IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 4 Ver. III (Jul. - Aug. 2015), PP 104-110
www.iosrjournals.org

Static Stress Analysis And Normal Mode Analysis of Horizontal Tail Structure of An Aircraft Using Analysis Software

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Abstract: *Aircraft consist of Horizontal tail and elevator at the rear end of the fuselage. Whose job is to provide stability for the aircraft to keep it flying straight. The horizontal stabilizer prevents up-and-down or pitching, motion of the aircraft nose. The material used for construction of horizontal tail are aluminum alloy, titanium alloy, fiber reinforced composites. Now a day's all aircraft manufacturing industry are using composite materials instead of metallic materials. Composite materials are well known for their excellent combination of high structural stiffness and low weight. CFC is seen to have a modulus twice &strength three times that of aluminum alloy, the conventional material used in aircraft construction. In the present work we are going to compare the percentage of weight for both carbon fiber composite material and aluminum alloy 2124 series. The parametric study conducted using Msc Nastran and Hypermesh. From the studies conducted regarding the weight reduction, it is estimated that replacement of Al alloy by CFC results in 54.73% saving in the total structural weight of the aircraft Horizontal Tail. The normal mode analysis the resonance frequency of aircraft is 10Hz but for Horizontal tail the frequency is almost zero so the design is safe.*
Keywords: *CFC,Hypermesh, Horizontal Tail, Static Analysis, Normal Mode Analysis.*

I. Introduction

At the rear of the fuselage of most aircraft consist of horizontal stabilizer and an elevator. The stabilizer is a fixed horizontal tail section whose job is to provide stability for the aircraft, to keep it flying straight. The horizontal stabilizer prevents up-and-down or pitching, motion of the aircraft nose. The elevator is the small moving section at the rear of the stabilizer that is attached to the fixed sections by hinges. Because the elevator moves, it varies the amount of force generated by the tail surface and is used to generate and control the pitching motion of the aircraft. There is an elevator attached to each side of the fuselage. The elevators work

In pairs when the right elevator goes up, the left elevator also goes up. This slide shows what happens when the pilot deflects the elevator. The elevator is used to control the position of the nose of the aircraft and the angle of attack of the horizontal tail. Changing the inclination of the horizontal tail to the local flight path changes the amount of lift which the horizontal tail generates. This in turn causes the aircraft to climb or dive. During takeoff the elevators are used to bring the nose of the aircraft up to begin the climb out. During a banked turn, elevator inputs can increase the lift and cause a tighter turn. That is why elevator performance is so important for fighter aircraft. The elevators work by changing the effective shape of the airfoil of the horizontal stabilizer. As described on the shape effects slide, changing the angle of deflection at the rear of an airfoil changes the amount of lift generated by the foil. With greater downward deflection of the trailing edge lift increases. With greater upward deflection of the trailing edge, lift decreases and can even become negative as shown on this slide. The lift force is applied at center of pressure of the horizontal stabilizer which is some distance from the aircraft center of gravity. This creates a torque on the aircraft and the aircraft rotates about its centre of gravity. The pilot can use this ability to make the airplane loop or since many aircraft loop naturally, the deflection can be used to trim or balance the aircraft, thus preventing a loop. If the pilot reverses the elevator deflection to down, the aircraft pitches in the opposite direction.

II. Materials And Method

2.1Material and Configuration of Aircraft Horizontal tail

In this project first we are considering Al-Cu (2124). This material is low strength and high weight to reduce that we are using carbon fiber composite material. This material has high strength and low density and also has a less deformation.

2.2 Structural Layout

The horizontal tail aircraft considered in the present study is rectangular taper horizontal tail. The cross section of the wing is aero foil.The aerofoil structure of a horizontal tail obey Bernoulli's Principle, the pressure above the horizontal tail is less than it is below the horizontal tail, generating a lift force over the upper curved surface of the horizontal tail in the direction of the low pressure. The dimension of the horizontal tail is 8026mm is overall length, space in b/w the two ribs is 803mm, root chord of 4643mm and tip chord of 1725mm. the various structural component for horizontal tail are Top skin ,bottom skin, 11 ribs, rare spar, front spar.

