Design and Analysis of Composite Propeller Blade for Aircraft R14.5

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Abstract— In this project, the work basically deals with the modelling and analysis of the propeller blade of an aircraft for its strength. A propeller blade is complex 3D model geometry. This requires high end modelling 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 also we are conducted linear layer analysis using orthotropic materials. In this work two different types of propeller i.e. Aluminium6061 and 7075, E-glass and carbon fibre, were studied using FEA techniques.

Keywords: Propeller Blade, Aircraft R14.5

I. Introduction

Recently, the need for developing the environmental and eco-friendly aircrafts with increased fuel efficiency is being emphasized as an eco-friendly requirement in response to high oil prices. Aircrafts take up 3-5% of the world's carbon dioxide emission amount and the aircraftindustry is placed at the top in the emission amount as a single industry. The amount ofcarbon dioxide being discharged in high altitude atmosphere is larger than that being discharged by every vehicle on the earth. Accordingly, it is necessary to develop the next generation eco-friendly & high fuel efficiency engine technology to enhance the fuel eThink of a propeller as a spinning wing.

Like a wing, it produces lift, but in a forward direction—a force we refer to as thrust. Its rotary motion through the air creates a difference in air pressure between the front and back surfaces of its blades. In order for a propeller blade to spin, it usually needs the help of an engine. efficiency and aerodynamic performance of aircrafts for the purpose of reducing carbon the study of aero elastic tailoring analysis for advanced turbo propellers with composite blades. In this study, the aero elastic model of advanced composite materials is proposed. Many studies have shown that the efficiency of advanced turboprop is higher than that of the current turbofan design. After many years of study, various aerodynamic design theories were proposed. However, little research work has been carried out to propose the design method of propeller structure. In this work, aerodynamic and structural designs of the propeller blade for an advanced turboprop aircraft, which will be used for a next generation regional commercial aircraft in Korea, are carried out. In the aerodynamic design, the parametric studies are performed to decide an optimum aerodynamic configuration having a specific HS1 series airfoil. In structural design, the proposed propeller blade uses the carbon/epoxy composite skin and spar and urethane foam core sandwich type structure, so-called skin-spar-foam sandwich, is adopted. In order to confirm the initially designed propeller using the netting rule and the rule of mixture, the structural analysis including stress, Eigen value and buckling analyses is performed using finite element code. To finalize the proposed propeller structure design, the prototype propeller is manufactured, tested and compared with the structural analysis results.

II. Materials and Methods

A. Aluminum Alloy 7075

The 7000 series aluminium alloys are usable in a variety of applications. The light weight andtoughness characteristics of grade 7075 are valued highly by manufacturers and end users. Asa strong, machinable aluminium alloy, it is highly used in the automotive, aircraft andaerospace industries.

1) Aluminum Alloy 6061

6061 (Unified Numbering System (UNS) designation A96061) is a precipitation-hardened aluminium alloy, containing magnesium and silicon as its major alloying elements. Originallycalled "Alloy 61S", it was developed in 1935.[2] It has good mechanical properties, exhibits good weldability, and is very commonly extruded (second in popularity only to 6063).[3] It isone of the most common alloys of aluminum for general-purpose use. It is commonly available in pre-tempered grades such as 6061-O (annealed), tempered grades such as 6061- T6 (solutionized and artificially aged) and 6061-T651 (solutionized, stress-relieved stretched and artificially aged).

B. Carbon Fiber

In fiber reinforced composites, fiberglass is the "workhorse" of the industry. It is used inmany applications and is very competitive with traditional materials such as wood, metal, and concrete. Fiberglas products are strong, lightweight, non-conductive, and the raw material costs of fiberglass are very low.In applications where there is a premium for increased strength, lower weight, or for cosmetics, then other more expensive reinforcing fibers areused in the FRP composite.

C. E-Glass Fiber

Glass fiber has roughly comparable mechanical properties to other fibers such as polymers and carbon fiber. Although not as rigid as carbon fiber, it is much cheaper and significantly less brittle when used in composites. Glass fibers are therefore used as a reinforcing agent for many polymer products; to form a very strong and relatively lightweight fiber-reinforced polymer (FRP) composite material called glass-reinforced plastic (GRP), also popularly known as "fiberglass". Unlike glass wool, GRP contains little or no air or gas, is more dense, and thus is a poor thermal insulator compared to glass wool; it is instead used structurally due to its strength and relatively low weight.

D. Mechanical Properties of Materials

Materials	Young's Modulus (Mpa)	Tensile Strength (Mpa)	Poisson's ratio	Density (kg/mm3)
Aluminium 7075	71700	280	0.33	0.00000028
Aluminium 6061	68900	260	0.33	0.00000027
Carbon fiber	70000	3900	0.30	0.00000020
E-glass fiber	76000	3455	0.31	0.00000258

1) Propeller Design Efficiency

Propeller design efficiency is judged by the useful power output it produces. For example, the useful power output for a fan is how quickly the fan can accelerate the surrounding airflow. Due to their dynamic nature, propellers' efficiency is instead measured by thrust developed on the blades and how this powers the respective system, whether it be a boat, plane, or other application. To work out the true efficiency, the following equation is used:

$$Efficiency, \eta = \frac{Useful\ Power\ Output}{Shaft\ Power\ Input} = \frac{Thrust \times Axial\ Speed\ of\ Fluid}{Resistive\ Torque\ \times Rotational\ Speed}$$

Where:
Thrust in N
Axial Speed in m/s
Resistance torque in Nm
Rotational Speed in rev/s

2) Design of a Propeller

Design parameters can impact the performance of the propellers or fans. These variables can include the number of blades needed, the size of the outer diameter, the pitch-affecting angle of attack, as well as the leading and trailing edge blade angle along with many others.

III. Propeller Design Efficiency Factor

A. The Number of Blades

Increasing the number of blades will actually reduce the efficiency of the propeller but with a higher number of blades there is a better distribution of thrust helping to keep the propeller balanced, therefore a trade off must be established.

B. The Diameter

The diameter of the propeller has a significant impact on its efficiency. Larger propellers have the capacity to create more power and thrust on a larger fluid volume. Yet, most designs face limitations when it comes to diameter, so optimization must occur elsewhere.

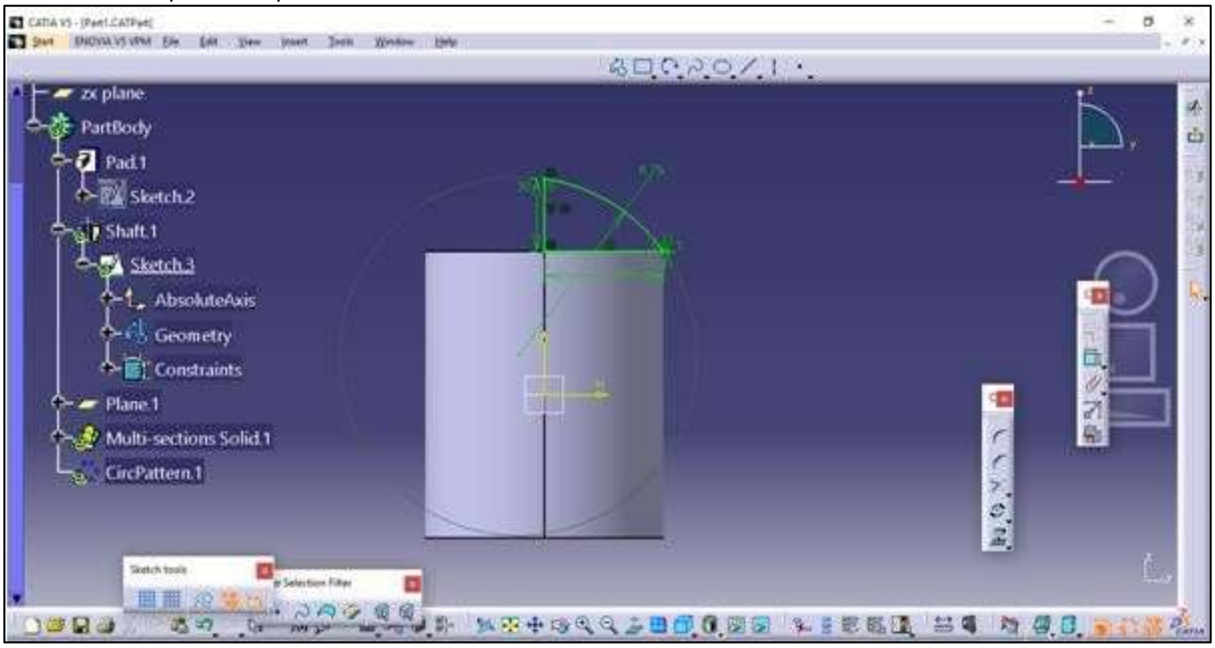
C. Velocity of Flow

The presumed velocity of the fluid flow, whether it be air or water, is another important variable to consider. This force, along with the velocity of rotation (RPM) determines the pitch distribution of the system. Large propeller designs can become less effective operating at the axial velocity. The most efficient designs are those which maintain a pitch to diameter ratio of 1:1.

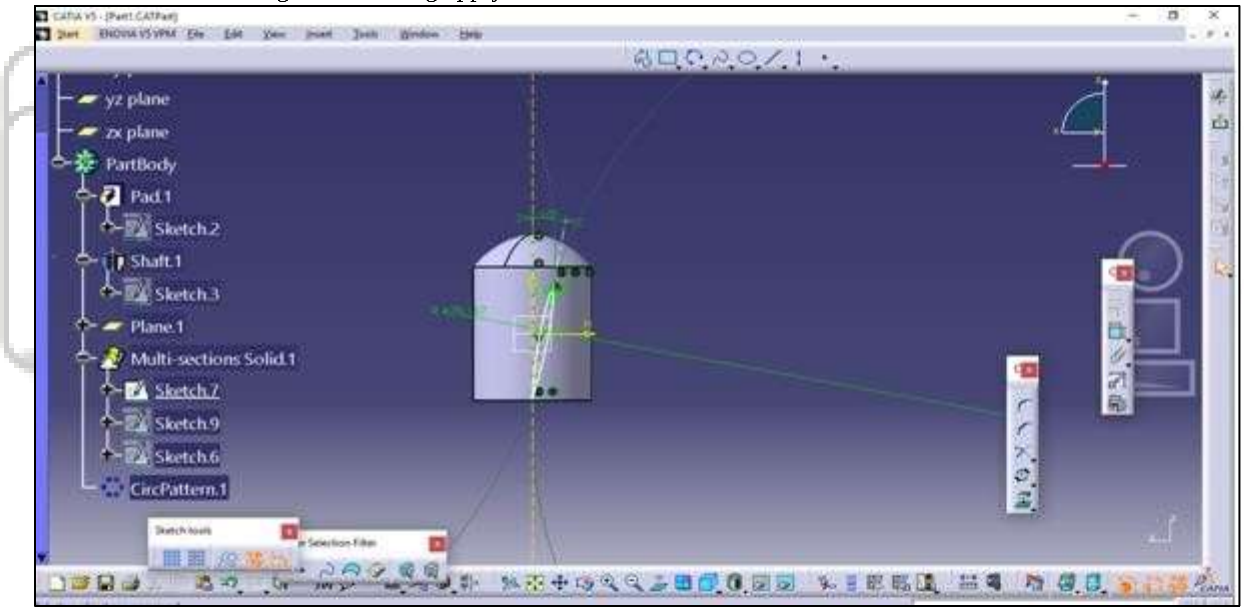
D. Flow Density

While the actual density of the fluid has no effect on the efficiency of the system, it does play a role in defining the shape and size in the early phase of the design process. For example, an air propeller used for planes and drones will have a bigger face than its aquatic counterparts, as the fluid density is less.

