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INITIAL APPLICATION OF CAP-TSD TO WING FLUTTER

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INTRODUCTION

The purpose of this presentation is to present a brief status report on the initial application of the CAP-TSD computer program for wing flutter analysis. The CAP-TSD program (for Computational Aeroelasticity Program - Transonic Small Disturbance) is based on an approximate factorization (AF) algorithm that is stable and efficient on supercomputers with vector arithmetic. The program has been described by Batina* in an earlier presentation. CAP-TSD has been used to calculate steady and unsteady pressures on wings and configurations at subsonic, transonic, and supersonic Mach numbers. Comparisons of these results with other methods and with experimental data have been favorable. However, the CAP-TSD code has been developed primarily for aeroelastic analysis. The present paper reports on the initial efforts for validation of the aeroelastic analysis capability. The initial applications include two series of symmetric, planar wing planforms. Well-defined modal properties are available for these wings; this is vital for accurate flutter calculations. In addition, transonic flutter boundaries are available for evaluation of the transonic capabilities of CAP-TSD. Additional comparisons are also being made with linear theory and with the 2-D code XTRAN2L. (Fig. 1.)

*Batina et al., NASA CP- 3022, 1989, Paper No. 4, pp. 63-96.

- COMPUTATIONAL AEROELASTICITY PROGRAM - TRANSONIC SMALL DISTURBANCE
- PREVIOUS EMPHASIS HAS BEEN ON PRESSURES
  - GENERALLY GOOD RESULTS
  - HAVE CONSIDERED STEADY AND UNSTEADY CASES
  - CONFIGURATIONS
- PROGRESS REPORT ON AEROELASTIC VALIDATION
- CONSIDERING SYMMETRIC PLANAR WINGS
  - WELL-DEFINED MODAL PROPERTIES
  - TRANSONIC FLUTTER BOUNDARIES
- COMPARISONS WITH 2-D CODE XTRAN2L ARE ALSO UNDER WAY (NOT PRESENTED)

Figure 1

WINGS

Two series of wing planforms are being used for the initial flutter calculations with CAP-TSD. The first set of wings is a series of swept and tapered wings that are being considered as an AGARD standard configuration for aeroelastic analysis. These wings are swept back 45° at the quarter chord. They are described further by Dr. E. C. Yates' presentation* of this workshop. The wings and test data are presented in NASA TN D-1616, dated March 1963.

The other wing planform is a clipped delta wing that was used in some early flutter suppression studies. It is described in NASA TN D-7544, June 1974, and NASA TR R-450, December 1975. The leading edge sweep for this wing is 50.5° and it is highly tapered. (Fig. 2.)

* Yates, E. C., NASA CP-3022, 1989, Paper No. 12, pp. 243-260.

- **45° SWEPT WINGS - NASA TN D-1616 AND YATES' PRESENTATION**

- **CLIPPED DELTA WING - NASA TN D-7544 AND TR R-450**

Figure 2

PLANVIEW OF 45° SWEPT WING

The planview of the 45° swept wing is shown in figure 3. The wings were semispan, wind-tunnel-wall-mounted models that had a quarter chord sweep of 45° (leading-edge sweep of 46.3°), a panel aspect ratio of 1.65, and a taper ratio of 0.66. The wings had an NACA 65A004 airfoil section and were constructed of laminated mahogany. In order to obtain flutter for a wide range of Mach number and density conditions, some of the wings had holes drilled through the wing to reduce the stiffness. To maintain the airfoil shape, the holes were filled with a rigid foam plastic as can be seen in figure 3.

