

Design and Comparative Analysis of an UAV Propeller Using Lightweight Metallic Alloys

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ABSTRACT

This study focuses on evaluating aluminum and magnesium alloys as potential alternatives to carbon fibre for UAV propellers, addressing the challenges of high cost and manufacturing complexity associated with carbon fibre. A detailed propeller model was designed using SolidWorks based on essential geometric parameters. The model was then analyzed in ANSYS Workbench through static structural analysis to assess total deformation, von-Mises stress, strain, and factor of safety under realistic operational conditions, including rotational speed and aerodynamic loads. The analysis revealed that aluminum alloy provides good strength and is easier to manufacture, making it a practical choice. On the other hand, magnesium alloy offers advantages in terms of lower weight and higher specific strength, which can improve UAV performance by reducing overall weight. To ensure the reliability of the simulation results, analytical calculations were also performed for validation. By comparing the structural performance and weight efficiency of these materials, the study identifies the most suitable alternative to carbon fibre that balances strength, weight reduction, and cost-effectiveness. This research contributes to developing more affordable and efficient UAV propellers without compromising structural integrity.

Index Terms: UAV, propeller, design, simulation, structure, material.

1. INTRODUCTION

This project focuses on designing a UAV propeller and conducting structural analysis using finite element methods. It evaluates the feasibility of replacing carbon fibre with aluminium and magnesium alloys by comparing stress, deformation, and strength-to-weight ratio. The objective is to identify a material that offers improved structural stability, reduced weight, and cost-effectiveness. Unmanned Aerial Vehicles (UAVs), or drones, are widely used in applications such as surveillance, agriculture, defense, mapping, and delivery. The propeller is a critical component that generates thrust by converting rotational motion into lift. Its performance depends on blade geometry, material properties, and rotational speed. A strong and lightweight propeller enhances efficiency, stability, and battery life while resisting centrifugal and aerodynamic forces. Material selection significantly impacts the propeller's weight, strength, durability, and efficiency. Ideal materials should be lightweight, strong, and resistant to deformation, fatigue, and corrosion. While plastics and composites are commonly used, aluminium and magnesium alloys are being explored as alternatives to improve performance in advanced UAV applications.

2. LITERATURE REVIEW

i.J. Gordon Leishman (2006) presented fundamental principles of rotor and propeller aerodynamics, focusing on airflow behavior, lift generation, and blade element theory,

which are essential for UAV propeller performance analysis.

ii.Barnes W. McCormick (1995) discussed aerodynamic theory and performance characteristics of propellers, including thrust, efficiency, and power coefficients, providing a strong foundation for propeller design evaluation.

iii.John D. Anderson Jr. (2010) explained modern aerodynamic design methods used in propeller development, emphasizing computational approaches and design optimization techniques.

iv.P. K. Mallick (2007) described the mechanical behavior of fiber-reinforced composites, highlighting the high strength-to-weight ratio and stiffness characteristics of carbon fiber materials.

v.Derek Hull and Trevor W. Clyne (1996) examined the structure and properties of composite materials, including carbon fiber, with emphasis on microstructure and failure mechanisms.

vi.Autar K. Kaw (2006) focused on the analysis and design of composite materials, particularly their application in aerospace structures due to their superior mechanical properties.

vii.Joseph R. Davis (1999) discussed the properties and selection criteria of aluminium alloys, emphasizing their corrosion resistance, lightweight nature, and good mechanical strength for engineering applications.

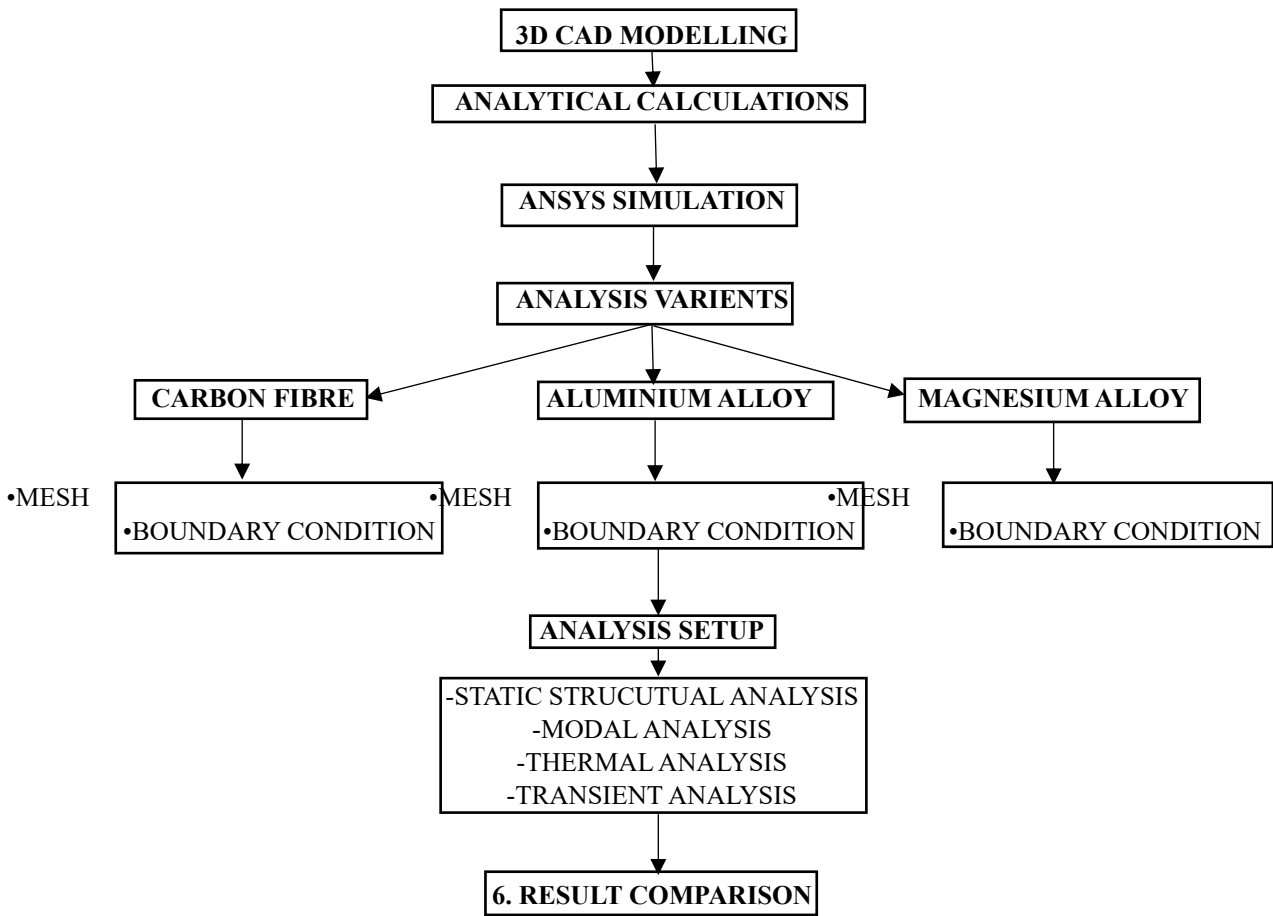
viii.Ian J. Polmear (2006) presented detailed insights into the metallurgy and mechanical behavior of aluminium alloys, including their deformation mechanisms and heat treatment processes.

ix.B. L. Mordike and T. Ebert (2001) reviewed the properties

and engineering applications of magnesium alloys, highlighting their ultra-lightweight characteristics and potential in aerospace industries.

x. **Karl U. Kainer (2003)** discussed the processing techniques and performance aspects of magnesium alloys, focusing on their mechanical behavior and manufacturing considerations.

3. METHODOLOGY



4. 3D Modelling of Propeller

The propeller was designed with dimensions of 1.19 m length, 0.09 m width, and 0.005 m thickness. A drone propeller is a rotating aerodynamic component that generates thrust by accelerating air downwards.

Key Design Parameters:

- Blade length
- Pitch angle
- Diameter
- Material selection
- Number of blades

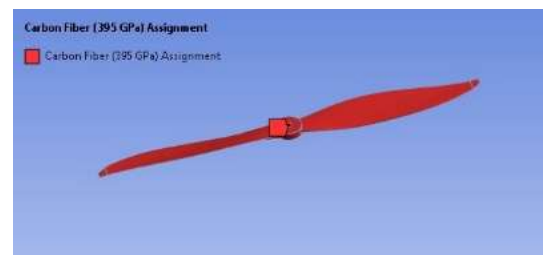
Steps Involved in 3D Modelling:

1. Part Creation: A new part file was created in SolidWorks.
2. Reference Sketch: Blade layout and centreline were sketched on the Front Plane.
3. Reference Planes: Multiple offset planes were generated along the blade length.
4. Blade Profiles: Air foil cross-sections were sketched on each plane.
5. Blade Twist: Progressive angular variation was applied to achieve pitch distribution.
6. Loft Operation: A lofted boss feature was used to create

the 3D blade geometry.

