Hypersonic Viscous Flows over Sphere Cones at High Angles of Attack

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Abstract

A PARABOLIZED Navier-Stokes (PNS) prediction 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 cone at angles of attack up to 38 deg. The basic method treats the flowfield between the body and the bow shock by one set of equations that are valid in both the viscous and inviscid regions. A description is given of the computational methods used, and results are compared with inviscid flowfield calculations and experimental data. The shock shape predictions were found to be in good agreement with most of the inviscid results as well as in reasonable agreement with some low Reynolds number heat transfer experimental data.

Contents

Theoretical Method

The parabolized Navier-Stokes method developed by Lubard and Helliwell[1] is applicable only to flow over a sharp cone. For computing the flow over a blunt cone, it was necessary to use another technique to treat the spherical nose region and then transform the results into the form required to begin the conical afterbody solution. This calculation procedure is indicated schematically in Fig. 1.

Rakich and Lubard[2] used an approximate patching of an axisymmetric boundary-layer flow with an inviscid outer flow to provide starting data at the sphere-cone juncture of a 15-deg half-angle blunt cone at 15-deg angle of attack. At this low angle of attack ($\alpha = \theta_c$), their heat-transfer predictions were in good agreement with experimental data.

An axisymmetric viscous shock-layer (VSL) procedure[3,4] was used to compute the flowfield over the spherical nose cap in a wind-axis coordinate system. Initial data for the PNS code at the sphere-cone tangent point were obtained by transforming the fully viscous shock-layer flowfield solution from a wind-axis to a body-axis coordinate system. This approximate procedure has been found to give accurate starting data by comparison with three-dimensional viscous flowfield solutions over the nose.[4]

The PNS code was used to obtain the flowfield along body normals over the conical afterbody at a series of streamwise locations with 19 circumferential locations at each streamwise step. Three types of axial pressure gradient models[1] were studied to determine their effects on the solution.

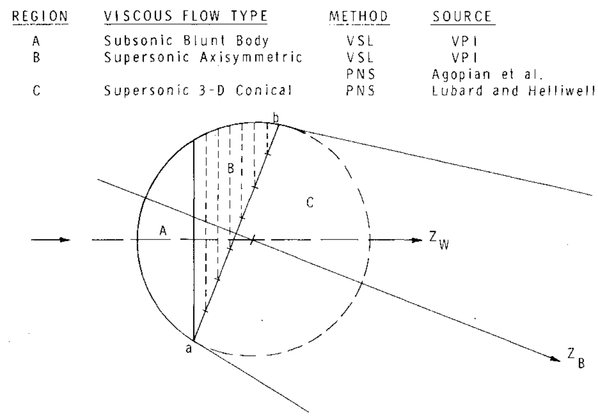

Fig. 1 Flow regimes for parabolized Navier-Stokes calculations.

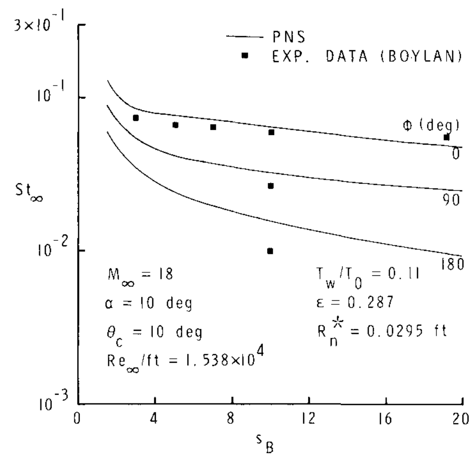

Fig. 2 Predicted and experimental surface heat-transfer distribution along the cone.

Results of Calculations

Figure 2 compares the measured[5] surface heat-transfer distribution on a 10-deg spherically blunted cone in a Mach 18 flow at 10-deg angle of attack with that computed by the PNS method. The experimental data were obtained in the AEDC/vKF Tunnel M. Agreement on the windward side is good; however, not enough data exist at other locations around the body to make further detailed assessments. In making comparisons for this case, it should be noted that the PNS method used the standard Rankine-Hugoniot shock-jump relations without including slip effects. Since the Reynolds number for this case was low enough to make slip effects important, the PNS predictions should be higher than the experimental measurements.

Figure 3 shows shock-layer thickness predictions for a 7-deg spherically blunted cone in a Mach 22.8 flow at 23-deg angle of attack obtained using the present method compared with inviscid results. The agreement is excellent since the Reynolds number was high and the viscous layer was thin, making the inviscid solution a good approximation, at least on the

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

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Table 1 Computing times

Case	Number of steps[a]	Number of iterations	Total[b] run (hr:min:s)	Average number of iter/step	Average number iter/min	Range[c] of solutions
			VSL (Sphere)			
1	20	78	1:26	3.9	54.6	s_w = 0-1.9
2	23	103	1:50	4.48	56.18	s_w = 0-2.2
3	22	121	2:08	5.5	56.72	s_w = 0-2.1
4	23	107	1:51	4.65	57.84	s_w = 0-2.2
			PNS (Sphere)[d]			
1	12	181	37:45	15.08	4.79	s_w = 1.0-2.1
2			No solution			
3	12	172	42:49	14.33	4.02	s_w = 0.9-2.0
4	18	283	58:47	15.72	4.81	s_w = 0.7-2.4
			PNS (Cone)[e]			
1	85	283	3:44:49	3.33	1.26	s_B = 1.40-22.0
2			No solution			
3	85	377	4:10:17	4.44	1.51	s_B = 1.45-30.0
4	76	478	5:44:16	6.29	1.39	s_B = 1.45-30.0

