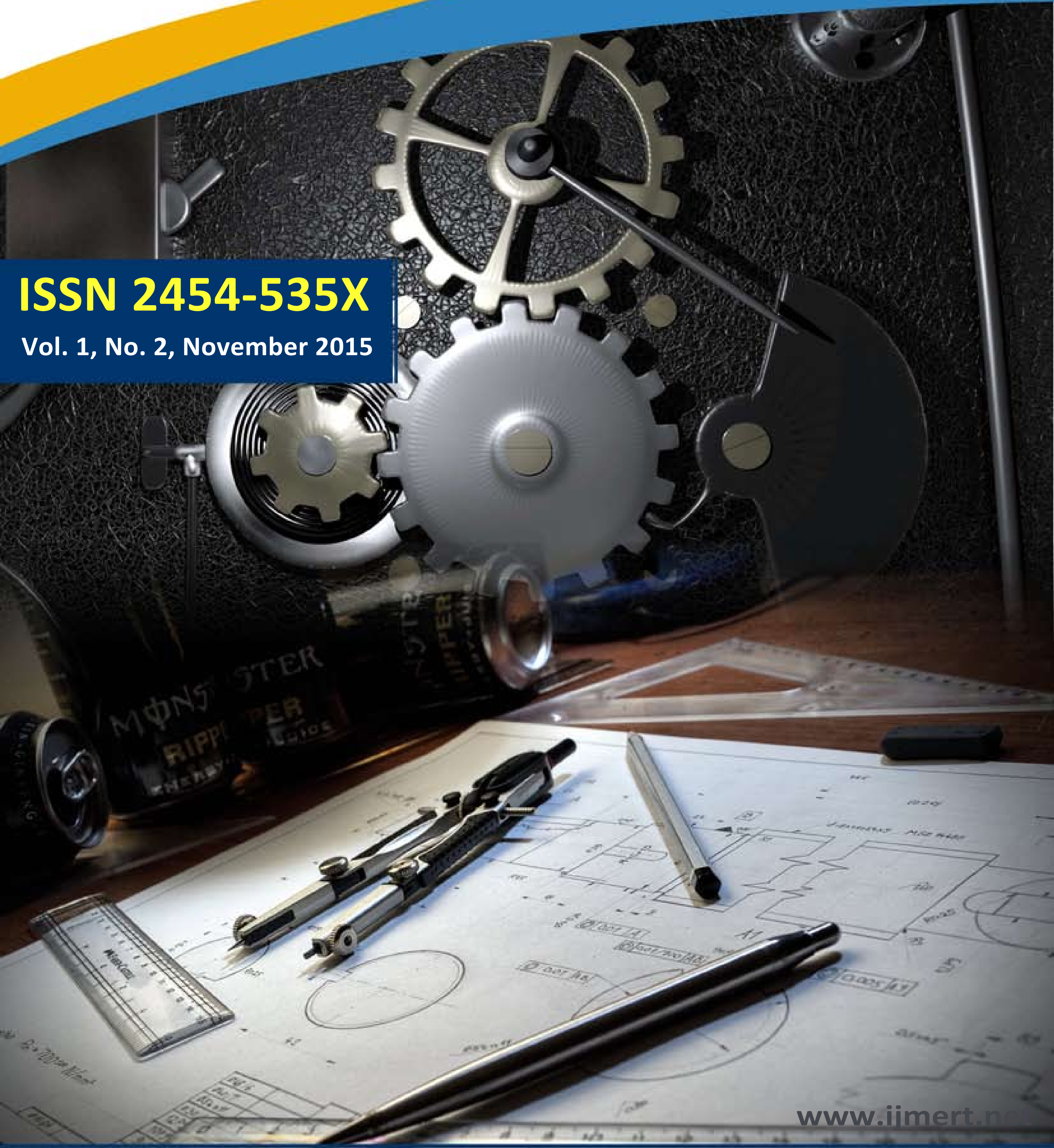
International Journal of Mechanical Engineering Research and Technology

ISSN 2454-535X

Vol. 1, No. 2, November 2015



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International Journal of Mechanical Engineering Research and Technology

ISSN 2454 – 535X www.ijmert.com
Vol. 1, No. 2, November 2015

Research Paper

DESIGN AND STRUCTURAL ANALYSIS OF HELICOPTER ROTOR BLADE FOR DIFFERENT MATERIALS

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In the helicopter, the main rotor blade is mostly influenced by the aerodynamic forces and centrifugal forces during rotation. In this project both aerodynamic and centrifugal forces are considered for analysis. Dynamic analysis is performed and mainly aimed at calculating the vibrations and controlling them. The main objective is to perform modal analysis and calculate natural frequencies of the rotor blade. Later on perform harmonic analysis to plot the rotor blade response at these natural frequencies due to operational load. There by checking for resonance and avoiding it , will reduce vibrations on helicopter. NX-CAD software is used to create a 3D model of the rotor blade. This 3D model is converted into parasolid and imported into Ansys to perform finite element analysis. From the analysis the strength and dynamic characteristics of rotor blade are calculated and documented. The Finite element analysis has been carried out for Aluminium, Eglass/Epoxy and Carbon/Epoxy materials. The results obtained are documented, compared and finally the best material is concluded.

Keywords: Rotor blade, static analysis, dynamic analysis, NX-CAD, ANSYS

INTRODUCTION

The wings of the airplane create a lift force when they move through the air. As we known, during flight, there are four forces acting on the helicopter or airplane and those are LIFT, DRAG, THRUST, and WEIGHT. In order to make the wings to move through 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 called Main Rotor Blades. The shape and the angle of the blades move through the air will determine how much Lift force is created. After the helicopter lifted off the ground, the pilot can tilt the blades, causing the helicopter to tip forward or backward or sideward.

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[2] Professor, Chebrolu Engineering College, Guntur, A.P. India.

The Main Rotor System: The rotor system found on helicopters can consist of a single main rotor or dual rotors. With most dual rotors, the rotors turn in opposite directions so the torque from one rotor is opposed by the torque of the other. This cancels the turning tendencies.

In general, a rotor system can be classified as either fully articulated, semi rigid, or rigid. There are variations and combinations of these systems. A fully articulated rotor system usually consists of three or more rotor blades. The blades are allowed to flap, feather, and lead or lag independently of each other. Each rotor blade is attached to the rotor hub by a horizontal hinge, called the flapping hinge, which permits the blades to flap up and down. Each blade can move up and down independently of the others. The flapping hinge may be located at varying distances from the rotor hub, and there may be more than one. The position is chosen by each manufacturer, primarily with regard to stability and control. Each rotor blade is also attached to the hub by a vertical hinge, called a drag or lag hinge, that permits each blade, independently of the others, to move back and forth in the plane of the rotor disc. Dampers are normally incorporated in the design of this type of rotor system to prevent excessive motion about the drag hinge. The purpose of the drag hinge and dampers is to absorb the acceleration and deceleration of the rotor blades. The blades of a fully articulated rotor can also be feathered, or rotated about their span wise axis. To put it more simply, feathering means the changing of the pitch angle of the rotor blades.

