Concluding Remarks

Wake rollup calculations, based on the Kutta condition, showed good agreement with available flow visualization data. It is concluded therefore that when TE displacement is small ($a/c<0.1$), the range of linearized theory calculations using the Kutta condition can be extended far beyond reduced frequencies of $\sigma>1$. There is also a need for an extensive experimental study of airfoil lift and wakes, over a wide range of Reynolds number, frequency, and TE amplitudes. When comparing these arguments to those of steady airfoil theory, it is noticeable that in steady flow under slight TE separation the airfoil lift is almost unaffected.[8] Similar reasons, probably, lead to the local pressure violation (compared to linearized theory predictions) reported[1-3] near the TE resulting in some phase shift. Measured pressures in the front section of the airfoil that provide the major contribution to the lift, however, were in agreement with linear predictions.

The effect of wake rollup on the calculated lift of the cases shown was small since the vertical velocities at the higher frequencies are mainly a result of the airfoil motion, and wake induced velocities are much smaller. Furthermore, both calculated and visualized data show that breakup occurs when $\sigma>2$.

References

[1] Commerford, G.L. and Carta, F.O., "Unsteady Aerodynamic Response of a Two-Dimensional Airfoil at High Reduced Frequency," *AIAA Journal*, Vol. 12, Jan. 1974, pp. 43-48.

[2] Archibald, F.S., "Unsteady Kutta Condition at High Values of the Reduced Frequency Parameter," *Journal of Aircraft*, Vol. 12, June 1965, pp. 545-550.

[3] Satyanarayana, B. and Davis, S., "Experimental Studies of Unsteady Trailing-Edge Conditions," *AIAA Journal*, Vol. 16, Feb. 1978, pp. 125-129.

[4] Kadlec, R.A. and Davis, S., "Visualization of Quasiperiodic Flows," *AIAA Journal*, Vol. 17, Nov. 1979, pp. 1164-1169.

[5] Fleeter, S., "Trailing Edge Condition for Unsteady Flows at High Reduced Frequency," AIAA Paper 79-0152, Jan. 1979.

[6] Katz, J. and Weihs, D., "Hydrodynamic Propulsion by Large Amplitude Oscillation of an Airfoil with Chordwise Flexibility," *Journal of Fluid Mechanics*, Vol. 88, Pt. 3, 1978, pp. 485-497.

[7] Bratt, J.B., "Flow Pattern in the Wake of an Oscillating Airfoil," Aeronautical Research Council, R&M 2773, 1953.

[8] Abbott, I.H. and Doenhoff, A.E., *Theory of Wing Sections*, Dover, N.Y., 1959, pp. 528-529.

[9] Katz, J., "Study of the Forces due to Large Amplitude Lateral Motions of a Flexible Wing," D.Sc. Thesis, Technion, I.I.T., Haifa, Israel, May 1977.

AIAA 81-4330

Asymptotic Suction Flow near a Corner

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I. Introduction

SUCTION has been used for boundary-layer control to increase lift and reduce the drag of airfoils. A surprisingly simple case can be obtained when the velocity components are independent of longitudinal coordinate. In this case, Schlichting[1] reported the case of a flat plate at zero incidence with uniform suction. Several unsteady cases were published in Refs. 2 and 3. The flow of non-Newtonian power-law fluid along a flat plate with uniform suction is considered in Ref. 4. Recently, Zierep[5] published a solution of the Rayleigh-Stokes problem near the corner formed by two perpendicular flat plates. The interference near the corner can be observed. Liu and Ismail[6] solved the case of asymptotic suction flow of natural convection near a corner formed by two perpendicular flat plates embedded in a porous medium. Both temperature and velocity profiles were obtained theoretically. This Note is intended to present an exact solution to the Navier-Stokes equations of the flow of incompressible fluid near a corner when the asymptotic suction condition is reached. The velocity profile is obtained and the interaction of the two plates can be observed.

Received Feb. 9, 1981; revision received May 29, 1981.

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II. Formulation and Solution

We consider the steady flow of a viscous incompressible fluid near a corner formed by two perpendicular flate plates at zero incidence with uniform suction. At large distances from the leading edge the asymptotic suction condition can be reached and the velocity profile is independent of the longitudinal distance.