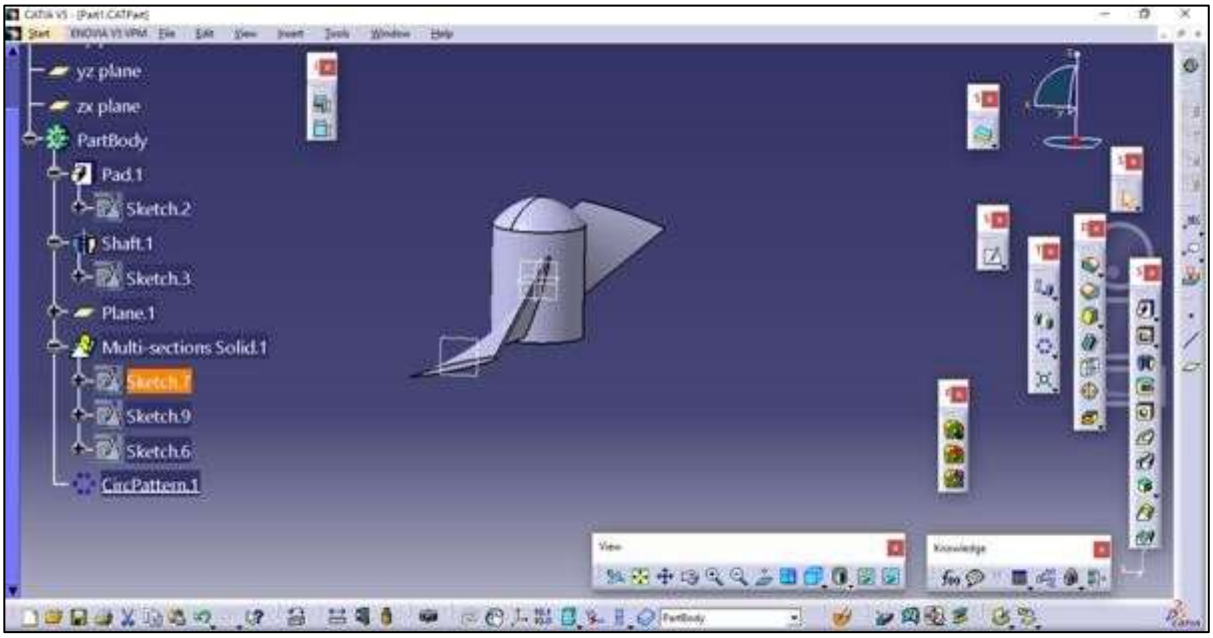
1) 3D CATIA Model for Aircraft Blade



– Draw a circle in the sketch and apply pad.
– Then draw the sketch as given in the fig apply shaft command.

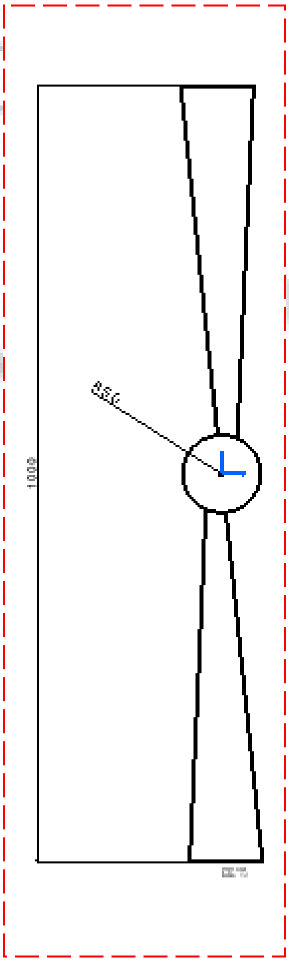


– Then draw the sketch as given in the fig and take another plane draw the same sketch with different angle and apply multi section solid.



– Apply circular pattern in that use complete crown.

IV. 2D CATIA MODEL FOR AIRCRAFT BLADE



S.No	Parameters
1	2bladed propeller
2	Radius of hub = 50 mm
3	Radius of Propeller = 500mm

A. Static Analysis of Propeller Blade

ANSYS workbench is a new generation solution from ANSYS that provides powerful methods for interacting with the ANSYS solver functionality. This environment provides a unique integration with CAD systems, and your design process, enabling the best CAE results

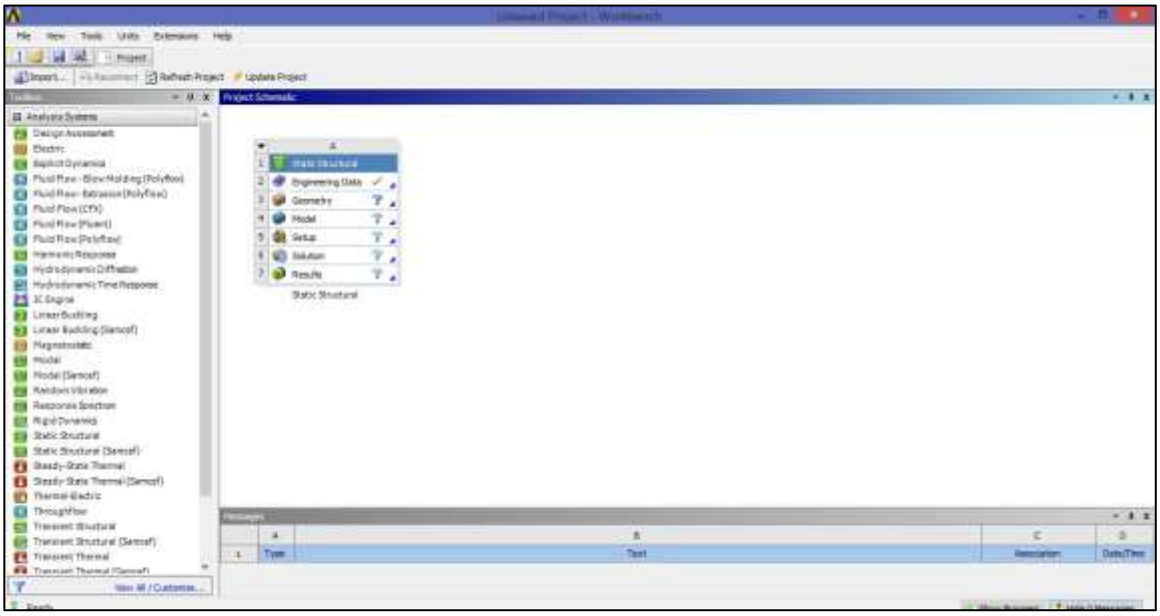
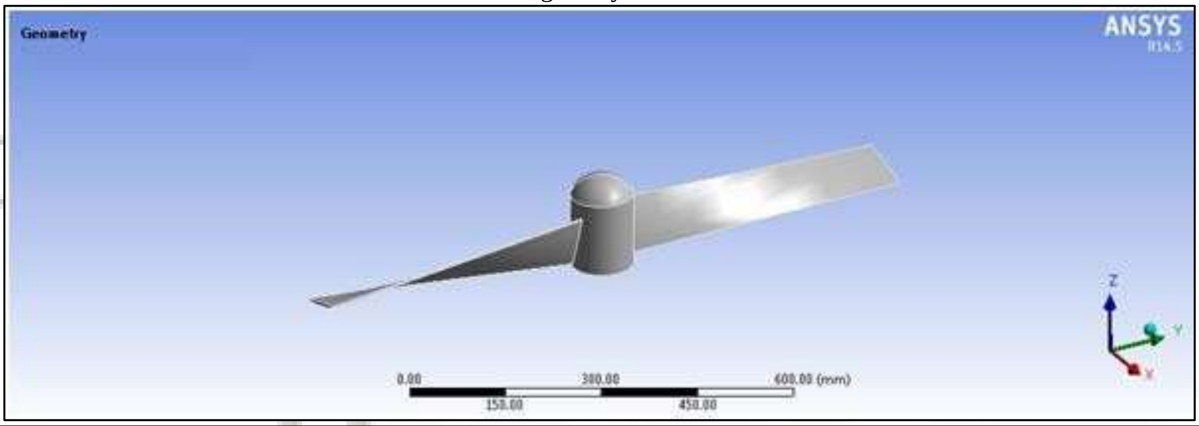
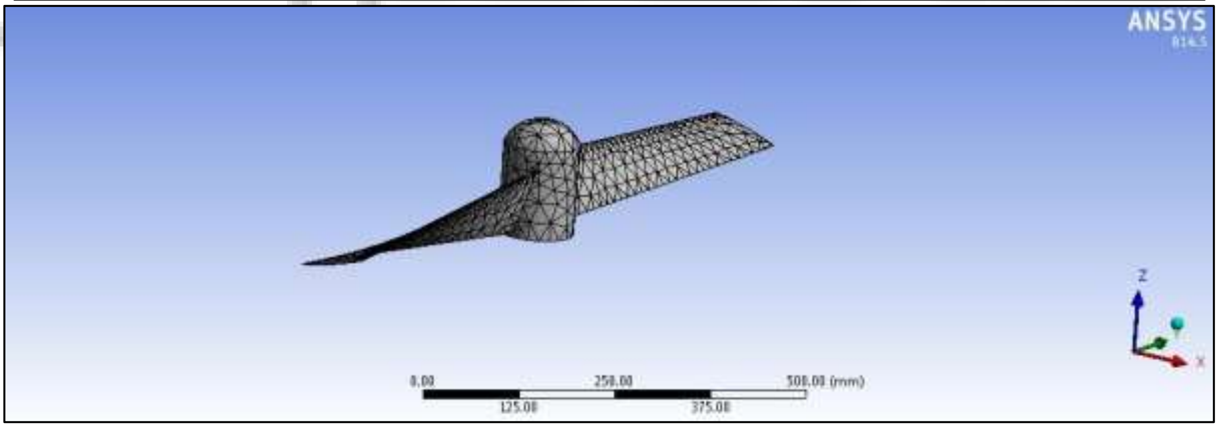
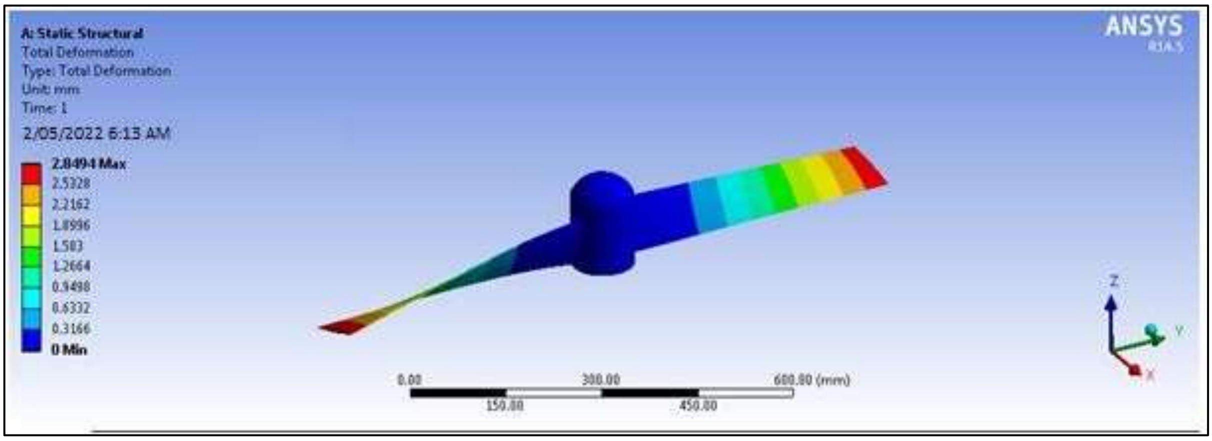


Fig: Ansys Gui

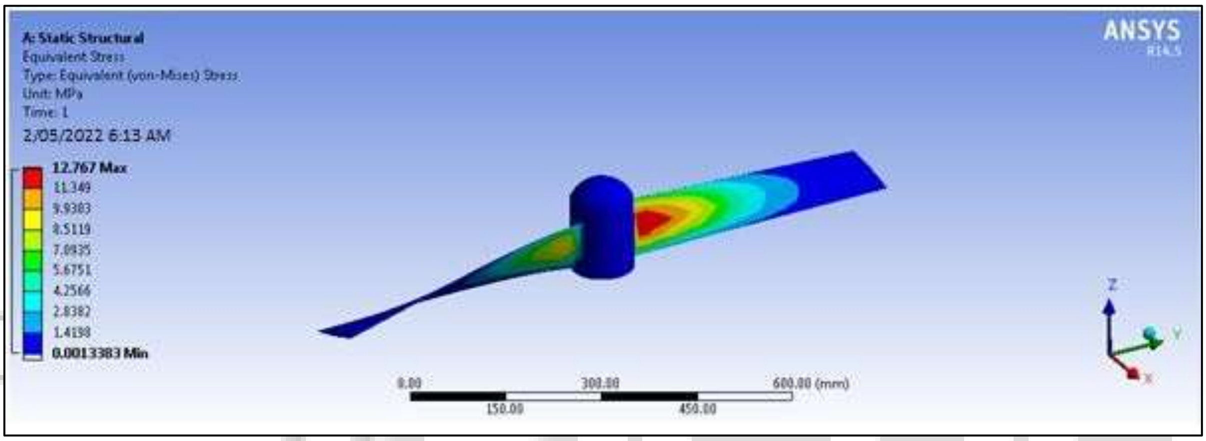




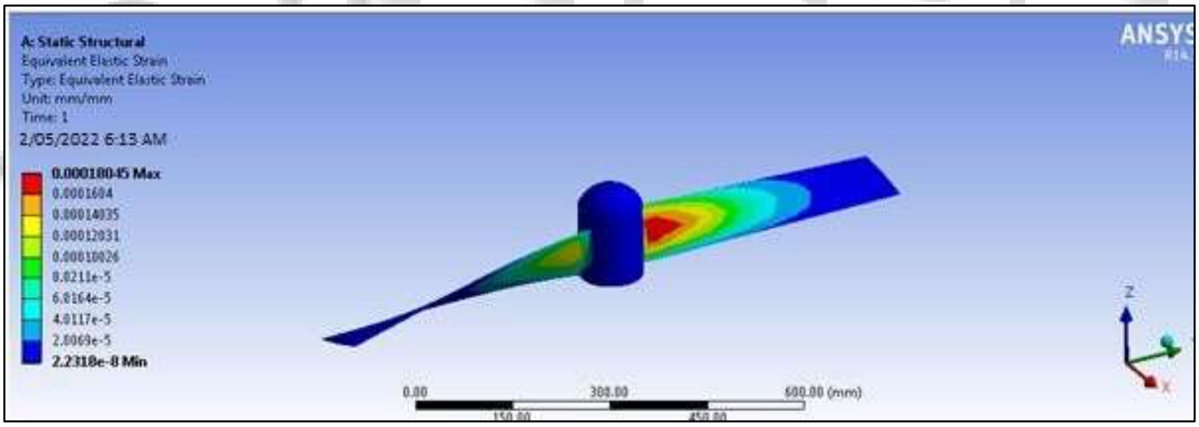
MATERIAL-ALUMINIUM ALLOY 7075
AT-7000 RPM
TOTAL DEFORMATION