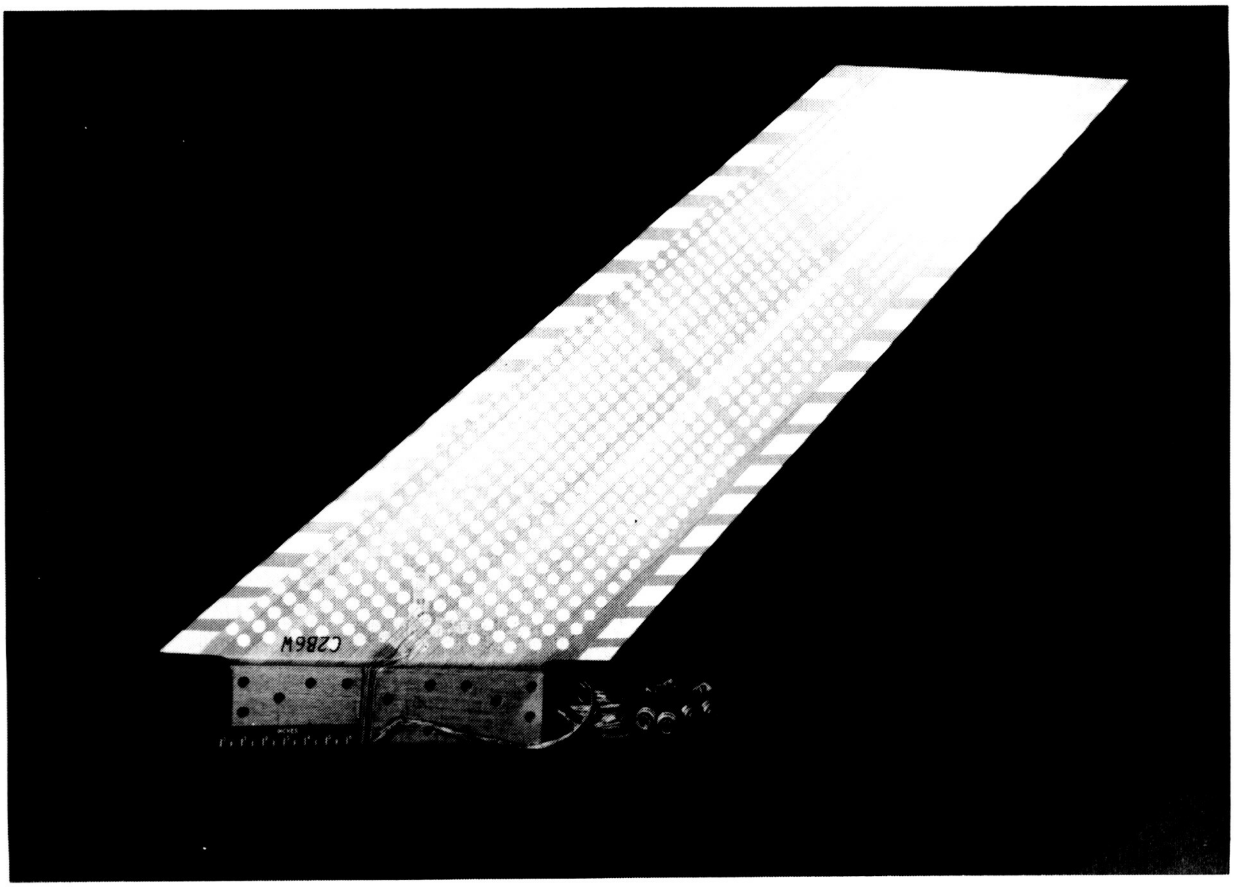

Figure 3

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45° SWEPT WING IN THE NASA TRANSONIC DYNAMICS TUNNEL

One of the 45° wings is shown mounted in the Transonic Dynamics Tunnel (TDT) at NASA Langley Research Center in figure 4. The models were tested in air and Freon+ test media. The semispan of most of these models was 2.50 feet, which is small compared to the 16-foot test section of the TDT. The models were tested at zero angle of attack.

+Freon: Registered trademark of E. I. duPont de Nemours and Co., Inc.

