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# An Investigation Of Design And Modal Analysis Of The Different Material On Helicopter Blade

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***ABSTRACT: In aviation, wings and blades play a major role for flight control. The helicopter rotor blade in both the symmetric and asymmetric airfoil type using CATIA software, Composite materials are widely opted in manufacturing industry because of high strength to weight ratio, hence carbon epoxy and boron epoxy are chosen for the design consideration and also it is compared with aluminum material and using ANSYS software package, the static strength and the dynamic characteristics will be analyzed in three modes. The high stressed area is identified in the von misses stress technique. The analysis is carried out in the symmetric and asymmetric airfoil separately by altering the material and the results are compared for the better solution. Thus resonance in rotor can be avoided by using the proper selection of material by calculating the natural frequency.***

**Keywords**: Resonance,rotor, vibration,blade, transient behavior of blade

## 1. INTRODUCTION

The Rotor is the main component of the helicopter which consists of blades and the blades are attached to the hub of the helicopter Rotor. Vibration plays a hazardous role in the factor of designing the helicopter since the blades are rotating parts. Thus the vibration has to be taken into account before designing the rotor blade. In this case Resonance also plays a vital role in limiting factor of design because if resonance occurs the helicopter will lose its balance and there will be higher degree of damage. The vibration behavior of the helicopter blade has been investigated by many researchers. The mode shapes and the natural frequency of the helicopter blade characterizes the dynamic behavior. The main aim of calculating the natural frequency and the determination of mode shape is to determine the resonance, hence by choosing the appropriate material resonance can be avoided. Since there is complex in designing the rotor blade it is considered to be an one dimensional beam for the design consideration. There are many theoretical methods to calculate the natural frequency such as Lagrange's Method, Galerkin's method, three moment distribution method, Rayleigh method and Finite element method. The Finite element method is considered here because of its accuracy among others.

Abdelkader Nour, Mohamed Tahar, Gherbi [1] have simulated the rotor blade using the finite elements method and the study was done under the aerodynamic loads and natural frequencies of the blade was calculated in the three different modes.The stress acting on the blade on the different modes are calculated and excitation of the modes are studied in the blade, Ganguli [8] optimized a helicopter blade as a rotating flexible beam and the aero elasticity behavior of the blade was considered to be analysis for studying the dynamic behavior of the blade.

Peretz P. Friedmann, Bryan Glaza, Rafael Palaciosb have studied the compatibility between a composite beam and the cross section has been taken into the analysis. They examined the rotor blade in the VABS analysis code and combined with the finite element approach and validated against the experimental data.

## 2. MODELLING OF HELICOPTER BLADE

The modeling of helicopter blade is done by considering the two important factors, Selection of airfoil and the Selection of the material. The Airfoil is the cross section of the rotor blade, The Rotor blade is the structure that produces the lift in the helicopter and makes it stable in the air. The cross sectional area of the rotor blade designed in such a way that it produces lift when air passes through it. Helicopter blades have different types of the airfoil sections designed for the particular type of missions because of its variable factors. Hence before designing the helicopter blade the missions are kept to be in consideration. The initial step of the helicopter blade design is to choose the airfoil section.

Airfoil sections are basically of two types, symmetrical and non-symmetrical. Symmetrical airfoils are identical in their upper and lower part. They are opted in the helicopter blade applications, since the center of pressure is nil for the symmetrical airfoil type. Unsymmetrical airfoils differs in their upper and lower surface, the upper and lower surface of the airfoil is not identical in the design. The Advantages of the Unsymmetrical airfoil are they have more lift and drag ratio as well as the stall characteristics which can be suited for the rotor blades. Initially Unsymmetrical airfoils are not used in the helicopter blade since variation of the angle of attack causes the movement of the center of pressure which causes the instability, but this problem has been overcome by the twisting force which is exerted on the rotor blades Hence the

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Recent systems has overcome the following problem, thus Asymmetrical airfoil can be opted for the helicopter blade. The other important factor which has to be taken into account is the material selection of the helicopter rotor blade. Since the material selection plays the important role in calculating the natural frequency of the helicopter blade.

