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Numerical Simulation of Wing-Fuselage Interference

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Abstract

THE wing-fuselage problem is investigated by means of the Navier-Stokes equations incorporated with an approximate turbulence model. The numerical solution yields a reasonable global agreement with experimental data in static and impact pressure distributions. However, in order to better describe the flowfield structure near the leading edge of the wing, an alternative choice of coordinate system is required.

Contents

Aerodynamic interference around the juncture of the wing and fuselage is a direct consequence of three-dimensional inviscid and viscous interaction.[1,2] Recent improvements in computational efficiency of numerical methods which use vector processors allow numerical simulation of this important design problem.

In the present effort, the flowfield around a wing-body configuration is simulated by numerically solving the mass-averaged Navier-Stokes equations. Turbulent closure is accomplished by an algebraic eddy viscosity model previously used to predict successfully the flow structure over a three-dimensional corner.[3] The mesh-point distribution for the complex wing-fuselage configuration is generated by a body-oriented homotopy scheme.[4,5] The basic configuration contained several geometrical singularities for which conventional mapping procedures yield a vanishing Jacobian of coordinate transformation. In the present analysis, this difficulty is alleviated by numerically rounding the leading edge of the wing.

The calculation is performed for a hypersonic cruise vehicle at a Mach number of 6.2 and a Reynolds number of 14.6 million. The wing-fuselage configuration consists of a tangent-ogive forebody and sharp leading edge, 70-deg swept delta wing (Fig. 1). The numerical results are verified by comparing them with both the static and impact pressure measurements of Wang et al.[7]

Numerical generation of body-oriented coordinates imposes additional difficulties for a wing-body configuration. First, the grid points must be redistributed from body to wing to yield a good definition of the wing as the sweptback wing increases its span downstream of the wing root (Figs. 1 and 2). The clustering of surface points at the wing-root area achieves the desired result but at a cost of extremely small local mesh spacings. Second, the piecewise continuous segments of the body contour pose fundamental problems at the wing-body juncture and the wing tip. Small but finite (0.03-cm) fillets are incorporated to permit the transition from body to wing without significantly disturbing the flowfield structure. However, one cannot make the same statement for the wing tip, where the sharp leading edge will generate a vanishing Jacobian.

MacCormack's unsplit, explicit algorithm[8] is utilized to reduce the number of accessions of main memory, thereby developing efficient data flow for a vector processing (CRAY-1). The present effort has indicated that the achievable data processing rate can be as low as 4.0×10^{-5} (seconds/grid point/time step) for a vector length of 44. In comparison with early efforts,[9] the current development yields a 50% improvement in the data processing rate.

An indication of the vectorized efficiency of the present code can be revealed by comparing the data processing rates of a CDC 6600 and a CRAY-1 computer. The ratio of data processing rate of the same code between scalar and vector computers is 48:1. In order to achieve maximum efficiency in the CFL condition, an allowable time step size for a generalized coordinate has been derived from a stability analysis,

$$\Delta t_{\rm CFL} = l \Bigg/ \left\{ \frac{u_\xi}{\Delta\xi} + \frac{u_\eta}{\Delta\eta} + \frac{u_\zeta}{\Delta\zeta} + C\left[\left(\frac{\xi_x}{\Delta x} + \frac{\eta_x}{\Delta\eta} + \frac{\zeta_x}{\Delta\zeta} \right)^L + \left(\frac{\xi_y}{\Delta\xi} + \frac{\eta_y}{\Delta\eta} + \frac{\zeta_y}{\Delta\zeta} \right)^2 + \left(\frac{\xi_z}{\Delta\xi} + \frac{\eta_z}{\Delta\eta} + \frac{\zeta_z}{\Delta\zeta} \right)^2 \right]^{1/2} \right\}$$

where u_ξ, u_η, and u_ζ are the contravariant velocities.

The static pressure distributions at 50.81 cm downstream of the nose tip are presented in Fig. 3. A total of six specific pressure surveys are given.[7] Plots A, B, and C represent the meridian plane for the fuselage ($z = 0.0$ cm), the wing-fuselage conjuncture ($z = 3.8$ cm), and the wing tip ($z = 7.9$ cm) of the upper surface of the wing-body configuration. Similarly, plots D, E, and F designate the identical locations but for the lower surface of the wing-fuselage combination. The upper and lower surfaces are not symmetric about the z axis, because of the inverted wedge wing. Reasonable agreement on static pressure distributions between the data[7] and the present result is observed over the fuselage (Figs. 3A and 3D) and

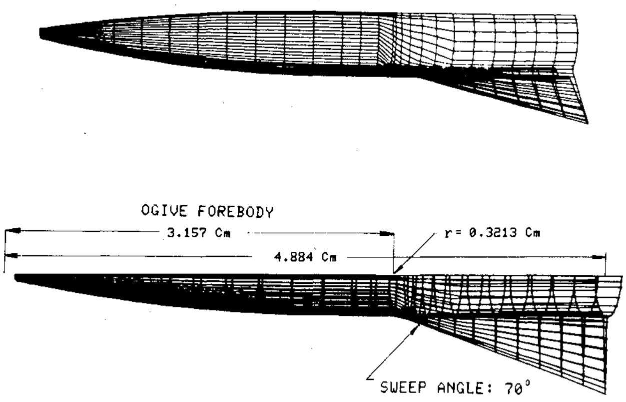

Fig. 1 Wing-fuselage configuration.

