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Analysis of Dynamic Instability of a Delta Wing at Transonic Flow

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***Abstract*-- Aeroelastic problem arises in an aircraft structure due to continuous interaction between aerodynamic forces, inertial forces and elastic forces. Wing flutter is one of the major dynamic aero elastic problem which leads to catastrophic failure of structure. The aerodynamic forces acting on the wing vary in accordance with altitude i.e., density and flight speed which contributes to wing flutter. The objective of this article is to predict the dynamic instability of the proposed delta wing model in transonic flow (0.8 < M < 1.2). Delta wing model is drafted using modeling software and both flow analysis and structural analysis is carried out using CFD and FEA approach. The pressure value is incorporated to attain structural deformation due to fluid structure interaction. The resulting structural deformation and stress is studied completely and validated with the help of numerical analysis.**

Keywords-- Deformation, Delta wing, Stress, FSI

I. INTRODUCTION

Aeroelastic problems are generally analysed using the combination of both computational fluid dynamic and structural dynamic tools the coupling of these two opens up lot of possibilities and has been of great interest lately. Aeroelastic problems are classified mainly into static and dynamic problems. Dynamic problems are of primary concern and interest of the researchers. Dynamic aeroelasticity is concerned with two distinct fundamental physical phenomena such as flutter or dynamic instability and response to various dynamic loadings.

Aircraft components especially wings are subjected to flutter which is an oscillatory aerodynamic condition with high frequency and large amplitude emerging due to the fluid structure interaction (*FSI*)[1]. The aircraft components life considerably reduces due to unwanted vibrations that take place due to air flow distributions over it.[1] In this FSI methodology, the structural deformation and stress distribution are found out using FEA tools which will be carried out using the results obtained from the CFD analysis. When the natural frequency of the object is equal to frequency of source flutter occurs[1]. FSI leads to external aerodynamic loadings such as atmospheric turbulence or/and gusts on the aircraft wings which causes flutter.

The major concern while dealing with the coupled calculations between the computational fluid dynamics and the structural dynamics is the time scale difference linking the two modules[7]. Aerodynamic loads in the past were computed using panel methods, transonic small perturbation (*TSP*) equations or full potential equations. TSP are only suitable for the flows at small angle of attacks only. The full potential equations tends to neglect both swirl and viscosity[7]. Euler and Navier-stokes equations provide much accurate result. Predicting the aero elastic effects using Navier strokes equation for fully coupled case is challenging due to the complex coupled physical phenomena involved.

There are two methods for calculating aero elastic effects due to FSI such as the fully coupled or 2-Way FSI and the partially coupled or 1-way FSI analysis.[7] In 2-way FSI the model responds by deforming to the loads applied on it from the flow analysis process at the same time. Logically the fully coupled model is rigorous in the physical sense, because the structural displacement responds instantly to the forces imposed by the fluid[8][9]. In this the process is complicated as it requires the combination of equations based on fluid and structural analysis to a single set. This implies solving the complete system in one step; hence there is no information transfer in fully coupled method[7].

The fully coupled algorithm usually requires an almost complete rewrite of the CFD and CSD codes into one single coupled code[10]. In partly coupled fluid structure interaction, the structural deforms only after flow field analysis results are completely attained. This methodology widely adopted because it solves CFD and FEM codes separately and links the results so there is no need of generating separate codes for this partially coupled FSI process.

The main approach of this FSI method is to get the realistic pressure distribution over the aircraft wing and to provide proper results for stress, deformation due to fluttering of the wing. Though several achievements have been made in the study of FSI problems, still it is challenging to solve coupled flow computations, such as the treatment of structural nonlinearity, time efficiency of the algorithm and the grid quality during deformation[11]. Numerical methods are the appropriate choice to investigate the unsteady flow problem accurately and efficiently[12]. However preparing a proper mesh for the model is challenging and time consuming in case of fully coupled analysis hence it is preferable to use partially coupled FSI method for analyzing aero elastic problems although fully coupled results provide much more accurate results.

II. METHODOLOGY

The aeroelastic effect occurring on a delta wing due to flow separation is considered for the present analysis. The model of the wing is selected after literature survey.