7. Geometry Refinement: Surface features were refined for smoothness and analysis readiness.
8. Axis Definition: A central axis was created for rotational reference.
9. Blade Duplication: Circular pattern was applied to generate multiple blades.
10. Hub Modelling: The hub was extruded, combined with blades, and a central hole was created using cut extrude.

5. Material Details



Carbon Fibre (T700)

Carbon Fiber Reinforced Polymer (CFRP) is a high-performance composite material consisting of carbon fibres

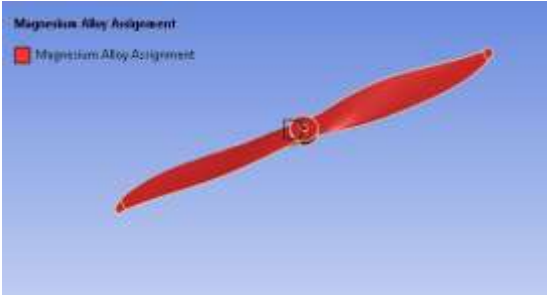
embedded in an epoxy matrix. It is commonly used in UAV propellers due to its superior strength-to-weight ratio.

Characteristics:

- Anisotropic behavior
- High specific strength and stiffness
- Excellent fatigue resistance
- Good thermal stability

Application in Propellers:

- Minimizes centrifugal deformation
- Enhances aerodynamic efficiency
- Provides longer service life



Aluminium Alloy 7050-T7451

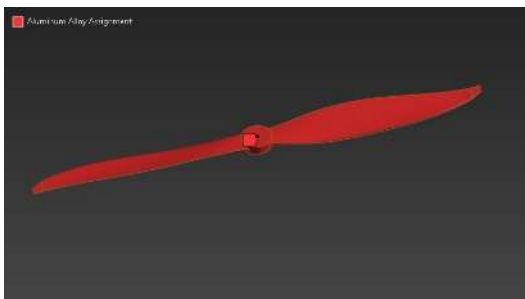
Aluminium 7050-T7451 is a commonly used structural alloy known for its balanced mechanical properties and manufacturability.

Characteristics:

- Isotropic material
- Good thermal conductivity
- Corrosion resistance
- High ductility

Application in Propellers:

- Easy fabrication and repair
- Suitable for moderate-speed UAVs
- Cost-effective for prototyping



Magnesium Alloy (AZ31B)

Magnesium AZ31B is a lightweight structural alloy used in applications where weight reduction is critical.

Characteristics:

- Very low density
- Good vibration damping
- Moderate strength
- Lower corrosion resistance

Application in Propellers:

- Ideal for lightweight UAVs
- Improves flight endurance
- Limited use in high-load conditions

Property	Carbon fibre	Aluminium alloy	Magnesium alloy
Density	1600 kg/m ³	2700 kg/m ³	1800 kg/m ³
Strength	Very high	High	Moderate
Weight	Very low	Medium	Low
Stiffness	Very high	Moderate	Low
Fatigue resistance	Excellent	Good	Moderate
Corrosion resistance	Excellent	Good	Moderate
Cost	High	Moderate	High

6. CALCULATION

6.1 ALUMINIUM

6.1.1 Centrifugal Force Acting on Blade

Formula :

$$F_c = mr\omega^2$$

Where,

Mass of blade (m) = 1.26 kg

Length of the blade (L) = 557mm = 0.557m

Centre of mass location (r) = $\frac{L}{2}$ = 0.2785m

Calculation of force :

$$F_c = 1.26 \times 0.2785 \times (523.6)^2$$

$$F_c = 1.26 \times 0.2785 \times 274156$$

$$F_c \approx 96100 \text{ N}$$

6.1.2 Stress Due To Centrifugal Force

Formula :

$$A_c = b \times t$$

Where,

Width (b) = 90mm = 0.09m

Thickness (t) = 5mm = 0.005m

Calculation of stress :

$$A_c = 0.09 \times 0.005$$

$$A_c = 0.00045 \text{ m}^2$$

Now tensile stress :

$$\sigma_c = \frac{F_c}{A_c}$$

$$\sigma_c = \frac{96100}{0.00045}$$

$$\sigma_c \approx 213 \text{ MP}_a$$

6.1.3 stress due to pressure

$$\sigma_p = P$$

$$\sigma_p = 1 \text{ MP}_a$$

6.1.4 Combined stress (von mises stress)

$$\sigma_{total} = \sigma_c + \sigma_p$$

$$\sigma_{total} \approx 214 MP_a$$

6.2 MAGNESIUM

6.2.1 Centrifugal Force Acting on Blade

Formula :

$$F_c = mr\omega^2$$

Where,

Mass of blade (m) = 1.26 kg

Length of the blade (L) = 557mm = 0.557m

Centre of mass location (r) = $\frac{L}{2} = 0.2785m$

Calculation of force :

$$F_c = 1.26 \times 0.2785 \times (523.6)^2$$

$$F_c = 1.26 \times 0.2785 \times 274156$$

$$F_c \approx 96100 N$$

6.2.2 Axial Stress Due To Centrifugal Force

Formula :

$$A_c = b \times t$$

Where,

Width (b) = 90mm = 0.09m

Thickness (t) = 5mm = 0.05m

Calculation of stress :

$$A_c = 0.09 \times 0.005$$

$$A_c = 0.00045 m^2$$

Now tensile stress :

$$\sigma_c = \frac{F_c}{A_c}$$

$$\sigma_c = \frac{96100}{0.00045}$$

$$\sigma_c \approx 213 MP_a$$

6.2.3 Bending Stress Due To Aerodynamic Pressure

Total pressure force :

$$F_p = P \times A$$

Pressure (P) = 1 MP_a

Area (a) = 0.092089 m²

Calculation of force :

$$F_p = 10^6 \times 0.092089$$

$$F_p = 92089 N$$

Moment at blade root :

$$M = F_p \times \frac{L}{2}$$

Where,

Force (F_p) = 92089 N

Length of the blade (L) = 0.557m

$$\frac{L}{2} = \frac{0.557}{2} = 0.2785 m$$

$$M = 92089 \times 0.2785$$

$$M \approx 25633 Nm$$

6.2.4 Moment of Inertia of Blade Section

For rectangular section :

$$I = \frac{bt^3}{12}$$

Where,

Width (b) = 0.09 m

Thickness (t) = 0.005 m

Calculation of MOI :

$$I = \frac{0.09(0.005)^3}{12}$$

$$I = 9.375 \times 10^{-9} m^4$$

Distance from neutral axis :

$$c = \frac{t}{2} = 0.0025m$$

6.2.5 Bending Stress

Formula :

$$\sigma_b = \frac{Mc}{I}$$

Where,

Bending moment (M) = 25633 Nm

Distance from neutral axis (c) = 0.0025m

Moment of inertia (I) = 9.375 × 10⁻⁹ m⁴

Calculation of bending stress :

$$\sigma_b = \frac{25633 \times 0.0025}{9.375 \times 10^{-9}}$$

$$\sigma_b \approx 342 MP_a$$

6.2.6 Combined Stress (von mises stress)

$$\sigma_{total} = \sigma_c + \sigma_b$$

$$\sigma_{total} = 213 + 342$$

$$\sigma_{total} \approx 555 MP_a$$

6.3 CARBON FIBRE

6.3.1 Centrifugal Force Acting On Blade

Formula :

$$F_c = mr\omega^2$$

Where,

Mass of blade (m) = 1.26 kg

Length of the blade (L) = 557mm = 0.557m

Centre of mass location (r) = $\frac{L}{2}$ = 0.2785m

Calculation of force :

$$F_c = 1.26 \times 0.2785 \times (523.6)^2$$

$$F_c = 1.26 \times 0.2785 \times 274156$$

$$F_c \approx 96100 \text{ N}$$

6.3.2 Stress Due To Centrifugal Force

Formula :

$$\sigma_c = \frac{F_c}{A}$$

Where,

Area (A) = 0.092089 m

Force (F_c) = 96100 N

Calculation of stress due to centrifugal force :

$$\sigma_c = \frac{96150}{0.092089}$$

$$\sigma_c \approx 1.043 \text{ MP}_a$$

6.3.3 Stress Due To Pressure

$$\sigma_p = P$$

$$\sigma_p = 1 \text{ MP}_a$$

6.3.4 Combined stress

$$\sigma_{total} = \sigma_c + \sigma_p$$

$$\sigma_{total} = 1.043 + 1$$

$$\sigma_{total} \approx 2.043 \text{ MP}_a$$

6.3.5 Von Mises Stress

Formula :

$$\sigma_v = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \sigma_2}$$

Where ,

$$\sigma_1 = 1.043 \text{ MP}_a$$

$$\sigma_2 = 1 \text{ MP}_a$$

Calculation of von mises stress :

$$\sigma_v = \sqrt{(1.043)^2 + (1)^2 - (1.043)(1)}$$

$$\sigma_v = \sqrt{1.088 + 1 - 1.043}$$

$$\sigma_v = \sqrt{1.045}$$

$$\sigma_v \approx 1.022 \text{ MP}_a$$

7. Geometry Import

Overview:

3D Propeller Model Development and Analysis Procedure:

i. Developed the 3D propeller model using CAD software.

ii. Imported the model into ANSYS Workbench for structural analysis.

iii. Steps in ANSYS Workbench:

- Opened ANSYS Workbench.
- Inserted the required analysis system.
- Imported geometry via the geometry cell.
- Selected CAD file formats such as STEP, IGES, or Parasolid.