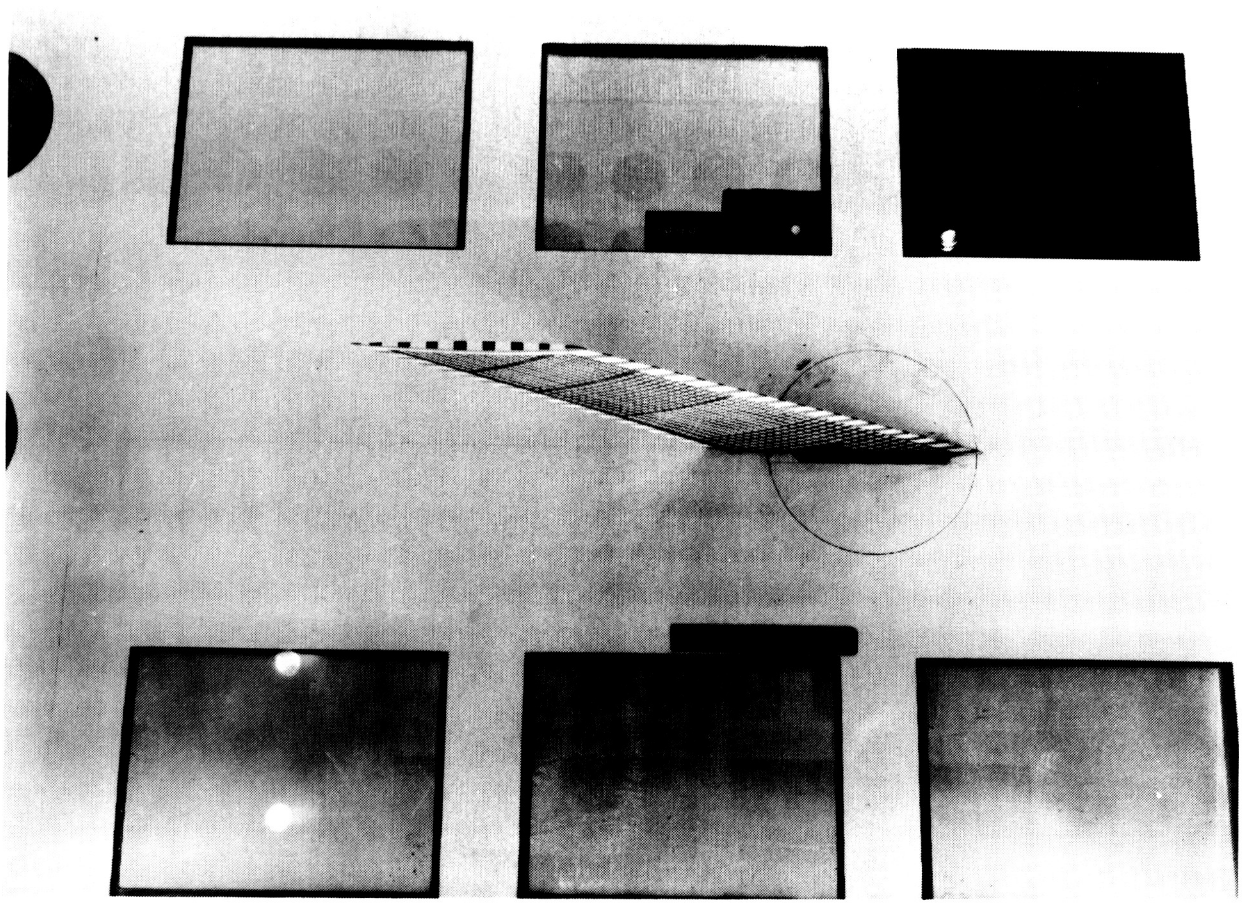
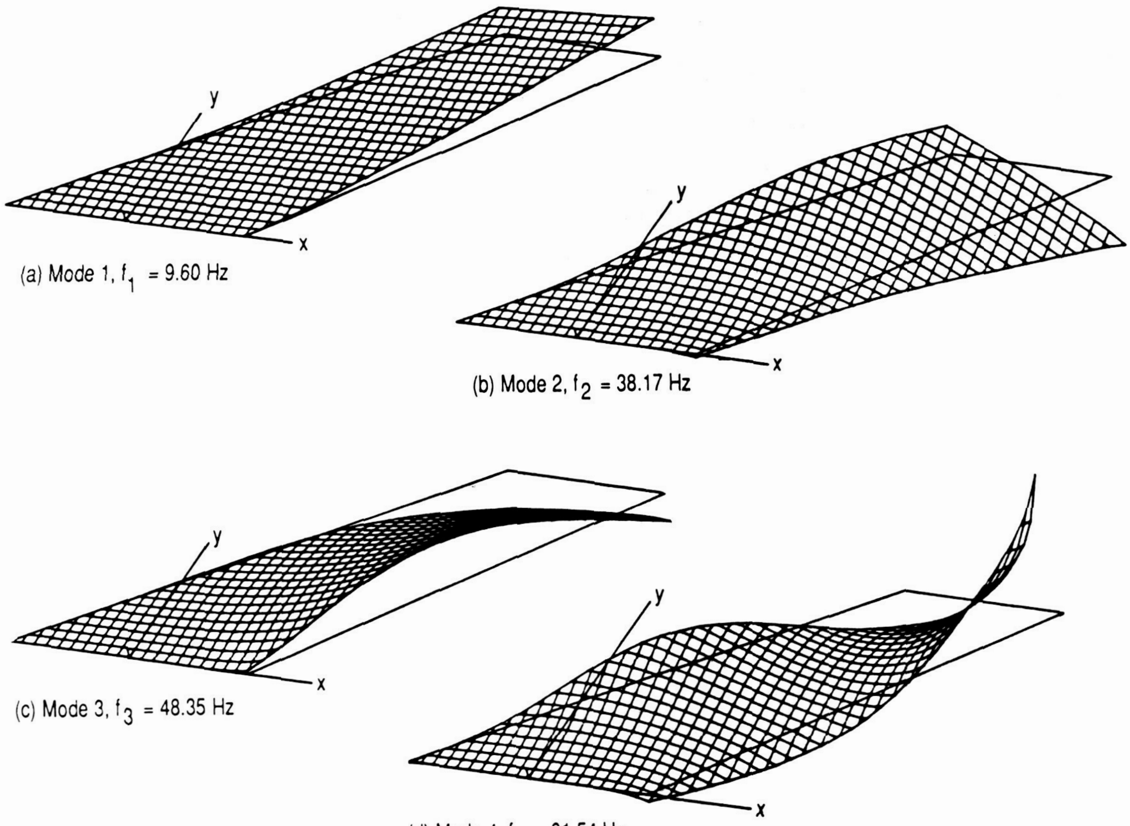


