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Design and Analysis of Composite Propeller Blades for Aircraft

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Abstract

In this project, the work basically deals with the modeling and analysis of the propeller blade of an aircraft for its strength. A propeller blade is complex 3D model geometry. This requires high end modeling CAD software is used for generating the blade model in CATIA V5 R20. This paper consists of brief details about Fiber Reinforced Plastic materials and the advantages of using composite propeller over the conventional metallic propeller blade. This project focus on the metal and composite strength analysis of the propeller blade carried out by using the finite element analysis. By using ANSYS software static and modal analysis were carried out for isotropic material and, we also conducted linear layer analysis using orthotropic materials. In this work two different types of propellers i.e. Aluminium, E-glass and carbon fiber, were studied using FEA techniques.

1. Introduction

Thrust is the force that moves the aircraft through the air. Thrust is generated by the propulsion system of the aircraft. There are different types of propulsion systems develop thrust in different ways, although it usually generated through some application of Newton's Third Law. Propeller is one of the propulsion systems. The purpose of the propeller is to move the aircraft through the air. The propeller consists of two or more blades connected together by a hub. The hub serves to attach the blades to the engine shaft. The blades are made in the shape of an airfoil like wing of an aircraft. When the engine rotates the propeller blades, the blades produce lift. This lift is called thrust and moves the aircraft forward. Most aircraft have propellers that pull the aircraft through the air. These are called tractor propellers. Some aircraft have propellers that push the aircraft. These are called pusher propellers.

Propeller Geometry: Propeller geometry is normally a complicated shape at the edges because of the complex nature of profile. The important terms which determine the shape of the blade profile are as follows:

Propeller Diameter: Diameter of the propeller is two times the distance from the centre of the hub to the tip of the blade. It is the distance across the circle that the propeller would make when rotating as shown in below Figure.

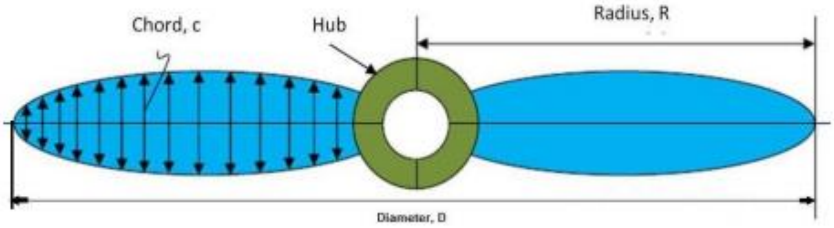

Fig. 1: Propeller

The composite propeller blades perform better than the wooden propeller blade. To avoid the deflection of the blade poly materials are used inside the composite propeller blade. One of most commonly adopted manufacturing of composite propeller is hand layup. The finite element method is so popular and has been used many researchers. The back drop to this advancement is the fact that composites can provide a wide variety of special characteristics that metals cannot. The usage of composite is rapidly increasing in industries due to its properties and cost effectiveness. As the technology advances the usage of composites is increasing and cost is becoming less. The present work is mainly focused on converting the metal blade into a composite propeller in terms of weight reduction, improve in performance of blade and reduce deflection.

2. Literature review

Changduk Kong et al, structural design and analysis of the propeller blade for turboprop aircraft, which will be a high speed transportation system for the next generation, were performed. The propeller of turboprop shall have high strength to get the thrust to fly at high speed. The high stiffness and strength carbon/epoxy composite material was used for the major structure and skin-spar-foam sandwich structural type was adopted for improvement of lightness. As a design procedure for the present study, firstly the structural design load was estimated through investigation on aerodynamic load and then flanges of spars from major bending loads and the skin from shear loads were preliminarily sized using the netting rule. In order to investigate the structural safety and stability, stress analysis was performed by finite element analysis code MSC. NASTRAN. Finally, it is investigated that designed blade have high efficiency and structural safety to analyze of aerodynamic and structural design results

Wang et al. analysed the marine propeller performance using a transition-sensitive turbulence modeling for CFD analysis. Turbulence intensity of 1% and was chosen throughout all the study cases, with an advance ratio (J) range from 0.0 to 1.60. The transition sensitive turbulence model was incorporated in the analysis, as it was found that large laminar and transition flow regions existed. The analysis provides the method to minimize the discrepancy between CFD and the experimental results by including the transitional analysis. The study proves that the results improve prediction accuracy for propellers, compared to the standard k-ω SST turbulence model.

