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Investigation of Structural and Thermal Analysis of Drone Propeller Materials

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INVESTIGATION OF STRUCTURAL AND THERMAL ANALYSIS OF DRONE PROPELLER MATERIALS

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Abstract. Drones, also known as unmanned aerial vehicles (UAVs), have become an Irreplaceable part of modern-day society. They are used for various operations such as delivery, surveillance, defense, and rescue. One of the most important parts of the drone that lifts, thrusts or balances the drone is its propeller. The weight of the drone is one of the important aspects that affects the efficiency of the drone, and the variation in speed may damage the drone propeller, or harsh environmental changes also affect the propeller. So, the material used must be able to withstand these effects such as carbon fiber, and nylon. The various material is analyzed using the ANSYS software to identify the structural and thermal properties of drone propellers at various speeds to identify the most satisfactory material for drone propellers. The result is verified by Ashby method of material selection. The experimental value is validated using the statistical analysis using python programming. As a result, carbon fiber is proven to be the most suitable material for high-speed drone propeller than the nylon.

Keywords: drone propellers, materials, analysis, Ashby's method

1. INTRODUCTION

Drones are now becoming an irreplaceable part of modern-day society for their convenience in various operations such as delivery, surveillance, defence, and rescue. There are various types of drones used for these applications. A few important aspects that affect the performance of a drone are their weight, payload capacity, strong wind current, and maintaining the balance of the drone. All these factors are mainly maintained by the propellers of a drone [1]. These propellers help the drone maintain its balance in strong wind current, and they also determine the speed and payload capacity of a drone. The drone propeller must be made to maintain the above-mentioned aspects as well as the surrounding environmental changes. So, the materials used to make a drone propeller must be a specific material to withstand the above-mentioned conditions. The most commonly used materials for drone propellers are carbon fiber, and nylon. By analysing the three materials under various speeds to identify the changes in their structural and thermal properties by using ANSYS version R17.2 software, to identify the most suitable material to make the drone propeller in the three materials to withstand the various aspects that affect the performance of the drone in various environments.

The result is verified using the Ashby's method [2] of material selection. The importance of material selection in UAV applications is emphasized by the authors of "Material selection for Unmanned Aerial Vehicles (UAVs) wings using Ashby Indices integrated with grey relation analysis approach based on weighted entropy for ranking" by Al-Taie and Doos, 2023[2]. They point out that Ashby's method can effectively rank materials based on multiple criteria, a concept that is similar to our analysis of drone propeller materials. A thorough analysis of various propeller designs is provided in the paper "Investigating Propellers for Drone Applications: Analysing Varied Designs and Characteristics" by Krishna et al., 2024[3], which reinforces our emphasis on material properties and how they affect performance, especially in high-speed situations.

Optimizing Propeller Performance for a Quadcopter Drone by Applying Aerodynamic Propeller-Ducts by Elmenshawy and Alshwaily, 2021[4] discusses how improving aerodynamic efficiency is essential for drone performance. Our study adds to this by focusing on material characteristics and showing how carbon, fiber enhances structural and thermal performance both of which are critical for high-speed applications. According to Gupta et al. 2019[5], fiberglass lacks the requisite strength and stiffness at high speeds in their work Evaluating the Structural and Thermal Properties of Fiberglass in Drone Propeller Applications. This supports our results that carbon fiber is still the best choice for overall performance, even though nylon can be useful at lower speeds.

In Development of a Low Noise Drone Propeller, Schulz, 2023[6] states Computational fluid dynamics (CFD) simulations are essential for optimizing drone propeller designs, with an emphasis on reducing noise while preserving structural integrity. This validates our examination of material characteristics under different circumstances. The importance of propeller design on thrust generation and performance is emphasized by Bahrom et al. 2023[7] in Thrust Force for Drone Propeller with Normal and Serrated Trailing Edge. Their results are consistent with what we found when examining the thermal and structural characteristics of several materials to improve drone efficiency. Drone Propeller Blade Material Optimization by Krmela et al. 2021[8] Utilizing Modern Computational Methods emphasizes the benefits of applying cutting-edge computational methods to choose the best materials, which supports our usage of ANSYS R17.2 software to analyse the thermal and structural properties of materials for drone propellers.

Carbon fiber is the better material when compared to the results of previous investigations, such the study on aluminium and composite propellers by Smith et al. 2020[9]. According to Smith's research, aluminium propellers are less suited for high-performance drones because they experience greater deformation and heat stress at high speeds. In a similar vein, Gupta et al. 2019[5] pointed out that fiberglass is lightweight but not strong or rigid enough to be durable at higher speeds. Utilizing Ashby's technique and validated by ANSYS R17.2 analysis, our investigation demonstrates that carbon fiber performs better than nylon as well as substitute materials like aluminium and fiberglass. It is the best option for drone propellers in all speed ranges due to its remarkable blend of rigidity, strength, and heat resistance. Therefore, in comparison to earlier research, this work presents the optimal material choices for drone propellers.

2. DRONE PROPELLER

A drone propeller is a rotating blade that generates an air force to lift a drone and thrust to enable the drone to fly and move across the sky. It converts the motor's mechanical energy into aerodynamic force to propel the drone in various directions. There are various sizes, shapes, and materials of propellers that affect the drone's performance and stability in flight. So, there are various types of propellers for various types of operations and applications [7]. Each propeller has its own usage, advantages, limitations, and applications. So, the propeller is selected by determining the type of drone used and the operation of the drone.

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1. Two-Blade Propellers
2. Three-Blade Propellers
3. Four-Blade Propellers
4. Pusher vs. Puller Propellers and
5. Foldable Propellers

Two-blade propellers are mostly used due to their simple design and good balance between efficiency and power consumption. Their low drag makes them suitable for long flights where endurance and energy conservation are essential for drones.

Three-blade propellers are used because of their increased thrust and stability, making them suitable for precise control in drone racing and aerial photography. While they consume more power, they offer smoother flight.

Four-blade propellers have high added lift and control and excel in high-performance drones, particularly in turbulent conditions, but they also need more power, reducing flight time.

Pusher propellers, at the rear of the drone, propel the air backward for forward thrust, enhancing aerodynamic efficiency, while puller propellers, at the front, pull air forward, moving the drone in the opposite direction with high stability and control.

Foldable propellers are portable, as they fold when not in use, making them easier to store and transport. But they still provide the necessary lift and thrust, making them perfect for travel-friendly drones, recreational use, and commercial UAVs where space and durability are important.