[a]Number of axial solution locations on the body. [b]Computing time on IBM 370/158, H = OPT2 compiler. [c]Region of body over which solution is performed (PNS unable to be used upstream of sonic line). [d]PNS solution on sphere is axisymmetric (3 ϕ planes, 101 η points). [e]PNS solution on cone is full three-dimensional (19 ϕ planes, 101 η points).

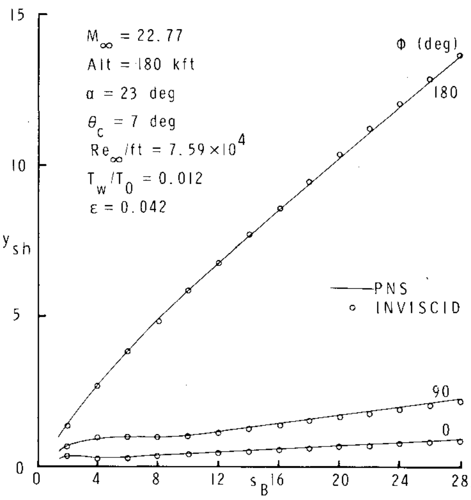

Fig. 3 Shock-layer thickness distribution along the cone.

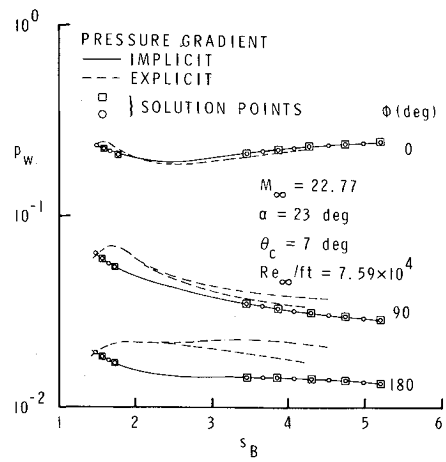

Fig. 4 Effects of pressure-gradient models and streamwise stepsize on the cone surface pressure distribution.

windward side. No experimental data are available for this case.

The implicit pressure gradient model,[1] which has been shown in our research to yield the most consistent results, was used for the 10- and 23-deg angle-of-attack cases. The effects of pressure-gradient models and streamwise step size on the cone surface pressure distribution for the $\alpha = 23$-deg case is shown in Fig. 4. We found the explicit pressure gradient model produced results strongly dependent on step size, whereas the implicit model predictions were independent of step size. For the 38-deg case, an explicit model had to be used because a large adverse streamwise pressure gradient occurred primarily on the leeward side where the implicit model became unstable.

Computing times for the VSL and PNS solutions over the sphere and conical afterbody are shown in Table 1. PNS solutions over the supersonic portion of the sphere[6] are shown for comparison. From our studies, good agreement was found between VSL and PNS predictions over the sphere. Substantial computing times are required for PNS solutions, and the VSL predictions are recommended where appropriate over the sphere.

Conclusions

The combination of the conical parabolized Navier-Stokes method[1] and the method used to generate blunt nose starting data[3,4] has been shown to yield a method which is applicable to the problem of computing the laminar viscous flowfield over a spherically blunted cone at high angles of attack in supersonic or hypersonic streams. The approach has been tested in the angle-of-attack range considered by comparison with inviscid predictions and experimental data.

References

[1]Lubard, S. C. And Helliwell, W. S., "Calculation of the Flow on a Cone at High Angle of Attack," R&D Associates, Santa Monica, Calif., RDA-TR-150, Feb. 1973; also *AIAA Journal*, Vol. 12, July 1974, pp. 965-974.

[2]Rakich, J. V. and Lubard, S. C., "Numerical Computation of Viscous Flows on the Lee Side of Blunt Shapes Flying at Supersonic Speeds," NASA SP-347, March 1975, pp. 531-542.

[3]Davis, R. T., "Numerical Solution to the Hypersonic Viscous Shock-Layer Equations," *AIAA Journal*, Vol. 8, May 1970, pp. 843-851.

[4]Waskiewicz, J. D., Murray, A. L., and Lewis, C. H., "Hypersonic Viscous Shock-Layer Flow over a Highly Cooled Sphere," *AIAA Journal*, Vol. 16, Feb. 1978, pp. 189-192.

[5]Boylan, D. E., "Laminar Heat Transfer on Sharp and Blunt Ten-Degree Cones in Conical and Parallel Density Flow," AEDC-TR-73-106, Aug. 1973.

[6]Agopian, K., Collins, J., Helliwell, W. S., Lubard, S. C., and Swan, J., "NASA Viscous 3-D Flowfield Computations," RDA-TR-6100-007, Oct. 1975.