Transonic flutter prediction of delta wings using coupled CSD-CFD approach

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1. INTRODUCTION & OBJECTIVE

Aeroelastic flutter is a critical phenomenon in aircraft design, and its accurate prediction is essential for certification. While established techniques exist for flutter clearance in subsonic and supersonic regimes, their applicability to transonic flows is limited due to simplified assumptions in flow-field modelling. The transonic regime, characterized by shock waves and complex boundary layer interactions, demands more advanced computational approaches. Computational Fluid Dynamics (CFD), coupled with Computational Structural Dynamics (CSD), has emerged as a viable solution for transonic flutter prediction, capable of capturing key aerodynamic phenomena. The objective of the present work is to employ a Fluid-Structure Interaction (FSI) approach based on coupled CFD-CSD approach to study the transonic flutter characteristics of delta wing and clipped delta wing models [1].

2. METHODS OF ANALYSIS

The FSI approach adopted here is based on a staggered or explicit coupling approach where both CFD solver (CFD++) and CSD solver (CSM++) interact sequentially in time. For flutter prediction, CFD solves the unsteady form of the RANS equations in a coupled manner with the turbulence modelled using the 2-eqn SST model. For the finite element analysis, CSD solves the structural dynamic equations in modal coordinates and time integration is carried out using the Newmark/HHT time integration algorithm. The morphing of the CFD grid in FSI problems is modelled using a radial basis interpolation function.

3. NUMERICAL RESULTS

Figure 1(a) shows the geometric details of the clipped delta wing. The model has a 72° sweep with aspect ratio of 0.54. The wing cross-section is made of a 3.0-percent-thick modified biconvex airfoil. The leading edge and trailing edge of the model are rounded as indicated in figure providing smooth aerodynamic contour resulting in modified biconvex airfoil section.

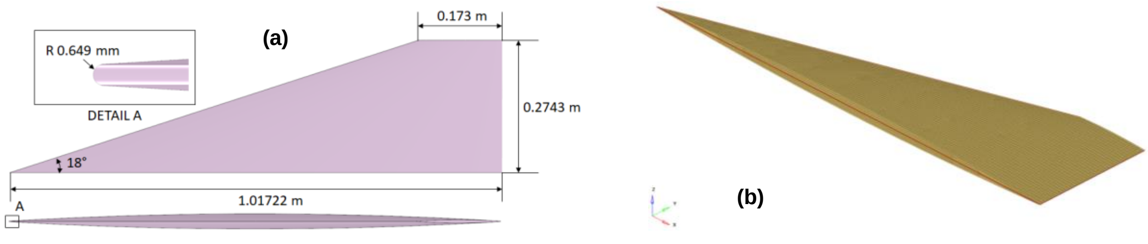

Figure 1: Geometry of clipped delta wing, and its finite element model

The finite element model of the clipped delta wing is shown in Fig. 1(b). It consists of 61594 nodes and 275128 solid elements. The model is constructed using two different materials [1]: 0.051inch thick aluminium alloy plate (2024 T3) at the middle covered by balsa wood. The aluminium plate is rounded along its edges and the balsa wood is faired into these rounded edges to provide a smooth aerodynamic contour. The total weight of the model is 1.04 kg. Free vibration analysis is then carried out and the obtained natural frequencies are compared with the experimental data [1] (indicated in bracket) as follows: Mode 1: 22.1 Hz (20.8 Hz), Mode 2: 46.548 Hz (45.2 Hz), Mode 3: 79.134 Hz (84.4 Hz), and

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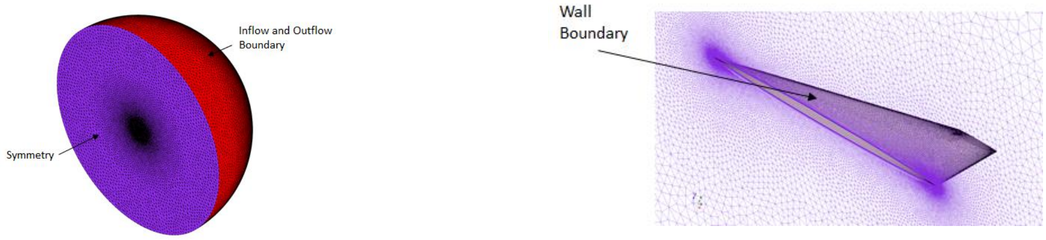
Mode 4: 106.287 Hz (104 Hz). All the modal frequencies match well with experiment with a maximum difference of ~6% observed for Mode1, and Mode3.