Two-Blade Propeller

Three-blade propeller

Figure 1. Types of drone propellers

3. DESIGN OF DRONE PROPELLER

The drone propeller is designed using CATIA V5 software. The two-blad propeller is designed as it is the most commonly used drone propeller. Dimensions of propeller are

- **Diameter**: 152 mm
- **Pitch**: 114 mm
- **Blade Width**: 15 mm
- **Blade Thickness**: 2.5 mm (near the hub, tapering)
- **Hub Diameter**: 10 mm
- **Blade Twist**: Varies along the length from 10° to 20°

After designing the two-blade drone propeller using the above given dimensions, finally the design is checked for potential issues such as weight distribution or structural weakness using Finite Element Analysis (FEA) in CATIA V5 software.

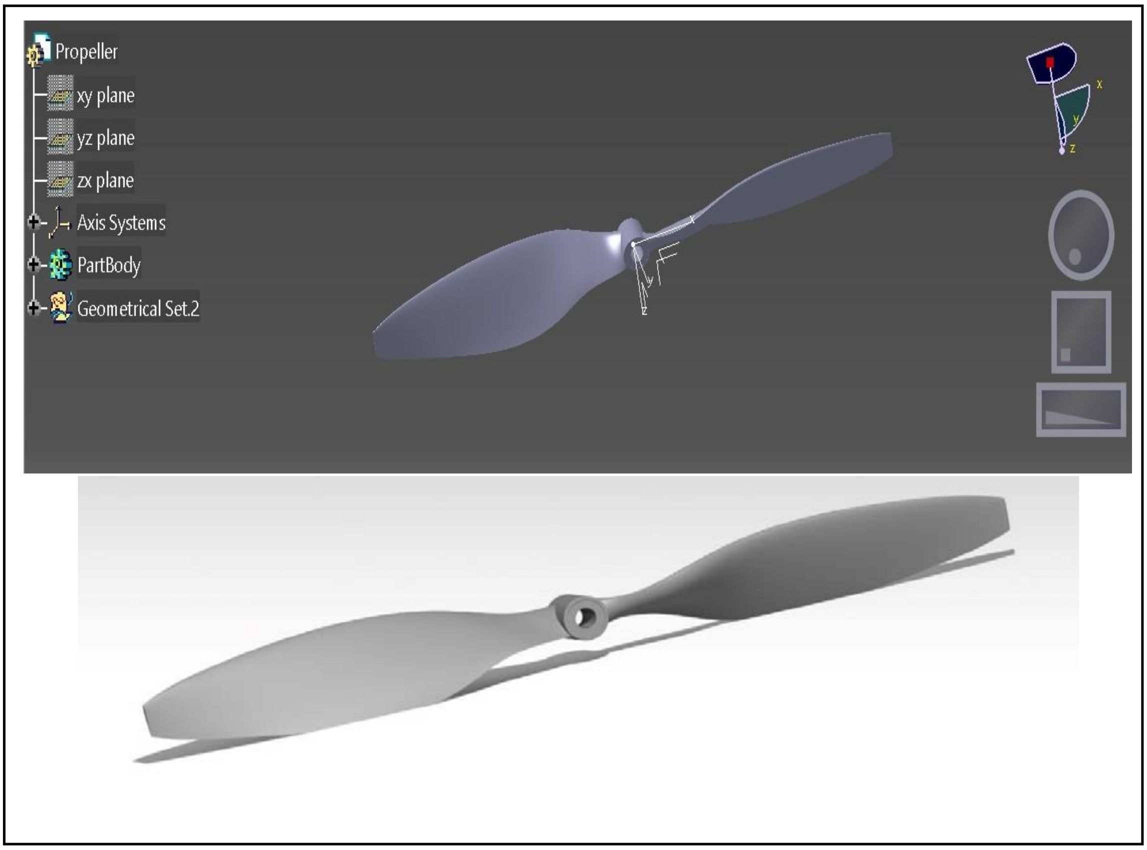

Figure 2. Design of Two-Blade Drone Propeller using CATIA V5

4. TYPES OF MATERIAL USED TO MAKE DRONE PROPELLER

There are various types of materials used to make drone propellers for various applications.

1. Carbon Fiber
2. Nylon

4.1. Carbon Fiber

Carbon fiber drone propellers are well-known for their exceptional strength and rigidity, providing superior aerodynamic performance and increase the efficiency of drone. A propeller's design may call for the usage of carbon fiber in a number of different forms, including chopped fiber, woven textiles, and unidirectional tape. To create a stiff structure, these fibers are usually mixed with thermosetting or thermoplastic resins. The propeller can tolerate high loads and harsh climatic conditions because to the filler qualities of carbon fiber, which also improve the strength and toughness of the matrix material.

Epoxy resin is used with carbon fiber as filler material because it is a perfect substance to use in place of carbon fiber as a filler for drone propellers. Epoxy offers superior adhesion, resilience to weather conditions, and durability. It combines with carbon fiber to generate a composite material that is robust, light, and stiff, improving performance, decreasing weight, and boosting efficiency in drone applications.

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Because of its stiffness, light weight, and great tensile strength, carbon fiber is perfect for drone propellers. It performs exceptionally well in terms of strength to weight due to its low density. Carbon fiber also provides vibration dampening, resistance to fatigue, and corrosion, all of which enhance flight stability and propeller longevity while lowering noise.

A propeller's design may call for the usage of carbon fiber in a number of different forms, including chopped fiber, woven textiles, and unidirectional tape. To create a stiff structure, these fibers are usually mixed with thermosetting or thermoplastic resins. The propeller can tolerate high loads and harsh climatic conditions because to the filler qualities of carbon fiber, which also improve the strength and toughness of the matrix material.

Figure 3. Carbon Fiber Propeller

4.2. Nylon

Nylon drone propellers are often reinforced with fiberglass offers a balanced combination of strength, flexibility and to improve the efficiency of the propeller according to the applications of the drone [18]. Because of its special qualities, nylon is a material that is frequently utilized for drone propellers. This synthetic polymer is well-known for being lightweight, flexible, and durable qualities that make it perfect for use in aviation applications. Propellers made of nylon have an excellent combination between stiffness and durability, which enables them to endure mild impacts without breaking readily.

A lightweight, strong thermoplastic that is frequently used in drone propellers is nylon. Because of its superior toughness, flexibility, and impact resistance, it can withstand harsh environments and absorb shocks. Long-lasting performance in a variety of environmental circumstances is ensured by nylon's resistance to wear, chemicals, and UV damage.

Figure 4. Nylon Propeller

However, nylon propellers may be heavier than carbon fiber, which can impact flight efficiency and affect the time of flight. They also may not provide the same level of aerodynamic performance as carbon fiber, potentially affecting the drone's overall speed and efficiency.

