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Flutter Analysis on an HALE UAV- Morphing Wing

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Abstract

This project consists of flutter analysis of UAV wing. The process starting with literature survey to find out the existing design parameters of UAV wing and supported documents, to show the flutter problem on wing .From the existing conclusion portion of flutter prediction on wing we can understand that even few Company are not able to prove that aircraft is completely safe from flutter.

Specially in HALE UAV (High Altitude Long Endurance UAV) class of UAV it as to reach high altitude at short period of time, so the chances of flutter is more, In this project morphing wing is introduced to avoid flutter and to achieve high rate of climb.

Main objective of this project is to make a stable UAV wing which can overcome all flutter related problems in the design limit region.

Studying these phenomena requires modeling of both fluid and structure. Many approaches in computational aero elasticity seek to synthesize independent computational approaches for the aerodynamic and the structural dynamic subsystems. This strategy is known to be fraught with complications associated with the interaction between the two simulation modules. UAV wings will be generated along with the fluid domain. The transonic flow in subsonic flow regime (M= 0.9) over the wing will be simulated and the results will be validated. The stresses induced corresponding to the flow will be computed using the ANSYS Workbench. This project provides basic knowledge of FSI in aerodynamics.

Key Words: **FSI, Aero-Elasticity, Flutter, HALE UAV, Wing, Straight wing, morphing wing.**

Nomenclature

Cr = Root chord
b = Half-wing span
λ = Quarter chord sweepback angle
AR = Aspect ratio
T = Taper ratio
C_d= Sectional drag coefficient (2D-Airfoil)
C_l=Sectional lift coefficient (2D- Airfoil)
C_D= Drag coefficient (3D-Wing)
C_L= Lift coefficient (3D- wing)
C_{Dmin} = Minimum drag Coefficient
C_{Lmax}= Maximum lift coefficient
C_{Lmin}= Minimum lift Coefficient
C_m= Pitching moment coefficient
$C_{mo}/4$= Zero Angle Pitching moment coefficient
C_{mc}= pitching moment about the quarter-chord
$C_{L\alpha}$= Lift-Curve slope
L/D= Lift-to-Drag Ratio
CG= Center of Gravity
t/c = Thickness to Chord Ratio
E = Young's modulus
G= sectional modulus
α= Angle Of Attack
PR= Poison's Ratio

1. INTRODUCTION (FLUTTER)

In Fluid-structure interaction (FSI) is the interaction of movable or deformable structure with an internal or surrounding fluid flow, FSI results in the leads to Flutter. This flutter is a subset of aero elasticity which involving unfavorable interaction of aerodynamic, inertia and elastic forces on structures like aircraft to produce an unstable oscillation that often results in structural failure [2].

FSI problems play major roles in many scientific and engineering field, studying this kind of such problems remains a challenge due to their strong nonlinearity and multidisciplinary nature [1]. Fluid-structure interaction (FSI) occurs when a fluid interacts with a solid structure, exerting pressure on it which may cause deformation in the structure. As a return, the deformed structure alters the flow field. The altered flowing fluid, in turn exerts another form of pressure on the structure with repeat of the process. This kind of interaction is called Fluid-Structure Interaction (FSI).

Flutter is a dynamic, oscillatory structural instability enabled by interactions between unsteady aerodynamic forces and moments created by vibratory motion of lifting surfaces and the vehicles to which these surfaces are attached. Flutter occurs due to Fluid–structure interaction [3]. Fluid–structure interaction problems in general are often too complex to solve analytically and so they have to be analyzed by means of experiments or numerical simulation.

Flutter belongs to a special class of mechanics problems called non-conservative problems, the flutter mechanism depends on flying at or above a speed and altitude to allow two or more aircraft vibration modes to interact or couple together.

1.1 Categorization of Flutter

a. Classical flutter
   - Wing bending and torsion.
b. Control surface flutter
   - Fuselage torsion and tail torsion.
c. Stall flutter
   -Wing torsion.
d. Empennage flutter
   – Fuselage torsion and tail torsion
e. Body freedom flutter
   -Wing bending and fuselage pitch.
f. Panel flutter

2. PROBLEM DEFINITION.

High-aspect-ratio wings have come into prominence, Due to the interest in High Altitude Long Endurance (HALE) aircrafts for future military missions.
HALE aircraft have high lift-to-drag ratio wings, thus leading to high aspect ratios. Long wings tend to have large deflections.so chances of flutter will be more. Also now a days flutter analysis is a primary requests.