PROBLEM DEFINITION

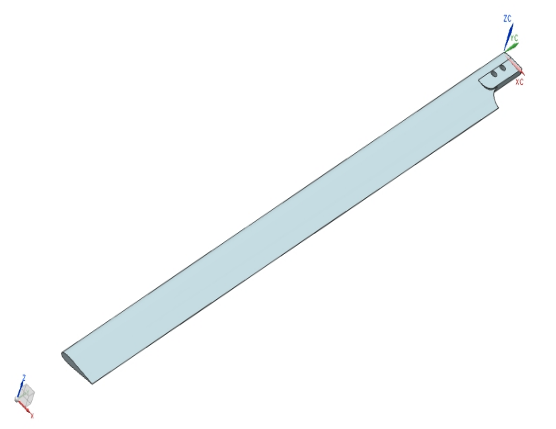
The objective of my project is to:

- Perform static analysis to calculate stresses and deflections of rotor blade.
- Perform modal analysis to calculate natural frequencies of rotor blade.
- Perform harmonic analysis to check component behavior at the obtained natural frequencies due to operating loads to check resonance.
- Static and dynamic analysis of rotor blade shall be done for aluminum and composite materials.

3D MODELING OF HELICOPTER ROTOR BLADE

The 3D model of the helicopter rotor blade is done by using UNIGRAPHICS NX software from the reference papers. UNIGRAPHICS NX is the world's leading 3D product development solution. This software enables designers and engineers to bring better products to the market faster.

Figure 1: Shows 3D Model of Helicopter Rotor Blade



MATERIAL PROPERTIES

Rotor blades are made out of various materials, including aluminum, composite structure, steel, titanium. Rotor blade of the helicopter are assigned as per the below material properties in this paper.

Table 1: Material Properties of HM Carbon /Epoxy and E-glass/Epoxy

Property	Units	HM Carbon/Epoxy	E-Glass/ Epoxy
E_{11}	GPa	190.0	50.0
E_{22}	GPa	7.7	12.0
G_{12}	GPa	4.2	5.6
n_{12}	-	0.3	0.3
$S^t_1 = S^c_1$	MPa	870.0	800.0
$S^t_2 = S^C_2$	MPa	94.0	40.0
S_{12}	MPa	30.0	72.0
ρ	Kg/m³	1600.0	2000.0

Table 2: Material Properties of Aluminum

	Material Specifi-cation	Young's Modulus (N/mm²) (kg/mm³)	Poisson's Ratio Density	Yield Stress (N/mm2)
Aluminum alloys-2014	7.0E+04	0.3	2700	414

METHODOLOGY

Finite element analysis was carried in the following steps:

- Create a 3D model of the helicopter rotor blade using NX-CAD software and export this model into parasolid file.
- Import parasolid file into Ansys to perform static analysis using ANSYS software and obtain the deflections and von mises stresses for aluminum material.
- Perform modal analysis of helicopter rotor blade for natural frequency and mode shapes.
- Perform harmonic analysis of helicopter rotor blade due to operating loads to find deflections and stress values at critical frequencies.
- Perform static analysis using ANSYS software and obtain the deflections and stresses for composite materials HM carbon/epoxy material.
- Perform modal analysis of helicopter rotor blade for natural frequency and mode shapes HM carbon/epoxy material.
- Perform harmonic analysis of helicopter rotor blade due to operating loads to find deflections and stress values at critical frequencies for HM carbon/epoxy material
- Perform static analysis using ANSYS software and obtain the deflections and stresses for composite materials E-glass/ epoxy material.
- Perform modal analysis of helicopter rotor blade for natural frequency and mode shapes for E-glass/epoxy material.
- Perform harmonic analysis of helicopter rotor blade due to operating loads and find deflections and stress values at critical frequencies for E-glass/epoxy material.

FINITE ELEMENT ANALYSIS OF HELICOPTER ROTOR BLADE FOR ALUMINIUM MATERIAL

Static Analysis of Helicopter Rotor Blade

Figure 2: Shows Boundary and Loading Conditions for Static Analysis.

- Blade is arrested on the bolting locations are fixed in all dof which is connected to hub.
- Angular velocity is applied to helicopter rotor blade.
- Gravitational force is applied to helicopter rotor blade in z direction.

Deformations and Stresses

Figure 3: Shows Total Deflection of Helicopter Rotor Blade

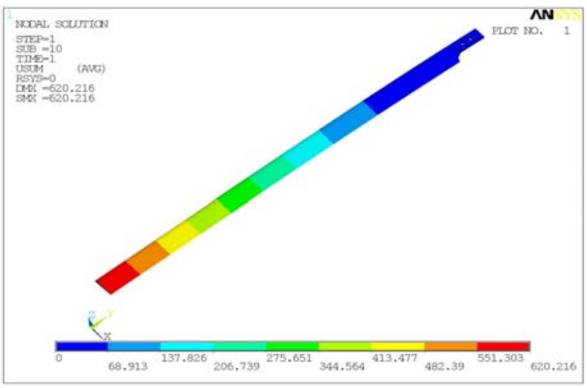


Figure 3: Shows Total Deflection of Helicopter Rotor Blade

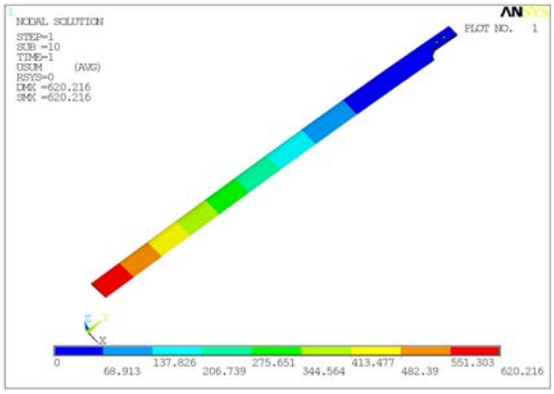
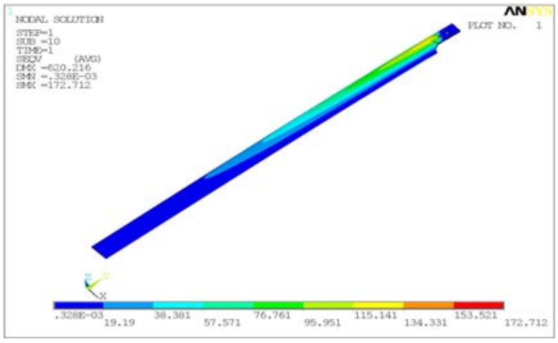


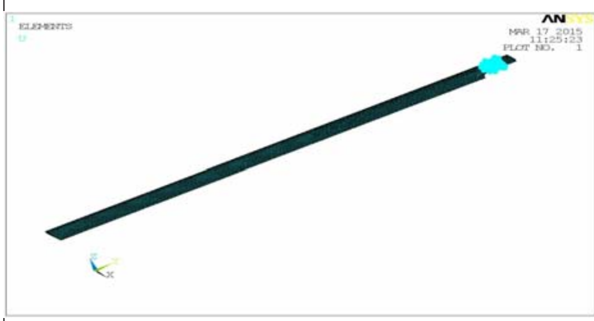
Figure 4: Shows Von Misses of Helicopter Rotor Blade



MODAL ANALYSIS OF HELICOPTER ROTOR BLADE

Modal analysis was carried out to determine the natural frequencies and mode shapes of a structure in the frequency range of 0 -12Hz.