5. EFFECTS OF VARIATION OF SPEED IN DRONE PROPELLER

1. The variation of propeller speed can cause may cause instability to the drone during the flight.
2. When the speed fluctuates, it can lead to inconsistent lift and thrust, resulting in unstable flight and difficulty maintaining a steady altitude.
3. High speeds may cause excessive vibration and increased wear on the propellers, potentially leading to premature failure or damage.
4. Low speeds can reduce control responsiveness and make the drone less capable of handling sudden manoeuvres or gusts of wind.
5. These speed variations can also strain the drone's battery and power systems, leading to reduced flight time and overall efficiency.
6. Adjusting the propeller speed can thus fine-tune the drone's balance between power, stability, and energy efficiency, affecting its responsiveness and operational range [3].

6. METHODOLOGY

The drone propeller is simulated and the structural and thermal properties are analysed using ANSYS version R17.2 for carbon fiber, and nylon these materials for three different speeds such as 2000 rpm, 4000 rpm and 6000 rpm. To identify the best material for making drone propeller

6.1. Structural Properties

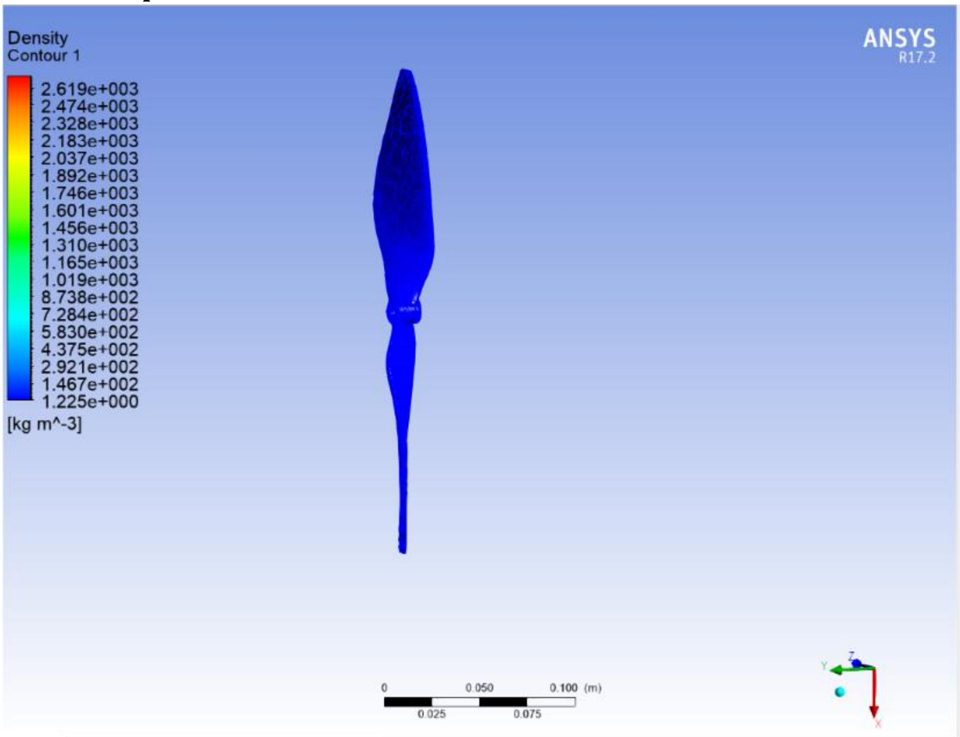

Figure 5. Analysis of density of nylon at 2000 rpm

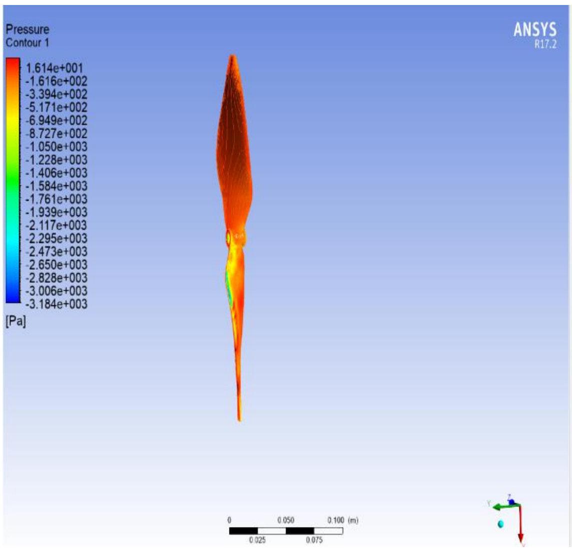

Figure 6. Analysis of pressure of nylon at 2000 rpm

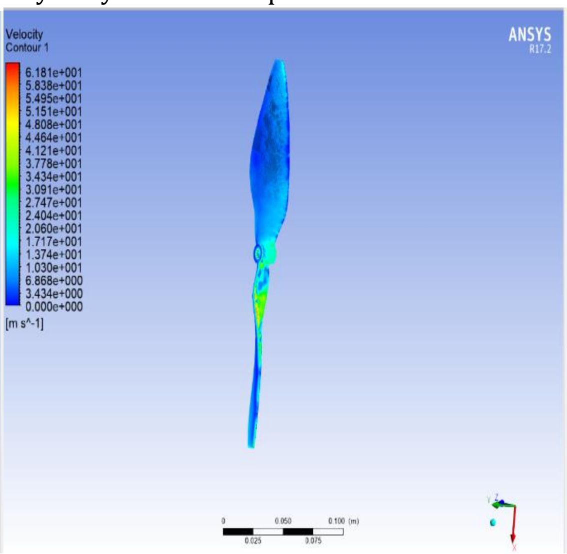

Figure 7. Analysis of velocity of nylon at 2000 rpm

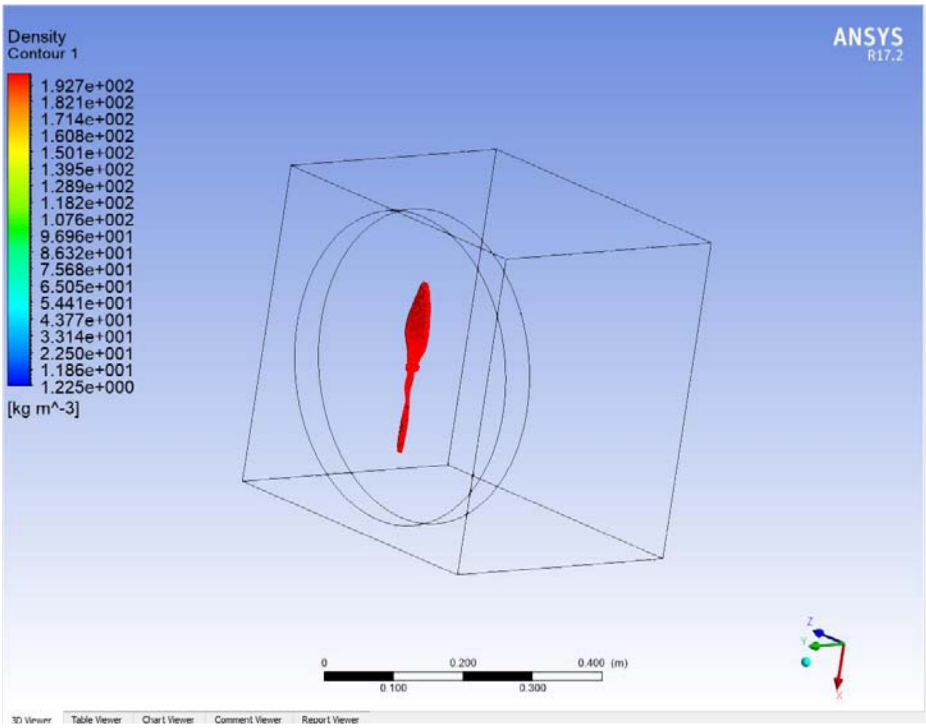

Figure 8. Analysis of density carbon fiber at 2000 rpm

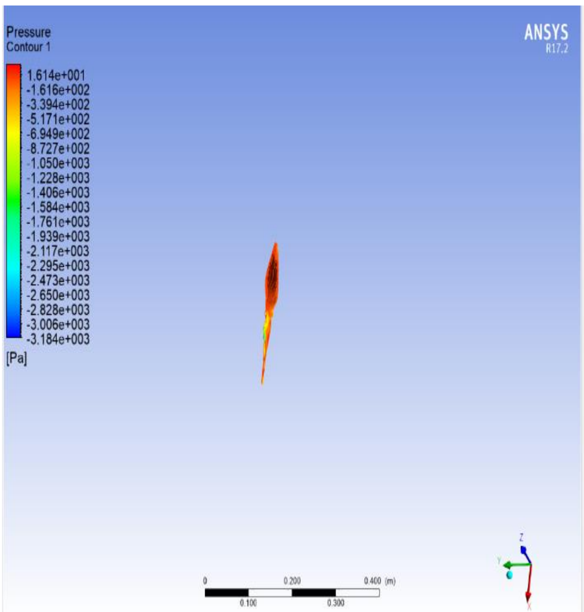

Figure 9. Analysis of pressure of carbon fiber at 2000 rpm

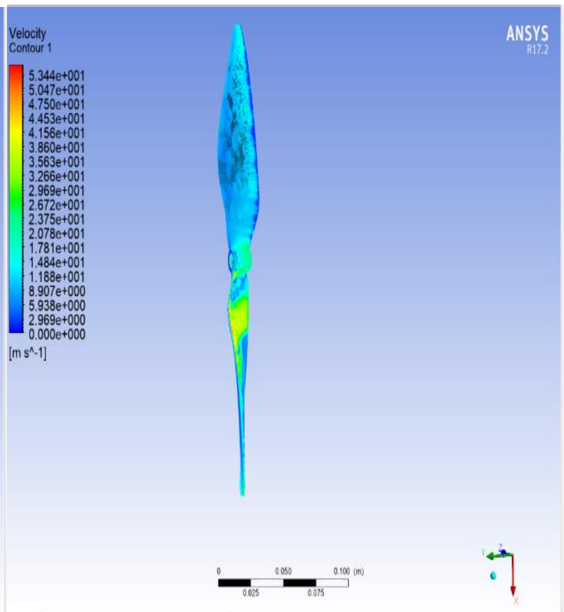

Figure 10. Analysis of velocity of carbon fiber at 2000 rpm

The above figure 5, 6, 7, 8, 9, & 10 shows the structural analysis of nylon, and carbon fiber at 2000 rpm such as density, pressure, and velocity at 2000 rpm. The variation of colour in the propeller picture shows the changes in these properties along the propeller. By this we can identify where these properties affects the propeller the most and reinforces the propeller materials at that particular area to increase the efficiency and life-span of the propeller.