3. WORKING METHODOLOGY

Working methodology involves modeling of the desired wing in the CATIA V5R21. Later, the wing is analyzed for the aerodynamic performance under the given flight conditions. The pressure distribution resulted from the Fluent (flow) analysis is then applied as a structural load over the wing in Ansys 14.5. The results are then validated using MATLAB.

4. MISSION PROFILE OF AIRCRAFT

The complete design of aircraft are considered, all aircraft design starts with initial weight estimation based on mission profile.

Mission profile includes startup, taxing, takeoff, climb, loiter, decent and landing.

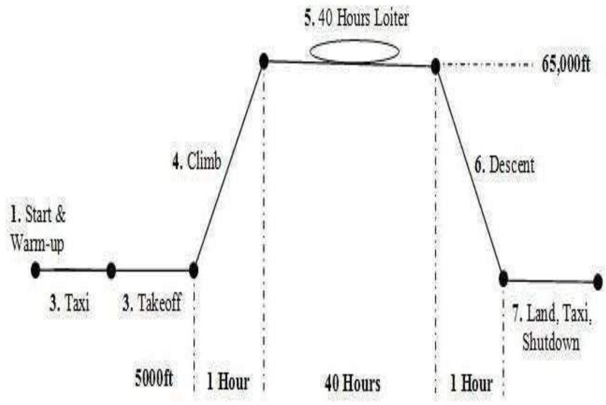


Fig. 1. Mission profile

Which includes over all weight, empty weight, fuel weight, pay load weight. Based on all this selection of engine by comparing similar class of UAV. Later based on empty weight the design of aircraft. Wing has been designed based on the overall lift required.

4.1 AIRFOIL.

NACA 23015 is selected

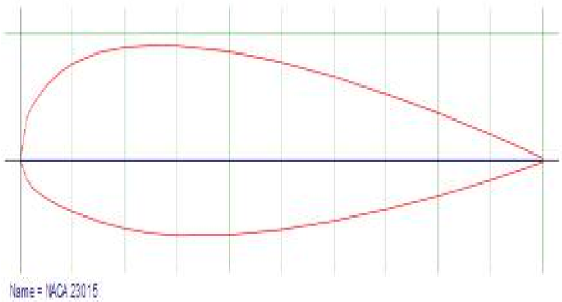


Fig. 2. NACA 23015 Airfoil

The selection of airfoils are carried out based on the cruise condition and Reynolds's number of the aircraft. NACA 4 digit series and 5 digit series are chosen for its better aerodynamic charateristics. In HALE UAV a 5 digit series airfoil is selected based on the configuration of wing and for its high aerodynamic performances. The combination of all configuration and characteristic is used for preference of this project to make it viable in accordance to standard requirements.