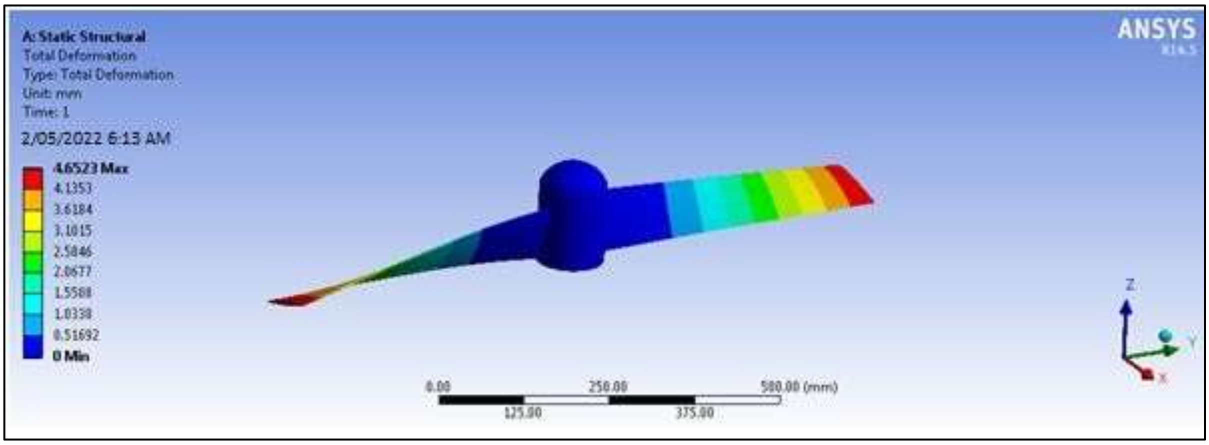
VON-MISES STRESS



VON-MISES STRAIN



AT-9000 RPM
TOTAL DEFORMATION



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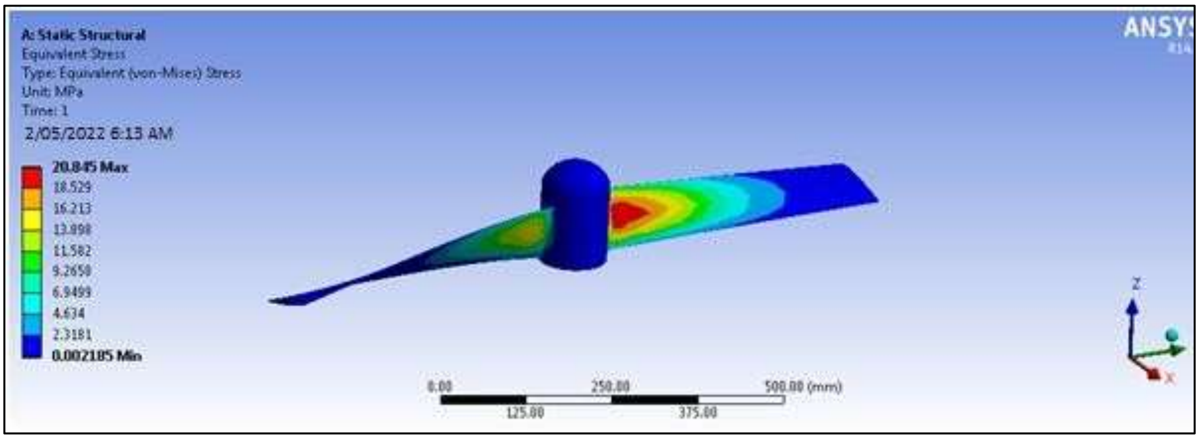

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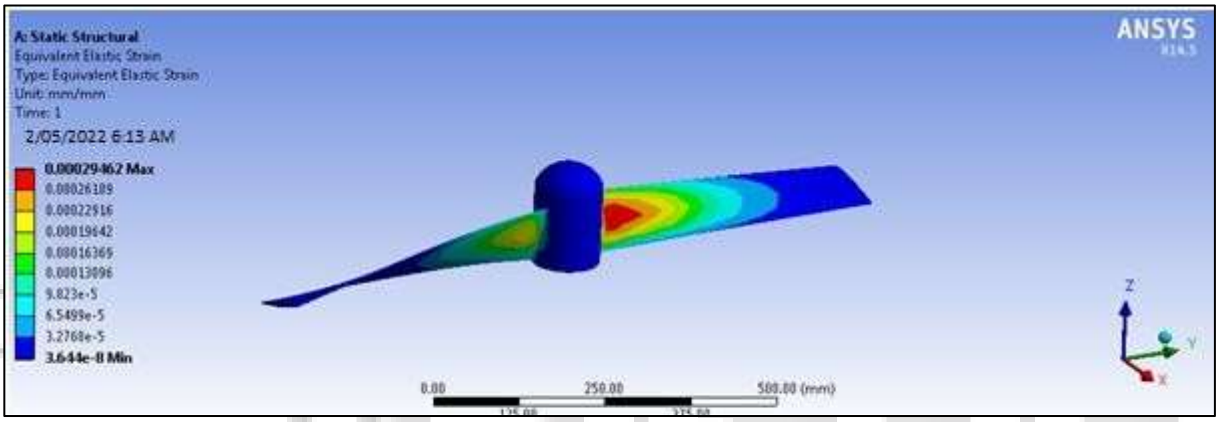
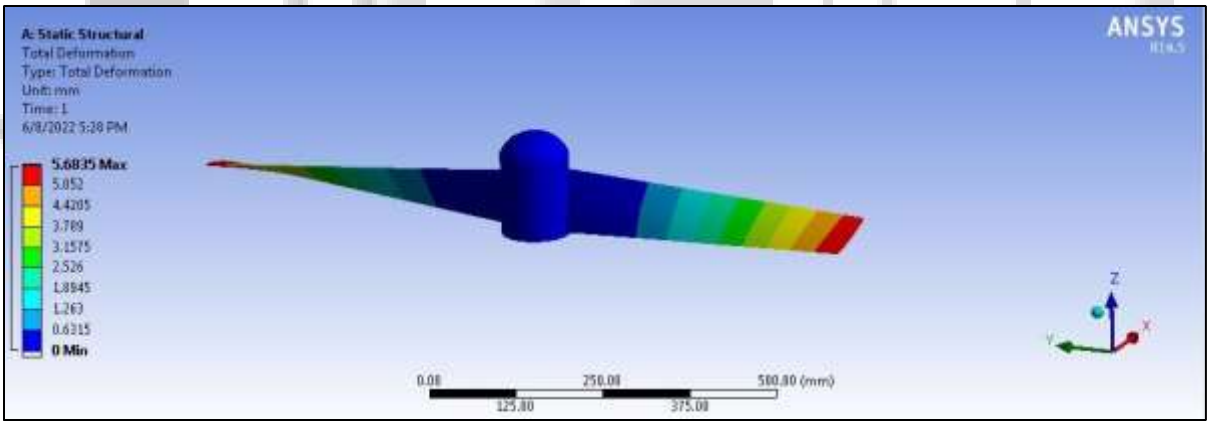


MATERIAL-ALUMINIUM ALLOY 6061

TOTAL DEFORMATION



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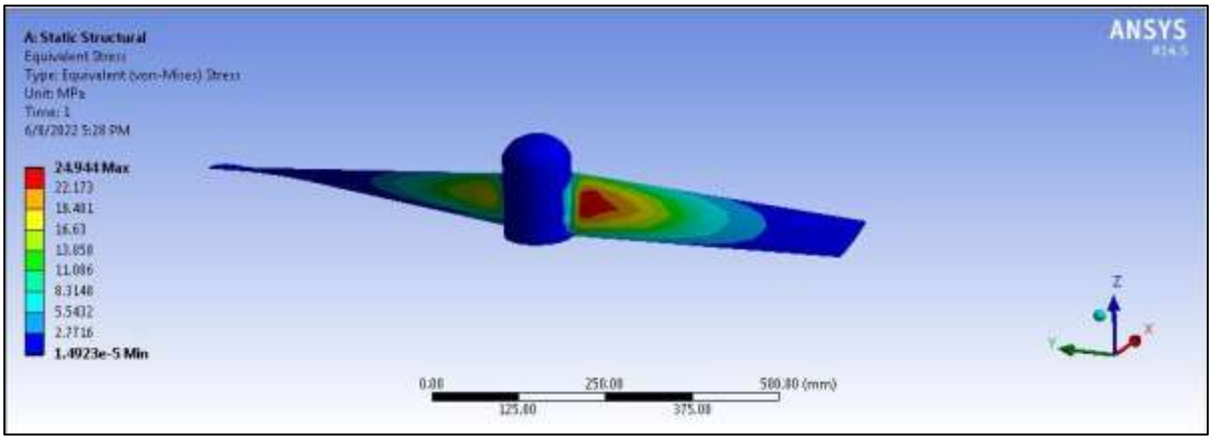

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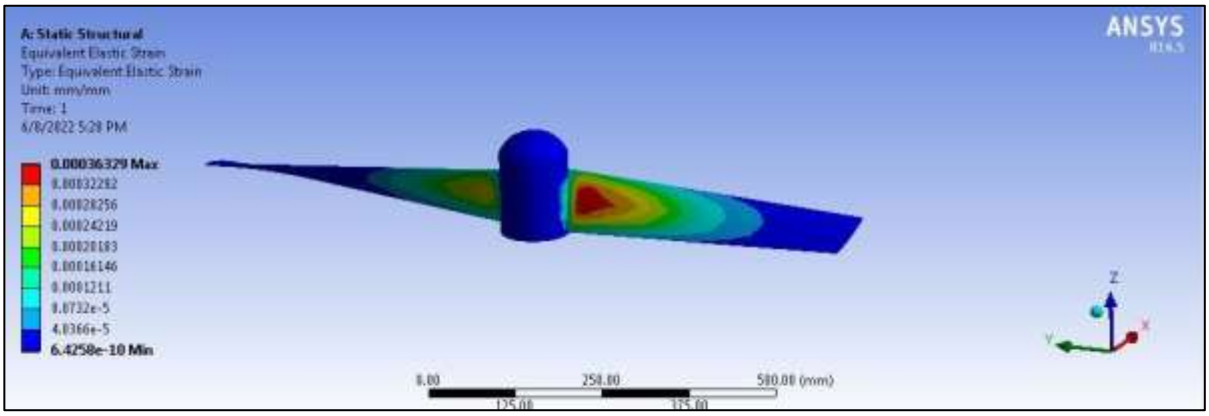
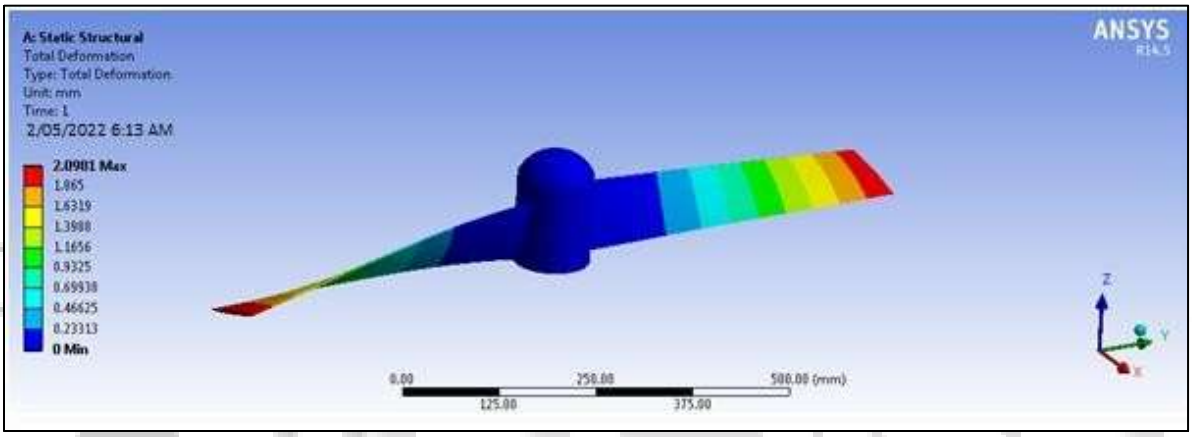