Figure 5 Shows Boundary Conditions for Modal Analysis



- Blade is arrested on the bolting locations are fixed in all dof which is connected to hub.

MODE SHAPES

Figure 6: Shows Mode Shape 1@0.787 Hz for Helicopter Rotor Blade

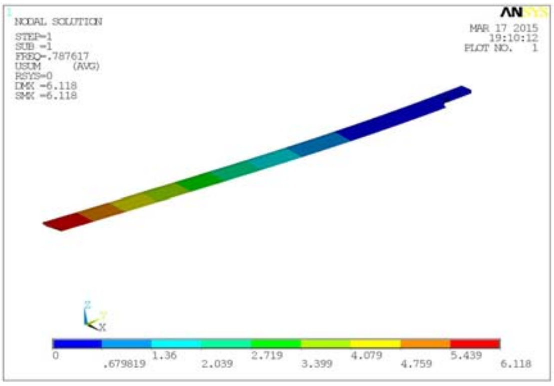


Figure 7: Shows Mode Shape 2@4.9 Hz for Helicopter Rotor Blade.

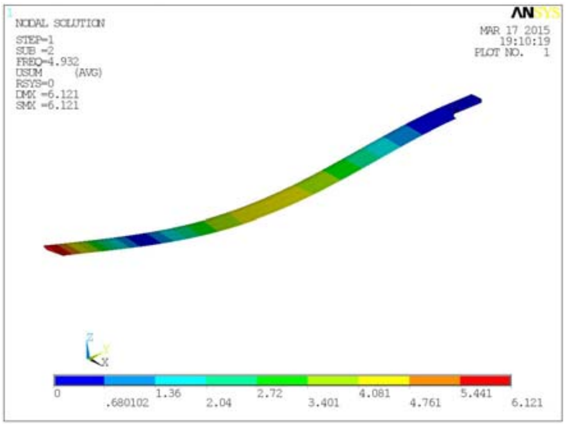
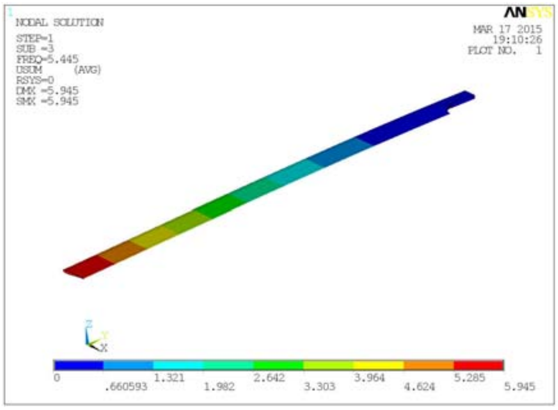
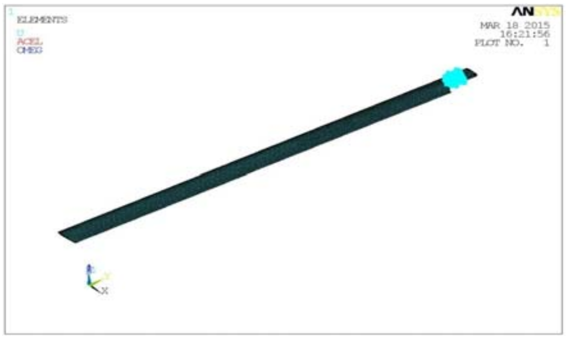


Figure 8: Shows Mode Shape 3@5.4 Hz for Helicopter Rotor Blade



HARMONIC RESPONSE ANALYSIS OF HELICOPTER ROTOR BLADE

Figure 9 Shows Boundary Conditions Applied on the Helicopter Rotor Blade



DEFLECTION AND STRESS OF FREQUENCY @ 6HZ

Table 3 Shows Frequencies and Mass Participations for Modes in the Range of 0-12 Hz

Mode	Frequency	Partic Factor			Effective Mass(tons)		
		X	Y	Z	X	Y	Z
1	0.787	0.1e-05	0.4E-07	0.25	0.2e-11	0.1E-14	0.6E-01
2	4.93	-0.5e-04	0.3E-06	-0.14	0.2E-08	0.1E-12	0.2E-01
3	5.44	0.26	0.6E-03	-0.2e-4	0.6E-01	0.3E-06	0.7E-09

Figure 10 Shows Total Deformation of Helicopter Rotor Blade

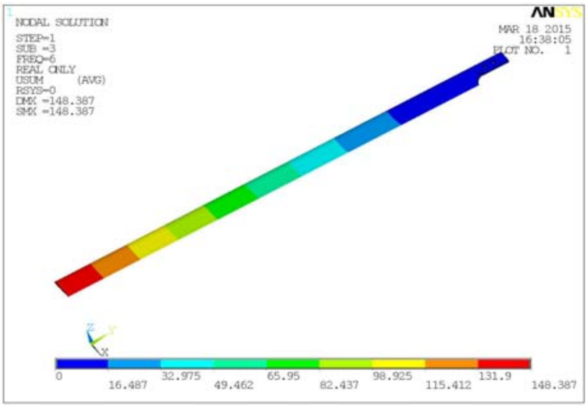
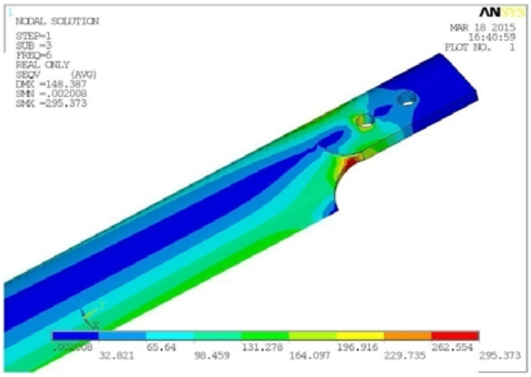


