Table 5 Rolling moment derivatives C_l^β/C_L of an untapered 45-deg swept plane wing (aspect ratio $\lambda = 2.61$) as computed by MFES

Chordwise panels × spanwise panels $M \times N$	C_l^β/C_L	
	Projected C.P.	Midpanel C.P.
2 × 2	−0.4941	−0.5236
2 × 8	−0.4971	−0.5045
2 × 16	−0.4981	−0.5012
4 × 4	−0.4932	−0.5095
4 × 8	−0.4928	−0.5002
6 × 6	−0.4910	−0.5025

In Chiao's computation[8] of nonlinear vortex lift based on Polhamus' suction analogy, he recommended that the projected C.P. was the best arrangement of MFES to calculate suction forces acting on wing side edges.

DeJarnette[9] had treated the problem of spanwise distribution of control points in 1976. In his paper, the present projected C.P. distribution was called "conventional" and was quoted to have the same unsatisfied results as the midpanel C.P. arrangement. He had proposed another C.P. arrangement which was almost identical with ours except the positions of panel side and control point were interchanged. But, our work on this subject has already shown that the projected C.P. arrangement is far from "conventional," it behaves more superior to the midpanel C.P. When compared with DeJarnette's, the projected C.P. provides the same accuracy and rate of convergence.

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Aerodynamics of a Round Jet in a Counterflowing Wind

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Introduction

FLOWS involving the interaction of a circular jet and an unconfined, opposing stream may be encountered during V/STOL, thrust reversal, or dispersive operations. Limited information about these complex flows has thus far been obtained from a few experimental[1-4] and analytical[5-7] studies. This Note presents and appraises a numerical model of the flowfield.

The flow configuration and pertinent physical quantities are shown in Fig. 1. An incompressible, turbulent jet of diameter d_j and velocity U_j discharges into an expansive, uniform velocity (U_∞) counterflow of the same fluid. The backward deflection of the jet by the opposing stream generates a highly turbulent flowfield characterized by a large stationary recirculation zone along the periphery of the jet.

Mathematical Model

The numerical analysis of the flowfield is accomplished by simultaneously solving the governing time-averaged differential equations for mass, momentum, and turbulence properties listed in the following equations.

$$\frac{\partial}{\partial x_i}(\rho U_i) = 0 \tag{1}$$

$$\frac{\partial}{\partial x_i}(\rho U_i U_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_i} \tag{2}$$

$$\frac{\partial}{\partial x_i}(\rho U_i k) = \frac{\partial}{\partial x_i}\left(\frac{\mu_{\text{eff}}}{\sigma_k}\frac{\partial k}{\partial x_i}\right) + G - \rho\epsilon \tag{3}$$

$$\frac{\partial}{\partial x_i}(\rho U_i \epsilon) = \frac{\partial}{\partial x_i}\left(\frac{\mu_{\text{eff}}}{\sigma_\epsilon}\frac{\partial \epsilon}{\partial x_i}\right) + \frac{\epsilon}{k}\left(c_1 G - c_2 \rho\epsilon\right) \tag{4}$$

where

$$\tau_{ij} = -\rho\overline{u_i u_j} = \mu_{\text{eff}}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) - \frac{2}{3}\rho k \delta_{ij}$$

$$\mu_{\text{eff}} = c_\mu \rho k^2/\epsilon, \qquad k = \tfrac{1}{2}\overline{u_i u_i}$$

$$\epsilon = \nu(\partial \bar{u}_i/\partial x_j)^2, \qquad G = -\rho\overline{u_i u_j}\partial U_i/\partial x_j$$

The constants appearing in the preceding equations are $\sigma_k = 1.0$, $\sigma_\epsilon = 1.22$, $c_\mu = 0.09$, $c_1 = 1.44$, and $c_2 = 1.92$. A detailed description of the two-equation k-ϵ (kinetic energy-dissipation rate) turbulence model adopted for this work may be found in Ref. 8.

The model also prescribes conditions at the periphery of the open, axisymmetric flowfield. Along the symmetry axis ($r = 0$), $V = 0$, and $\partial/\partial r$ of all other variables $= 0$. $\partial/\partial x$ of all variables $= 0$ at the exit plane and as $r \to \infty$, all properties conform to freestream conditions. The values of $U, V, p, k,$ and ϵ are assigned at the jet and freestream inlet planes.

The computational procedure used to solve the above set of equations in conjunction with specified boundary conditions

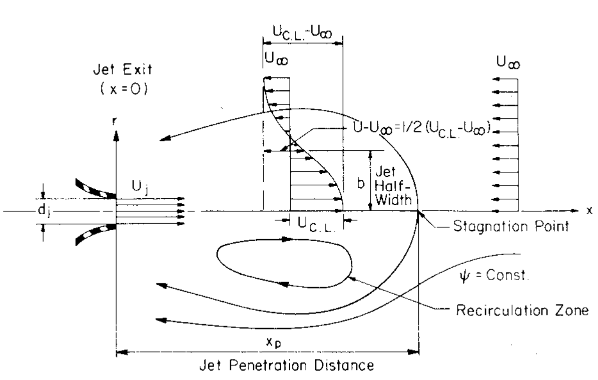

Fig. 1 Flowfield schematic.

