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LINEAR STATIC AND MODAL ANALYSIS OF MAIN ROTOR BLADE FOR A LIGHT HELICOPTER

K.Sandeep [1*], Dr E.Surendar [2] and N.Suresh [3]

[1]Department of Mechanical Engineering, Warangal Institute of technology and science, Warangal-506342, India
[2]Department of Mechanical Engineering, Warangal Institute of technology and science, Warangal-506342, India
[3]Department of Mechanical Engineering, Warangal Institute of technology and science, Warangal-506342, India

Abstract:
Structural vibration problems presents a major Design limitation for a wide range of engineering product. The main aim of study of the vibration phenomenon includes determining the nature and extent of vibration response level.
Considering the above said facts this project presents a linear static analysis and modular vibration analysis of the main rotor blade for the light utility helicopter. To simulate the mechanical behavior of the blade, a finite element analysis method was used. The analysis includes finding out the different Mode shapes, Displacement and Stress of helicopter rotor blade for case of Hovering Flight Mode and compare them for different material such as Aluminium Alloy and CFRP material using Hypermesh,ANSA and Abacus, NASTRAN.

Keywords: Hypermesh,Nastran and Abacus

1. INTRODUCTION

In this chapter, the reader is first introduced to a brief background of rotor blade design and the motivation for this research work. Then, Finite Element method ,Fundamental Of Aerodynamics , Hovering Flight Mode.

1.1 Motivation

The most critical parts of helicopters are main rotors, which provide thrust and lift as well as enable manoeuvres. Rotor blade design is a complex coupling process, which involves several usually competing disciplines, including aerodynamics, structures, acoustics, and dynamics . In fact, the blades of helicopter main rotors are slender, flexible beams.

1.2 Introduction To The Helicopters

Helicopters are the most flexible flying machines in presence today . The flexibility is in ability to move in three-dimensional space in a manner that no plane can.The astounding adaptability of helicopters implies that they can fly anyplace. Be that as it may, it additionally implies that flying the machines is confounded and they are more unsteady than the planes.

Fig No 1.1: Possible directions helicopter can move

1.3 Methodology

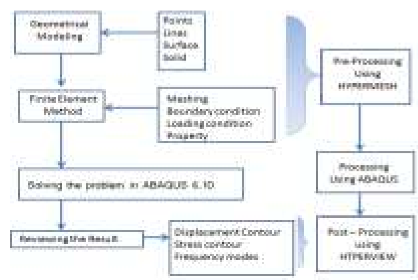

Fig No 1.2 : Flow chart of Process Methodology

3D model of Main rotor blade is imported into the HyperMesh for pre processing. Pre processing of model consist of meshing, selection of material properties, creation of load collectors and apply boundary conditions on model. Then model is exported to ABAQUS for solving problem. Results of solution plotted in HyperView which is well known postprocessor of HyperWorks software.

2. LITERATURE SURVEY

[1] Diana CAZANGIU , et al

The airplane business bargains from the earliest starting point with structures with unique necessities as great lightweight and withstanding to a major number of burden cases. Flight science requirements lead to supplementary confinements, the outcomes being the perplexing shape to support the fuselage, the rotor complex sharp edges or the wings skin. This paper displays a static basic examination of the primary rotor complex sharp edge for the light helicopter. To re-enact the mechanical conduct of the razor sharp edge, a limited components system was utilized. An instance of Hovering flight mode was considered.

DESIGNING AND MODELING

while designing on rotor blade we have to consider designing of Airfoil this having following characteristics and nomenclature .

3.2 DESIGN OF ROTOR BLADE.

For the case of the helicopter blade, the 3D modeling was done with the help of the specialized designing software, CATIA, using the real geometrical data from the technical standards and taking into account the practical recommendations from Fig. 3.4 illustrates the geometry and the main dimensions of the rotor blade.

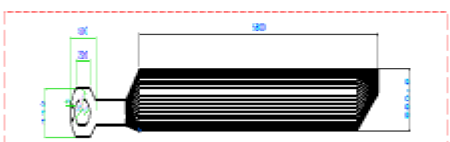

Fig No 3.4 : CAD Modal of the Rotor Blade

3.3 MATERIAL SELECTION & PROPERTY

The aerospace industry deals from the beginning with structures with special requirements as extreme light weight and withstanding to a big number of load cases. We chose Aluminum Alloy and CFRP material to reduce the whole weight of the rotor blade and also increase the stiffness of the rotor blade.