Verification:

- Checked for missing surfaces and gaps.
- Ensured proper connectivity of the model.
- Confirmed the geometry was error-free.

Validated the geometry to ensure accuracy and suitability for simulation.

8. Material Selection:

Carbon Fibre (T700):

High-performance composite with excellent strength-to-weight ratio and fatigue resistance.

Key Properties:

- High tensile strength and stiffness.
- Low density (~1.8 g/cm³).
- Fatigue and corrosion resistance.

Justification:

- Lightweight with high rigidity.
- Superior fatigue life.
- Ideal for high-performance UAV propellers.

Aluminium Alloy (7050-T7451):

Offers a balance between strength, cost, and manufacturability.

Key Properties:

- Moderate strength and stiffness.
- Density: ~2.7 g/cm³.
- Good thermal and corrosion resistance.

Justification:

- Cost-effective and widely available.
- Easy to machine.
- Suitable for moderate load applications.

Magnesium Alloy (AZ31B):

Preferred where weight reduction is critical.

Key Properties:

- Very low density (~1.77 g/cm³).
- Moderate strength.
- Good damping characteristics.

Justification:

- Reduces overall weight.
- Improves flight endurance.
- Suitable for lightweight UAVs.

9. Mesh Generation

Overview:

Meshing divides the geometry into finite elements to enable numerical analysis.

Procedure:

- Open the Mesh module.
- Apply the meshing method.
- Define element sizing.
- Generate the mesh.
- Check mesh quality.

Mesh Details:

- Tetrahedral elements were used.

- Default body sizing was applied.
 - Mesh generation was automatic.
- Quality Check:
- Mesh skewness was within acceptable limits.
 - Element transition was smooth.
 - No distorted elements were present.

The generated mesh provides a balance between computational efficiency and solution accuracy, ensuring reliable simulation results.

10. FEM SIMULATION OF DRONE PROPELLER

i. Static structural analysis

ii. Modal analysis

iii. Thermal analysis

iv. Transient analysis

10.1 FEM ANALYSIS FOR CARBON FIBRE

i. Static Structural Analysis :

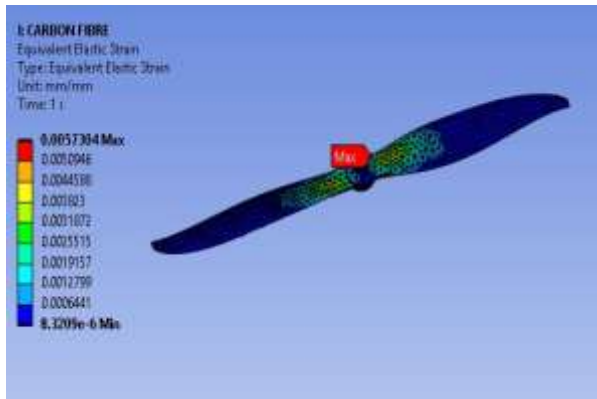


Fig 10.1.1 Equivalent Elastic Stress

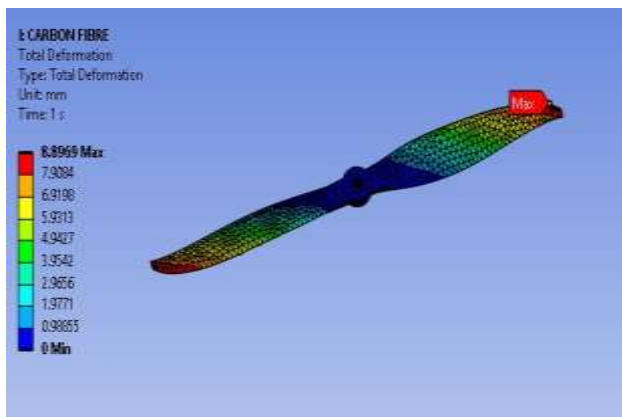


Fig 10.1.2 Total Deformation

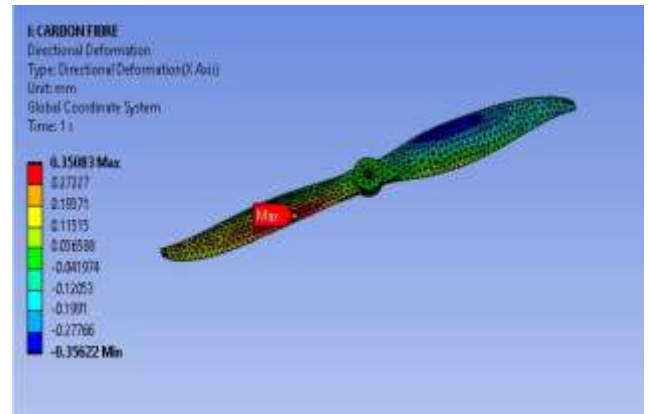


Fig 10.1.3 Deformation (X-axis)

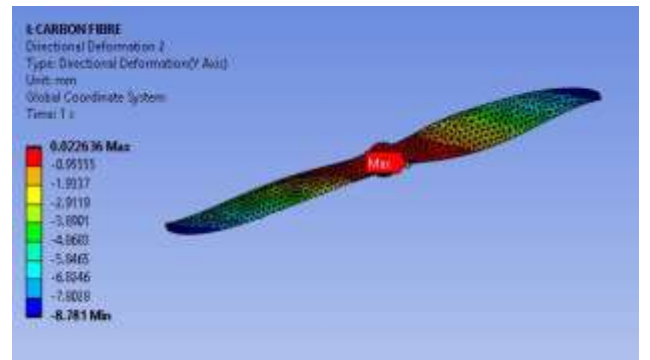


Fig 10.1.4 Deformation (Y-axis)

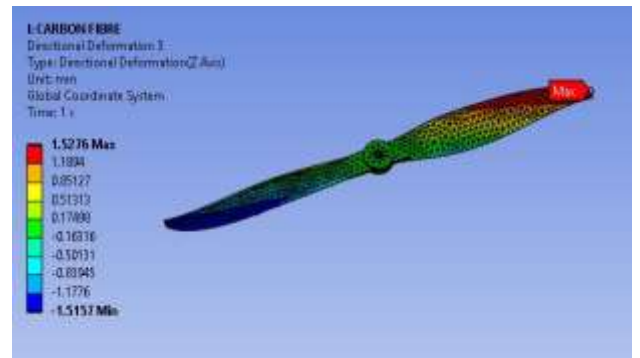


Fig 10.1.5 Deformation (Z-axis)

ii. Modal analysis :

