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COMPUTATIONAL, UNSTEADY TRANSONIC AERODYNAMICS AND AEROELASTICITY ABOUT AIRFOILS AND WINGS

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INTRODUCTION

This article will survey some of the research in the area of computational, unsteady transonic flows about airfoils and wings, including aeroelastic effects.[1,2] In the last decade, there have been extensive developments in computational methods in response to the need for computer codes with which to study fundamental aerodynamic and aeroelastic problems in the critical transonic regime. For example, large commercial aircraft cruise most effectively in the transonic flight regime and computational fluid dynamics (CFD) provides a new tool, which can be used in combination with test facilities to reduce the costs, time, and risks of aircraft development.

One of the major uses of unsteady transonic aerodynamics is in the flutter analysis of supercritical wings. Experiments have shown that dips occur at transonic Mach numbers in the flutter boundaries for wings and such dips are especially severe for supercritical wings. This phenomenon is attributable to the motion of shock waves on the wings. The proper modeling of the physics of such moving shock waves requires that the CFD methods solve nonlinear partial differential equations for regions of mixed subsonic and supersonic flow. Currently, the most advanced codes use potential equations for modeling the flow; such codes are being used for generic research in aeroelasticity. More advanced codes are being developed that use the Euler and Navier-Stokes equations; such codes also model vortices.

In this article, first an early result[3] will be described of transonic flow with moving shock waves over an airfoil. Then a current result[4] will be shown of flow over a variable sweep wing, including comparisons with experimental data. Then the effect of varying the sweep on the aeroelastic damping will be shown.

TRANSONIC FLOW OVER AIRFOILS

The development of algorithms and codes for simulating unsteady transonic flows by solving the unsteady transonic small disturbance potential equation was started at NASA Ames Research Center by Ballhaus and Lomax. Initially a code, called LTRAN2, was developed[3] for a low-frequency approximation to the governing equation. Later the code was generalized to account for all frequencies and was called ATRAN2. The algorithm used in the code is an alternating-direction, implicit (ADI), finite-difference scheme. It is conservative and time-accurate so that shock wave motions are modeled correctly. There have been many improvements to the code, including improvements in: (1) accuracy, such as the use of second-order differencing; (2) stability, such as the use of monotone schemes; and (3) capability, such as the inclusion of viscous modeling and the capability to model wind tunnel walls and supersonic free streams. See refs. 1-2 for details.

In Fig. 1, a sample calculation[3] is shown from the LTRAN2 code. The results are for transonic flow over a NACA-64A006 airfoil with an oscillating flap. For this case, the shock-wave motion is classified[3] as type B; notice that the shock wave disappears during a portion of the cycle of flap motion. Comparisons are made with results obtained by using the Euler equations by Magnus and Yoshihara. The LTRAN2 results were calculated over a 100 times faster than the Euler results. The improved efficiency was due primarily to the use of an implicit method compared to the explicit method that was used to obtain the Euler results.

TRANSONIC FLOW OVER WINGS

The two dimensional algorithm has been extended to three dimensions and there have been extensive code developments and computations of transonic flow over wings.[1,2,4] These applications include the computation of flow around transport wings and low-aspect-ratio wings. Some results include viscous modeling and aeroelastic effects, such as the calculation of flutter boundaries.

Here calculations are shown of aeroelastic simulations for a variable sweep wing. The aerodynamic and aeroelastic equations are simultaneously integrated at every time-step in order to properly account for the interaction of the nonlinear aerodynamics with the structural motion. Figure 2 shows the wing planforms and Fig. 3 shows the six vibrational modes that were modeled in the calculations. Figures 4 and 5 show the comparisons with experiment of the steady flow calculations at the two sweep angles (computed results denoted by ATRAN3S). Finally, Figs. 6 and 7 show the dynamic aeroelastic responses at the two sweep angles. Notice that the aeroelastic damping has been severely reduced as a result of sweeping back the wing.

