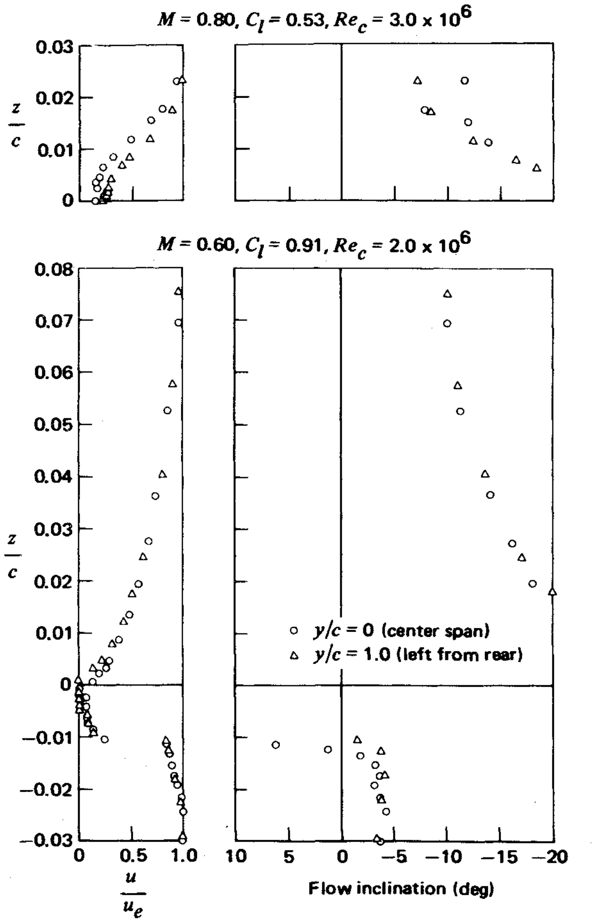

Fig. 4 Trailing-edge vector velocity profiles at different spanwise stations.

for the higher Mach numbers, especially for $M = 0.86$. The jaggedness of this plot demonstrates a cellular spanwise separation pattern, as described qualitatively by the surface flow data of Ref. 1. A clearly separated boundary-layer profile was measured on the trailing edge upper surface at the center-span location ($y/c = 0$), where the $C_{p_{te}}$ is negative.

Figure 4 compares spanwise-displaced upper surface trailing edge boundary-layer profiles for both $M = 0.60$ and $M = 0.80$. A triple-tube pressure probe with a tip depth of 0.08 mm, developed for this series to yield velocity vector data, was employed. It is seen that the spanwise deviation is much greater at the higher Mach number, whether measured by speed or by angularity. (This was the case despite the fact that the lower Mach number case carries a higher C_l, which is manifest in a larger over-all pressure rise and a much thicker upper surface boundary layer.)

The main conclusion from the data discussed herein is that significant three-dimensional effects occur in transonic airfoil tests, even for an aspect ratio of four. This is especially true at the supercritical Mach numbers, for which lateral propagation of disturbances is effective. Onset of trailing edge separation is cellular. These observations do not necessarily preclude the existence of approximately two-dimensional flow at any one spanwise section, for spanwise gradients may not be large; however, they indicate the importance of obtaining all measurements at a single spanwise location, e.g., chordwise surface pressure distributions (lift) and wake total pressure profiles (drag). In fact, C_l rather than α is the independent variable to be used, and the observed spanwise variations may be viewed as representing primarily spanwise differences in effective section angle of attack.

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Separation of Turbulent Boundary Layer on a Lifting Cylinder

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Nomenclature

b = width of the slot
d = diameter of the cylinder
ρ = density of the fluid
ν = kinematic viscosity of the fluid
θ = angular position from the slot
θ_{SL} = angular position of the slot measured from the freestream
C_J = jet momentum coefficient = jet momentum/freestream dynamic head

Introduction

LIFT can be generated on a circular cylinder with its axis normal to an airflow by blowing a sheet of air tangentially around the surface from a narrow slot or slots. Such a method has been attempted by Cheeseman[1,2] to generate lift on a rigid helicopter rotor and on a parkable rotor aircraft. The air injected through the slot re-energizes the boundary layer and delays its separation. The purpose of this Note is to study the flow beyond the slot until the flow separates. A similar problem of the Coanda effect on a cylinder has been studied by Newman.[3] It is observed there that the boundary-layer flow attaches itself up to large values of θ and separates. At high Reynolds numbers the point of separation becomes invariant.

Along with the parameters governing the flow beyond the slot in the Coanda effect on a cylinder one can recognize in the present problem of a lifting circular cylinder the additional parameters of jet momentum coefficient and the position of the slot governing the flow beyond the slot.

Dimensional Analysis

The parameters sufficient to define the flow after the slot on a lifting cylinder in an incompressible flow are $P - p_{SL}$ = the supply pressure related to the static pressure outside the slot, b, d, ρ, ν, θ, θ_{SL}, C_J. The surface pressure p_s at any angular position θ may be related nondimensionally to these parameters as,

$$\frac{p_{SL} - p_S}{P - p_{SL}} = f\left[\frac{\theta}{\theta_{SL}}, \frac{b}{d}, \left\{\frac{(P - p_{SL})}{\rho \nu^2} bd\right\}^{1/2}, C_J^{1/2}\right]$$

At some distance downstream of the slot one can expect the flow to become independent of the parameters $P - p_{SL}$ and b separately and depend on the product $(P - p_{SL})b$. Therefore

$$\frac{(p_{SL} - p_s)}{(P - p_{SL})}\frac{d}{b} = f\left[\frac{\theta}{\theta_{SL}}, \left\{\frac{(P - p_{SL})bd}{\rho \nu^2}\right\}^{1/2}, C_J^{1/2}\right]$$

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Index categories: Boundary-Layers and Convective Heat Transfer—Turbulent; Jets, Wakes, and Viscid-Inviscid Flow Interactions.