### 2.1 Airfoil Selection

In order to select the airfoil, we must know the value of maximum $C_L$ of the airfoil. We have chosen NACA 4 series (4-digit), which is used in, after referring $C_L$ Vs α graph in Theory Of Blades Different airfoils are chosen in each section by considering the $C_L$ value. The following are the types of the airfoil which are chosen for the design consideration,

- NACA 0015 (Symmetric Airfoil)
- NACA 23015 (Asymmetric Airfoil)

Airfoils have been classified by the National Advisory Committee for Aeronautics (NACA),Hence a specific airfoil can be identified by NACA WXYZ where,

W: maximum camber as % of the chord length.

X: Location of the maximum camber form the leading edge along the chord line in tenths of chord length.

Y&Z: Maximum thickness in % of the chord length .

NACA 0015 is opted in the symmetric airfoil selection due to its feasibility in design and the reliability in critical conditions of the flight. Upper and lower surfaces are identical in the upper and lower surface and chosen due to its reliability factor.NACA 23015 is selected in the asymmetric airfoil section since they have more lift and drag ratio as well as the stall characteristics which can be suited for the rotor blades. In the Asymmetrical airfoil the upper and lower surface design are different hence the airflow in the upper section is large which makes the air to move faster and the lift which is created in the asymmetrical airfoil is high. The Airfoil geometry of NACA 0015 and NACA 23015 is depicted in below Fig 1 and Fig 2

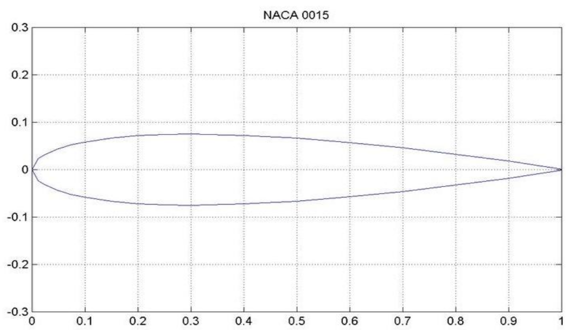


**Fig 1: Airfoil Geometry of NACA 0015**

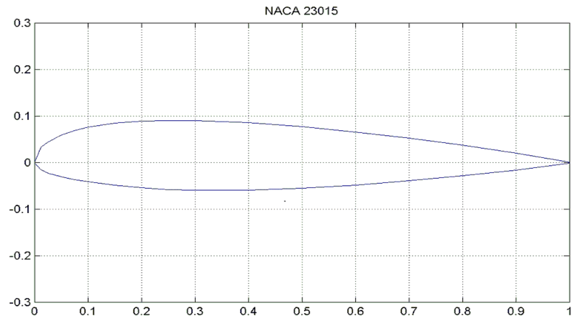


**Fig 2: Airfoil Geometry of NACA 23015**

### 2.2 Material Selection

Material Selection plays a important factor in the blade design. Composite materials are widely opted in manufacturing industry because of high strength to weight ratio, hence carbon epoxy and boron epoxy are chosen for the design consideration among the orthotropic materials and aluminium is considered for design among the isotropic materials.

**Table 1: Material Properties of Orthotropic materials**

| Orthotropic material | Carbon Epoxy | Boron Epoxy |
|---|---|---|
| Ex (Mpa) | 159000 | 224600 |
| Ey (Mpa) | 14000 | 12700 |
| Ez (Mpa) | 14000 | 12700 |
| Gxy (Mpa) | 4800 | 4400 |
| Gzx (Mpa) | 4800 | 4400 |
| Gyz (Mpa) | 4300 | 2400 |
| $\upsilon_{xy}$ | 0.32 | 0.25 |
| υzx | 0.14 | 0.01 |
| υyz | 0.14 | 0.01 |
| ρ $Kg/m^3$ | 1550 | 2440 |

