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Numerical Simulation of Aircraft Rotary Aerodynamics

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Introduction

AERODYNAMIC load evaluation for aircraft maneuvers such as the coning motion is much needed during the development process of modern fighter aircraft. Such aerodynamic data can be obtained by rotary-rig experiments, which can simulate aircraft coning and spinning conditions.[1-3] Because of the complex nature of this type of testing, the number of facilities having rotary rigs in their wind tunnels is small. Additionally, the experimental data reduction process must account for effects such as model dynamics, wind-tunnel blockage, and model mounting interference.[3] Computational simulation of these aircraft maneuvers can complement the experimental determination of the aerodynamic coefficients and, thereby, accelerate vehicle development process.

In the present study, a three-dimensional panel model for a generic fighter airplane (Standard Dynamic Model,[1,2] or SDM) was prepared, and its capability of simulating the three-dimensional coning motion was investigated.

Contents

The numerical scheme used here is based on a three-dimensional potential-flow method combined with a time-dependent vortex wake model to simulate the shear layers emanating from the trailing edges of lifting surfaces. The baseline code[4] uses quadrilateral panel lattice with piecewise constant doublet and source surface elements. This approach was widely used before[5] for steady-state, high Reynolds number, lifting, nonseparated, and subsonic flows. For this case of coning motion, the spiral wake behind the airplane is constructed by the time-stepping method. The motion begins with a "no-wake" condition, and for the case of coning motion will evolve until the starting-vortex effect on the solution becomes negligible (about one complete revolution for $\omega b/2U<0.05$). More details about the methodology and the particular formulation used here are provided in Ref. 4.

For this preliminary study of modeling the coning motion, the SDM was presented by 718 panels, and its geometry is shown in the inset of Fig. 1. More detailed dimensions of the model are provided in Refs. 9–11. Since the experimental data of Refs. 1 and 2 were taken at a Mach number M of 0.6, the effect of compressibility was investigated briefly by conducting a lower-speed static test (at $M=0.15$) with a similar model. The results of this test, and the normal force C_z data of Ref. 1, is compared with the computed results in Fig. 1. At the lower angles of attack ($\alpha<15$ deg), the computed curve falls close to the two sets of experimental data, but a closer inspection reveals that the low-speed data are slightly lower than the

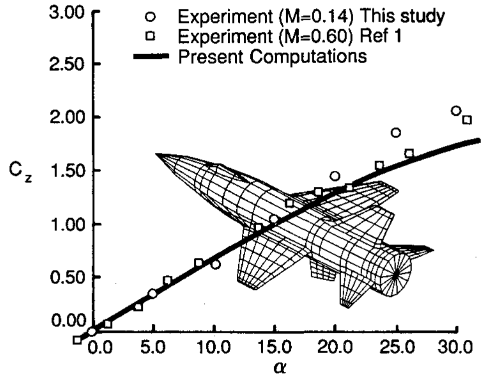

Fig. 1 Normal force coefficient vs angle of attack and geometry of the Standard Dynamic Model (SDM).

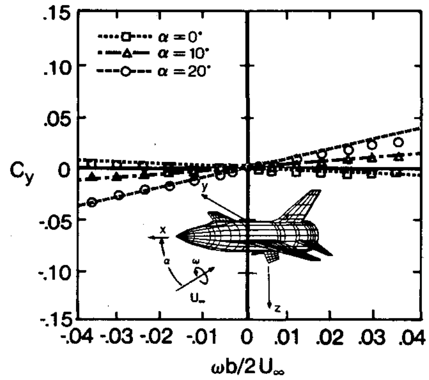

Fig. 2 Side force C_y vs roll rate $\omega b/2U_\infty$ for the SDM, and description of the coning motion.

