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Experimental and Design, CFD, Modal analysis of E 387 Helicopter Blade

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Abstract - Now a days it is observed that weight parameter is a specific issue for many companies for better efficiency of any product. So, in resent a specific profile of E 387 light weight helicopter blade is designed. Due to composite material of carbon epoxy it is light in weight but also high strength carrying blade. In present research, design using standard airfoil tool website is presented along with CFD simulation is been performed to know lift carrying capacity and also modal analysis is been performed using ANSYS software. Similarly, validation is concluded with FFT technique in which results obtained through modal analysis with mode shape and respective natural frequency are compared.

Keywords—ANSYS, CATIA, CFD, MODAL ANALYSIS, FFT

I. INTRODUCTION

Similar to a bird's wing, an aircraft wing is the lifting surface with the chosen aerofoil section, whose shape/geometry can be varied span wise to search better performance. The lift generated by the wing sustains the weight of the aircraft to make flight in the air. Again, from an aerodynamic perspective, the main source of the airplane drag is associated with the wing. Around two-thirds of the total drag of typical transport aircraft at cruise conditions is produced by the wing. Therefore, the effects of wing shape and size are crucial to aerodynamic characteristics (lift, drag, lift to drag ratio, etc) on which the efficiency as well as the performance of aircraft depend.

An aerofoil is the shape of an aircraft wing as seen in the below cross section shows the four main forces of flight acting on the aerofoil. The weight of the aircraft is directed downwards towards the earth. To achieve flight, the weight must be overcome by the lift force generated by the motion of the airplane through the air. The wing deflects the air downward and the opposite reaction pushes the wing up. The forward motion of the aircraft is attained by the thrust force generated by the engines. As the aerofoil pushes the air out of its way, the air pushes back on the aerofoil generating a drag force. This force is opposite to the motion direction and can be thought of as an aerodynamic friction. Wing structures are also used in boats, submarines and ships where the idea is similar but the fluid is water instead of air. When used in watercraft, these are often called hydrofoils.

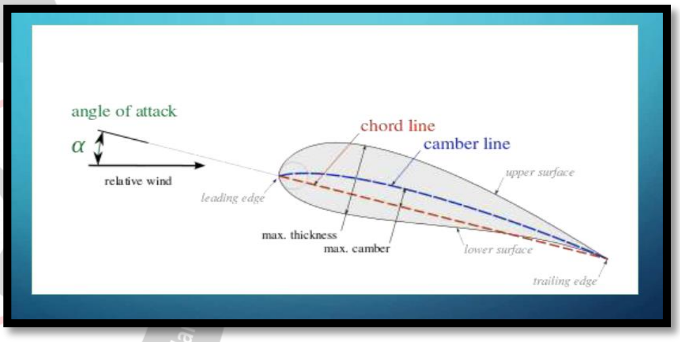

Fig.1 Nomenclature of airfoil blade

II. LITERATURE REVIEW

(GENC & ILYAS, 2015)[2] In this paper fabrication of an UAV having aerofoil shaped fuselage using NACA 4416 profile and compared the result between the aerodynamic characteristics with that of the same model. Open circuit subsonic wind tunnel has been used to test the fabricated UAV model and collection of data. The wind tunnel is associated with Versatile Data Acquisition System (VDAS) to measure the lift & drag force coefficients and point surface pressures. The aerodynamic characteristics of UAV model have been carried out at two different Reynolds Number (1.37×10^5 and 2.74×10^5 respectively) with different angles of attack from -3° to 18°. It is concluded that the stalling angle of this design is found at about 14° during experimental investigation. The L/D Ratio of 'Aerofoil shaped fuselage configuration' at the stalling angle (14° AOA) at 20 & 40 m/s are 6.84 & 8.02 respectively for experimental design and for theoretical design the L/D Ratio of same model at the stalling angle (15° AOA) at 20 and 40 m/s are 5.13 & 7.40 respectively.

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G.M. Jahangir Alam [1] this paper explains the fabrication of an UAV having aerofoil shaped fuselage using NACA 4416 profile and compared the result between the aerodynamic characteristics with that of the same model obtained from CFD investigation.