**Table 2: Material Properties of Isotropic materials**

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| | |
|---|---|
| Isotropic Material | Aluminum |
| E (Mpa) | 70000 |
| G(Mpa) | 26000 |
| υ | 0.35 |
| ρ Kg/m$^3$ | 2700 |

## 3. DESIGN OF BLADE

Modeling of helicopter blade is done by using CATIA. The modeling activity involves the creation of airfoil geometry with the design attributes representing blade model. The 3D Airfoil for the blade has been converted into a multi body model. The below figures 3 and 4 depicts the developed model of NACA 0015 and NACA 23015.Both the models are created in the CATIA software by extracting the airfoil geometry.

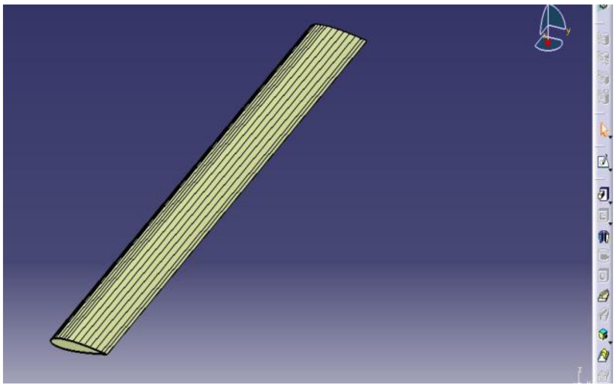

**Fig: 3 CATIA Model of cross section of NACA 0015**

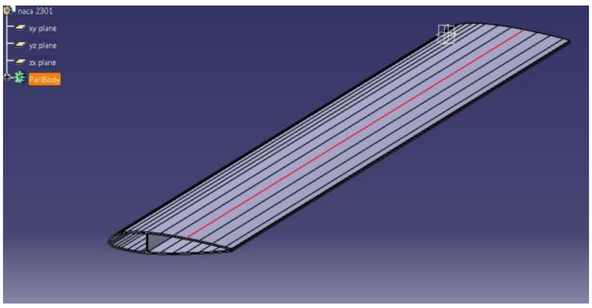

**Fig: 4 CATIA Model of Modified cross section of NACA 23015**

## 4. FINITE ELEMENT MODELLING

The model is completed in the designing software hence the next step is to analyze the model. The Initial step in the finite element analysis is meshing; meshing is the process of discretizing the structure into the finite elements for the accurate solution. The Element used for meshing in the blade is SOLID 185.It has 2391 nodes and 7582 elements. Meshed view NACA 23015 is depicted in Fig 5 below,

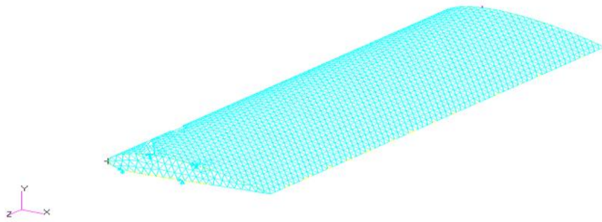

**Fig: 5 Meshed view NACA 23015**

### 4.1 Loads Acting on the Blade

The Meshing is done in the ANSYS software, the next step is the application of the load, before applying the load, the load has to be calculated in the appropriate method. The structural design of the blade involves in the application of the load which is involved during its flight of operation, The Major loads acting on the blade are,

- Distributed loads **-** Loads such as aerodynamic loads
- weight of the blade.

In order to find the distribution on blade, we use the schrenk's method, which can be explained as the plane from the blade is drawn with semi span which is along the X- axis and the chord is along the Y-axis .The ellipse is drawn whose area is equal to the area of the blade span. The semi major axis of the ellipse is taken as the semi span .A curve joining the mid points of the plan from and the elliptic quadrant is drawn. This curve is known as schrenk's curve [19]. This gives the lift distribution. The calculation is given below,
Blade span = 6 m
Blade semi span = 3 m

Schrenk's method is used to find the span wise lift distribution. In general it has two lift components which are trapezoidal ($L^t$) and elliptic distribution ($L^e$). The formulas shown below are to calculate the distribution.