Liu and Ismail[6] demonstrated that, under this condition, the velocity components normal to the plates are both constants and equal to b throughout the flowfield in the asymptotic region. Then the Navier-Stokes equations reduce to

$$-b\frac{\partial u}{\partial y}-b\frac{\partial u}{\partial z}=\nu\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2} \tag{1}$$

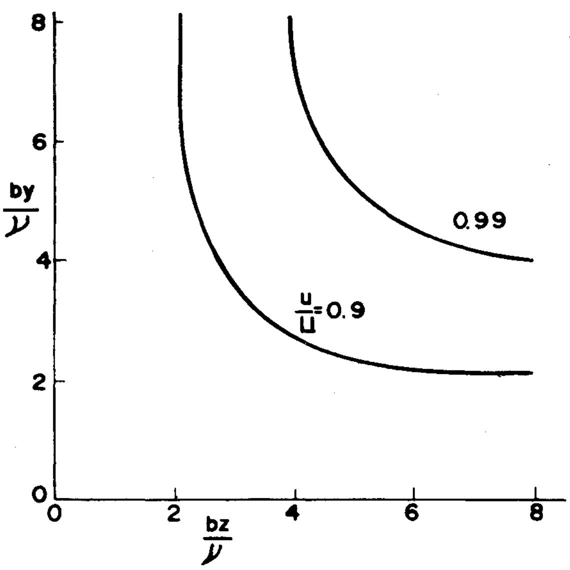

Fig. 1 Constant velocity contours.

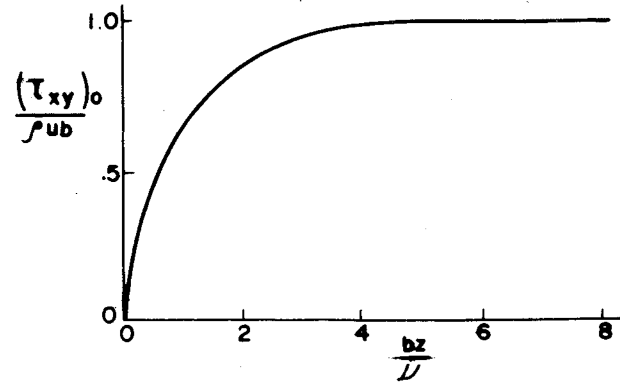

Fig. 2 Variation of the wall shearing stress from the intersection line.

where b is suction velocity at the walls and is a positive constant, ν is the viscosity of the fluid, u is the velocity component along the corner in the x direction, and y and z are the coordinates normal to the plates.

The boundary conditions are

$$u(x,0,z)=0 \quad u(x,y,0)=0 \quad u(x,\infty,\infty)=U$$

where U is the freestream velocity.

Equation (1), when solved with the above boundary conditions, yields the following velocity profile:

$$u/U=(1-e^{-(b/\nu)y})(1-e^{-(b/\nu)z}) \tag{2}$$

The constant velocity contours for $u/U=0.9$ and 0.99 are shown in Fig. 1. It can be observed that when the distance is greater than $6b/\nu$ the interaction is very small. The variation of the wall shearing stress can be calculated by

$$(\tau_{xy})_0=Ub\rho(1-e^{-(b/\nu)z}) \tag{3}$$

where $(\tau_{xy})_0$ is the wall shearing stress in the x-y direction and ρ is the density of the fluid. Equation (3) shows that the wall shearing stress is equal to zero at the intersection line of the plates ($z=0$ and $y=0$) and is equal to ρUb at large distance from the corner. The variation of $(\tau_{xy})_0$ with distance from the corner is shown in Fig. 2.

References

[1] Schlichting, H., *Boundary Layer Theory*, 6th Ed., McGraw-Hill Book Co., New York, 1968, pp. 369-370.

[2] Waston, E. J., "A Solution of the Navier-Stokes Equation Illustrating the Response of the Laminar Boundary Layer to a Given Change in the External Stream Velocity," *Quarterly Journal of Mechanics and Applied Mathematics*, Vol. 11, April 1958, pp. 302-325.

[3] Liu, C. Y., "Note on the Unsteady Asymptotic Suction Solutions to the Boundary Layer Equations," *Proceedings of the Astronautical Society of the Republic of China*, Vol. 4, Dec. 1971, pp. 96-99.

[4] Liu, C. Y., "Asymptotic Suction Flow of Power Law Fluid," *Journal of Aircraft*, Vol. 7, July 1973, pp. 135-136.