Figure 4

OBLIQUE PROJECTIONS OF NATURAL VIBRATION MODES
45° WING WEAK3

The vibration mode shapes for the 45° wings were not measured, but node lines, frequencies, and stiffnesses are available from the report (NASA TN D-1616, 1963). Mode shapes were calculated with a finite-element analysis and the wing properties were adjusted to match the measured nodes lines and frequencies for the lower vibration modes. Oblique projections for the first four modes for wing WEAK3 are shown in figure 5. The modes numbered 1 through 4 represent first bending, first torsion, second bending, and second torsion, respectively. The modal frequencies range from 9.60 Hz for the first bending mode to 91.54 Hz for the second torsion mode. Similar mode shapes have been calculated for the wing SOLID2.



(a) Mode 1, f_1 = 9.60 Hz

(b) Mode 2, f_2 = 38.17 Hz

(c) Mode 3, f_3 = 48.35 Hz

(d) Mode 4, f_4 = 91.54 Hz

Figure 5

AEROELASTIC TRANSIENT AND LEAST-SQUARES CURVE FIT

For aeroelastic analysis, the steady-state flow field is first calculated to account for wing thickness, camber, and mean angle of attack. The wing is then disturbed with an initial condition and free decay transients are calculated. The resulting transients are then analyzed to determine growth or decay for aeroelastic stability. Dynamic pressure is changed, and the transients computed again to determine the variation of stability with dynamic pressure.

An example transient for the 45° wing calculated by CAP-TSD is shown in figure 6. All four modes used in the analysis were excited by specifying an initial condition for each modal velocity which produces a complicated decay record. This record is analyzed using a least-squares curve-fit of the response data with complex exponential functions. The program utilized is a derivative of the one described by Bennett and Desmarais in NASA SP-415, May 1975.

