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RESEARCH ARTICLE

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DESIGN AND STUDY OF HELICOPTER ROTOR BLADE FOR VIBRATION REDUCTION USING FINITE ELEMENT TECHNIQUES

K.MEGHANA[1], T.ANAND[2]

[1]M.Tech, Student, Department of Mechanical Engineering, Chirala College of Engineering, Chirala, A.P

[2]Assoc.Professor, Department of Mechanical Engineering, Chirala College of Engineering, Chirala,A.P

ABSTRACT

The significance of title of the project is to calculate the static and the dynamic characteristics of Helicopter rotor wings have been analyzed with ANSYS software package. During the analysis of rotor blades, the influence of aerodynamic force and centrifugal forces are applied with the comparison of weight for two different materials (Aluminium and composite material). In static analysis, analyze angular velocity and gravity of earth. During dynamic analysis, to calculate the natural frequency and modal shape of rotor blade is modulating those frequencies and avoiding resonance during rotational speed, then the vibration level of helicopter may reduce. The procedural step includes various aspects such as selecting the material based on American Institute of Aeronautics & Astronautics(AIAA), 1990. and then designing on the standards procedures with referring standard manuals based on ASME. Further we have included the different manufacturing methods practice by the industries and different aspects of it.

Key Words: Rotor System, Aerodynamics, Finite Element Analysis, Mode Shape, Frequency, Vibration, Weight, Air Compressibility

I. INTRODUCTION

The lift force is acting on the wings then they move in the air. As we known, during flight, there are four forces acting on the airplane. Those are LIFT, DRAG, THRUST, and WEIGHT. In order to make the wings to move in the air, of course, the plane itself has to move. A helicopter works by having its wings move through the air while the body stays still. The helicopter's wings are also called Main Rotor Blades. Depend on the shape and the angle of the wings will determine how much Lift force is needed. After the helicopter lifted off the ground, the pilot can tilt the blade, which causes the helicopter to move side to side in any way. Helicopters may come in several sizes and shapes, but most are having same major components. These components are stay in a cabin where the payload and crew are carried out over there. a engine; which is used to takes the power and a transmission; which transmits power from the engine to the main rotor which gives the aerodynamic forces that make the helicopter to fly. The helicopter turns due to torque, there must be some anti torque system acting on the plane. Finally there is the landing gear, wheels, and floats.

FEM is the numerical technique for getting approximate solutions to wide variety of engineering problems.

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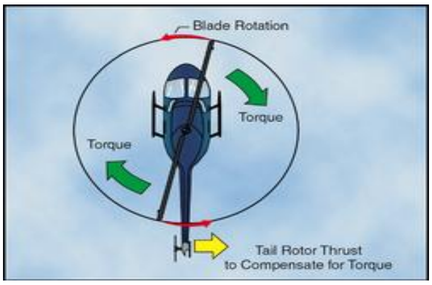


II.Finite Element Method

2.0 Material Properties:

Aluminum Mechanical Properties:

Young's modulus = 70Gpa

Yield Strength = 170 Mpa

Poison's ratio = 0.3

Density = 2700 kg/m3

Element Type Used:

Type of Element: Solid92

No. of nodes: 10

Degrees of freedom: 3 (UX, UY, UZ)

Solid92:

The element is defined by ten nodes, each node having three degrees of freedom and node translations are x, y, and z directions.

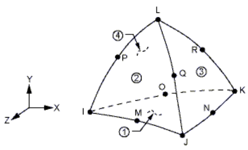
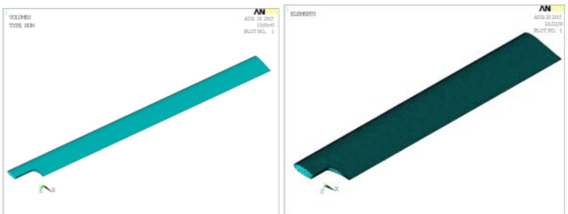


Figure 1: Solid92 geometry

3D model of the helicopter rotor blade was developed in PROE.



