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Computational Parametric Study of the Aerodynamics of Spinning Slender Bodies at Supersonic Speeds

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Abstract

THREE-DIMENSIONAL, finite-difference flowfield computational techniques have been employed to generate a parametric aerodynamic study at supersonic speeds. Computations for turbulent viscous and inviscid flow have been performed for cone-cylinder, secant-ogive-cylinder, and tangent-ogive-cylinder bodies for a Mach number range of $1.75 \leq M \leq 5$. All aerodynamic coefficients are computed in a conceptually exact manner. The only empirical input is that required for turbulence modeling. Parametric comparisons illustrate the effects of body configuration and Mach number for ten aerodynamic coefficients. The results for Magnus and pitch damping are of particular interest.

Contents

Recent trends in projectile design have led to shapes with greater length and more slender ogives. Unexpected flight stability problems have been encountered recently due to the decreased aerodynamic stability of these new shapes. Clearly, conventional aerodynamic predictive capabilities were not adequate. In an effort to avoid these problems in the future, the Ballistic Research Laboratory has been applying finite-difference numerical computational techniques for computing projectile aerodynamic characteristics to improve shell design technology.

Three-dimensional, finite-difference flowfield computational techniques for inviscid and turbulent viscous flow have been applied to generate aerodynamic coefficients for cone-cylinder (CC), tangent-ogive-cylinder (TOC), and secant-ogive-cylinder (SOC) body configurations. Body lengths up to 7 calibers and ogive lengths of 2, 3, and 4 calibers have been considered. The aerodynamic coefficients computed are pitching moment, normal force, center of pressure, Magnus moment, Magnus force, Magnus center of pressure, form and viscous drag, roll damping, and pitch damping. These computations were performed for an angle of attack of 1 deg, a nondimensional spin rate (PD/V) of 0.19, and for sea-level atmospheric freestream conditions assuming an adiabatic wall temperature boundary condition for a Mach number range of $1.75 \leq M \leq 5$. The computation time for a single body configuration and flowfield condition is about 10 min on a CDC 7600 computer.

The sequence of computations that are run in order to compute the static aerodynamic parameters, including turbulent viscous effects, is shown in Fig. 1. Each block represents a separate computer code. Reference 1 provides a detailed discussion of each computational step. These codes have been combined using the overlay technique on the BRL Cyber 173/76 computer. The two main codes are those which compute three-dimensional turbulent boundary-layer development and three-dimensional inviscid flow.

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The computation of the effects of viscosity is of crucial importance when such parameters as roll damping, Magnus, and drag are of interest. The technique employed here is a fully implicit, finite-difference numerical scheme developed by Dwyer and Sanders.[2] This technique takes into consideration the changes in direction of the cross flow velocity that occur on the side of the shell where the inviscid crossflow opposes the surface spin. The equations of motion solved are the basic equations defining the three-dimensional compressible, turbulent boundary-layer flow over a body of revolution described by the relation $r=r(x)$.

The gasdynamic equations for inviscid flow are solved using MacCormack's[3] two-step, prediction-corrector finite-difference scheme. The unique feature of the program used here, which was developed by Sanders and Dwyer[4] for the Magnus problem, is that the flowfield is computed about an axisymmetric model plus displacement surface which, due to the distortion of the viscous layer caused by interaction with surface spin, has no plane of symmetry.

In order to compute the effective pitch damping, the technique developed by Schiff[5] is used. This computational technique relates the side moment on a body undergoing a steady coning motion about the center of gravity location to the pitch damping ($C_{M_q}+C_{M_{\dot\alpha}}$). This computation involves the solution of the Euler equations including terms for Coriolis ($2\rho \times \bar\Omega \times \bar v$) and centrifugal [$\rho\bar\Omega \times (\bar\Omega \times \bar r)$] forces in a body-fixed coordinate system.

