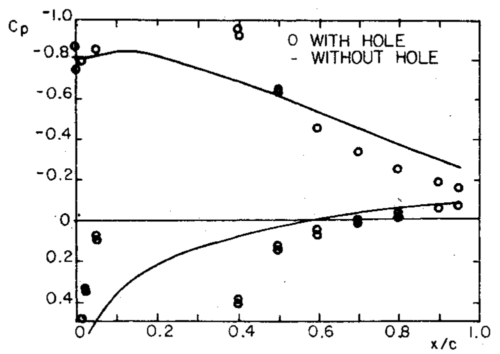

Fig. 2 Chordwise C_p along centerline of 1.5% area hole at 75% span, $\alpha = 9.8$ deg.

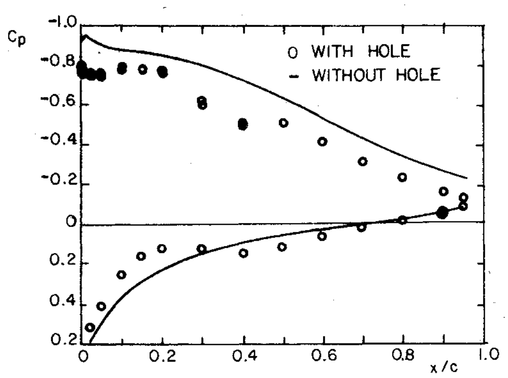

Fig. 3 C_p along a chord 7-cm inboard of hole, $\alpha = 9.8$ deg.

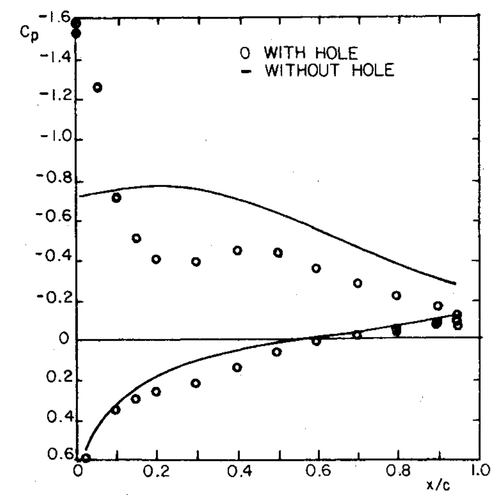

Fig. 4 C_p along a chord 7-cm outboard of hole, $\alpha = 9.8$ deg.

turbulent wake behind and under the hole outflow, with substantial reverse flow on the upper surface. The upper-surface pressures were increased at most stations in a manner similar to that seen in Fig. 3.

The largest perturbations occurred outboard of the hole on the upper surface, as shown in Fig. 4. In this region, oil-flow data indicated strong reverse flow in the separation bubble on the stabilator without any hole. When the hole was added, the flow over the aft 80% chord was restored to the streamwise direction, with the hole outflow acting somewhat as a fence. The C_p distribution of Fig. 4, with a leading-edge suction peak, is similar to that found at lower angles where the flow was attached.

Conclusions

The hole effects were found to be dependent on the extent of leading-edge separation on the stabilator. At angles of attack below about 6 deg, separation was limited and the effects extended laterally beyond the hole to a distance approximately equal to the hole width and streamwise to about 60% chord; these localized effects were moderate in magnitude. At higher angles of attack with separation, all upper surface pressures were perturbed; the strongest effects were outboard of the hole where the normally separated flow was attached by the fence-like action of the flow through the hole. At the higher angles, the effects were also localized on the lower surface.

Acknowledgment

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References

[1] Scott, D.S., Westkaemper, J.C., Sigal, A., and Stearman, R.O., "The Influence of Ballistic Damage on the Aeroelastic Characteristics of Lifting Surfaces," AFOSR TR 80-0220, May 1979.

[2] Scott, D.S., "Potential Flow Modeling of a Through-Hole Type Damage in a Lifting Surface Utilizing a Kernel Function Procedure," M.S. Thesis, Aerospace Engineering, University of Texas at Austin, May 1979.

[3] Westkaemper, J.C. and Chandrasekharan, R.M., "The Effects of Warhead-Induced Damage on the Aeroelastic Characteristics of Lifting Surfaces, Vol. II - Aerodynamic Effects," AFOSR TR 80-1039, July 1980.

