International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 12 (2015) pp. 32071-32085
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# Aeroelastc Analysis Of Aircraft Tail Wing Section Using Nastran Code

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**Abstract**

Modern aircrafts are built with a stringent weight budget. There is a every quenchable thirst for the reduction of weight and thereby increase in the performance of the aircraft. The reduction in the weight leads into the flexible structure. Flexible aircrafts leads to the dynamic instability to the structure. Unlike any other vehicle aero elasticity is a special subject for the aeronautical engineers. It is the study of interaction of aerodynamic force, elastic force and inertial force. Flutter is a one such instability that if it is not clearly understood on the aircraft it may lead to the catastrophic failure of the aircraft. Until 1940 flutter phenomenon is not very clearly understood and many lives were lost due to the flutter phenomenon. After 1940 considerable amount of work has been done to understand the flutter phenomenon such that the aircraft is safe in its flight envelop.

In the current work a flutter analysis of horizontal tail of an aircraft will be carried out. Finite element technique will be used for the analysis. Commercial finite element software will be used for the solution. Nastran a finite element solver has the capability of giving aero elastic solutions. The fin will be meshed using quad and tri elements and applicable material and properties will be given. Normal mode analysis is carried out extract the natural frequencies of the structure. The calculated normal mode analysis is used in the calculation of the flutter speed of the fin. The estimated flutter speed is checked with the dive speed of the aircraft. If the estimated flutter speed is more than the dive speed of the aircraft the structure is declared as flutter free else structural modifications has to be carried out such that the structure clears flutter.

## 1. Introduction

Aeroelasticity studies the effects of interacting aerodynamics, elastic and inertia forces on aircraft structures. In order to demonstrate the interdisciplinary nature of aeroelasticity Collar created the famous triangle of aeroelasticity, which is shown in Figure 1. 1

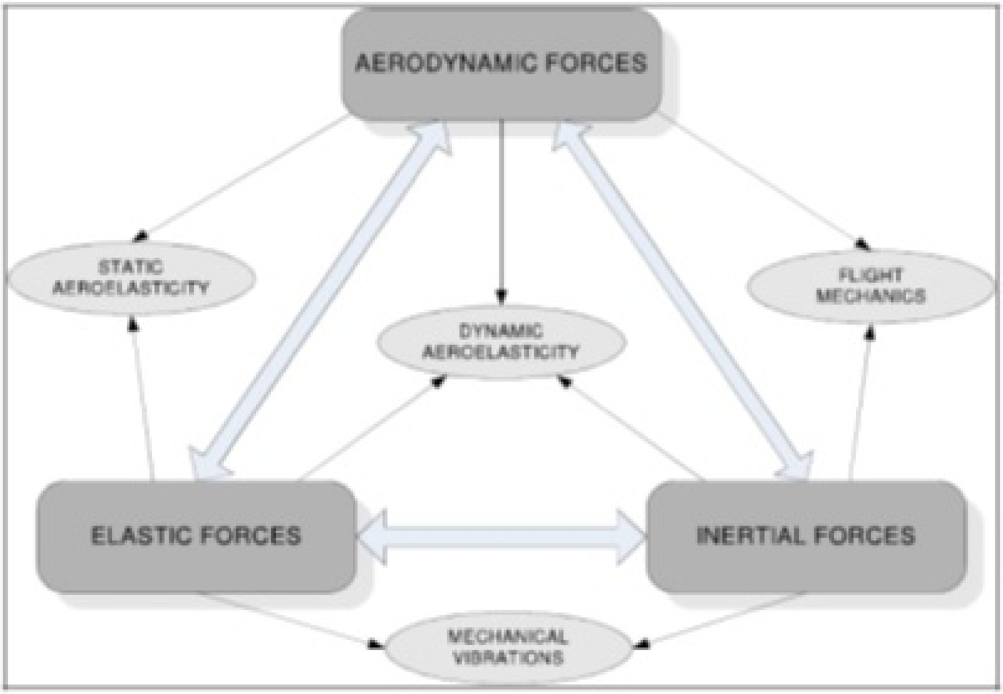


**Figure 1. 1 Collar's Triangle**

In all aeroelastic problems a common characteristics is observed: the aerodynamic forces give rise to structural deformations change the aerodynamic forces and in turn which change the structural deformation again. This process repeats until a state of equilibrium or, undesirably, a failure is reached.