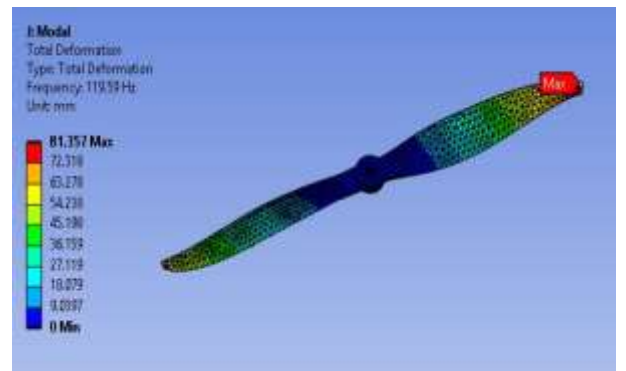


Fig 10.1.6 Total Deformation

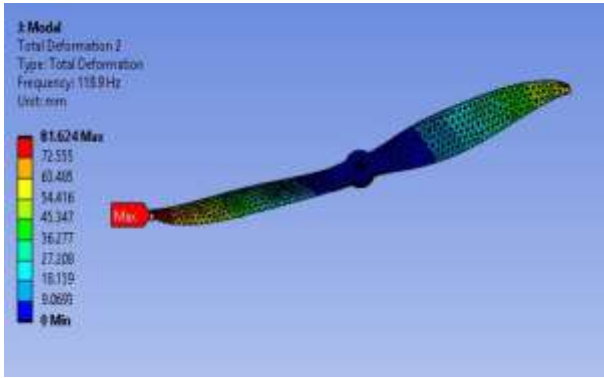


Fig 10.1.7 Total Deformation 2

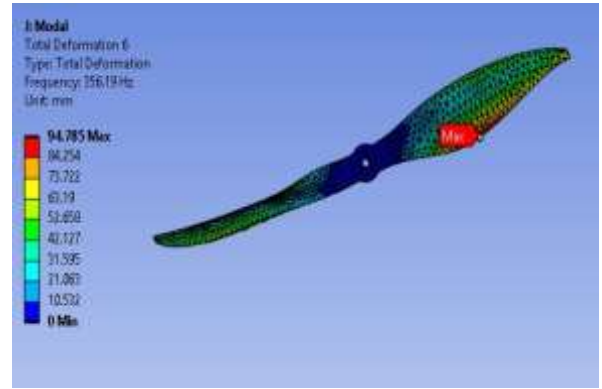


Fig 10.1.11 Total Deformation 6

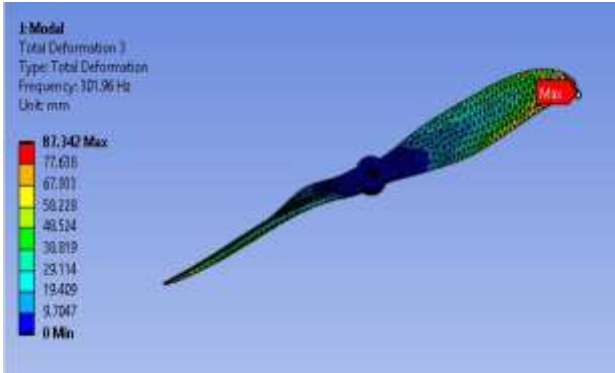


Fig 10.1.8 Total Deformation 3

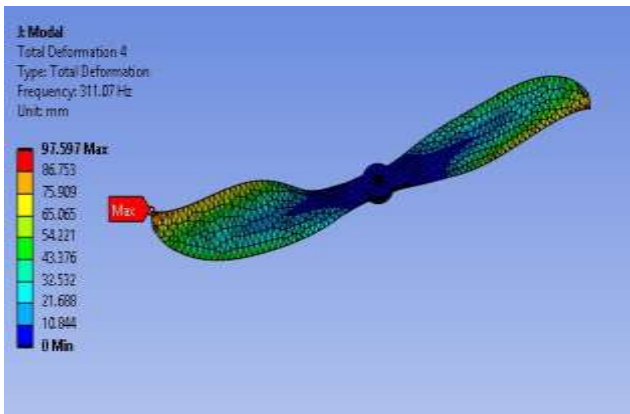


Fig 10.1.9 Total Deformation 4

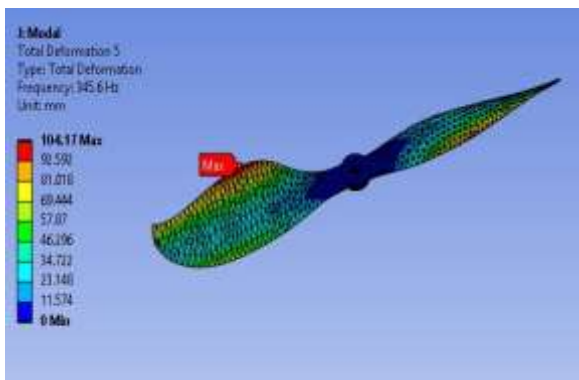


Fig 10.1.10 Total Deformation 5

10.2 FEM ANALYSIS FOR ALUMINIUM ALLOY

i. Static Structural Analysis :

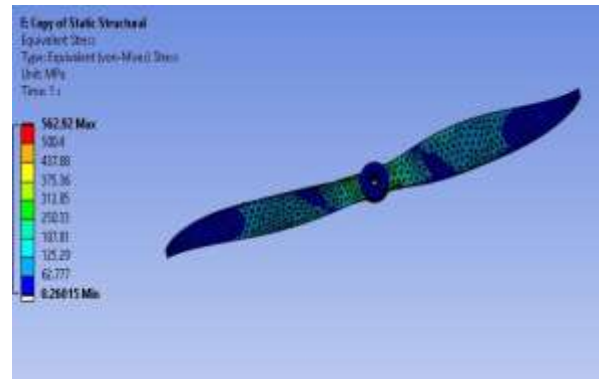


Fig 10.2.1 Equivalent Stress

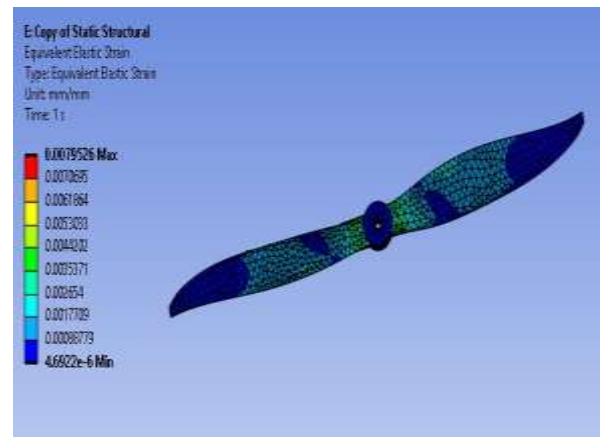


Fig 10.2.2 Equivalent Strain

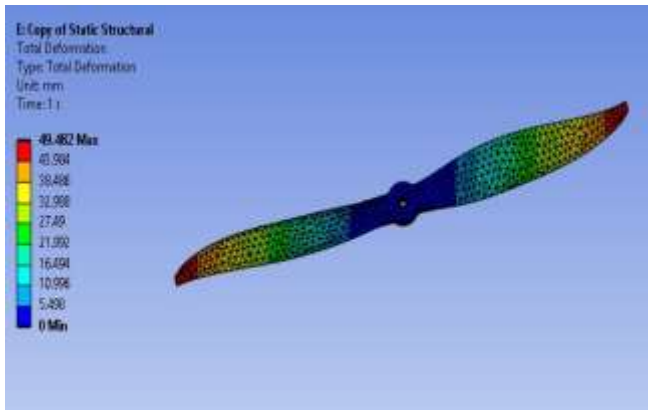


Fig 10.2.3 Total Deformation

ii.Modal Analysis :

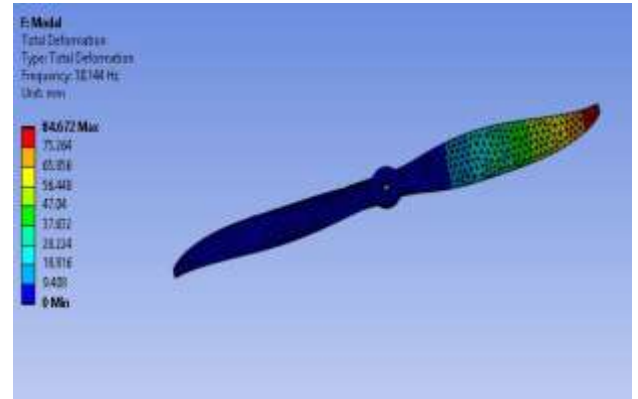


Fig 10.2.7 Total Deformation

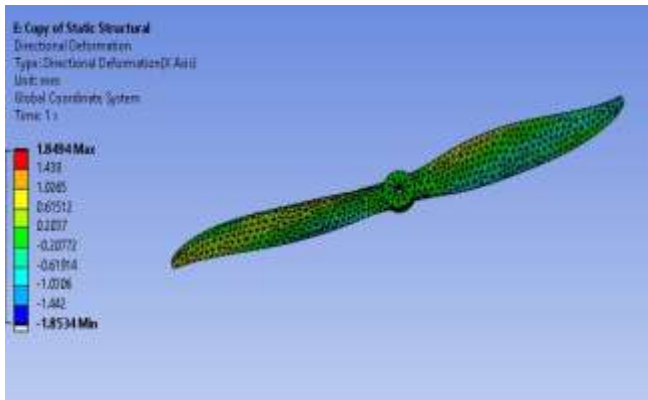


Fig 10.2.4 Deformation (X-Axis)

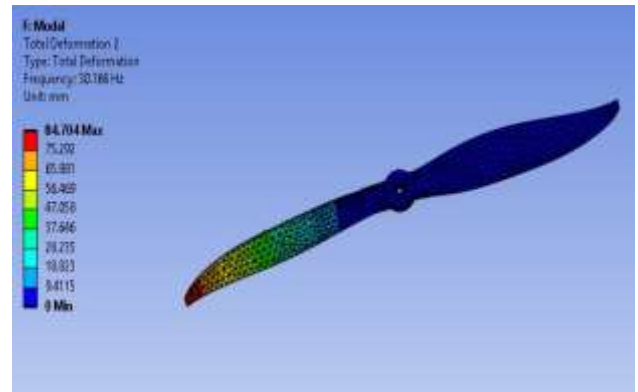


Fig 10.2.8 Total Deformation 2

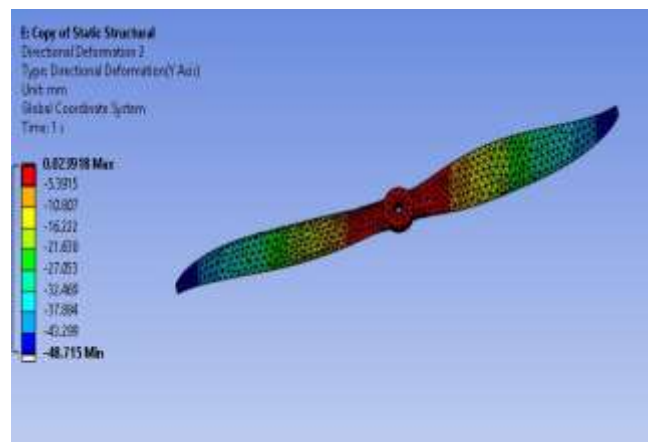


Fig 10.2.5 Deformation (Y-Axis)

