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A Finite Element Approach to Modal Parameter Estimation of Vertical Tail Fin

[1]Neethu Merlin Rajan, [2]Aman Kalra, [3]Pawan G Rebinal, [4]Ramesh Sharma
[1, 2, 3] UG Students, [4]Associate Professor
Department of Mechanical Engineering, R.V. College of Engineering, Bangalore, India.

Abstract: *The vertical stabilizers or fin of aircraft, missiles or bombs are typically found on the aft end of the fuselage or body, and are intended to reduce aerodynamic side slip and provide direction stability. Vertical tails designed for aircrafts suffer from reduced stability and control effectiveness at high dynamic pressures due to aeroelastic effects. Adequate tail performance requires a detailed study on dynamic performance before investigating aeroelastic effects. Experimental modal analysis is a very extensive, time consuming and expensive process while finite element analysis is quick, accurate, fast and economical. Hence, in the present work it is purposed to carry out a detailed finite element simulation of vertical tail fin for a UAV to evaluate modal parameters such as natural frequencies and its corresponding modal shapes. CAD modeling of the vertical tail fin was done in UG NX using spline and swept commands. The vertical fin is sandwiched with polyurethene foam of density 70kg/m^3 bonded with thin Aluminum sheet of 1mm thickness as face sheets. Similarly, biwoven e-glass fiber was considered as face sheets along with PU foam as core. The meshing of model was carried out using a 10 noded solid tetrahedral element. Boundary conditions were simulated and dynamic analysis was performed to evaluate natural frequencies and corresponding modal shapes.*

Keywords: *Modal Analysis, Natural Frequencies, Mode Shapes, Vertical Tail, FEM*

I. Introduction

For modern UAV’s, the ability to fly and maneuver at high angles of attack and at high loading conditions gives tactical advantages. For UAV’s the maneuverability at very high angles of attack is achieved through a combination of the wing root leading edge extensions (LEXs) and the placement of vertical tails. A pair of large vortices generated by highly swept wing root LEXs contribute to enhanced vortex lift by developing high suction areas over the wings. The UAVs are designed to utilize unique characteristics of these vortex structures which are prime contributors to the aerodynamics of an aircraft during high angle of attack flight. The vertical tails of the UAV’s are placed in closer proximity to the LEX vortex flow field to take full advantage of the concentrated energy contained in the LEX vortices to provide the directional stability and control necessary for high angle of attack maneuverability. Large buffet loads and associated fatigue damage have been observed on the tails of such aircrafts during certain flight conditions, including rapid maneuvering at subsonic Mach numbers and dynamic pressures considerably less than the maximum allowable values [1, 2].The interactions of a flexible structure with the aerodynamic forces acting on it are severe enough to influence the structural and aerodynamic design. The dynamic and aeroelastic analysis of an aircraft with main reference to its lifting and control surfaces is an essential aspect for finalization of the design cycle and is also required for obtaining flight clearance and certification of the aircraft. Correlation of the dynamic characteristics of the aircraft obtained from analysis with the Ground Vibration Test results of the aircraft was studied [3]. The airframes of high performance aircraft, have suffered from an aeroelastic tail buffet problem for many years. This problem is inherent to vertical flows used to generate lift at high angles of attack as they tend to break down causing severe empennage dynamic loading and premature fatigue failures. Better understanding of the empennage buffeting problem is required for development of reliable fatigue usage monitoring systems and for the fleet management of aircraft. The challenges associated with computational simulation of empennage buffet vary from prediction of the nonlinear separated vortical flows about complex configurations to the coupled interaction between the flow and the dynamic response of the tail structure [4].Vibration analysis of an aircraft component can characterize the structural dynamics, determine the fundamental frequencies and define the complete modal data of the component. From this data, engineers can objectively evaluate their concerns about the impact of vibrations on adjacent aircraft components. These concerns have very real consequences since excessive vibrations can lead to premature component fatigue and failure [5, 6]. Vertical tail fin is a critical component that must meet very high quality standards. Vertical tails designed for aircrafts suffer from reduced stability and control effectiveness at high dynamic pressures due to aeroelastic effects. Therefore, adequate tail performance requires a detailed study of dynamic performance before investigating aeroelastic effects [7, 8]. Also, modal analysis is not only useful in its own right, but it also provides the basis for a number of further dynamics analyses. To this end, modal test plays an important role in the certification process of any new or

extensively modified aircraft. Modal testing of an aircraft structure determines its natural frequencies, normal mode shapes and modal damping over a specified frequency bandwidth.
From the above literature, it is evident that there is no single source of literature on modal analysis of vertical tail fin using finite element techniques, although modal parameters are very essential in the predictions of aeroelastic flutter analysis. To this end, an attempt has been made to evaluate modal parameters of vertical tail fin with two different materials for face sheets and results are discussed.