Aeroelastic problems occur due to the elastic behaviour of aircraft structures. In other words, if the structures were perfectly rigid then aeroelastic problems would not have occurred. Increasing the stiffness of an aircraft may be achieved by the use of recent, high technology materials or by increasing the thickness of the structure that results in weight penalty, which are both far from being cost effective solutions. On the other hand, increasing the rigidity of the structure will have unfavourable effects, as it will not necessarily protect the passengers or the payload from sudden gusts. Furthermore, the increase of design speeds leads to more slender aircraft with thinner wings and therefore requires a relatively less stiff structure. This also in turn creates an aircraft that is susceptible to aeroelastic problems.

[1] Theodore Theodorsen and I. E. Garrick published a report that attempts to explain mechanism of flutter. It included both theoretical studies and experimental results. The agreement between theoretical and experimental results is shown. Also a simple method, requiring no reference to the theory is given for numerical calculation of flutter speed. [2]Bursnall's study on flutter experiments in Langley Blowdown Tunnel made comparison between transonic wind tunnel tests and free-fall flight flutter tests. Scaled models are tested in the tunnel and results showed good correlation with the free-fall flight test. After these studies, it is understood and accepted the feasibility to use wind tunnel tests in the design phase. [4], DeBaets, Battoo and Mavris published their work on effects of root flexibility on aeroelastic behavior. A composite wing box is selected as the test case and sensitivity of aeroelastic properties to composite skin lay-up, fibre orientation and especially, root flexibility variation is examined. They showed the root stiffness's significant influence on the modal response and aeroelastic properties of the wing box. [6] M. Hasan developed an automated multidisciplinary design optimization code and published his study in his Ph. D. Thesis. In the study, static strength, aeroelastic stability and manufacturing requirements are employed as the design variables. In the aeroelastic stability requirements studies, hypothetical jet transport wing (BAIT wing) and intermediate complexity wing (ICW) are examined and flutter analysis are conducted using finite element approach. Finally an unswept cantilever wing with constant cross section is chosen for the optimization analysis and aeroelastic calculations are done during the process. [11] N. G. VijayaVittala, A. C. Pankaj, R. Swarnalatha explained the dynamic and flutter analysis carried out on the first prototype of SARAS. Correlation of the dynamic characteristics of the aircraft obtained from analysis with the Ground Vibration Test results of the aircraft is studied. The doublet lattice method has been used to estimate the appropriate unsteady air loads generated on the lifting surfaces of the aircraft. In an attempt to realize the realistic flutter margins, the analysis results of the aircraft for the control surfaces rotational modes have been tuned to the Ground Vibration Test results after establishing the first cut analysis results. Flutter analysis of the complete aircraft has been carried out by both PK and KE methods and the critical flutter velocities have been evaluated. The flutter margins for the aircraft are established with respect to the FAR 25 requirements. All the considered aircraft configurations have been found to satisfy the FAR 25 requirements and have been subsequently cleared from flutter criteria with substantial flutter margins. [21]Yan Mursal&MohRisdayaFadil, in their paper considered aircraft control surfaces that are driven by a pair of hydraulically powered servo actuators. One actuator is normally in an active mode and the other is normally in a stand-by mode. This paper describes an aeroelastic modeling technique where a control system has two hydraulic failures, the active mode actuator is failed (e. g. a structural disconnect) and no hydraulic power comes to the stand-by mode actuator. In this situation the stand-by mode acts as a hydraulic damper.

In the failure condition, the stand-by actuators must provide sufficient damping in order the airplane still maintain flutter free condition. To perform the aeroelastic analysis of the system, the generalized mass, stiffness and damping of the plan (airplane) equation must be modified. These tasks were done using the combination of epoint, tfmsc/Nastran bulk data entry and dmap. The epoint entry was used to add one generalized coordinate. In this case it is due to the moment of the actuator introduced to the airplane. The Nastran TF bulk data was used to introduce to the diagonal terms of the MHH, BHH and KHH matrices. A small dmap routine was created to add off-diagonal terms of these matrices and to perform the analysis automatically. The calculation was done using SOL 145. Some results are presented as an example and also compared with another method. They developed a new approach to analyze failure cases of a flight control system. In the alternative to the existing method which uses the same equation of motion. The approach has an advantage, that there is no need to transfer input data from MSC/NASTRAN to a PC-type computer or Workstation. But on the other hand, this method also had a disadvantage; because it is running on a Mainframe, the problem turn-around time may be large depending on whether the mainframe is overloaded or not. But nevertheless it could be used to double-check the existing method.

