Conclusions

An accurate continuous solution to a general class of nonlinear integral equations with known boundary conditions is obtained directly from the result of previous step (constant) solutions without appreciable work and computing time. Since the continuous solution with a small number of steps provides an adequate description of the exact solution, it is expected that even faster and more accurate solutions will be obtained if one uses the continuous solutions, which are derived from the step function solutions for a small number of intervals, as initial trial functions.

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Use of Slotted Walls to Reduce Wind-Tunnel Boundary Corrections in Subsonic Flow

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THE author has been working for some time on basic experimental research into the phenomena of the dynamic stall of helicopter rotors. This work has been conducted using a two-dimensional airfoil oscillating in pitch in the Texas A&M University 7 ft × 10 ft low speed wind tunnel. Initially,[1] a 2-ft chord airfoil was used but it became apparent from this and other work[2–4] that the stall process is dominated by the behavior of the leading edge laminar separation bubble and that pressure and velocity measurements in the vicinity of the bubble would be required for a complete understanding of the stall process. In steady flow the length of the bubble is approximately 2% of the chord making detailed measurements in that region difficult. To alleviate the problem a larger airfoil is required. For the same size tunnel this means larger corrections because of tunnel constraints. These corrections, which are nonlinear for a large model at high angles of attack, can be calculated[5] for steady flow and for unsteady sinusoidal motions with attached flow. No documented calculations of corrections for large amplitude oscillations through stall are available.

Since corrections could not be calculated it was decided that, prior to starting oscillatory tests with a 4 ft chord NACA 0012 airfoil, an investigation should be undertaken into methods of eliminating or at least minimizing the corrections required.

Considerable data are available on the use of slotted and porous walls for the reduction of corrections in transonic tunnels,[6–8] but very little has been done to extend this work to low speed subsonic flow where it should also be possible to reduce both lift interference and blockage corrections with the appropriate porosity distribution.

Received June 19, 1974. This work was sponsored by NASA Ames Research Center under Contract NAS2-7917.

Index category: Subsonic and Transonic Flow.

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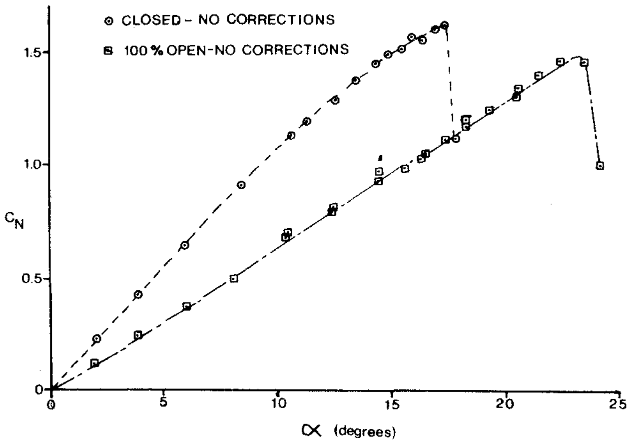

Fig. 1 C_N vs α—tunnel closed and open without corrections.

Since corrections can only be calculated for steady flow it was assumed, but not rigorously justified, that if the steady flow corrections could be reduced the unsteady corrections should be similarly reduced. This assumption is probably reasonable at the oscillatory frequencies to be used (1.4Hz max corresponding to a reduced frequency of 0.15).

The solid side walls of the tunnel were therefore removed and replaced with walls having four longitudinal slots the width of which could be varied. The 4 ft chord airfoil was instrumented with ten pressure transducers connected between the upper and lower surfaces. The outputs of these transducers were summed electronically to give normal force (C_N) and pitching moment (C_M) coefficients directly.

Tests were then run at a Reynolds number of 2×10^6 for several angles of attack (α) from zero lift to beyond stall using slot openings from zero to fully open.

Plots of the uncorrected normal force data for the tunnel sidewalls fully closed and fully open are presented in Fig. 1. As can be seen the stall angle in the open case is about 35% greater than in the closed case. Corrections for lift interference and blockage were then applied. For the closed tunnel[5] the corrections for lift interference included terms of order $(c/h)^4$ and blockage terms of order α^2. For the open tunnel results linear corrections were applied.[5,9] Corrected data are plotted in Fig. 2. The two curves are not coincident but this was expected as the corrections for the open sidewalls are linear and only valid for small wings at small angles of attack. The open wall results are therefore overcorrected. The author has considerably more confidence in the results for the closed tunnel and, therefore, these are assumed to be correct.

In Fig. 3 the effect of slot size on $C_N \sim \alpha$ is shown. As the slot size increases from zero, the values of C_N at a given α near

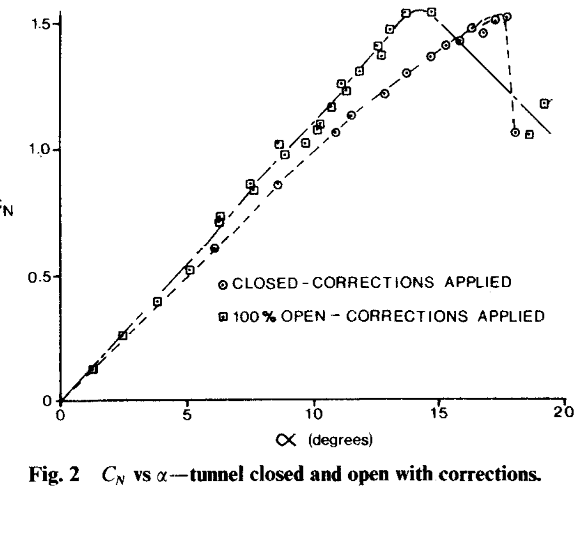

Fig. 2 C_N vs α—tunnel closed and open with corrections.

