Afterbody Pressure Correlations for Vehicles with Ablated Nose Shapes

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Abstract

A CORRELATION method is presented for determining the afterbody pressure distributions over the conical afterbodies of slender re-entry vehicles at small angles of attack that have been severely ablated or eroded in the nosetip region. The technique utilizes flowfield solutions for the pressure distributions over symmetrical sphere-cone re-entry vehicles at zero angle of attack. The method is shown to reduce the afterbody pressure data obtained using seven distinctly different nosetip configurations to a single correlation curve.

Contents

A comprehensive wind tunnel test program to obtain pressure distribution data was conducted at $M_\infty = 8$ in tunnel B at the Arnold Engineering Test Center, Arnold Air Force Station, Tenn. The baseline sphere-cone model which was tested was a 6.7-deg half-angle conical afterbody with a bluntness ratio (R_N/R_B) of 0.227. The seven nose configurations shown in Fig. 1 were tested and the nose attachment plane was located at body station $X/L = 0.173$.

The pressure data from the present experiments were correlated using the axial distance parameter $(C_{P_c}/\sqrt{C_{A_N}} \cdot X_s/D_N)$ suggested by Mirels and Thornton[1] and a pressure parameter, C_P/C_{P_c} where C_{P_c} is the sharp cone pressure, D_N is the diameter of the nose, C_{A_N} is the nose axial force coefficient referenced to the nose base area, and X_s is the axial distance from the nosetip sonic point.

The experimental pressure data for each of the ablated nosetips is correlated against the spherical nosetip data in Fig. 2, using the modified distance parameter. The pressure parameter was not utilized in this exercise since experimental data were available for only one cone angle.

It can be seen from the plot that the axial distance correlation parameter has quite effectively collapsed the afterbody pressure data that were obtained with rather diverse nose shapes to the correlation curve obtained for the spherical nose. The pressures in the region less than one nose diameter from the nosetip are not well correlated.

The experimental results previously presented clearly indicate that reasonable afterbody pressure distributions for vehicles with severely ablated nosetips can be obtained from sphere-cone pressure distributions.

The $\alpha = 0$ pressure distribution along the length of a sphere-cone re-entry vehicle with a cone half-angle of 6.7 deg was calculated for $M_\infty = 8$, using the Rakich[2] method of characteristics solution, out to a distance of 160 nose radii

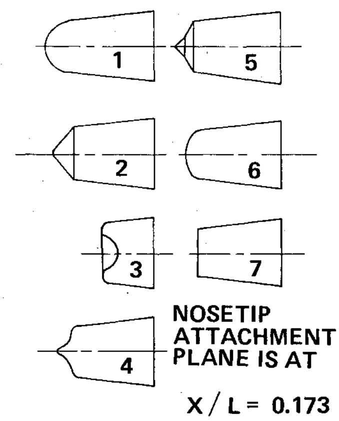

Fig. 1 Nosetip configurations tested.

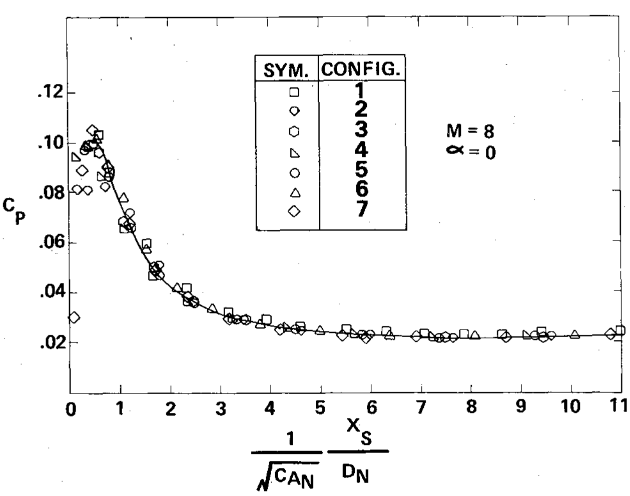

Fig. 2 Correlation curve for test data.