3.1 infinite model 3.2 finite

3.3 Static Analysis of Helicopter Rotor Blade

Structural static analysis has been analyzed on the helicopter rotor blade by applying the angular velocity and gravity of earth. The locations are fixed in all degrees of freedom.

The boundary conditions and loading applied for static analysis

Angular velocity and gravity of earth are applied to helicopter rotor blade.

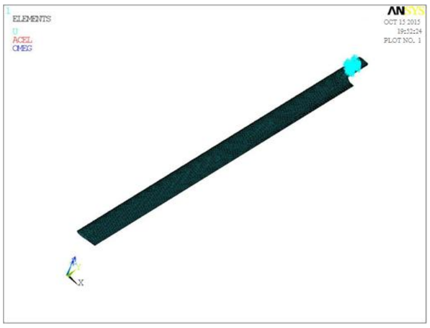
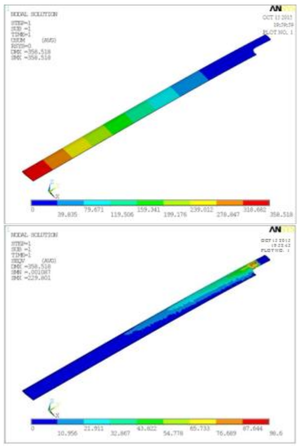


Fig. 3.4 Loads are applied



3.5 Total Deflection 3.6 Von Mises stress

It is observed that the maximum VonMises stresses observed in 98 Mpa. When the pointing location is located, the maximum stress occurs. The yield strength of the material is 170 Mpa. Further modal analysis is done to check the dynamic behavior of helicopter rotor blade.

1.7.Dynamic Analysis Of Helicopter Rotor Blade

The dynamic analysis of rotor blade is mainly involved in the parameters of about natural frequency and modal shape. The main objective to calculate the natural frequency and modal shape of rotor blade and modulating those frequencies for avoiding resonance at rotational speed, thus the vibrations in the helicopter may reduce.

In theory, the stiffness of composite material is not the simple summation of stiffness of each constituted material, viz. $EI \neq \Sigma E I i$. On the other hand, the inter laminar constrainer has little effect on stiffness (< 2%),$EI = \Sigma E I i$, Young's Modulus E , equivalent Poisson's Ratio μ and equivalent density ρ .

Methodology:

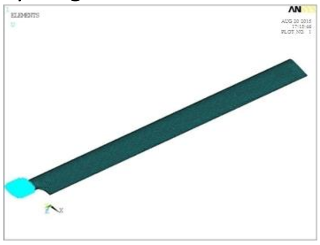
Develop a 3D model. The 3D model is created using PRO E software. The 3D model is converted into parasolid and imported into ANSYS to do modal analysis. Calculate natural frequencies and plot their mode shapes.

3.8 Mode Shapes

For every natural frequency there is a corresponding vibration mode shape. Most mode shapes can generally be described as being an axial mode, torsion mode, bending mode, or general modes.

3 Model Analysis:

The frequency range of 0 -100Hz.



3.10 Boundary Conditions:

Total helicopter blade weight is 108kgs.

Frequencies and mass participations for modes in the range of 0- 100Hz

Mode Shape 2@4.62Hz

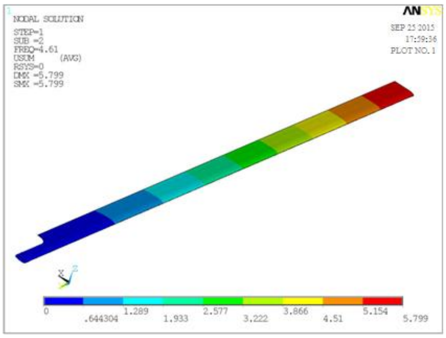
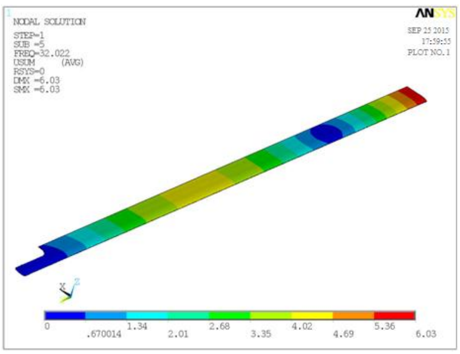
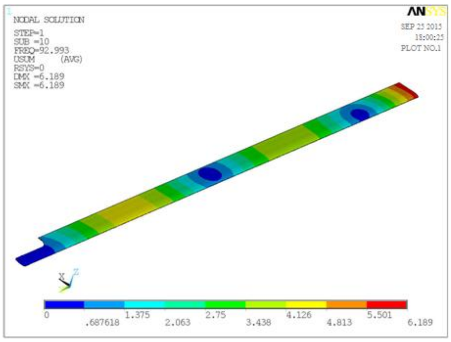