The Material property of the Aluminum Alloy are

Young's Modulus (E)	75GPa
Poisons Ratio (μ)	0.33
Density Of The Material (ρ)	2700 kg / m^3

Table No 3.1 : Aluminium Alloy Material

Property: The Material property of the CFRP material is

Density (ρ)	**1600 kg/m^3**
E_{11}	**181 GPa**
E_{22}	**10.3 GPa**
E_{33}	**10.3 GPa**
G_{12}	**7.17 GPa**
G_{13}	**7.17 GPa**
G_{23}	**7.17E8 Pa**
μ_{12}	**0.28**
μ_{13}	**0.28**
μ_{23}	**0.33**

Table No 3.2 : CFRP Material Property

The CFRP material have 6 layers and + 45 and -45 Degree orientation.

3.4 MESH GENERATION

Before Meshing we have to follow below procedure

.3.4.1 Process Methodology

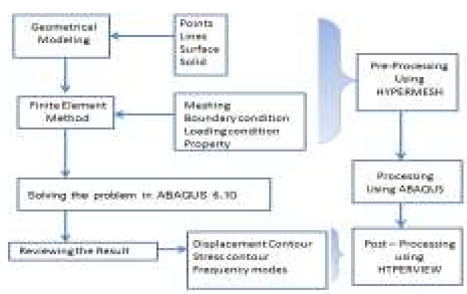

Fig No 3.5: Flow chart of Process Methodology

Figure 3.5 shows Flow chart of process methodology of Rotor Blade Analysis. 3D model of Main rotor blade is imported into the HyperMesh for pre processing. Preprocessing of model consist of meshing, selection of material properties, creation of load collectors and apply boundary conditions on model. Then model is exported to ABAQUS for solving problem. Results of solution plotted in HyperView which is well known postprocessor of HyperWorks software.

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FEA is a technique to simulate loading conditions on designs and determine the design's Response to those conditions.

3.4.2. Finite Element Modeling:

Finite Element Modeling is important preprocessing model is imported into HyperMesh properties and boundary conditions. After completion of preprocessing finite element model is export to ABAQUS for analysis purpose.

3.4.3. why do we carry out Meshing :

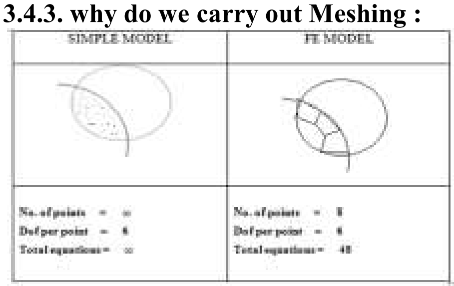

Table No. 3.3 Difference b/w Simple model to FE model

Any continuous object has infinite degree of freedom & it not possible to solve the problem in this format. Finite element method reduces DOF from infinite to finite with the help of meshing.

3.4.4. The CAE Includes Following Types Of Analysis

- Linear static analysis
- Non linear analysis
- Dynamic analysis
- Thermal analysis
- Buckling analysis
- Fatigue analysis
- Optimization
- CFD analysis
- Crash analysis
- NVH analysis

3.4.5 . Types of elements used in linear static analysis:

TRIA	QUAD
▲	■
Less accurate	More accurate
More stiffer	Less stiffer
Take more time to solve the problem	Take less time to solve the problem

Table No. 3.4 Types of Elements

Element	PSOLID
Mesh Type	3D
Element type	HEXA (solid)
Element size	20 mm

.Table No 3.5 Type and Size of Element

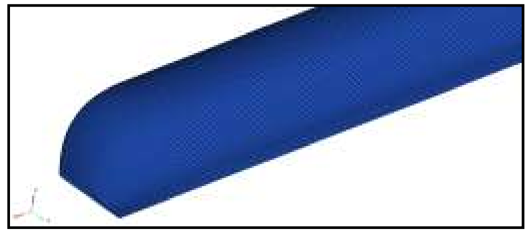

Fig 3.6[a]

