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Analysis of Noise Reducton in Helicopter Rotor Blades Using Composite Materials

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Abstract—*Helicopter rotor blade noise is one of the most severe noise sources and is very important both in community annoyance and military detection. Research over the decades has substantially improved basic physical understanding of the mechanisms generating rotor blade-vortex interaction noise and also of controlling techniques, particularly using active rotor control technology. Each concept is evaluated using best practice design and analysis methods, achieving the study's aim to significantly reduce noise with minimal performance degradation and no vibration increase. The helicopter rotor blades are made up of Steel or titanium alloy and generate noise that causes disturbance. The present work aims at observing the choice of composite material an alternative to metal for better vibration control. The three dimensional model of the Rotor Blade was created using the CATIA software. The model was meshed and Boundary conditions were given on the finite element model through ANSYS 14 workbench and then the analyzed value was also proved by theoretically.*

Keywords: *Helicopter, Rotor Blade Noise, Composite Materials, Noise Reduction, Blade Design and Analysis*

1. INTRODUCTION

Noise made by a helicopter, is very complex and is comprised of multiple forms of noise sources. Whether both a civilian or military helicopter, it generates noise that sounds very different from noise emitted made by airplanes. A helicopter main rotor generates primarily low frequency noise and, in certain operating regimes, high amplitude low-to-mid-frequency noise modulated at the blade passage frequency. A helicopter main rotor or rotor system is the combination of several rotary wings (rotor blades) and a control system that generates the aerodynamic lift force that supports the weight of the helicopter, and the thrust that counteracts aerodynamic drag in forward flight. Each main rotor is mounted on a vertical mast over the top of the helicopter, as opposed to a helicopter tail rotor, which connects through a combination of drive shaft(s) and gearboxes along the tail boom.

2. SOURCES OF NOISE GENERATION IN HELICOPTER ROTOR BLADES

The noise generated from the helicopter rotor blades are as follows:

Thickness noise can be caused by the displacement of the air by the rotor blades.

Loading noise is due to the acceleration of the force distribution on the air around the rotor blade.

Blade-Vortex Interaction (BVI) noise occurs when a rotor blade passes within a close proximity of the shed tip vortices from a previous blade.

Broadband noise due to the turbulence ingestion through the rotor, the rotor wake itself and blade self-noise.

High-Speed Impulsive (HSI) noise can be caused by transonic flow shock formation on the advancing rotor blade.

Tail rotor noise most of the noise from a helicopter is generated by the main rotor, the tail rotor is a significant source of noise for observers relatively close to the helicopter.

When compared to above discussed noise 65% of noise generated from rotor blades and hence rotor blade noises give more annoyance and disturbance to peoples. These noise also alert enemies in military fields and it generate more vibration. As know that BVI noise due to blade vortex noise, occurs when a rotor blade passes within a close proximity of the shed tip vortices from a previous blade. This generates more noise to helicopter. Therefore, we decided to reduce the blade-vortex interaction noise.

3. MATERIAL SELECTION

3.1. Carbon Fiber Epoxy

Carbon fiber–reinforced polymer, carbon fiber–reinforced plastic or carbon fiber–reinforced thermoplastic (CFRP, CRP, CFRTP or often simply carbon fiber, or even carbon), is an extremely strong and light fiber-reinforced polymer which contains carbon fibers. The matrix is usually a polymer resin, such as epoxy, to bind the reinforcements together. The binding polymer is often a thermoset resin such as epoxy, but other thermoset or thermoplastic polymers, such as polyester, vinyl ester or nylon, are sometimes used. The composite may contain other fibers, such as aramid e.g. Kevlar, Twaron, aluminium, Ultra-high-molecular-weight polyethylene(UHMWPE) or glass fibers, as well as carbon fiber.

3.2. Glass Fiber Epoxy

Fiber glass is a type of fiber reinforced plastic where the reinforcement fiber is specifically glass fiber. The glass fiber may be randomly arranged but is commonly woven into a mat. The plastic matrix may be a thermosetting plastic- most often epoxy, polyester resin- or vinyl ester, or a thermoplastic. The glass fibers are made of various types of glass depending upon the fiber glass use. These glasses all contain silica or silicate, with varying amounts of oxides of calcium, magnesium, and sometimes boron. To be used in fiber glass, glass fibers are made with very low levels of defects.