## 2. Horizontal tail specifications and calculations

Horizontal tail area is 44. 6479 ft^2= 13608. 67992mm.
Horizontal tail span is 13. 3638 ft= 4073. 28mm.
Horizontal tail root chord is 4. 4546 ft= 1357. 76mm.
Horizontal tail tip chord is 2. 2273 ft= 678. 88mm.
Horizontal tail taper ratio is 0. 5
Horizontal tail 1/4 chord sweep is 4. 7636 deg
Horizontal tail max thickness is 0. 53455 ft =162. 9mm.
Aerofoil used is NACA 0012.
Loaded weight = 2, 750 lb = 1, 247 kg.
Never exceed speed = 190 mph (306 km/h).
Cruise speed = 155 mph (250 km/h).
Stall speed = 64 mph (103 km/h).
Load acting on ht
To calculate the load acting on the horizontal tail, we have the loaded weight that is the take-off weight of the aircraft.
Loaded weight of Ryan navion aircraft = 1247kg (2, 750lb)
In general, 20% of the take-off weight acts on the horizontal tail of the aircraft as the load.
Therefore, 1247*0. 2 = 249. 4(250kg).
The load calculated is for the full HT. Here, we are considering only for the semi-span and hence only half of it.
Load acting on the semi span of HT = 125 kg (250/2) = 1250N(1kg=1N).
We are including the factor of safety and F. O. S is taken as 1. 5.
Load acting on the semi span of ht including F. O. S = 1875(1250*1. 5).

### Line loads

In an aircraft the load acting on the wing will be in the elliptical form. Hence the load distribution on the horizontal tail will also be in the elliptical form. The load distribution over the wing will be as shown in the fig.

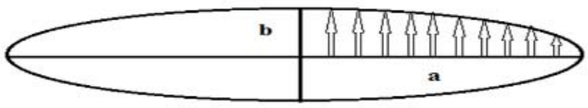


**Fig 2. 1 Load distribution over HT**

Semi span of ht = 2037mm (4073. 28/2mm).
Area of ellipse = πab
Where, a – semi-major axis
b – Semi-minor axis
For quarter section of the ellipse, 1875 = 1/4 πab
b=1. 1725mm.
From the equation of ellipse,

Were, x is interval on the x-direction of semi span i. e. on the chord.

y is line load points on ht.

Therefore, Line loads acting along the semi-span given by,

Line load is the load acting per unit length.
Concentrated loads
Concentrated loads are the line loads and the multiple of the distance along the span and it gives the sum of the loads acting along the semi span.
Concentrated loads = line load * distance of the intervals along the semi span.
Location of spars
If we consider the airflow over an airfoil, the load distribution over it is such that the maximum load will be acting on the region of 25-65% of the chord from the leading edge of the airfoil. Near the leading and trailing edge of the airfoil load acting will be minimum. So the spars are to be placed at this region since they take the bending stresses acting on it.
Front spar is placed at a distance of 25% of the chord length from the leading edge.
Rear spar is placed at a distance of 65% of the chord length from the leading edge.

**Depth of spars**

The depth of the front and rear spar is found from Catia.

Here, the depth of the front at the root and tip of the HT is found from Catia and the depth of the spar along the distance in between the front and rear spar is to be found from the equation of the line.

Depth of the spars that is the distance between the chord line and the flange of the spars. Since, symmetrical aerofoil is used.

The depth of spars along the semi-span can found from the Equation of line,

## 3. Flutter Analysis using Finite Element Method

The analysis has been carried out using the finite element analysis to obtain the flutter value of the horizontal tail. The purposes of this analysis are to evaluate and optimize the results.

**Step I:**

The horizontal tail structure was modelled using CATIA software to create the model as shown in figure 3. 1.