Experimental condition- Open circuit subsonic wind tunnel has been used to test the fabricated UAV model and collection of data. The wind tunnel is associated with Versatile Data Acquisition System (VDAS) to measure the lift & drag force coefficients and point surface pressures. The aerodynamic characteristics of UAV model have been carried out at two different Reynolds Number (1.37×10^5 and 2.74×10^5 respectively) with different angles of attack from -3^o to 18^o.

Result-The stalling angle of this design is found at about 14^o during experimental investigation. The L/D Ratio of 'Aerofoil shaped fuselage configuration' at the stalling angle (14° AOA) at 20 & 40 m/s are 6.84 & 8.02 respectively for experimental design and for theoretical design the L/D Ratio of same model at the stalling angle (15° AOA) at 20 and 40 m/s are 5.13 & 7.40 respectively.

Sara Arbo Torrentet [4] This study explores the geometry of sliver steel supports have on aero mechanics performance of a membrane aerofoil.

Experimental condition-Test are performed at low Reynolds number $Re=9 \times 10^4$ and incidence of $2\text{-}25^0$,high speed photogrammetric as well as force measurements are carried out to explore the effects of four different leading edge (LE) and trailing edge (TE) designs on the performance of membrane aerofoil.

Results indicate that mean camber as well as membrane vibration (both mode shape and frequency) change with geometry and size of LE and TE support. The LE/TE supports with a rectangular cross section consistently provide higher lift forces and higher mean camber deformation compared to the circular cross section.

M. Nazmul Haque [3] This paper represents the experimental investigation to explore better aerodynamic performance by incorporating curvature at the leading edge of a wing.

Experimental condition- A wooden model with straight leading and trailing edge i.e. rectangular platform and another model with curved leading edge and straight trailing edge are prepared with NACA 4412 airfoil in equal length (span) and surface area. Both the models are tested in a closed-circuit wind tunnel at air speed of 85.35 kph (0.07 Mach) i.e. at Reynolds's number 1.82×10^5. The static pressure at different angles of attack (-4˚, 0˚, 4˚, 8˚, 12˚, 16˚, 20˚ & 24˚) are measured from both upper and lower surfaces of the wing models through different pressure tapings by using a multi-tube water manometer. From the static pressure distribution, lift coefficient, drag coefficient and lift to drag ratio of both the models are analyzed.

Results-After analyzing the data, it is found that the curved leading edge wing platform is having higher lift coefficient and lower drag coefficient than the rectangular wing platform. Thus, the curved leading edge platform is having higher lift to drag ratio than the rectangular platform.

Nour, A., Gherbi, M.T., Chevalier, Y. (2012) [8]

This study concerns the dynamic behavior of a helicopter blade. The objective is to simulate by the finite elements method, the behavior of a blade of different materials under an aerodynamic load. This study was conducted to evaluate the aerodynamic loads applied and evaluated by a numerical simulation the frequencies and Eigen modes and calculate the stresses acting on the structure for different modes.

Experimental condition-The geometry of the blade is determined using CATIA software. Data is processed by the ANSYS software to mesh. The NACA 23012 wing airfoil is studied 5-digit serial. It is composed of 26 static pressure taken, numbered from 1 to 12 extrados side, and 13 to 24 from intrados side. The wing span for b = 6 m and chord c = 0.4 m

To describe the variation of the second degree of the centrifugal inertial force in the axial direction, it has an element of 8 nodes (I.J.K.L.M.N.O.P) has five degrees of freedom to each node: three translations in (Ux.Uy.Uz) following x, y, z, and two rotations (θx.θz) along x, z.

Result- We can conclude from these analytical and numerical modeling approaches that the dynamic behavior of the helicopter blade of different materials, as frequencies of isotropic material are higher compared to the orthotropic material. The stresses of an isotropic material is larger compared to the orthotropic material and becomes more rigid in the loading direction and is more ductile in other directions. The results of numerical simulation for transient behavior, at the resonance, show clearly that the graphs representing the spectrum of various displacements are distributed over the entire range of time, which means that our blade works by the three modes (flapping, lagging, and twisting).

PROBLEM STATEMENT

In present research light weight helicopter blade of E 387 series is been designed. Due to aerodynamic structure of E387 profile it generates a high lift on small angle of attack. So, in present research it is designed, CFD, FEA analysis along with FFT technique is used to study the parameters on blade design.