3.3. Titanium Alloy

Titanium alloys are metals that contain a mixture of titanium and other chemical elements. Such alloys have very high tensile strength and toughness (even at extreme temperatures). They are light in weight, have extraordinary corrosion resistance and the ability to withstand extreme temperatures. However, the high cost of both raw materials and processing limit their use to military applications, aircraft, spacecraft, medical devices, highly stressed components such as connecting rods on expensive sports cars and some premium sports equipment and consumer electronics.

3.4. Comparison of Various Materials

Table3.1: Comparison of Various Material Properties

MATERIAL	COST	STRENGTH
Carbon fiber epoxy	High	Very high strength and stiffness.
Glass fiber epoxy	Low	Brittle in nature.
Titanium alloy	High	High temperature resistance.
Aramid fiber	High	High toughness but very expensive.
Ceramic fiber	High	High oxidation resistance in high temperature applications.

4. AIRFOIL SELECTION

The cross-sectional shape obtained by the intersection of the wing with the perpendicular plane is called an airfoil. Nowadays, NACA 23011 series airfoil is mostly used in helicopter rotor blade. Hence we selected the NACA 23011(see fig.4.1) series airfoil.

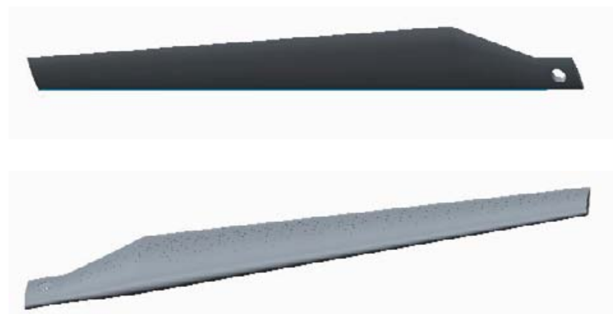
5. ROTOR BLADE MODELING USING CATIA

Model is a representation of an object, a system, or an idea in some form other than that of the entity itself. Modeling is the process of producing a model; a model is a representation of the construction and working of some system of interest. A model is similar to but simpler than the system it represents. One purpose of a model is to enable the analyst to predict the effect of changes to the system.

5.1. Blade Design

A number of concept design tools that provide up-front Industrial Design concepts can then be used in the downstream process of engineering the product. These range from conceptual Industrial design sketches, reverse engineering with point cloud data and comprehensive free-form surface tools.

The Sketched Views of the Rotor Blade shown in the Figures below:



5.1: CATIA Model of Helicopter Rotor Blade

The helicopter rotor blade can be applied by carbon fiber epoxy using ANSYS software. By applying composite material, the natural frequency and the static structural analysis can be determined. Then the noise generated by the helicopter rotor blades can be reduced by applying composite material and can be obtained by ANSYS workbench14.

6. FORCE AND FREQUENCY CALCULATION:

6.1. Theoretical Calculation:

A theoretical (or conceptual) definition gives the meaning of a word in terms of the theories of a specific discipline. This type of definition assumes both knowledge and acceptance of the theories that it depends on. To theoretically define is to create a hypothetical construct. This method of operationalization is not to be confused with operationally defining.

6.2. Calculation of Natural Frequency:

Natural frequency is the frequency at which a system tends to oscillate in the absence of any driving or damping force. Free vibration of any elastic body is called natural vibration and happens at a frequency called natural frequency. Natural vibrations are different from forced vibration, which happen at frequency of applied force (forced frequency). If forced frequency is equal to the natural frequency, the amplitude of vibration increases manifold. This phenomenon is known as resonance.

Helicopter rotor blade producing frequency after applying carbon epoxy composite material can be calculated. Rotor blade is an rotating component, in which natural frequency can find out by assuming an torsional component and the calculation as follows:

Calculation for natural torsional frequency is given by

$$I_P\ddot{\theta} = -k_t\theta$$

Then by substituting the values of θ and $\ddot{\theta}$ we get

$$-k_t\,(\widehat{\theta}\,\sin\omega_n\,\text{ft}) = I_P\,(-\omega_n\,\text{f}\,\theta)$$

Then by reducing the values we get

$$I_P\,\omega_n^2\text{f} = k_t$$

Therefore,

$$\omega_n\text{f} = \sqrt{k_t}\,/\,\sqrt{I_P}$$

Here $I_P\ddot{\theta}$ is the external torque of the disc.