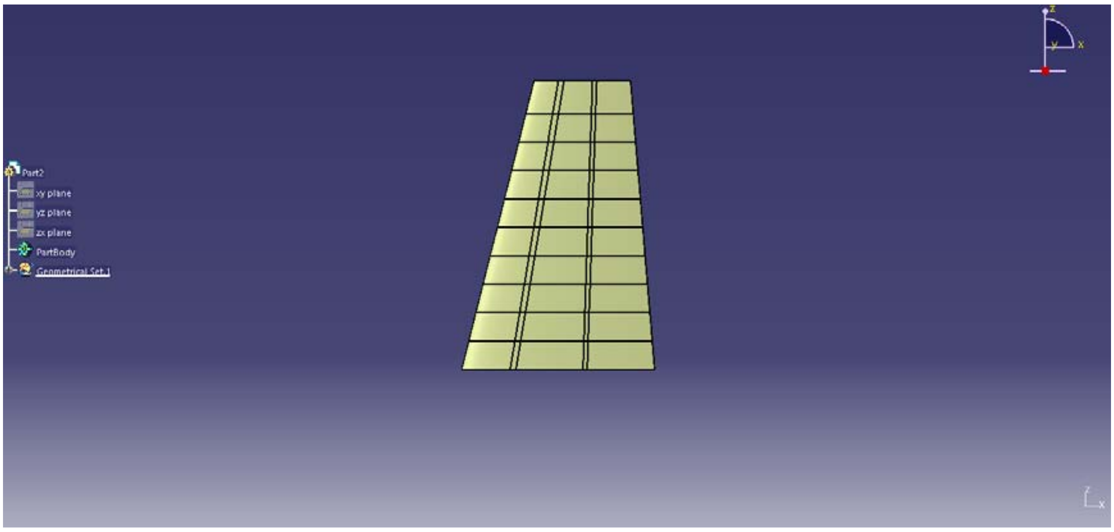

**Fig. 3. 1 Model of HT**

**Step II:**
Meshing of the HT of Ryan navion aircraft done in patran.

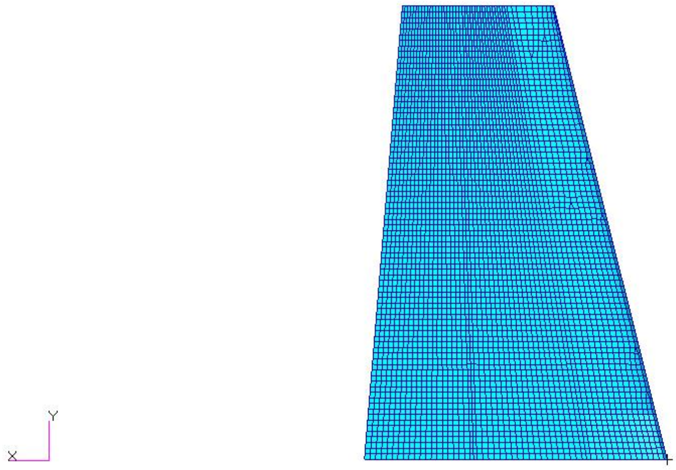


**Fig. 3. 2 Mesh Model of HT isometric view**

**Step III:**
The model of the HT is given the boundary conditions such that the front and rear spars are fixed.

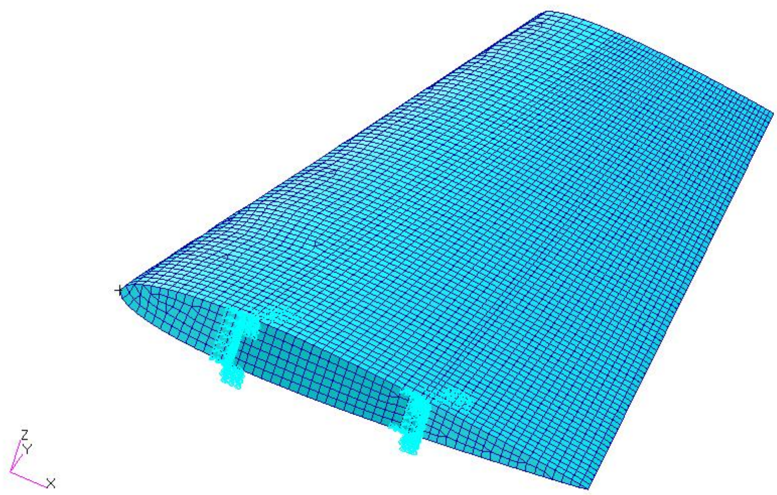


**Fig 3. 3 mesh model with boundary conditions**

**Step IV:**
A linear static analysis is carried out for the HT. In the linear static analysis pressure loads are given as the input. Pressure loads acting on the HT are calculated using the load acting on the HT and the area of the HT.