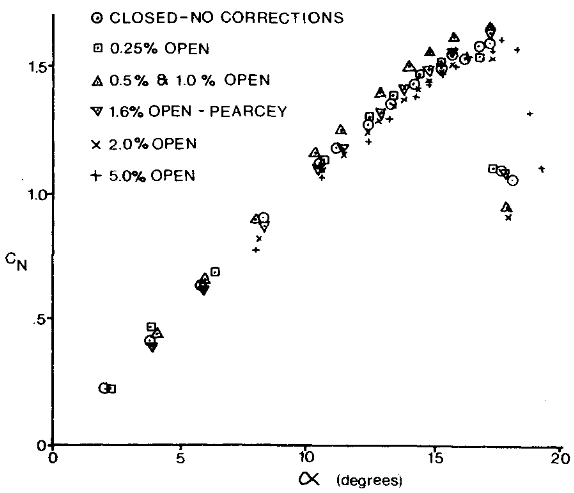

Fig. 3 C_N **vs** α**—various slot sizes.**

stall increase slightly until 0.5%–1% open after which they decrease, falling below the uncorrected closed values for 2% open (the 1.6% open configuration was of the type suggested by Pearcey[6] where the upper and lower slots are half the size of the middle ones). Increasing from 2% to 5% open continues to decrease C_N but also causes a sharp increase in the stall angle.

From these results it appears that the results for the 2% open walls are closest to the corrected values and a comparison is shown in Fig. 4. Whilst C_N is still slightly high (about 2%) for the slotted configuration at high angles of attack, the stall angle is correct. With larger slots the C_N values could be lowered (decreasing blockage) but would result in a greater stall angle (increasing stream curvature).

Quarter chord pitching moments for both the closed with corrections and the 2% open configuration remained zero up to stall at which point they both went negative.

The above results agree closely with those of Pearcey,[6] who found for his tunnel configuration that four slots 1.6% open gave zero blockage and lift interference.

Both Pearcey's and the current slot openings are considerably above values predicted by theory[5] which indicates that for an ideal (i.e., zero viscous effects at the slots) tunnel of the type used, blockage should have been eliminated and lift interference considerably reduced with the walls 0.002% open. The theory does not predict the initial move away from "correct" data for small slot openings that the current results reveal.

These vast discrepancies between experimental results and theoretical predictions render the latter suspect. Even consideration of the viscous effects for the flow through the slots is unlikely to provide good agreement. A more complex representation of the boundary conditions at the slotted walls

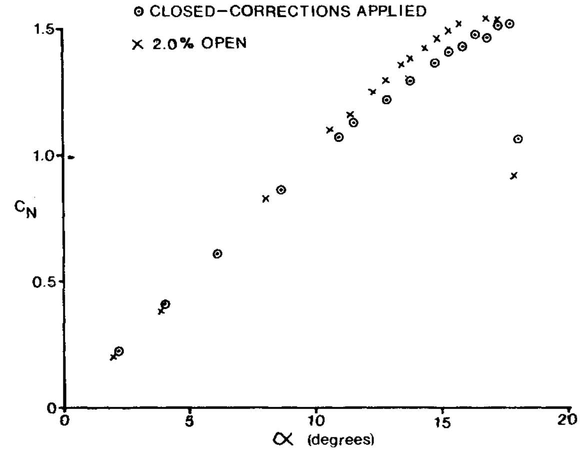

Fig. 4 C_N **vs** α**—closed and 2.0% open.**

is probably required, the linearized condition being insufficient particularly for large models at high angles of attack.

Conclusions

For the particular configuration tested, i.e., a 4-ft chord airfoil in the Texas A&M 7 ft × 10 ft low speed tunnel, it was found that corrections due to the tunnel boundaries could not be completely eliminated by using slotted sidewalls in the test section. However, by using four slots, 2% open, lift interference could be removed (i.e., stall occurred at the correct angle) and blockage reduced such that at stall the normal force coefficient was only 2% high. This is considered to be a distinct improvement over uncorrected results from a closed tunnel where α stall is 2.5% low and C_N max is 7% high. Based on these results, a series of oscillatory tests using the 4-ft chord airfoil will be undertaken with the test section sidewalls 2% open.

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Separating Laminar Boundary Layers with Prescribed Wall Shear

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Introduction

KELLER and Cebeci[1] have presented some solutions computed by a finite-difference method to what are termed "inverse problems" in the study of the boundary-layer equations for laminar, two-dimensional, incompressible flow. An inverse problem is one in which the streamwise distribution of wall shear is given, while the pressure distribution is an unknown function to be determined. This is in contrast to a "standard problem," in which the pressure distribution is given while the wall shear distribution is unknown.

Inverse problems are of particular interest in the context of separation, since solutions of standard problems exhibit singular behavior in the vicinity of separation which prevents continuation

Received July 15, 1974.
Index category: Boundary Layers and Convective Heat Transfer—Laminar.

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