III. OBJECTIVES

1. Design of helicopter blade (E 387) using standard process with use of airfoil tools website procedure.

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2. Modeling of blade using CATIA software and CFD simulation in ANSYS fluent to determine lifting force, velocity distribution and pressure contour on both surfaces.
3. Manufacturing of blade using composite material (Carbon epoxy).
4. FEA analysis using ANSYS software to determine mode shape and respective frequency in modal analysis.
5. Experimental validation using FFT technique to determine natural frequency and validation with numerical results.

IV. METHODOLOGY

Step 1:- Firstly **identify problem** regarding material of helicopter blade and go through literature survey with the help of various previous research papers.

Step 2:-**Define objectives and problem statement** by Survey on research papers which are relevant to this topic. After going through these papers, we learnt about Engine mounting bracket.

Step 3:- Selection of material for manufacturing of helicopter blade

Step 4:- After that the components which are required for our project are decided.

Step 5:- **Design and Development**- After deciding the components, the 3D Model and drafting will be done with the help of CATIA software.

Step 6:- The **modal Analysis** of the components will be done with the help of ANSYS using FEA.

Step 7:- The **Experimental Testing** will be carried out with FFT analyzer.

Step 8:- Comparative analysis between the experimental & analysis result & then the result & conclusion will be drawn.

DESIGN OF E 387 BLADE

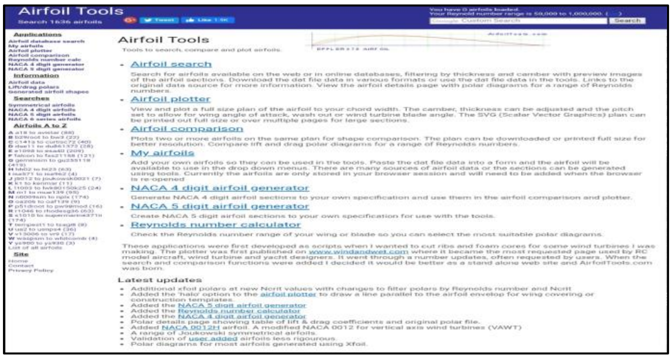

Fig. 2 Airfoil tools website (www.airfoiltools.com)

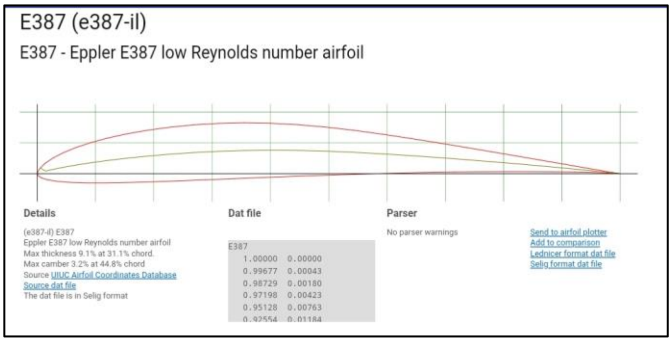

Fig.3 E 387 blade design

- Selection of airfoil coordinates from airfoil tools website as per suggested blade specification.
- Imported coordinates of E 387 blade from airfoil tools website in excel.
- Use macro command to run and generate profile in CATIA.
- Modeling has been done with the help of www.airfoiltools.com
- Go the application select E 387 airfoil generator
- Enter the following values
  Chord line = 50, 70 and 100 m

  Number of points = 200

  Close trailing edge = yes
- Import the coordinates in MS EXCEL and use macro command and run the main file and select point 3 to use loft and in CATIA open shape generative design and it will automatically generate shape in CATIA and close the sketch using thick surface command.