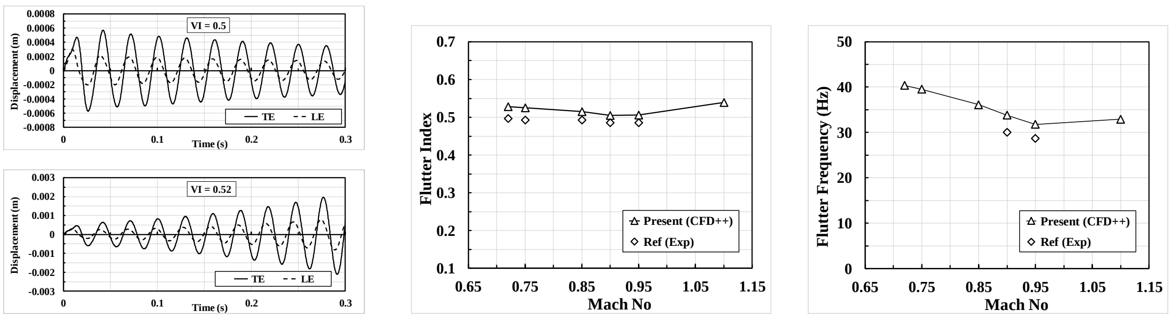
The CFD domain considered is shown in Fig. 2(a) where hemispherical far-field is chosen with a radius of 50 m. The total cell count is 3845247 with 1st cell height of 1.2e-5 m and maximum skewness angle of 84.2°. The boundary conditions applied in CFD analysis are also indicated in the figure.



(a) Farfield domain (b) Sectional view of the model

Figure 2: CFD model of clipped delta wing

For flutter analysis at a given Mach number and mass ratio, steady flow solution at zero angle of attack is used as an initial condition for FSI simulation. Here, the structure is excited with a step input of infinitesimal pressure for a duration of 3 timesteps. Then, the excitation is removed and the system is allowed to respond to the surrounding flow field. The unsteady RANS equations are solved using CFD solver and the structural dynamics in modal coordinates using CSD solver, with five modes retained. A time step of 2.5e-4 s, 10 inner CFD iterations, and a CFL of 50 are employed. Simulations are run for 0.5s, monitoring wing-tip displacements at various velocity indices (VI). The flutter index (FI) is identified at velocity where oscillations reach a small constant amplitude. Figure 3(a) shows the time histories of wing tip displacements for various VI at M=0.9. Figure 3(b) shows the comparison of flutter index and flutter frequency between the present computation and experiment [1] at various Mach numbers. The present results show a good agreement with the experimental data. It is also observed that the simulated flutter index and frequency are slightly over-predicted for all Mach numbers considered.



(a) (b)

Figure 3: (a) Time history of wing tip displacements at M = 0.9 and (b) Comparison of flutter index and flutter frequency of clipped delta wing

4. CONCLUSIONS

In this study, a FSI framework based on coupled CSD - CFD is employed to predict the transonic flutter boundary of a clipped delta wing. The applicability of the present approach is investigated by comparing the present results with the available WT data. The present results show a good agreement with the experimental data with small discrepancy potentially arise from the structural model.

5. REFERENCES

[1] R. V Doggett Jr, D. L. Soistmann, C. V Spain, E. C. Parker, and W. A. Silva, “Experimental transonic flutter characteristics of two 72 deg-sweep delta-wing models,” NASA TM 101659, 1989.