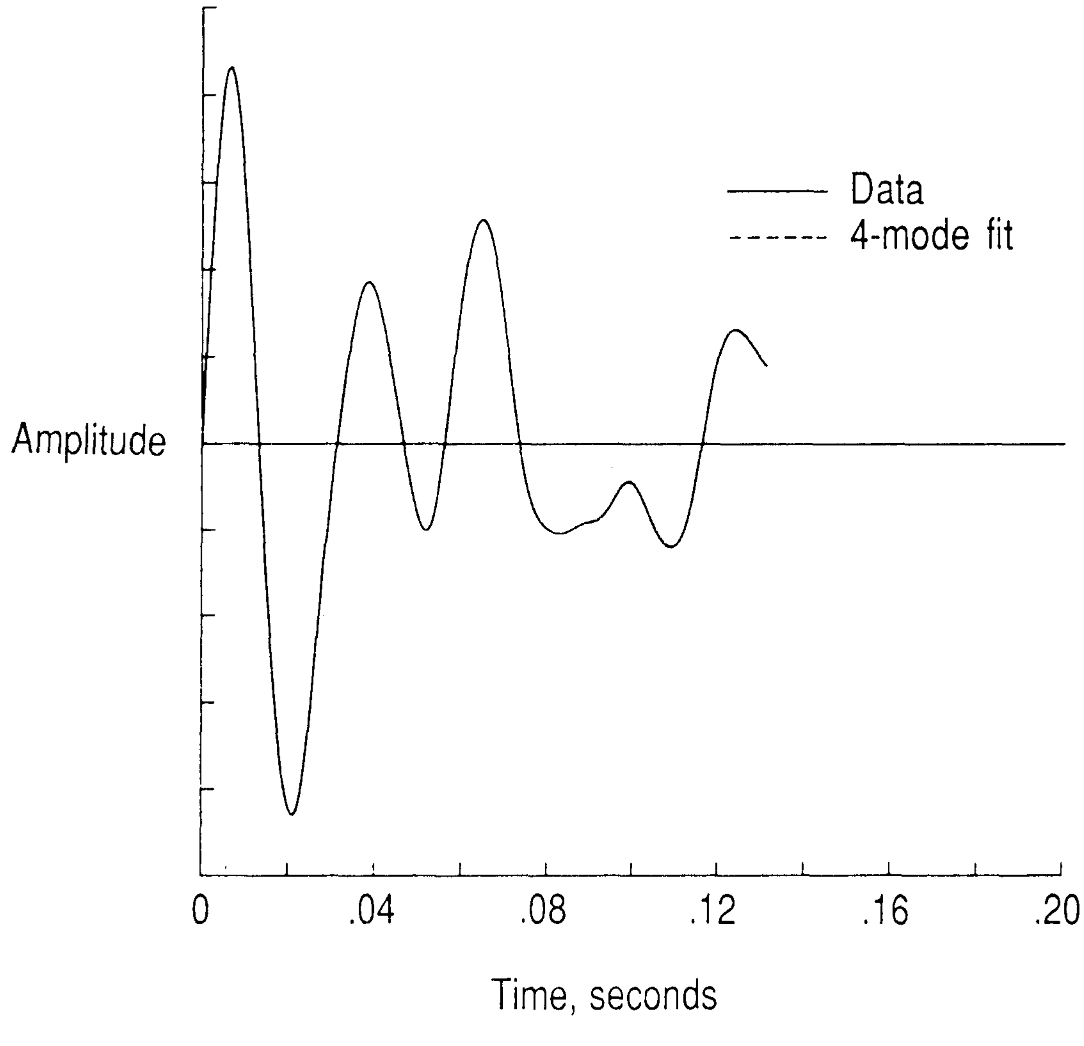


Figure 6

COMPONENT MODES FROM CURVE FIT

The components of the transient presented in the previous figure are shown in figure 7 to the same scale as that used in figure 6. The free decay properties of each mode for this condition are readily apparent after the least-squares fit, whereas the complexity of the complete decay record is such that the stability is not recognizable in the previous figure. The instability of the first mode might have been missed unless many more time steps were run. A post-processing program of this type is essential to efficient use of these types of programs where large resources are used for the CFD flow field calculations.

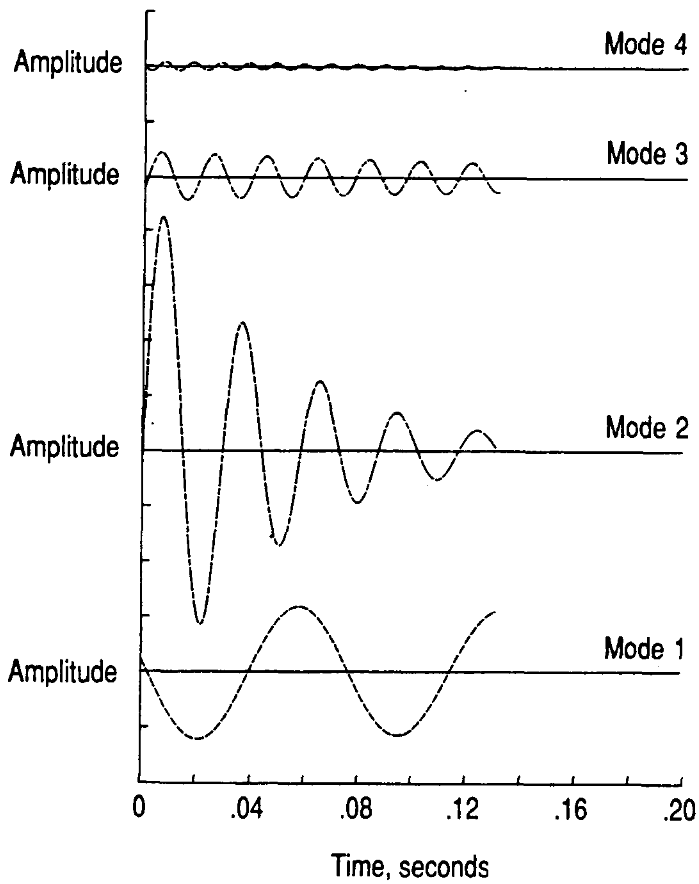


Figure 7

EXAMPLE OF ROOT LOCUS FROM CAP-TSD RESULTS
45° WING, M = 0.499

The potential of this methodology to produce complete root loci for the aeroelastic system is illustrated in figure 8. The variation of frequency and damping for all four modes used in the analysis is deduced for various dynamic pressures as shown in the figure (note change in frequency scale for the higher modes). It is apparent that the first mode increases rapidly in frequency and flutters, whereas the damping in the other three modes increases rapidly with dynamic pressure.