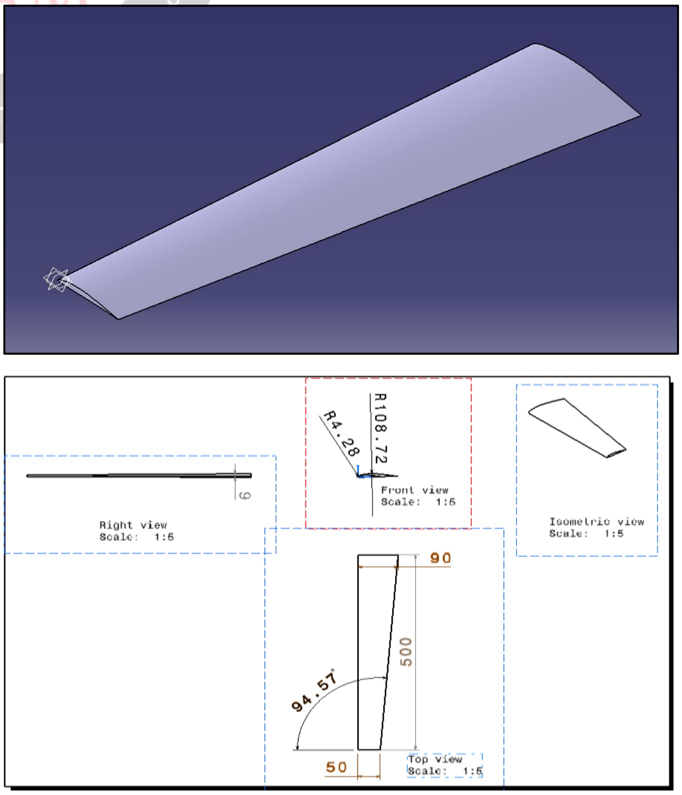

Fig. 4 Catia and drafting of E 387 blade design

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COMPUTATIONAL FLUID DYNAMICS (CFD) is a branch of fluid mechanics that uses numerical analysis and data structures to analyze and solve problems that involve fluid flows.

CFD is now recognized to be a part of the computer-aided engineering (CAE) spectrum of tools used extensively today in all industries, and its approach to modeling fluid flow phenomena allows equipment designers and technical analysts to have the power of a virtual wind tunnel on their desktop computer.

CFD PROCEDURE

- In CFD simulation bounding box is created across blade profile for simulation of velocity and pressure distribution across surface of blade.
- Fine meshing is performed for CFD simulation.
- Named selection is performed in CFD to define air inlet, outlet and blade surface.
- In general box model gravity is defined in perpendicular direction and energy is kept on to perform conservation of mass, momentum and energy equation to solve.
- In viscous model k epsilon, realizable and standard wall function is selected to maintain turbulence flow.
- Inlet velocity is defined as 180 m/s.
- Hybrid initialization is performed.
- 100 number of iterations is considered.

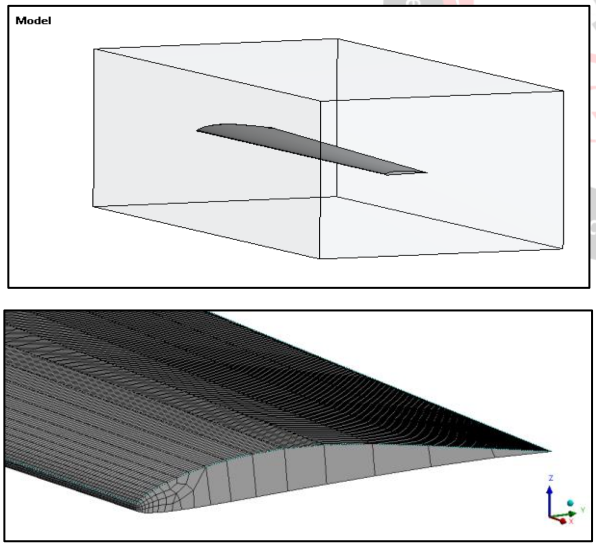
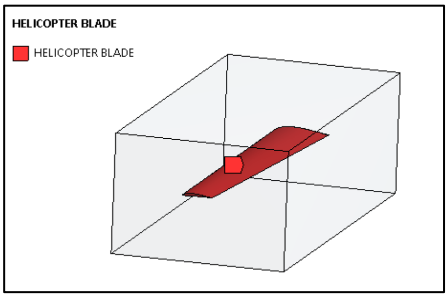


