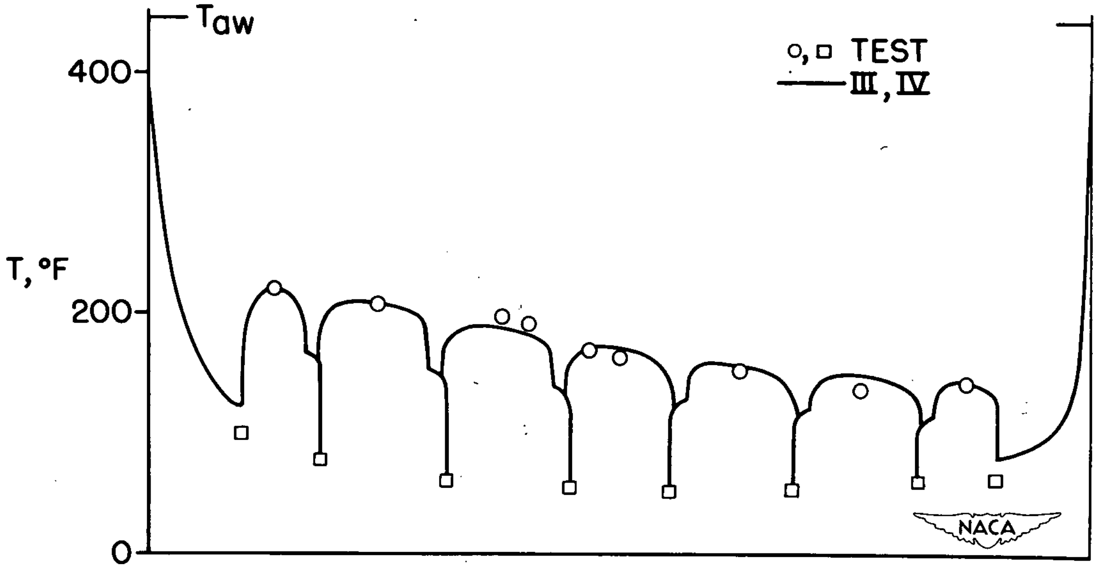

Figure 7.- Chordwise temperature distribution at 4 seconds.

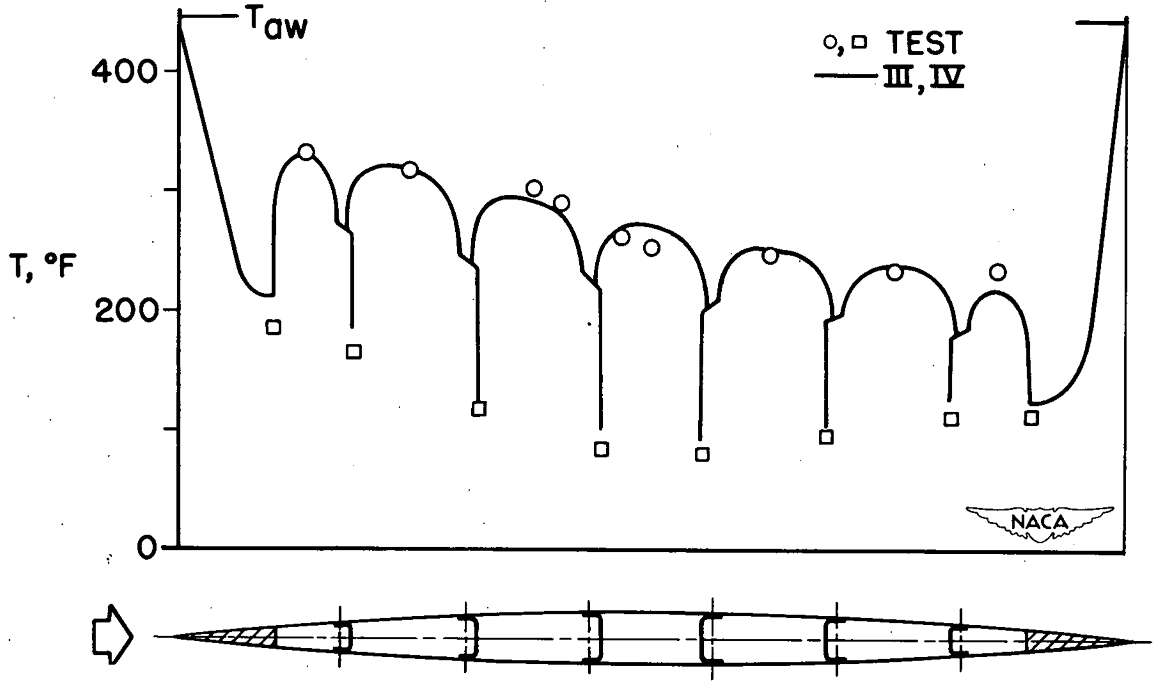

Figure 8.- Chordwise temperature distribution at 8 seconds.

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