Then by considering

$$\theta = 45^{\circ}$$

T (buckling torque) = 3209.95 Nm

Then,

$$k_t = \frac{T}{\theta} = \frac{3209.95}{45} = 71.3111$$

Then the known value of I is 15.8293 then by substituting the value of I_p and k_t we get

$$\omega_n\text{f} = \sqrt{k_t}\,/\,\sqrt{I_P}$$

$$= \sqrt{71.3111/15.8293}$$

$$= \sqrt{4.505}$$

$$\omega_n\text{f} = 2.2025\text{Hz}$$

Therefore,

natural frequency, ω_nf = 2.2025Hz

Thus, theoretically say the helicopter rotor blade produces the natural frequency for applying carbon epoxy fiber is 2.2025Hz.

6.3. Calculation of Drag Force

During powered flight, the rotor drag is overcome with engine power. When the engine fails, or is deliberately disengaged from the rotor system, some other force must be used to sustain rotor RPM so controlled flight can be continued to the ground. This force is generated by adjusting the collective pitch to allow a controlled descent. Airflow during helicopter descent provides the energy to overcome blade drag and turn the rotor.

The drag force calculation is given by

Drag force, F = 0.5 C_D ρ A V^2

where

A	=	Reference area, m2.
C_D	=	Drag coefficient (no unit).
F	=	Drag force, N.
V	=	Velocity, m/s.
ρ	=	Density of fluid (liquid or gas), kg/m^3.

Here,

Air density =1.2754 Kg/m^3

Velocity = 100 m/s

C_D = 0.0063

Area = 7.5m^2

Therefore,

Drag force, F = 0.5 × 0.0063 × 1.2754 × 7.5 × 10000

Drag force, F = 301.31 N

7. COMPUTATIONAL METHODOLOGY:

7.1. Analysis using Ansys:

The ANSYS structural analysis software suite is trusted by organizations around the world to rapidly solve complex structural engineering problems with ease.FEA analysis (finite element) tools from ANSYS provide the ability to simulate every structural aspect of a product:

- Linear static analysis that simply provides stresses or deformations
- Modal analysis that determines vibration characteristics
- Advanced transient nonlinear phenomena involving dynamic effects and complex behaviours.

7.2. Frequency Analysis Results for Titanium Alloy, Glass Epoxy and Carbon Fibre Epoxy Rotor Blade:

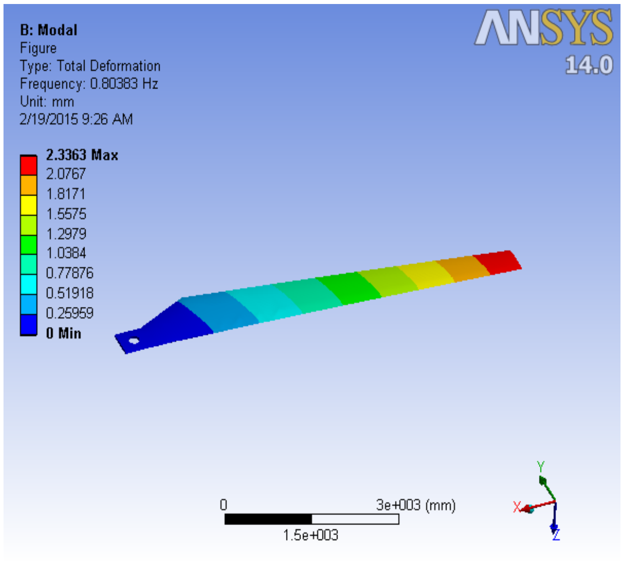


Fig.7.1.Total Deformation of Glass Fiber Reinforced Polymer Rotor Blade in Frequency 0.80383Hz