Fig.5 Geometry and meshing of blade



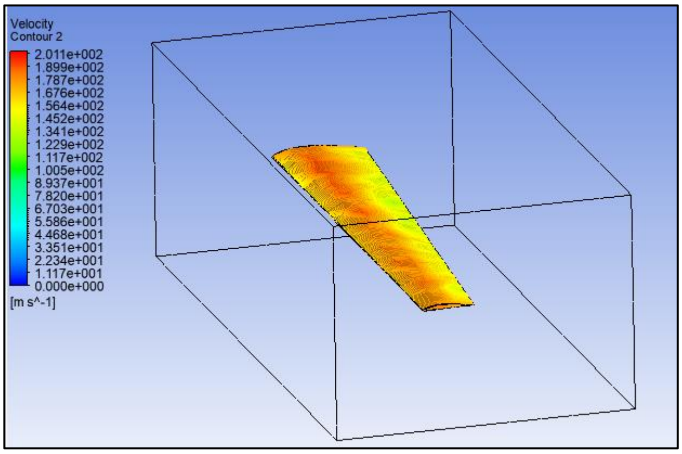


Fig .6 Velocity contour of E 387 blade

It is observed that all aerofoil section or profile follow Bernoulli's equation, high velocity = low pressure low velocity = high pressure. From, velocity contour it is observed high velocity at upper surface but low pressure at upper surface. So, to produce lift high pressure at lower surface is required It is observed from pressure contour that at upper surface low pressure is observed with high pressure at bottom surface.5 probe location are used (Pa)1381, 1241, 1315, 1414, 1149In bottom surface pressure of 1300 Pa is observed in below plot So, lift force is calculated by pressure x surface area of lower surface lift force = 1300 x 0.0352lift force = 45.76 N = 4.5 kg

MODAL ANALYSIS OF E 387 BLADE

Properties of Outline Row 3: Epoxy Carbon UD (230 GPa) Prepreg

	A	B	C
1	Property	Value	Unit
2	Density	1490	kg m^-3
3	Orthotropic Secant Coefficient of Thermal Expansion		
8	Orthotropic Elasticity		
9	Young's Modulus X direction	1.21E+11	Pa
10	Young's Modulus Y direction	8.6E+09	Pa
11	Young's Modulus Z direction	8.6E+09	Pa
12	Poisson's Ratio XY	0.27	
13	Poisson's Ratio YZ	0.4	
14	Poisson's Ratio XZ	0.27	
15	Shear Modulus XY	4.7E+09	Pa
16	Shear Modulus YZ	3.1E+09	Pa
17	Shear Modulus XZ	4.7E+09	Pa
18	Orthotropic Stress Limits		
19	Tensile X direction	2.231E+09	Pa
20	Tensile Y direction	2.9E+07	Pa
21	Tensile Z direction	2.9E+07	Pa
22	Compressive X direction	-1.082E+09	Pa
23	Compressive Y direction	-1E+08	Pa
24	Compressive Z direction	-1E+08	Pa
25	Shear XY	6E+07	Pa
26	Shear YZ	3.2E+07	Pa
27	Shear XZ	6E+07	Pa

Table. Engineering material properties

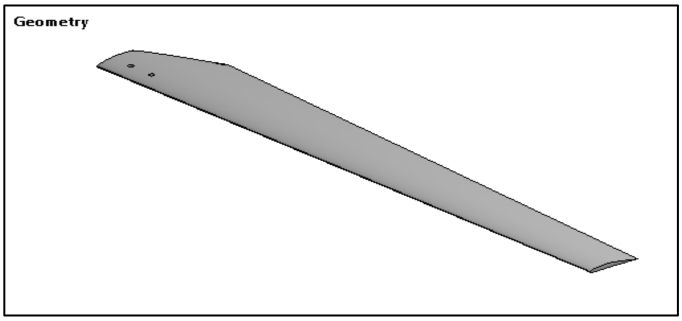


Fig.7 Geometry imported in ANSYS

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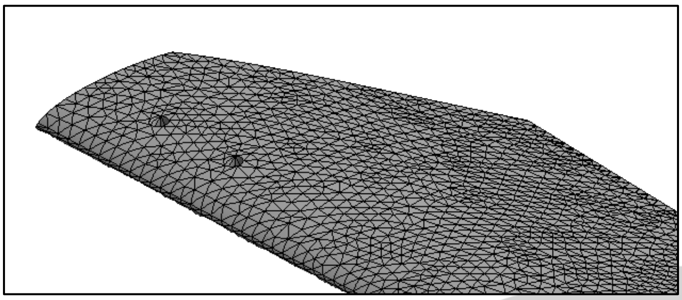
Mesh