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New Frequency Parameter for Unsteady Aerodynamics

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Background and Basis

AEROELASTIC analyses require unsteady aerodynamic coefficients at a large number of reduced frequency values (k). For transports the range of reduced frequency that must be accurately defined is from $k = 0$ to about $k = 1.0$ (where $k = b\omega / V$, and b is the reference semichord, ω is the circular frequency, and V is the freestream velocity). Because the computation of these unsteady coefficients is expensive, many aeroelastic programs rely on precomputed tables which are interpolated to determine the unsteady aerodynamics. An accurate representation of the aerodynamics requires a large number of entries in the table, particularly in the low k area, where the aerodynamics vary most rapidly. The cost of the computation and the need for accuracy, therefore, motivate the search for a parameter that would transform the reduced

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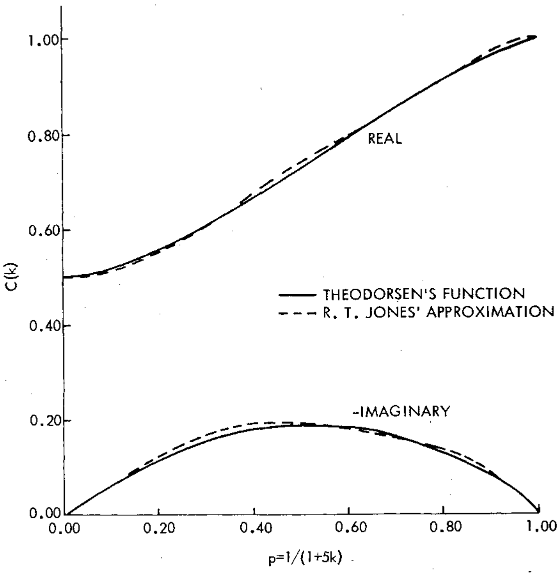

Fig. 1 Theodorsen's function.

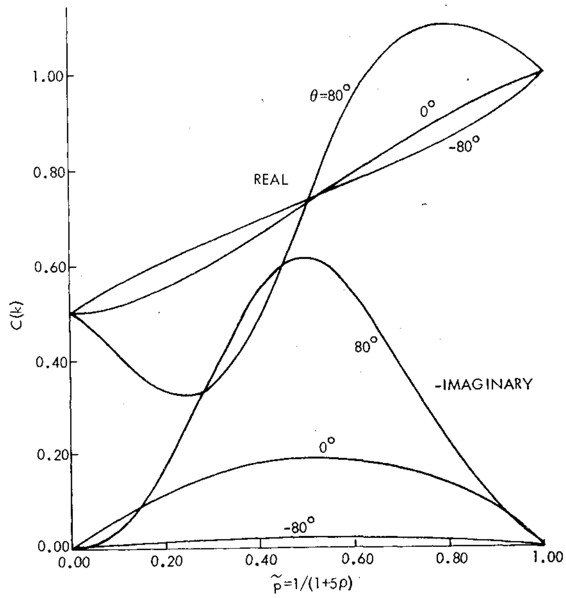

Fig. 2 Generalized Theodorsen's function.

frequency scale in such a way as to minimize the number of unsteady aerodynamic calculations while retaining the required accuracy.

The requirements on such a parameter may be summarized as follows: 1) The entire reduced frequency range of interest must be represented. 2) The low end of the reduced frequency scale must be expanded in order to ensure accuracy. 3) The moderate-to-high reduced frequencies must be compressed in order to avoid redundant calculations.

A parameter that meets these three requirements is $p=1/(1+5k)$. The entire reduced frequency range is compressed into the interval from 1 to 0; low-to-moderate reduced frequencies, up to $k=0.8$, are expanded to occupy 80% of the scale and the higher reduced frequencies are compressed into the remaining 20%. It should be noted here that what is referred to as high reduced frequency is based on typical flutter reduced frequencies for transport aircraft.