Fig. 3.11

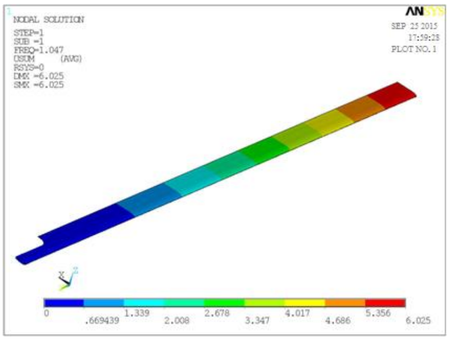
3.11 Mode shape 5@32 Hz



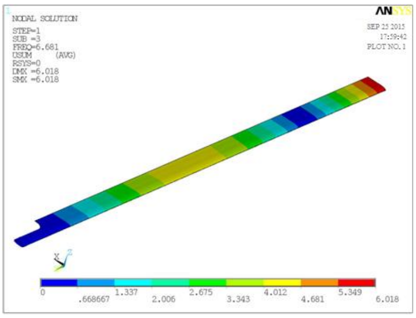
3.12 Mode shape 10@92.9 Hz



3.13 Mode shape 1@1.4 Hz



3.14 Mode shape 3@6.6 Hz



From the above,

- It is observed that the maximum mass participation of 71.6kgs and 18.9kgs are observed in X-dir for the frequency of 4.6Hz and 32Hz.
- It is observed that the maximum mass participation of 0.39kgs is observed in Y-dir for the frequency of 92.9Hz.
- It is observed that the maximum mass participation of 67.3kgs and 20.3kgs are observed in Z-dir for the frequency of 1.04Hz and 6.6Hz.

Harmonic analysis is carried out on the helicopter rotor blade.

3.15 .Harmonic Analysis

Any sustained cyclic load will produce a sustained cyclic response (a harmonic response) in a structural system.