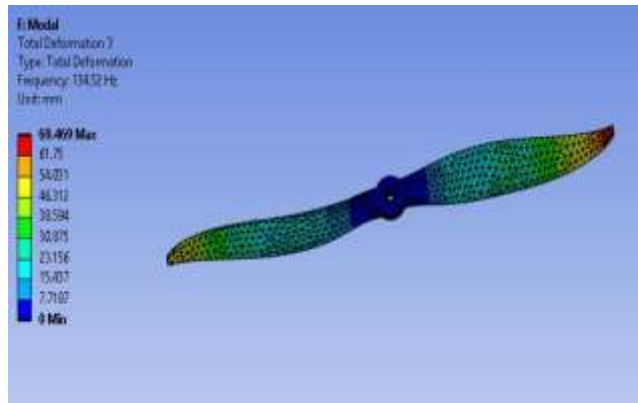


Fig 10.2.9 Total Deformation 3

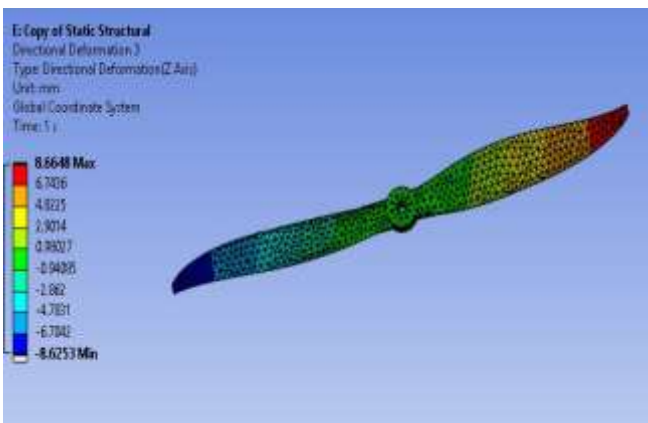


Fig 10.2.6 Deformation (Z-Axis)

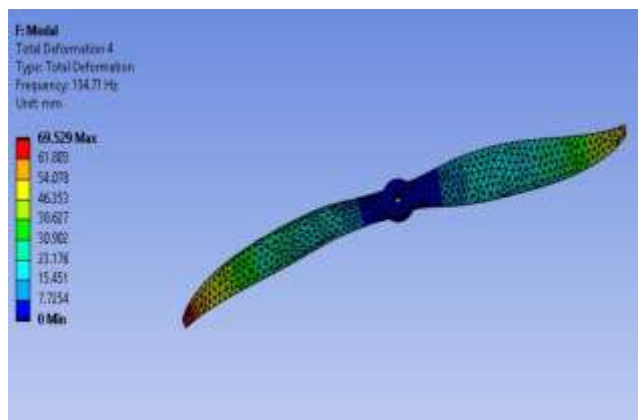


Fig 10.2.10 Total Deformation 4

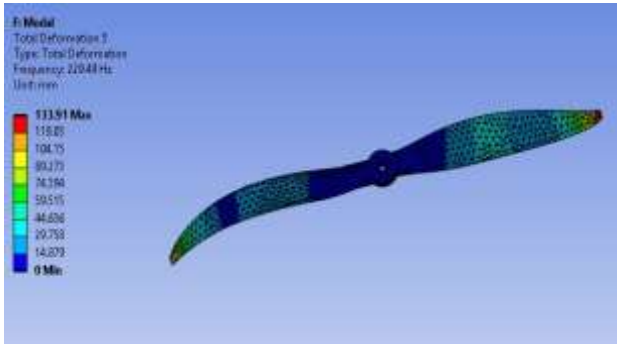


Fig 10.2.11 Total Deformation 5

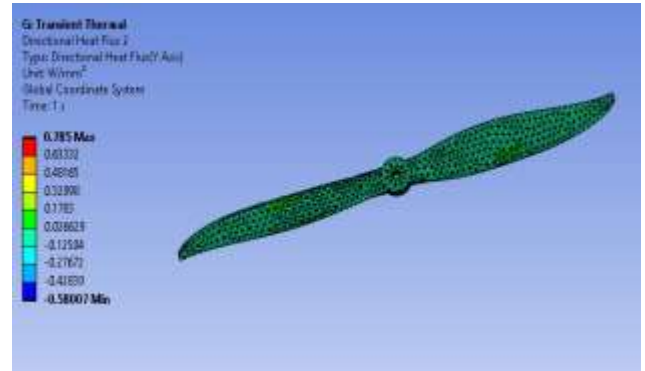


Fig 10.2.15 Heat Flux (Y-Axis)

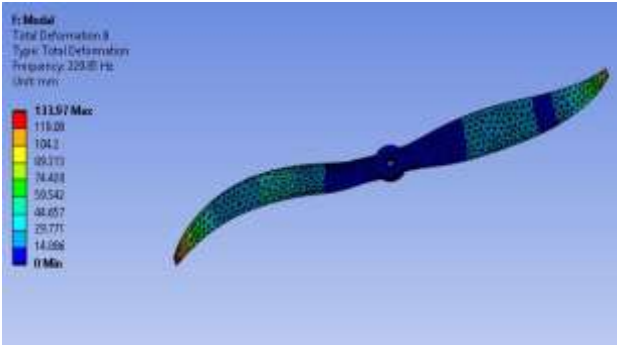


Fig 10.2.12 Total Deformation 6

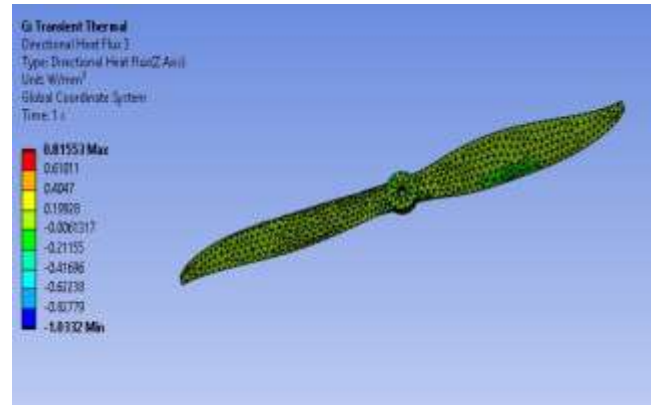


Fig 10.2.16 Heat Flux (Z-Axis)

iii. Thermal Analysis :

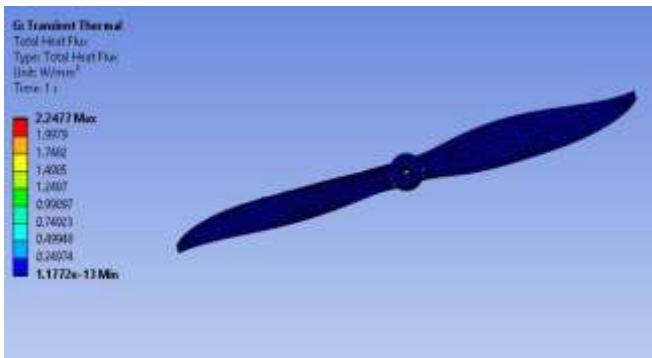


Fig 10.2.13 Total Heat Flux

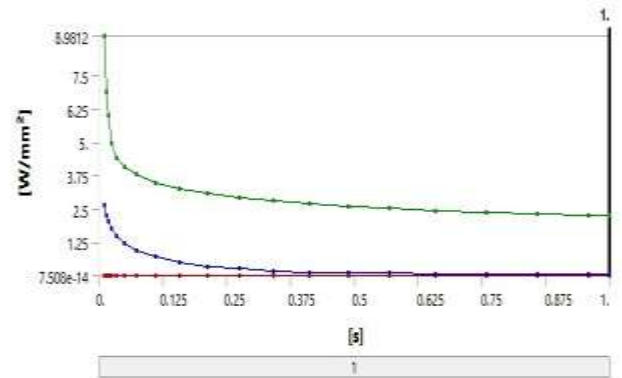


Fig 10.2.17 Total Heat Flux Graph

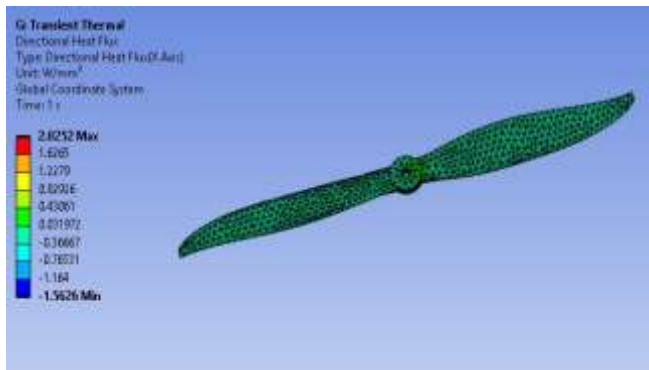


Fig 10.2.14 Heat Flux (X-Axis)

iv. Transient Structural Analysis :