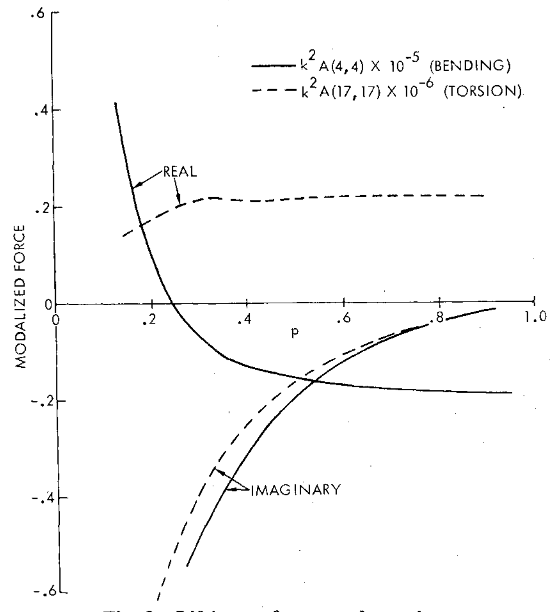

Fig. 3 Lifting surface aerodynamics.

Applications

The validity and usefulness of the parameter p is illustrated through some examples. The four cases presented certainly do not represent the only applications of this parameter, but they do cover the more common areas of interest in unsteady aerodynamics for aeroelastic analyses.

Theodorsen's Function

Because Theodorsen's function is a familiar representation of unsteady aerodynamics and because it is relatively simple compared to other unsteady aerodynamic functions, it is chosen as the means for illustrating the features of the parameter p. Theodorsen's function, $C(k)$, is plotted against the parameter p in Fig. 1. The advantage of the parameter is immediately apparent when this plot is compared with a standard plot of $C(k)$ vs $1/k$ (see, for example, Ref. 1). The smoothness of the function is such that second degree interpolation is adequate and can be used to calculate any intermediate points with only ten precomputed entries in the table of aerodynamic coefficients.

For gust and dynamic maneuver analysis in the time domain, R.T. Jones' approximation to the Wagner indicial lift growth function is often used. Since the Wagner function and Theodorsen's function are Fourier transform pairs, the transform of R.T. Jones' approximation is compared with Theodorsen's function in Fig. 1. Although it does not exactly match Theodorsen's function, the approximation is still smooth and interpolatable.

Aerodynamics for Generalized Motion

Interest in active controls leads to the requirement for unsteady aerodynamics for generalized motion, that is, other than simple harmonic motion. Edwards suggests that the generalized motion aerodynamics may be computed by replacing the Fourier transform frequency parameter k by the complex Laplace transform parameter $k=\rho e^{i\theta}$, allowing for decaying or divergent motion.[2] A complex parameter p is defined for numerical interpolation, but for illustration the parameter $\tilde{p}=1/(1+5\rho)$ is defined as the independent parameter. That the parameter is complex may then be seen by plotting the unsteady aerodynamics against $\tilde{p}$ for different values of θ. Theodorsen's function for generalized motion is shown in Fig. 2 for three values of θ, representing damped, harmonic, and divergent motion ($\theta=-80$, 0, and 80 deg, respectively).

Modalized Aerodynamics

Aeroelastic analyses of large systems are usually carried out in terms of a truncated set of modal coordinates, requiring modalized aerodynamic forces. A table of the modalized

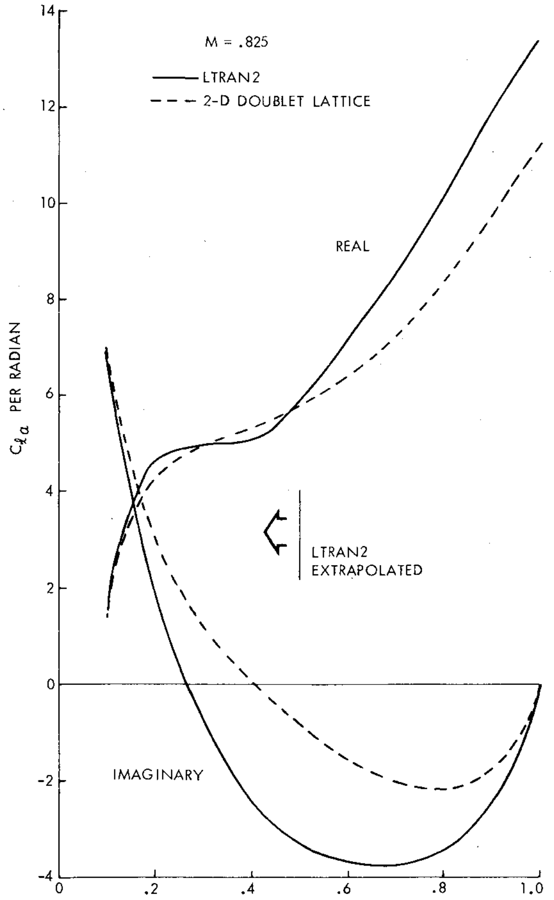

Fig. 4 CFD aerodynamics.