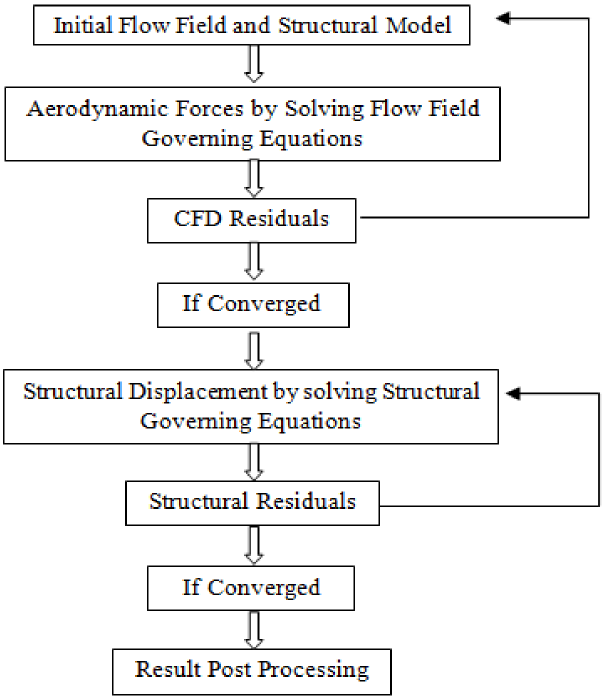

Fig. 1. Algorithm For Partially Coupled For Fluid Structural Interaction Analysis[7]

A. Model Description

The proposed delta wing model is build using NACA 64A204 airfoil. The model is drafted using modeling software with a span of 4.762m.

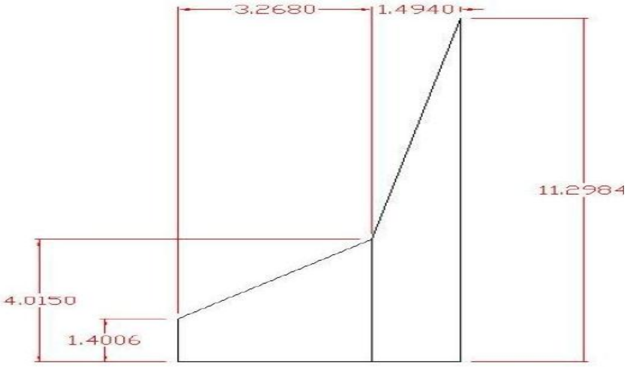

Fig. 2. Geometry of Delta wing

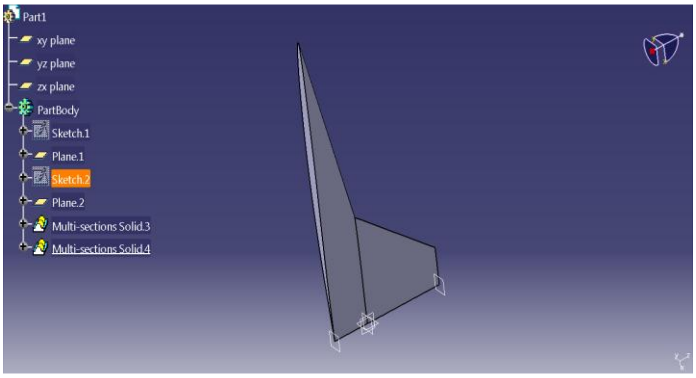

Fig. 3. Drafted Delta wing model

B. Grid Generation

The drafted wing model is imported into analysing software and meshing is created with the help of the software. For flow field analysis, C-domain is created as the control volume.

A fine tetrahedron grid is generated for both the control volume with wing structure and wing model as shown in figure 4 and figure 5. Tetrahedron grid is preferred for 3-D solid structures.