Trapezoidal lift distribution, $L^t$,

$$L^t = \frac{2L}{b\,(1+\lambda)}\left[1 - \frac{2y}{b}\,(1-\lambda)\right]$$

Elliptical lift distribution, $L^e$ ,

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$$L^e = \frac{4L}{\pi b}\left[1 - \left(\frac{2y}{b}\right)^2\right]^{\frac{1}{2}}$$

Total lift distribution,

$$L^- = \frac{L^t + L^e}{2}$$

DATAS:

b – span of helicopter blade – 6 m

L –Lift of the Helicopter Blade.
L = $\frac{1}{2}\rho\, v^2 S\, C_L$

ρ = Density of the air at which the helicopter flies

ρ = 0.17 $Kg/m^3$

S – Disc Area

S = 100 $m^2$

$C_{L\,=}$ Coefficient of Lift of Blade

$C_L$ of NACA 0015 = 1.1

$C_L$ of NACA 0015 = 1.8

L = $\frac{1}{2}\ X\ 0.17\ X\ 100\ X\ 1.1\ X 66^2$

= 40728.6 N (NACA 0015)

L =$\frac{1}{2}\ X\ 0.17\ X\ 100\ X\ 1.8\ X 66^2$

= 66646.8 N (NACA 23015)

The Value of L is substituted in the Trapezoidal and Elliptical Distribution Formula which is given below,

Trapezoidal lift distribution, $L^t$,

$$L^t = \frac{2L}{b\,(1+\lambda)}\left[1 - \frac{2y}{b}\,(1-\lambda)\right]$$

Elliptical lift distribution, $L^e$ ,

$$L^e = \frac{4L}{\pi b}\left[1 - \left(\frac{2y}{b}\right)^2\right]^{\frac{1}{2}}$$

The total Lift Distribution is calculated by,

$$L^- = \frac{L^t + L^e}{2}$$

Following table 3 depicts the lift distribution for NACA 0015.The lift force cannot be applied as pressure at specific surface. There are 12set of pressures that have been applied at different surface as shown in below table 3. These pressure sets are portion of the lift where it concentrates on the span. To make it real and even, it has been divided into 12 different pressure sets so that the stress is not only concentrates at specific place.

**Table 3: Lift Distribution of NACA 0015 along span**

| Y(m) | $L^e(y)$ | $L^t(y)$ | $L^-$ |
|---|---|---|---|
| 0 | 12121.02 | 11458.23 | 11789.625 |
| 0.5 | 11343.76 | 10243.28 | 10793.52 |
| 1 | 10265.28 | 9036.6 | 9650.94 |
| 1.5 | 9275.5 | 8663.3 | 8969.4 |
| 2 | 8218.6 | 7290.6 | 7754.6 |
| 2.5 | 7054.8 | 6916.7 | 6985.75 |
| 3 | 5945.8 | 5543.1 | 5744.45 |
| 3.5 | 4817.5 | 4170.1 | 4493.8 |
| 4 | 4668.8 | 3796.8 | 4232.8 |
| 4.5 | 3521.3 | 2423.6 | 2972.45 |
| 5 | 2497.5 | 2100.3 | 2298.9 |
| 5.5 | 2301.8 | 1877 | 2089.4 |
| 6 | 2078.8 | 1903.7 | 1991.25 |

Similarly For NACA 23015,

The Value of Lift (L) = 66646.8 N

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The Value of L is substituted in the Trapezoidal and Elliptical Distribution Formula which is given below,

$$L^{t} = \frac{2L}{b\,(1+\lambda)}\left[1-\frac{2y}{b}\,(1-\lambda)\right]$$

$$L^{e} = \frac{4L}{\pi b}\left[1-\left(\frac{2y}{b}\right)^{2}\right]^{\frac{1}{2}}$$

The total Lift Distribution is calculated by,

$$L^{-} = \frac{L^{t}+L^{e}}{2}$$

Following table 4 depicts the lift distribution for NACA 23015 by substituting the L Value in the above formula.

