Comparison of Thermal Techniques for Determining Boundary-Layer Transition in Flight

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Theme

TWO techniques for determining boundary-layer transition in flight have been compared using data from the NASA Re-entry *F* experiment.[1] The methods define transition from a rise either in the temperature history at a given sensor location or in the laminar heating-rate distribution at a given altitude. Since there are no previous comparisons of these techniques, the results of this study are considered to be a major contribution to the state-of-the-art.

Contents

Considerable boundary-layer transition data have been generated from flight tests conducted for research purposes other than defining the thermal environment. The thermal instrumentation for these flights was basically diagnostic in nature. Accordingly, the thermal sensor design was not always appropriate for heat flux determination, and the number installed was insufficient to define the heating distribution along the spacecraft. Lacking heating distributions, it has become accepted practice in these flights[2] to determine the onset of transition at a measurement location from a rapid rise in the temperature history, as shown in Fig. 1. Furthermore, these "transition" locations along with equivalent sharp cone flow conditions have been used in correlations of flight transition results.

For the Re-entry *F* flight experiment, heating rates at each thermal measurement station along the beryllium spacecraft were computed from the smoothed temperature histories of the near-surface thermocouple (0.010 in. beneath the surface) by a single thermocouple method.[3] (The near-surface thermocouple in previous tests was usually much deeper, approximately 0.05 to 0.10 in. beneath the surface and would therefore be less sensitive to small heating-rate changes.) This inverse method accounts for thermal transient time to produce the surface thermal input from a measured temperature within, but near the surface, of the wall. The method can detect sudden changes in the slope of the heat flux such as are experienced when the boundary layer becomes transitional or when the heating-rate history fluctuates as a result of body motion in flight. The locations of the beginning and end of transition were then determined at a given altitude from the experimental heating distributions. The locations were defined as the intersection of curves faired through the laminar, transitional, and turbulent heating data.[1]

The forward movement of transition on the spacecraft as determined by the two methods is compared in Figs. 2 and 3. The data show that temperature-history-determined transition occurs at a more rearward location at each altitude than does heating-rate-distribution-determined transition. Also, above 77,000 ft, beginning of transition data as determined from temperature histories more closely agree with the end of transition as determined from the heating-rate distributions. In Fig. 3, the heating-rate distributions at altitudes of 96,000, 87,000, 80,000, and 74,000 ft are presented with the beginning of transition as determined by each method noted. These distributions show that the heating rate is minimum at the location of the beginning of transition and, therefore, temperature changes with time or altitudes are small and difficult to detect. As the transition region moves upstream and the heating rate rises, the temperature change at the measurement station within, but near the surface of the wall, becomes significant. For flight transition studies, it is apparent that using the rapid rise in the temperature history to indicate the beginning of transition does not provide an accurate substitute for the heating-rate-distribution method. These differences in the transition location will influence transition correlations developed for blunted cones (using variable entropy conditions)[4,5] not only through the increase in length

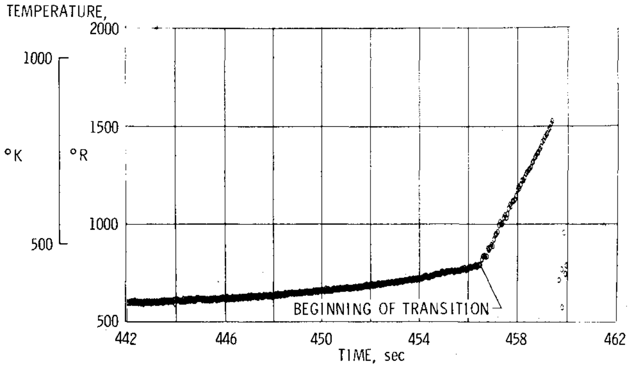

Fig. 1 Transition determination from temperature history.

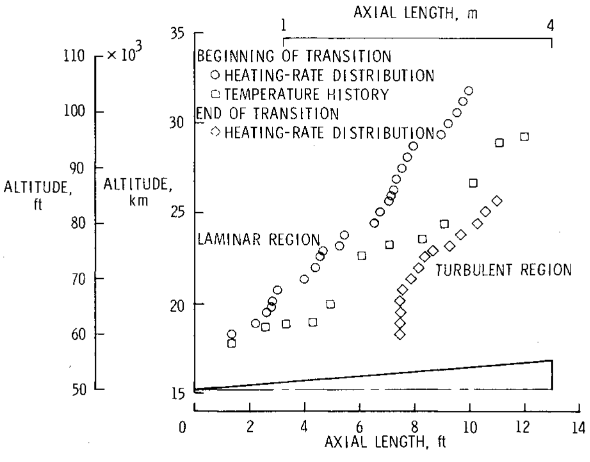

Fig. 2 Transition distributions.

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Index category: Boundary-Layer Stability and Transition.

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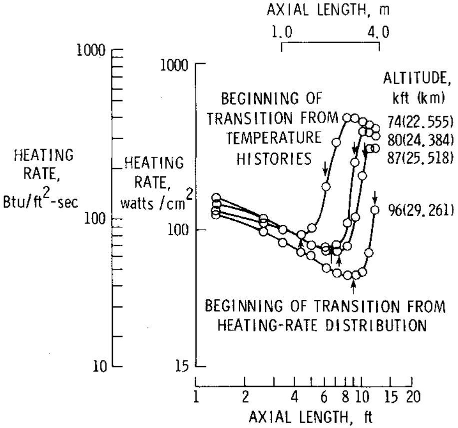

Fig. 3 Comparison of transition locations.

to transition, but also through the higher local flow conditions at the more rearward location on the blunted cone.

However, a common practice for using previous flight data in developing transition correlations is to present the transition Reynolds number based on the temperature-determined location as a function of local Mach number with the flow properties computed for the equivalent sharp cone. In Fig. 4, transition Reynolds numbers and Mach numbers based on an equivalent sharp cone and using the location of transition from the temperature history are compared with the transition Reynolds numbers and Mach numbers based on variable entropy conditions and using the location of transition from the heating-rate distribution. The transient attitude of the vehicle is not considered in computing local conditions, but it is evident that the discrepancy between the two methods will remain, irrespective of local state conditions. It is apparent that the use of the transition location from temperature histories and equivalent sharp cone local conditions will produce erroneous transition correlations.

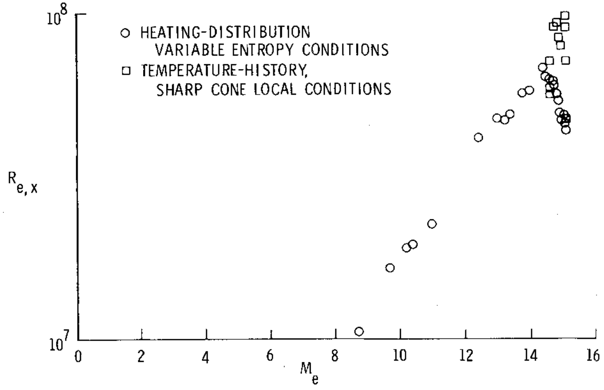

Fig. 4 Comparison of transition data used in correlations.

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