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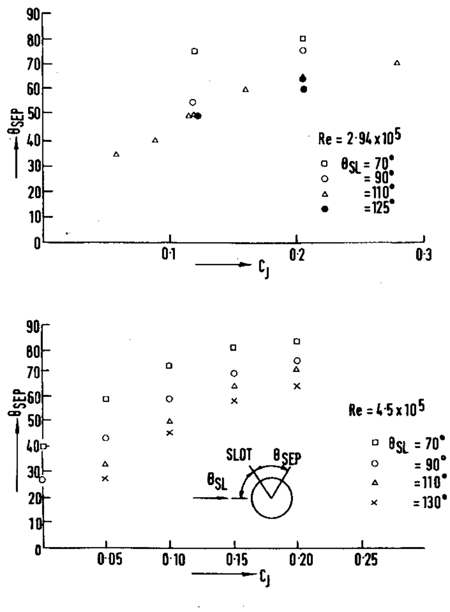

Fig. 1 Upper separation point, lifting cylinder.

defining Reynolds number as

$$R_e = [(P - p_{SL})bd/\rho v^2]^{1/2}$$

At large Reynolds number, the jet flow tends to become independent of viscosity[4]

$$\frac{(p_{SL} - p_S)\,d}{(P - p_{SL})\,b} = f\left[\frac{\theta}{\theta_{SL}}, C_J{}^{1/2}\right]$$

Similar results can be stated for the angular position of separation θ_{sep} as

$$\theta_{sep} = f\left[\frac{b}{d}, \left\{\frac{(P - p_{SL})bd}{\rho v^2}\right\}^{1/2}, \frac{\theta_{sep}}{\theta_{SL}}, C_J{}^{1/2}\right]$$

If the position of separation is sufficiently far from the slot

$$\theta_{sep} = f\left[\frac{\theta_{sep}}{\theta_{SL}}, \left\{\frac{(P - p_{SL})bd}{\rho v^2}\right\}^{1/2}, C_J{}^{1/2}\right]$$

At large values of Reynolds numbers

$$\theta_{sep} = f[\theta_{sep}/\theta_{SL}, C_J{}^{1/2}] \qquad (1)$$

Experimental Results and Conclusions

Figure 1 shows the two sets of separation point values taken from the pressure distribution measured by Herrick (1972) on a lifting cylinder of diameter 15.05 cm, with a slot of 0.6 mm wide

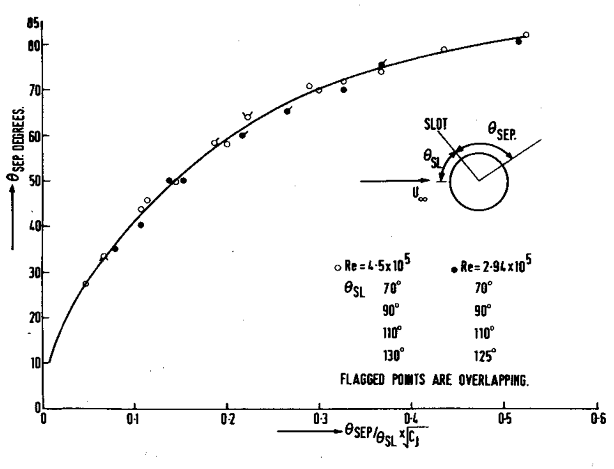

Fig. 2 Separation point correlation, lifting cylinder.

at Reynolds number of 2.94×10^5 and 4.5×10^5. Pressure distributions were measured for various values of the jet momentum coefficient and slot positions. All the separation point data of Fig. 1 have been plotted in Fig. 2 in the co-ordinates of Eq. (1).

A clear agreement of a simple form of Eq. (1) can be seen in Fig. 2 establishing a good similarity. The angle between the separation point and the slot is therefore independent of Reynolds number (at sufficiently high Reynolds number) and is a function of the position of the slot and the jet momentum coefficient only.

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Miniature Probe for Transonic Flow Direction Measurements

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Probe Description and Calibration

FIGURE 1 includes a photograph and a sketch of the tip geometry of a probe developed to measure flow direction and stagnation pressure in the boundary layer and near wake of a transonic airfoil. The probe may be viewed as a smaller, flattened version of the multiple-tube configurations described in Refs. 1 and 2, and is intended for flow direction measurements in one plane. The advantages of this design are ruggedness, ease of fabrication, ability to measure flow direction at a point, and insensitivity to out-of-plane velocity components. The tip was fabricated from three pieces of 0.010 in. (0.25 mm) o.d., 0.005 in. (0.13 mm) i.d. stainless steel tubing which were squeezed around a 0.001 in. (0.025 mm) pointed shim, thus reducing the height dimension to 0.006 in. (0.15 mm). An Arkansas stone was then used to bevel both upper and lower surfaces to produce a tip height of approximately 0.0035 in. (0.089 mm). The desired face angles were fashioned by stoning in a jig. The space curves required for the three tubes to converge at the tip were formed manually by trial and error. Larger tubing and epoxy (cured at 250°F or 395°K) were used for bracing and for structural carry-through. A microscope and an optical comparator were employed during fabrication. The small tubes were frequently flushed with distilled

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