Transonic Flutter Analysis Using Time-Linearization Aerodynamics

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Introduction

OVER the past decade there has been considerable progress in the development of numerical simulation techniques for unsteady transonic flow calculations. This activity was motivated by the need to supplement the expensive and time-consuming wind-tunnel investigations and flight tests with inexpensive, fast, and efficient computer simulation programs to accurately predict flutter boundaries and many other important aeroelastic phenomena in the transonic regime.

Although the basic fluid motion in unsteady aerodynamics is governed by the Navier-Stokes (NS) equations, numerical simulations of the complete NS equations for general three-dimensional flow problems are not yet sufficiently developed for flutter applications. Computational methods in three-dimensional unsteady transonic flows concentrate mainly on the transonic small disturbance (TSD) equation or full potential (FP) equation. The major advantage of the simpler model using TSD or FP approach over those based on Euler and NS formulation is the large reduction in computational time and memory requirements.

In Ref. 1, the TSD code UST3D was described. This code utilizes the time-linearization approach for solving the transonic small disturbance equation. It was demonstrated that the technique could be used with confidence for computations of three-dimensional unsteady transonic flows over an isolated thin wing. An improved version of the UST3D program was given in Ref. 2 and results from a validation study were presented. This transonic aerodynamics code was incorporated into the Institute for Aerospace Research (IAR) Flutter Analysis Program. This Note presents some results from an aerodynamic and flutter analysis of the AGARD 445.6 wing[3] which was recommended by AGARD as a standard configuration for code validation.

Computational Results

The formulation of the TSD equation, grid system, and method of solution in UST3D were described in Ref. 2. The code utilizes a time-linearization approach to solve the three-dimensional transonic small-disturbance equation which is solved by the semi-implicit ADI algorithm.

Unsteady pressure distributions for the F5 wing have been documented in numerous references. Figure 1 illustrates the real and imaginary pressure distributions with distance along the chordwise direction at several span locations, for the F5 wing undergoing pitching motion about midchord. The freestream Mach number is 0.95, frequency of oscillation is 40 Hz, and the number of time-steps per cycle is 250. These results are compared with NLR experimental data[4] and good agreement was obtained.

Comparisons between results from UST3D and other numerical models were carried out for the LANN wing and the ONERA M6 wing and these results are given in Ref. 2. Again, good agreement was obtained.

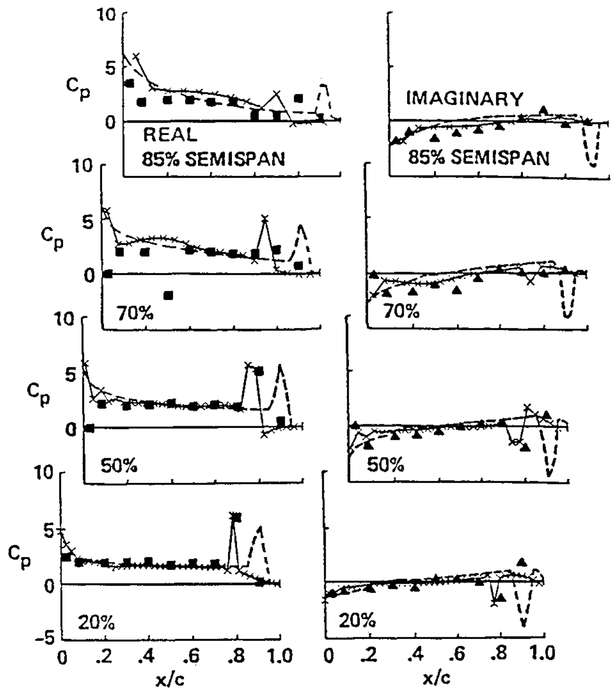

Fig. 1 Comparison of unsteady pressure distributions between UST3D (xxxx), XTRANS3S (----) and NLR experiment (■, ▲) for an F5 Wing at M_∞ = 0.95, α = 0 deg and k = 0.528.

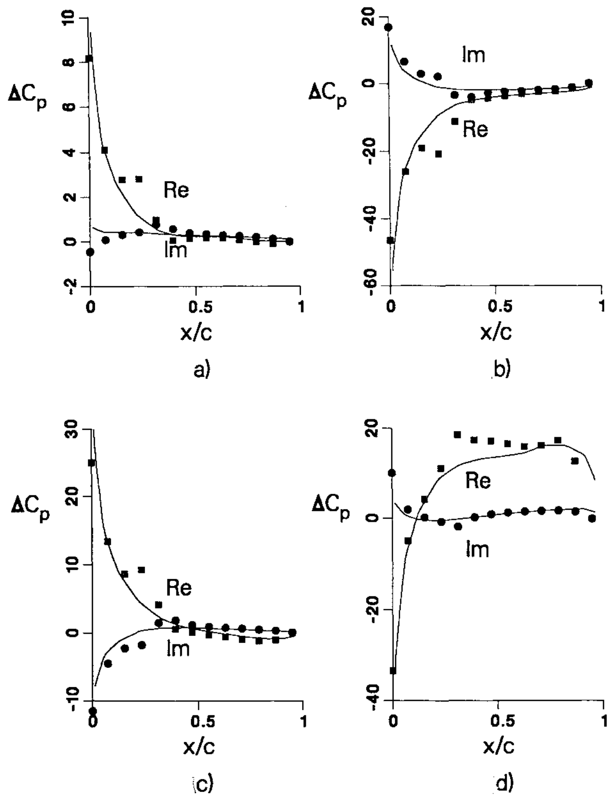

Fig. 2 ΔC_p vs x/c for the AGARD 445.6 wing at M_∞ = 0.95, k = 0.1 for a) mode 1; b) mode 2; c) mode 3; and d) mode 4 at spanwise location y/s = 0.85 using UST3D (●, ■) and doublet latice (----).