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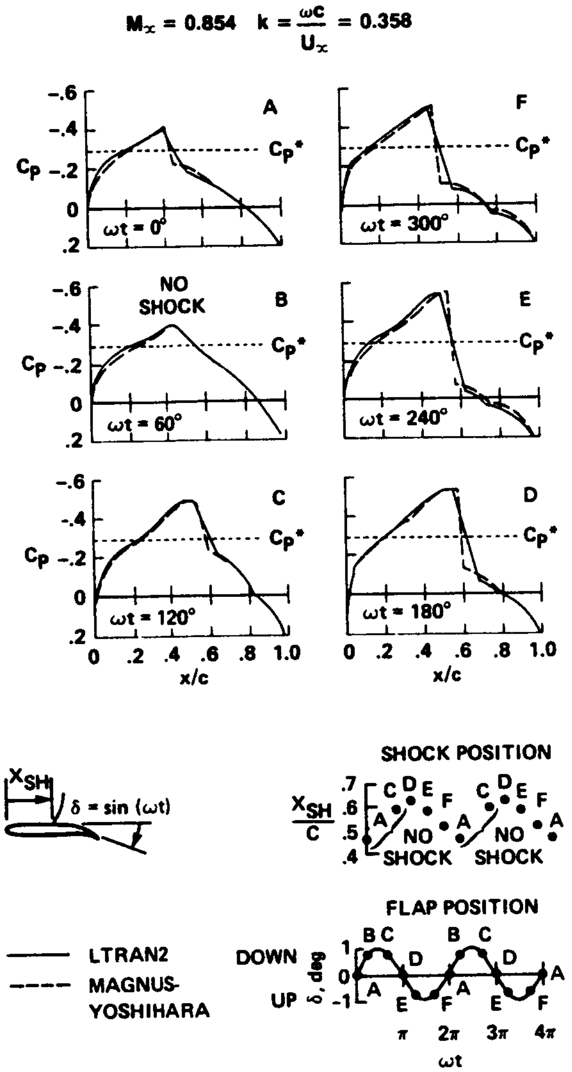

Fig. 1 Unsteady upper surface pressure coefficients for an airfoil with an oscillating flap. Type B shock wave motion.

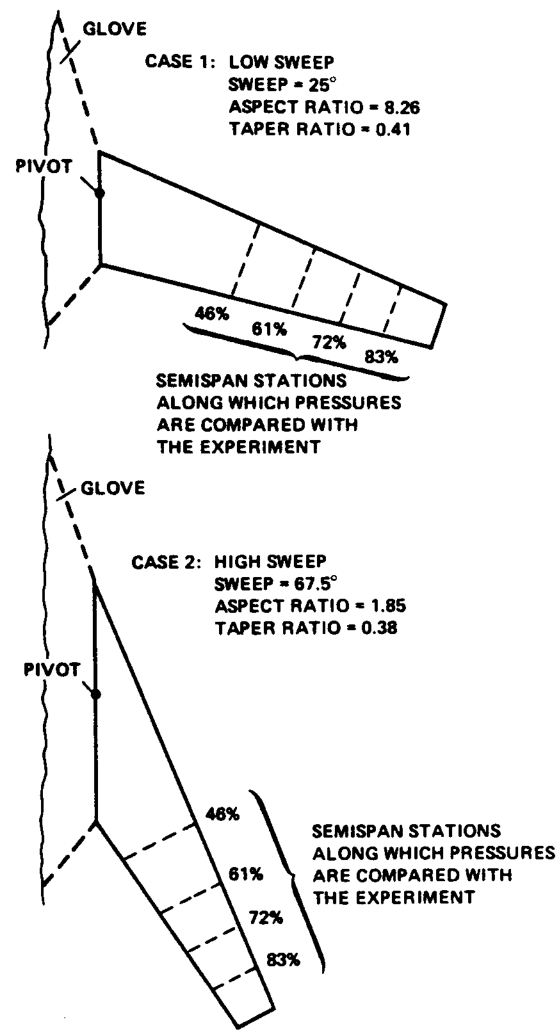

Fig. 2 Wing planforms for analysis.

