Discussion

The axial singularity methods developed in Refs. 7 and 8 have been shown to yield accurate pressure coefficient solutions with little computational expense for both axial and inclined flows. Use of the linear source singularity and linear crossflow doublet singularity with twenty cosine spaced elements and the optimal inset of the singularity line yielded pressure coefficient results which were accurate to four significant figures for ellipsoidal bodies of slenderness ratios between two and ten, over the entire 0-30 deg range of angle of attack studied. However, a key requirement for obtaining such solution accuracies was use of optimal inset of the singularity line away from the blunt nose and tail. For ellipsoidal bodies this optimal inset distance has been found to be proportional to the nose radius of curvature. No inset was utilized for sharp nosed bodies such as an ogival body. It is anticipated that the optimal inset should vary for other classes of axisymmetric bodies, but it is recommended that inset distances obtained using the criterion developed for ellipsoids be used initially for all blunt nosed bodies.

The axial singularity method has been extended to allow accurate pressure coefficient solutions to be obtained for axisymmetric bodies having discontinuous changes in surface curvature. However, axial singularity methods have not been found suitable for bodies having discontinuities in surface slope, such as a cone-cylinder. Surface singularity methods appear necessary for such geometries.Accurate solutions for bodies having jumps in curvature were obtained by using higher order source singularity distributions, but only by allowing discontinuous changes in source strength across the point where the jump in curvature occured. Indeed, the resulting source intensity distributions were observed to jump from a small positive value to a negative value across such a juncture for the cylindrical bodies having ogival or ellipsoidal noses studied.

Acknowledgment

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References

[1] von Karman, T., "Calculation of Pressure Distribution in Airship Hulls," NACA TM 574, 1930.

[2] Oberkampf, W. L. and Watson, L. E., "Incompressible Potential Flow Solutions for Arbitrary Bodies of Revolution," *AIAA Journal*, Vol. 12, March 1974, pp. 409-411.

[3] Karamcheti, K., *Principles of Ideal-Fluid Aerodynamics*, John Wiley & Sons, N.Y., 1966, pp. 331-344.

[4] Zedan, M. F., and Dalton, C., "Potential Flow Around Axisymmetric Bodies: Direct and Inverse Problems," *AIAA Journal*, Vol. 16, March 1978, pp. 242-250.

[5] Zedan, M. F. and Dalton, C., "Higher Order Axial Singularity Distributions for Potential Flow About Bodies of Revolution," *Computer Methods in Applied Mechanics and Engineering*, Vol. 21, North-Holland Publishing Co., N.Y., 1980, pp. 295-314.

[6] Dalton, C. and Zedan, M. F., "Design of Low Drag Axisymmetric Shapes by the Inverse Method," published in ASME Book Number G00147, New York, 1979.

[7] Shu, J.-Y. and Kuhlman, J. M., "Calculation of Potential Flow Past Non-Lifting Bodies at Angle of Attack Using Axial and Surface Singularity Methods," NASA CR-166058, Feb. 1983.

[8] Kuhlman, J. M. and Shu, J.-Y., "Calculation of Potential Flow About A Fuselage for Inclusion of Fuselage Effects in a Wing-Design Computer Program," NASA Technical Progress Report, Grant NSG-1357, Sept. 1981.

[9] Lamb, H., *Hydrodynamics*, 6th edition, Dover Press, N.Y., 1932, pp. 139-156.

[10] Fox, C. H., Jr., "Experimental Surface Pressure Distribution for a Family of Axisymmetric Bodies at Subsonic Speeds," NASA TM X-2439, 1971.

Modifying TRANDES to Obtain Given Lift Coefficient

G. F. Hall*
Texas A&M University, College Station, Texas

Nomenclature

C_l	= section lift coefficient
C_p	= pressure coefficient, $(p-p_\infty)/q_\infty$
p	= local pressure, psf
P_∞	= freestream static pressure, psf
q_∞	= freestream dynamic pressure, psf
Re	= Reynolds number
x	= airfoil chordwise location, nondimensional in chord length
α	= airfoil angle of attack, deg
α_{in}	= airfoil angle of attack; refer to a normal TRANDES run using α_{out} as input
α_{out}	= airfoil angle of attack; calculated by TRANDES with convergence to C_l specified

Introduction

LOCAL flowfields in the vicinity of lifting surfaces, particularly propeller/rotary wing surfaces, can be so complex that an accurate value of angle of attack is difficult to obtain, whereas a desired lift coefficient generally can be specified rather easily.