The air loads act directly on the horizontal tail cover, which transmits the loads to the ribs. The ribs transmit the loads to the spar webs and distribute the load between them in proportion to the web stiffness. The use of several spars permit a reduction in rib stresses and also provides a better support for the span wise bending ribs are used to hold the panel to contour shape. The rib also has another major purpose, to transfer or distribute the loads. The ribs provide stability to spars and panels. The primary function of the horizontal tail skin is to form an impermeable surface for supporting the aerodynamic pressure distribution from which the lifting capability of the horizontal tail is derived.

2.3 Horizontal Tail Model

This aircraft modal consist of a two material one is Al-Cu alloy and other is carbon fiber composite material. Here dimensional specifications are same for both the materials but first we find the stress analysis for Al-Cu alloy for horizontal tail and then just changing the material to CFC for upper skin and lower skin of horizontal tail and also we get the weight reduction for horizontal tail.

2.4 Analysis Method

Horizontal tail model can be done in CATIA V-5. Then the model is imported to hyper mesh for generating mesh and the mesh model is further allowed to run in the Nastran software we get the (.bdf) and (.op2) file these two will run in hyperview so we will get all animated results.

III. Results And Discussion

The static stress analysis and normal mode analysis both can be carried for horizontal tail using the pre and post processing of finite element model using Hypermesh and Nastran. The total weight of horizontal tail carried out two iterations for metallic structure and composite structure and we got the optimum structure the metallic horizontal tail lower skin and upper skin is replaced by CFRC and we have seen there is saving of 45% & 55% of weight of an aircraft. And in normal mode analysis the resonance frequency of aircraft is 10Hz but the frequency for horizontal tail is 0.981 so it shows horizontal tail is safe.

IV. Figures And Tables

Table 1: Material Properties of Al-Cu Alloy

Sl.NO	MECHANICAL PROPERTIES	Aluminum 2124T6511
1	Young's Modulus E	$70x10^3 N/mm^2$
2	Poisson's Ratio µ	0.35
3	Density ρ	$2.70x10^{-6}$ Kg/mm^3
4	Ultimate tensile stress	$460N/mm^2$
5	Shear strength	$276\ N/mm^2$
6	Yield strength	385Mpa

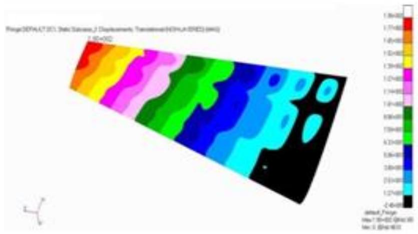
Table 2: Horizontal Tail Specification

Sl.NO	COMPONENT	TYPE OF ELEMENT	PROPERTIES
1	Rib	2D	Material: Aluminum 2124 Thickness: 2mm
2	Spar-flange	1D	Cross section: Rectangle W= 100; H=30; Material: Aluminum 2124
3	Spar web	2D	Material: Aluminum 2124 Thickness: 20mm
4	skin	2D	Material: Aluminum2124 Thickness: 3mm

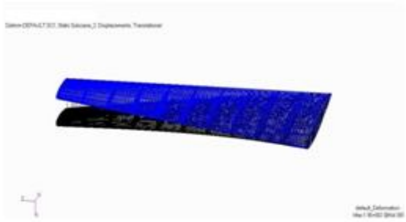
Table 3: Carbon Fiber Composite Material Property

