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Laminar Heating in Interior Corners at Mach 19

J. WAYNE KEYES* AND RALPH D. WATSON*
NASA Langley Research Center, Hampton, Va.

Nomenclature

h = measured heat-transfer coefficient
h_w = calculated undisturbed heat-transfer coefficient on vertical wedge
L = length of wedge along x axis
$R_{\infty,L}$ = freestream Reynolds number based on length of wedge
x,y,z = Cartesian coordinates
$\bar{y},\bar{z}$ = orthogonal coordinates measured from corner juncture and parallel to leading edge of wedge
β = inclination of vertical wedge surface with the freestream flow

HYPERSONIC vehicle designs require a knowledge of the interacting flow field in the vicinity of interior corners as, for example, at wing-fuselage junctures and in two-dimensional inlets. Experimental results at Mach 3 (Ref. 1) and Mach 8 (Ref. 2) have shown a complicated corner flow structure exists with surface heat transfer and pressure distributions significantly different from local wedge or plate values. Recent studies made at Mach 20 (Refs. 3 and 4) considered symmetrical corners; however, in practical cases one generally encounters asymmetrical corners. The present study examines heat transfer and surface oil flow on symmetrical and asymmetrical corner configurations at Mach 19 in the Langley 22-in. helium tunnel at a freestream Reynolds number of approximately 1.5×10^6.

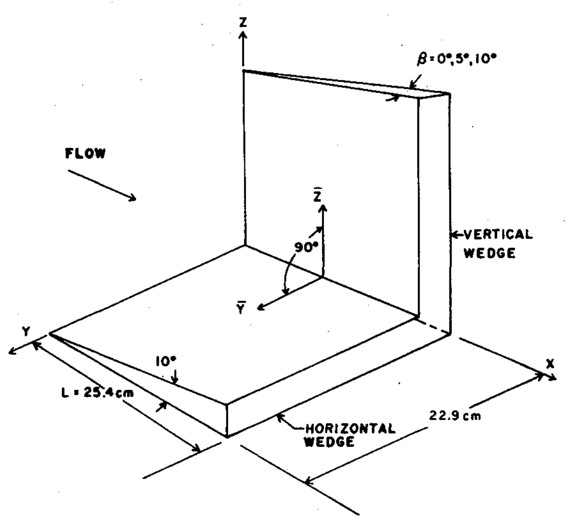

Fig. 1 Sketch of corner model.

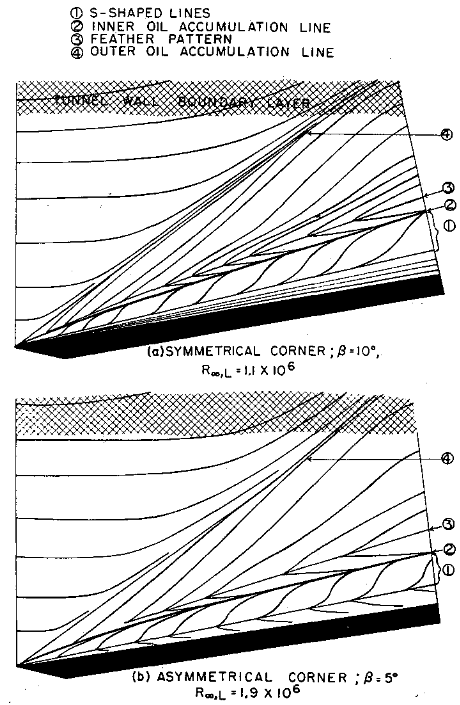

Fig. 2 Comparison of oil-flow patterns on the vertical wedge for symmetrical and asymmetrical corners.

Horizontal and vertical wedges intersecting at 90° formed the corner model which is shown in Fig. 1. The horizontal wedge angle was fixed at 10° and the vertical wedge angle, β, was set at 0°, 5°, and 10°. Heat-transfer coefficients were obtained on the vertical wedge surface by the phase change (melting point) technique.[5] In this technique, if the time required for the phase change to occur is known along with the thermal properties of the model wall material, then heat-transfer coefficients can be calculated from the transient one-dimensional heat-conduction equation for a semi-infinite slab. For these tests, phase change time was determined from motion-picture photography. The wall-to-total temperature ratio was 0.56 and a laminar recovery factor of 0.829 was assumed. Surface oil-flow patterns were obtained using a

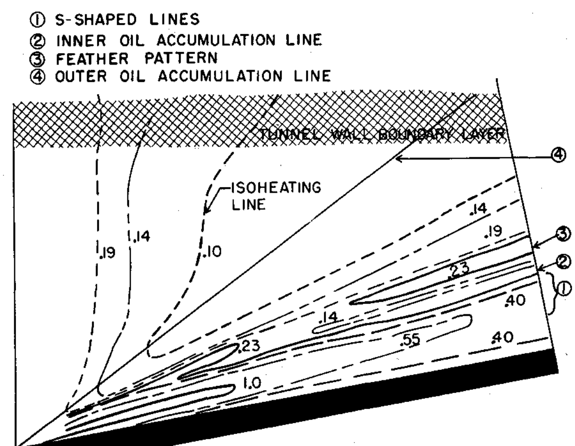

Fig. 3 Typical heat-transfer distribution on the vertical wedge of the 10° symmetrical corner. $R_{\infty L}$, = 1.1 × 10⁶.