Figure 11: Shows Von Misses Stress of Helicopter Rotor Blade



GRAPHS

Figure 12: Shows The Harmonic Response Near Rotor Blade Edge in Linear Scale

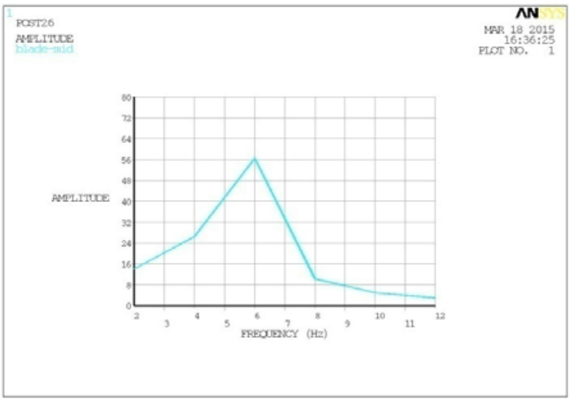


Figure 13: Shows The Harmonic Response Near Rotor Blade Centre In Linear Scale

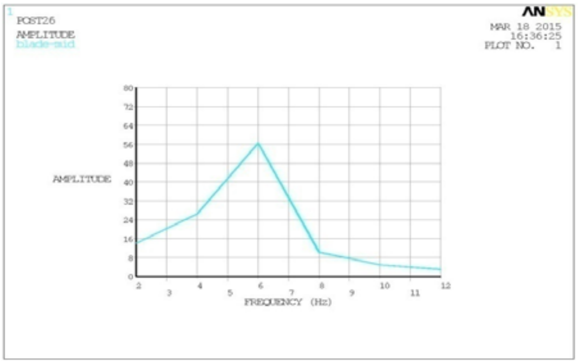
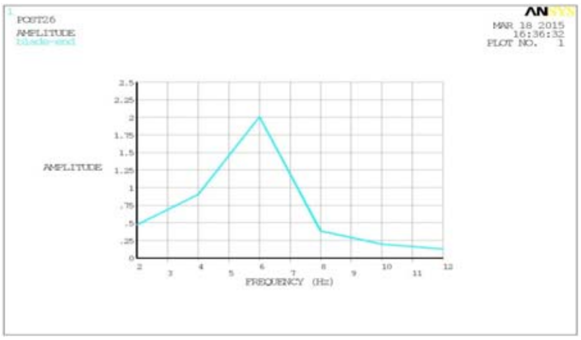


Figure 14: Shows The Harmonic Response Near Rotor Blade Fixed End In Linear Scale



FINITE ELEMENT ANALYSIS OF HELICOPTER ROTOR BLADE FOR CARBON/EPOXY MATERIAL

Static Analysis of Helicopter Rotor Blade

Deflections and Stresses

Figure 15 Shows Total Deflection of Helicopter Rotor Blade

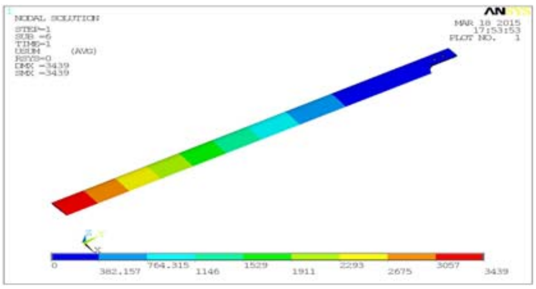


Figure 16: Shows 1st Principal Stress of Helicopter Rotor Blade

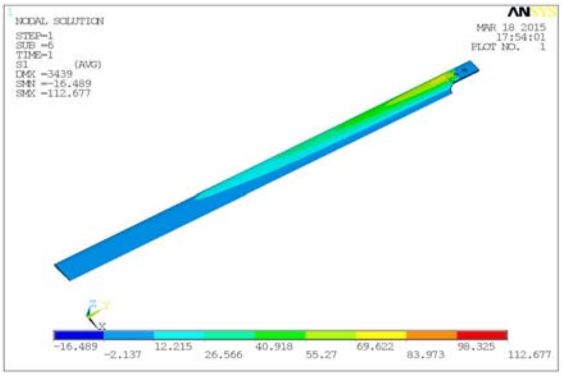


Figure 17: Shows 2nd Principal Stress of Helicopter Rotor Blade

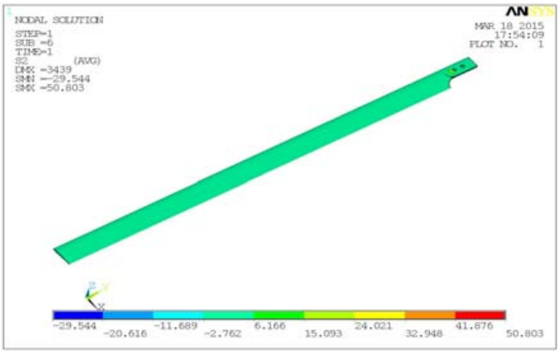


Figure 18 Shows 3rd Principal Stress of Heliopter Rotor Blade

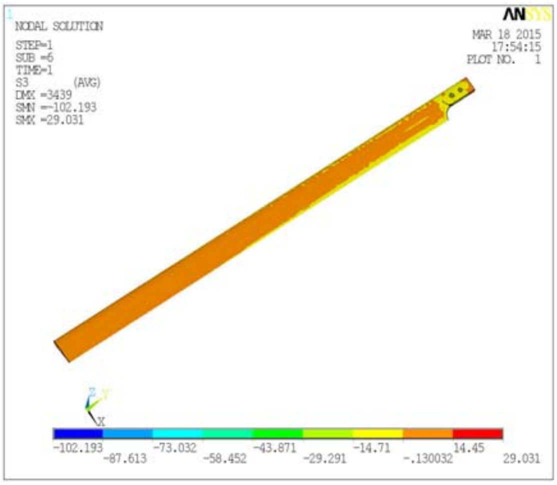
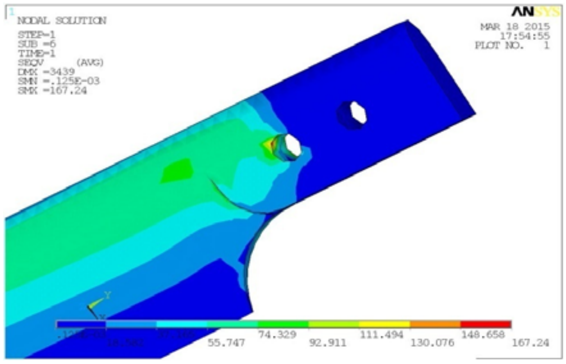


Figure 19: Shows Von Misses Stress of Helicopter Rotor Blade.



MODAL ANALYSIS OF HELICOPTER ROTOR BLADE

Mode Shapes

Figure 20: Shows Mode Shape 1@0.33hz for Helicopter Rotor Blade

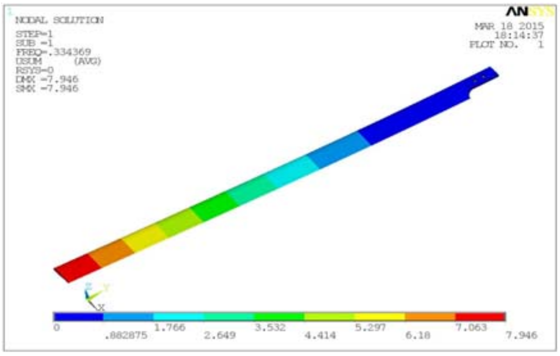


Figure 21: Shows Mode Shape 2@2.1 Hz for Helicopter Rotor Blade

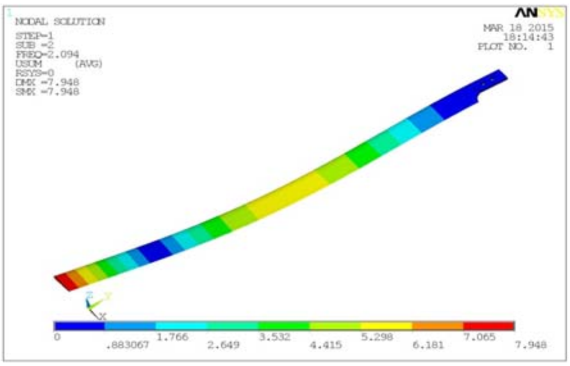


Table 4: Shows Frequencies and Mass Participations for Modes in the Range of 0-12 Hz