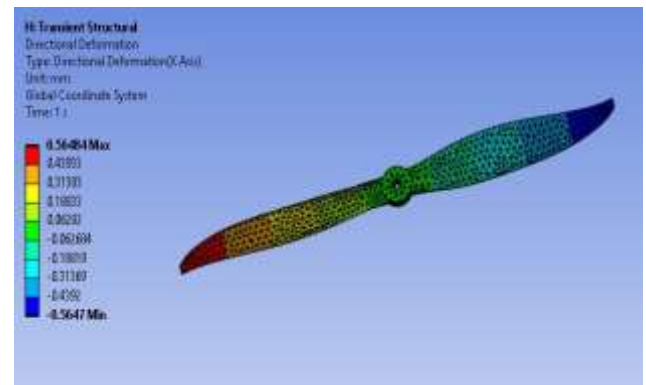


Fig 10.2.18 Deformation (X-Axis)

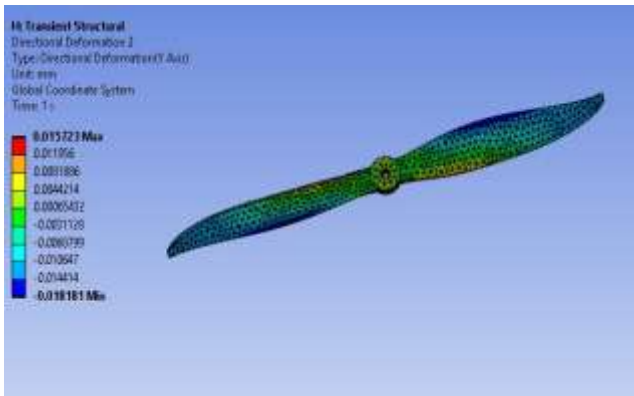


Fig 10.2.19 Deformation (Y-Axis)

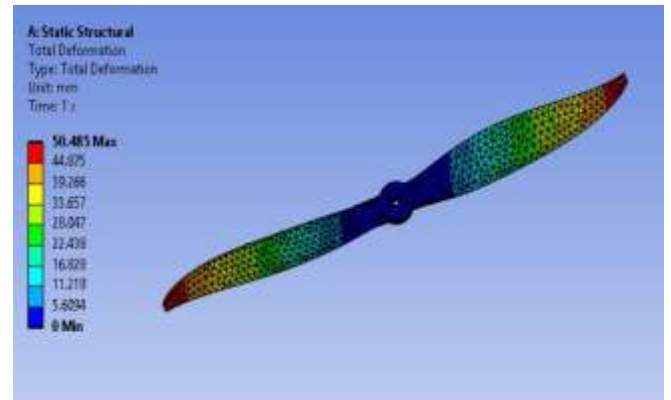


Fig 10.3.3 Total Deformation

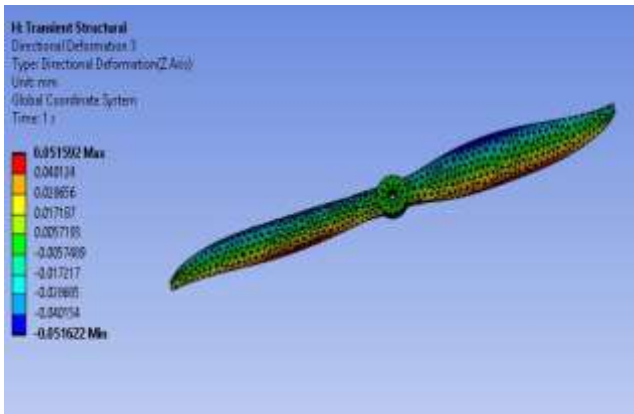


Fig 10.2.20 Deformation (Z-Axis)

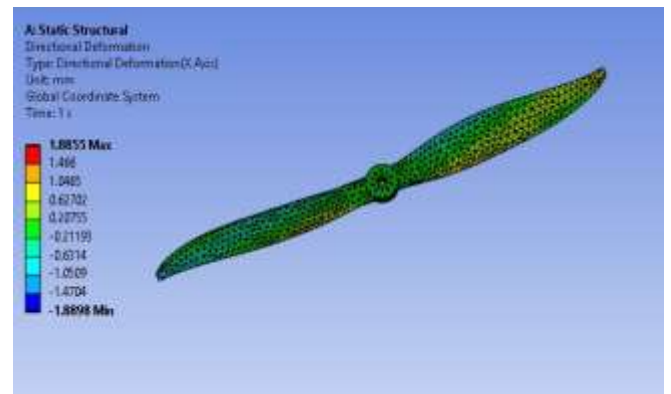


Fig 10.3.4 Deformation (X-Axis)

10.3 FEM ANSYS FOR MAGNESIUM ALLOY

i. Static Structural Analysis :

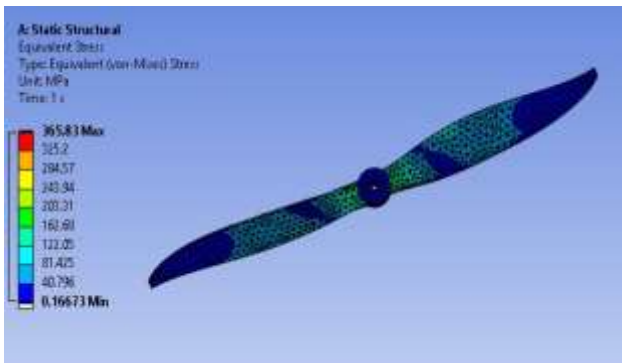


Fig 10.3.1 Equivalent Stress

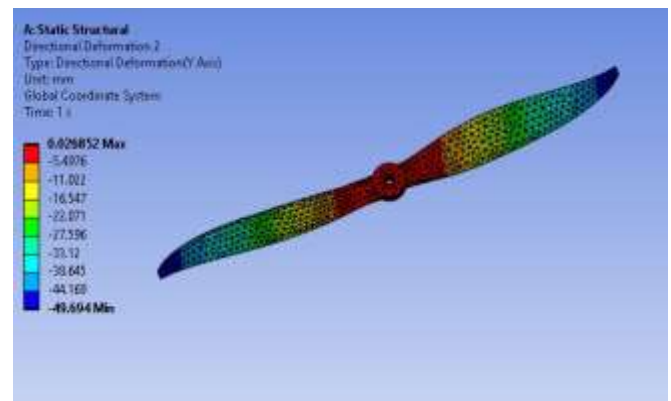


Fig 10.3.5 Deformation (Y-Axis)

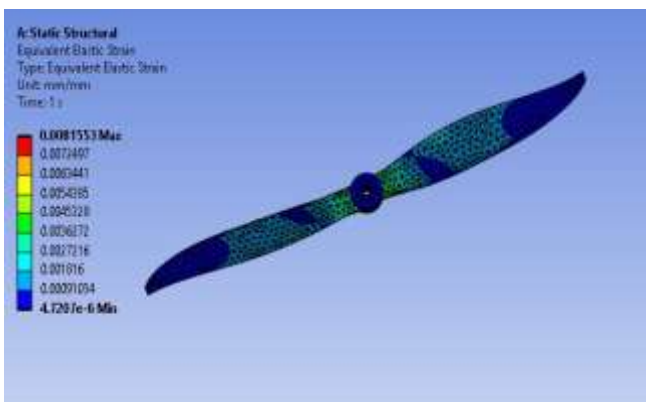


Fig 10.3.2 Equivalent Strain

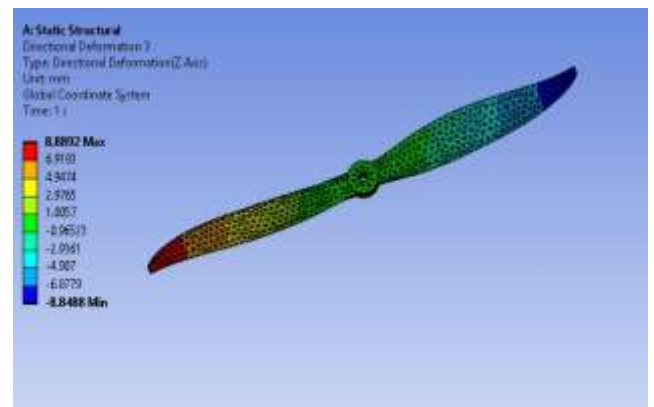


Fig 10.3.6 Deformation (Z-Axis)

ii.Modal analysis :