**Table 4: Lift Distribution of NACA 23015 along span**

| Y(m) | $L^e(y)$ | $L^t(y)$ | $L^-$ (N) |
|---|---|---|---|
| 0 | 14244.02 | 13603.23 | 13923.63 |
| 0.5 | 13466.76 | 12388.28 | 12927.52 |
| 1 | 12388.28 | 11181.6 | 11784.94 |
| 1.5 | 11398.5 | 10808.3 | 11103.4 |
| 2 | 10341.6 | 9435.6 | 9888.6 |
| 2.5 | 9177.8 | 9061.7 | 9119.75 |
| 3 | 8068.8 | 7688.1 | 7878.45 |
| 3.5 | 6940.5 | 6315.1 | 6627.8 |
| 4 | 6791.8 | 5941.8 | 6366.8 |
| 4.5 | 5644.3 | 4568.6 | 5106.45 |
| 5 | 4620.5 | 4245.3 | 4432.9 |
| 5.5 | 4424.8 | 4022 | 4223.4 |
| 6 | 4201.8 | 4048.7 | 4125.25 |

**Load Due To Blade Structure Weight:**

For calculating the structural load of the blade, the structural load is assumed to vary with the square of the chord .This is because of the variation of the cross sectional shape of the blade in the span wise direction. Had the aircraft blade had the same cross sectional throughout, then the lift intensity would have been constant along the span. The weight of the structure of one blade was estimated to be 5% of the empty weight. The blade structural load intensity at any location is given by $kc_x^{2}$, when K is a constant and $C^x$ is the chord at a location of X.
Chord at any section, $C_x = A+Bx$
Boundary condition are $C_x$ =0.1 m at x=0 and $C_x$=0.6m at x=6 m
Solving we get A = 2.76 and B = -0.27.
Therefore, $c_x = 2.76 – 0.27$ x
Load of the wing section $W_b = \int_0^{b/2} kC_x^2 dx$

$W_b$=70 x 9.81 = 687.6 N

From $W_b$=687.6 N and $c_x$= 2.76 – 0.27 x , we get k=121.03

Load intensity at each section is given by $W_x = Kc_x^2$

(i.e.)$W_x$= 50.12(2.76 – 0.27 x)$^2$

The structural load is applied in the chord and tabulated in the below table 5,

**Table: 5 Weight Distribution along span of NACA 23015**

| Point | Chord (m) | Structural Load Intensity (N) |
|---|---|---|
| 1 | 0.1 | 374.36 |
| 2 | 0.2 | 367.02 |
| 3 | 0.3 | 359.71 |
| 4 | 0.4 | 352.49 |
| 5 | 0.5 | 345.35 |
| 6 | 0.6 | 338.29 |

***Constraints and Boundary Conditions***

- One end is constrained fully by arresting all DOF

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- Self weight is given at top of the blade
- Aerodynamic loads are given as couple loads around the airfoil.

The Right Side of the blade is fully constrained and fixed to the Blade Hub hence all Degrees of Freedoms are arrested as a constraint.

## 5. ANALYSIS OF HELICOPTER BLADE

After the pre-processing steps (i.e.) modeling the blade, fixing the boundary condition the next step is to solve the model. Import the model on ANSYS software which acts as a solver. The main goal of a finite element analysis is to examine how a structure or component responds to certain loading conditions. Total load has been applied in different sub-steps to apply the loads gradually so that an accurate solution can be obtained.

### 5.1 Static Analysis

The Static Analysis is carried out in NACA 0015 and NACA 2305 for the materials Glass epoxy, Boron Epoxy, Carbon Epoxy and Aluminum. Aerodynamic loads and self weight has been applied in different sub-steps to apply the loads gradually so that an accurate solution can be obtained.