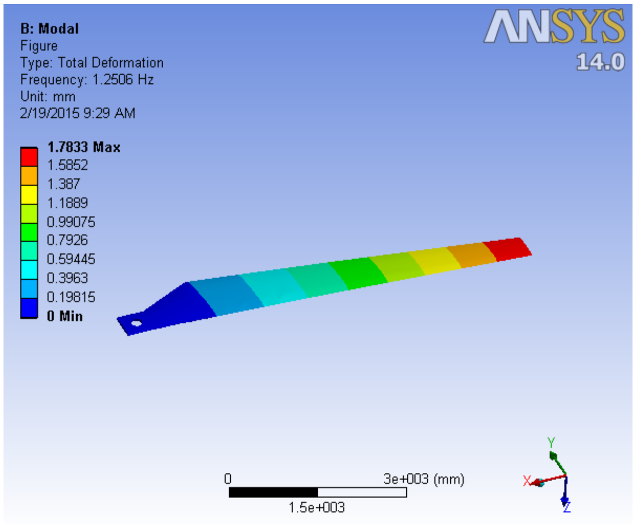


Fig.7.2: Total Deformation of Titanium Alloy Rotor Blade in Frequency 1.2506Hz

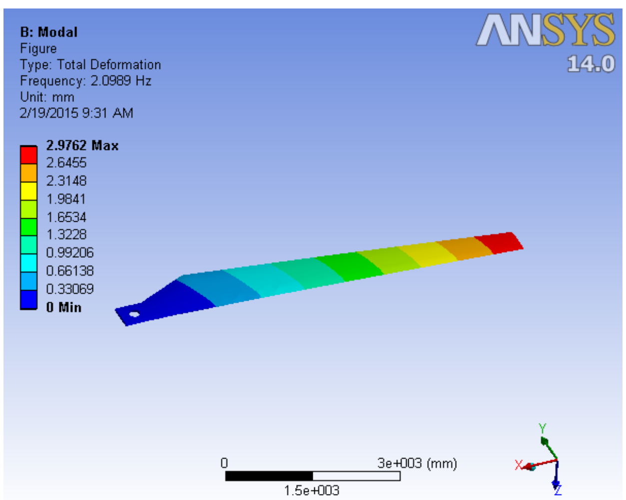


Fig. 7.3: Total Deformation of Carbon Fiber Epoxy Rotor Blade in Frequency 2.0989Hz

Thus, the total deformation of different materials like carbon epoxy fiber, glass epoxy fiber and titanium alloy of different frequency ranges like 1.2506Hz, 7.7042Hz, 8.7368Hz, 20.405Hz , 28.884Hz, 42.04Hz, 2.0989Hz, 13.798Hz, 21.225Hz, 37.029Hz, 58.684Hz, 0.80383Hz, 5.4009Hz, 9.369Hz, 14.361Hz, 25.376Hz. Then the average value of these material frequencies (see fig.7.1, 7.2, 7.3) and its total deformation are as follows:

Table 7.1: Comparison from Results

Materials	Frequency(Hz)	Total Deformation(Mm)
Titanium alloy	1.2506	1.7833
Carbon fiber epoxy resin	2.0989	2.9762
Glass fiber epoxy resin	0.80383	2.3363

8. STATIC STRUCTURAL ANALYSIS

A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time. A static structural load can be performed using the ANSYS or Samcef solver. The types of loading that can be applied in a static analysis include:

- Externally applied forces and pressures
- Steady-state inertial forces (such as gravity or rotational velocity)
- Imposed (nonzero) displacements
- Temperatures (for thermal strain)