ANSYS Meshing may be a all-purpose, intelligent, automated high-performance product. It produces the foremost acceptable mesh for correct, economical metaphysics solutions. A mesh well matched for a selected analysis may be generated with one click for all elements in a very model. Full controls over the options accustomed generate the mesh are accessible for the skilled user who needs to fine-tune it. the ability of parallel processing is automatically accustomed reduce the time you have got to wait for mesh generation



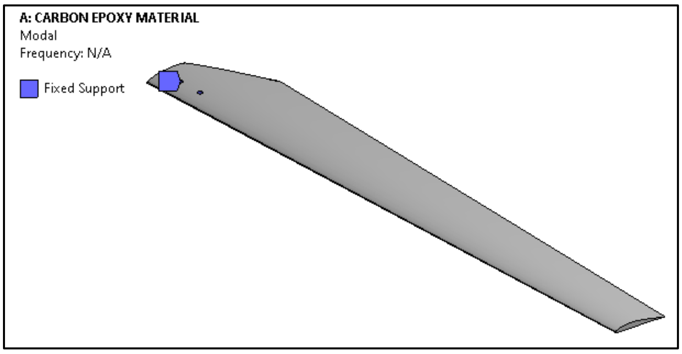
Statistics	
Nodes	84864
Elements	50777

Boundary Condition

A boundary condition for the model is that the setting of a well-known value for a displacement or an associated load. For a specific node you'll be able to set either the load or the displacement but not each.

The main kinds of loading obtainable in FEA include force, pressure and temperature. These may be applied to points, surfaces, edges, nodes and components or remotely offset from a feature.

Fixed support is applied at two holes in which bolt is to be mounted to fix with rotor.



Total Deformation

In finite element method the total deformation and directional deformation are general terms irrespective of software being used? Directional deformation may be place because the displacement of the system in a very particular axis or user defined direction. Total deformation is that the vector sum of all directional displacements of the systems