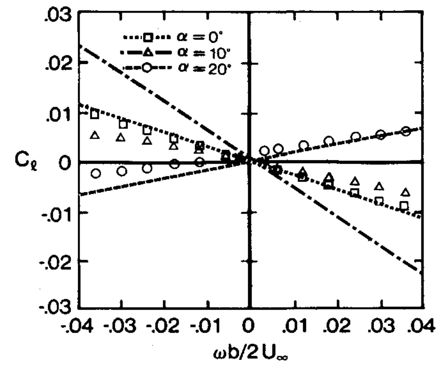

Fig. 3 Rolling moment C_ℓ vs roll rate $\omega b/2U_\infty$ for the SDM.

high-speed data (as predicted by the Prandtl-Glauert law). The wing's leading-edge sweep is only 40 deg and, therefore, at this angle-of-attack range, wing leading-edge separation will not dominate the lift characteristics. However, at angles of attack over 25 deg, the flow separation from the strakes intensifies and increases the experimental lift coefficients over the computed ones. This effect of strake vortex flow, which seems to cause larger C_z in the $M=0.15$ tests, was not modeled numerically here. Based on this normal force data of Fig. 1, and because of the low reduced frequencies in the experiments of Refs. 1 and 2, it is assumed that compressibility effects are small and fall within the limits predicted by the Prandtl-Glauert law.

Computed and experimental side force C_y and rolling moment C_ℓ are presented in Figs. 2 and 3, and the parameters such as angle-of-attack α and rotation rate ω for the coning motion are described in the inset to Fig. 2. For this case, the aircraft was rotated about its center of gravity at a rate of

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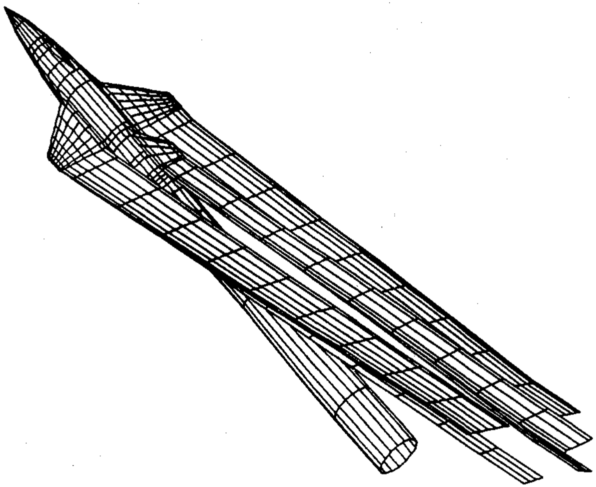

Fig. 4 Wake path behind the SDM at a coning rate of $\omega b/2U_\infty =$ 0.04 and $\alpha = 20$ deg.

$\omega b/2U_\infty = 0.04$. This rate is fairly low, but representative of possible aircraft flight conditions, and was selected to match the experiments of Refs. 1 and 2. The side force in this type of motion is influenced by the sideslip of the vertical and horizontal tail surfaces and, as expected, the computed values of C_y, for the above angle-of-attack range, are close to the experimental data.

The computed rolling moment of the configuration C_ℓ at $\alpha = 0$ is much larger than shown by the experiment. However, most important is that the trend of the curve slope (which is really the roll damping) becoming negative at the larger angles of attack is captured by the computation. This slope is also a function of the distance between the wing's center of pressure and the rotation axis, and the error in computing this distance is probably the reason for the larger (computed) rolling moments.

Another advantage of combining computational tools with wind-tunnel experiments is that model mounting interference effects can be investigated. In this case, the effects of the rotary-rig mounting on the model aerodynamics were briefly investigated by adding a panel model of the sting balance, as shown in Fig. 4. At these low-rotation rates and range of angles of attack, it was found that the potential-flow effect of the sting mounting is very small. The wake is clearing the sting, and the sting mount effect is mainly in bending upward the wake of the left wing (which increases its lift and reduces the damping).

At the higher angles-of-attack range ($\alpha > 25$ deg), flow separations can trigger some extremely violent nonlinear behavior.[3] These effects include vortex burst and vortex asymmetry, which cannot be modeled by the current method. However, graphical projections of wake location, as shown in Fig. 4, can help in explaining the triggering sequence to some of the observed nonlinear behavior.

Acknowledgments

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