forces may also be precalculated and the required analysis values interpolated using the parameter. Two elements of the modalized air force matrix corresponding to a bending mode and a torsion mode of a large transport are shown in Fig. 3. The aerodynamics are calculated using a lifting surface technique similar to the doublet lattice method of Ref. 3. The complex parameter p is also very useful for representing the modalized aerodynamics for the generalized motion required in active controls analysis.

Computational Fluid Dynamics

As unsteady aerodynamic programs become more sophisticated and costly to use, the parameter p becomes increasingly more valuable. The parameter was used in the first efforts in incorporating the LTRAN2 code of Ref. 4 into the flutter analysis of a three-dimensional wing. Typical aerodynamics, in this case the lift curve slope of the NACA 64A006 airfoil, are presented in Fig. 4. Because LTRAN2 is limited in reduced frequency, the aerodynamics had to be extrapolated to obtain the necessary range. This extrapolation was based on the convergence of the transonic aerodynamics to linear aerodynamics with increasing reduced frequency and is made in terms of the complex ratio of LTRAN2 aerodynamics to two-dimensional doublet lattice aerodynamics. For reference, the two-dimensional linear aerodynamics are also presented in Fig. 4.

Summary

Replacing the reduced frequency with the parameter p allows the entire frequency range to be represented on a finite scale, while expanding the low frequency range which is of most interest. The parameter has proved useful in flutter analysis, active controls analysis, and also in the incorporation of results from computational fluid dynamics (CFD) programs into conventional aeroelastic analyses. Its nature of emphasizing the most critical area in representing the unsteady aerodynamics, leads to an efficient selection of reduced frequencies for precalculating the aerodynamic coefficients and can provide guidelines in selecting the reduced frequencies in unsteady aerodynamic testing.

References

[1] Scanlan, R.H. and Rosenbaum, R., *Introduction to the Study of Aircraft Vibration and Flutter,* The Macmillan Co., New York, 1951.

[2] Edwards, J.W., "Unsteady Aerodynamic Modeling and Active Aeroelastic Control," SUDAAR 504, Stanford Univ., Calif., 1977.

[3] Albano, E. and Rodden, W.P., "A Doublet Lattice Method for Calculating Lift Distributions on Oscillating Surfaces in Subsonic Flows," *AIAA Journal,* Vol. 7, Feb. 1969, pp. 279, 285.

[4] Ballhaus, W.F. and Goorjian, P.M., "Implicit Finite Difference Computations of Unsteady Transonic Flows About Airfoils, Including the Treatment of Irregular Shock Wave Motions," AIAA Paper 77-205, Jan. 1977.

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Propeller Tip Vortex: A Possible Contributor to Aircraft Cabin Noise

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Nomenclature

D	= propeller diameter
C_p	= propeller power coefficient = power/[(density) (rpm)^3 $(D)^5$]
J	= propeller advance ratio = forward velocity/[(rpm) (D)]
M_0	= Mach number of wind-tunnel flow
M_T	= relative Mach number at propeller tip
R	= propeller radius
r	= radial position of vane microphone

Introduction

THE National Aeronautics and Space Administration, with industry participation, is conducting a broad-based turboprop technology development program that portends a new generation of highly fuel efficient turboprop aircraft with the speed and comfort potential of today's turbofan powered fleet.[1] A key technology area deals with the concern for reducing the passenger cabin noise level in these aircraft to a level comparable to current turbofan aircraft. The assumption is generally made that cabin noise levels are governed by the transmission of propeller generated noise through the fuselage side wall. However, past attempts at reducing turboprop aircraft cabin noise levels by modifications to the fuselage side wall have generally met with limited success, although new analysis and fuselage wall design concepts are currently being developed that may result in significant gains.[2,3]

Others have suggested that propeller induced vibrations may be generated, and transmitted via structural paths to the fuselage structure, to be radiated as noise to the cabin in-

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