Mode	Frequency	Partic Factor			Effective Mass(tons)		
		X	Y	Z	X	Y	Z
1	0.33	0.1e-05	0.2E-07	0.19	0.1e-11	0.7E-14	0.3E-01
2	2.1	-0.3e-04	-0.2E-06	-0.10	0.1E-08	0.5E-12	0.1E-01
3	2.3	0.20	0.4E-03	-0.6e-4	0.4E-01	0.1E-06	0.2E-09
4	5.8	-0.1e-05	0.5e-06	0.6e-01	0.2e-11	0.2e-12	0.4e-02
5	11.4	-0.4e-05	-0.9e-06	-0.4e-01	0.2e-10	0.9e-12	0.2e-02

Figure 22: Shows Mode Shape 3@2.3 Hz for Helicopter Rotor Blade

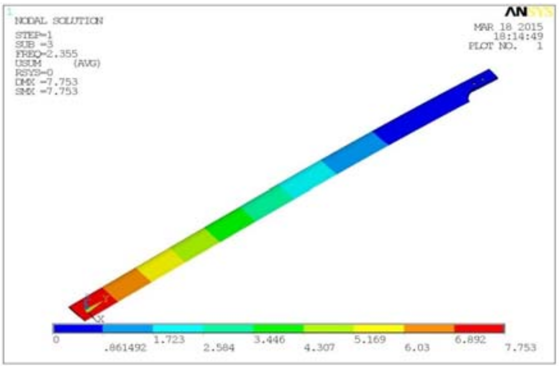


Figure 23: Shows Mode Shape 4@5.8 Hz for Helicopter Rotor Blade

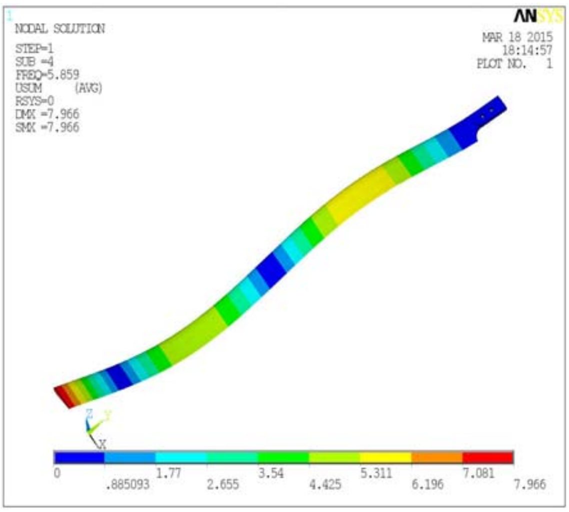
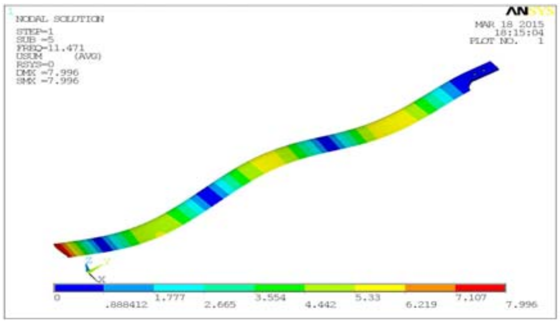


Figure 24: Shows Mode Shape 5@11.4 Hz for Helicopter Rotor Blade.



HARMONIC RESPONSE ANALYSIS OF HELICOPTER ROTOR BLADE

Deflection And Stress of Frequency @ 2hz

Figure 25 Shows Total Deformation of Helicopter Rotor Blade

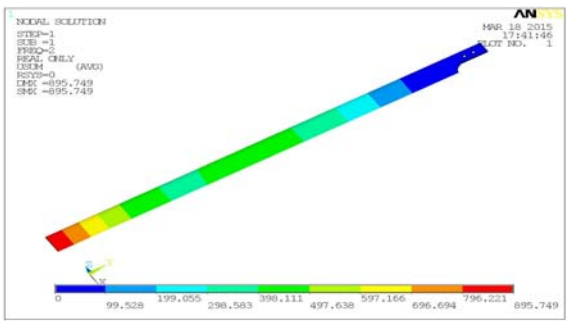


Figure 26 Shows 1st Principal Stress of Helicopter Rotor Blade

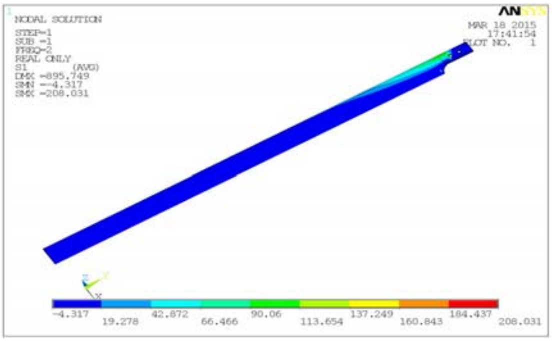


Figure 27 Shows 2nd Principal Stress of Helicopter Rotor Blade

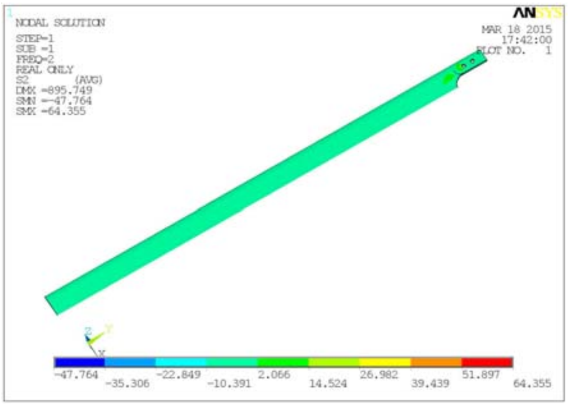


Figure 28 Shows 3rd Principal Stress of Helicopter Rotor Blade

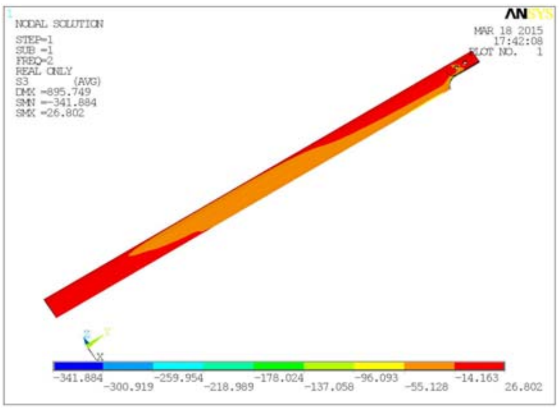
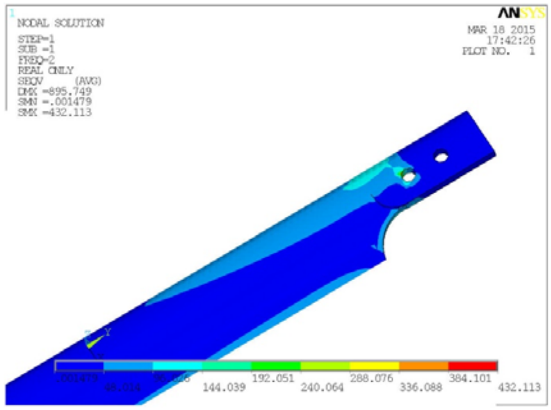


Figure 29 shows von misses stress of helicopter rotor blade.