MATERIAL-CARBON FIBRE
AT-7000 RPM
TOTAL DEFORMATION



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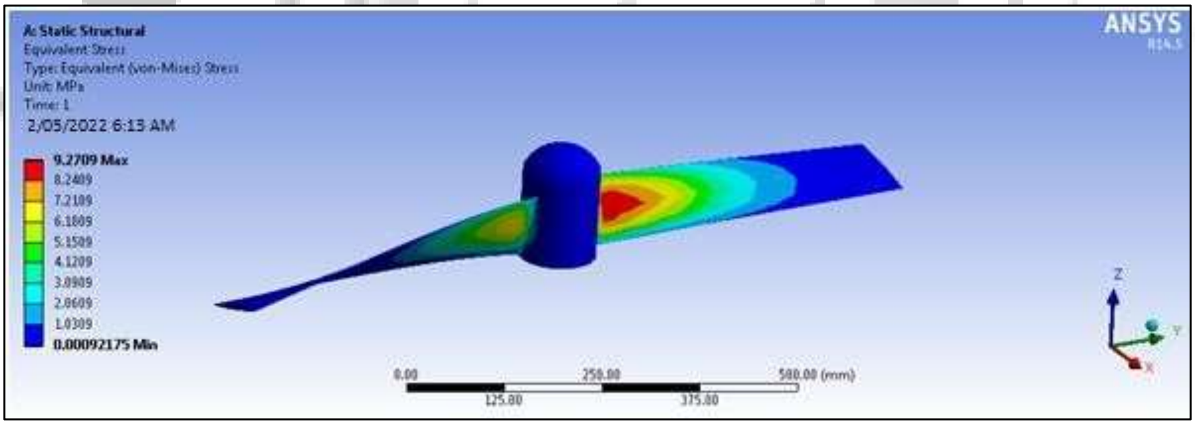

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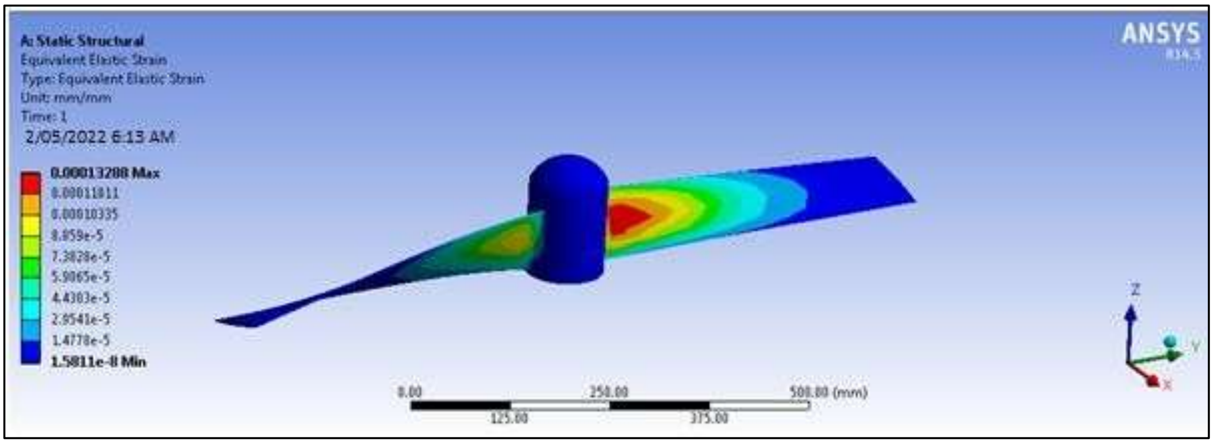
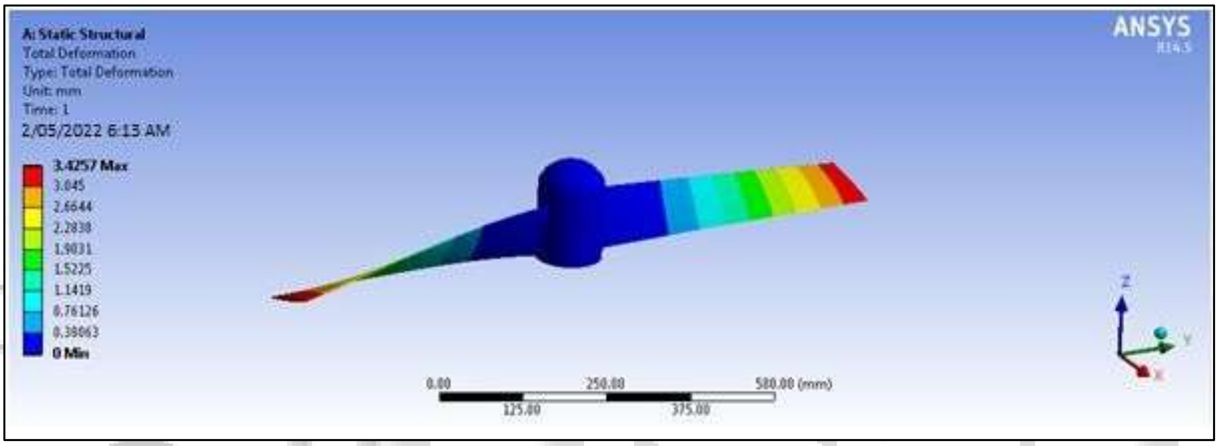


AT-9000 RPM

TOTAL DEFORMATION



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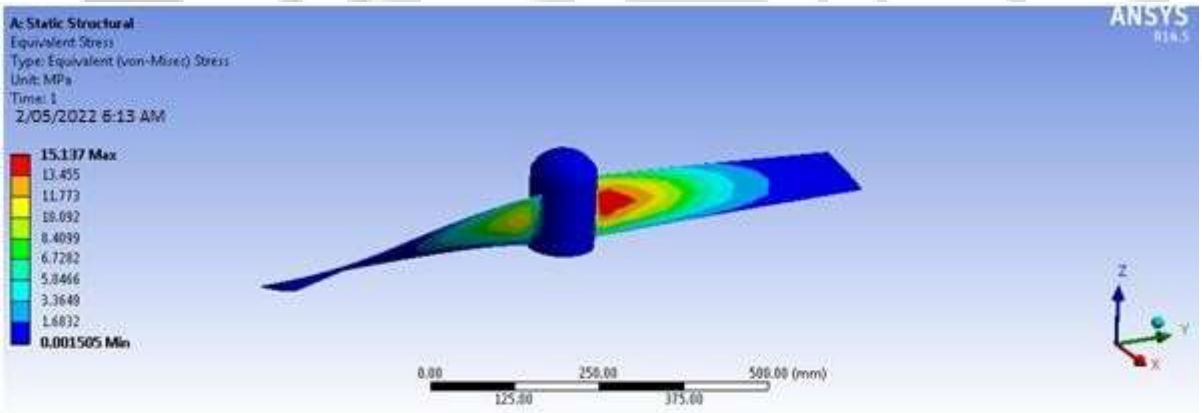

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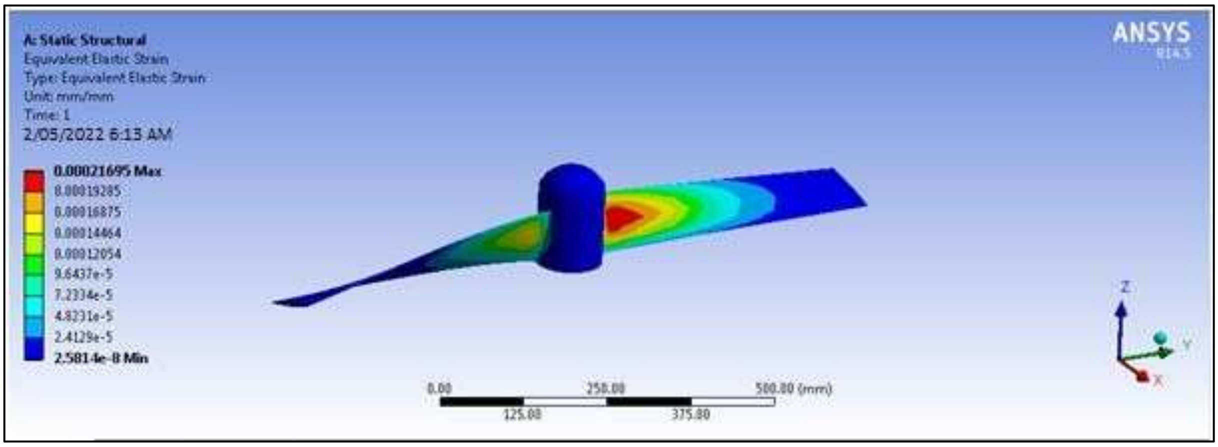
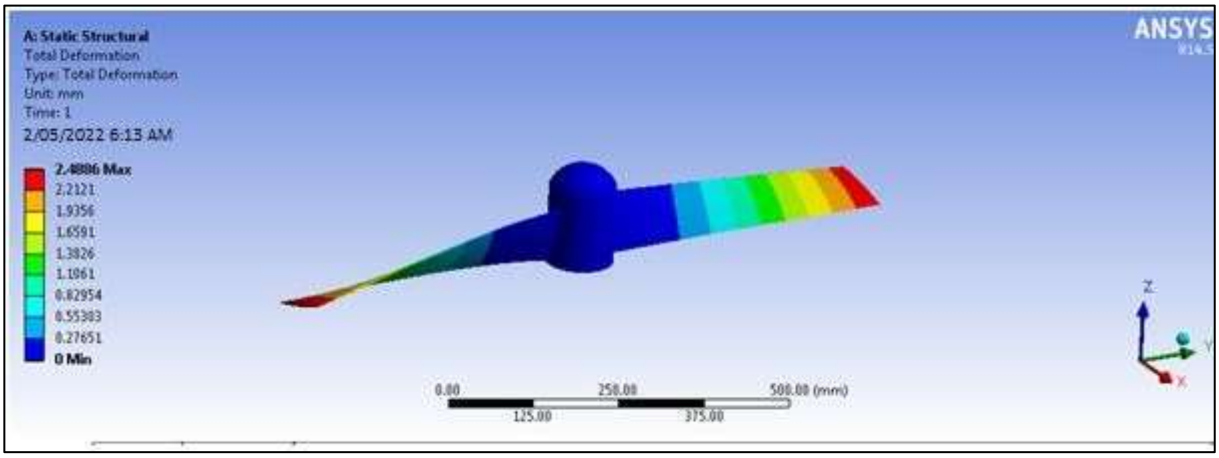


MATERIAL-E GLASS FIBRE
AT-7000 RPM
TOTAL DEFORMATION



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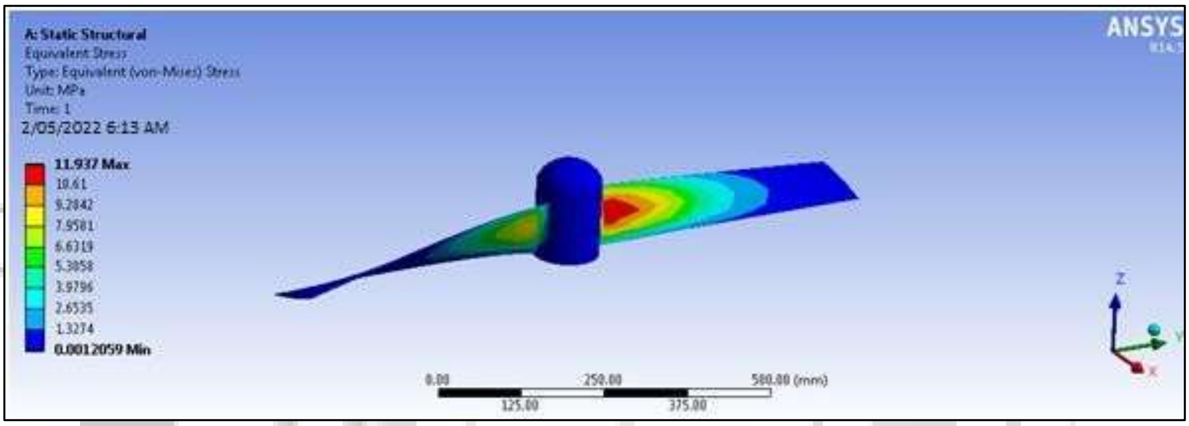

