Laminar Viscous Shock Layer on a Blunt Biconic at Incidence

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Theme

A FULLY viscous shock-layer computation method developed to treat laminar flow over a sharp cone at incidence to a supersonic or hypersonic freestream has been extended to consider flow over a spherically blunted biconic at angle of attack. The basic method treats the flow between the body and the bow shock by one set of equations which are valid in both the viscous and inviscid regions. A description is given of the computational methods used, and results are compared with results from inviscid flow calculations and experimental data. The technique is validated by the good agreement between the computed data and experimental data.

Contents

Theoretical Methods

The viscous shock-layer method developed by Lubard and Helliwell,[1] hereinafter referred to as the Hypersonic Viscous Shock-Layer (HVSL) code, is applicable only to flow over frustums of right-circular cones. To compute the flow over a blunt biconic body, it was necessary to develop a method to treat the nose-cap shock layer, to transform the results into a form to begin the fore-cone shock-layer solution, and then to take data from the end of the fore-cone shock-layer solution and transform it into a form to begin the aft-cone shock-layer solution. This procedure is indicated schematically in Fig. 1.

In the three-dimensional viscous shock-layer approach of Ref. 1, a system of governing equations is obtained by assuming that the viscous, streamwise derivative terms are small compared with the viscous normal and circumferential derivatives. The resulting equations are valid in both the inviscid and viscous regions. The equations are solved between the body surface and the bow shock; boundary conditions at the shock and its resulting shape are calculated by using the Rankine-Hugoniot relations and a one-sided differencing of the continuity equation. A thermally and calorically perfect air model is used in conjunction with the Sutherland viscosity law and a Prandtl number of 0.71.

The procedure devised to compute the shock-layer flow over the spherical nose cap is based on the flow there being axisymmetric in a wind-axis coordinate system. The method was based on the scheme used in Ref. 2 to compute boundary-layer flows with normal pressure gradient and longitudinal curvature effects, and it was used to obtain u, v, and H. The pressure field (in terms of $y/y_{\rm shock}$) was taken from a solution of the inviscid flow equations obtained using the method of Ref. 3.

Initial data for the HVSL code at the sphere-cone tangency were obtained by transforming the nose data from a wind-axis to a body-axis coordinate form.

The HVSL code is used to obtain the flowfield along body normals over the fore cone at a series of x locations along the body, treating a series of ϕ locations around the body at each x station. The fore-cone solution is extended beyond the end of the actual fore cone so that aft-cone surface normal interpolations can be carried from the body to the bow shock to yield starting data for the HVSL solution over the aft cone.

Results of Calculations

Figure 2 compares flowfield profiles for a 1-in.-radius hemisphere in a Mach 10 flow obtained using the present method with inviscid results obtained using the method of Ref. 3. The results are for the 90-deg location on the hemisphere, with respect to the stagnation location. As can be seen in the u velocity profile, the region of viscous influence (boundary layer) occupies less than 10% of the shock-layer thickness for this case. Outside the region of viscous influence, there is reasonably good agreement between the two sets of results for the density, normal velocity, and tangential velocity, although the computed thickness of the viscous shock layer is approximately 5% less than the thickness of the inviscid flowfield.

Figure 3 compares the heat-transfer distribution measured[4] on an 0.24-in. nose radius blunt biconic at 5-deg incidence in a Mach 10.23 freestream with that computed by the present methods. The data are presented as the ratio of the local heat-transfer coefficient to a reference heat-transfer coefficient.

Figure 3a shows circumferential heat-transfer distributions at two locations on the fore cone and two locations on the

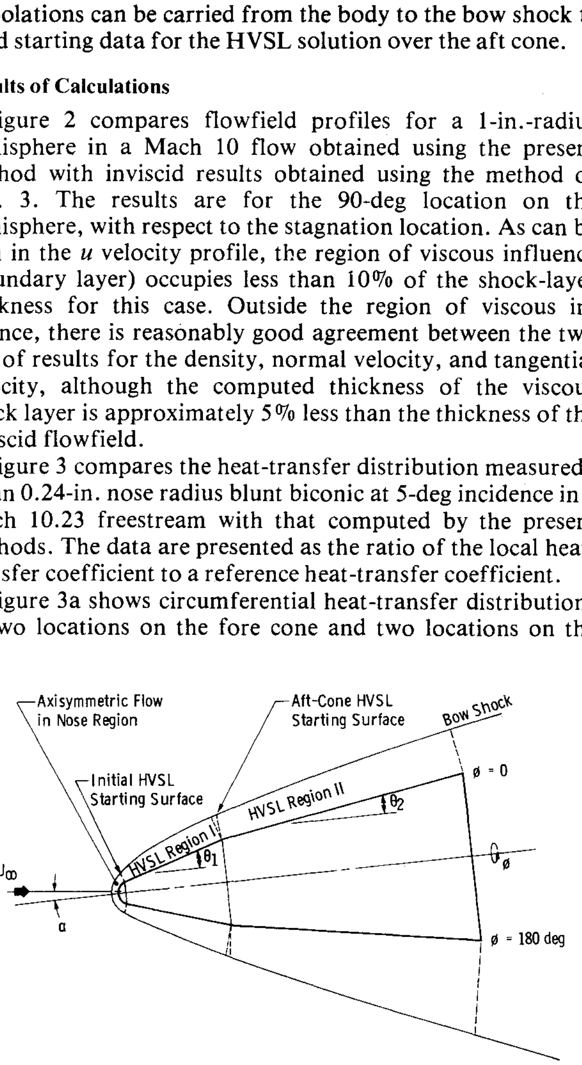

Fig. 1 Overall schematic of blunt biconic shock-layer treatment.