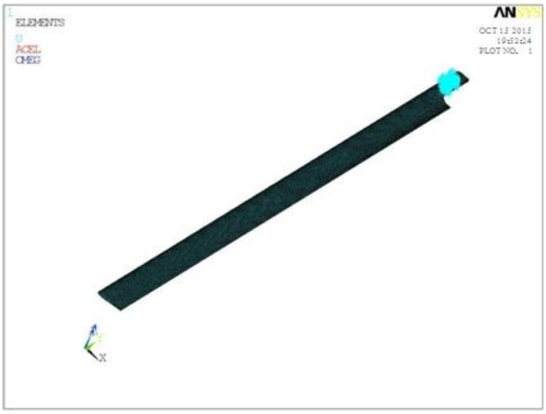


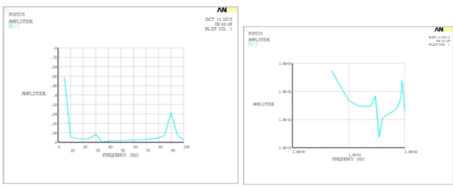
Fig. 3.16 shows Boundary conditions

MODE	FREQUENCY	PARTIC.FACTOR(Tone)			EFFECTIVE MASS(Tone)		
		X	Y	Z	X	Y	Z
1	1.04	2.9E-04	-7.7E-07	0.259	8.4E-08	5.9E-13	6.7E-02
2	4.61	0.267	1.8E-03	-8.5E-04	7.1E-02	3.5E-06	7.3E-07
3	6.68	-1.2E-3	-1.E-05	-0.14	1.4E-06	1.5E-10	2.0E-02
4	18.88	-1.2E-4	-2.3E-06	8.1E-02	1.4E-08	5.3E-12	6.6E-03
5	32.02	-0.131	-8.2E-03	1.4E-04	1.9E-02	6.7E-05	2.2E-08
6	37.15	-4.0E-4	-3.9E-05	-5.7E-02	1.6E-07	1.1E-09	3.3E-03
7	50.42	-4E-05	-1.4E-05	-5.1E-04	2.4E-09	2.1E-10	2.6E-07
8	61.74	9.7E-06	1.4E-05	4.4E-02	9.4E-11	2.1E-10	1.9E-03
9	91.47	-1.9E-3	-5.2E-04	-3.6E-02	3.8E-06	2.7E-07	1.3E-03
10	92.99	7.5E-02	1.9E-02	-9.9E-04	5.6E-03	3.9E-04	9.8E-07

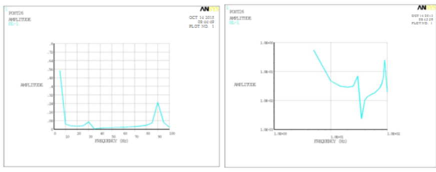
MODE	FREQUENCY	PARTIC.FACTOR(Tone)			EFFECTIVE MASS(Tone)		
		X	Y	Z	X	Y	Z
1	1.04	2.9E-04	-7.7E-07	0.259	8.4E-08	5.9E-13	6.7E-02
2	4.61	0.267	1.8E-03	-8.5E-04	7.1E-02	3.5E-06	7.3E-07
3	6.68	-1.2E-3	-1.E-05	-0.14	1.4E-06	1.5E-10	2.0E-02
5	32.02	-0.131	-8.2E-03	1.4E-04	1.9E-02	6.7E-05	2.2E-08

Graphs: Amplitude v_s forcing frequency:

3.16 Harmonic response at edge



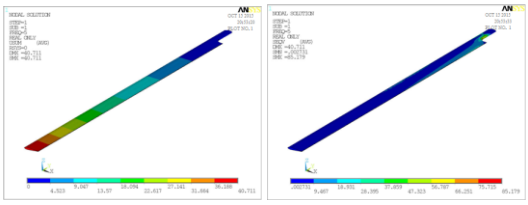
3.17 Harmonic locaton at center



Amplitude of 0.5 mm and .0.24mm are observed on the blade edge of helicopter rotor blade at a frequency of 5Hz and 90 Hz. Amplitude of 9mm is observed on the blade centre of helicopter rotor blade at a frequency of 5Hz.

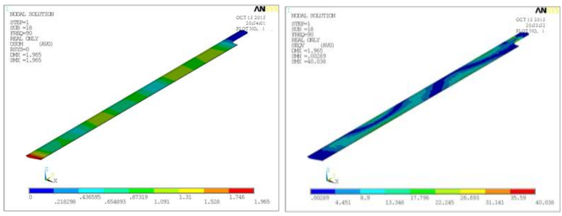
Deflections

3.18 Max. deflection and stress of frequency @ 5Hz



Total Deflection Von Mises stress

3.19 Max. Deflection and stress of frequency @ 90Hz



S.no	FREQUENCY(Hz)	DEFLECTIONS (mm)	VON MISES STRESS (MPa)
1	5	40.7	85.1
2	90	1.9	40

The critical frequencies 5 Hz, and 90 Hz are having stresses of 85MPa, and 40 MPa respectively. The yield strength of the material used for helicopter rotor blade is 170 MPa. According to the VonMises Stress Theory, the VonMises stress of helicopter rotor blade at frequencies 5 Hz, and 90 Hz are having less stresses than the yield strength of the material. Hence the design of helicopter rotor blade is safe for the above operating loading conditions.