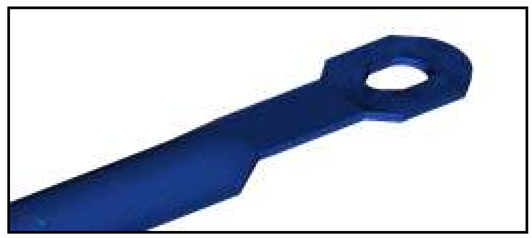

Fig 3.6[b]

Figure No 3.6[a] & 3.6[b] : Meshing Of The Blade Model

For proper Analysis we have to maintain some quality of the elements. The below table shows the quality of the rotor blade.

TYPE	VALUE
Warpage	20
Aspect	5
Jacobian	0.6
Minimum angle of quad face	45
Maximum angle of quad face	135
Minimum angle of tria face	20
Maximum angle of tria face	120

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Table No 3.6 Quality criteria of Rotor blade Element

LOAD DETERMINATION

4.1 Total Aerodynamic Force

A total aerodynamic force facilitating power is created when a surge of wind streams over and under an airfoil that is travelling through the air. The time when the air isolates to stream about the airfoil is known as the purpose of effect

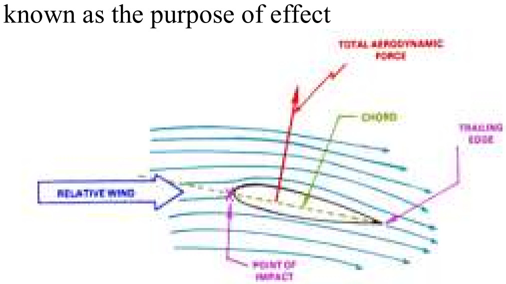

Fig No 4.1 : Airflow Around An Airfoil

A stagnation point or high weight region is framed at the purpose of effect. Ordinarily the high weight territory is situated at the lower segment of the main edge, contingent upon approach. This high weight region adds to the general power created by the sharpened steel.

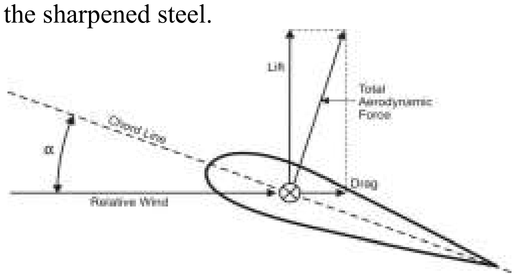

Fig No 4.2 : Total Aerodynamic Force

4.2 Pressure Patterns And LIFT Equation

The dissemination of pressure more than an airfoil segment may be a source of lift and in addition an air movement optimized curving power. The figure 4.3 demonstrates a commonplace case pressure distribution example grew by this cambered (non symmetrical) airfoil.

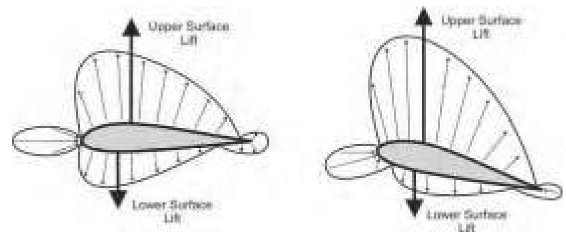

Fig No 4.3: Lift on a Symmetric & Cambered Airfoil

Upper surface lift and lower surface lift vectors are inverse one another as opposed to being isolated along the harmony line as in the cambered airfoil. At the point when the approach is expanded to create positive lift, the vectors remain basically inverse one another and the turning power is not applied.