GRAPHS

Figure 30 Shows The Harmonic Response Near Rotor Blade Edge In Linear Scale

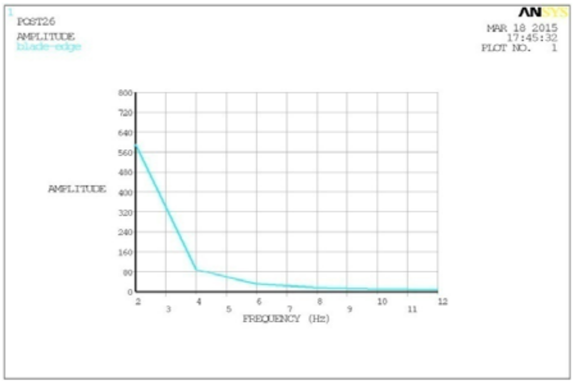


Figure 31 Shows The Harmonic Response Near Rotor Blade Center in Linear Scale

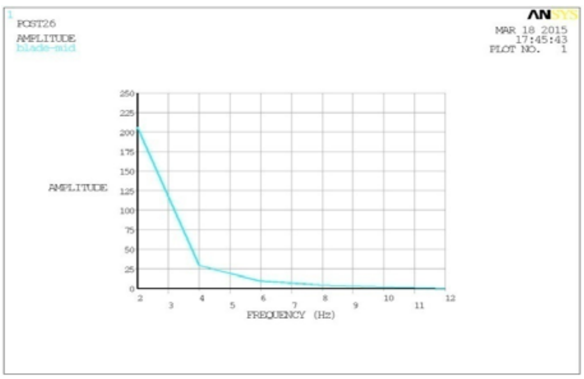
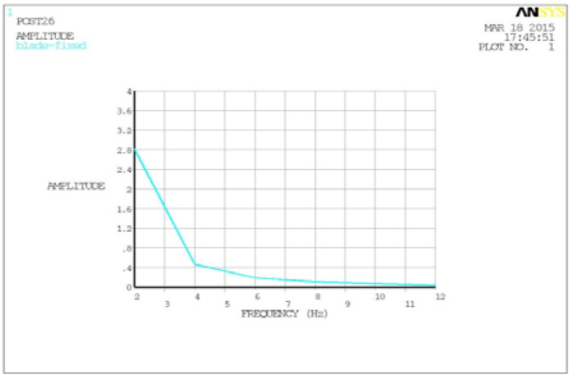


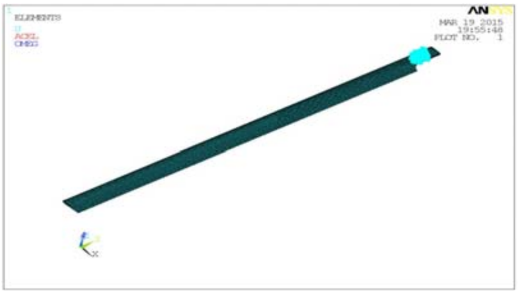
Figure 32 Shows The Harmonic Response Near Rotor Blade Fixed end in Linear Scale