4.2 WING SPECIFICATION AND AIRCRAFT DATA.

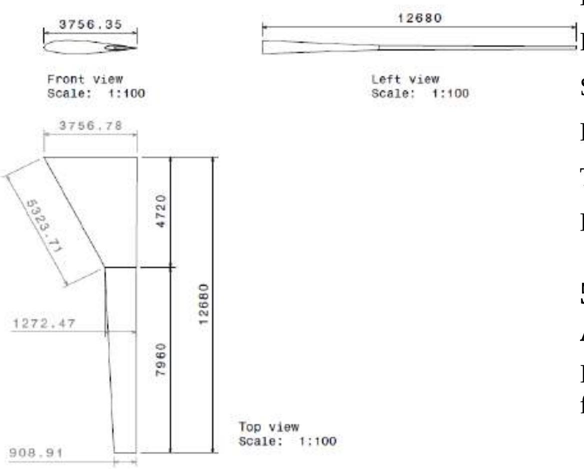


Fig. 3. Unswept wing dimension

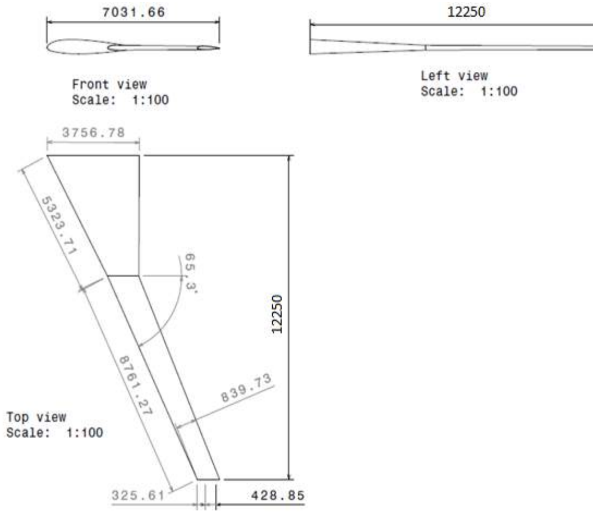


Fig. 4. Sweptback wing dimension

4.3 Dimensions:

Overall length : 37.55feet

Wing aspect ratio : Swept= AR 20,

: Unswept AR=22.15

Wing LE sweep : 22▫ backwards Span, 84.14 feet

Wing LE unsweep : 2▫ Span, 91.39 feet

Wheel base : 5,500mm (length) and 4,000mm (width)

4.4 Mass/Weight:

Takeoff weight : 1907 kg

Empty weight : 1076 kg

Fuel weight : 708 kg

4.5 Performance

Loiter speed : 296 km/hr.

Rate of climb : 1000fpm

Service ceiling : 65,000feet

Endurance : 40 hours

Take off distance : 2000feet

Landing distance : 2000feet

5. FLOW CHART FOR MODELING AND ANALYSIS

In this process the following methods are considered for modeling and analysis,

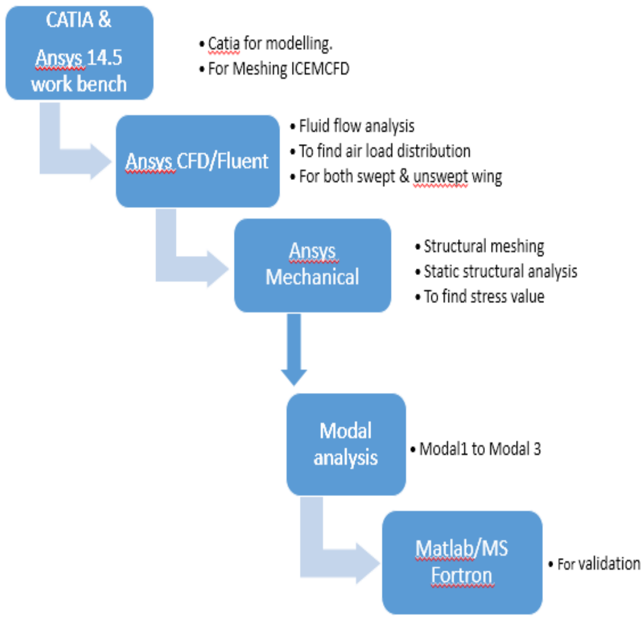


Fig. 5. Model and Analysis flow chart

5.1 MACROS

Selection of airfoil plays a vital role in design configuration of HALE UAV because of morphing wing. The selected airfoil coordinates is imported to CATIA V5 were modeling is done.
CATIA (Computer Aided Three-dimensional Interactive Application) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company Dassault Systems. Written in the C++ programming language, CATIA is the cornerstone of the Dassault Systems product lifecycle management software suite... The generated wing must be saved in .iges format for its further use in ANSYS workbench