Lift Equation is as follows

L = $\frac{1}{2}\,\rho V^2\ S\, C_L$

Where , L = Lift Force

$\frac{1}{2}$ = Constant

ρ = Density of the air

V^2 = airspeed (in feet per second) squared

S = Surface area (in square feet)

C_L = Coefficient of lift

To find the value of coefficient of lift we have to use below graph

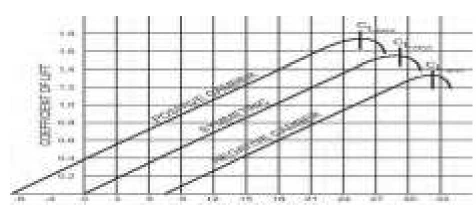

Fig No 4.5: Coefficient of lift VS AOA

Drag and Drag Equation

Drag is the power that restricts the movement of an airplane through the air. Aggregate drag created by an airplane is the whole of the profile drag, impelled drag, and parasite drag. Aggregate drag is essentially an element of velocity. The velocity that creates the

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most minimal aggregate drag ordinarily decides the air ship best-rate-of-trip pace, least rate-of-drop rate for autorotation, and greatest continuance speed. Drag equation is as follows

$D = \frac{1}{2}\rho V^2\ S\, C_D$

Where D = Drag force and C_D = coefficient 0f drag

To find the value of coefficient of drag we have to use below graph

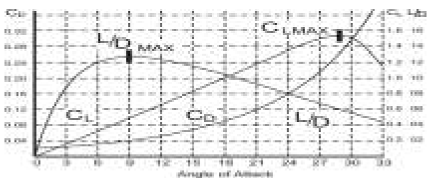

Fig No 4.6 : Coefficient of drag VS AOA

In Rotor Blade there are 3 force acting on the blade surface, they are

1. Lift
2. Drag
3. Centrifugal Forces

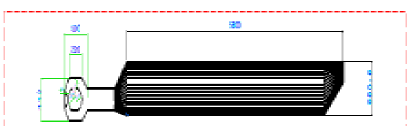

Fig No 4.7 : Rotor Blade

Before calculating the value of lift and drag we have to find out the value of Coefficient of Lift (C_L) and Coefficient of Drag (C_D).

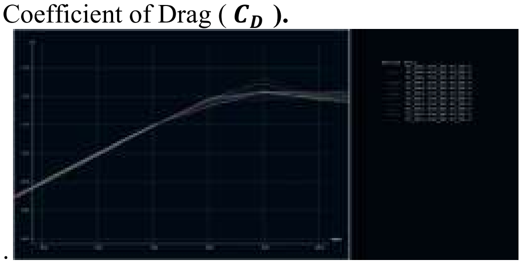

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Fig No 4.8 : Coefficient of Lift v/s Alpha

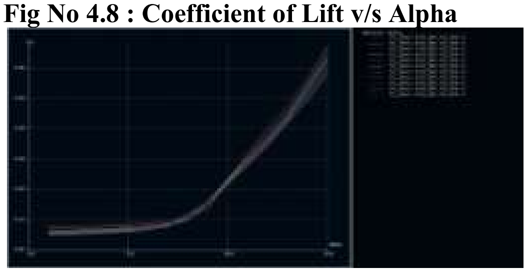

Fig No 4.9: Coefficient of Drag v/s Alpha

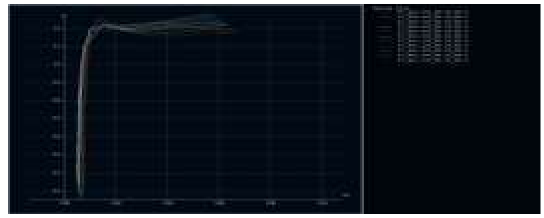

Fig No 4.10 : Coefficient of Lift v/s Coefficient of Drag

For finding lift &Drag we have to use below procedure.

For AOA 9 we got C_L & C_D values are (from graph)

$C_L = 1.264,\ C_D = 0.02$

Lift Formula : $L = \frac{1}{2}\rho\, c\, C_L\, \omega\, r_1 dx_1$

Where $\omega = \frac{2\pi N}{60} = \frac{2*3.14*314}{60}$ **= 32.88 rad/sec**

L = 1/2 * 12.53 * 1.264 * 0.55 * 32.88 * 1.992* 1.7

L = 484.95 N

Drag Formula : $D = \frac{1}{2}\rho\, c\, C_D\, \omega\, r_1 dx_1$

D = 1/2 * 12.53 * 0.02 * 0.55 * 32.88 * 1.992* 1.7

D = 15.34 N

Centrifugal force : $G = m\, r_1 \omega^2$

where ,m=117 Kg

G = 117 *9.81*1.992*32.88^2

G = 2.41E6 N

In similar way we have find Lift & Drag an each section , we got answer

SECTION NO.	LIFT in N	DRAG in N	Centrifugal Force in N
1	484.95	15.34	2.41E6
2	898.82	28.44	4.58E6
3	1312.68	41.54	6.6E6
4	293.80	9.29	1.5E5

Table No 4.1 : Different loads acting on Rotor Blade

For the structural analysis, the lift, the drag and the centrifugal forces were applied as distributed forces on the nodes on each blade segment, both on the upper side and the .lower surface.