II. Analysis of Helicopter Rotor Blade with Composite Material

Material Properties:

Fibers are available with widely differing properties. Review of the design and performance requirements usually dictate the fiber/fibers to be used.

S. No	Property	Units	HM Carbon/Epoxy
1.	E_{11}	GPa	190.0
2.	E_{22}	GPa	7.7
3.	G_{12}	GPa	4.2
4.	ν_{12}	-	0.3
5.	$S^t_1 = S^c_1$	MPa	870.0
6.	$S^t_2 = S^c_2$	MPa	54.0
7.	S_{12}	MPa	30.0
8.	P	Kg/m^3	1600.0

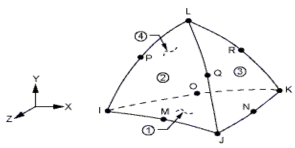
Table Properties of HM Carbon/Epoxy

Element Type Used:

Element type: Solid92

No. of nodes: 10

Dof: 3 (UX, UY, UZ)



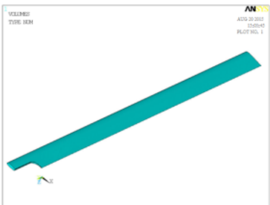
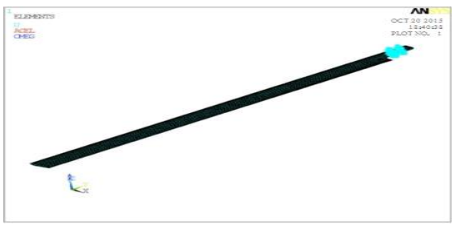
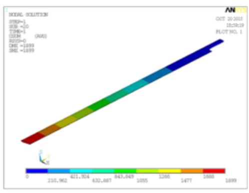


Fig.4.1 infinite model

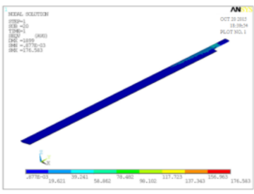
4.2 finite



4.3 Loads are applied



4.4 Total Deflection

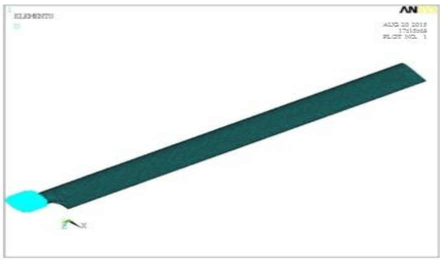


4.5 Von Mises stress

S.no.	DEFLECTION (mm)				STRESS			
	UX	UY	UZ	USUM	S_1	S_2	S_3	Von mises
1	28.7	7.7	0.02	1899	97	23	5	176

Table the max. Deflection and Max. Stress

4.6. Dynamic Analysis

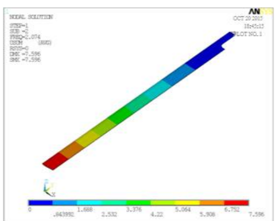


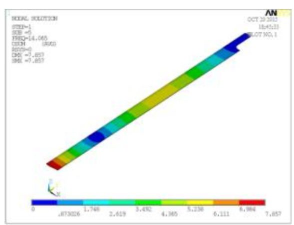
4.6 Loads are applied

Total helicopter blade weight is 35.8kgs.

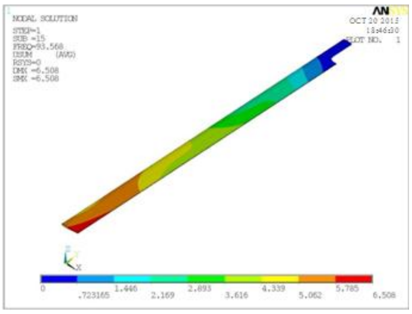
TABLE .frequencies and mass participations in the range of 0- 100 Hz