Alka Sawale et al the objective of this thesis is "Optimization of propeller for the existing UAV to produce maximum thrust of 1000N rotating at 8000rpm at higher speed". Diameter of propeller is restricted to 1000mm. Maximum power available is 40KW.The propeller will be made using carbon fiber composite to make it light weight .Propeller is one of the main component in a unmanned aerial vehicle which is responsible to produce thrust . The cross area of propeller edge is an airfoil segment which is ordinarily differing from tip to hub in terms of chord or twist distribution.

3. Modeling and Analysis of Propeller Blade

Modeling

Modeling of the propeller is done using CATIA V5 R20. Two propeller models are developed i.e., solid metal blade and composite blade. The propeller blades are developed at the length of 1100mm and at the width of 120mm. The diameter of the hub is 25mm. The developed model is further modified to get the exact aerofoil of the blade as shown in fig. The solid model is transferred to the composite module in CATIA software. The total weight of the metal blade is 2.071Kg. To design a composite propeller blade the blade is divided into ten sections along the span length of the blade at each section the outer profile of the blade is developed as shown in figure.

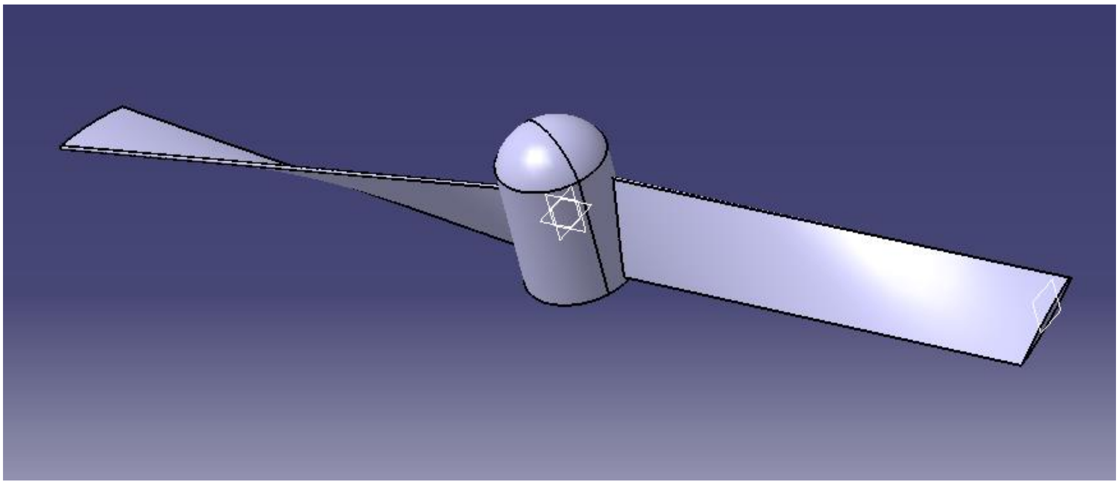

Fig 2: Solid blade

Table: 1 Mechanical properties of materials

Materials	Young's modulus (Mpa)	Tensile strength (Mpa)	Poisson's ratio	Density (kg/mm3)
Aluminum 7075	71700	280	0.33	0.00000028
Carbon fiber	70000	3900	0.30	0.00000020
E-glass fiber	72000	2050	0.21	0.00000019

Structural Analysis

Static analysis calculates the consequences of consistent loading situations on a shape, while ignoring inertia and damping outcomes, inclusive of the 1s resulting from time varying loads. A static analysis can, but, encompass steady inertia masses (including gravity and rotational speed), and time-various loads that can be approximated as static equivalent hundreds (along with the static equal wind arid seismic masses generally defined in lots of building codes). Static analysis is used to decide the displacements, stresses, lines, and forces in structural additives resulting from hundreds that don't set off big inertia and damping outcomes. Steady loading and reaction are assumed to differ slowly with respect to time.