For the final calculus the combination of all loads (the lift + the centrifugal force + the aerodynamic moment) case was considered, as in the Fig.4.11.

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Fig No 4.11 : The Loads Introduced In The Blade Structure.

CHAPTER 5

ANALYSIS

Free - Free Analysis of Helicopter Rotor Blade

After Meshing material property will be updated and prepare DECK for Free - Free analysis.

For preparing DECK for Free - Free analysis the Boundary condition and Loading Condition has not to be consider. Here we cannot give Frequency range, we can give only number of Modes.

There are 5 Types of Modes are their in Dynamic Analysis they are

- Linear Mode
- Lateral Mode
- Bending Mode
- Torsion Mode
- Mixed Mode

The below figures shows different mode shape of Aluminium Alloy Rotor blade.

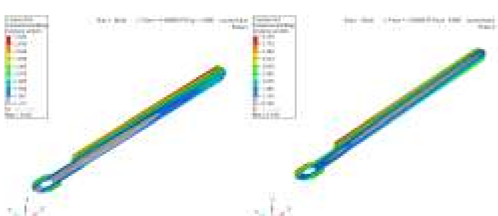

Fig 5.1 Mode 1 and Mode 2

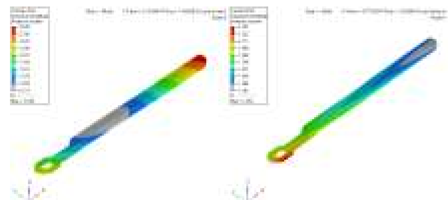

Fig 5.2 Mode 3 and Mode 4

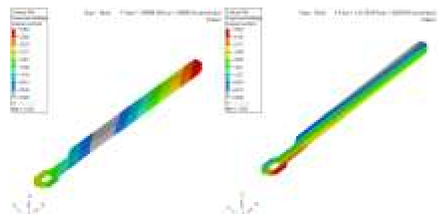

Fig5.3 Mode 5 and Mode 6

The below table shows the frequency range values & different Modes of Aluminium material.

MODES	Mode Value	Frequency in Cycle / Time
1	-4.10E-7	0
2	-3.52E-7	0
3	2.17E-7	7.42E-5
4	6.77E-7	1.31E-4
5	1.05E-6	1.63E-4
6	1.31E-6	1.82E-4
7	4158.2	10.26
8	21844	23.52
9	43273	33.108
10	92896	48.509
11	1.93E5	70.09
12	2.06E5	72.38

Table No 5.1: Frequency Range Values & Different Modes Of Aluminium Alloy Material.

The above table 5.1 shows the values of frequency of different modes. The above values are conclude that the first 6 Modes are rigid modes (zero Frequency) after seventh onwards we get Positive values, so our model is well connected .

The below figures shows different mode shape of CFRP Rotor blade.

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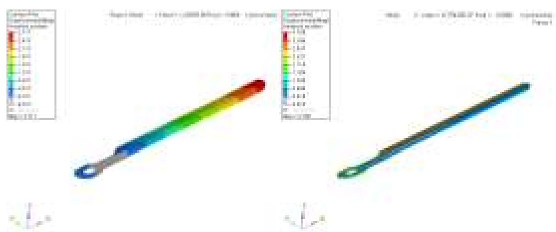