Pressure = 6. 1933e-4 N/mm^2
And the result obtained from the analysis is,
Max. Displacement= 3. 5451 mm.

**Step V:**
Flutter is dynamic aeroelasticity stability problem. It is self-excited and potentially destructive vibration where aerodynamic forces on an object couple with a structure's natural mode of vibration to produce rapid periodic motion.

**Table 3. 1 M-K Sets (Mach – Reduced frequency)**

| Parameters | Value |
|---|---|
| **Mach** | 0. 5 |
| **F min [Hz]** | 29. 7 |
| **V max [m/s]** | 85 |
| **F max [Hz]** | 185. 4 |
| **V min [m/s]** | 28. 6 |
| **Reduced frequency** | 1. 118, 1. 807, 2. 497, 3. 187, 3. 876 |

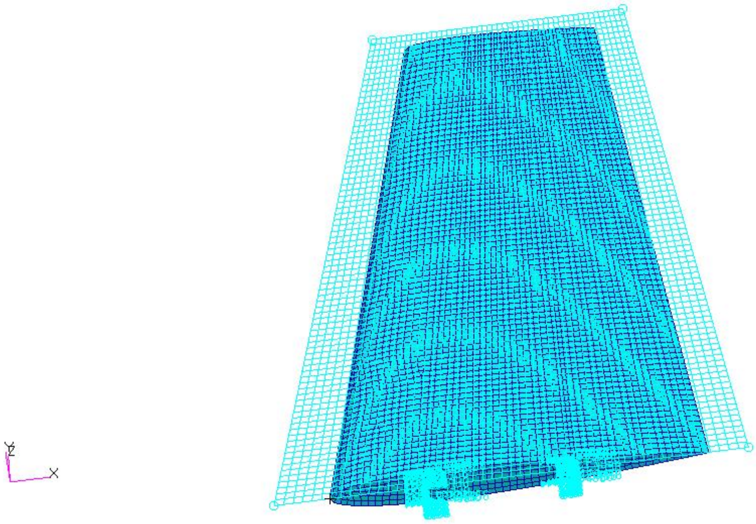

**Fig 3. 4 aerodynamic model and structural model of the HT**

In aeroelasticity the aerodynamic surfaces and the structural surfaces are combined to capture the flutter. Since, aeroelasticity is the interaction of the aerodynamic, elastic and inertial forces. To combine these surfaces a method called splining is used. The splining used is the infinite plate splining (IPS). Structural nodes are extracted from the surface of the Ht and these are combined with the aerodynamic surface.

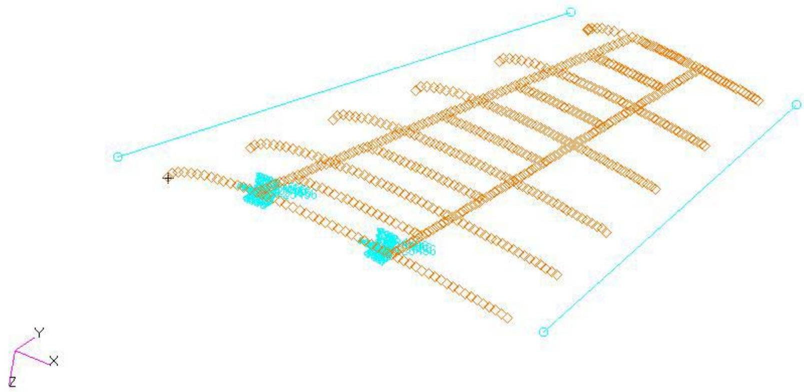


**Fig 3. 5 structural grid for spline connection**

Then the flutter analysis is carried out such that the velocity, density ratio sets are given. Here, the analysis is done in the sea level altitude. Then, modal damping that acts as the structural damping are given as the input. With these the analysis is meant to be run.