4. Results and Discussion

Material: carbon fiber

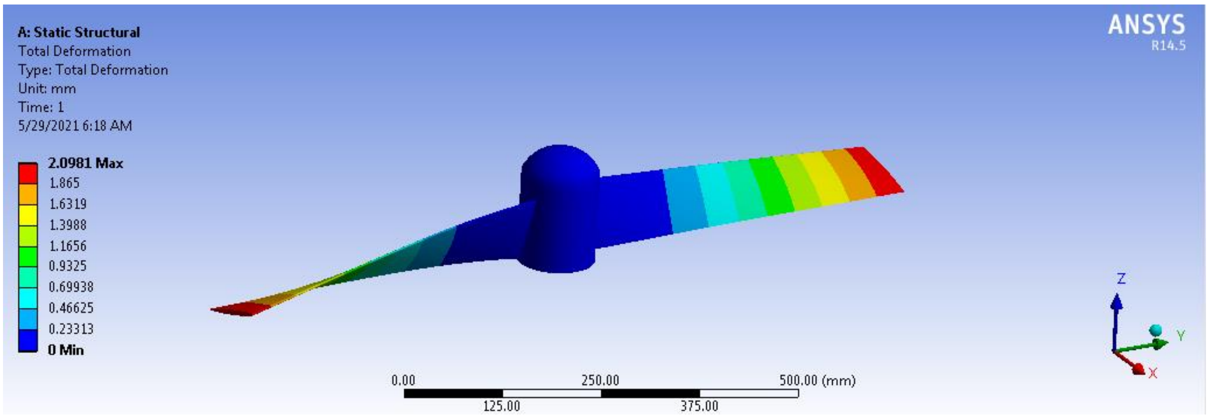

Fig 3: Total Deformation of CFRP aircraft propeller blade

Above figure 3 shows the maximum total deformation at edges of the propeller blade and mini deformation at hub of the propeller blade due to applied rotational velocity on the blades. The maximum deformation is 1.6139mm and minimum deformation is 0.179993mm.

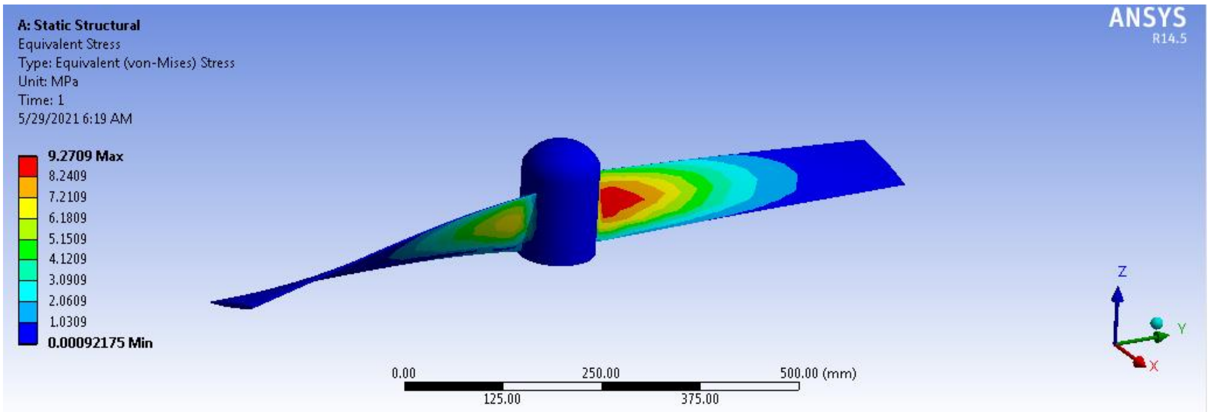

Fig 4: Von-Misses Stress of CFRP aircraft propeller blade

Above figure 4 shows the maximum stress at hub edge of the propeller blade and mini stress at hub of the propeller blade due to applied rotational velocity on the blades. The maximum stress is 7.189 N/mm^2 and minimum stress is 0.79883N/mm^2.