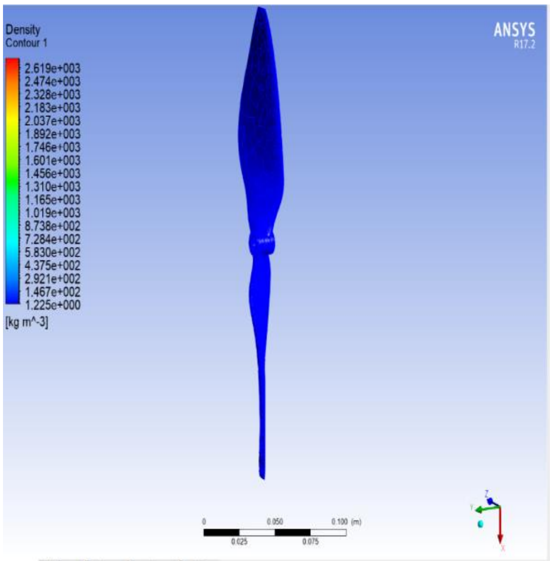

Figure 11. Analysis of density of nylon at 4000 rpm

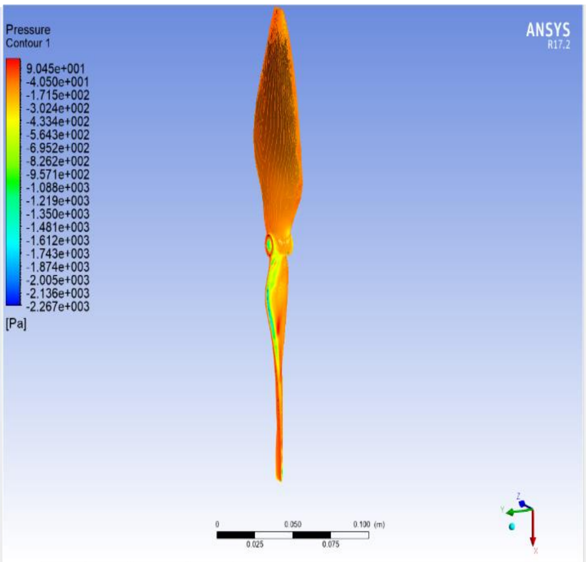

Figure 12. Analysis of pressure of nylon at 4000 rpm

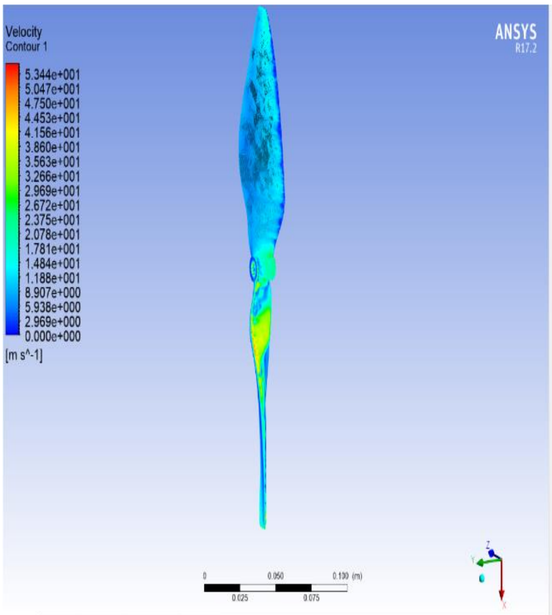

Figure 13. Analysis of velocity of nylon a 4000 rpm

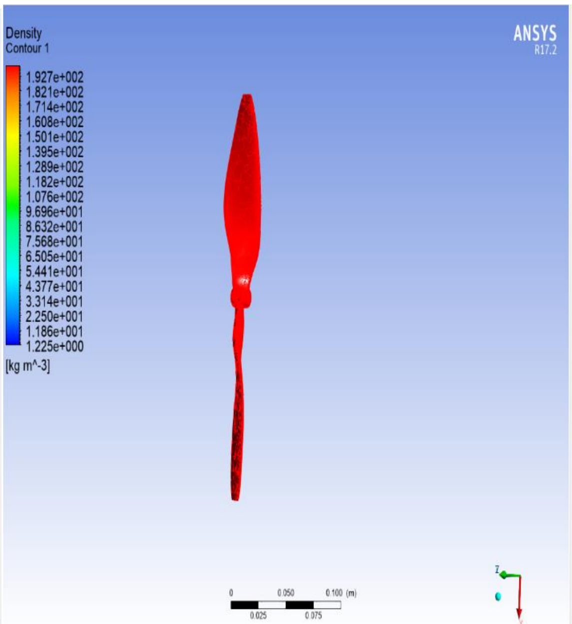

Figure 14. Analysis of density of carbon fiber at 4000 rpm

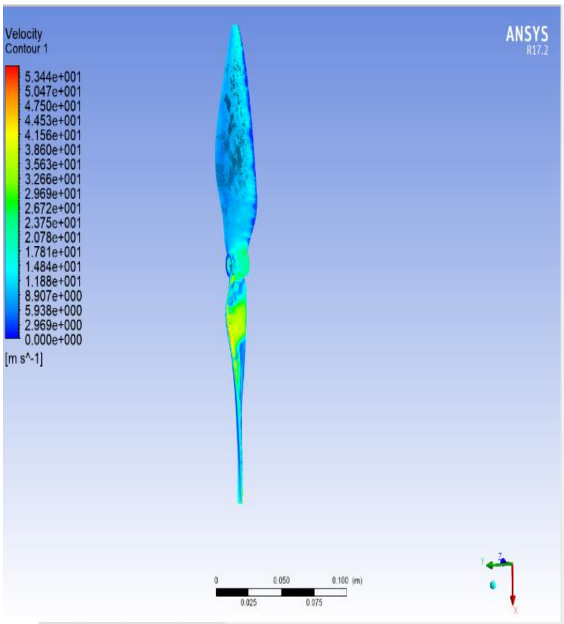

Figure 15. Analysis of velocity of carbon fiber at 4000 rpm

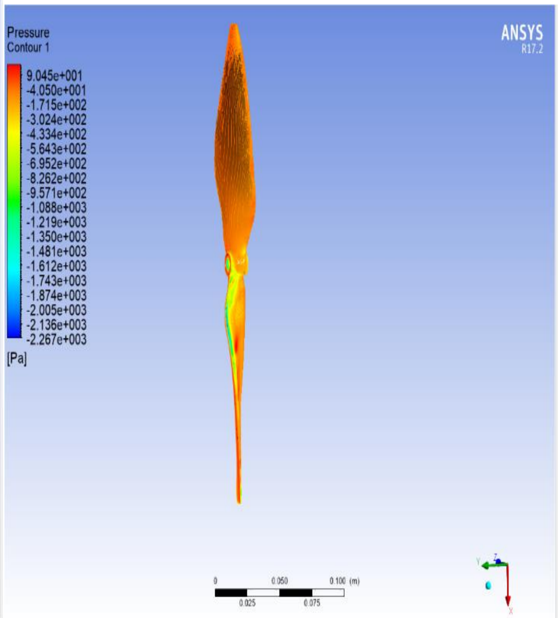

Figure 16. Analysis of pressure of carbon fiber at 4000 rpm

The above figure 11, 12, 13, 14, 15, & 16 shows the structural analysis of nylon, and carbon fiber at 4000 rpm such as density, pressure, and velocity.