1	Number of layers	14mm
2	Thickness of 1 layer	0.33
3	Thickness of 14 layers	14*0.33=4.62mm
4	Longitudinal modulus 11	138600Gpa
5	Transverse modulus 22	82700Gpa
6	Poisons ratio µ12	0.25
7	Shear modulus G12	4120Gpa
8	Tension stress limit 11	432Mpa
9	Ply orientation sequence	(0, 90, -45, 45, 45, -45, 90)
10	Tension stress 22	60Mpa
11	Compression stress11	560Mpa
12	Compression stress22	60Mpa
13	Shear stress limit	36Mpa
14	Bending shear stress limit	80Mpa

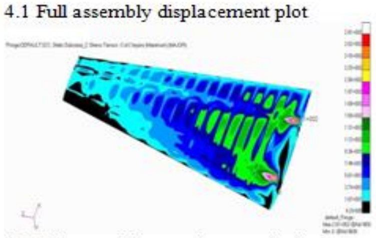
4.1 Iterationfor Aluminium Alloy



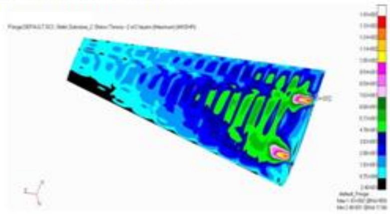
4.1 Full assembly displacement plot



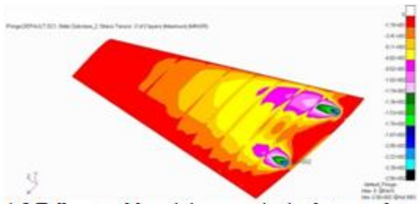
4.2 Full assembly displacement plot



4.3 Full assembly maximum principal stress plot



4.4 Full assembly maximum shear stress plot



4.5 Full assembly minimum principal stress plot

Table4: Stress Results for Aluminium Alloy

No	Component	Material Specification	Type of Stress/Strain	Developed Stress/Strain	Allowable Stress/Strain	Reserve Factor RF
1	Upper Skin	Al-Cu	Max Principal Stress	70.1	460	6.56 RF>1
			Minimum principal Stress	256	460	1.79 RF>1
			Max shear stress	139	276	1.98 RF>1
2	Bottom Skin	Al-Cu	Max Principal Stress	281	460	1.68 RF>1
			Minimum principal Stress	72.1	460	6.38 RF>1
			Max shear stress	143	276	1.93 RF>1
3	Full assembly part	Al-Cu	Max Principal Stress	281	460	1.63 RF>1
			Minimum principal Stress	256	460	1.79 RF>1
			Max shear stress	143	276	1.93 RF>1

Spars Result

1	Front	Al-Cu	Max Principal Stress	231	460	1.99 RF>1
			Minimum principal Stress	225	460	2.04 RF>1
			Max shear stress	118	276	2.33 RF>1
2	Rear	Al-Cu	Max Principal Stress	254	460	1.81 RF>1
			Minimum principal Stress	206	460	2.23 RF>1
			Max shear stress	127	276	2.17 RF>1