8.1. Static Structural Analysis Results for Titanium Alloy,Glass Epoxy Fiber and Carbon Epoxy Fiber Rotor Blade

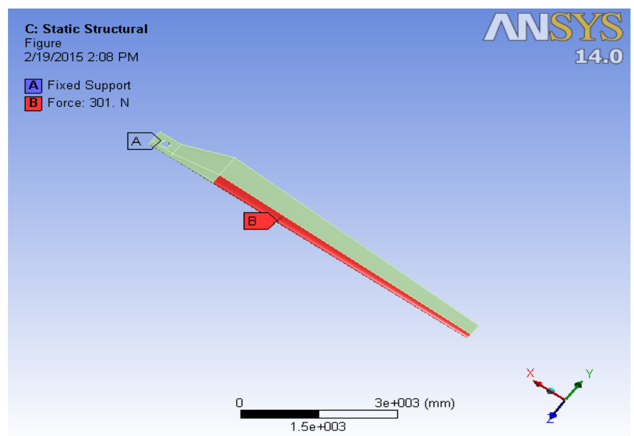


Fig.8.1.Fixed Support Model of Glass Fiber Rotor Blade

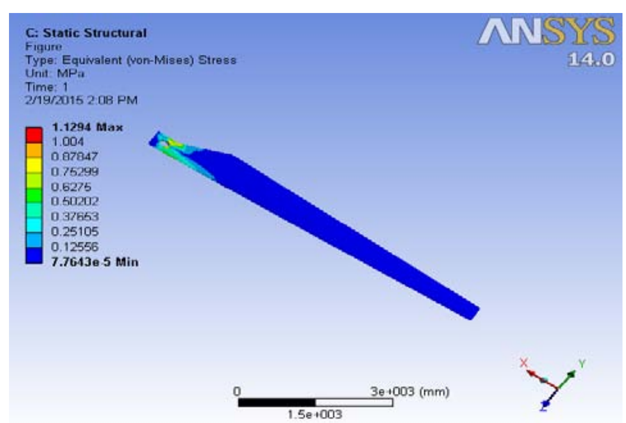


Fig.8.2: Equivalent Stress Distribution of Glass Fiber Rotor Blade

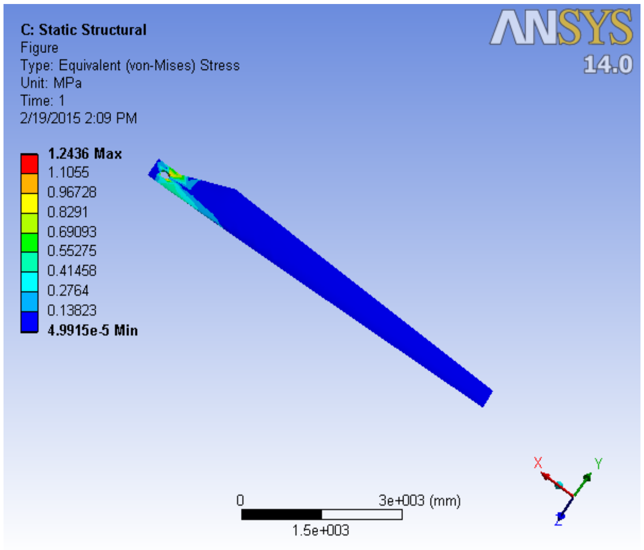


Fig. 8.3: Equivalent Stress Distribution of Carbon Fiber Rotor Blade

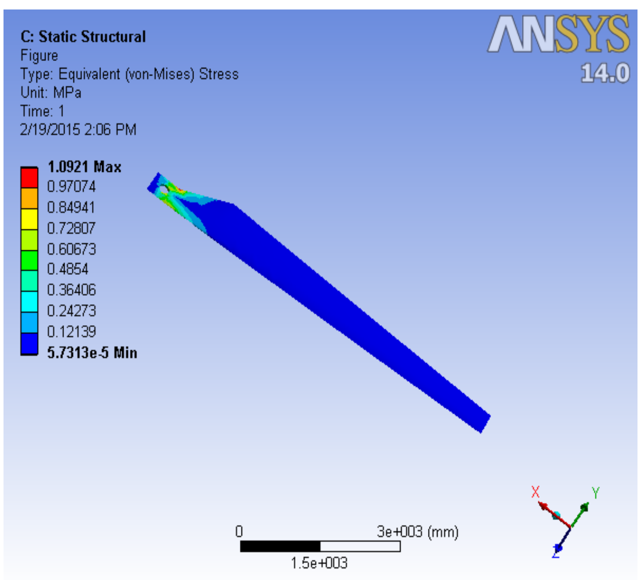


Fig. 8.4: Equivalent Stress Distribution of Titanium Alloy Rotor Blade

Thus, the structural analysis can be done by fixing the point A and applying the drag force on the point B. By applying these forces on the helicopter rotor blades Total deformation, Equivalent stress distribution, Equivalent elastic strain distribution, Stress intensity, Elastic strain intensity, Normal elastic strain, Shear Stress distribution and Shear Elastic strain distribution for the carbon epoxy fiber, glass epoxy fiber and titanium alloy can be obtained respectively. And hence the average values of the total deformation, stress and strain withstanding capacity of the titanium alloy, carbon fiber epoxy and glass fiber epoxy are as follows:

Table 8.1: Comparison from Results

Materials	Total deformation (mm)	Stress (Mpa)	Strain
Titaninum alloy	0.14829	1.0921	9.1226e-6
Carbon fiber epoxy resin	0.19328	1.2436	3.2738e-5
Glass fiber epoxy resin	0.73506	1.1294	0.0001046

9. CONCLUSION

To evaluate the effectiveness of composites in reducing noise of the casing, modal analysis and static analysis both metal and composite rotor blade were performed using FEA package ANSYS 14 workbench. The reduction in noise level of composite rotor blade over metal rotor blade was performed.

Carbon fiber epoxy high natural frequency compared to other materials, it can be analyzed by ansys and the structural analysis of the carbon fiber epoxy withstands the maximum stress and strain. Therefore, the noise reduced by applying carbon fiber epoxy resin.

The 3D model is prepared in CATIA and then CAE analysis is performed using ANSYS-14. From the results obtained from ANSYS, discussions have been made and it will be concluded.

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