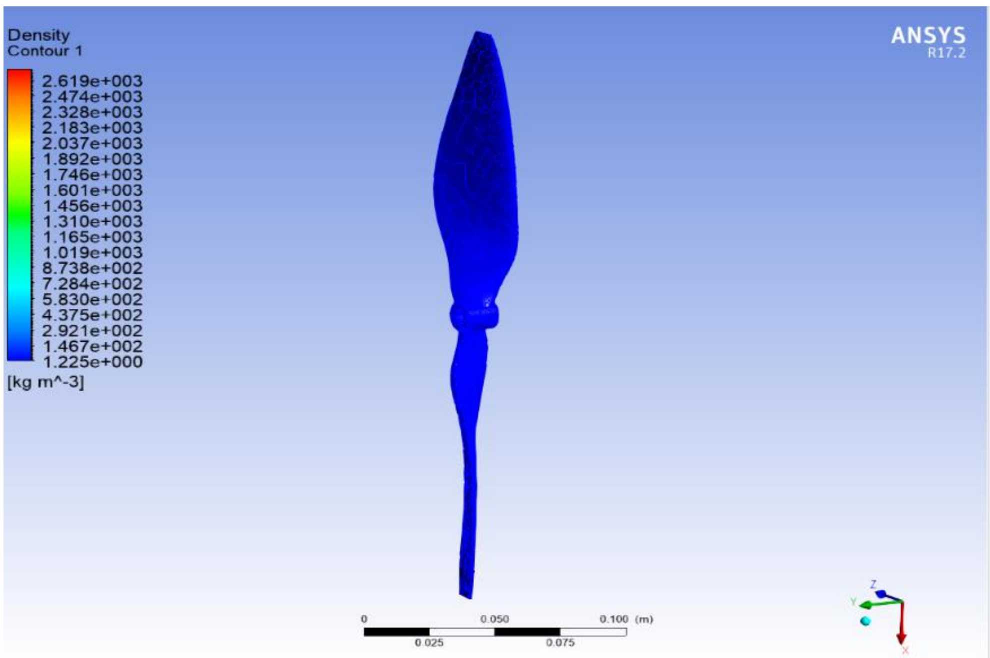

Figure 17. Analysis of density of nylon at 6000 rp

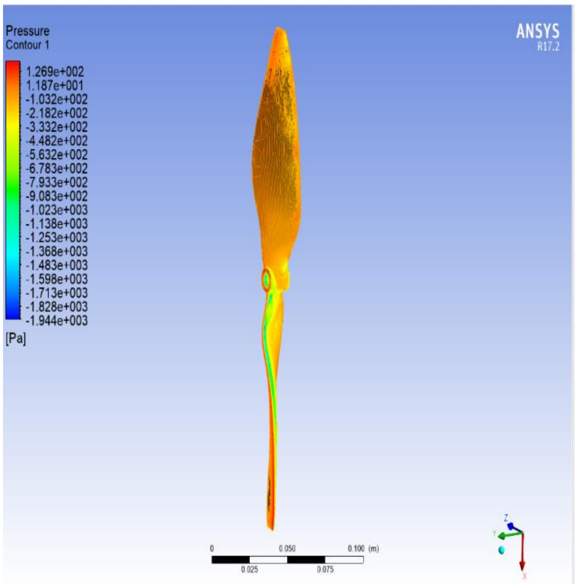

Figure 18. Analysis of pressure of nylon at 6000 rpm

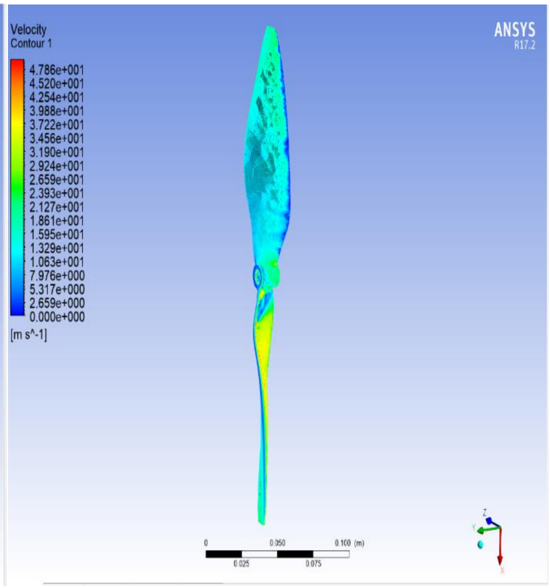

Figure 19. Analysis of velocity of nylon at 6000 rpm

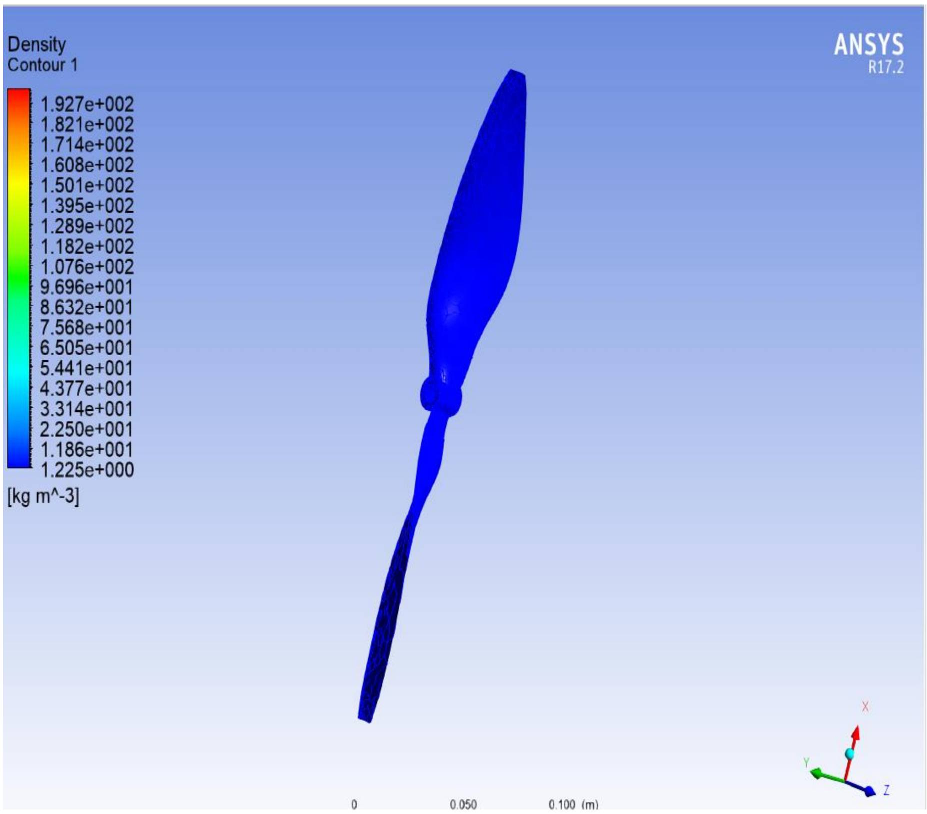

Figure 20. Analysis of density of carbon fiber at 6000 rpm

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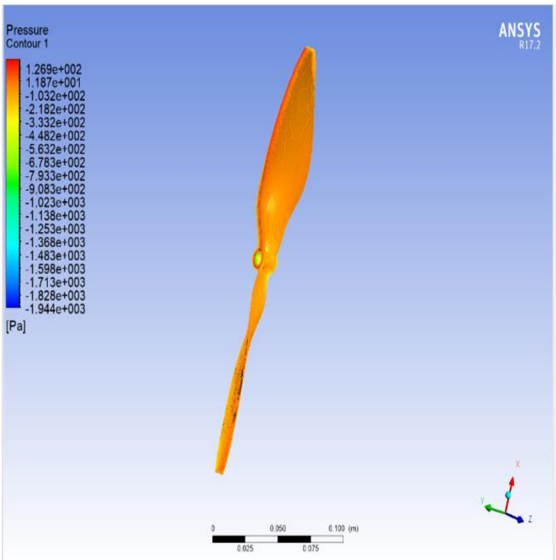

Figure 21. Analysis of pressure of carbon fiber at 6000 rpm

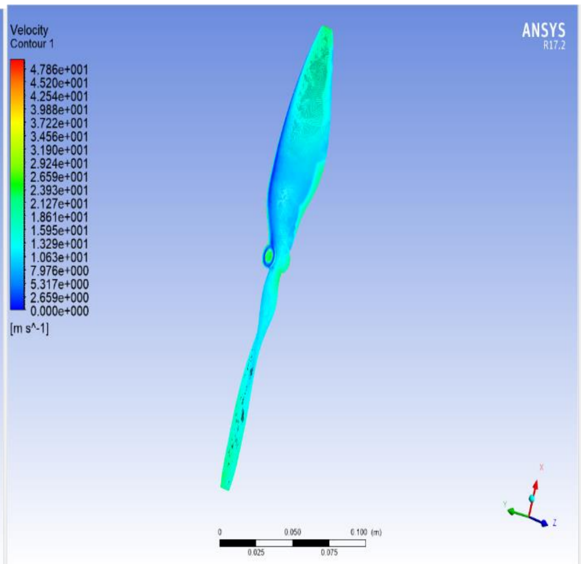

Figure 22. Analysis of velocity of carbon fiber at 6000 rpm

The above figure 17, 18, 19, 20, 21, & 22 shows the structural analysis of nylon, and carbon fiber at 6000 rpm such as density, pressure, and velocity. The variations of these properties at a high speed of 6000 rpm can be identified using change of colour along propeller to identify the place where the effects are greater or smaller to reinforce those areas.