[5] Zierep, J., "Das Rayleigh-Stokes-Problem für die Ecke," *Acta Mechanica*, Vol. 34, July 1979, pp. 161-165.

[6] Liu, C. Y. and Ismail, K.A.R., "Asymptotic Solution of Free Convection Near a Corner of Two Vertical Porous Plates Embedded in Porous Medium," *Heat and Mass Transfer*, Vol. 7, Nov.-Dec. 1980, pp. 457-463.

AIAA 81-4331

Smoke Visualization of Boundary-Layer Transition on a Spinning Axisymmetric Body

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Introduction

BECAUSE of the variety of transitional behavior observed, it is clear that there are a number of possible paths to turbulence.[1] Boundary layers on spinning and nonspinning bodies exhibit two modes of instability and transition which depend upon Reynolds number and spin rate. For axisymmetric bodies without spin, a two-dimensional viscosity-conditioned instability leads to the development of Tollmien-Schlichting waves and their breakdown. On the other hand, an inflectional crossflow instability generates vortices that spiral around the spinning body and break down, possibly after a helical instability. Each of these modes appears to possess distinct topology of nonlinear breakdown and onset of turbulence. The purpose of this Note is to present and discuss smoke flow visualization photographs of these breakdowns and to call attention to a new situation where both modes superimpose simultaneously. It should be noted that, with the possible exception of the Tollmien-Schlichting (T-S) waves, the phenomena, when identifiable from the smoke, are already nonlinear. It is the global and nonintrusive character of the flow visualization that makes these observations possible.

Received June 8, 1981.

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Experimental Apparatus and Technique

The experiments were conducted in one of the University of Notre Dame's low-turbulence, subsonic smoke wind tunnels. This indraft wind tunnel has 12 antiturbulence screens, followed by a 24:1 contraction in area to the test section which is 610×610 mm square and 1828 mm long. The wind tunnel in this configuration can achieve velocities in the range of 5-27 m/s with a turbulence intensity of approximately 0.10% over this range. The activity in the boundary layer was made visible using a single kerosene smoke filament which entered the wind tunnel upstream of the first screen and was positioned to impinge, in a symmetrical fashion, on the sharp nose of the model.

The axisymmetric model consisted of a 3-caliber secant ogive nose, a 2-caliber cylindrical midsection, and a 1-caliber, 7 deg conical boattail. There were discontinuities in the slope of the body surface at the junctions of the nose and midsection, and boattail and midsection. It was polished to a surface finish of 0.254 μm (10 μin.) and anodized black. Still photographs and high-speed movies were taken at an angle of attack of zero, over Reynolds numbers based upon body length R_L from 0.315×10^6 to 1.030×10^6 and spin rates of 0-4500 rpm.

Results

In the nonspinning experiments, two-dimensional (i.e., axisymmetric) Tollmien-Schlichting waves appear sporadically along the body at $R_L=0.631\times10^6$ and appear continuously at all higher Reynolds numbers. At the higher Reynolds numbers, these waves become three-dimensionally unstable as

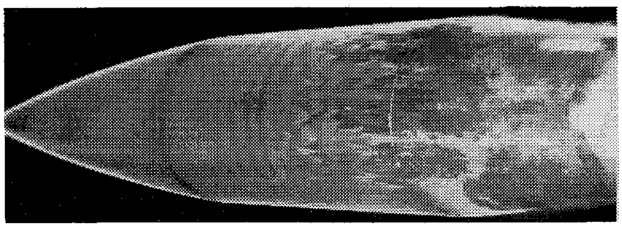

Fig. 1 Smoke photograph of nonspinning axisymmetric body for $\alpha=0$ deg and $Re_L=1{,}030{,}000$.

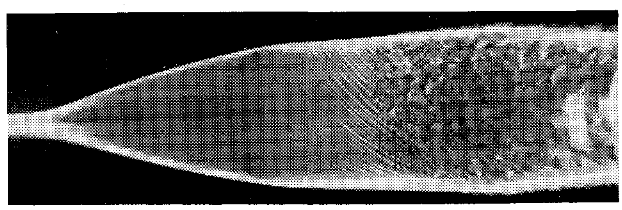

Fig. 2 Typical striations in the smoke resulting from crossflow vortices for $\alpha=0$ deg, $V/U_\infty=0.848$ (1250 rpm), and $Re_L=315{,}000$.