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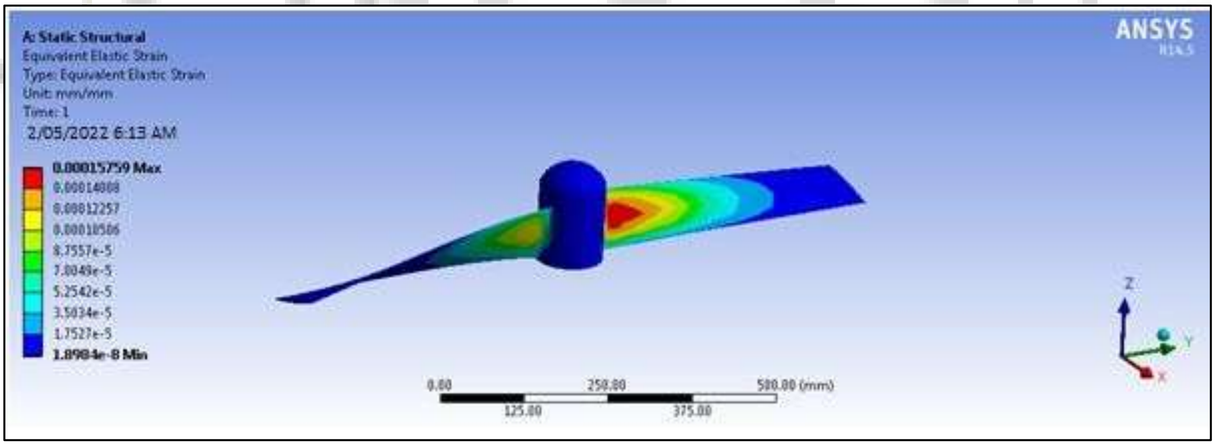
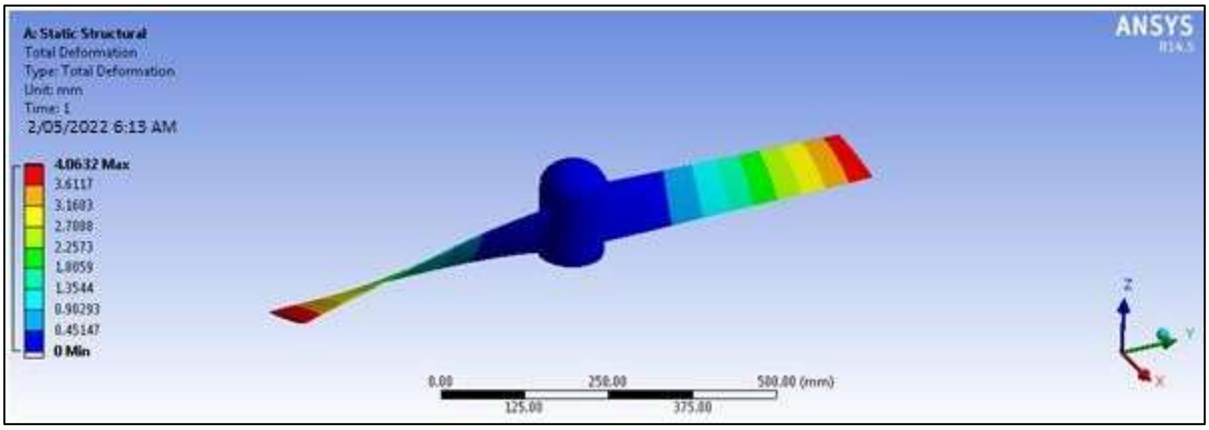


AT-9000 RPM
TOTAL DEFORMATION



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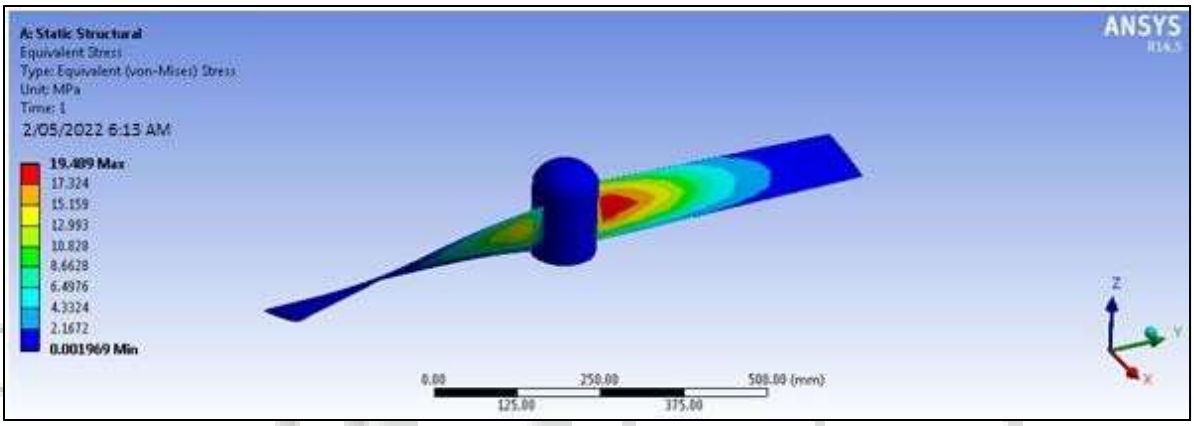

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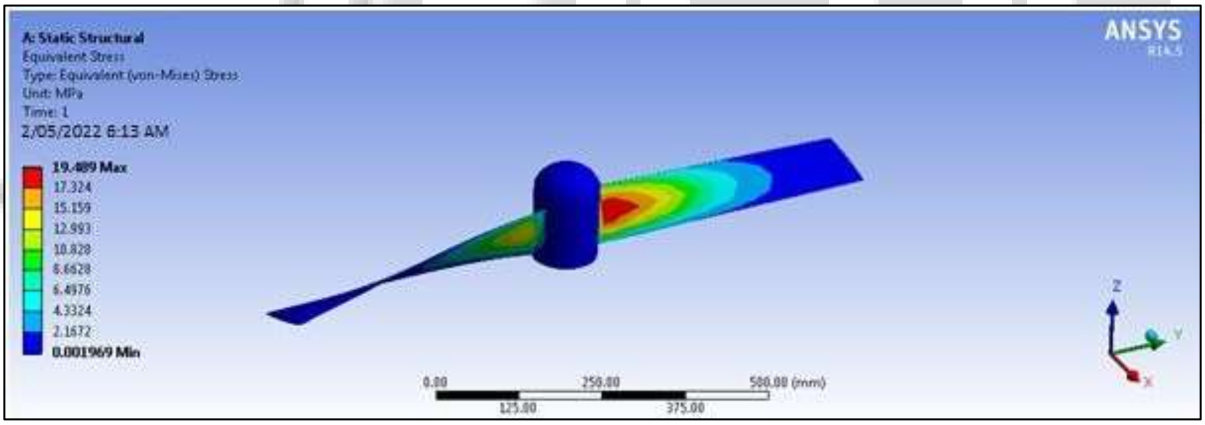
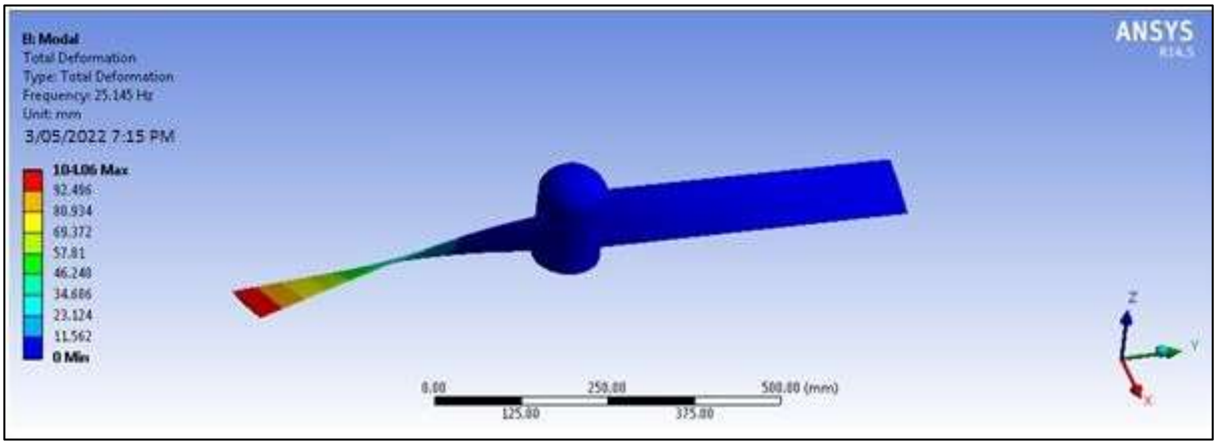
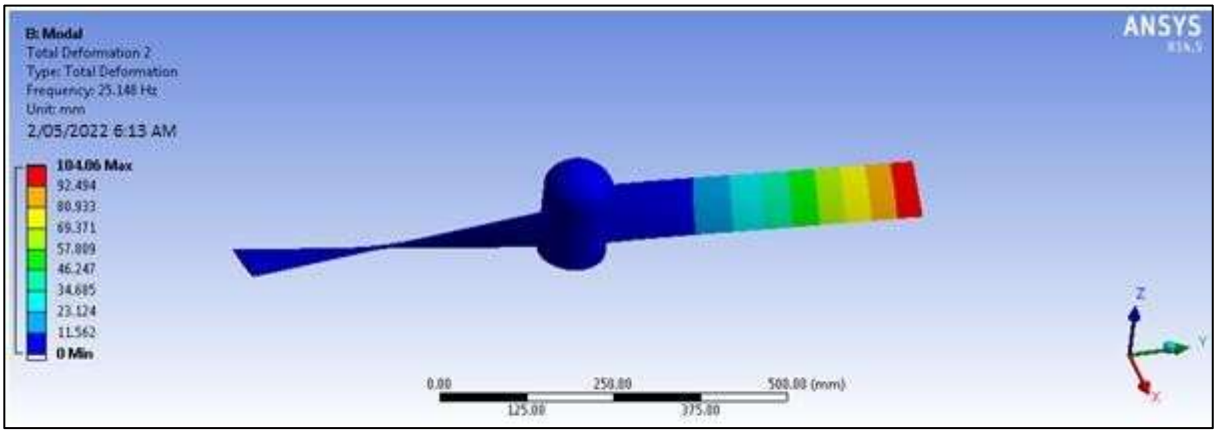