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Applications to Flutter Analysis

The menu-driven IAR flutter analysis program was used to carry out the flutter calculations. This program has the capability to analyze subsonic, transonic, and supersonic flowfields. The aerodynamic loads and moments, obtained from the aerodynamic codes N5KA,[5] UST3D, and ZONA51,[6] are used to determine the flutter conditions based on the p, p-k, and V-g methods. The flutter analysis program incorporates an accurate mode tracking algorithm to enable the user to identify the modes involved in the flutter mechanism. The AGARD standard configuration for aeroelastic analysis was used as a test case in this note. Experimental flutter boundaries and structural properties of these wings are well-documented. Comparisons were also made with results from CAP-TSD[7] and subsonic doublet lattice solutions.

Figure 2 shows the pressure distributions with chord for the AGARD 445.6 wing at a freestream Mach number of 0.95 and reduced frequency $k = 0.1$ for the first four modes at the 85% spanwise location. For this supercritical flowfield the agreement between the doublet lattice and UST3D is not good in the vicinity of the shock wave, as expected. Figure 3 shows the lift and moment coefficient distributions with span for the first two modes which are the dominant modes in the flutter mechanism. The difference in results from the doublet lattice computations and those from UST3D arises from the supercritical nature of the flowfield.

The five natural vibration modes of the AGARD wing designated as WEAK3[3] are: first bending (9.60 Hz), first torsion (38.10 Hz), second bending (50.70 Hz), and second torsion (98.50 Hz), and a mode at 118.11 Hz corresponding probably to the third torsion mode.

Flutter analysis using the p method at $k = 0.1$ were carried out on this wing. Plots of flutter speed index $U/b_s\omega_\alpha\sqrt{\mu}$ and nondimensional flutter frequency ω/ω_α as functions of freestream Mach number are shown in Figure 4. Here b_s is the root semichord, ω_α is the frequency of the first torsion mode, and μ is the ratio of wing mass to mass of air. These figures show the characteristic transonic dip near $M = 1$. Also included in these figures are the results from the CAP-TSD code. Flutter calculations at supersonic Mach numbers were carried out using the aerodynamics computed by the supersonic harmonic gradient code (ZONA51) which is included in the IAR flutter analysis program. The agreement between the results using the UST3D code, doublet lattice method, and CAP-TSD is fairly good.

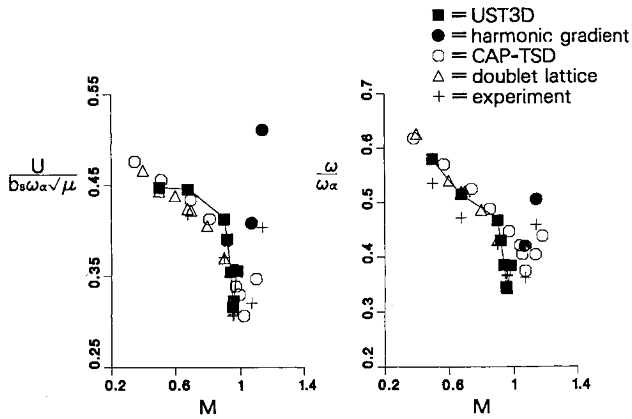

Fig. 4 Plots of the a) flutter speed index $U/b_s\omega_\alpha\sqrt{\mu}$; and b) frequency ratio ω/ω_α with Mach number for the AGARD 445.6 WEAK3 wing in air.

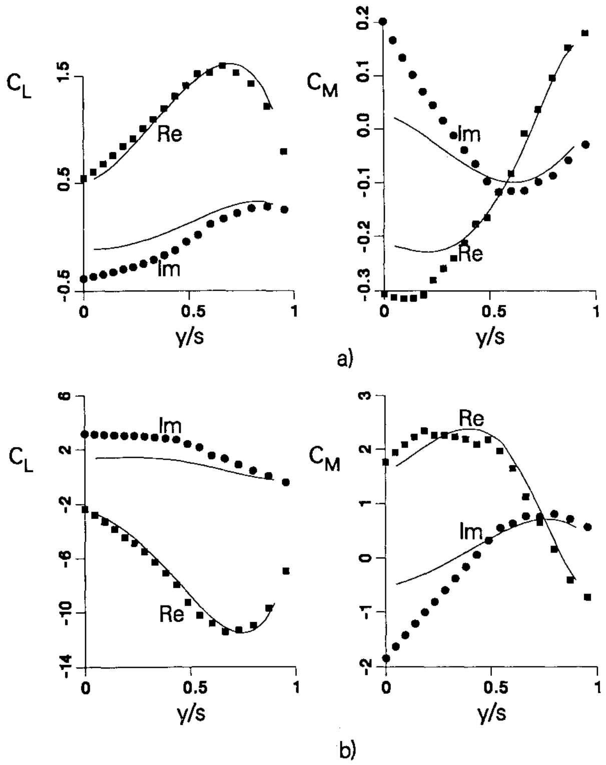

Fig. 3 C_L and C_M vs y/s for the AGARD 445.6 wing at $M_\infty = 0.95$, $k = 0.1$ for a) mode 1; and b) mode 2 using UST3D (●, ■) and doublet lattice (– – – –).

Conclusions

Validation of a three-dimensional, time-linearized, small-disturbance, unsteady, transonic flow code UST3D was carried out for the F5 and ONERA M6 wings. Flutter analysis carried out with the IAR flutter analysis program using UST3D for the AGARD 445.6 wing shows fairly good agreement with experimental data. The time linearization method is more efficient than the time integration approach. For thin wings, such as the example considered, time linearization of the TSD equation was shown to be suitable for flutter analysis.

Acknowledgments

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