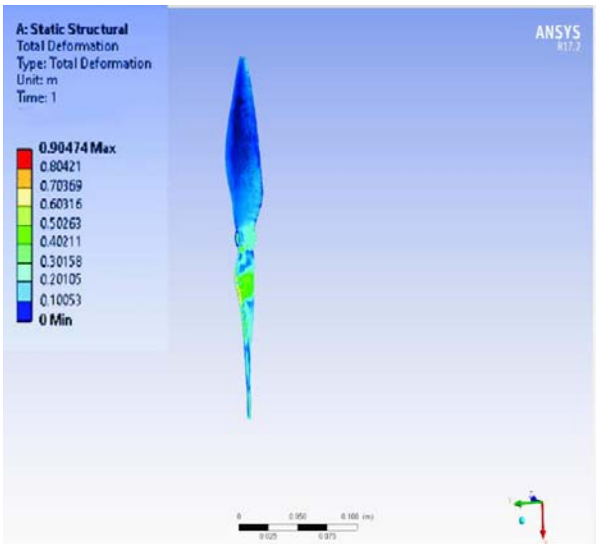

Figure 23. Analysis of deformation of nylon at 2000 rpm

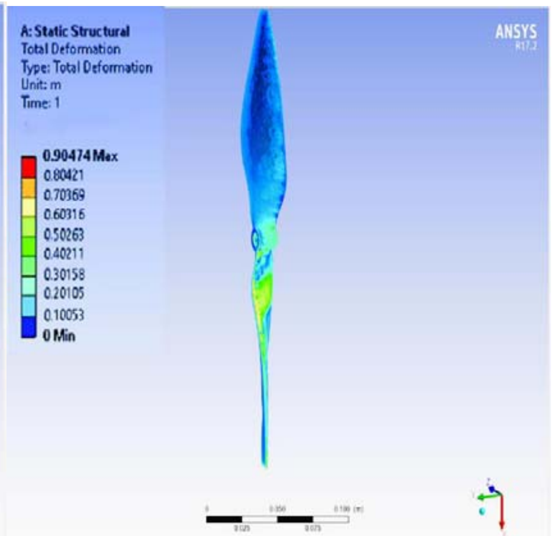

Figure 24. Analysis of deformation of nylon at 4000 rpm

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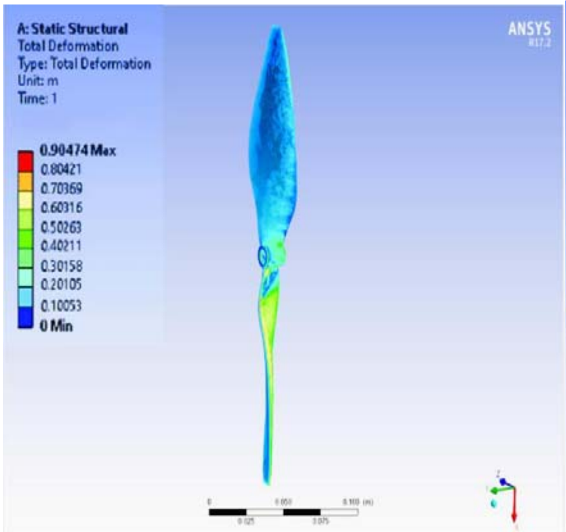