Fig :5.4 Mode 1 And Mode 2

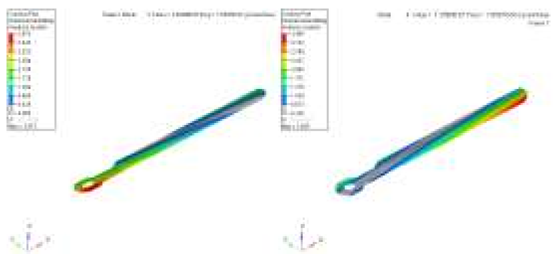

Fig No :5.5 Mode 3 And Mode 4

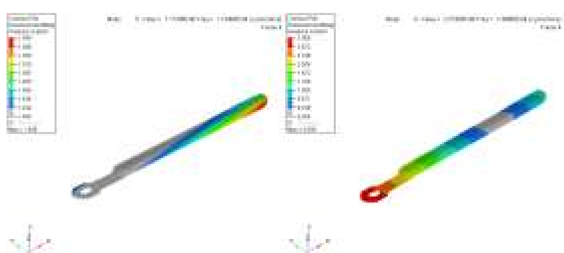

Fig No : 5.6 Mode 5 And Mode 6

The below table 5.2 shows the frequency range values of different Modes of CFRP material

MODES	Mode Value	Frequency in Cycle / Time
1	-1.25E-6	0
2	-6.75E-7	0
3	2.23E-7	7.52E-5
4	7.27E-7	1.35E-4
5	1.17E-6	1.72E-4
6	2.27E-6	2.39E-4

Table No 5.2: Frequency Range Values & Different Modes Of CFRP Material.

The table 5.2 shows the values of frequency of different modes. The above values conclude that the first 6 Modes are rigid modes (zero Frequency) after seventh onwards we get Positive values, so our

CHAPTER 6
Results and Discussion

In this chapter we will discuss about results of modular and static analysis of main rotor blade of light helicopter for different material (Aluminium Alloy and CFRP material) .

6.1 Natural frequency of Aluminium Alloy and CFRP Material :

For conducting Free - Free Analysis of main rotor blade of light helicopter for different material (Aluminium Alloy and CFRP material) , we won't consider first 6 modes that all are rigid modes i.e zero frequency mode. We consider only 7th mode, The value of 7th mode is the first natural frequency.

The table 4 shows Aluminium Alloy material values, The 1st Natural frequency i.e 7th mode value is 10.26 Cycle / Time.

The table 5 shows CFRP material values, The 1st Natural frequency i.e 7th mode value is 5.86 Cycle / Time.

The below Figure 6.1shows comparison of Aluminium Alloy and CFRP Material.

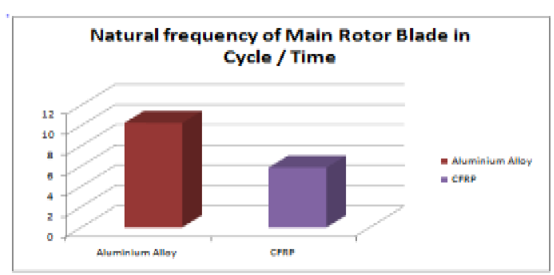

Fig No 6.1 : Natural frequency of Aluminium Alloy and CFRP Material

After Free - Free analysis we conduct liner static analysis of main rotor blade of light helicopter for different material (Aluminium and CFRP material) we get following result. Maximum Displacement of stright Aluminium Alloy Rotor blade is 512.23 mm and Maximum Displacement of inclined Aluminium Alloy Rotor blade is 557.23 mm.

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Maximum Displacement of CFRP Rotor blade is 153.67 mm and Maximum Displacement of inclined CFRP Rotor blade is 167.168 mm.

The below Figure hows comparison of Maximum Displacement of Aluminium Alloy and CFRP Material.

6.2 Maximum Displacement of main rotor blade :

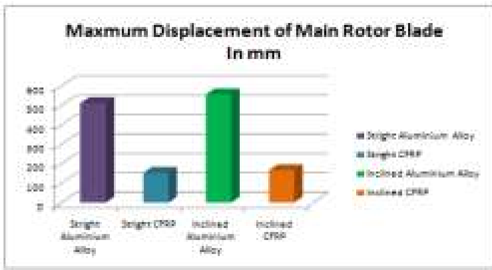


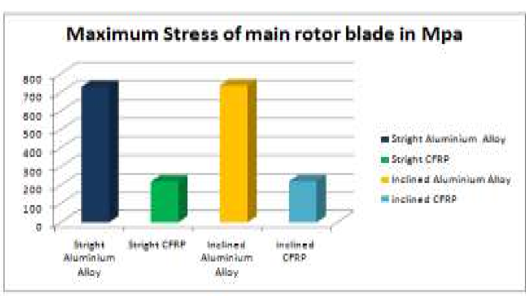
Fig No 6.2 : Maximum Displacement of main rotor blade

