Real Gas Flows Over Complex Geometries at Moderate Angles of Attack

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Abstract

NUMERICAL simulation of supersonic and hypersonic flows over arbitrary geometries at moderate angles of attack is presented in this paper.[1] The different geometries considered for analysis include a sphere-cone-cylinder-flare, a blunt-nosed inlet, and a 7-deg half-angle spherically blunted cone. The three-dimensional flowfields over these geometries are analyzed by a parabolized Navier-Stokes code (HYTAC) and a new viscous shock-layer code (VSLET), and the results are compared. Both laminar and turbulent flowfield results for both perfect gas and equilibrium air are presented. In general the surface pressure distributions are in good agreement, whereas the heat-transfer results differ depending on the differencing scheme used in the calculation of gradients and turbulent modeling. Aerodynamic force and moment coefficients are presented for some typical cases.

Contents

The design and successful flight of complex lifting and reentry vehicles and high-speed inlets can be aided by the use of accurate and efficient computational fluid dynamics. The flowfield over such general bodies can be quite complicated. The blunt nosed generates a bow shock and within the shock-layer, depending on the body geometry, imbedded shocks and expansion waves may exist. At moderate angles of attack, there can be large regions of cross-flow separation. The flowfields over a supersonic blunt-nose inlet, a sphere-cone cylinder flare, and a 7-deg half-angle sphere cone are solved by a viscous shock-layer code (VSLET)[2] and a parabolized Navier-Stokes code (HYTAC)[3] and the results are compared.

The viscous shock-layer equations in VSLET are parabolic in both streamwise and cross-flow directions and are solved by efficient methods which require substantially less computing time than the parabolized Navier-Stokes (PNS) method, whereas the PNS equations are elliptic in the cross-flow direction and hence can treat cross-flow separation. Both the methods are capable of treating laminar, transitional, and/or turbulent flow regimes. For the turbulent flow regime, both the methods use a two-layer eddy-viscosity model. The parabolized Navier-Stokes code has an additional option of using a one-equation kinetic energy of turbulence model (HYTAC2). The viscous shock-layer method, as well as parabolized Navier-Stokes method, is capable of solving real gas flows of air in chemical equilibrium. For the calculation of density and viscosity either COHEN or BADE curve-fit option can be used. HYTAC uses a body-normal, shock-normal, nonorthogonal coordinate system, whereas VSLET uses an orthogonal body-normal coordinate system. At the shock, Rankine-Hugoniot conditions are used; and at the wall, no-slip and no-temperature-jump conditions are assumed.

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The inlet is a blunt sphere cone with an afterbody of smooth curvature. The blunt nose has a radius of 0.0127 m (0.5 in.) and the cone angle is 12.5 deg. The afterbody is expressed in analytical form, and the complete inlet is shown in Fig. 1. In the present study, the external flowfield up to the cowl lip has been analyzed. The analysis of the inlet is done for a freestream Mach number of 7 at 0- and 5-deg angles of attack. The second geometry is a sphere-cone-cylinder-flare with a 0.0127-m (0.5-in.) nose radius and a cone half-angle of 16 deg and flare angle of 12 deg. The total length of the body is 30 nose radii, and the cylindrical length is 10 nose radii. The analysis is performed for freestream conditions of Mach number 25 at an altitude of 60,000 ft for 0- and 2-deg angles of attack.

Figure 2 shows the variation of surface heat transfer for the inlet geometry at zero lift. The surface heat-transfer predictions by HYTAC1 are considerably higher than those from VSLET and HYTAC2. On the cone the surface heat-transfer results from VSLET agree well with those from

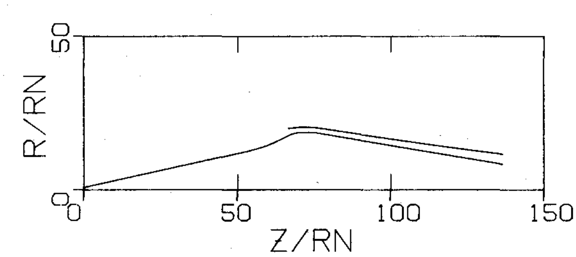

Fig. 1 Inlet geometry.

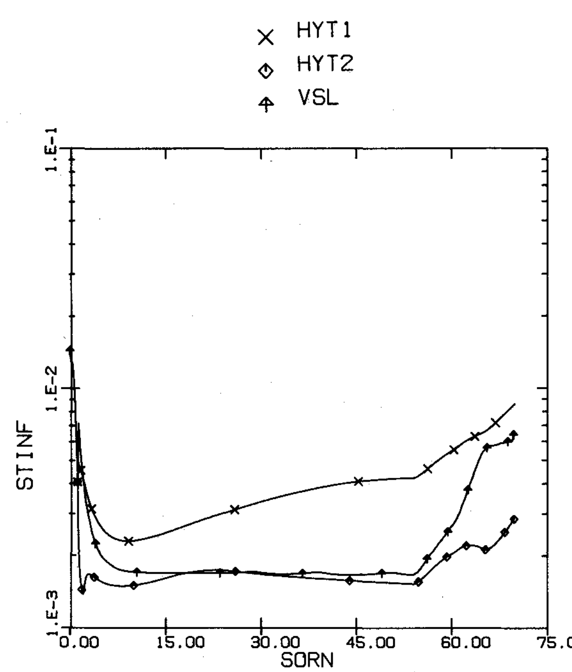

Fig. 2 Surface heat-transfer distribution for inlet at $\alpha = 0$ deg.