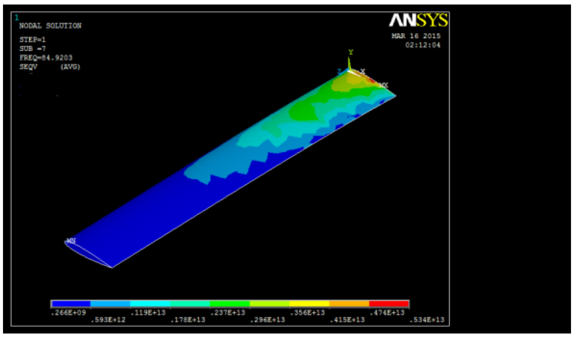


**Fig: 6 Static Analysis of NACA 0015 of carbon epoxy**

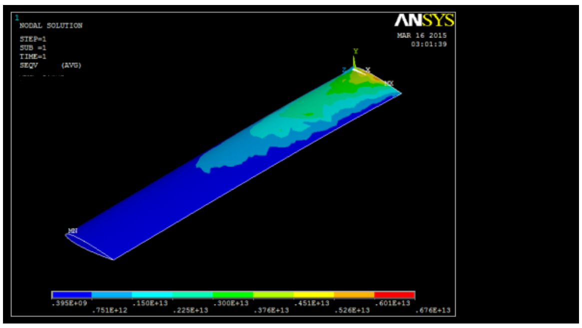


***Fig: 7 Static Analysis of NACA 0015 of boron epoxy***

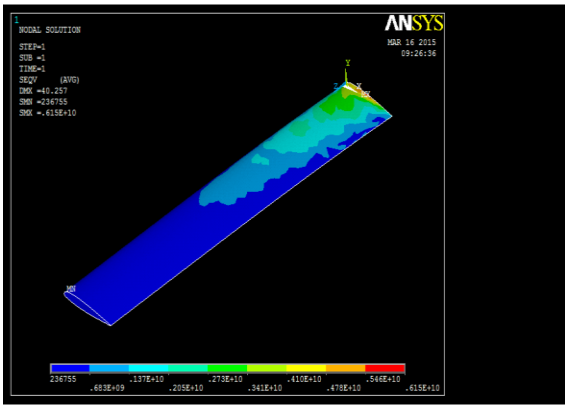


**Fig: 8 Static Analysis of NACA 0015 of Aluminium**

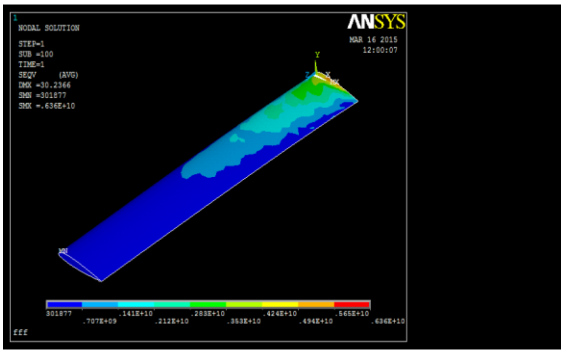


**Fig: 9 Static Analysis of NACA 23015 of carbon epoxy**

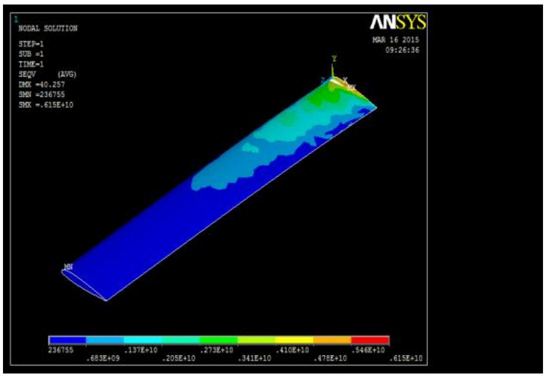


**Fig: 10 Static Analysis of NACA 23015 of boron epoxy**

The simulation gives the results as figure above where maximum von mises stress occurs at the wing root region Hence for symmetrical airfoil we get the von misses stresses as the value of 124 MPa for carbon Epoxy, 212 MPa for boron Epoxy, 95 MPa for Aluminum. The von mises stress is used to calculate the yielding of materials under any loading condition. When a von misses stress reaches to the maximum value occurs, the von misses stress at which the yielding occurs is called as yielding strength, the different between maximum von mises stress and yield stress is very large. Hence for symmetrical airfoil we get the von misses stresses as the value of 124 MPa for Graphite Epoxy, 212 MPa for boron Epoxy, 95 MPa for Aluminum. The stress of isotropic