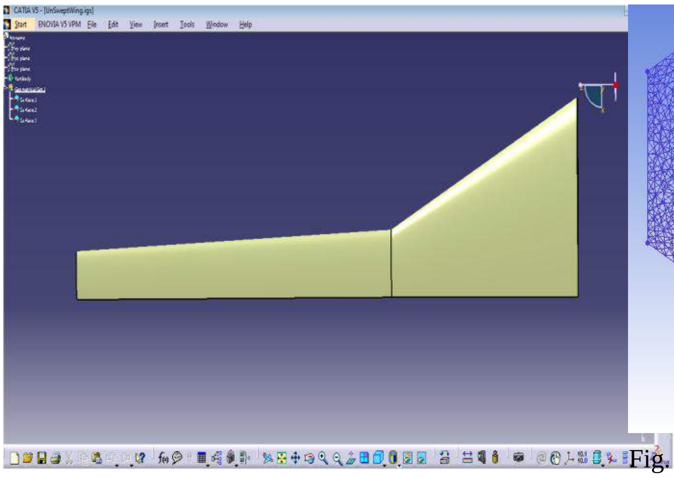


Fig. 6. Unswept wing catia model

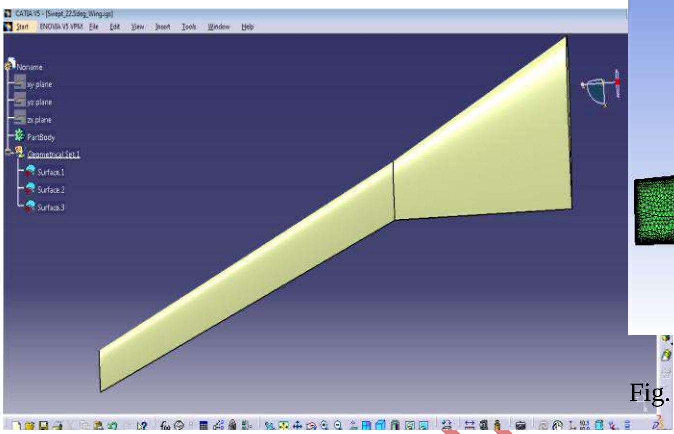


Fig. 7. Sweptback wing catia model

6. ANALYSIS

The model is then imported to the ANSYS design modeler for further analysis.

6.1 ANSYS WORKBENCH

The following steps are carried for analysis

- ANSYS Meshing (ICEMCFD)
- ANSYS CFX/FLUENT
- ANSYS MECHANICAL

7. CFD MESHING

Tria meshing is done and domine is created in ICEM CFD and the wing is place at suitable position inside the domine which is fixed at root chord as show in figure 8 and the fluid is allowed to flow over semi wing at certain velocity form leading edge to trailing edge.

Wing is placed in domain which is shown in fig.8

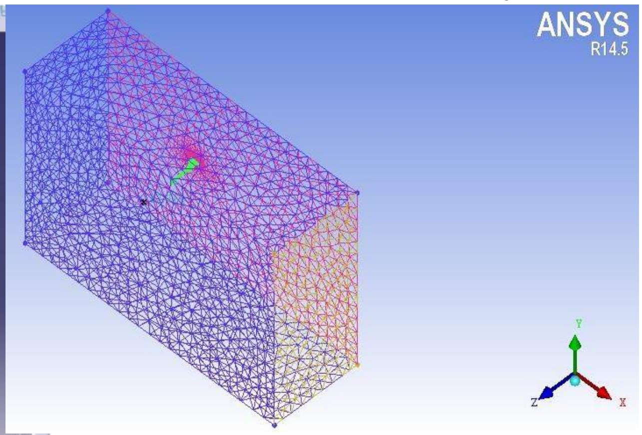


Fig. 8. Wing with domain

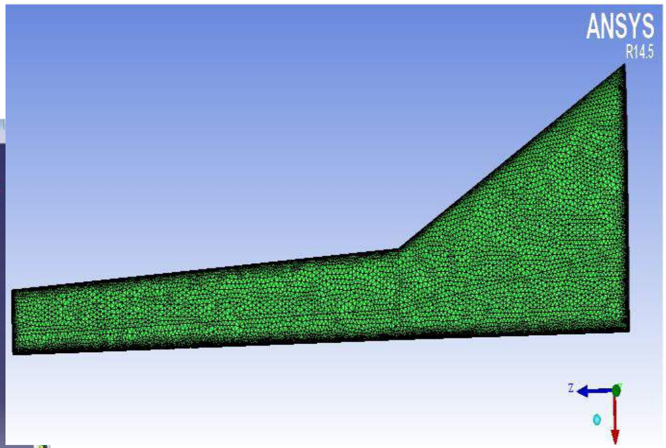


Fig. 9. Tria mesh for Unswept wing

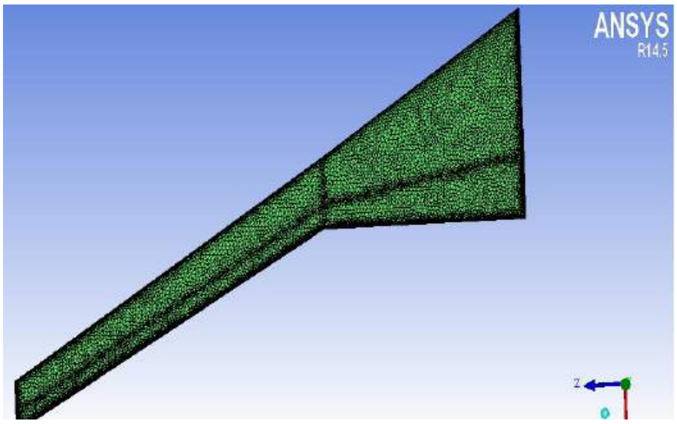


Fig. 10. Tria mesh for Swept back wing

Fine mesh for the edge face of the wing will leads to good quality mesh which leads to better result.