MODE	FREQUENCY	PARTIC.FACTOR			EFFECTIVE MASS		
		X	Y	Z	X	Y	Z
1	0.449	1.6E-04	-7.00E-07	0.198	2.6E-08	4.9E-13	3.9E-02
2	2.073	0.204	1.31E-03	-6.2E-04	4.1E-02	1.7E-06	3.9E-07
3	2.8525	-9.1E-04	-5.58E-06	-0.109	8.3E-07	3.1E-11	1.2E-02
4	8.040	-6.3E-05	-3.44E-06	6.2E-02	4.0E-09	1.1E-11	3.9E-03
5	14.06	-0.106	-5.94E-03	1.5E-04	1.1E-02	3.5E-05	2.2E-08
6	15.81	-4.03E-04	-2.48E-05	-4.4E-02	1.6E-07	6.1E-10	1.9E-03
7	26.24	3.3E-05	5.87E-06	3.4E-02	1.1E-09	3.4E-11	1.1E-03
8	37.74	2.5E-03	6.05E-04	4.6E-03	6.4E-06	3.6E-07	2.2E-05
9	39.02	4.5E-04	1.13E-04	-2.7E-02	2.0E-07	1.2E-08	7.5E-04
10	40.66	5.8E-02	1.49E-02	-1.4E-05	3.4E-03	2.2E-04	1.9E-10
11	54.64	6.0E-05	3.18E-05	2.3E-02	3.6E-09	1.0E-09	5.3E-04
12	72.68	1.7E-04	1.89E-04	-2.0E-02	2.8E-08	3.5E-08	4.1E-04
13	80.07	-3.7E-02	-6.27E-02	-2.9E-05	1.4E-03	3.9E-03	8.6E-10
14	93.3	-2.4E-05	5.24E-04	1.7E-02	5.8E-10	2.7E-07	2.9E-04
15	93.56	-1.3E-02	0.21907	-3.1E-05	1.7E-04	4.8E-02	1.0E-09

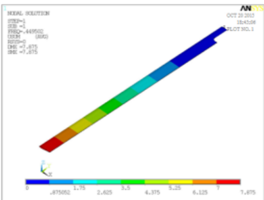


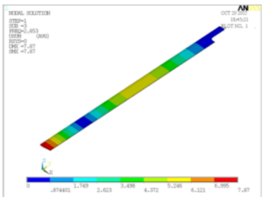


Mode shape@2Hz Mode shape@14Hz-X



Mode shape@93.5-Y





Mode shape@.44Hz Mode shape@2.8Hz-Z

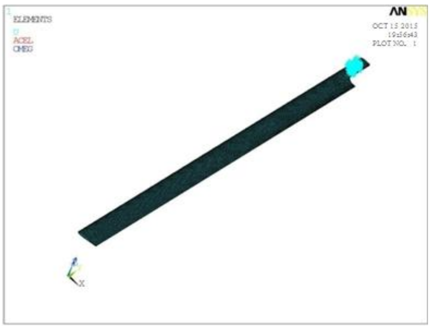
TABLE .frequencies and mass participations in the range of 0- 100 Hz

MODE	FREQUENCY	PARTIC.FACTOR			EFFECTIVE MASS		
		X	Y	Z	X	Y	Z
1	0.449	1.6E-04	-7.00E-07	0.198	2.6E-08	4.9E-13	3.9E-02
2	2.073	0.204	1.31E-03	-6.2E-04	4.1E-02	1.7E-06	3.9E-07
3	2.8525	-9.1E-04	-5.58E-06	-0.109	8.3E-07	3.1E-11	1.2E-02
5	14.06	-0.106	-5.94E-03	1.5E-04	1.1E-02	3.5E-05	2.2E-08
15	93.56	-1.3E-02	0.21907	-3.1E-05	1.7E-04	4.8E-02	1.0E-09

From the modal analysis,

- It is observed that the maximum mass participation of 41kgs and 11kgs are observed in X-dir for the frequency of 2Hz and 14Hz.
- It is observed that the maximum mass participation of 47kgs is observed in Y-dir for the frequency of 93.5Hz.
- It is observed that the maximum mass participation of 39kgs and 11kgs are observed in Z-dir for the frequency of 0.44Hz and 2.8Hz.

