Static Stability Comparison of a Conical and Biconic Configuration

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Abstract

THE trend in strategic re-entry vehicles has been toward higher velocities (less deceleration) during atmospheric re-entry. Re-entry vehicle configurations have thus evolved into slender, low-drag configurations; with a slender cone and small nose tip bluntness being one logical choice. A slender cone, however, may present stability, structural, and storage problems due to its long length and internal volume limitations. A biconic configuration, that is, replacing the front portion of a cone with a larger angle cone, is a possible alternate configuration. This synoptic contains the results of a brief wind-tunnel study which examined the aerodynamic changes that resulted when the front half of a 5-deg half-angle cone was replaced with a 10-deg half-angle cone. Also, these experimental results provided an opportunity to make a comparison between experimental data and numerical results obtained by a shock capturing computer code recently developed by Solomon.[1]

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The test program was performed in the AFFDL 20-in. hypersonic wind tunnel at a Mach number of 14.3. The conical configuration tested was a 5-deg half angle circular-cone and the biconic configuration consisted of a truncated, 5-deg half-angle circular-cone afterbody and a 10-deg half-angle circular-cone forebody. The junction of the two cones was at $L/2$, where L was the length of the 5-deg sharp cone. The base diameter of the model was 3 in. (7.62 cm). Nose tip radii, nondimensionalized by base radius (R_N/R_B), were 0, 0.05, 0.10, 0.15, and 0.20. The moment reference center (X_{CG}) was chosen to be at the axial station $0.65L$.

The numerical solutions were obtained using a code developed by Solomon.[1] In a region of supersonic flow, inviscid equations may be written in weak conservation form and are solved with an explicit finite-difference method which marches along the longitudinal axis of the body. The body surface is assumed to be prescribed in the form $r=b(\phi,z)$ where the function $b(\phi,z)$ is continuous and piecewise twice continuously differentiable. Special logic is included to handle surface discontinuities. At the present time the program is limited to spherically blunted bodies due to the lack of a suitable sharp cone starting solution. However, sharp cone solutions can be approximated by allowing the nose radius to become very small. As all dimensions are nondimensionalized by the nose radius, this has the effect of allowing the program to relax to a sharp cone solution. Bodies of 2000 R_N have been computed with good results. Although the conservation form equations have the feature of capturing shocks automatically, the Solomon code captures only the embedded shocks; the bow shock is explicitly tracked and the Rankine-Hugoniot conditions satisfied across the shock.

Static stability derivatives, as a function of angle of attack, are shown in Fig. 1. The in-plane static stability derivative (C_{m_α}) was obtained by measuring the slopes of a curve drawn through the C_m vs α experimental data. The out-of-plane static derivative (C_{η_β}) was calculated from the relationship $[C_{\eta_\beta}]_{\beta=0} = -C_m/\sin\alpha$. (Note that C_{η_β} is related to the pitching moment and not its derivative.) This relationship is obtained for a body of revolution when the total moment vector in the cross-flow plane is transferred from the body coordinate system to the aerodynamic system. It has been shown that C_{η_β}'s calculated from the above equation agree very well with experimental data obtained by the free oscillation technique (e.g., Walchner and Sawyer[2]). With the exception of the sharp cone at low angles of attack, the static derivatives are generally nonlinear and the in-plane and out-of-plane derivatives are not equal.

Figure 2 shows a comparison of the center of pressure location for the two configurations. Nose tip bluntness produced large movements in the center of pressure on the 5-deg cone. For the biconic configuration the center of pressure changes were less and the center of pressure moved closer to

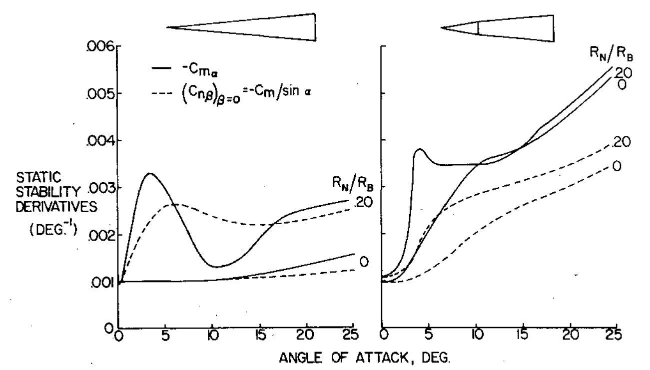

Fig. 1 C_{m_α} and C_{η_β} vs angle of attack.

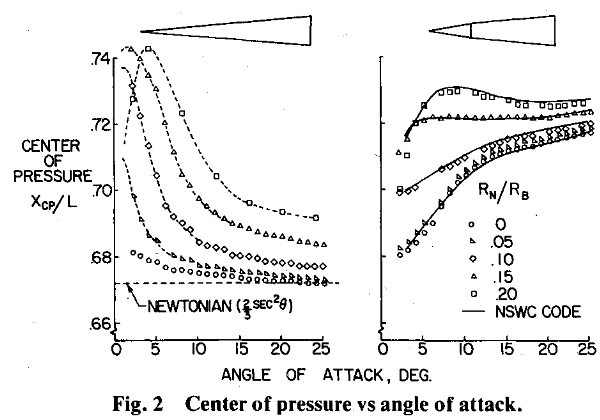

Fig. 2 Center of pressure vs angle of attack.

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the base of the model at large angles of attack. It is of interest to note that for the case of the biconic configuration with 15% bluntness, the center of pressure location was nearly constant in the angle of attack range from 5 to 25 deg. The numerical results for the biconic configuration with nose tip bluntnesses of 0, 10, 15, and 20% are in close agreement with the experimental data. Significant viscous effects are evident for the sharp cone configuration. The close agreement between the inviscid numerical calculations and the experimental data indicated that viscous effects are not large for the sharp biconic configuration for angles of attack from 3 to 25 deg.

With the exception of sharp slender configurations at small angles of attack, where viscous effects may be significant, one would expect the aerodynamic coefficients of both the cone and biconic configurations to be only weakly dependent upon Mach number for Mach numbers greater than 10. This reasoning is based upon limiting hypersonic flow considerations which indicate that, as the product of the freestream Mach number times the sine of shock angle ($M_\infty \sin\beta$) becomes large, the aerodynamic coefficients approach a limiting value. The results of Ref. 3, for a 15% blunt biconic configuration, found little variation in C_N, C_m, and X_{cp} for Mach numbers between 10 and 20. Likewise, the data comparison shown in this synoptic is expected to be representative of the aerodynamic characteristics of these configurations in the Mach number range of 10 to 20.

References

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