The boundary condition for CFD analysis is based on altitude, speed at which aircraft will fly.

8. FLUENT ANALYSIS

Later, the model is exported to the FLUENT for the flow analysis. The iterations are continued till the solution is converged.

The boundary condition are given below

- Velocity - 68 ms_{-1}
- Temperature - 300K
- Pressure - 1 bar
- Density - 1.225 kgm_{-3}

Pressure loads result are obtained from FLUENT for swept and unswept wing as shown in the fig 11 and fig 12 respectively.

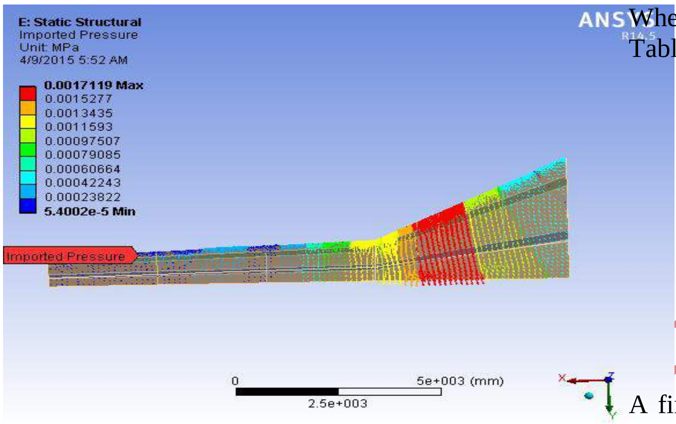


Fig. 11. Pressure load on unswept wings

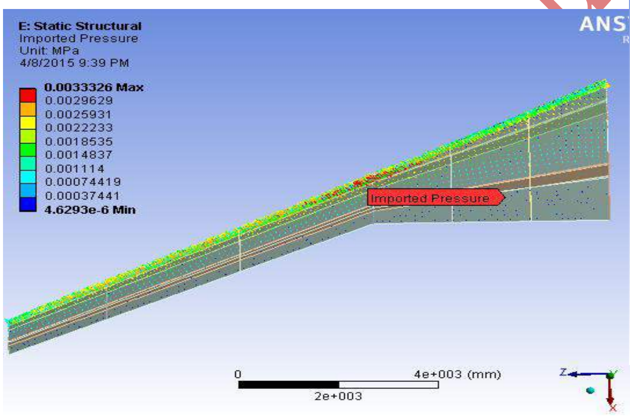


Fig. 12. Pressure load on Swept back wing

9. STRUCTURAL ANALYSIS

The structural analysis for the wing is carried for the pressure and shear distributions of the flow around the wing which are resulted from flow analysis. The material properties of the wing are shown in Table I. Al is considered as material.

TABLE I.– Properties of Material (Al)

PROPERTY	VALUE
Density	2.77e-006 kg mm^-3
Tensile Yield Strength	280 MPa
Tensile Ultimate Strength	310 MPa
Young's Modulus	71000 MPa
Poisson's Ratio	0.33

MESHING

Meshing is generated for aircraft wing component such as skin, ribs stringers etc. Were quad mesh is done for the whole structure of HALE UAV wing, Where quality parameters of wing are given below Table II.

TABLE II. –Mesh parameters

Parameters	Value
Aspect ratio	3
Skewness	0.6
Jacobin	0.6

A fine quad meshing is done on swept and unswept wing which is shown in fig 12 and fig13.