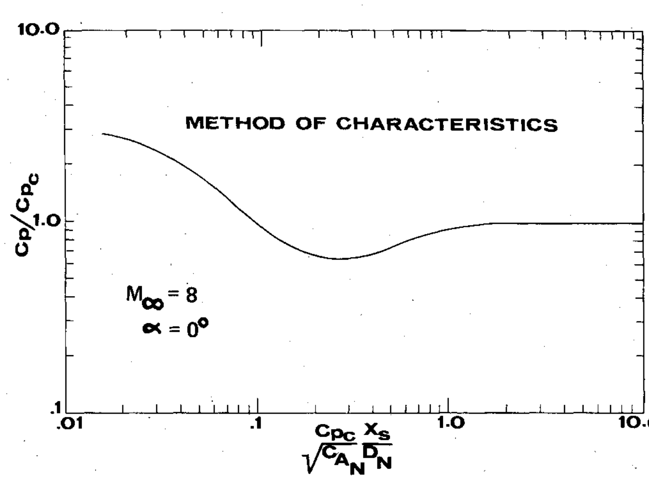

Fig. 3 Theoretical pressure correlation curve.

Presented as Paper 80-0312 at the AIAA 18th Aerospace Sciences Meeting, Pasadena, Calif., Jan. 14-16, 1980; submitted Jan. 18, 1980; Synoptic received May 6, 1980. Full paper available from AIAA Library, 555 W. 57th St., New York, N.Y. 10019. Price: microfiche, $3.00; hard copy, $7.00. **Remittance must accompany order.**

Index categories: Computational Methods; Supersonic and Hypersonic Flow.

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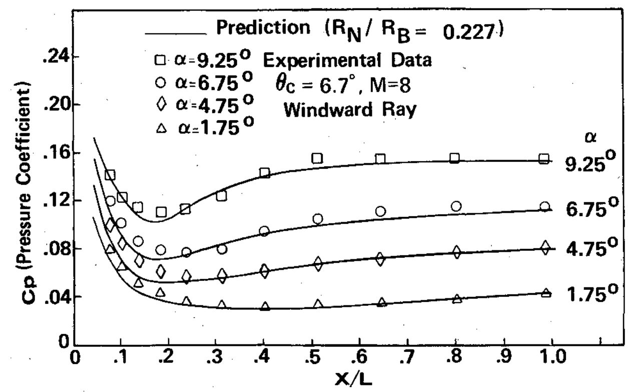

Fig. 4 Comparison of theoretical and experimental pressure distributions.

from the stagnation point. The resulting pressures were normlized by the sharp cone pressure and plotted against the axial distance parameter. The correlation results are presented in Fig. 3.

Pressures along any conical ray of a blunt vehicle at a small angle of attack and at $M_\infty = 8$ can be obtained using the tangent cone concept and the correlation curve of Fig. 3. The tangent cone is determined using the following relationship:

$$\theta_{TC} = \sin^{-1}(\sin\theta_c \cos\alpha + \cos\theta_c \sin\alpha \cos\phi)$$

where ϕ is the circumferential angle measured from the windward ray, α is the angle of attack, and θ_c is the vehicle cone half-angle.

The method now assumes that there is a new vehicle at $\alpha = 0$ with an afterbody cone angle of θ_{TC}. X_s is measured from the new sonic point, C_{AN} is the new nose drag, and C_{P_c} is for the new cone angle.

A comparison of theoretical and experimental data for the windward ray pressure distribution on a 6.7-deg cone at angles of attack up to 9.25 deg is shown in Fig. 4. The agreement is excellent at all the angles of attack.

The generalized solution presented in this paper can be used to estimate the pressure distributions over slender conical reentry vehicles at small angles of attack with either spherical or nonspherical nostips. The results compare very well with experimental data except in the region within one nose diameter aft of the nosetip. The nosetip drag must be known to use the method effectively. The method is ideally suited for use in trajectory codes which are attempting to couple the shape change taking place in a severe ablation or erosion environment with the trajectory that is being numerically integrated.

References

[1] Mirels, H. and Thornton, P.R., "Effect of Body Perturbations on Hypersonic Flow Over Power Low Bodies," NASA TR R-45, 1959.

[2] Rakich, J.V., "A Method of Characteristics For Three-Dimensional Supersonic Flow with Applications to Inclined Bodies of Revolution," NASA TN D-5341, 1969.