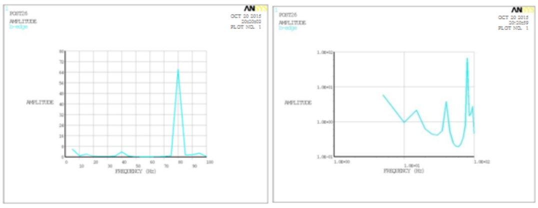
4.7 Harmonic Analysis



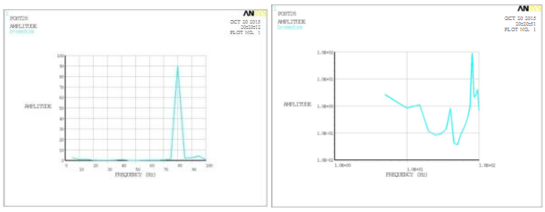
4.7Fig. Loads are applied

GRAPHS: amplitude v_s forcing frequency:

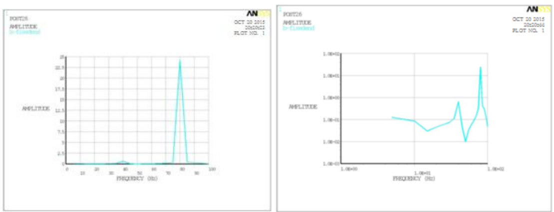
Harmonic analysis at location (blade edge)



4.8. Harmonic analysis at(blade at centre)

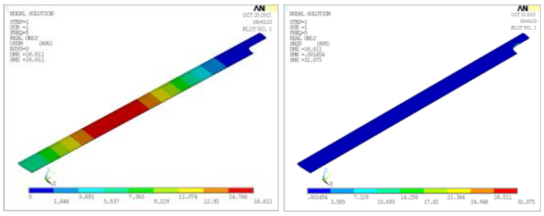


4.9 Harmonic response at (blade at fixed end)

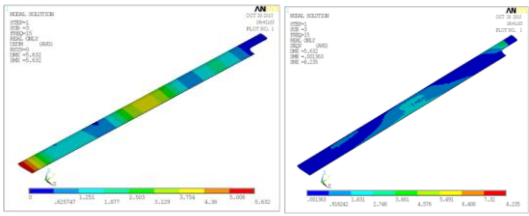


From the above graphs, the following amplitudes are observed

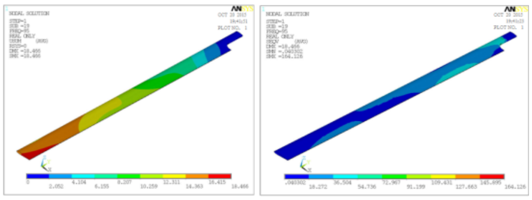
- Amplitude of 68mm is observed on the blade edge of helicopter rotor blade at a frequency of 95Hz.
- Amplitude of 90mm is observed on the blade edge of blade at centre at a frequency of 95Hz.
- Amplitude of 25mm is observed on the blade edge of blade at fixed end at a frequency of 95Hz.



Max.deflection Vonmisses stress@5Hz



Max.deflection Vonmises stress@15Hz



Max.deflection Vonmises stress@95Hz

Table: the max. Deflection and Stress

S.NO	FREQUENCY (Hz)	DEFLECTION (mm) Usum	VONMISES STRESS			
			S_1	S_2	S_3	Von mises
1	5	16.6	20	3.8	0.2	32
2	15	5	1.8	7.4	0.6	8
3	95	18	126	6	0.5	164

From the above results it is observed that the principal stresses of three frequency values are less than the principal stresses values of the material 870MPa, 54MPa, and 30MPa with respectively 1st, 2nd and 3rd principal stresses. Hence according to the Maximum Stress Theory, the Composite Helicopter blade design is safe for the above operating loads.

II. RESULTS

The Helicopter blade was studied for Structural analysis:

- Static analysis
- Modal analysis
- Harmonic analysis

From the Static analysis,

- It is observed that the maximum VonMises stress observed is 98 Mpa. The maximum stress is observed on the bolting location.
- The yield strength of the material is 170 Mpa. Further modal analysis is done to check the dynamic behaviour of helicopter rotor blade.