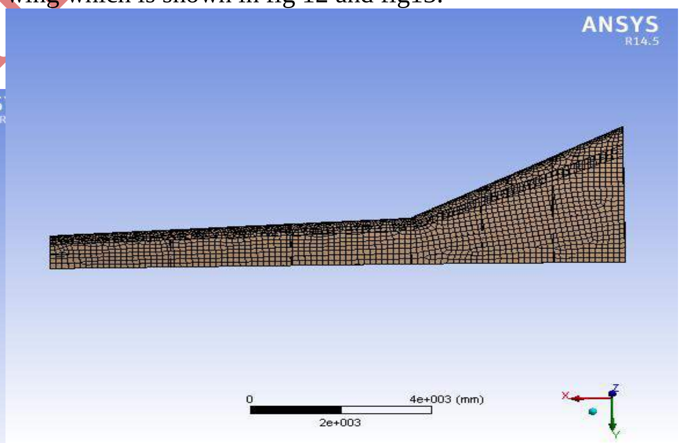


Fig. 13. Structural mesh on Unswept wing.

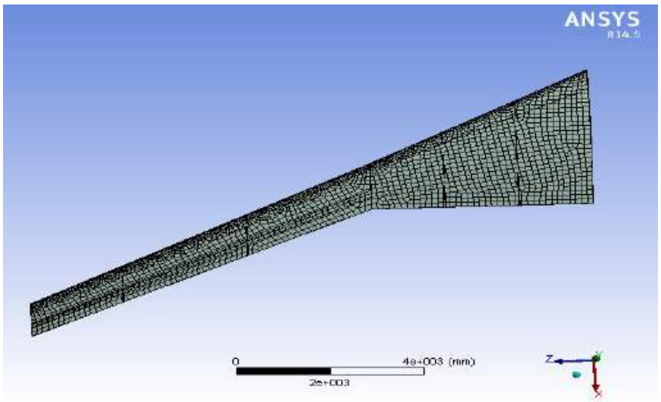


Fig. 14. Structural mesh on Swept back wing

10. RESULTS AND DISCISSION

10.1 STATIC STRUCTURAL RESULTS

A classic static was performed the result shows von-mises stress of unswept wing is within the elastic region.
i.e stress is maximum at root chord of around 20.82 Mpa and minimum at 2.3138 Mpa. Value is shown in fig 15.
Von-mises stress for swept back wing is with in elastic range, stress value is max at root chord which is 65.10 Mpa and which min value is 7.2343 Mpa.shown in fig 16.

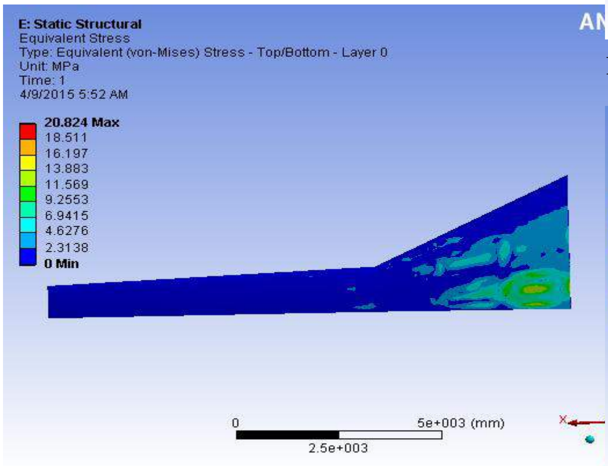


Fig. 15. Von-mises stress on Unswept wing.

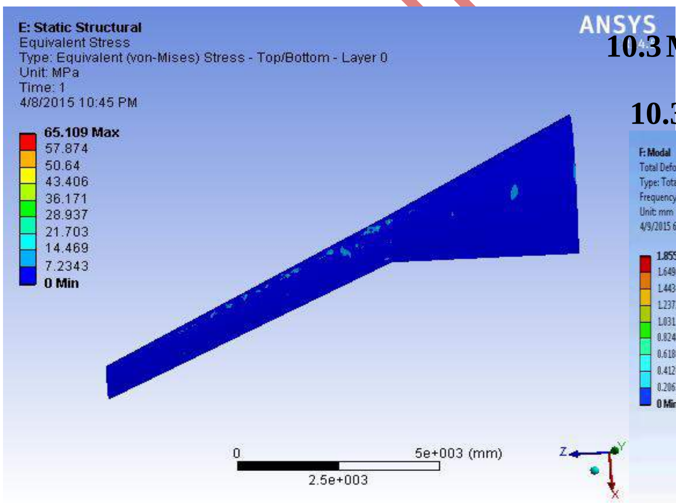


Fig. 16. Von-mises stress on Swept wing

10.2 DEFORMATION RESULTS

Deformation of wing is more at end of the tip. Value of deformation is 1.885 mm for unswept wing and 14.6648 for swept wing as indicated in fig 17 and fig 18 respectively.