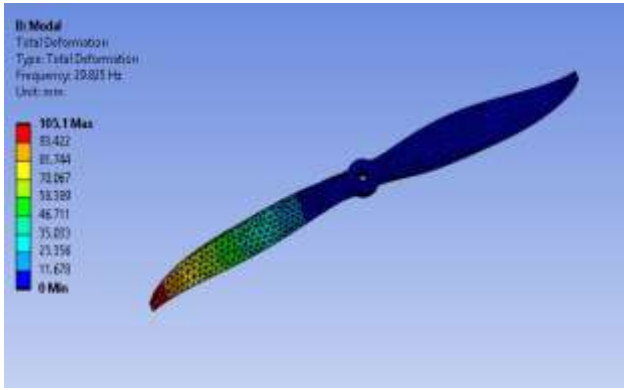


Fig 10.3.7 Total Deformation

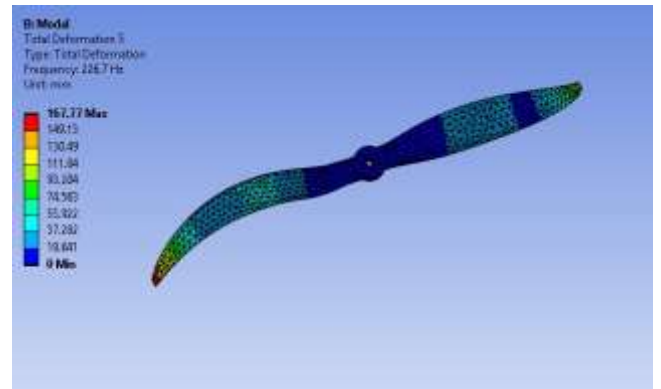


Fig 10.3.11 Total Deformation 5

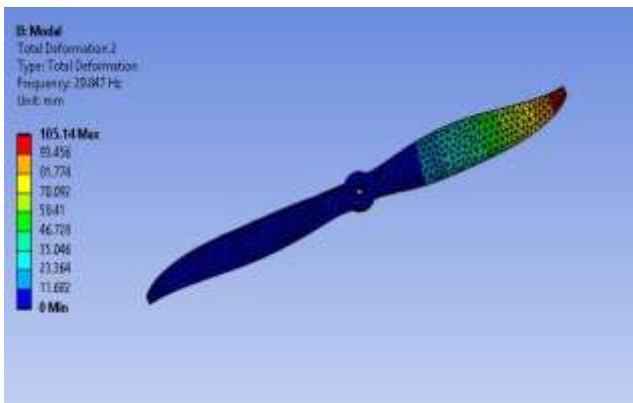


Fig 10.3.8 Total Deformation 2

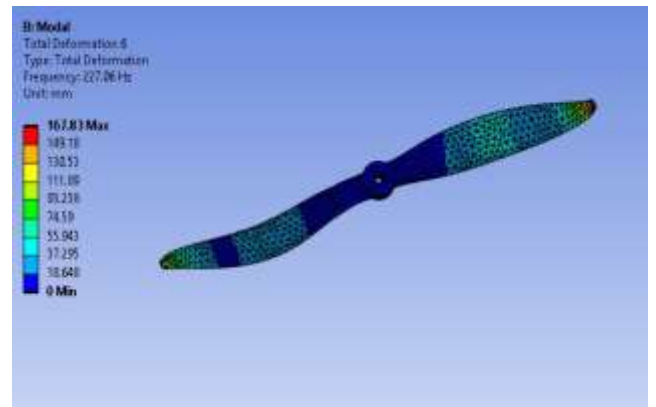


Fig 10.3.12 Total Deformation 6

iii.Thermal analysis :

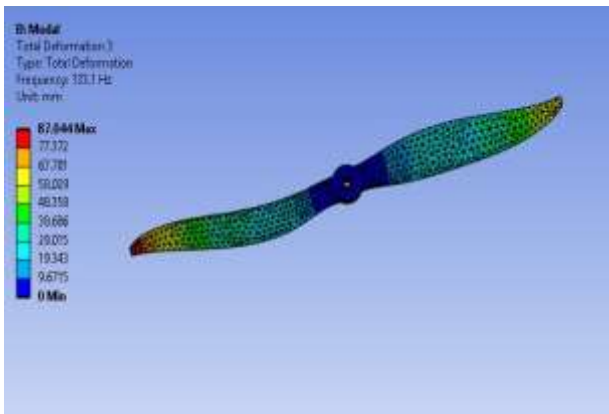


Fig 10.3.9 Total Deformation 3

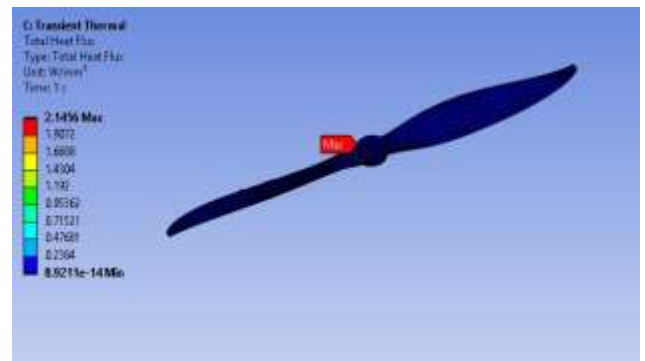


Fig 10.3.13 Total Heat Flux

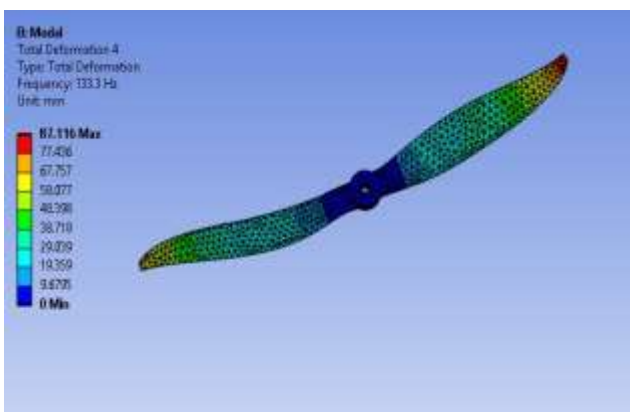


Fig 10.3.10 Total Deformation 4

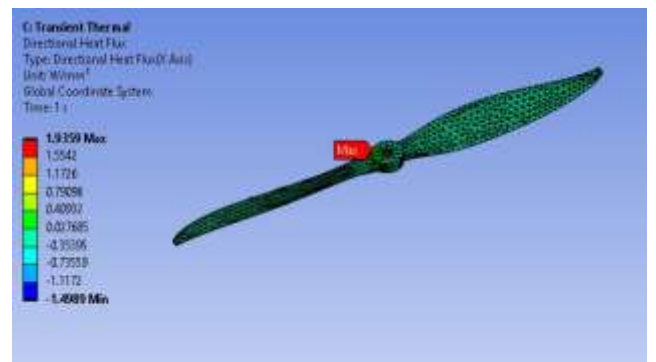


Fig 10.3.14 Heat Flux (X-Axis)

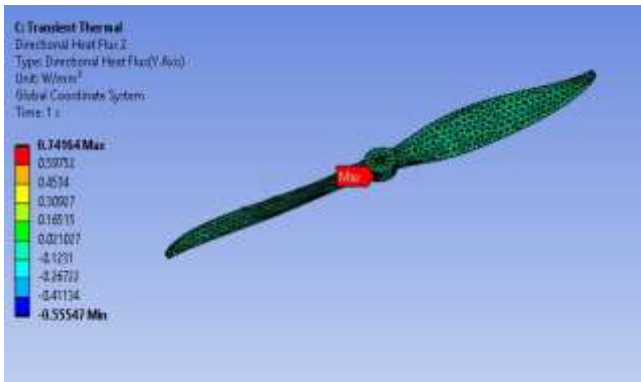


Fig 10.3.15 Heat Flux (Y-Axis)

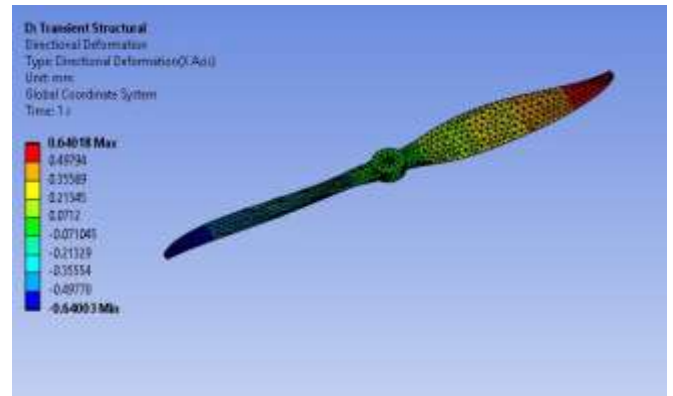


Fig 10.3.19 Deformation (X-Axis)

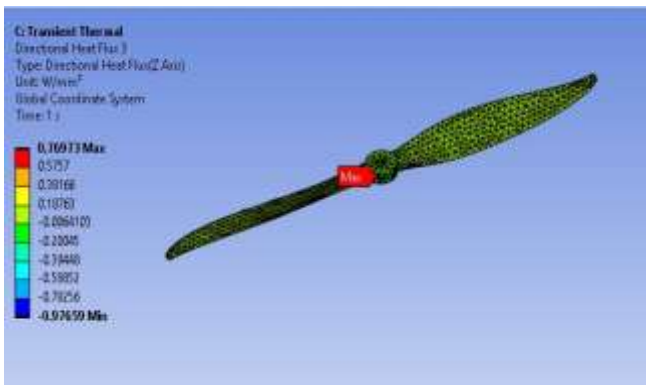


Fig 10.3.16 Heat Flux (Z-Axis)