MODAL ANALYSIS OF PROPELLER BLADE MATERIAL –ALUMINIUM ALLOY 7075

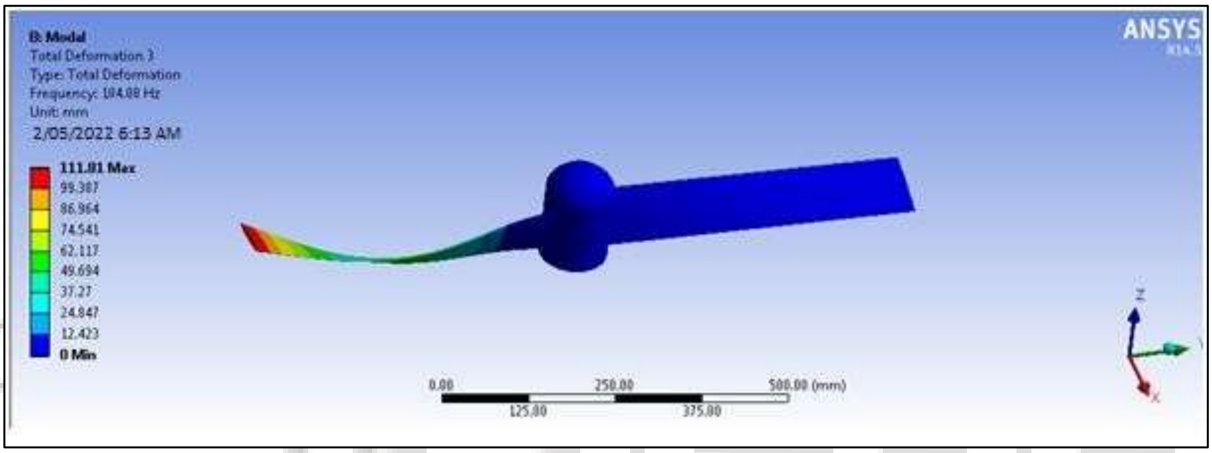
TOTAL DEFORMATION 1



TOTAL DEFORMATION 2

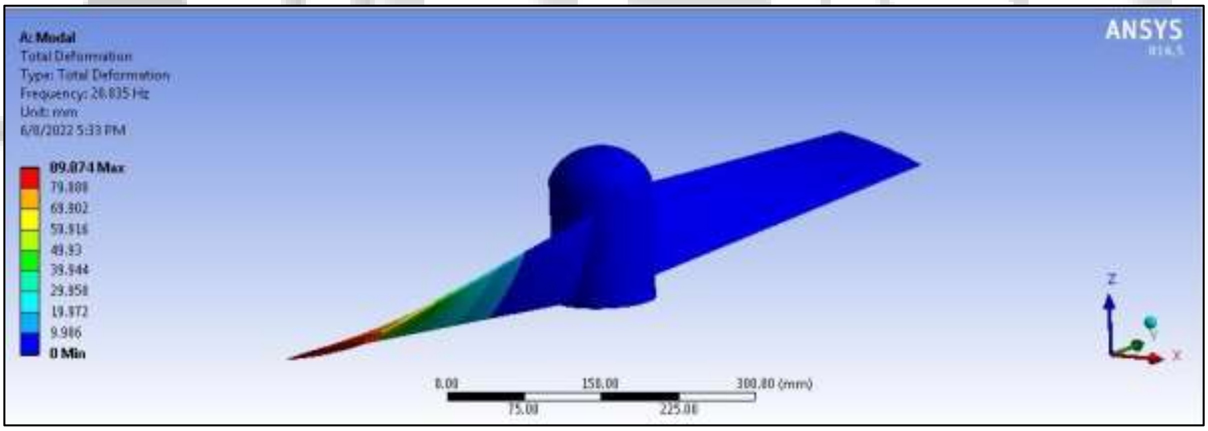


TOTAL DEFORMATION 3



MATERIAL –ALUMINIUM ALLOY 6061

TOTAL DEFORMATION 1



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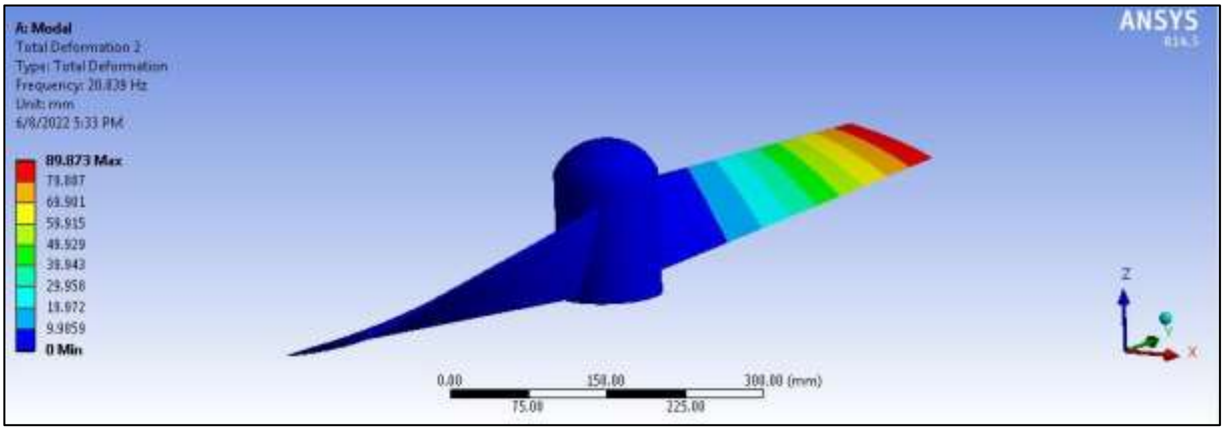

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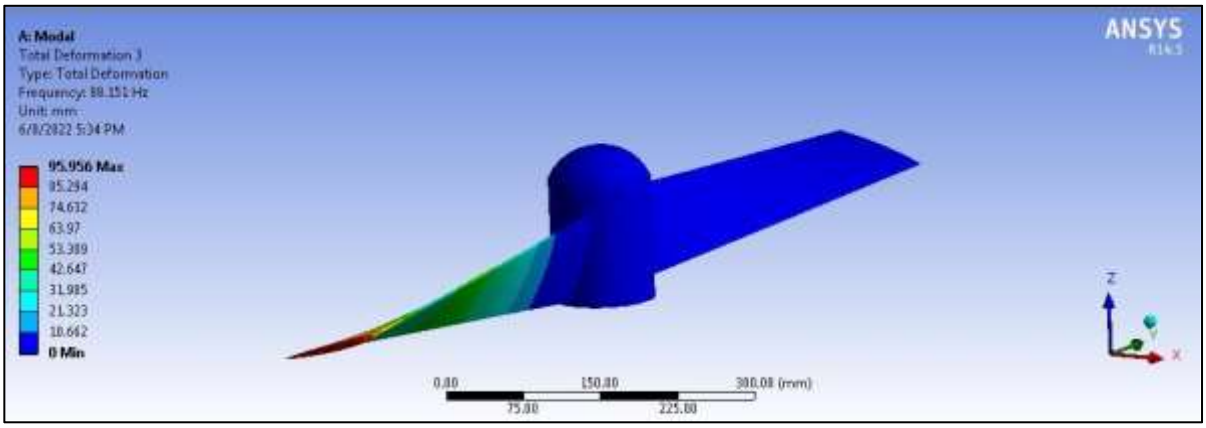
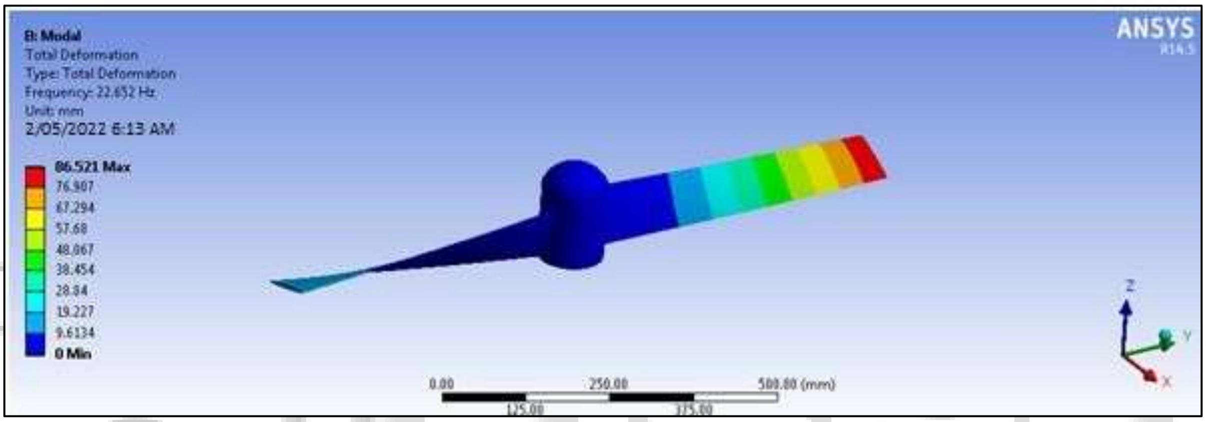


MATERIAL –CARBON FIBER

TOTAL DEFORMATION 1



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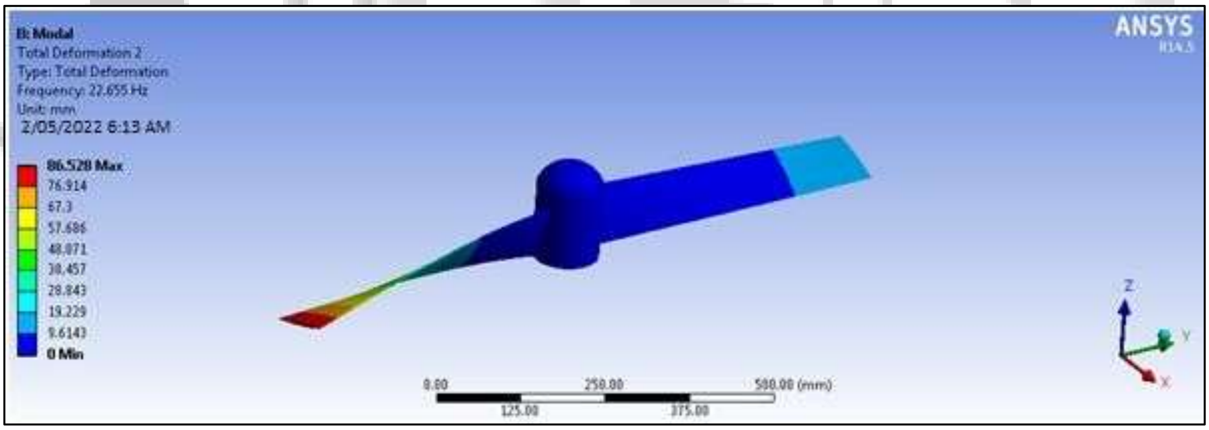

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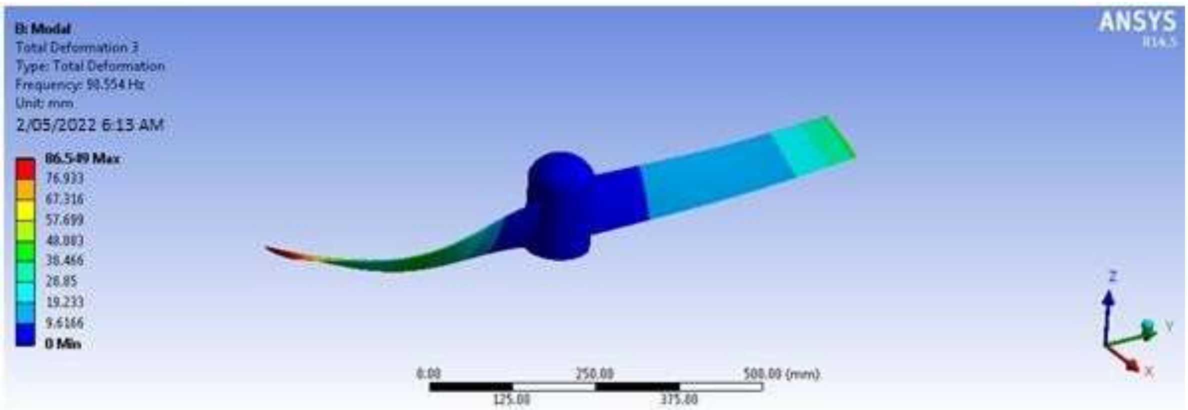
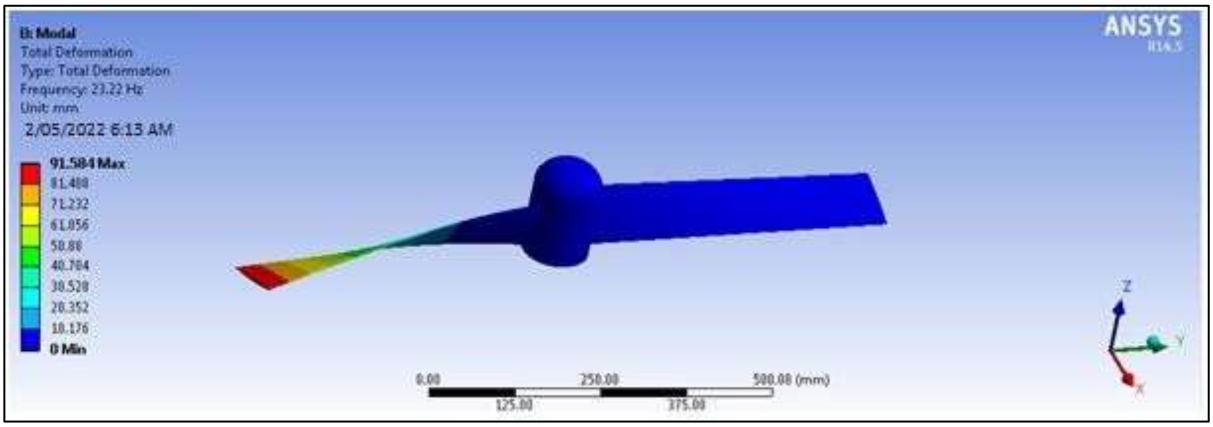


MATERIAL –E-GLASS FIBER

TOTAL DEFORMATION 1



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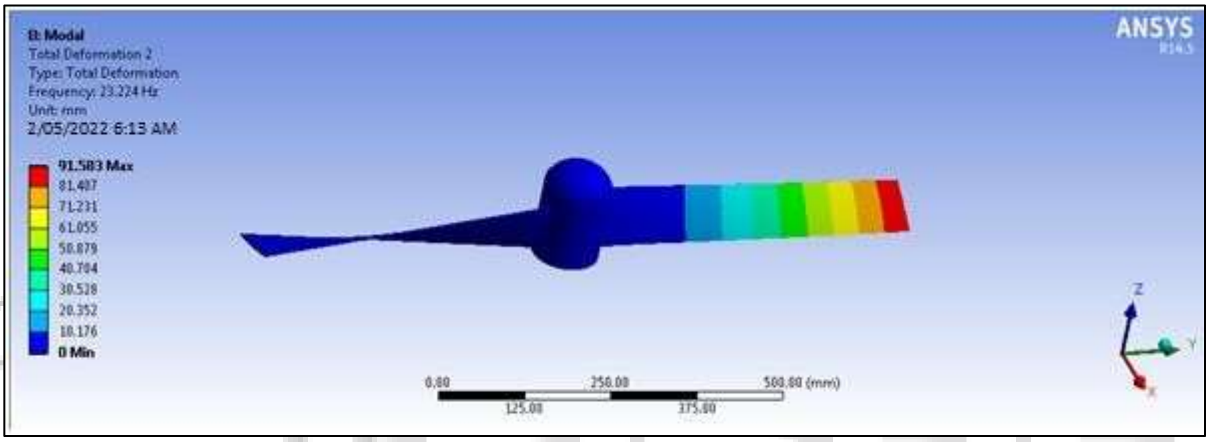