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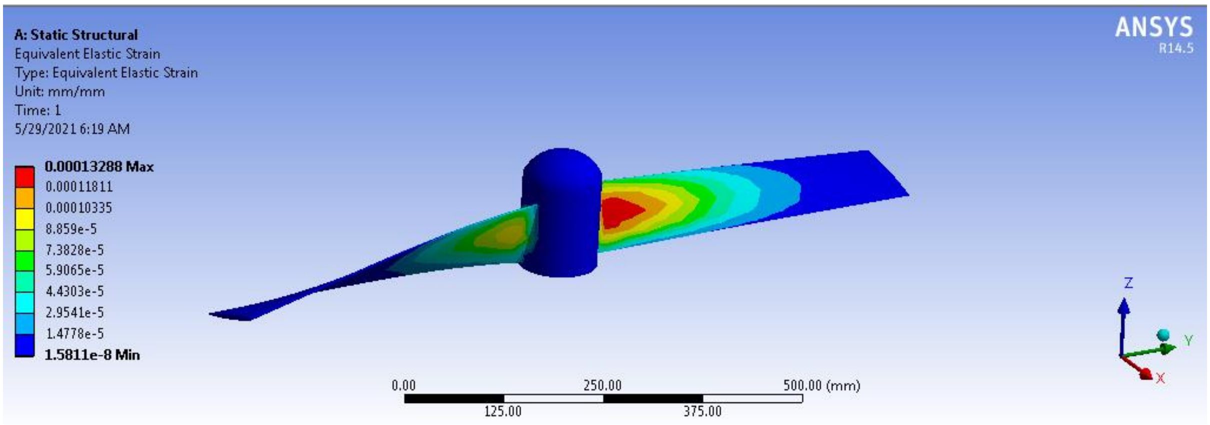
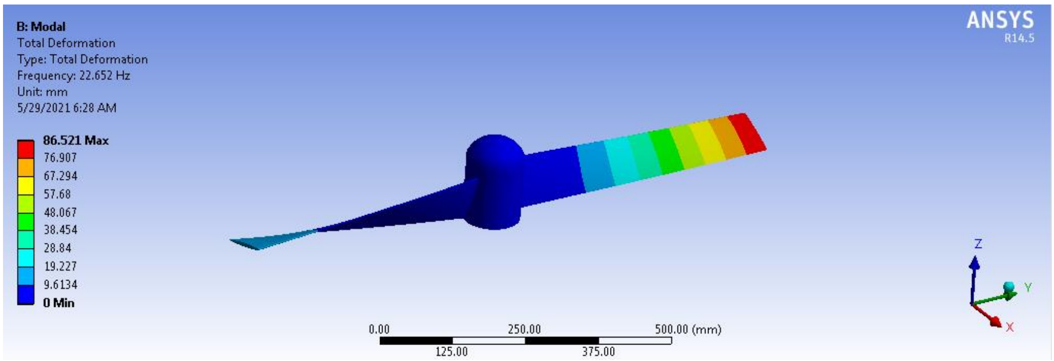