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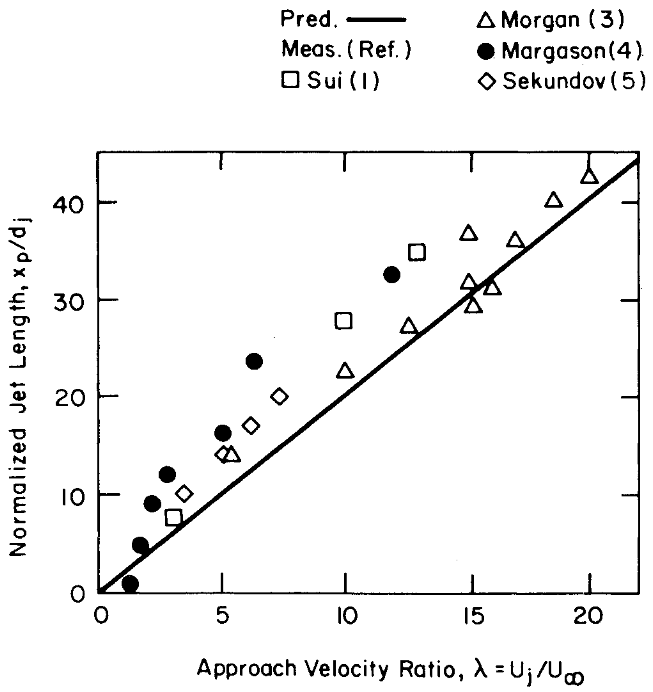

Fig. 2 Jet length variation with velocity ratio.

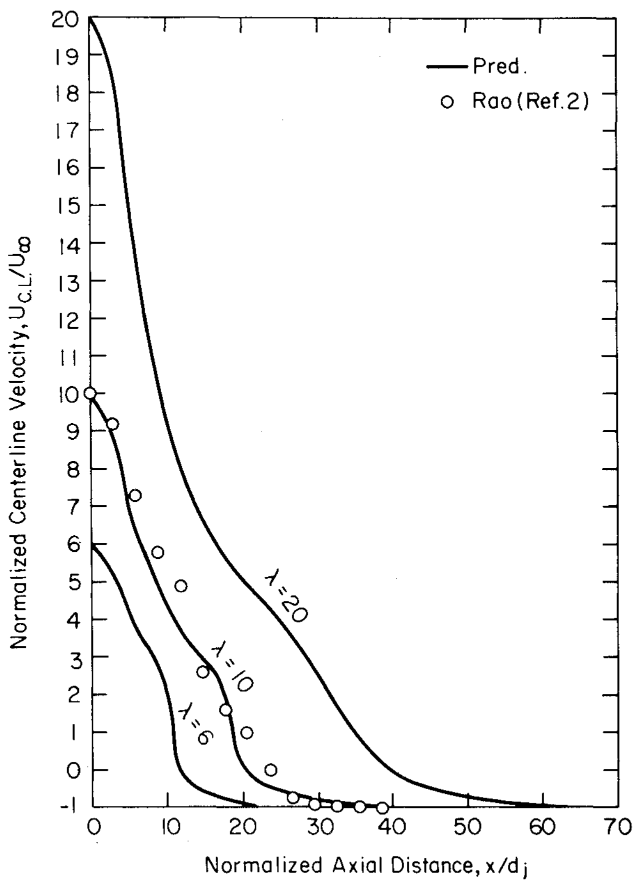

Fig. 3 Centerline velocity profiles.

is based on the TEACH method described in Ref. 9. The finite-difference calculations are carried out line-by-line over a 28×49 nonuniform grid covering the half-plane of the axisymmetric flowfield. About 300 iterations on an IBM 370-165 machine are required for a converged solution.

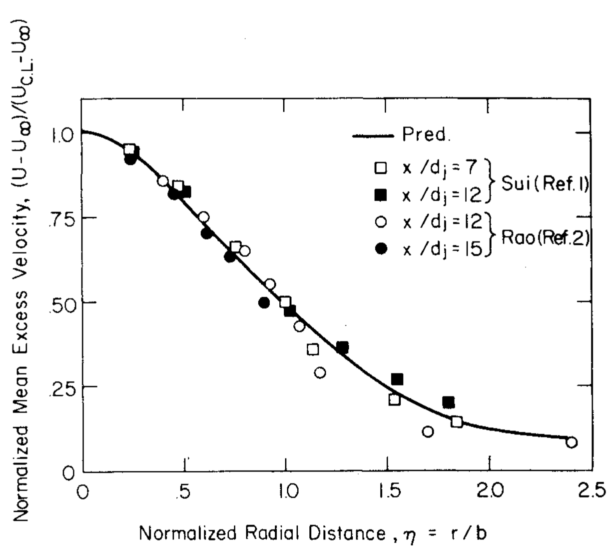

Fig. 4 Excess velocity radial profiles.

Results and Discussion

The accuracy of the numerical model is tested by comparing predicted and measured mean flow patterns. These results are presented in generalized form and illustrate the variation of jet length and spread rate with main flow parameters.

Figure 2 indicates a slight underprediction of jet penetration distance as a function of approach velocity ratio ($\lambda = U_j/U_\infty$). Figure 3 shows centerline velocity ($U_{C.L.}$) profiles for different values of λ. Good agreement between predicted and experimental results at $\lambda = 10$ is observed. Improved estimates of the axisymmetric jet length may require adjusting the turbulence model constants as suggested in Ref. 8.

A freejet-like similarity rule is predicted for the radial velocity distribution shown in Fig. 4. The results compare favorably to experimental data, especially in the fully developed jet expansion region inside the stagnation streamline.

In conclusion, the ability of the mathematical model to simulate the bulk hydrodynamic flowfield associated with a round jet in a counterflow has been corroborated. The model also provides a basis for examining the detailed flow structure.

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