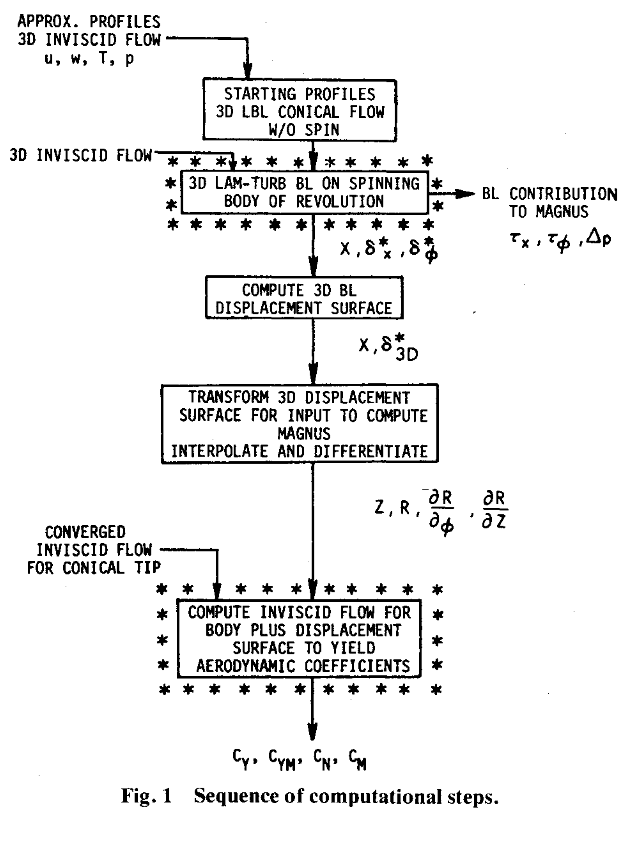

Fig. 1 Sequence of computational steps.

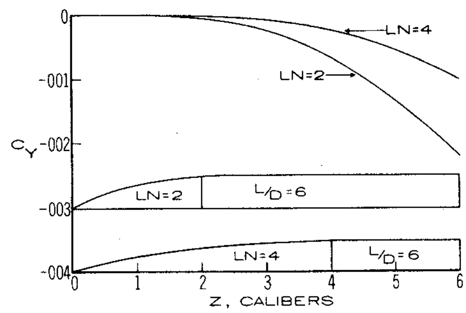

Fig. 2 Development of Magnus force vs axial position, SOC model, $M=2.75$, $\alpha=1$ deg, $PD/V=0.19$.

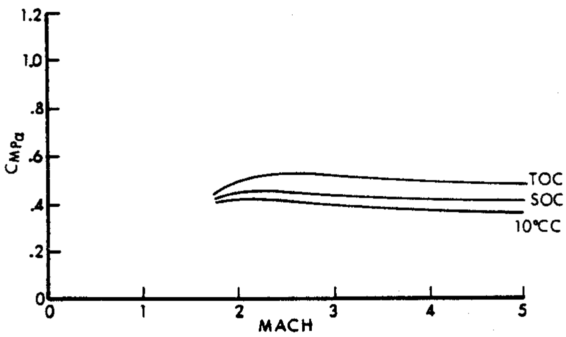

Fig. 3 Parametric comparison for Magnus moment, $L/D=6$, ogive length = 3 calibers, center of gravity at 60% from nose.

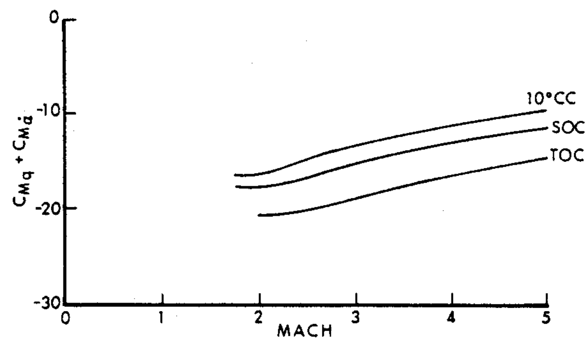

Fig. 4 Parametric comparison for pitch damping, $L/D=6$, ogive length = 3 calibers, center of gravity at 60% from nose.

For the case of steady coning motion, the flowfield is time-invariant in the body-fixed coordinate system. The effective pitch damping $(C_{M_q}+C_{M_{\dot\alpha}})$ is determined using the relation $C_{n\dot\theta} \approx \sin\sigma(C_{M_q}+C_{M_{\dot\alpha}})$, where $C_{n\dot\theta}$ is the side moment at coning rate $\dot\theta$ and effective angle of attack σ, which is valid for small values of σ and $\dot\theta$. Thus, a dynamic aerodynamic parameter is determined using a steady flowfield computation.

The development of the Magnus force over the full length of a shell is shown in Fig. 2 for two ogive configurations and a total length of 6 calibers. This figure shows that the Magnus effect is strongly dependent on the length of the cylindrical afterbody. Only a small portion of the Magnus force is generated on the ogive. Two additional examples are shown in Figs. 3 and 4 illustrating the effects of variations in ogive shape for fixed forebody and total projectile lengths. These comparisons show that Magnus moment and pitch damping are increased as ogive bluntness is increased. Examples are shown in Ref. 6 that illustrate the full scope of the parametric results.

Acknowledgment

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