FINITE ELEMENT ANALYSIS OF HELICOPTER ROTOR BLADE FOR E-GLASS/EPOXY MATERIAL

Static Analysis of Helicopter Rotor Blade

Figure 33 Shows Boundary Conditions of Helicopter Rotor Blade



Deflections and Stresses

Figure 34 Shows Total Deformation of Helicopter Rotor Blade

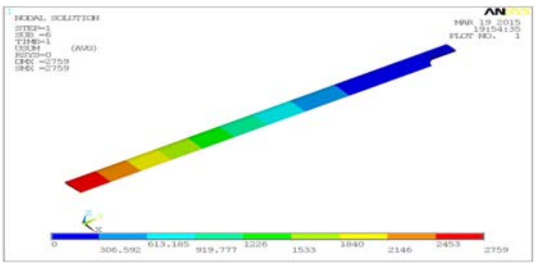


Figure 35 Shows 1st Principal Stress of Helicopter Rotor Blade

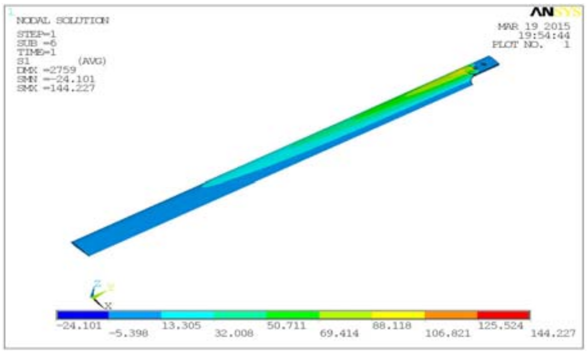


Figure 36 Shows 2nd Principal Stress of Helicopter Rotor Blade

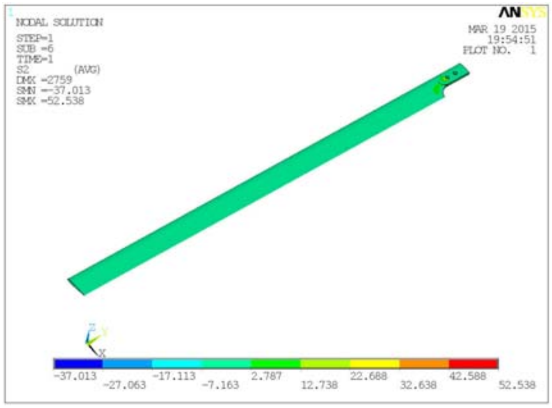


Figure 36 Shows 3rd Principal Stress of Helicopter Rotor Blade

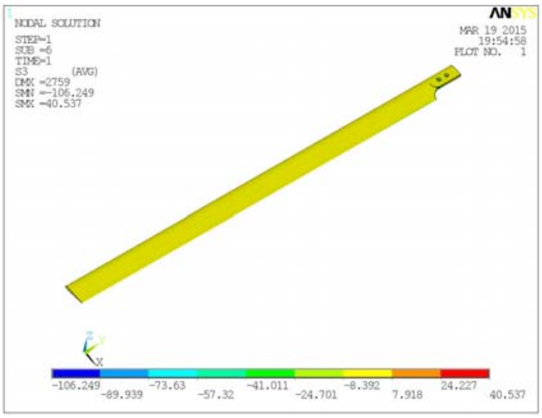
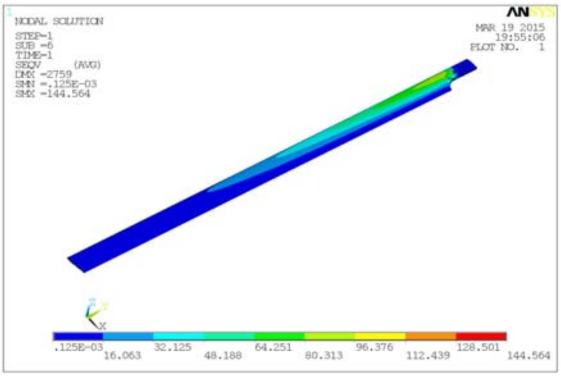


Figure 38 Shows Von Misses Stress of Helicopter Rotor Blade



MODAL ANALYSIS OF HELICOPTER ROTOR BLADE

Mode Shapes

Figure 39 shows Mode shape 1@0.37Hz for helicopter rotor blade

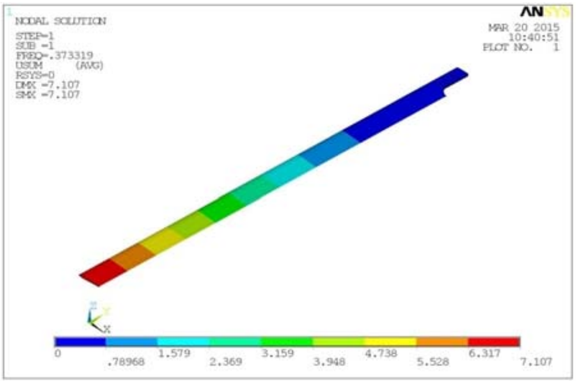


Figure 40 Shows Mode Shape 2@2.3 Hz for Helicopter Rotor Blade

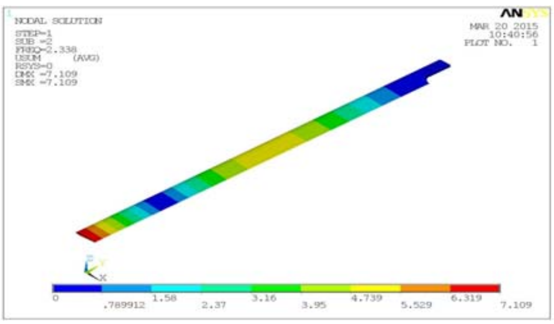


Figure 41 Shows Mode Shape 3@2.6 Hz for Helicopter Rotor Blade

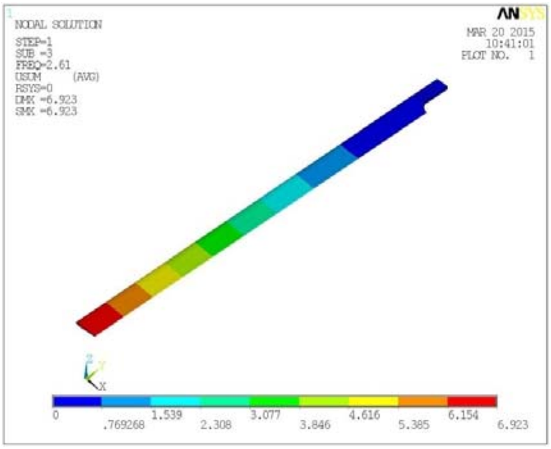
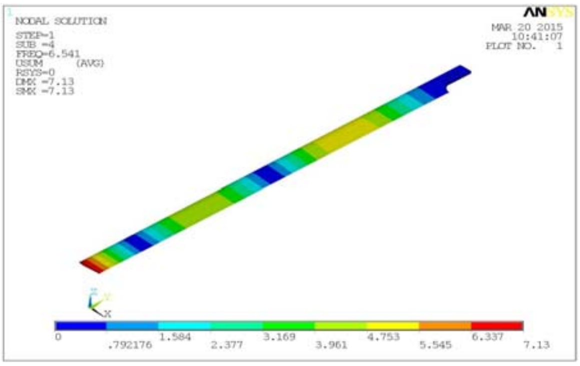


Figure 42 Shows Mode Shape 4@6.4Hz for Helicopter Rotor Blade



Harmonic Response Analysis of Helicopter Rotor Blade

Figure 43 shows boundary and loading conditions of helicopter rotor blade.

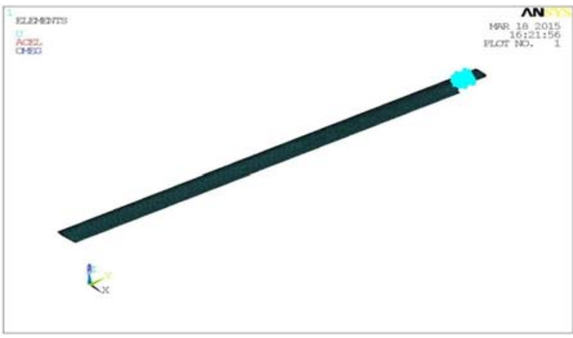


Table 5: Shows Frequencies and Mass Participations for Modes in The Range of 0-12 Hz

Mode	Frequency	Partic Factor			Effective Mass(tons)		
		X	Y	Z	X	Y	Z
1	0.37	0.14e-05	0.3E-07	0.19	0.2e-11	0.1E-14	0.48E-01
2	2.3	-0.4e-04	-0.2E-06	-0.10	0.1E-08	0.8E-13	0.14E-01
3	2.6	0.225	0.49E-03	-0.6e-4	0.5E-01	0.2E-06	0.4E-09
4	6.4	-0.18e-05	0.59e-06	0.6e-01	0.3e-11	0.3e-12	0.5e-02