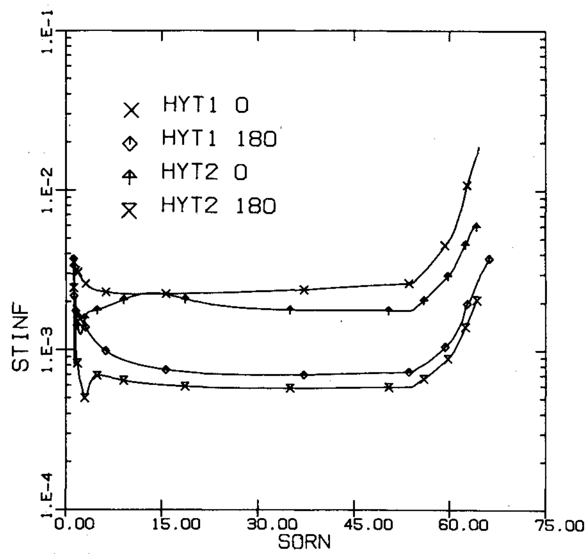

Fig. 3 Surface heat-transfer distribution for inlet at $\alpha = 5$ deg.

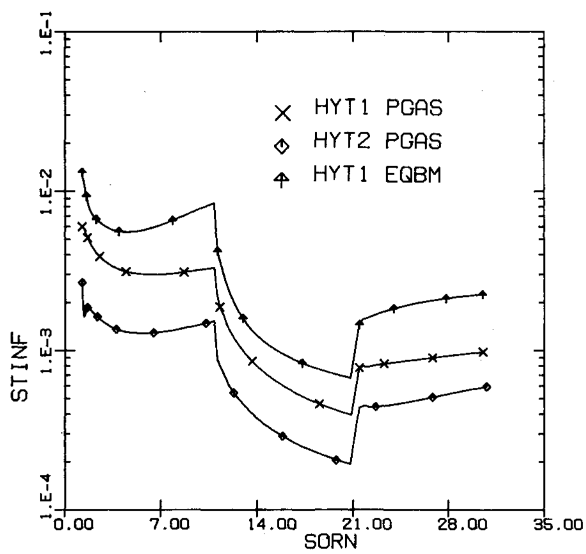

Fig. 4 Surface heat-transfer distribution for a 16/0/12 sphere-cone cylinder flare at $\alpha = 0$ deg.

HYTAC2, while in the nose region and on the afterbody, VSLET predictions are higher. The reason for the large difference in the heat-transfer predictions by HYTAC1 and HYTAC2 must be attributed to different turbulence modeling. Due to lack of experimental data, the computational results cannot be verified further. Figure 3 shows

Table 1 Aerodynamic forces and moments for sphere-cone cylinder flare

	CA[a] $\alpha = 0$	CA $\alpha = 2$	CN	CM	ZCP/L
Inviscid PG	0.09167	0.09444	0.05254	−0.03007	0.5724
HYTAC1 PG	0.09427	0.09643	0.05439	−0.03287	0.6043
HYTAC2 PG	0.08593	0.08899	0.05520	−0.03378	0.6121

CA = axial force coefficient; CN = normal force coefficient; CM = moment coefficient about the nose of the body; ZCP/L = center-of-pressure location as a fraction of body length

[a] CA at $\alpha = 0$ for equilibrium air case is 0.11099.

the variation of heat transfer predicted by HYTAC1 and HYTAC2 for angle of attack of 5 deg for the windward and leeward planes. The surface heat-transfer results from these two codes differ throughout the length of the inlet, and HYTAC1 predictions are consistently higher than those by HYTAC2.

Figure 4 shows the variation of surface heat transfer for the sphere-cone-cylinder-flare predicted by HYTAC1 and HYTAC2 for zero lift. The heat-transfer results predicted by HYTAC1 are higher by about 40% than that computed by HYTAC2. The heat-transfer results for equilibrium air are included for comparison and are higher than the perfect gas results by about 1.2 times. Table 1 gives the force and moment coefficients for the sphere-cone cylinder flare. The center-of-pressure location measured from the nose tip computed by the inviscid and viscous codes differs by about 5%.

In conclusion, HYTAC and VSLET are capable of solving both laminar and turbulent flowfields over geometries with large changes in axial direction and with expansion and/or compression corners within reasonable time. Due to a lack of experimental data, the accuracy of the codes cannot be completely verified at this time. Further work is in progress to establish the accuracy of all codes for both perfect gas and equilibrium airflows including laminar, transitional, and/or turbulent flows over complex vehicles at moderate angles of attack.

References

[1] Swaminathan, S., Kim, M.D., and Lewis, C.H., "Real Gas Flows Over Complex Geometries at Moderate Angles of Attack," AIAA Paper 82-0392, Orlando, Fla., Jan. 11-14, 1982.

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