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* Aerospace Engineer, Flow Analysis Section, Aero-Physics Division. Member AIAA.

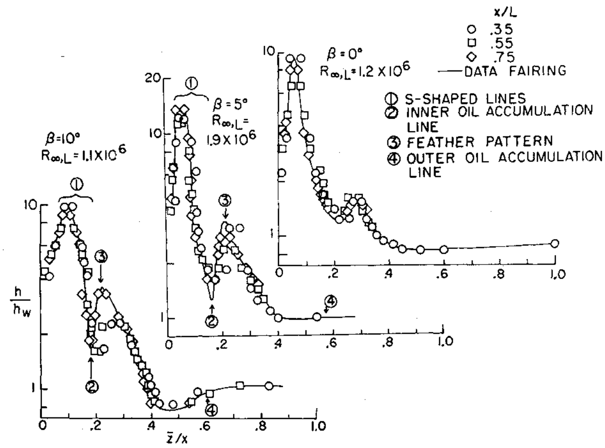

Fig. 4 Comparison of heat-transfer data for various vertical wedge angles.

mixture of silicone oil and lampblack distributed over the model surface in a random dot pattern.

Oil-flow patterns on the vertical wedge surface are shown in Fig. 2 for β angles of 5° and 10°. In both symmetrical and asymmetrical cases, the flow can be divided into similar regions. *S*-shaped lines (area 1) indicate a vortex near the corner (see Ref. 4 for a more detailed discussion of this vortex). A featherlike pattern (area 3) is separated from the *s*-shaped pattern by a thin oil accumulation line (area 2). Outside of the feather pattern a region of strong crossflow terminates in a heavy oil accumulation line (area 4), and beyond this the flow gradually approaches two-dimensional, undisturbed wedge flow. Near the top of the wedge the flow is not two-dimensional due to the projection of the wedge into the tunnel-wall boundary layer. One significant difference in the symmetrical and asymmetrical oil-flow pattern occurs in the region between area 1 and the corner juncture. For the $\beta = 10°$ case, the flow appears to be approximately radial from the tip of the model; for the $\beta = 5°$ case, the flow is turned toward the corner juncture. A possible explanation for this effect is that the vortex on the horizontal wedge moves toward the corner as β decreases.

Isoheating lines obtained from sequential photographs of the melting point boundary are shown in Fig. 3 for the $\beta = 10°$ corner. Data are presented as ratios of local to maximum heating measured on the vertical surface. The previously discussed flowfield regions from Fig. 2 are also shown. From a comparison of Figs. 2 and 3 it is apparent that the maximum heating is associated with the vortex in the near corner region.

A summary of the heating data for the three corner configurations is presented in Fig. 4 as the ratio of experimental to theoretical heat-transfer coefficients. Theoretical values were calculated for a given β from local similarity laminar boundary-layer theory, including the effects of boundary-layer self-induced pressures.[6,7] The nearly conical nature of the flow is evident from the correlation of data at different x locations when plotted in $\bar{z}/x$ coordinates. Oil-flow results show the flow to be nonconical for x/L less than about 0.35.

Peak heating near the corner (relative to undisturbed heating on the vertical wedge) is higher at $\beta = 5°$ than at $\beta = 10°$ due to the strong influence of the horizontal wedge on the 5° vertical wedge flow. At $\beta = 0°$, however, the peak heating level decreases to approximately 10 times local flat-plate heating. Evidently, the vortex system which influences peak heating is weaker at $\beta = 0°$ than at $\beta = 5°$. It is possible that the internal structure of the flow field changes between the $\beta = 5°$ and $\beta = 0°$ cases, however, this seems unlikely since the general shape of the heat-transfer distribution remains the same. A second lower peak in heating corresponds closely to the center of the feather pattern (area 3), and has been related to the presence of an internal shock in the flowfield.[4] Finally, heating rates approach the undisturbed two-dimensional wedge value outside the region where the outer oil accumulation line (area 4) occurs.

In general, the results of this investigation have shown that the surface flowfield and heating in asymmetrical corners are similar to that observed in symmetrical corners.[4] One exception, however, is the higher heating measured on the vertical wedge due to the asymmetry of the vortex system of the corner.

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A Correlation of the Minimum Thermal Resistance at Soldered Joints

M. MICHAEL YOVANOVICH*
University of Waterloo, Waterloo, Ontario, Canada

IN an earlier Note[1] this author reported that thermal resistances for soldered joints ranged from 0.025°C-cm²/w for the best joint (brass/brass) to 0.14°C-cm²/w for a badly soldered joint. These values considerably exceed the theoretical value of 0.00246°C-cm²/w calculated for an average solder thickness of 15 μ. All the tests were performed with identical surfaces. Correlation of all of these data is very difficult because of the many parameters, both geometric and physical, that play a part in the resistance. This Note reports the results of a preliminary analysis and further experimental work done to obtain a correlation.

Thermal Analysis

It is assumed that the best soldered joints can be modeled as shown in Fig. 1. The solder (k_2) of average thickness e separates two solids (k_1,k_3) and is assumed to be homogeneous, devoid of gas cavities and scale. There is metal-to-metal contact between the solder and the solids at every point of the

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* Associate Professor of Mechanical Engineering. Member AIAA.