Maximum Stress of Aluminium Alloy Rotor blade is 729.06 MPa and Maximum Stress of Inclned Aluminium Alloy Rotor blade is 736.39 MPa.

Maximum Stress of stright CFRP Rotor blade is 218.419 MPa and Maximum Stress of Inclned CFRP Rotor blade is 220.85 MPa.

6.3 Maximum Stress of main rotor blade

The Figure 6.3 shows comparison of Maximum Stress of Aluminium Alloy and CFRP Material.



FigNo 6.3 : Maximum Stress of main rotor blade

The main aim of this project is to reduce the weight of helicopter main rotor blade.

6.4 Total weight of main rotor blade :

The total weight of aluminium alloy main rotor blade is 478 Kg and total weight of CFRP main rotor blade is 191 kg.

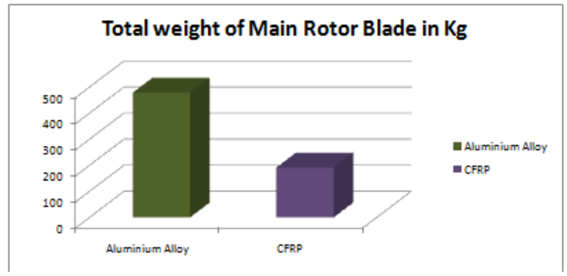


Fig No 6.4 : Total weight of main rotor blade

CHAPTER 7
CONCLUSION

The above table 4 and table 5 shows the value of natural frequency of Aluminum Alloy and CFRP material. In free – free analysis we won't consider first 6 modes that all are rigid modes i.e zero frequency mode. We consider only 7th mode, The value of 7th mode is the first natural frequency.

The table 4 shows Aluminum material values, The 1st Natural frequency i.e 7th mode value is 10.26 Cycle / Time.

The table 5 shows CFRP material values, The 1st Natural frequency i.e 7th mode value is 5.86 Cycle / Time.

The above results has been shown that the comparative study of Free – Free analysis of two different material (Aluminum and CFRP) of Helicopter main rotor blade. In above table result conclude that the 1st Natural frequency of CFRP material (5.86 Cycle / Time) is lesser than 1st Natural frequency of Aluminum Alloy material (10.26 Cycle / Time).

Which conclusively suggest use of composite material has the better option for the helicopter main rotor blade.

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In liner static analysis the following results are obtained

- Maximum Displacement of stright Aluminium Rotor blade is 512.23 mm and Maximum Displacement of inclined Aluminium Rotor blade is 557.23 mm.
- Maximum Stress of Aluminium Alloy Rotor blade is 729.06 MPa and Maximum Stress of Inclned Aluminium Alloy Rotor blade is 736.39 MPa.
- Maximum Displacement of CFRP Rotor blade is 153.67 mm and Maximum Displacement of inclined CFRP Rotor blade is 167.168 mm.
- Maximum Stress of stright CFRP Rotor blade is 218.419 MPa and Maximum Stress of Inclned CFRP Rotor blade is 220.85 MPa.

The obtained Maximum Displacement and Maximum stress value is getting more which is above the permissible limit. If we use alluminium alloy as a material we get more displacement and stress so rotor blade get fail so we prefer CFRP material to reduce the displacement and stress.

The main aim of this project is to reduce the weight of helicopter main rotor blade.

- The total weight of aluminium alloy main rotor blade is 478 Kg
- The total weight of CFRP main rotor blade is 191 kg.

By analysing above result we conclude that by using CFRP material instead of Aluminium Alloy we can reduce 60 % of Total Weight of Helicopter main rotor blade.

As future research directions, studies of topological optimization in order to reduce the structure weight and to maintain the rigidity at an acceptable level are considered.

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