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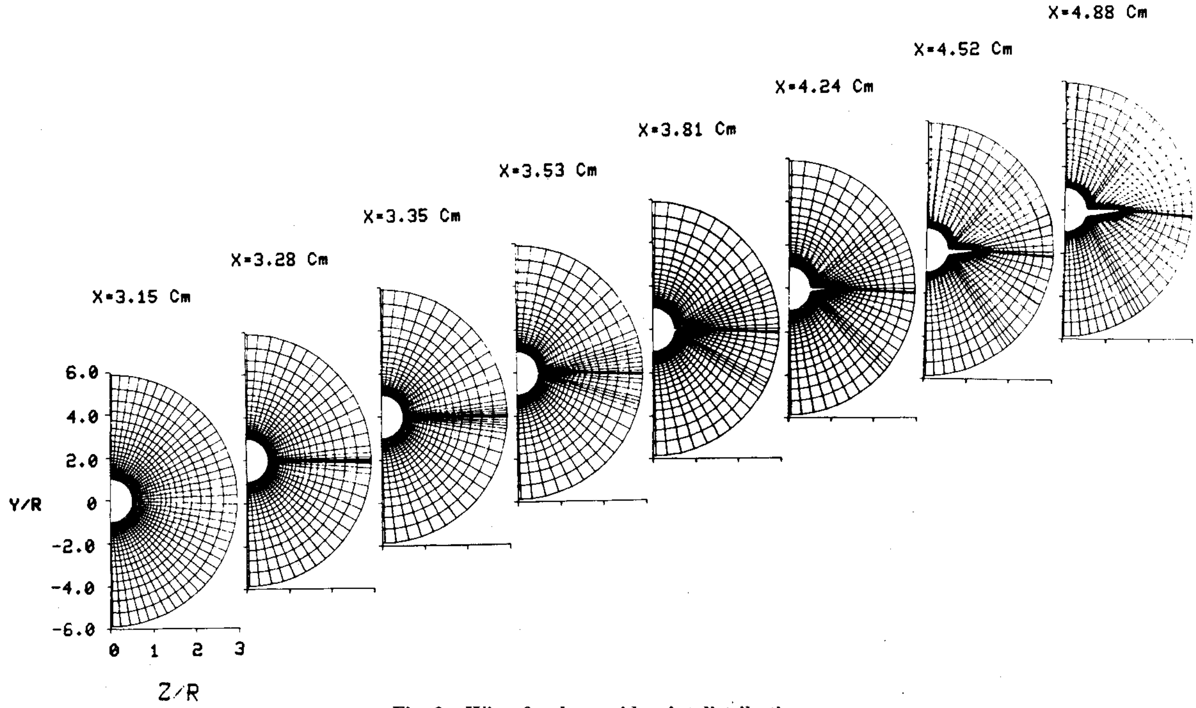

Fig. 2 Wing-fuselage grid-point distribution.

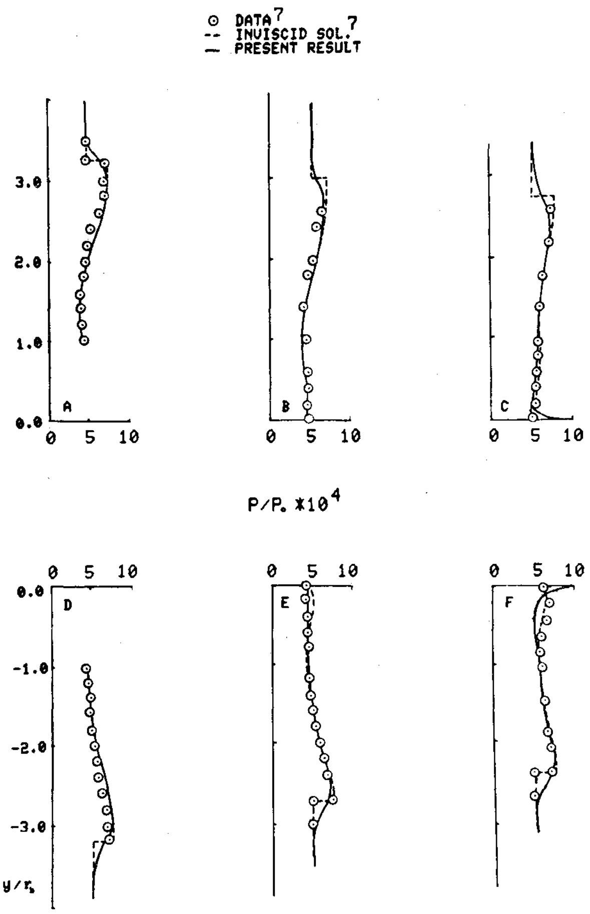

Fig. 3 Comparison of static pressure distributions.

wing-body juncture (Figs. 3B and 3E). The only serious discrepancies between data and present results appear around the wing tip formation. The numerically rounded wing tip exerts little influence on the inviscid solutions[6,7] because the asymptotic condition has been imposed locally. For the Navier-Stokes solution, however, the no-slip condition of the velocity components must be enforced at the wing tip.

The numerical solution of the mass-averaged Navier-Stokes equations is accomplished for a wing-fuselage configuration at a Mach number of 6.2 and a Reynolds number of approximately 15 million. A fundamental weakness of the body-oriented coordinate system for a three-dimensional configuration containing geometric singularities is revealed. Two recommendations follow: 1) adopt a small departure from a true body-oriented coordinate system using a branch cut on coordinates to satisfy the limiting form of the body or 2) employ an alternate of the basic formulation to a finite volume approach. Both recommendations are designed to desensitize the dependence of numerical solutions on grid geometry.

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