Ribs Result

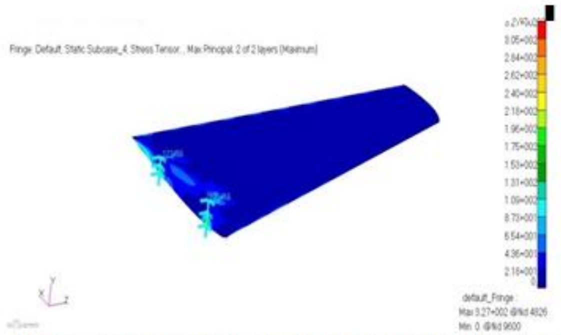
1	Rib1	Al-Cu	Max Principal Stress	357	460	1.28 RF>1
			Minimum principal Stress	225	460	2.04 RF>1
			Max shear stress	193	276	1.43 RF>1
2	Rib2	Al-Cu	Max Principal Stress	320	460	1.43 RF>1
			Minimum principal Stress	73.9	460	6.22 RF>1
			Max shear stress	163	276	1.69 RF>1
3	Rib3	Al-Cu	Max Principal Stress	289	460	1.59 RF>1
			Minimum principal Stress	81.9	460	5.61 RF>1
			Max shear stress	148	276	1.86 RF>1
4	Rib4	Al-Cu	Max Principal Stress	284	460	1.61 RF>1
			Minimum principal Stress	52	460	8.84 RF>1
			Max shear stress	145	276	1.90 RF>1
5	Rib5	Al-Cu	Max Principal Stress	289	460	1.59 RF>1
			Minimum principal Stress	33	460	13.9 RF>1
			Max shear stress	147	276	1.87 RF>1
6	Rib6	Al-Cu	Max Principal Stress	291	460	1.58 RF>1
			Minimum principal Stress	32	460	14.37 RF>1
			Max shear stress	149	276	1.85 RF>1
7	Rib7	Al-Cu	Max Principal Stress	289	460	1.59 RF>1
			Minimum principal Stress	33.2	460	13.85 RF>1
			Max shear stress	147	276	1.87 RF>1
8	Rib8	Al-Cu	Max Principal Stress	282	460	1.63 RF>1
			Minimum principal Stress	33.4	460	13.77 RF>1
			Max shear stress	144	276	1.91 RF>1
9	Rib9	Al-Cu	Max Principal Stress	272	460	1.69 RF>1
			Minimum principal Stress	34	460	13.52 RF>1
			Max shear stress	139	276	1.98 RF>1

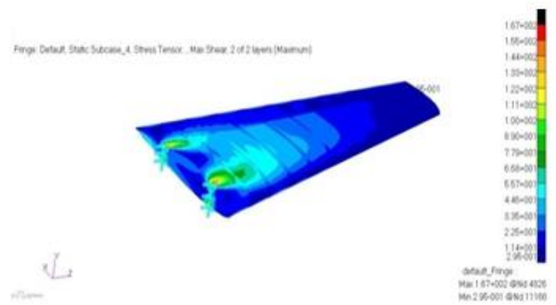
- Allowable principle stress for skin, spar, rib is 460Mpa
- Allowable shear stress for skin, spar, rib is 276Mpa
- So the acting stresses from FEM should be less than 460Mpa for principle stress and 276Mpa for shear stress.
- Reserve Factor= Allowable stress/acting stress(FEM stress)
- Reserve Factor should be greater than 1 for safe design.
- If RF is less than one, redesign the component and analysis should be carried out.
- The HT structure components whose RF less than 1 as shown in the stress result table.

Conclusions for Aluminum alloy Iteration

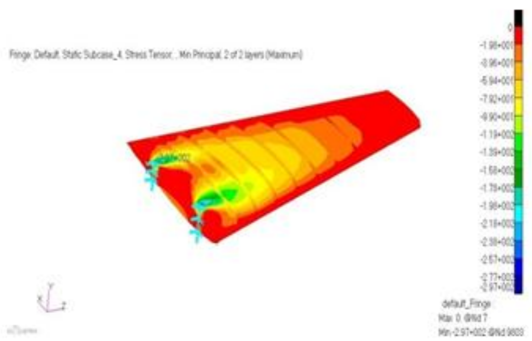
- From the iteration-1 stress results, for the bottom skin max principal stress generated is 281Mpa.so the allowable stress is ,460Mpa, so the Reserve Factor is 460/281=1.63. So the design of the bottom skin is safe for the applied loads.
- From the iteration-1 stress results, for the front spar and rear spar max principal stress generated is 231 & 254Mpa. The Allowable stresses are 460Mpa.so the RF is 1.99& 1.81So the design of the Front spar and Rear Spar is safe for the applied loads.
- From the iteration-1 stress results, for the Upper skin max principal stress generated is 70.1Mpa.so the allowable stress is ,460Mpa, so the Reserve Factor is 460/70.1=6.56. So the design of the Upper skin is safe for the applied loads.
- From the iteration-1 stress results, for the Ribs max principal stress generated is 266Mpa.so the allowable stress is 460Mpa, so the Reserve Factor is 460/266=1.72. So the design of the Ribs is safe for the applied loads.
- For 2nd series Al alloy the density, mass, volume is 2.7e-6, 344.5, 1.27e8 so using these value we find out the stress by FE method. So these value are compare to the allowable stress so here design is safe so we need to reduce the weight or mass of the HT so in the next iteration we are considering the carbon fiber as a composite material so to reduce the weight and to increase the stiffness of the HT.