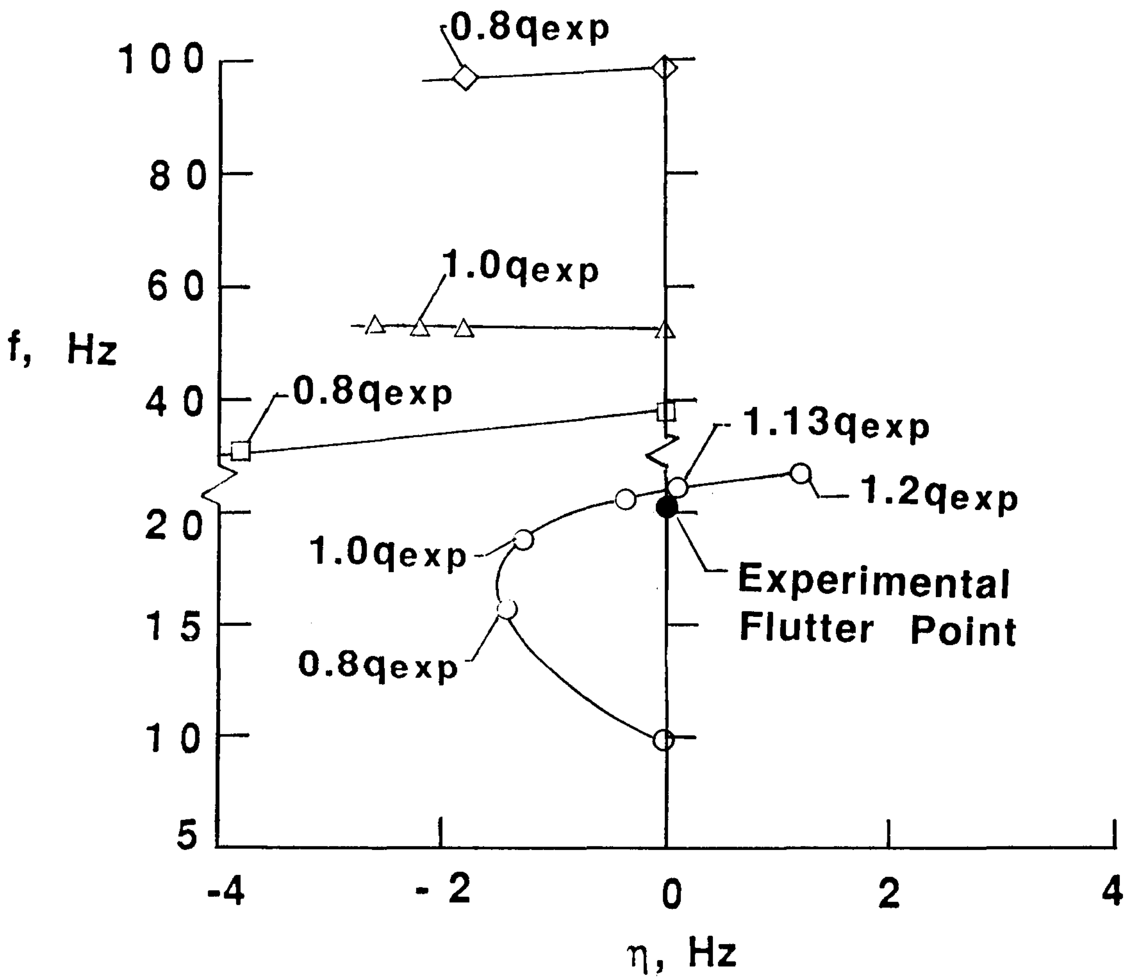


Figure 8

PRELIMINARY FLUTTER CALCULATIONS FOR 45° SWEPT WINGS

Preliminary flutter calculations for the 45° wing WEAK3 in air are shown in figure 9. The circles indicate the measured flutter points which are faired by the solid line. The bottom of the dip near Mach 1.0 is estimated from the no flutter data obtained while going to the point at M = 1.07. The squares indicate the results from subsonic kernel function linear theory (program FAST). There is very good agreement of the linear theory with the four data points shown, even for the point near M = 0.95. The two diamonds indicate two subsonic points calculated using CAP-TSD. The two points are in fair agreement with the data. Effort to extend these results to other Mach numbers and to obtain direct comparisons with linear theory is continuing. These initial results are encouraging however.