Fig 5: Von-Misses Strain of CFRP aircraft propeller blade

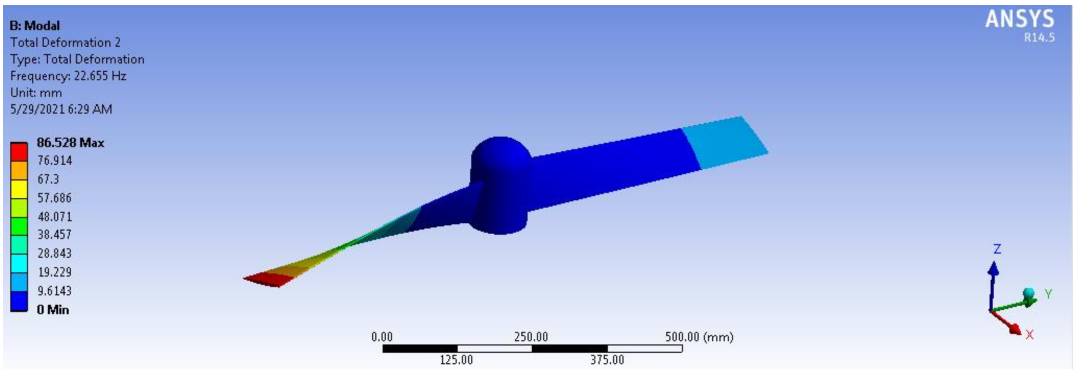
Above figure 5 shows the maximum strain at hub edge of the propeller blade and mini strain at hub of the propeller blade due to applied rotational velocity on the blades. The maximum strain is 0.0001034 and minimum strain is 1.14e-5.

Modal analysis of propeller blade

Total deformation 1



Total deformation 2



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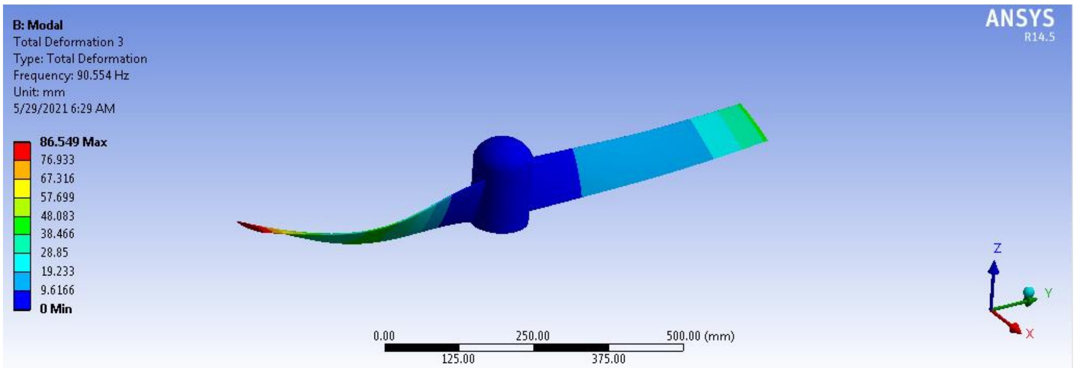
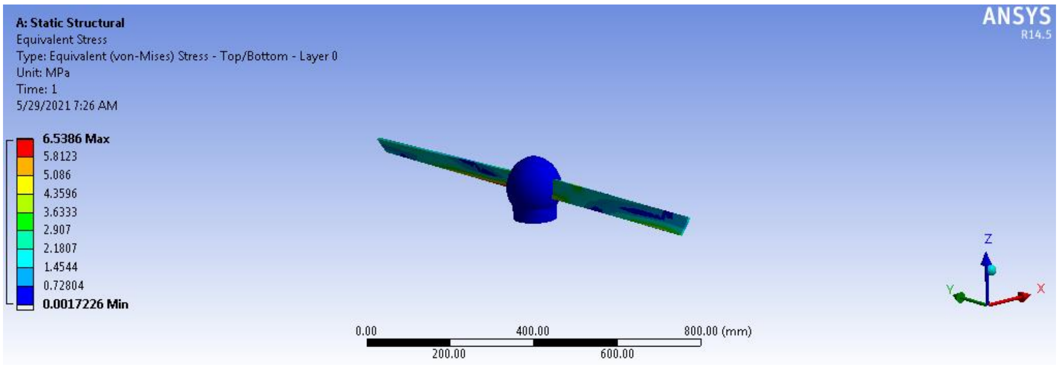
Total deformation 3