From the modal analysis,

Total weight of helicopter rotor blade is 108kgs.

- It is observed that the maximum mass participation of 71.6kgs and 18.9kgs are observed in X-dir for the frequency of 4.6Hz and 32Hz.
- It is observed that the maximum mass participation of 0.39kgs is observed in Y-dir for the frequency of 92.9Hz.
- It is observed that the maximum mass participation of 67.3kgs and 20.3kgs are observed in Z-dir for the frequency of 1.04Hz and 6.6Hz.

From the Harmonic Analysis

S.no	FREQUENCY (Hz)	DEFLECTIONS (mm)	VON MISES STRESS (MPa)
1	5	40.7	85.1
2	90	1.9	40

- From the above results it is observed that the critical frequencies 5 Hz, and 90 Hz are having stresses of 85MPa, and 40 MPa respectively. The yield strength of the material used for helicopter rotor blade is 170 MPa.
- According to the VonMises Stress Theory, the VonMises stress of helicopter rotor blade at frequencies 5 Hz, and 90 Hz are having less stresses than the yield strength of the material.
- Hence the design of helicopter rotor blade is safe for the above operating loading conditions.

The Composite Helicopter blade was studied for Structural analysis:

- Static analysis
- Modal analysis
- Harmonic analysis

From the Static analysis,

Table the max. Deflection and Max. Stress

S.no.	DEFLECTION (mm)				STRESS			
	UX	UY	UZ	USUM	S_1	S_2	S_3	Von mises
1	28.7	7.7	0.02	1899	97	23	5	176

- From the above results it is observed that the principal stresses values 97MPa, 23MPa, and 5MPa are less than the principal stresses values of the material 870MPa, 54MPa, and 30MPa with respectively 1st, 2nd and 3rd principal stresses.
- Hence according to the Maximum Stress Theory, the Composite Helicopter blade design is safe for the above operating loads.

From the Modal Analysis:

Total weight of composite helicopter rotor blade is 35kgs.

- It is observed that the maximum mass participation of 41kgs and 11kgs are observed in X-dir for the frequency of 2Hz and 14Hz.
- It is observed that the maximum mass participation of 47kgs is observed in Y-dir for the frequency of 93.5Hz.
- It is observed that the maximum mass participation of 39kgs and 11kgs are observed in Z-dir for the frequency of 0.44Hz and 2.8Hz.

From the Harmonic analysis:

Table: the max. Deflection and Stress

S.NO	FREQUENCY (Hz)	DEFLECTION (mm) Usum	VONMISES STRESS			
			S_1	S_2	S_3	Von mises
1	5	16.6	20	3.8	0.2	32
2	15	5	1.8	7.4	0.6	8
3	95	18	126	6	0.5	164

- From the above results it is observed that the principal stresses of three frequency values are are less than the principal stresses values of the material 870MPa, 54MPa, and 30MPa with respectively 1st, 2nd and 3rd principal stresses.
- Hence according to the Maximum Stress Theory, the Composite Helicopter blade design is safe for the above operating loads.

III. CONCLUSION

The Helicopter rotor blade was studied for3 different cases:

- Static analysis
- Modal analysis
- Harmonic analysis

From the above structural analysis it is concluded that that the helicopter rotor blade has stresses and deflections within the design limits of the material used. The deflections and stresses obtained in the harmonic analysis are also under the design limits of the material. The comparison of the results for two materials for both baseline model of Helicopter rotor blade is given in the below table.

Table: comparison of static results for baseline and modified models

MODELS	VONMISES STRESS (MPA)	WEIGHT (Kgs)	FOS
Aluminium	98	108	1.9
Composite	176	35	4.2

From this project, it is concluded that with the advent of parametric CAD systems, the productivity for adapting models made process optimization together with finite element techniques feasible.

Therefore it concluded that the helicopter rotor blade is safe under the given operating conditions.

From the above results we can conclude that the composite material helicopter blade is better than the aluminium materials.

IV. REFERENCES

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