## 4. Analytical Approach

The analytical approach to capture the flutter is done by calculations. To determine the flutter speed a method followed in the Aviation Publication Standard is taken. And the flutter speed obtained is the theoretical flutter speed that is to be compared with the result obtained from analysis.

### Calculation

The formula to determine the flutter speed is given by the formula,

$$\upsilon = \left(\frac{m_\theta}{\rho_\circ d c_m^2}\right)^{0.5} \left(\frac{(0.9 - 0.33k)(1 - 0.1r)}{0.9(g - 0.1)(1.3 - h)}\right) \sec^{\frac{3}{2}} \left(\Delta - \frac{\pi}{16}\right) . f(M)$$

$$M = M_o(\cos)$$

$$f(M) = (1 - M^2)^{1/4}$$

Where,

V-Critical flutter speed (F. P. S)

$m_\theta$ -Wing torsional stiffness (antisymmetric) measured at 0. 7s from wing root given by the rotation in a plane at right angles to the wing due to a torque applied in the same plane.

$\rho_o$ -Density at sea level

$c_m$ -Wing mean chord (ft) measured perpendicular to the main spar
d-Distance from wing root (ft) to equivalent tip (0. 9s)
k-Taper ratio subject to limitation 0. 25<k<1. 0
r-Stiffness ratio
$l_{\phi}$ -Wing flexural stiffness
g-Position of inertia axis aft of leading edge (as fraction of chord) subject to the limitation 0. 35<g<0. 55
h-Position of flexural axis aft of the leading edge (as fraction of chord)
$\Lambda$ -Angle of sweep back
$M_0$ -Greatest forward Mach number at which the aero plane can achieve the maximum speed.
M – Mach number.

The values are given by,

| parameters | values |
|---|---|
| $m_{\theta}$ | 123878874. 18527 (N-ft^2) |
| $\rho_o$ | 43. 227 (Kg/ft^3) |
| $c_m$ | 3. 4649ft |
| $l_{\phi}$ | 7231572. 91356 (N-ft^2) |
| $\Lambda$ | 4. 7636 deg |
| $M_0$ | 0. 249 |
| **M** | 0. 2481 |
| **S** | 6. 6819ft |
| **D** | 6. 01371ft |
| **K** | 0. 5 |
| **R** | 0. 0193 |
| **G** | 0. 42 |
| **H** | 0. 45 |