DEFORMATION AND STRESS OF FREQUENCY @ 2HZ

Figure 44 Shows Total Deformation of Helicopter Rotor Blade

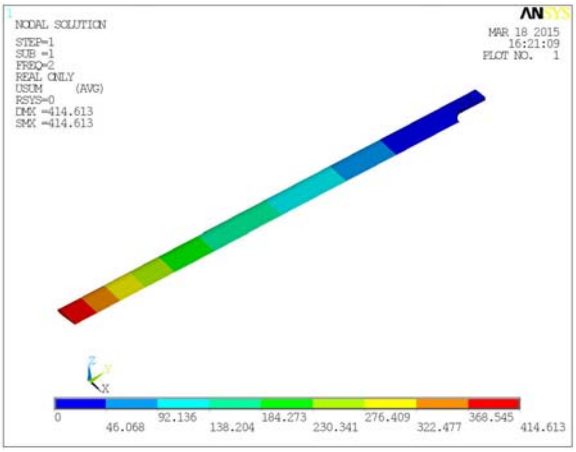


Figure 45 Shows 1st Principal Stress of Helicopter Rotor Blade

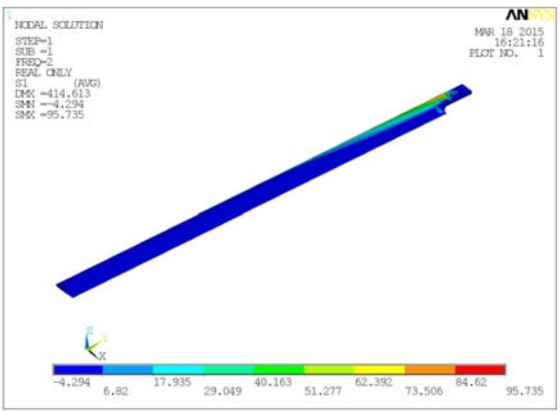


Figure 46 Shows 2nd Principal Stress of Helicopter Rotor Blade

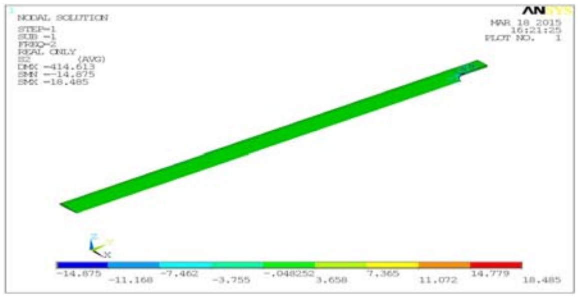


Figure 47 Shows 3rd Principal Stress of Helicopter Rotor Blade

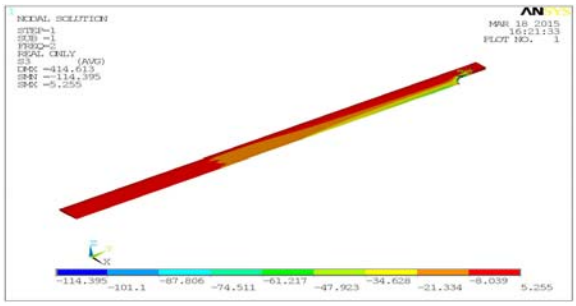
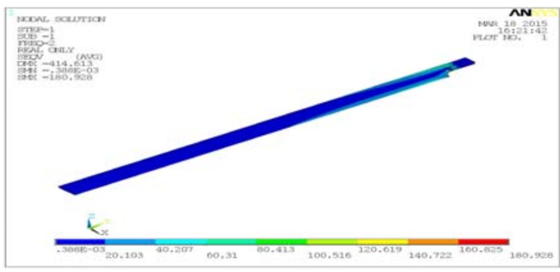


Figure 48 Shows Von Misses Stress of Helicopter Rotor Blade



GRAPHS

Figure 49 Shows the Harmonic Response Near Rotor Blade Edge in Linear Scale

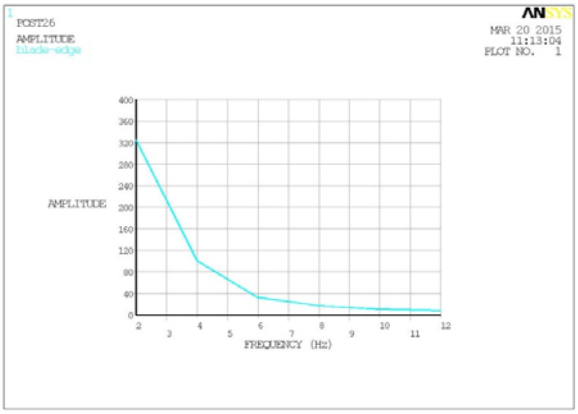


Figure 50 Shows The Harmonic Response Near Rotor Blade Centre in Linear Scale

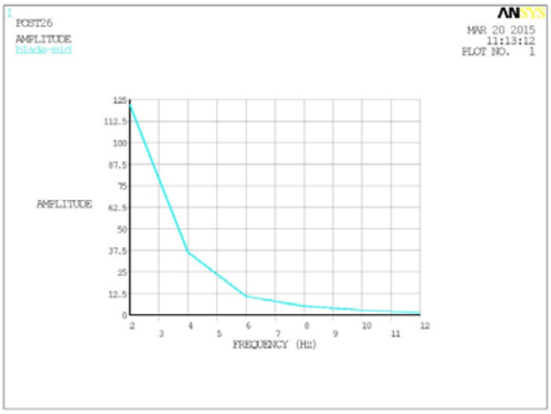
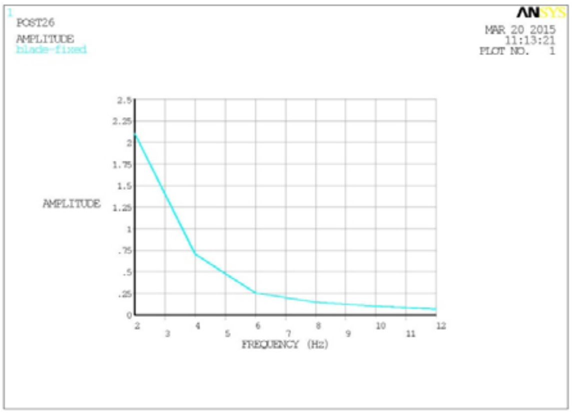


Figure 51 Shows the Harmonic Response Near Rotor Blade Fixed End in Linear Scale



RESULTS AND DISCUSSION

In the present project, the helicopter rotor blade has been studied for structural behavior and compared for different materials (aluminum and composite materials).

The helicopter rotor blade was studied for 3 different materials**:**

- Aluminum
- HM carbon/ epoxy
- E-glass/ epoxy

Summary of results of static, modal and harmonic analysis of helicopter rotor blade for different materials are listed in the following table.

Table 6 Shows Comparison of Aluminum Alloy, HM Carbon / Epoxy and E Glass / Epoxy Materials

S.No.	Material	Maximum Deflection	Stress			FOS	Weight
			S1	S2	S3		
1	Aluminium alloy	620	211	84	79	414/172=2.4	111
2	HM carbon/Epoxy	343	112	50	29	870/167=5.2	66
3	E glass/ Epoxy	2759	144	52	40	800/144=5.5	82

CONCLUSION

In this project NX-CAD software was used to create a 3D model of the rotor blade. This 3D model was converted into parasolid and imported into Ansys to perform finite element analysis. From the analysis the strength and dynamic characteristics of rotor blade were calculated and documented. The Finite element analysis was carried out for Aluminium, Eglass/Epoxy and Carbon/Epoxy materials. The results obtained were documented, compared and finally the best material was concluded.

From the above analysis it is concluded that the helicopter rotor blade has stresses and deflections within the design limits for the all three materials (aluminum and composite materials). However from the results it is observed that HM carbon/ epoxy material has less weight and better factor of safety. Hence it is concluded that HM carbon/ epoxy material is the best alternate material for rotor blade in terms of weight, strength and vibrations.

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