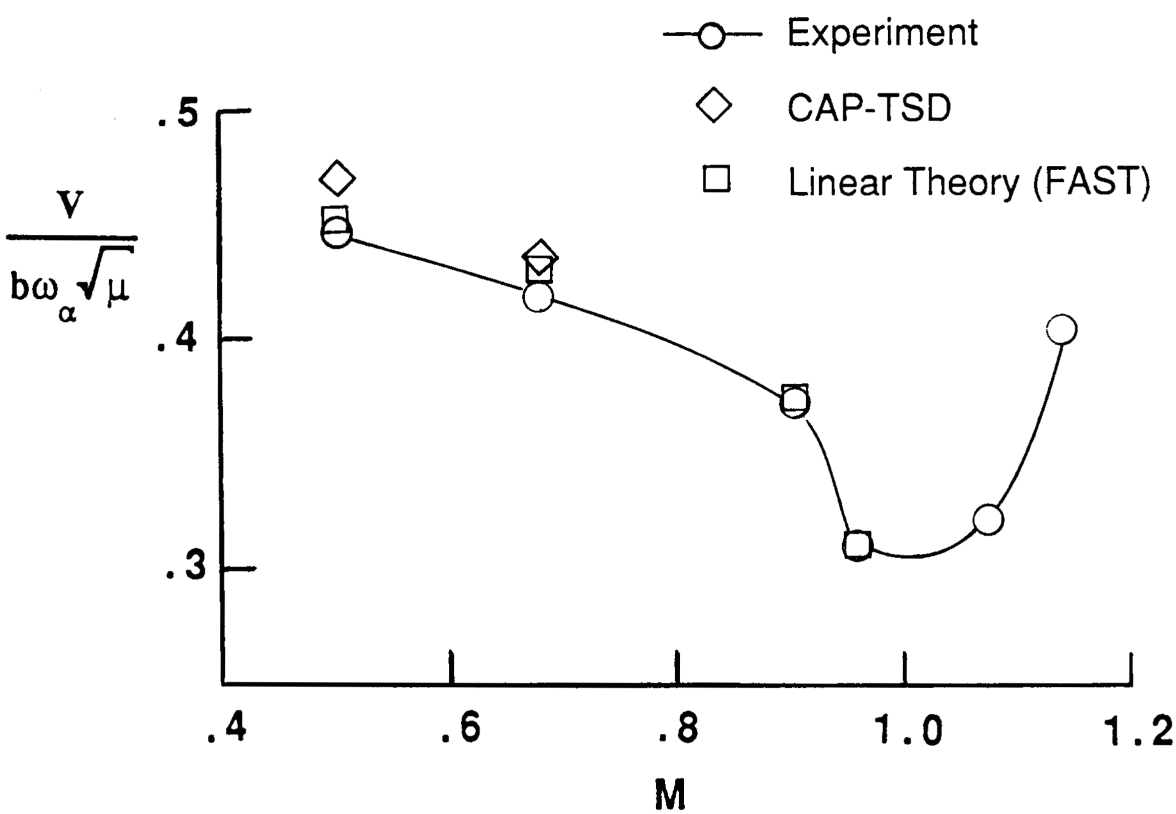


Figure 9

CLIPPED DELTA WING IN THE NASA LANGLEY TRANSONIC DYNAMICS TUNNEL

The second wing to be analyzed is a clipped delta wing model that was also tested in Freon in the Langley Transonic Dynamics Tunnel. A view of the model mounted in the TDT is shown in figure 10. The wing has a leading-edge sweep of 50.5°, a panel aspect ratio of 1.24, and a taper ratio of 0.142. The airfoil section is a circular arc with a maximum thickness of 0.03. The wing was constructed of a load-carrying plate structure with cutouts to simulate a beam structure and was covered with balsa wood which was contoured to the required airfoil shape. The model also had two slender underwing bodies to simulate engine nacelles. The total mass of these bodies was about the same as the total mass of the wing. A fuselage fairing was used to ensure that the wing root was outside the tunnel wall boundary layer. Nine natural vibration modes and their associated generalized masses were measured for this wing.