9 layers stacking

Layer	Material	Thickness (mm)	Angle (°)
(+Z)			
9	CARBON FIBER	0.66	90
8	E GLASS FIBER	0.66	0
7	CARBON FIBER	0.66	0
6	E GLASS FIBER	0.66	0
5	CARBON FIBER	0.66	0
4	E GLASS FIBER	0.66	0
3	CARBON FIBER	0.66	0
2	E GLASS FIBER	0.66	0
1	CARBON FIBER	0.66	-90
(-Z)			

STRESS



Strain

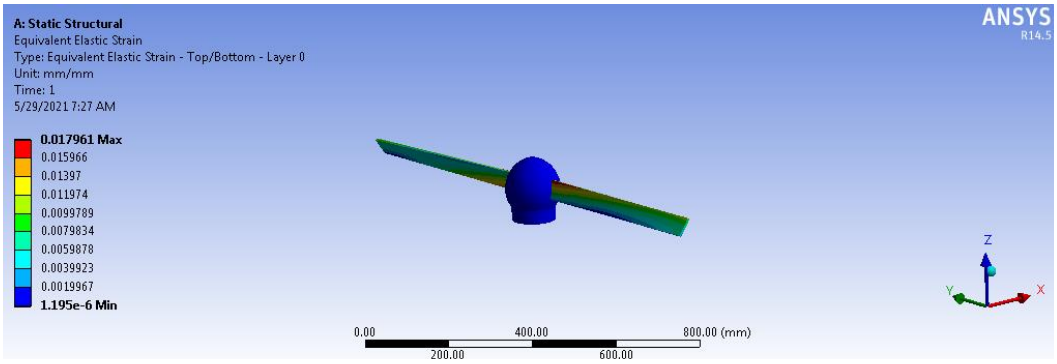


Table 1. Static analysis results.

Material	Speed(rpm)	Deformation (mm)	Stress (n/mm^2)	Strain
Aluminum alloy 7075	7000	2.8494	12.767	0.00018045
	9000	4.6523	20.845	0.00029462
Carbon fiber	7000	2.0981	9.2709	0.00013288
	9000	3.4257	15.137	0.00021695
E-glass fiber	7000	2.4886	11.937	0.00015759
	9000	4.0632	19.489	0.00025729

By observing the table, static analysis performed on the propeller blade at different materials (al 7075, carbon fiber and E glass fiber) and different propeller speeds i.e., 7000 and 9000 RPM. The maximum stress value of 20.845 N/mm^2 with aluminium alloy 7075 at 9000 Rpm and minimum stress value of 9.2709 N/mm^2 with material of carbon fiber at speed 7000 Rpm.

Table 2. Modal analysis results.

Materials	Frequency (Hz)	Mode 1	Frequency (Hz)	Mode 2	Frequency (Hz)	Mode 3
Aluminum alloy 7075	25.145	104.06	28.148	104.07	111.81	104.08
Carbon fiber	22.652	86.521	22.655	86.528	90.554	86.549
E-glass fiber	23.224	98.58	23.22	91.583	98.5	95.77

Table 3. Linear layer analysis results.

Layer stacking	Speed (rpm)	Stress (n/mm^2)	Strain
3	7000	4.3305	0.017729
	9000	5.7736	0.031581
6	7000	5.1744	0.019739
	9000	8.4484	0.03228
9	7000	6.5386	0.017961
	9000	9.1129	0.025033

5. CONCLUSION

In structural analysis, the carbon fiber and E-glass fiber composite structure is used to endure effectively various speeds. In order to evaluate the designed structure, structural analysis is performed using the finite element analysis.

By observing the static analysis of aircraft propeller blade, the stress values are increases by increasing the speed (7000 and 9000 Rpm) of the aircraft propeller blade, the less stress value for carbon fiber than E-glass and aluminium alloy. Carbon epoxy material has more strength because it is a composite material.

By observing the linear layer analysis, the stress values les for 3 layers with orthotropic materials when we compared to static analysis results. So, it can be concluded that layer composite materials suitable for aircraft propeller blade.

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