II. Modeling of Vertical tail fin

The drawing details of an existing vertical tail fin of an Unmanned Aerial Vehicle as shown in Fig. 1. Data was created from the co-ordinates table for the base aerofoil obtained from the drawings. Similarly, another data was created for the top aerofoil. To sketch the base aerofoil in UG NX, the spline command was chosen. “Spline through points” option was selected and the option for “points from file” was selected. The above steps were repeated to obtain the top aerofoil. Fig. 2 shows the base and top aerofoil. A guide connecting the base and top aerofoil was drawn and using the “swept” command, the surface was modeled as shown in Fig. 3.

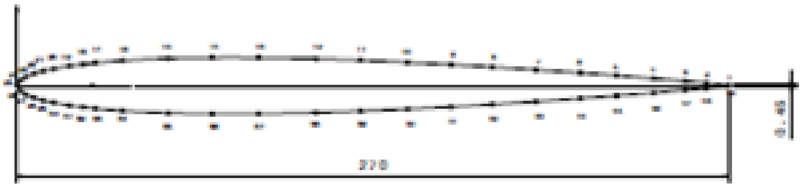


Fig – 1 Drawing details of base and top aero foil

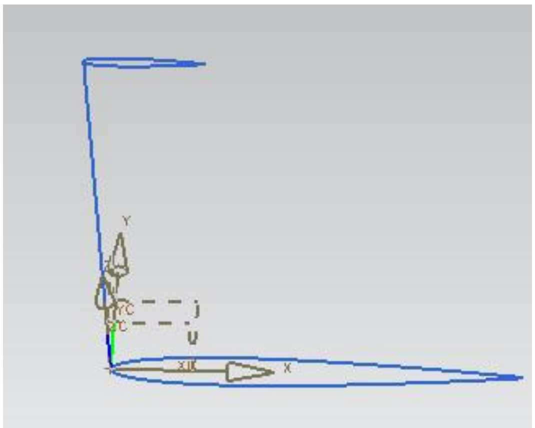


Fig – 2 CAD Modeling of base & top

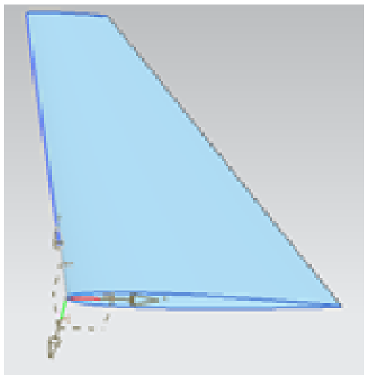


Fig – 3 Surface Modeling of Vertical Tail Fin

III. Finite Element Analysis of Vertical Tail Fin

The model was created in UG NX & then imported to ANSYS. In general, the vertical tail fin had a sandwich construction with bi-wovenglass cloth material on the top and bottom, and a layer of PU foam as the core. Each layer was assigned with different properties shown in Table -1. Top & bottom layers were meshed with Shell99 element and core was meshed with solid 92 elements. Ply thickness was maintained at 0.3mm throughout the model.

Table – 1 Properties of different materials

Material	Properties	Value
Aluminum	Density (ρ)	2700 kg/m^3
	Young’s Modulus (E)	72 GPa
	Poisson’s Ratio (ν)	0.28
Bi-woven Glass cloth	E_x	16.84 GPa
	E_y	16.84 GPa
	E_z	7.78 GPa
	G_{xy}	2.46GPa
	G_{yz}	2.38GPa
	G_{xz}	2.38GPa
	ν_{xy}	0.15
	ν_{yz}	0.49

	ν_{xz}	0.49
PUF	Density (ρ)	70 kg/m^3
	Young's Modulus (E)	12.3 MPa
	Poisson's Ratio (ν)	0.4

