Three-Dimensional Base-Flow Calculation for a Projectile at Transonic Velocity

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Abstract

As part of an ongoing research program to develop productive capabilities for projectile areodynamics at transonic speeds, a three-dimensional base-flow code has been developed to compute the base region or wake flow behind a projectile. A time-marching, thin-layer, Navier-Stokes computational technique has been used, in conjunction with a unique flowfield segmentation procedure, to compute the full flowfield over a projectile, including the base region at angle of attack. A solution has been obtained for a typical artillery projectile at a Mach number M of 0.96 and an angle of attack α of 4 deg. A few details of the flowfield on the boattailed afterbody and in the base region are presented.

Contents

The contribution of this Synoptic lies in its computational approach used to compute transonic flow over a projectile at angle of attack. It is an extension of a recently developed axisymmetric thin-layer Navier-Stokes base-flow code and uses a unique flowfield segmentation procedure[1] to compute the entire projectile flowfield, including the base region. The base-region flow may have a strong effect on the location of shock waves on the afterbody of the projectile and thus on the pitch plane projectile aerodynamics at transonic speeds. This asymmetric shock pattern that exists on the projectile and possible base-region influence are felt to be the major contributors to the critical aerodynamic behavior at transonic speeds where the aerodynamic coefficients have been found to increase by as much as 100%.

The equations solved here are the three-dimensional,[1] thin-layer, Navier-Stokes equations in strong conservation law form. A fully implicit, approximately factored, finite-difference algorithm is used. A unique flowfield segmentation procedure has been used for three-dimensional flow over over a projectile, including the base flow. This is similar to the one previously used in the axisymmetric flow situation[2] where two two-dimensional adjoining grids were used. The segmentation process allowed the existing finite-difference algorithm to be applied to two three-dimensional adjoining grids by making modifications in the internal structure of the block tridiagonal matrix and boundary conditions. This greatly simplified the development of the code for computations of flow over a projectile at angle of attack including the base region. No approximation of the actual sharp corner at the base is made. Thus, realistic representation of the base is inherent in the current procedure.

The model used for the computational study consists of a three-caliber secant-ogive nose, a two-caliber cylindrical midsection, and a one-caliber 7-deg concial afterbody or boattail. Experimental pressure data[3] are available for this model for comparison with computed results. The flow conditions were $M_\infty = 0.96$, $\alpha = 4$ deg, and Reynolds number of 4.5×10^6 based on model length. Converged solution has been obtained on the grid with 105,840 points. The particle paths in the base region for both the windward and the leeward planes are shown in Fig. 1. This figure shows the general feature of the flow in the base region. The recirculatory flow in the base is evident. In addition, this figure shows the expected asymmetry in the recirculatory flow pattern in the windward side and the leeward side. The size of the separation bubble in the leeward side is much larger than that on the windward side. Comparison between the computation and experiment[3] for the circumferential surface pressure distribution is shown on Fig. 2 for a longitudinal position $X/D = 5.56$ (at the middle of the boattail). As seen in this figure, the computation predicts the correct trend of the data. The agreement is good near the windward side ($\phi = 0$) and gets worse as the leeward side ($\phi = 180$ deg) is approached. The discrepancy can be attributed partly to the lack of adequate grid resolution on the boattail. The effect that the asymmetrically located shock structure

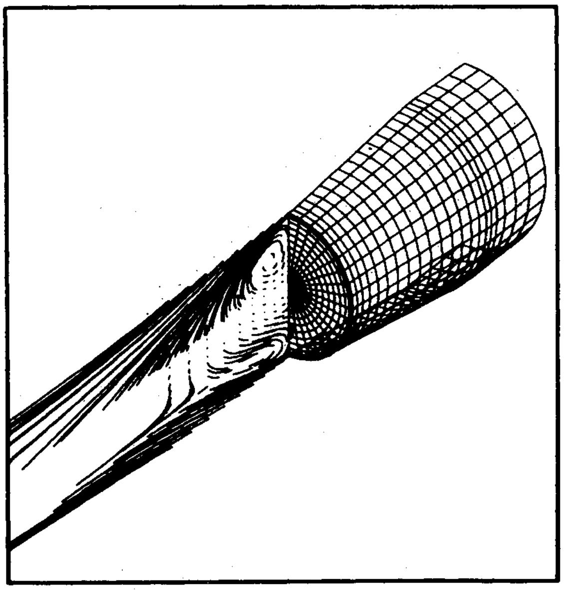

Fig. 1 Particle paths in windward and leeward planes in the base region; $M_\infty = 0.96$, $\alpha = 4$ deg.