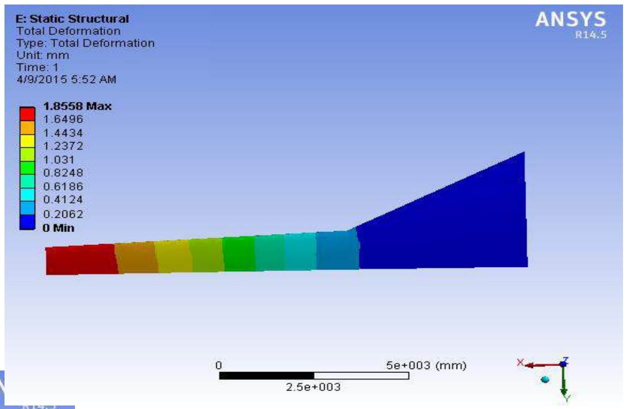


Fig. 17. Deformation on Unswept wing

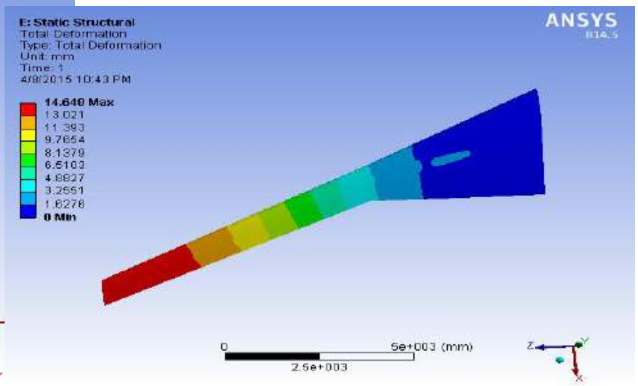


Fig. 18. Deformation on Swept back wing.