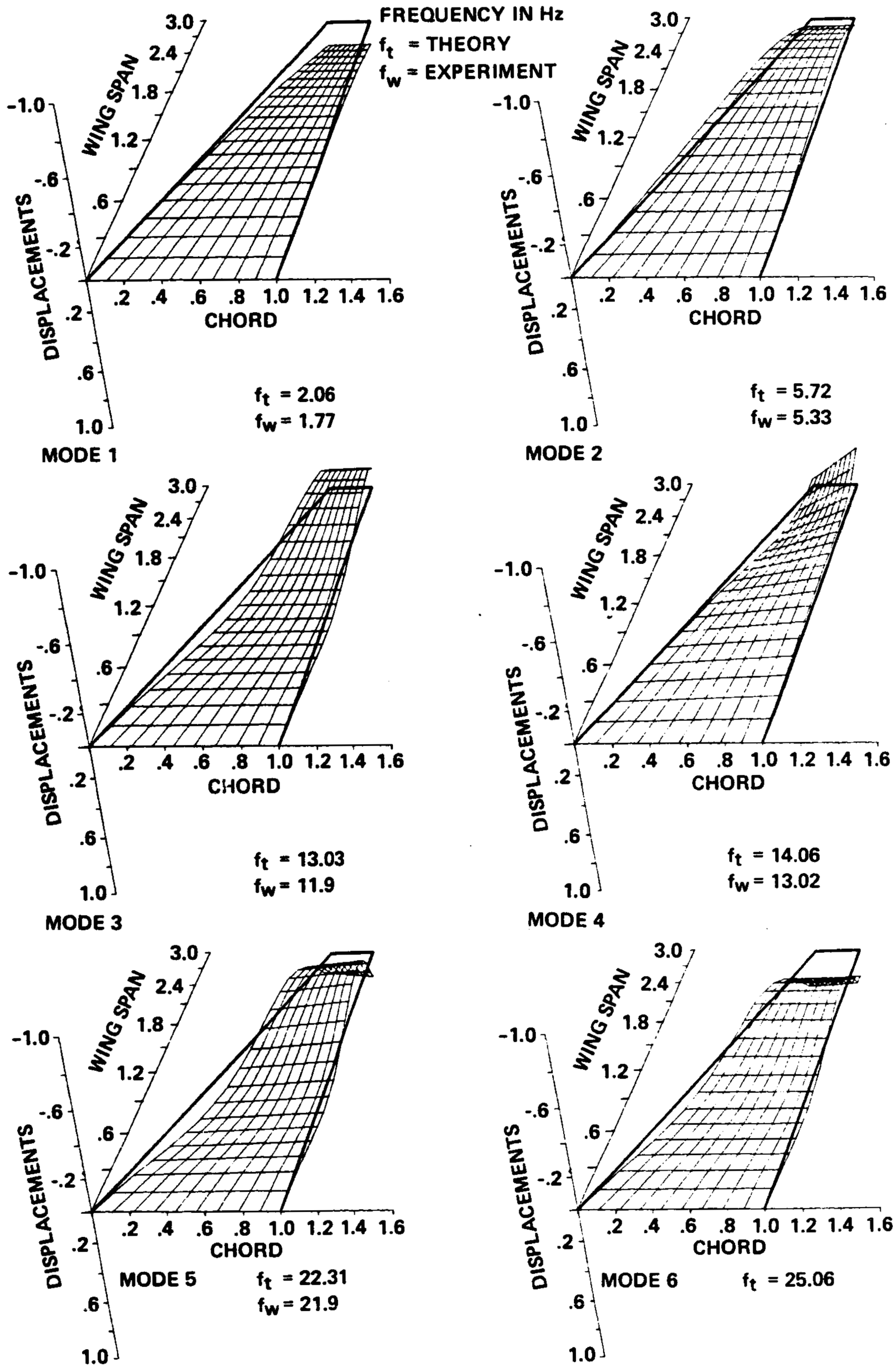

Fig. 3 Six natural vibrational modes.

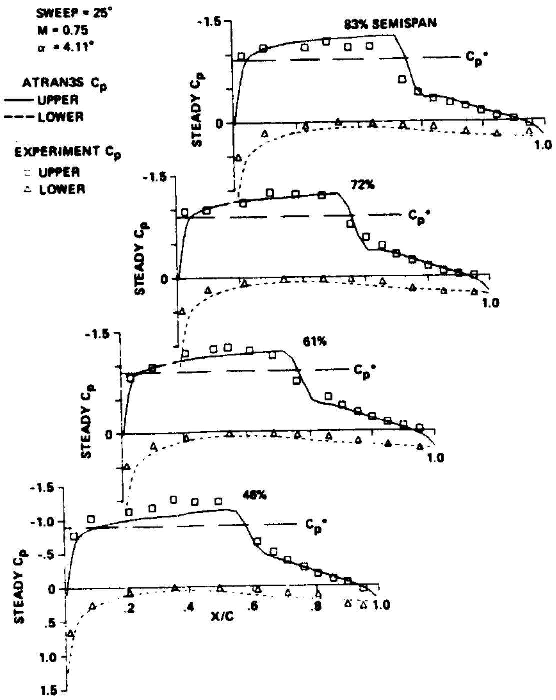

Fig. 4 Steady pressure distributions for the 25 deg sweep case at M = 0.75 and alpha = 4.11 deg.