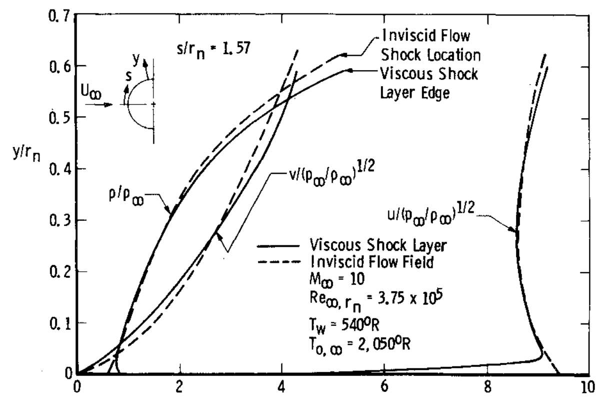

Fig. 2 Flowfield data at $s/r_n = 1.57$ on hemisphere in a Mach 10 flow.

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Index categories: Computational Methods; Supersonic and Hypersonic Flow; Viscous Nonboundary-Layer Flows.

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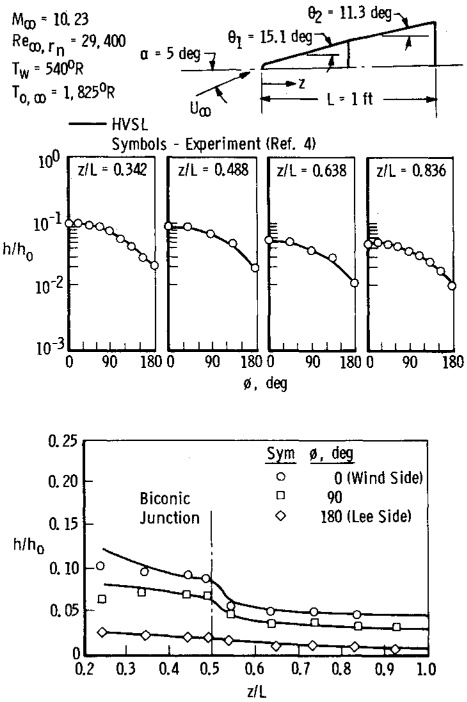

Fig. 3 Heat-transfer distributions on a blunt biconic in a Mach 10.23 flow.

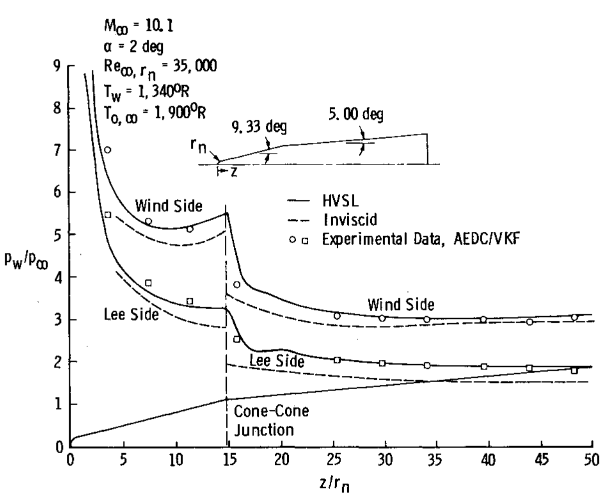

Fig. 4 Blunt biconic longitudinal surface pressure distribution.

second conical frustum. Figure 3b shows longitudinal distributions along the windward and leeward sides and along the line midway between the windward and leeward sides. Except for some discrepancy on the windward side near the front of the body, the measured and computed heating agree quite well in both the circumferential and longitudinal comparisons.

Figure 4 shows surface pressure data on a spherically blunted biconic at 2-deg incidence in a Mach 10.1 freestream. The experimental data shown in these figures were obtained in the AEDC/VKF Tunnel C. Descriptions of the experiment are as given in Ref. 5. The model had a nose radius of 0.23 in. and a base radius of 1.50 in. The radius of the model at the junction of the two conical frustums was 0.755 in. This figure compares wind- and lee-side surface pressure data computed by the HVSL method with inviscid calculation results[6] and with experimental data. Significant viscous effects are indicated by comparing the inviscid data with the HVSL results or the experimental data, especially on the lee side of the model. While the inviscid results are consistently below the experimental data, the present HVSL results agree well with the experimental data except for the point immediately past the cone-cone junction on the wind side.

Conclusion

The combination of the cone frustum viscous shock-layer method of Ref. 1 and the methods developed in this investigation to generate blunt nose starting data and to treat the biconic junction has been shown to yield a method which is applicable to the problem of computing the laminar viscous shock layer over a blunt biconic at incidence in a supersonic or hypersonic stream. The approach has been validated by the good agreement between the results of calculations and experimental data.

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