It has been shown that the transonic airfoil analysis and design program, TRANDES,[1] does not correlate pressure well with experimental data using angle of attack as a parameter, but does provide good correlation if lift coefficient is used as the correlation parameter.[2] If one wishes to use TRANDES as a design tool, this ambiguity in angle of attack can lead to erroneous results; or it can result in an excessive number of computational runs to obtain the desired result. However, if lift coefficient can be specified and a resulting pressure distribution obtained, then this distribution should be reasonably close to the expected one.

A method[3] similar to TRANDES has been used successfully as a design tool for several years; however, this method does correlate pressure with experimental results using either angle of attack or lift coefficient as a correlation parameter. The method of Ref. 3 has only a simple turbulent boundary layer, whereas TRANDES has independent upper and lower surface boundary layers with laminar/turbulent runs and natural transition[4] as well as a low-speed maximum lift coefficient prediction method.[4] TRANDES has an improved and expanded methodology compared to the method of Ref. 3.

In keeping with the improvements to TRANDES, it would be an enhancement to provide the capability of obtaining a pressure distribution directly for a desired lift coefficient. This paper reports alterations to the program that permit convergence to lift coefficient. Details of the changes to the changes to the program may be obtained by contacting the author.

Technical Approach

TRANDES has as an independent parameter, the angle of attack α. In Ref. 1 α is an input parameter and held constant. In order to alter the method to accept a required lift coefficient, angle of attack is allowed to vary with each relaxation sweep through the grid. As angle of attack is updated with

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*Assistant Professor. Member AIAA.

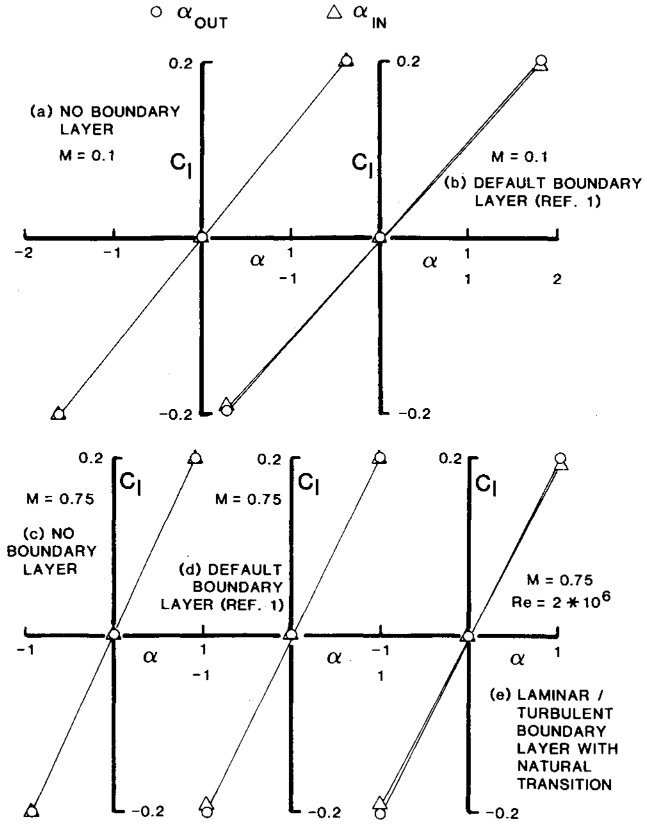

Fig. 1 Variation in airfoil lift coefficient with angle of attack.