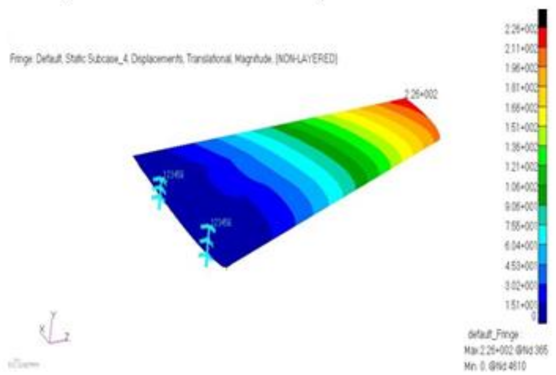
4.2 Iteration for Carbon Fiber Composite Material





4.6Full assembly maximum principal stress plot4.7Full assembly maximum shear stress plot





4.8 Full assembly Minimum principal stress plot4.9 Full assembly Displacement plot

Table5: Stress Results for Carbon Fiber Composite Material

No	Component	Material Specification	Type of Stress/Strain	Developed Stress/Strain	Allowable Stress/Strain	Reserve Factor RF
1	Top Skin	CFC	Max Principal Stress	194	432	2.22 RF>1
			Minimum principal Stress	202	560	2.77 RF>1
			Max shear stress	48	80	1.66 RF>1
			Major Principal Strain	2980	3400	1.14 RF>1
			Minor principal strain	3330	3900	1.17 RF>1
			Failure index	0.48	1.0	0.48 FI<1
2	Bottom Skin	CFC	Max Principal Stress	282	432	1.53 RF>1
			Minimum principal Stress	91	560	6.15 RF>1
			Max shear stress	52	80	1.53 RF>1
			Major Principal Strain	3250	3400	1.04 RF>1
			Minor principal strain	2410	3900	1.61 RF>1
			Failure index	0.51	1	0.51 FI<1

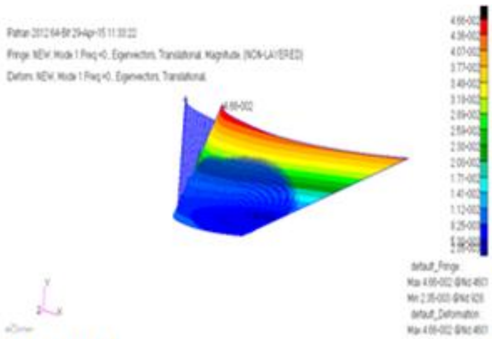
- Reserve Factor= Allowable stress/acting stress(FEM stress)
- Reserve Factor should be greater than 1 for safe design.
- If RF is less than one, redesign the component and analysis should be carried out.
- The HT structure components whose RF less than 1 as shown in the stress result table.