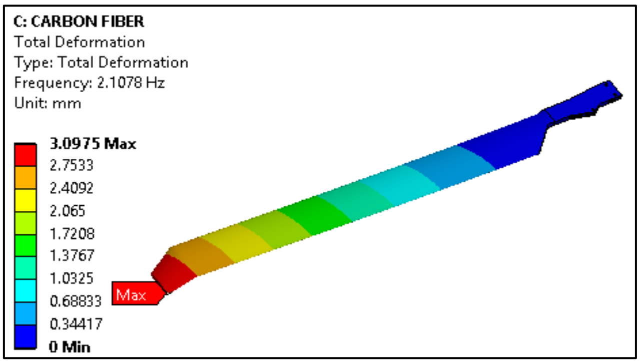


Fig.8 Mode shape 1

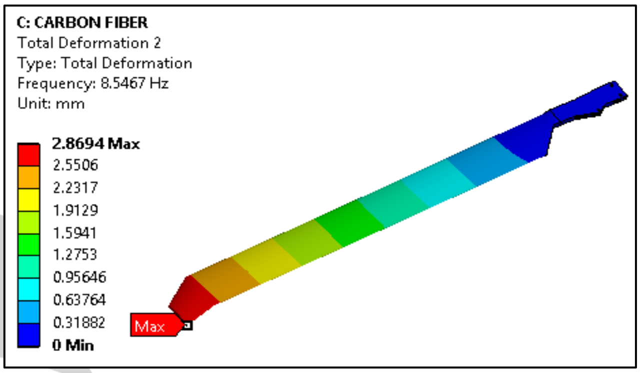


Fig.9 Mode shape 2

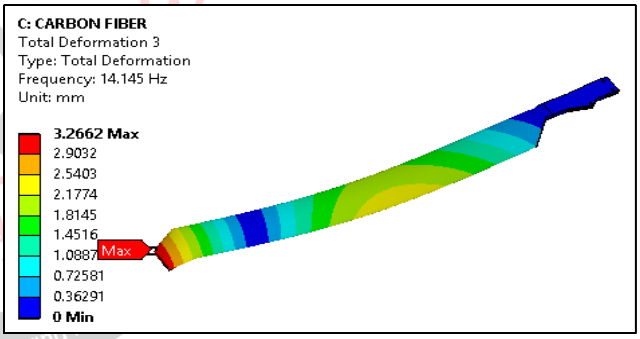


Fig.10 Mode shape 3

Tabular Data

	Mode	Frequency [Hz]
1	1.	2.1078
2	2.	8.5467
3	3.	14.145
4	4.	17.283
5	5.	40.243

MANUFACTURINGPROCESS (COMPOSITE MATERIAL)

- Fixture of C channel section is prepared with dimension of 90mm x 550 mm x 100 mm with thickness of 2 mm GI sheet.
- Carbon fiber sheet is cut out with respective dimension of 90mm x 550 mm with 10 layers.
- Solution is prepared with epoxy (50 ml) and hardener (1.5 bottle cap) is poured and gently stirred to form homogeneous solution.

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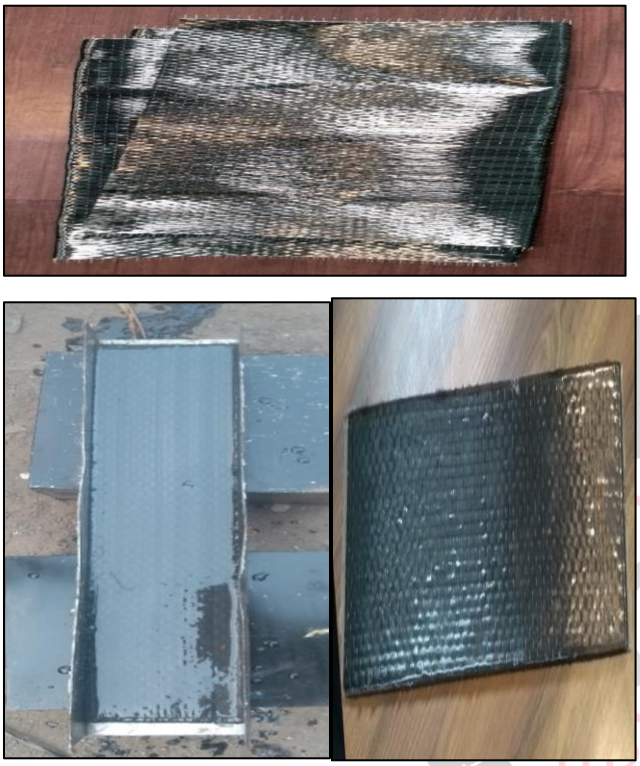
- Before mounting of first layer of carbon fiber, wax is applied at base of fixture so that after solidification of layer it can be easily removed.
- Layer by layer reinforcement is provided with first layer lying up and gently applying epoxy solution with brush and repeating this process for 10 layers.
- After application of layers it is left to solidify for 24 hours and is removed from fixture.
- Desired shape is cut out from mould of blade to obtain required shape and size.



BLADE WITH COMPOSITE MATERIAL

(CARBON FIBER)

V. CONCLUSION

1. In present CFD simulation is used to determine the pressure and velocity distribution on blade surface.
2. Modal analysis from ANSYS software presented the mode shape for respective natural frequency.
3. The strain value after the analysis is 111.9 micro strain and strain value after the testing is 122 micro strain.
4. We can conclude from that 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. The 3D model is prepared in CATIA and then CAE analysis is performed using ANSYS-14.
5. Comparing the composite material and the conventional material, composite material has the low values of total deformation, stress and strain. Hence it is concluded that composite material is suitable for the helicopter rotor blade.

Comparison from result (Different Material)-

FREQUENCY OF DIFFERENT MATERIAL (HZ)

MODE NO.	STEEL BLADE	EPOXY GLASS BLADE	CARBON FIBER BLADE
1	1.1738	1.1349	2.108
2	5.0562	5.1208	8.5467
3	7.879	7.3746	14.145
4	22.177	15.083	17.283
5	27.263	21.176	40.243

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