On substituting the above values on the equation, we get the flutter speed,

$$V = 605.37 \text{ ft/s}$$

**5. Results**

## 5. 1 Normal Mode Analysis

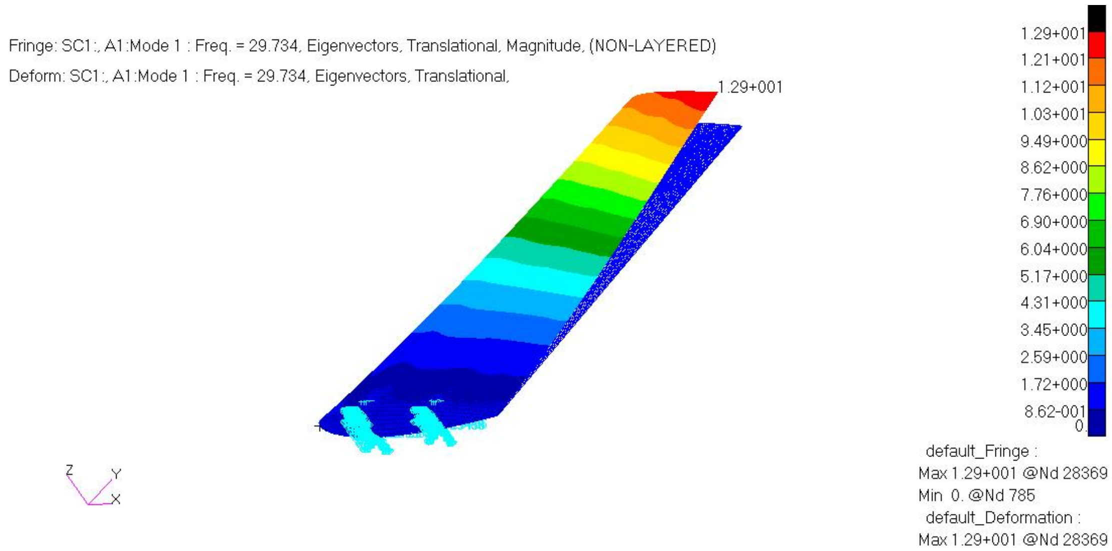


**Fig 5. 1 first mode shape of HT**

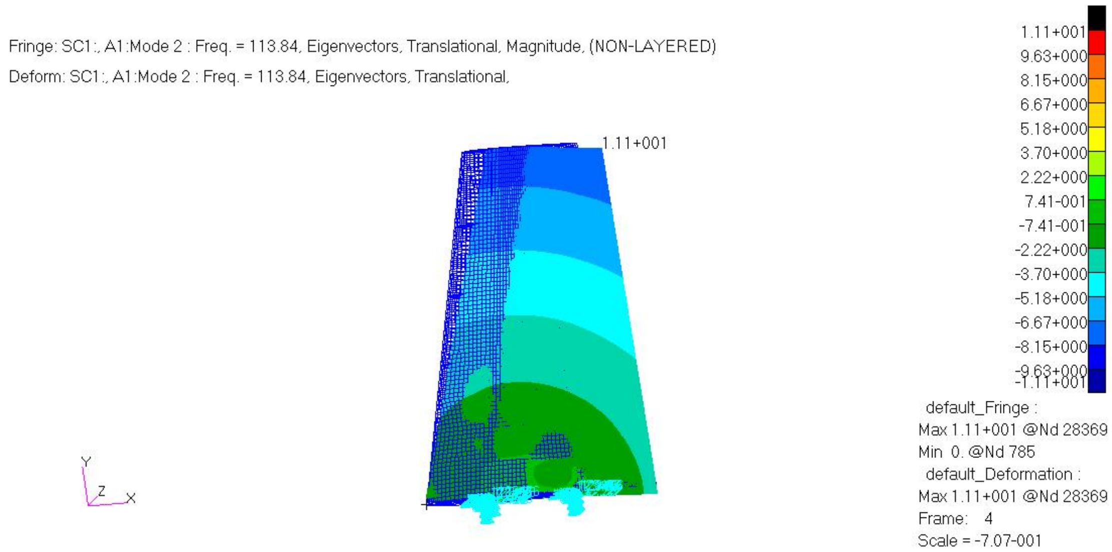


**Fig 5. 2 Second mode shape of HT**

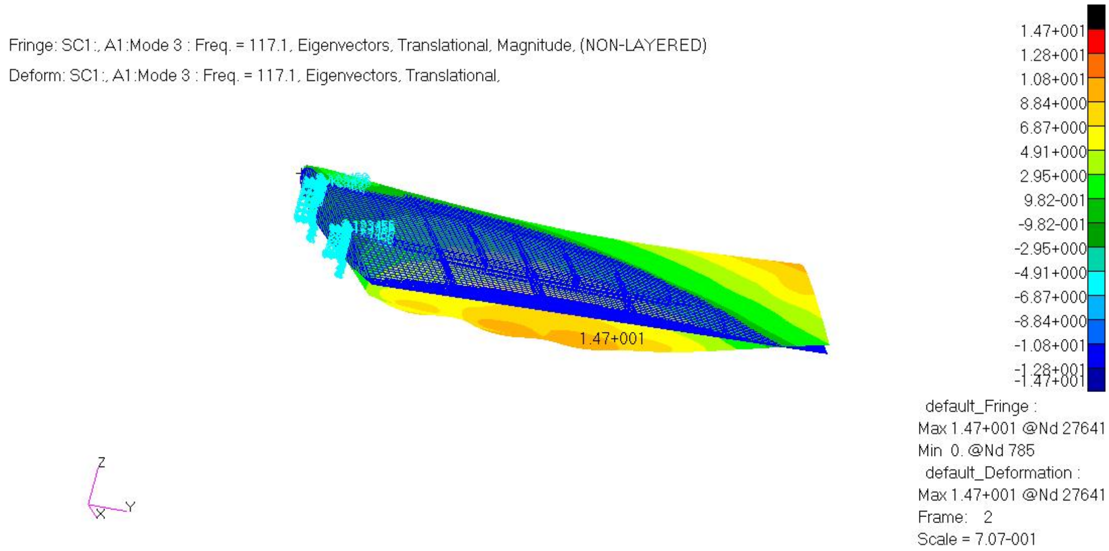


**Fig 5. 3 Third mode shape of HT**

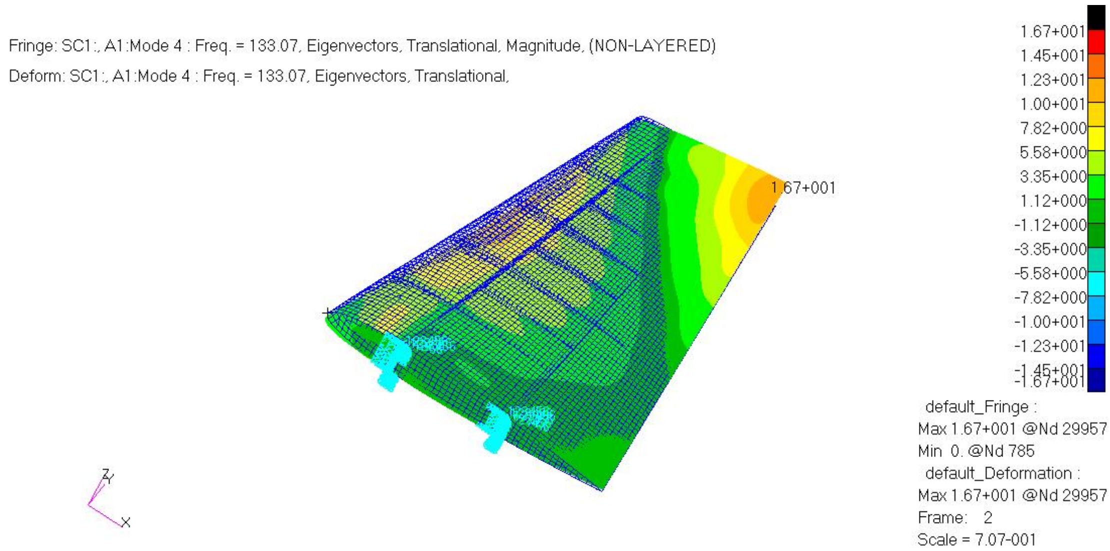


**Fig 5. 4 Fourth mode of HT**

## Frequencies obtained through normal mode analysis

- Frequency, mode 1= 29. 734 Hz
- Frequency, mode 2= 113. 84 Hz
- Frequency, mode 3= 117. 1 Hz
- Frequency, mode 4= 133. 07 Hz
- Frequency, mode 5= 185. 4 Hz