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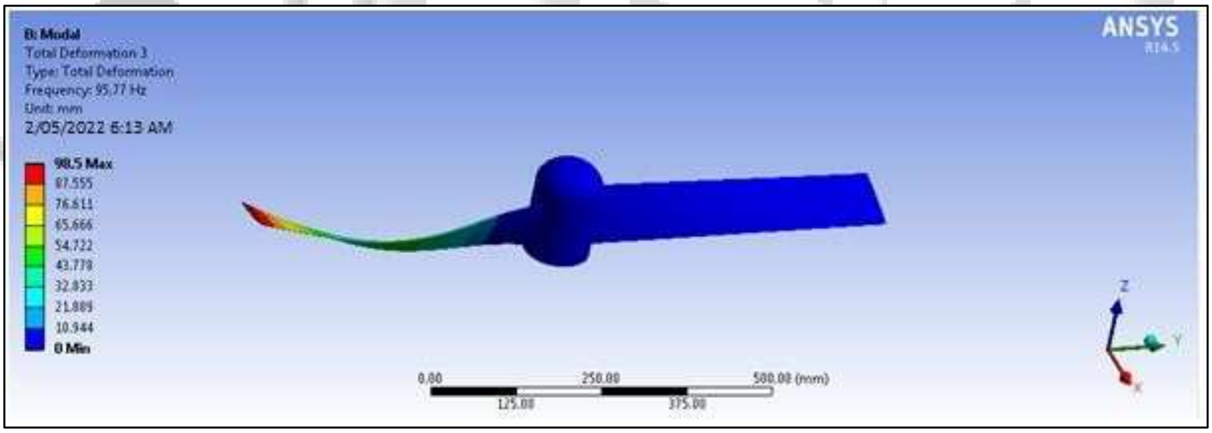


LINEAR LAYER ANALYSIS OF PROPELLER BLADE
CARBON FIBER

Properties of Outline Row 5: CRABON FIBER

	A	B	C
1	Property	Value	Unit
2	Density	2000	kg m^-3
3	Orthotropic Elasticity		
4	Young's Modulus X direction	1.18E+05	MPa
5	Young's Modulus Y direction	7200	MPa
6	Young's Modulus Z direction	7200	MPa
7	Poisson's Ratio XY	0.27	
8	Poisson's Ratio YZ	0.34	
9	Poisson's Ratio XZ	0.27	
10	Shear Modulus XY	2.8	MPa
11	Shear Modulus YZ	2.7	MPa
12	Shear Modulus XZ	2.8	MPa

E-GLASS FIBER

Properties of Outline Row 4: E-GLASS

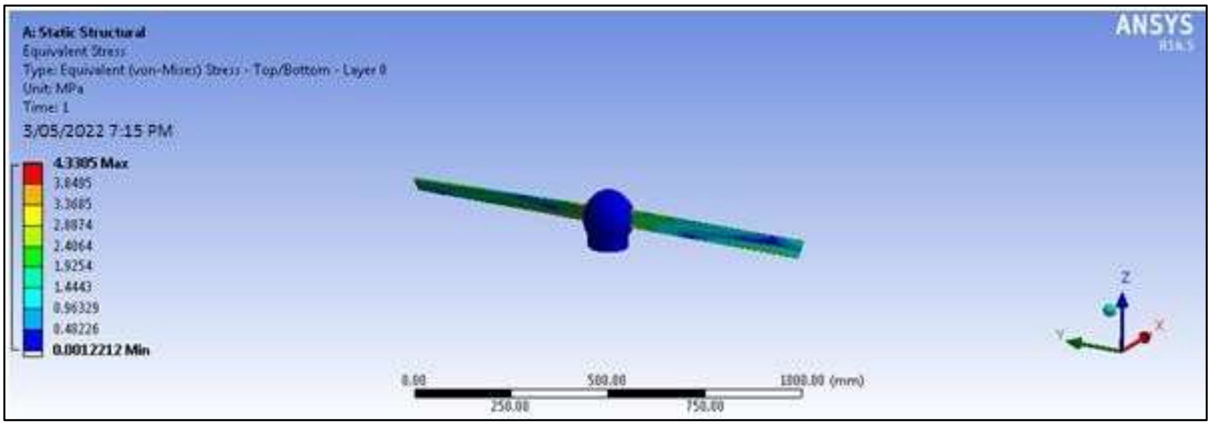
	A	B	C
1	Property	Value	Unit
2	Density	2580	kg m^-3
3	Orthotropic Elasticity		
4	Young's Modulus X direction	37000	MPa
5	Young's Modulus Y direction	9500	MPa
6	Young's Modulus Z direction	9500	MPa
7	Poisson's Ratio XY	0.27	
8	Poisson's Ratio YZ	0.34	
9	Poisson's Ratio XZ	0.27	
10	Shear Modulus XY	3.1	MPa
11	Shear Modulus YZ	3.5	MPa
12	Shear Modulus XZ	3.1	MPa

3 LAYERS STACKING

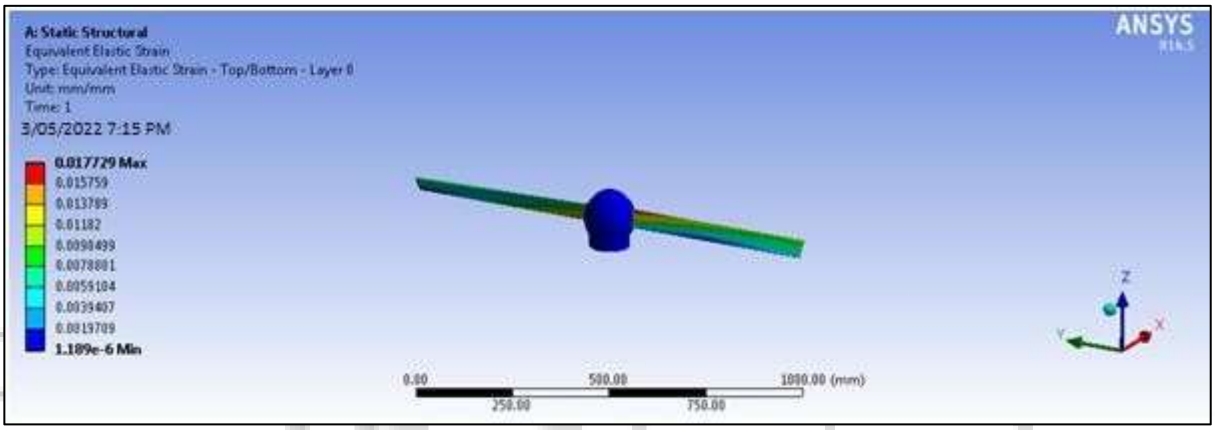
Layer	Material	Thickness (mm)	Angle (°)
(+Z)			
3	CARBON FIBER	1	90
2	E GLASS FIBER	1	0
1	CARBON FIBER	1	-90
(-Z)			

AT SPEED-7000 RPM

STRESS

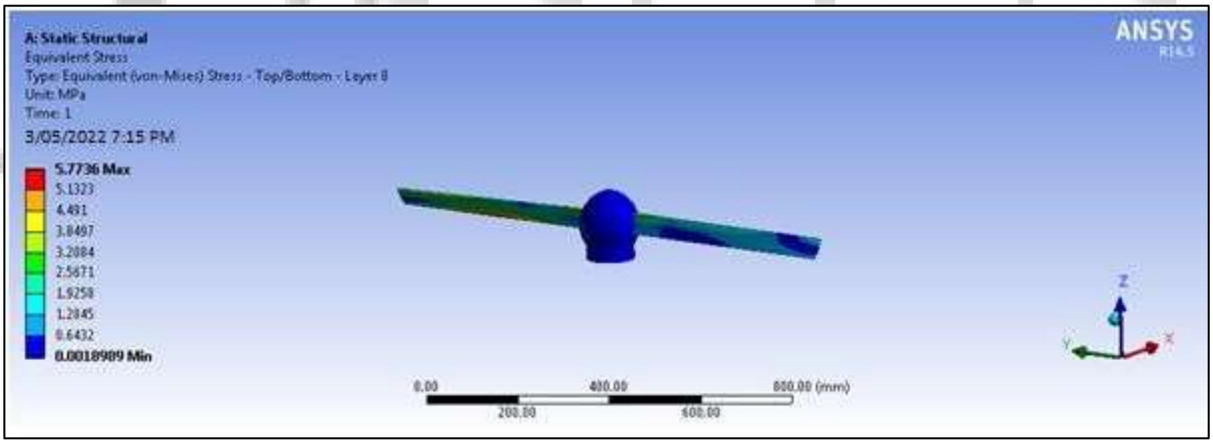


STRAIN



AT SPEED -9000RPM

STRESS



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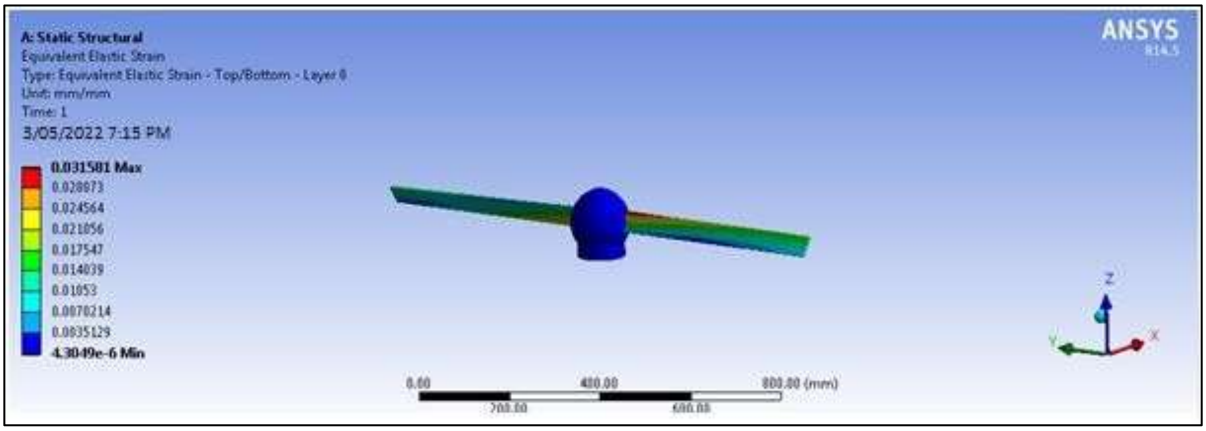
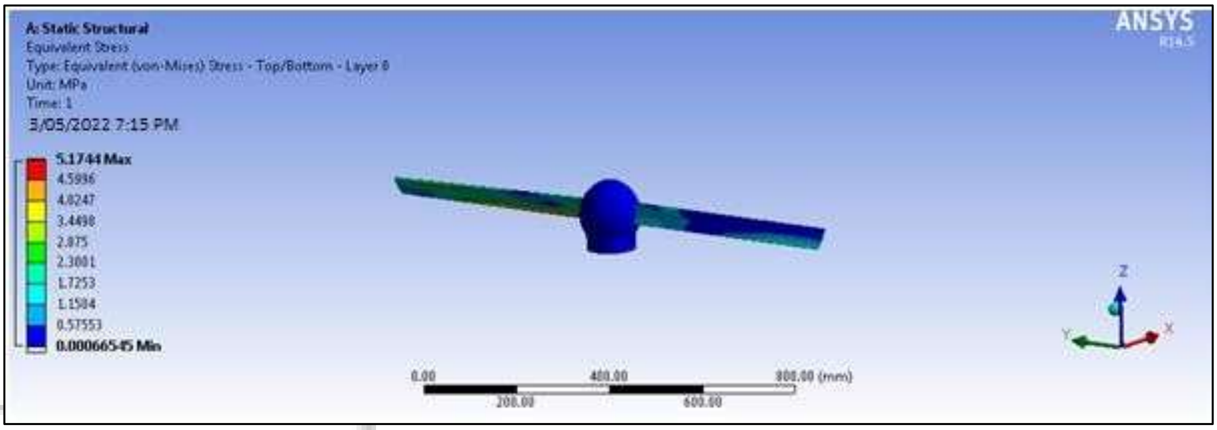