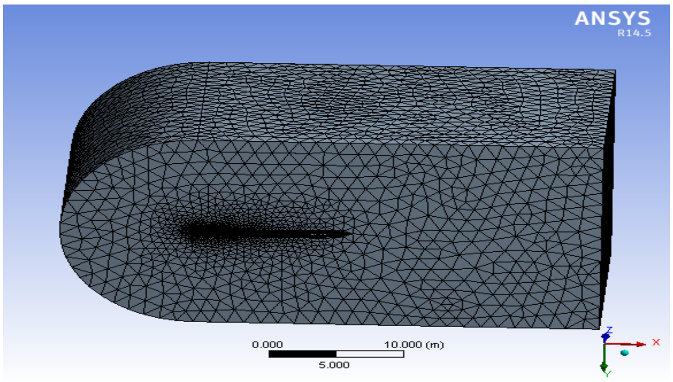

Fig. 4. Meshed Model Of C-Domain With Delta Wing Structure

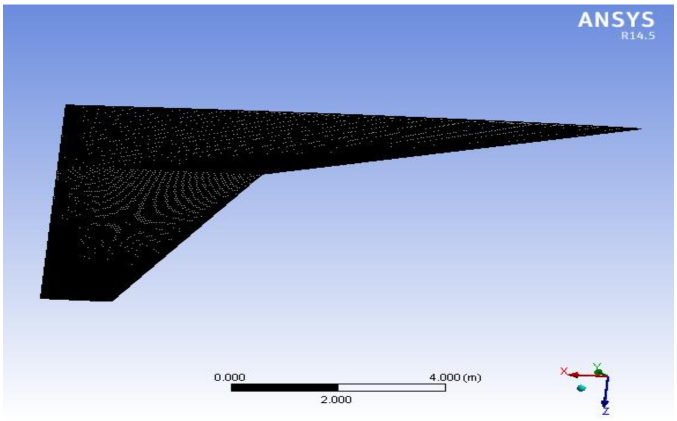

Fig. 5. Fine Meshed View Of Wing Structure

Totally 161754 nodes and 708772 elements are generated for the control volume with wing structure which is used for flow field analysis as shown in figure 4. Totally 154671 nodes and 86048 elements are generated for wing which is used for structural analysis as shown in figure 5.

C. *Boundary Condition*

The meshed control volume is kept with atmospheric conditions at 6000m altitude for flow field analysis. In the control volume the C shaped section is named as inlet and is considered as pressure far field. The face containing the wing attachment is taken as symmetry and rest of the faces is considered as pressure far field. The flow field around the delta wing model is assumed as a turbulent flow with turbulent intensity (ε) and turbulent kinetic energy (k) [7]. Density based solver is used for analysis and two equations method is employed for turbulent flow analysis. The pressure and temperature values for 6km altitude are taken from international standard atmosphere (ISA) which is tabulated in table I[13]. The velocity range is considered from 0.8 to 1.2 mach number. One face which is attached to the control volume is considered as fixed support for structural analysis. Once the flow field analysis is over, the pressure load is applied on the structure for attaining structural deformation due to the fluid structure interaction[7]. Aluminium alloy is used on the delta wing model and its properties are shown in table 2.

TABLE 1. INTERNATIONAL STANDARD ATMOSPHERIC (ISA) PROPERTIES AT 6000M ALTITUDE[13]

S.No	Variables	ISA Properties
I.	Temperature	249.2 K
II.	Pressure	47217 pa
III.	Density	0.6601 kg/m^3
IV.	Viscosity	1.6047E-5 kg/ms
V.	Speed of sound	316.4309 m/s

TABLE 2. PROPERTIES OF MATERIAL

S.No	Variables	Properties of material
I.	Material	Aluminium alloy
II.	Young’s Modulus	71GPa
III.	Density	2770 kg/m3
IV.	Bulk Modulus	69.608GPa
V.	Poisson’s Ratio	0.33

III. RESULTS AND DISCUSSIONS

A. *Modal Analysis*

The fundamental vibration analysis of wing model carried out using modal analysis software package. The main objective of modal analysis is to determine the dynamic characteristics of aircraft wing such as natural frequency and mode shapes. The contour of mode shape 4 is shown in figure 6.

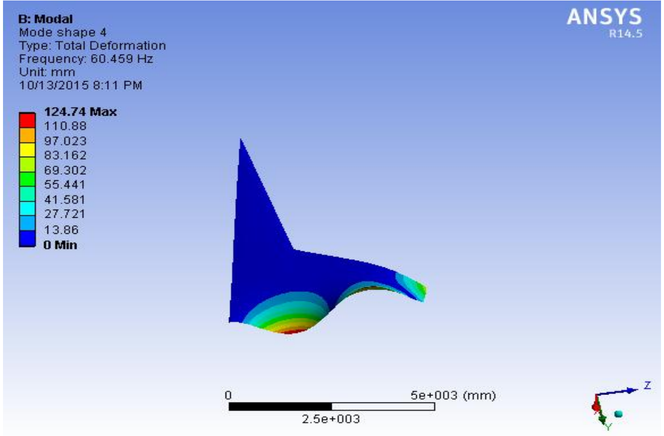

Fig. 6. Contour Of Mode Shape 4

TABLE 3. NATURAL FREQUENCY OF DELTA WING MODEL

Mode shape	Natural frequency
I	10.017
II	30.739
III	34.336
IV	60.659
V	60.056
VI	90.894
VII	103.63
VIII	108.1
IX	123.58
X	145.53

B. *Flow Field Analysis*

The flow field analysis carried out for a delta wing at 0.8 to 1.2 Mach number in 6000m altitude. The resulted maximum pressure value increased from 0.8 to 1.2 Mach as show in figure 7. In figure 7, the graph shows the variation of static pressure.