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material is comparatively greater than the orthotropic material. It is observed that the high stress area is developed on the inner edge of the blade, in the fitting zone. Hence more stresses are developed around the fixed part since the fixing part is fully constrained.

**5.2 Modal Analysis**

The mode shapes and the natural frequency of the helicopter blade characterizes the dynamic behavior.

The main aim of calculating the natural frequency and the determination of mode shape is to determine the resonance, hence by choosing the appropriate material resonance can be avoided. The Different vibration modes are created depends on the way of blade attachment to the rotor because degree of freedom differs for each case. Mode shapes are nothing but how the blades vibrate. First two cases are flap that is it can move in one direction with respect to rotor shaft since it is attached to the hub and it acts like a cantilever beam. However, in the case of fully articulated rotor it allows to flap up and down and back and forth and the fifth mode is the torsion case where the torsion load is applied and mode shape is derived which is mentioned in below Fig. 11

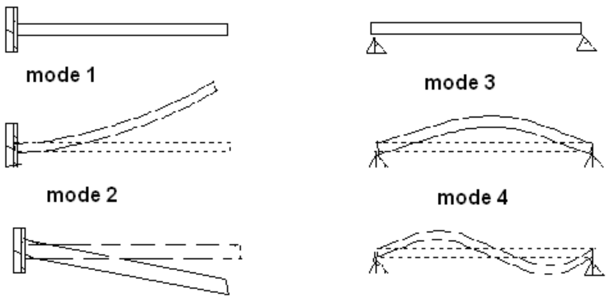


**Fig: 11 Description of Various modes used in Analysis**.

The Fig 12 represents the first mode vibration and we got the natural frequency as 1.15 Hz.

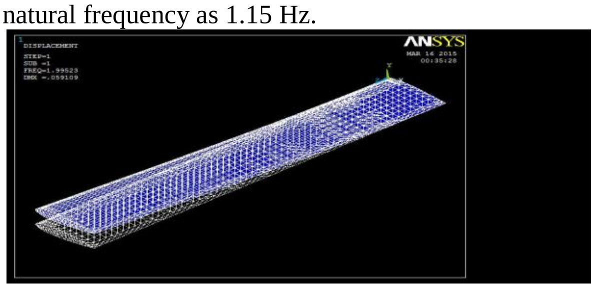

**Fig:12 Modal Analysis of NACA 0015 in 1st Mode of Carbon Epoxy**

The Fig 13 represents the second mode vibration and we got the natural frequency as 6.52 Hz

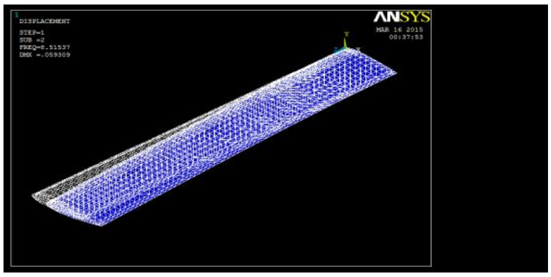

**Fig:13 Modal Analysis of NACA 0015 in 2nd Mode of Carbon Epoxy**

The Fig 14 represents the third mode vibration and we got the natural frequency as 11.85 Hz

