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Boundary Layers and Convective Heat Transfer—Laminar; Supersonic and Hypersonic Flow

Theme

An experimental investigation of blunt slender cones in hypersonic flow to study viscous-inviscid coupling and determine the applicability of present theoretical interaction solutions.

Content

Detailed experimental measurements including surface pressures and heat transfer, shock-wave shapes, and velocity and Pitot pressure flowfield surveys were obtained on blunt 3° half-angle cones in helium at Mach 40. The ratios of cone nose to base diameter were 0.15 to 0.30. Data were obtained at angles of attack equal to 0°, ±3°, ±5°, and ±10°. The tests were conducted in the NASA Ames Mach-50 helium tunnel at a freestream Reynolds number of 58,000/in. The freestream Reynolds numbers based on cone nose diameter varied from 8700 to 17,400. These test conditions provided a flow regime where the viscous boundary layer was of the same order of thickness as the local cone radius.

At zero angle of attack, the coupling of the large boundary layer with the inviscid flowfield resulted in large pressure increases due to viscous-inviscid interaction but only minor heat-transfer rate increases above thin boundary-layer predictions. Significant changes in the inviscid flowfield structure due to boundary-layer entropy-layer coupling were also measured. The results are compared with an approximate viscous-inviscid calculation technique previously published by Levine.

This technique combines through an iterative procedure a nonsimilar boundary-layer solution including transverse curvature with a characteristic solution using a mass balance procedure to determine boundary-layer edge properties. In each case the computation is started with an inviscid characteristics calculation. A boundary-layer solution is then obtained by assuming the pressure to be equal to the inviscid valve at the body surface. The other edge conditions are found by equating the boundary-layer mass flow at the point of interest to the stream tube of equal mass in the freestream at the bow shock wave. No attempt is made to match the normal gradients of the flow properties in the boundary-layer solution to the inviscid solution. The procedure is then repeated, replacing the model configuration in the inviscid characteristics calculation with an effective model shape (defined by adding the displacement thickness to the true model surface) until convergence is obtained. The results gave reasonable agreement with the experimentally determined surface quantities and shock-wave shapes. However, for the calculation of the details of a flowfield, a more complicated analysis such as a complete solution of the viscous-inviscid equations from the body to the shock wave would be required.

Using the present data and previously published results, a surface heat-transfer correlation was developed. For a given cone angle, the data from widely differing flow regimes correlated in the sense that the ratio of local heat transfer to the continuum stagnation-point value for a given location on a cone is independent of Mach and Reynolds numbers. The data included encompass merged, viscous-layer, and continuum nose-flow regimes and strong and weak interaction and thin boundary-layer cone-flow regimes.

At angle of attack ($\alpha = 5°$ and $10°$) on the windward cone rays, the flowfield structure and surface distribution suggest that viscous-inviscid coupling can be neglected and that inviscid equivalent cone techniques are sufficient to predict the results. However, the surface heat-transfer results indicate that neither equivalent cone nor approximate two-dimensional techniques are sufficient to predict the data. A more complicated three-dimensional boundary-layer analysis would be necessary.