The maximum and minimum static pressures obtained for the Mach number 0.8 to 1.2 are presented in Table 4. The static pressure variation over the wing at 1.0 Mach number is shown in figure 8.

TABLE 4. MACH NUMBER VS MAXIMUM AND MINIMUM STATIC PRESSURE

S.NO	Mach no	Maximum static pressure(pa)	Minimum static pressure(pa)
I	0.8	6397	0.47257
II	0.9	11811	1.3525
III	1.0	19105	58.662
IV	1.1	19116	70.244
V	1.2	21803	83.4808

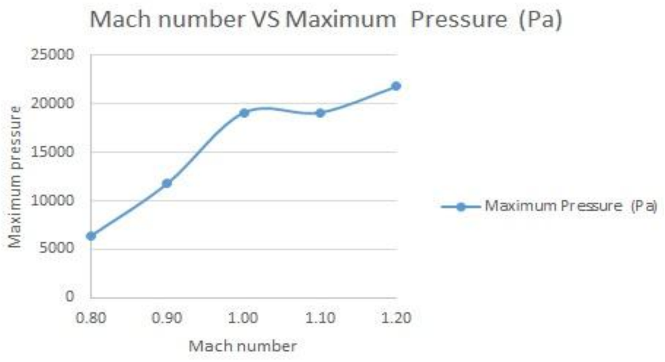

Fig. 7. Mach number vs Maximum Static Pressure

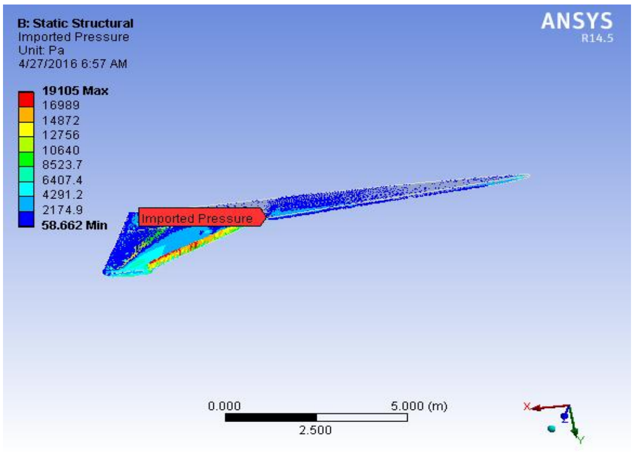

Fig. 8. Static Pressure Variation Over A Delta Wing At Mach 1.0

C. *Structural analysis*

The structural analysis is carried out for a delta wing at 0.8 to 1.2 Mach number in 6000m altitude. In structural analysis, the static pressure is imported over a wing and the deformation and stress are determined using FEA approach. The maximum and minimum static pressures obtained for the Mach number 0.8 to 1.2 are presented in Table 5. The resulted maximum stress increased from 0.8 to 1.0 Mach number and decreased from 1.0 to 1.2 Mach number as show in figure 9. The maximum stress increased region is partly subsonic range and decreased is partly supersonic range. The stress variation of the wing at 1.0 Mach number is shown in figure 10.

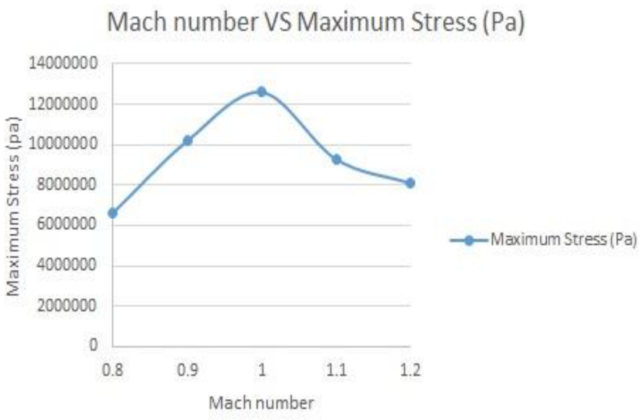

Fig 9. Mach number vs Maximum Stress

TABLE 5. MACH NUMBER VS MAXIMUM AND MINIUM STRESS

S.No.	Mach Number	Maximum Stress (Pa)	Minimum Stress(Pa)
1	0.8	6631400	647
2	0.9	10192000	871.61
3	1.0	12596000	1224.4
4	1.1	9283200	1427.6
5	1.2	8090900	1499.1