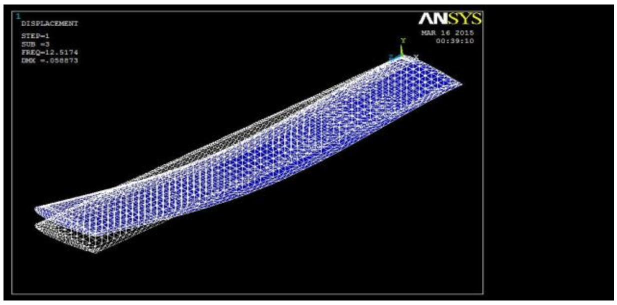

**Fig:14 Modal Analysis of NACA 0015 in 3rd Mode of Carbon Epoxy**

The Fig 15 represents the fourth mode vibration and we got the natural frequency as 32.15 Hz

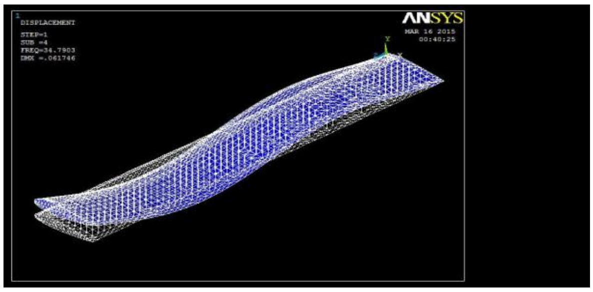

**Fig:15 Modal Analysis of NACA 0015 in 4th Mode of Carbon Epoxy**

The Fig 16 represents the fifth mode vibration and we got the natural frequency as 34.12 Hz

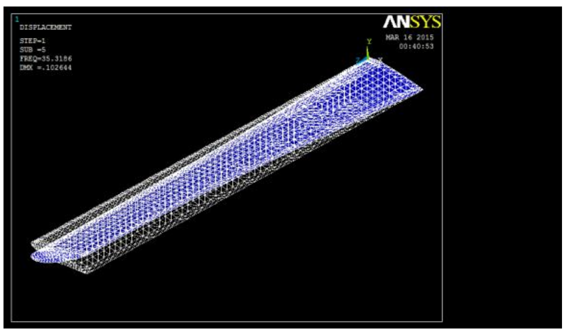

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**Fig:16 Modal Analysis of NACA 0015 in 5th Mode of Carbon Epoxy**

**Table 6: Frequency interpretation of NACA 0015**

| Mod e | Type | Carbon Epoxy (Hz) | Boron Epox y (Hz) | Aluminiu m (Hz) |
|---|---|---|---|---|
| 1 | First flap | 2.78 | 2.07 | 4.97 |
| 2 | Second flap | 11.07 | 8.41 | 19.04 |
| 3 | First lag | 17.19 | 12.73 | 30.82 |
| 4 | Third flap | 48 | 35.54 | 73.83 |
| 5 | First torsion | 48.2 | 38.98 | 85.78 |

**Table 7: Frequency interpretation of NACA 23015**

| Mode | Type | Carbon Epoxy (Hz) | Boron Epoxy (Hz) | Aluminium (Hz) |
|---|---|---|---|---|
| 1 | first flap | 2.52 | 1.89 | 4.51 |
| 2 | second flap | 10.96 | 8.32 | 18.85 |
| 3 | first lag | 15.82 | 11.87 | 28.88 |
| 4 | Second lag | 43.95 | 32.89 | 70.72 |
| 5 | first torsion | 44.27 | 34.82 | 78.75 |

The mode shapes and the natural frequency of the helicopter blade characterizes the dynamic behavior. The main aim of calculating the natural frequency and the determination of mode shape is to determine the resonance, hence by choosing the appropriate material resonance can be avoided.The frequencies of isotropic material are higher, hence orthotropic material is chosen for its low natural frequency behaviour. Boron Epoxy is chosen since it has lesser natural frequency.

## 6. CONCLUSION

**Based on the results obtained we come to the following major conclusions.**

- The vonmisses stress on the orthotropic material is larger than isotropic material which means that the blade structure has a good rigidity to orthotropic materials
- The frequencies of isotropic material are higher, hence orthotropic material is chosen for its low natural frequency behavior.
- Among the orthotropic material the natural frequency of the boron epoxy is lesser hence it can be opted

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