6 LAYERS STACKING

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

AT SPEED-7000 RPM

STRESS



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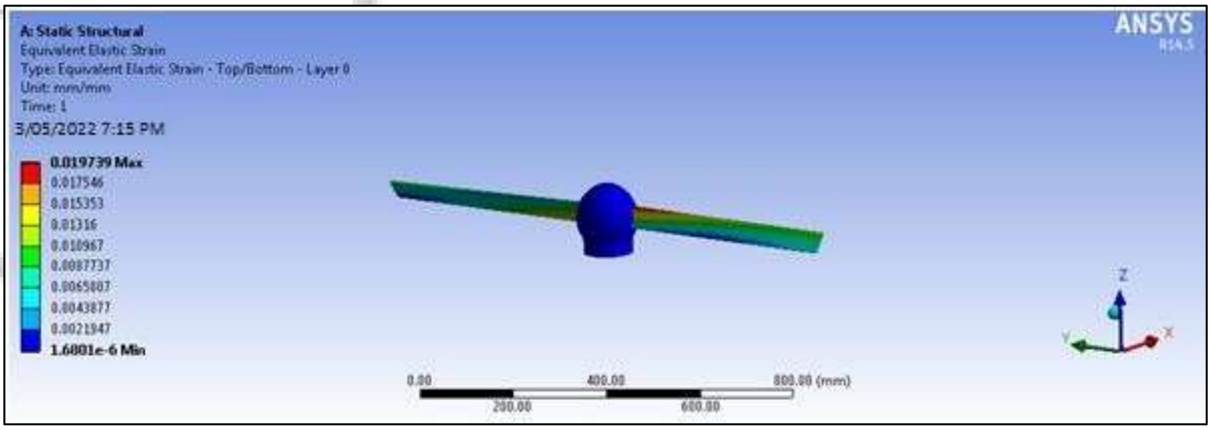
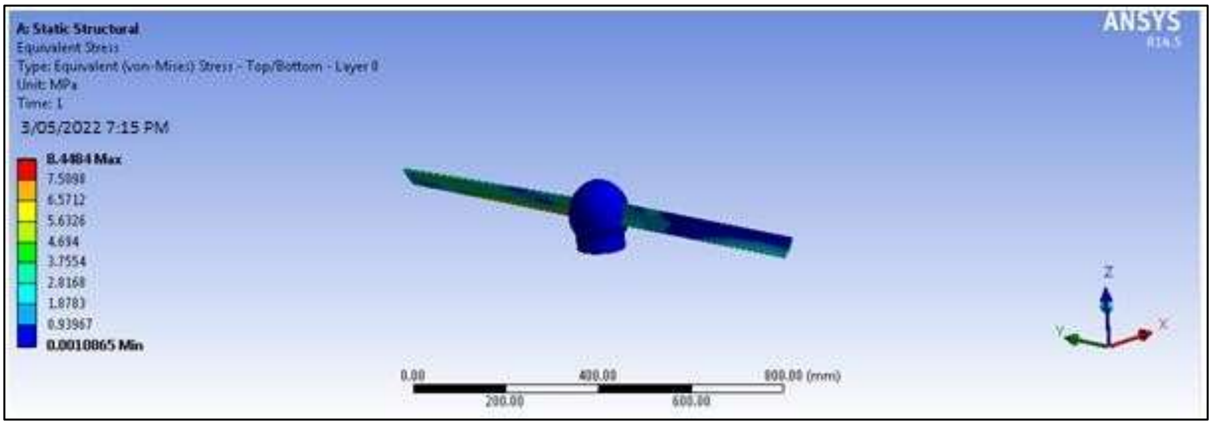
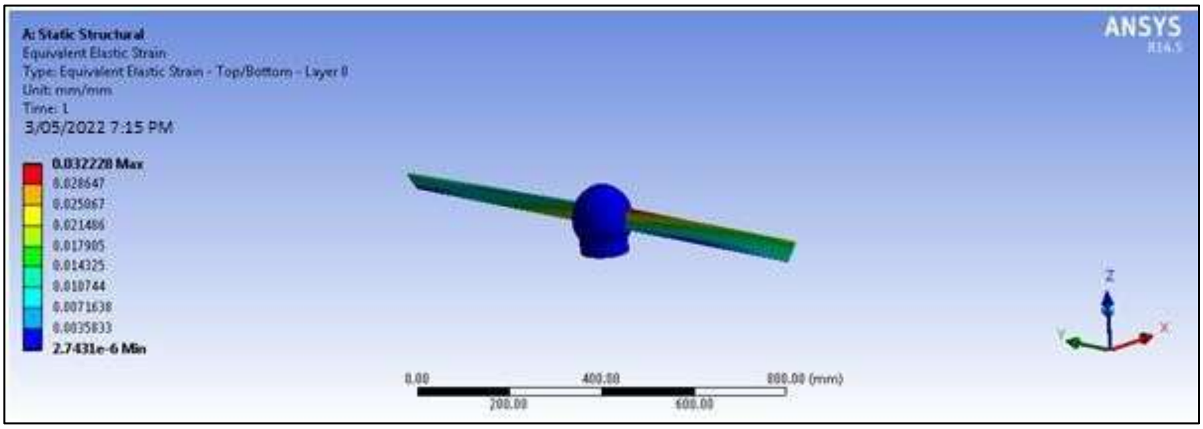


AT SPEED -9000RPM

STRESS



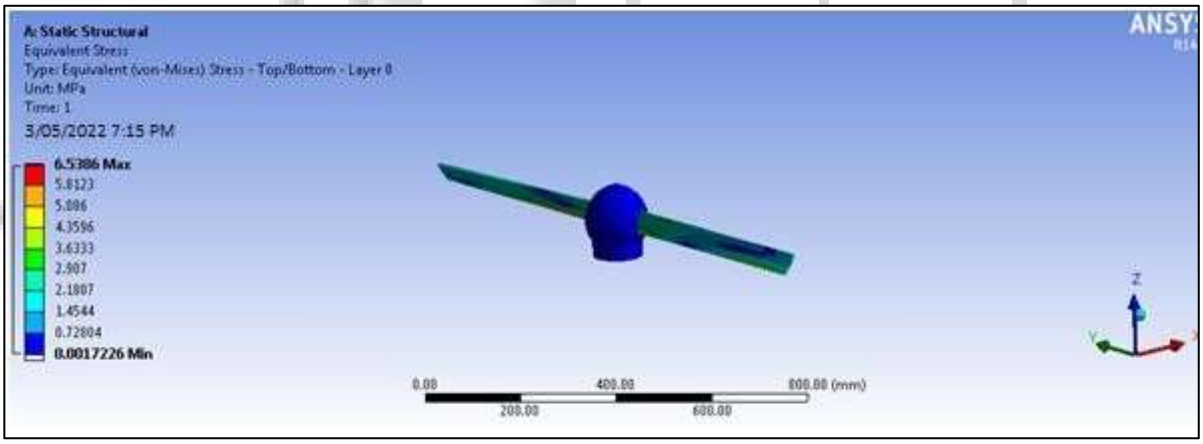
STRAIN



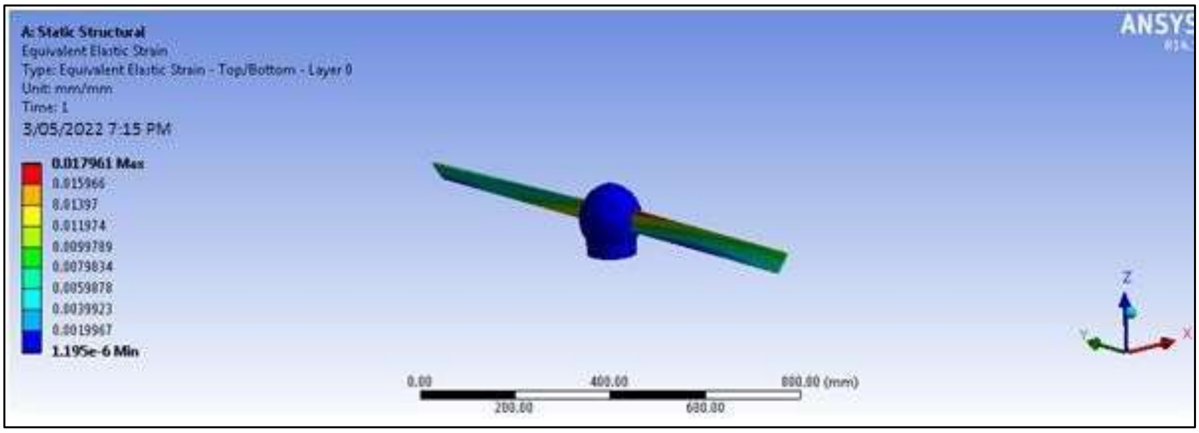
9 LAYERS STACKING

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)			

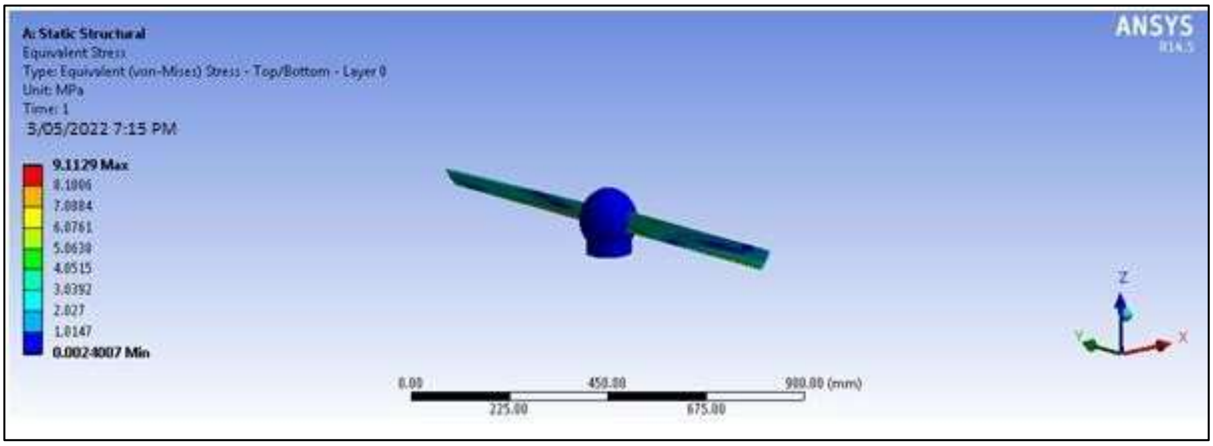
AT SPEED-7000 RPM
STRESS



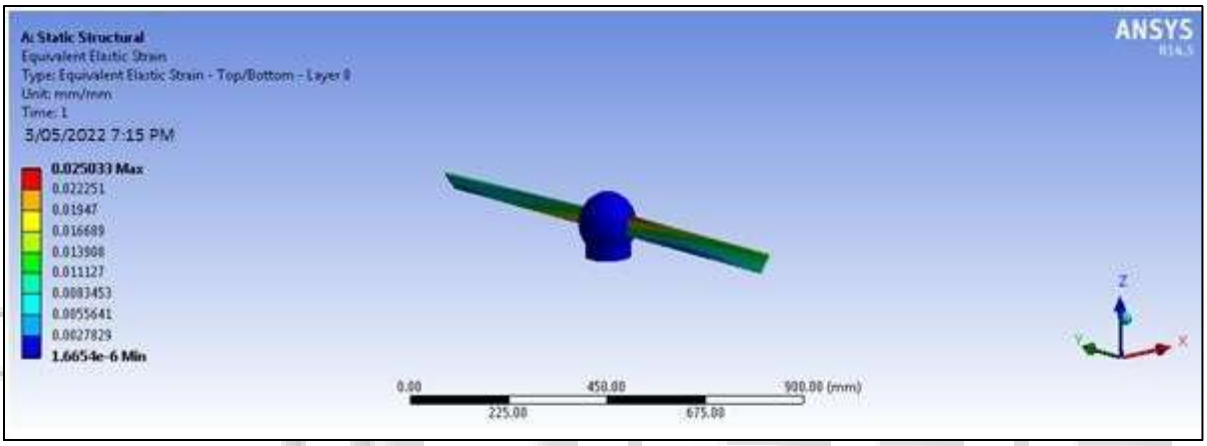
STRAIN



AT SPEED -9000RPM
STRESS



STRAIN



V. RESULTS TABLES

MATERIAL	SPEED (RPM)	DEFORMATION (mm)	STRESS (N/mm^2)	STRAIN
Aluminumalloy 7075	7000	2.8494	12.767	0.00018045
	9000	4.6523	20.845	0.00029462
Aluminum alloy 6061	7000	3.41	14.72	0.000201
	9000	5.61	24.657	0.0003451
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

Table 1: Static Analysis Results

By observing the table, static analysis performed on the propeller blade at different materials (al 7075 and 6061, carbon fibre and E glass fibre) 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 fibre at speed 7000 Rpm.

MateriaLs	Frequency(HZ)	Mode1	Frequency(HZ)	Mode 2	Frequency(HZ)	Mode 3
Aluminum Alloy 7075	25.145	104.06	28.148	104.07	111.81	104.08
Aluminum Alloy 6061	20.835	89.871	20.839	89.783	88.15	95.961
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 2: Modal 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

Table 3: Linear Layer Analysis Results

VI. CONCLUSION

In structural analysis, the carbon fibre and E-glass fibre 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 fibre 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 air craft propeller blade.

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