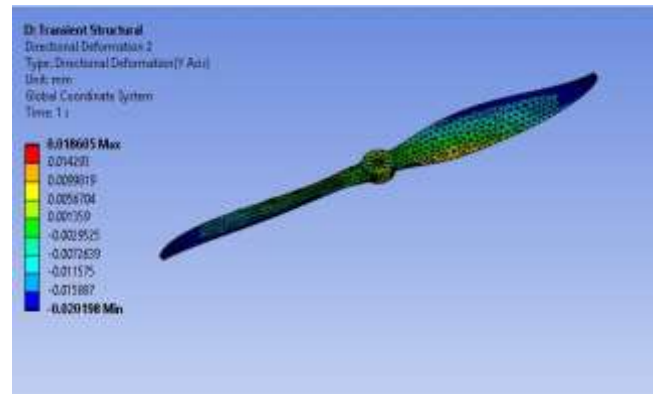


Fig 10.3.20 deformation (Y-axis)

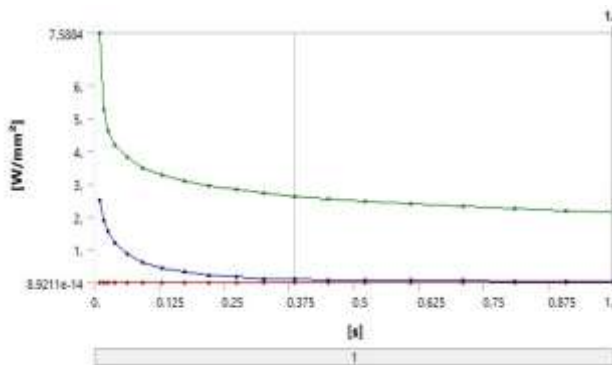


Fig 10.3.17 Total Heat Flux Graph

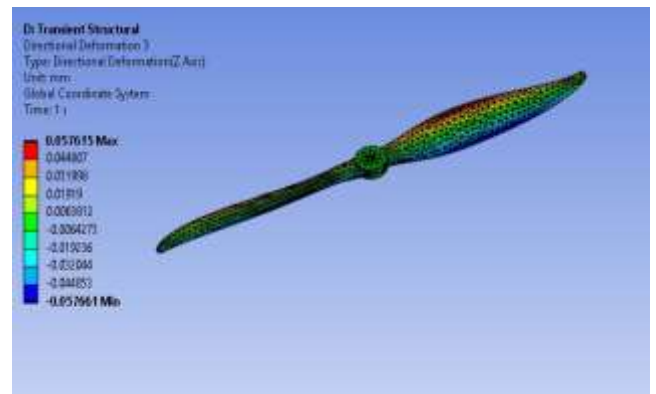


Fig 10.3.21 deformation (Z-axis)

iv. Transient Structural Analysis

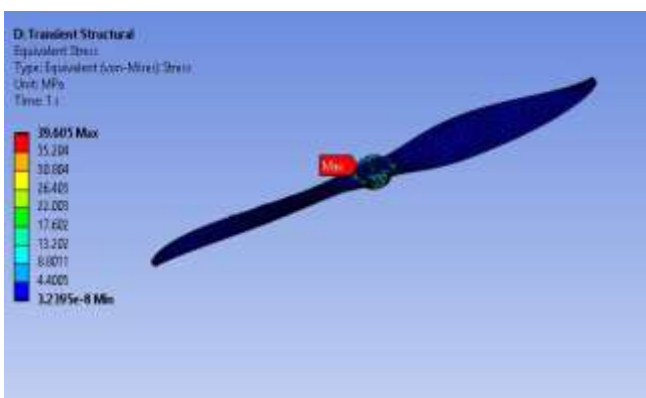


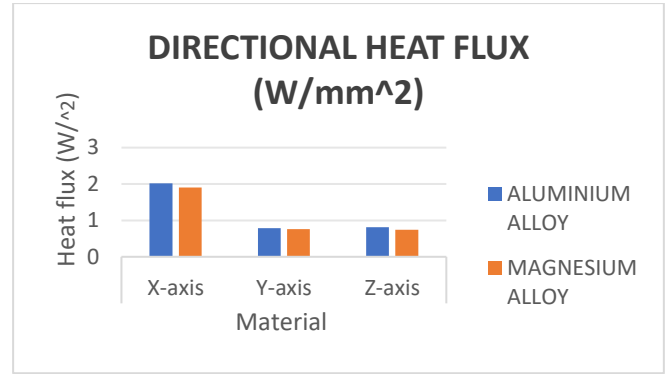
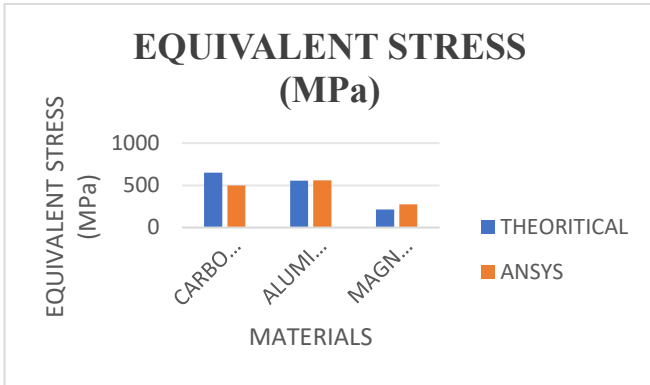
Fig 10.3.18 Equivalent Stress

Result comparison tables

Comparison of equivalent stress

	EQUIVALENT STRESS (MPa)	
	Theoretical values	Ansys values
CARBON FIBRE	651	499
ALUMINIUM ALLOY	555	560

MAGNESIUM ALLOY	214	276
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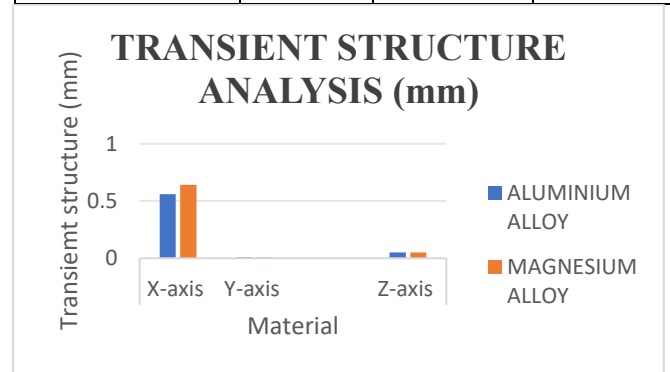
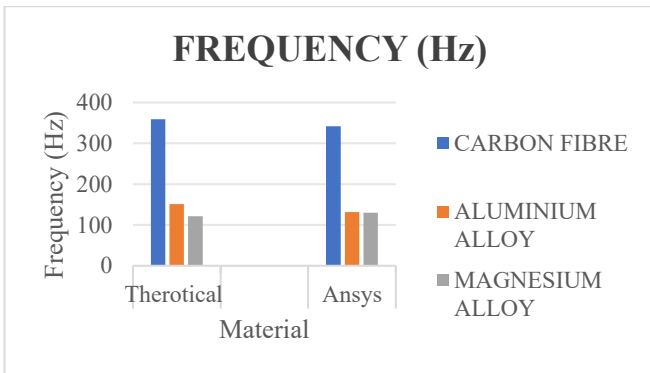


Comparison of frequencies

	Frequency (Hz)	
	Theoretical values	Ansys values
CARBON FIBRE	359.14	34209
ALUMINIUM ALLOY	151.19	131.47
MAGNESIUM ALLOY	121.33	129.97

Comparison of transient structure analysis

	TRANSIENT STRUCTURE		
	X-axis	Y-axis	Z-axis
ALUMINIUM ALLOY	0.56	0.01	0.05
MAGNESIUM ALLOY	0.64	0.01	0.05



Comparison of heat flux

	DIRECTIONAL HEAT FLUX		
	X-axis	Y-axis	Z-axis
ALUMINIUM ALLOY	2.02	0.785	0.81
MAGNESIUM ALLOY	1.9	0.76	0.74

CONCLUSION

This project focused on the design of a drone propeller using SolidWorks and its structural analysis using ANSYS by considering three materials: carbon fibre, aluminium alloy, and magnesium alloy. The objective was to evaluate their performance and identify suitable alternatives to carbon fibre. From both analytical calculations and simulation results, it was observed that all materials experience stresses well below their yield limits under the applied centrifugal and pressure loads, confirming that the propeller design is structurally safe. Carbon fibre showed the best performance with minimum stress and highest factor of safety due to its high strength-to-

weight ratio. However, aluminium alloy demonstrated good strength, durability, and ease of manufacturing, making it a practical and cost-effective choice. Magnesium alloy, being lighter than aluminium, also showed acceptable performance, though with slightly lower strength.

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