Figure 10

CLIPPED DELTA WING FLUTTER BOUNDARY
NASA TN D-7544

The experimental flutter boundary for the clipped delta wing is shown in figure 11. Calculations with CAP-TSD are under way, but results have not yet been obtained. The figure shows a composite boundary obtained by normalizing the boundaries for three wings of differing sizes in terms of the flutter speed index. The data for the wing of the previous figure are shown as the diamond symbols. The flutter boundary has a significant transonic dip with a minimum near M = 0.92, a rapid rise after the dip, and a supersonic level near that of subsonic speeds.

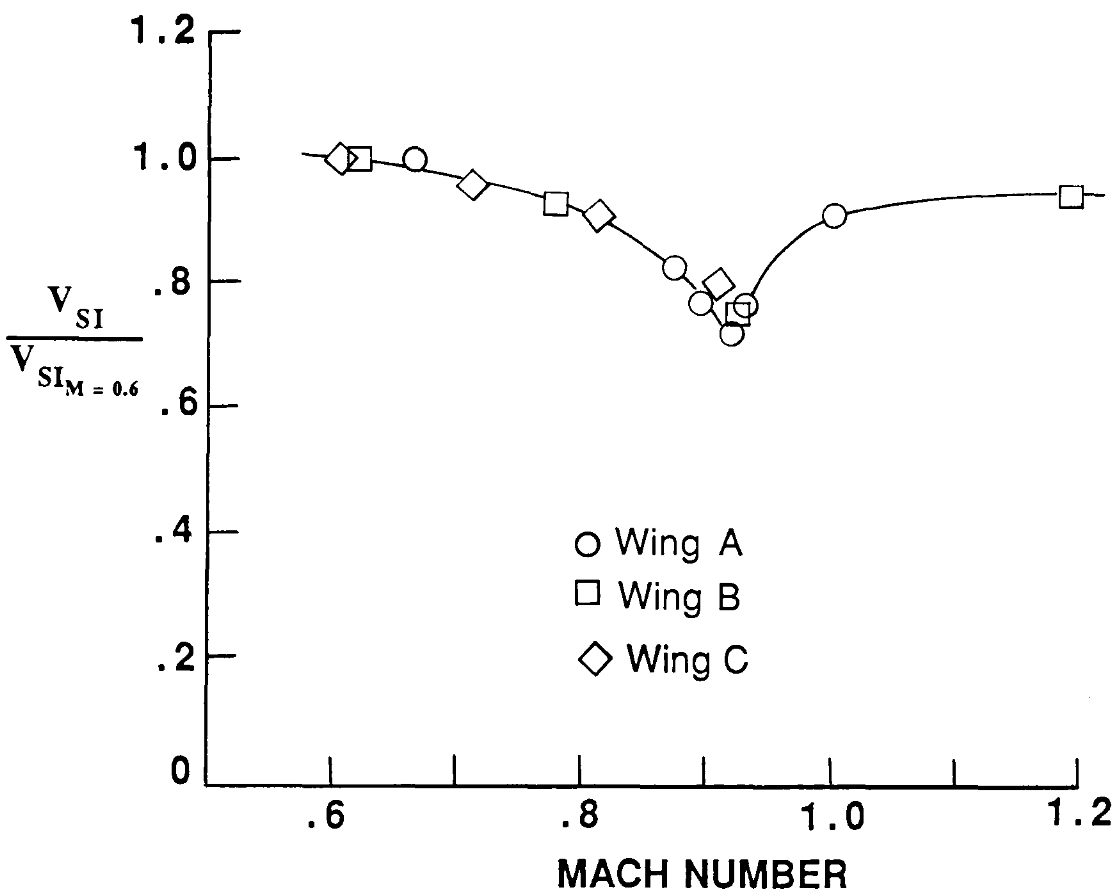


Figure 11

CONCLUDING REMARKS

In an effort to assess the accuracy of the CAP-TSD program for aeroelastic applications, flutter calculations are under way for several wings of two different planforms varying in sweep and taper and with thin airfoil sections. One planform is a series of 45° swept wings which have been proposed as an AGARD standard configuration for aeroelastic analysis. The other planform is a clipped delta wing that was used in some early active controls work. The physical properties and experimental flutter boundaries for these wings are well defined for validation purposes. Some initial results have been obtained and are encouraging. Further effort to extend and refine the results is under way. (Fig. 12.)

- **CAP-TSD AEROELASTIC VALIDATION UNDER WAY**
- **HAVE INITIAL RESULTS WHICH ARE BEING EVALUATED AND REFINED**

Figure 12