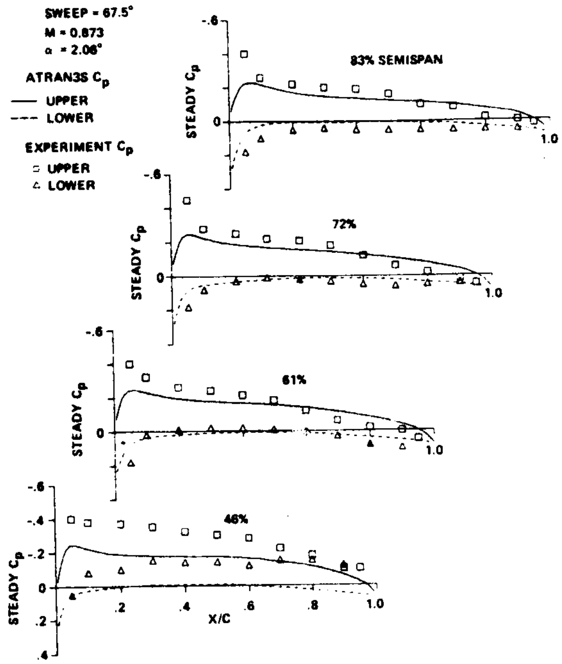

Fig. 5 Steady pressure distributions for the 67.5 deg sweep case at M = 0.873 and alpha = 2.06 deg.

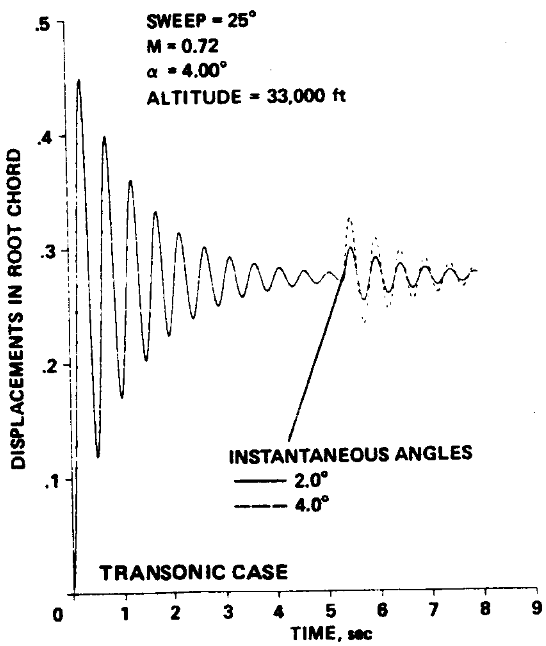

Fig. 6 Dynamic aeroelastic response of the first normal mode for the 25 deg sweep case at M = 0.72.

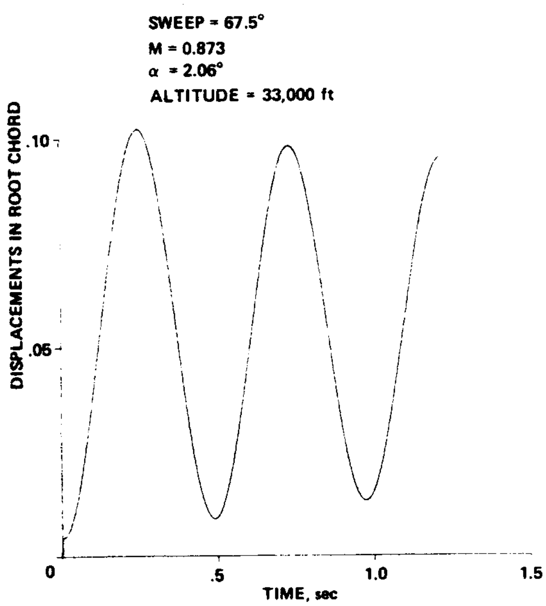

Fig. 7 Dynamic aeroelastic response of the first normal mode for the 67.5 deg sweep case at M = 0.873.

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16. Abstract

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