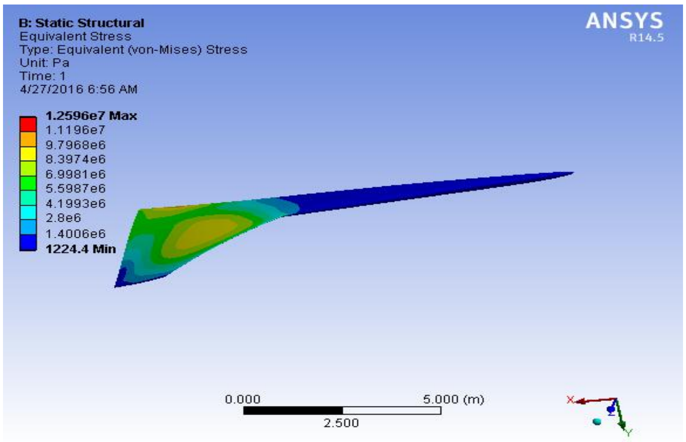

Fig.10. Stress Variation of a Delta Wing at Mach 1.0

The total deformation distribution produced on the wing because of the pressure load acting on it (1.0 Mach number) is shown in figure 12. The total deformation value increases gradually from the wing root to winglet tip for all transonic mach number and its values are shown in table 6. Total Deformation Contour at Mach 1.0 is shown in figure 12.

TABLE 6: MACH NUMBER VS TOTAL DEFORMATION

S.No.	Mach Number	Total Deformation (m)
1	0.8	0.011425
2	0.9	0.017304
3	1.0	0.021370
4	1.1	0.015156
5	1.2	0.012897

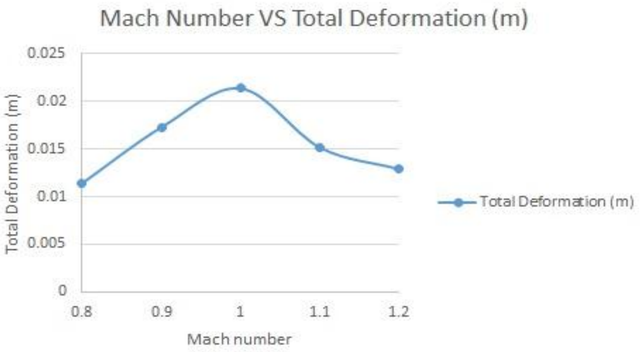

Fig. 11. Mach number vs Total Deformation

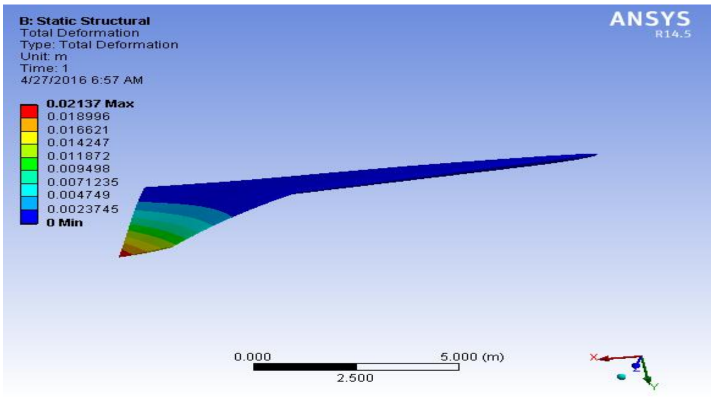

Fig. 12. Total Deformation Contour at Mach 1.0

IV. CONCLUSION

The numerical analysis is carried out for a delta wing model kept at zero degree angle of attack. The static and dynamic pressure distribution are obtained for various mach numbers ranging from 0.8 to 1.2 at 6000m altitude and these input pressure loads are used for structural analysis to get the total deformation and equivalent stress. The results are investigated tabulated and discussed for the proposed delta wing.

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