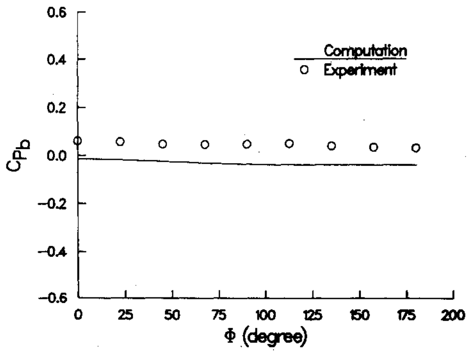

Fig. 2 Circumferential surface pressure distribution; $M_\infty = 0.96$, $\alpha = 4$ deg, X/D = 5.56.

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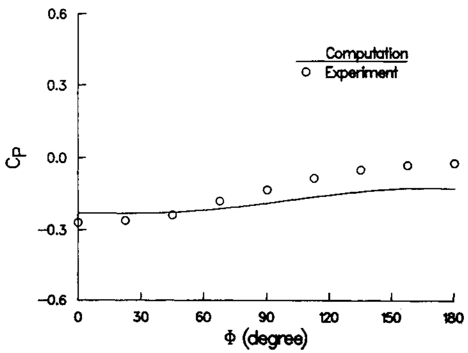

Fig. 3 Circumferential base-pressure distribution; $M_\infty = 0.96$, $\alpha = 4$ deg.

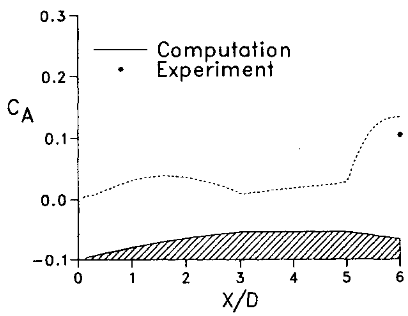

Fig. 4 Development of axial force coefficient over the projectile; $M_\infty = 0.96$, $\alpha = 4$ deg.

existing on the boattail can have on the pitching moment is not clearly understood and is a subject of further investigation.

The base pressure for this projectile has been obtained and plotted as a function of roll angle in Fig. 3. The computed result (solid line) is compared to experimental data shown in circles. This base pressure is taken at 44% of the base radius from the centerline. As seen in this figure, the base-pressure coefficient seem to decrease slightly in going from the windward side to the leeward side. This trend also is observed in the experiment. The computed result is underpredicted; however, it should be noted that these base pressures were measured with a sting mounted in the base region. The effect of the sting on the base pressure and the boattail flowfield has not been modeled in the present computation. In addition, the computational grid in the base region has been severely stretched in the streamwise direction.

The final result desired from the flowfield calculations is the determination of the aerodynamic coefficients. A typical result presented here is the axial force coefficient, which is obtained by integration of the pressure and viscous forces acting on the projectile. This is plotted in Fig. 4 as a function of longitudinal position and illustrates the development of the force over the length of the projectile. It begins to rise over the first half of the nose ($P > P_\infty$) and then drops as the ogive-cylinder junction is approached ($P < P_\infty$). This is followed by a small increase over the cylinder, which results from the viscous contribution only. There is no contribution to this increase due to the pressure forces on the cylinder. The axial force coefficient rises sharply over the boattail and then levels off. Comparison with accumulated axial force coefficient obtained experimentally shows favorable agreement.

Concluding Remarks

The elements of an unsteady, thin-layer, Navier-Stokes base-flow code to compute the three-dimensional flow of projectiles at transonic speeds are described. This capability was used to predict the base-region flowfield of a projectile at $M_\infty = 0.96$ and $\alpha = 4$ deg. Computed results show the recirculation region and the asymmetric wake in the base region. The initial results indicate the presence of asymmetrically located shock structure on the boattail upstream of the base corner. The poor agreement between the computed surface pressure and experimental data indicates the need for more grid resolution. The axial force coefficient is seen to be in good agreement with experimental data. The need for additional grid resolution exists for accurate numerical predictions. Further computations are needed at other Mach numbers in the transonic regime to determine the critical aerodynamic behavior of projectiles.

References

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