**5. 2 V-g plot**

V-g plot is defined as the Velocity vsDamping plot that is to determine the flutter speed that is found by the FE approach.

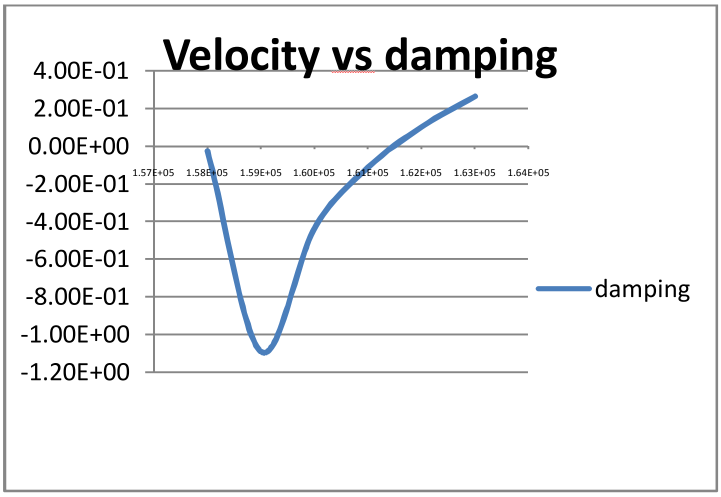


**Fig 5. 5 V-g plot**

**6. Conclusion**

From the V-g plot we can observe that the cross over occurs at 1. 61e-05 in the graph which is nothing but 161. 5m/s. This is the flutter speed we obtained through the FE analysis. Result obtained from analytical approach is about 605. 37ft/s that is about 184. 51m/s. Thus the HT we modelled and analysed satisfies the requirement such that the flutter velocity to be 1. 2 times the dive speed and the HT is said to be flutter free.

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