10.3 MODAL RESULTS

10.3.1 Modal 1

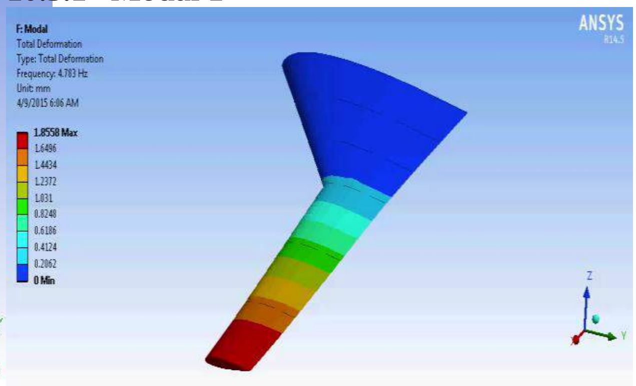


Fig. 19. Unswept wing Modal 1 result

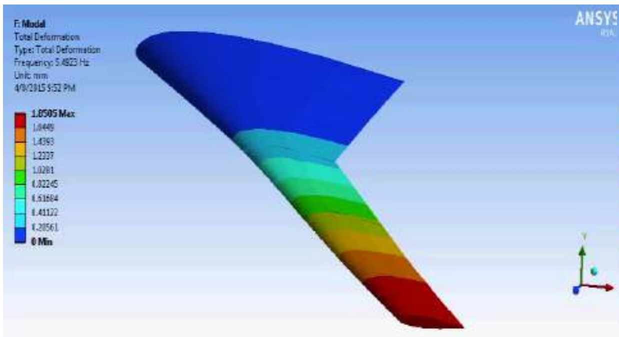


Fig. 20. Swept back wing Modal 1 result

10.3.2 Modal 2

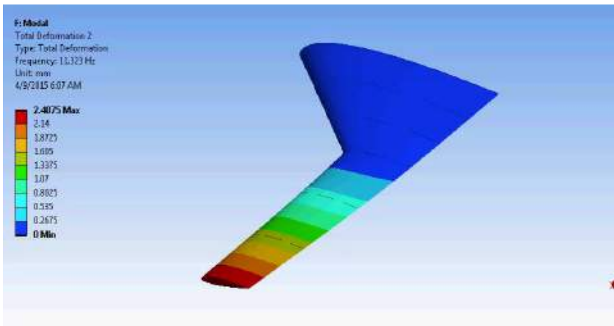


Fig. 21. Unswept wing Modal 2 result

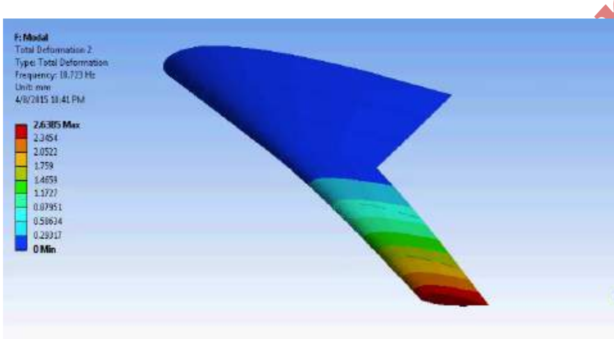


Fig. 22. Swept back wing Modal 2 result

10.3.3 Modal 3

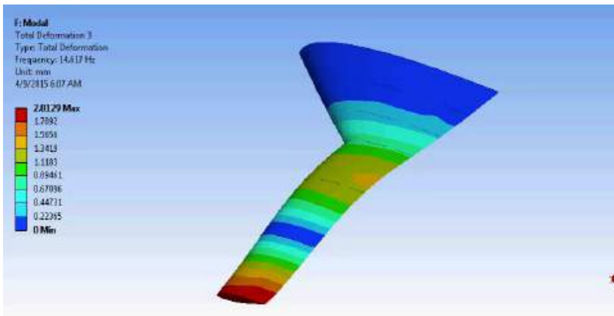


Fig. 23. Unswept wing Modal 3 result

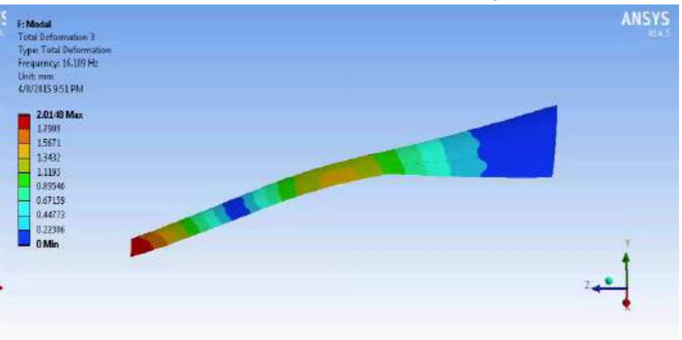
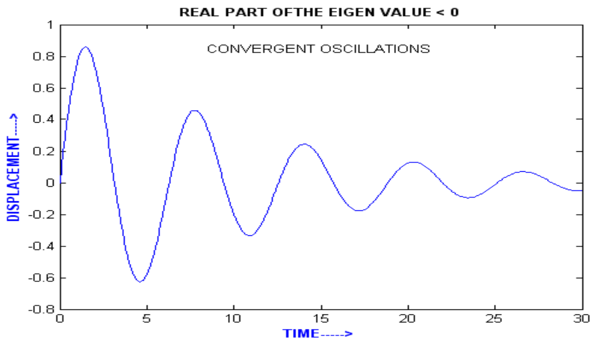


Fig 24. Swept back wing Modal 3 result

11. CONCLUSION

In this project the wing consideration play a major role. Because of its size and shape. Morphing wing with high aspect ratio and high lift to drag ratio.
As we have seen from the analysis that HALE UAV have undergo flutter due to fluid structure interaction.
A structural rigidity of the wing has been found by analyze w.r.t von-mises stress and deformation.
The obtained results shows the three modal shapes of both swept and unswept wing.
Moreover a comparisons has been used for swept back and unswept wing by choosing in terms of aerodynamics efficiency, i.e high lift to drag ratio.
Where the unswept wing was found to be stable as represent in the graph i.e. displacement v/s time. Since the amplitude decreases w.r.t to time, it is observed that flutter in the wing reduces over a period of time for the given wing structure.



This graph clearly shows the wing which is disturbed due to flutter, will have flutter but over a period of time it will come to stable.

12. SCOPE OF FUTURE WORK

For this analysis the material chosen was aluminum whereas the analysis can be performed by using composite material.
The wing component such as ribs, spars and stringers can be altered in an appropriate way so that the stiffness of the wing structure may be increased.
Flutter analysis can also be performed for flapping wing design, now a day the research and analysis is having more scope on flapping wing, were the flutter

analysis can be considered has primary requirement of flapping wing.

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