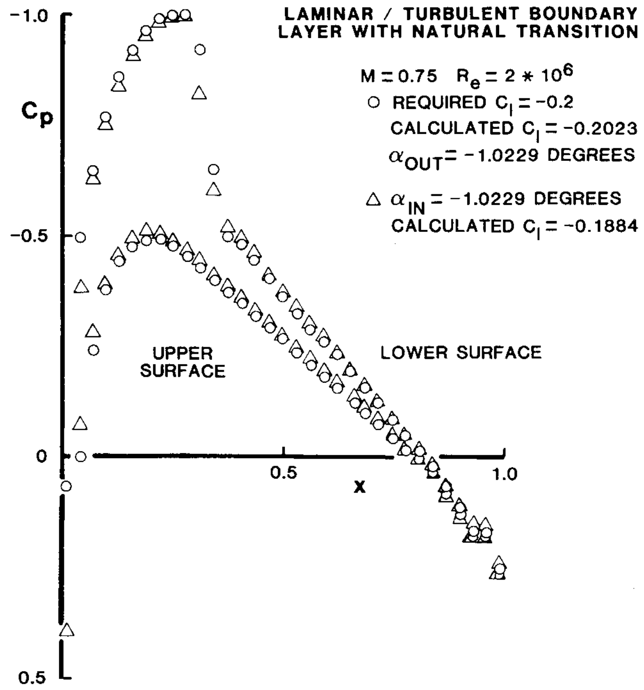

Fig. 2 Chordwise variation in airfoil pressure coefficient.

each relaxation, the circulation also is changed accordingly. In turn, the circulation is directly proportional to lift coefficient. Thus the change in circulation defines the change in lift coefficient required to bring the current value of angle of attack to that required to produce the required lift coefficient.

Sample Results

As a means of verifying the prescribed changes, an NACA 0012 airfoil section was investigated at the following operating conditions: Flight Mach number $= 0.1$ (subcritical), 0.75 (supercritical); no boundary layer; the default boundary layer of Ref. 1; and a laminar/turbulent boundary layer with natural transition.

The verification consisted of investigating a range of required lift coefficients. These values were taken to be -0.2, 0.0, and 0.2. The values of lift coefficient and angle of attack as calculated by TRANDES were obtained and the lift coefficient compared with the required input. The calculated angle of attack then was input to TRANDES to obtain a lift coefficient from a normal run. Figures 1 and 2 summarize the results of this investigation.

Figures 1a-e compare lift coefficient against angle of attack over the range tested. It was found that the program default value controlling the number of iterations was sufficient to provide acceptable results for the subcritical cases, with and without boundary layer (Figs. 1a and 1b), and the supercritical case without boundary layer (Fig. 1c).

Figure 1d shows the supercritical case with the default boundary of Ref. 1. Acceptable results required a doubling of the number of iterations. It should be noted from Fig. 1d that acceptable results at negative lift coefficient required that no constraint be imposed on the lower surface boundary-layer growth at negative angle of attack. Such constraints can conflict irrevocably with any shock effect on the boundary layer. The TRANDES methodology controls lower surface boundary-layer growth via an input quantity and also permits eliminating this control through the same input item.

Figure 1e describes a supercritical case with a laminar/turbulent boundary layer with natural transition. Again, the method converged satisfactory to the desired lift coefficient/angle-of-attack combination.

Figure 2 shows a pressure coefficient comparison from the two modes of TRANDES operation. This case is at a transonic Mach number of 0.75, and negative lift coefficient of -0.2. It also includes independent upper and lower surface boundary layers with natural transition. This combination represents the most difficult test for the TRANDES numerical methodology, and pressure distribution comparisons for the other test cases were at least as satisfactory.

Figure 2 shows the pressure distribution obtained by convergence to lift coefficient is fully acceptable when compared to the pressure distribution from a normal TRANDES run. It can be noted that any significant deviations in the calculated pressure coefficients occurred in regions of strong gradients such as the shock wave or the rapid expansion near the leading edge. These differences do not alter the characteristics of the pressure distribution significantly, nor do they introduce major error into the calculated lift coefficient. However, if greater accuracy is desired, more stringent convergence criteria, particularly increasing the number of iterative cycles, can be applied.

Concluding Remarks

The changes to the TRANDES program that permit a required lift coefficient to be specified and the corresponding pressure distribution determined give results that are consistent with the standard procedure of angle-of-attack input.

References

[1] Carlson, L.A., "TRANDES: A FORTRAN Program for Transonic Airfoil Analysis or Design," NASA CR-2821, June 1977.

[2] Freuler, R.J. and G.M. Gregorek, "An Evaluation of Four Single Element Airfoil Analytic Methods," NASA CP2045, Pt. 1, ATAR, Vol. I, March 1978.

[3] Bauer, F., Garabedian, P., Korn, D. and Jameson, A., "Supercritical Wing Sections II," *Lecture Notes in Economics and Mathematical Systems 108*, Springer-Verlag, N.Y., 1975.

[4] Carlson, L.A., "TRANSEP: A Program for High Lift Separated Flow About Airfoils," NASA CR-3375, Dec. 1980.