Table6: Comparison of weight reduction between CFC and aluminium alloy

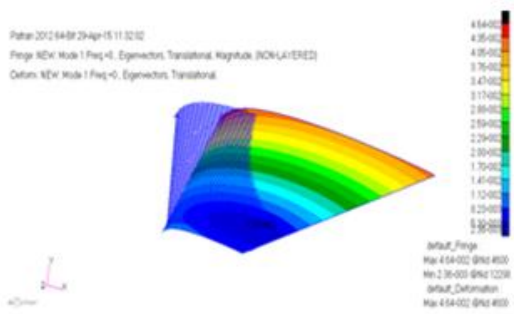
Since preliminary design of the HT structures carried out as per the industrial practices for the given applied loads by iteration process and we carried out two iterations for metallic structure And composite structure and at iteration we got the optimum structure the metallic HT skin, bottom and top is replaced by CFRC and we have seen there is saving of 45% & 55% of weight of an aircraft

METALLIC SKIN	Aluminum			
COMPONENT	Volume (mm3)	Density(Kg/mm3)	Mass kg	
Bottom skin	1.276×10^8	2.70E-06	344.5	
Top skin	1.337×10^8	2.70E-06	361	
COMPOSITE SKIN	CFC			
COMPONENT	Volume(mm3)	Density(kg/mm3)	Mass kg	
Bottom skin	1.071x10^8	1.76x10^-6	188.64	
Top skin	1.123x10^8	1.76x10^-6	197.64	
TOTAL WEIGHT SAVING	Mass(kg)-metallic	Mass(kg)-composite	Weight saving(kg)	%wt. saving
Bottom skin	344.5	188.64	155.86	45.24
Top skin	361	197.64	163.36	54.73

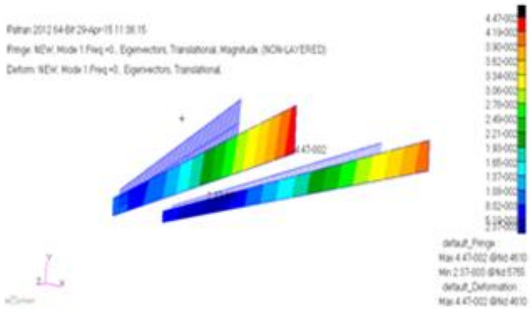
V. Normal Mode Analysis



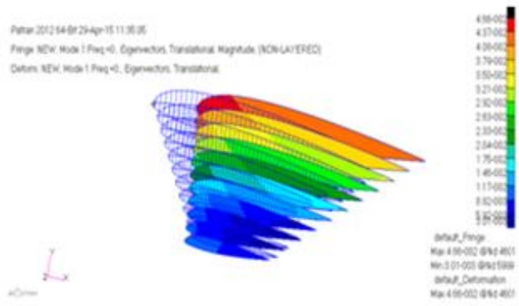
5.1 Model



5.2 Mode2



5.3 Mode3



5.4 Mode4

Natural frequency results

SL.NO	MODE	MODE SHAPE	Natural frequency
1	Mode-1	1st Bending	0.2226 Hz
2	Mode-2	1st twisting	0.98108 Hz
3	Mode-3	2nd twisting	1.1933 Hz
4	Mode-4	1st axial	1.2053 Hz
5	Mode-5	2nd axial	1.2768 Hz
6	Mode-6	3rd twisting	1.3094 Hz
7	Mode-7	3rd axial	1.3094 Hz
8	Mode-8	4th twisting	1.3593 Hz

Table7 : Natural frequency results

In a normal mode analysis there are four mode which are shown in above figure. The resonance frequency of aircraft is 10Hz but for Horizontal tail we are getting approximately zero as shown in the above table7 so the design of Horizontal tail is safe.

VI. Conclusion

Since preliminary design of the wing structures carried out as per the industrial practices for the given applied loads by iteration process and we carried out 2 iterations one for metallic structure and other iteration for composite. The iteration process for metallic (Al-Cu) is safe but still we need to reduce the weight of the Horizontal tail so in the iteration process we taken carbon composite material so using CFC material we reduced the weight of the horizontal tail almost 50% still there is a scope for weight reduction of the horizontal tail structure by replacing the metallic ribs and spars by composites. In this project we only found out the static stress and normal mode analysis but still more we need to analyses we can go for buckling, dynamic mode analysis can be done. This is consider for the future scope of the project.

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