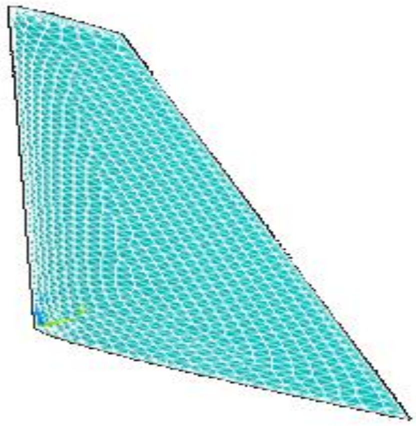
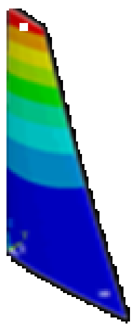


Fig – 4 Meshing of Vertical Tail Fin

IV. Results and Discussion

The 1st and 2ndmode shapes for the vertical tail with Aluminum& GFRP skins are shown in Fig. 5, 6, 7 & 8. Table1 shows the frequency values for different mode shapes for the vertical tail for both materials.

Fig – 5: Mode 1 – Bending Mode (Aluminum skin)



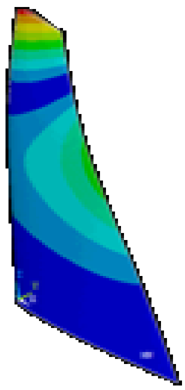


Fig – 6: Mode 2 – Torsional Mode (Aluminum skin)

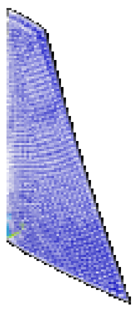


Fig 7: Mode 1 – Bending (GFRP skin)

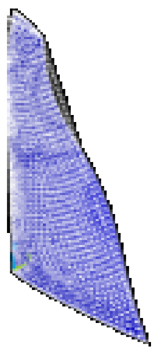


Fig 8: Mode 2 – Torsion (GFRP skin)

Table – 1 Frequency values of Aluminum and GFRP Skins

Mode No.	Aluminum	GFRP
	Frequency (Hz)	Frequency (Hz)
1	15.45	18.46
2	19.47	22.38
3	27.54	32.07
4	41.06	52.64
5	53.24	65.42

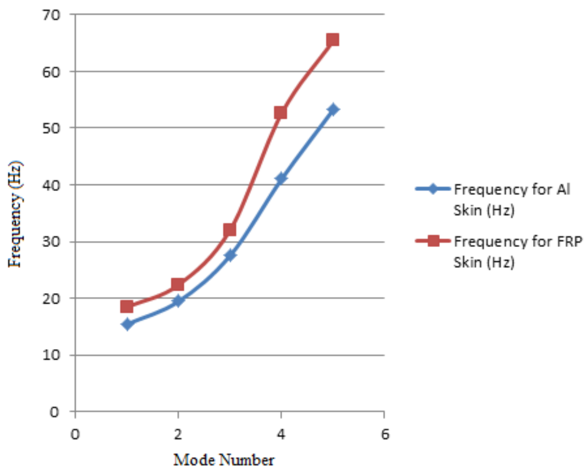


Fig – 9 Graph of Frequency Vs Mode No.

Figure 9 shows the graph of FEM simulation results of Aluminum and GFRP skins. The mode shapes correspond very well with previous studies available in literature. The natural frequencies are shown in Table – 1. Generally, the natural frequency of the first mode lies between 15-20 Hz. If the natural frequencies are extraordinarily high or close to each other, then there may be errors in the simulation. If a model gives reasonable results, we can then simply adjust the material properties and the geometries to modify the design, which would be much faster and easier to manage than manually crafting the prototype. Since most of the important conclusions of vertical tail fin are based on the low frequency range(and no previous literature have shown the fin mode shapes up to the sixth mode), the scope here is limited to the first few modes for comparison. As evident, both the mode shapes and the natural frequencies fit quite well comparing the two. Another notable difference between the two materials (Aluminum and GFRP) is the natural frequency which is higher in case of GFRP skin since glass fiber is stiffer than aluminum. If is found that there is 16% increase in frequency between the two materials provided all parameters remain constant.

V. Conclusions

The aim of this work was to study the vibrational behavior of vertical tail fin using Finite element analysis and to explore the possibility of using composite material (GFRP) as a substitute for traditional Aluminum for Vertical Tail fin. FE simulations were carried out; the results thus obtained were convincing and also strongly agree with many previously published works by other researchers [9, 10]. Thus, we can conclude that GFRP which attracts designers because of its lightweight characteristics as compared to traditional Aluminum can be replaced for better performance and efficiency. Further, the results of this modal analysis form a vital input for flutter analysis in aeroelasticity.

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