Figure 25. Analysis of deformation of nylon at 6000 rpm

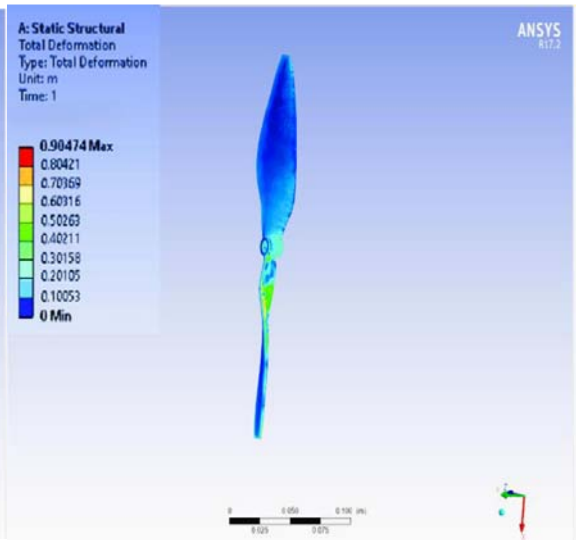

Figure 26. Analysis of deformation of carbon fiber at 2000 rpm

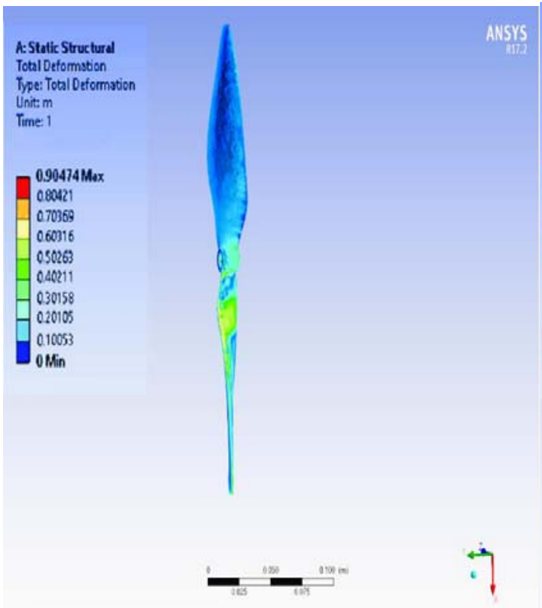

Figure 27. Analysis of deformation of carbon fiber at 4000 rpm

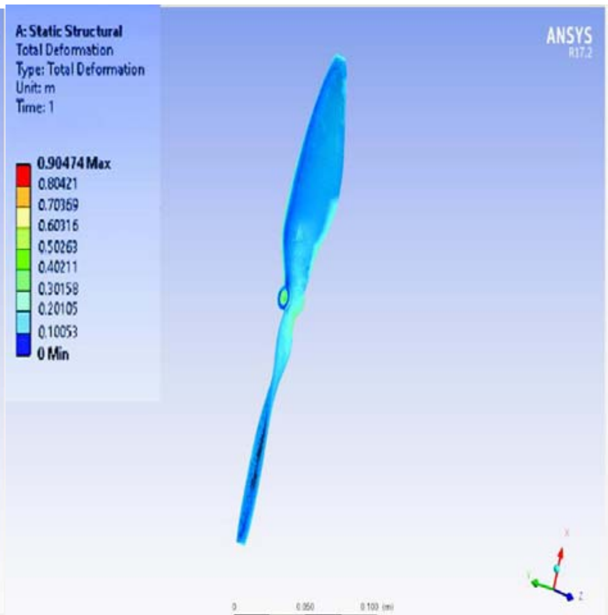

Figure 28. Analysis of deformation of carbon fiber at 6000 rpm

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The figure 23, 24, 25, 26, 27, & 28 are the total deformation of the nylon and carbon fiber at 2000, 4000 and 6000 rpm respectively.

Table 1. The velocity, density, pressure, and total deformation of carbon fiber and nylon are analysed, and the values are distinguished between them at 2000, 4000, & 6000 rpm.

Materials	Speed(RPM)	Velocity(ms-1)	Density(kgm-3)	Pressure(pa)	Deformation(m)
Carbon Fiber	2000	30.9	187.1	16.4	0.245
	4000	32.6	121.7	40.4	0.590
	6000	29.6	146.5	90.5	1.006
Nylon	2000	34.3	146.7	16.1	0.801
	4000	41.2	112.2	106.9	1.449
	6000	27.2	155.9	123.2	1.807

6.2. Thermal Properties

The change in stress due to the temperature produced by the speed of the drone propeller is listed in thermal properties to identify the best material for a high-speed drone. Both nylon and carbon fiber have some effects due to the heat produced by the rotation of the propeller. This heat may affect the properties of the propeller, and one of the important properties affected is thermal stress.

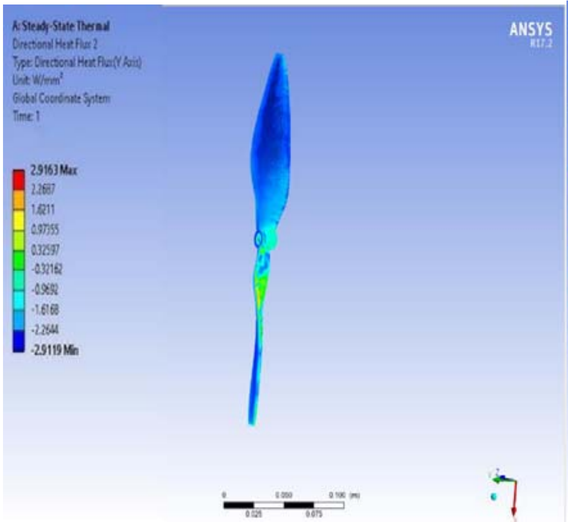


Figure 29. Analysis of heat flux of nylon at 2000 rpm

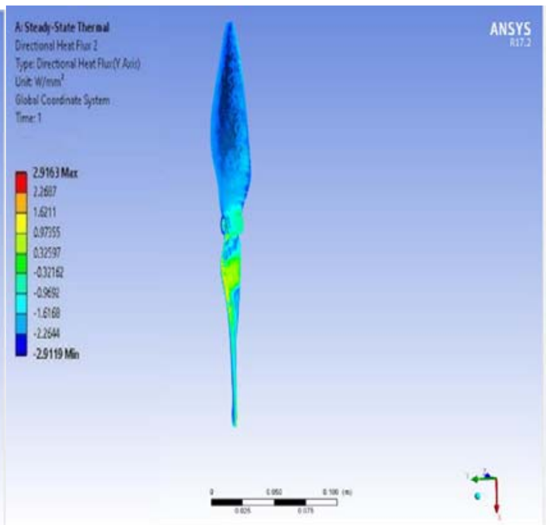


Figure 30. Analysis of heat flux of nylon at 4000 rpm

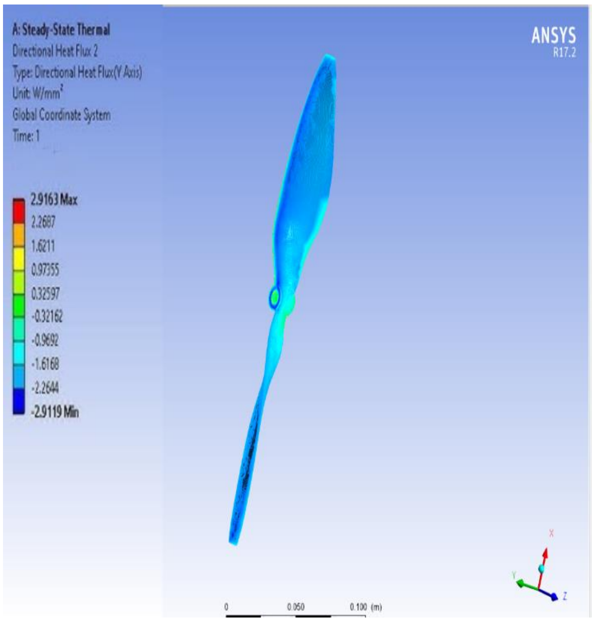


Figure 31. Analysis of heat flux of nylon at 6000 rpm

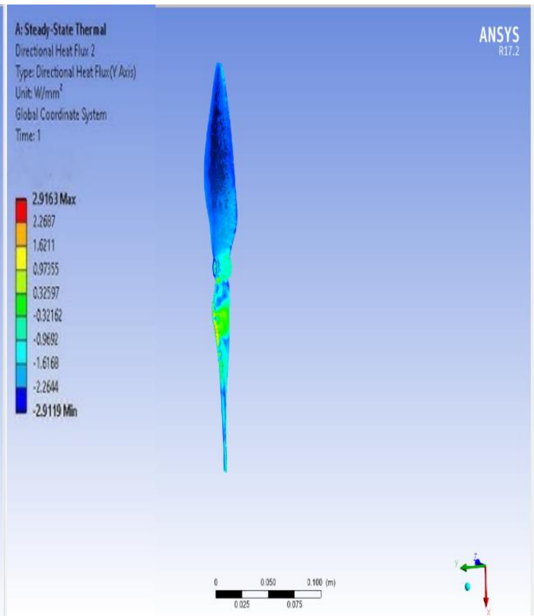


Figure 32. Analysis of heat flux of carbon fiber at 2000 rpm

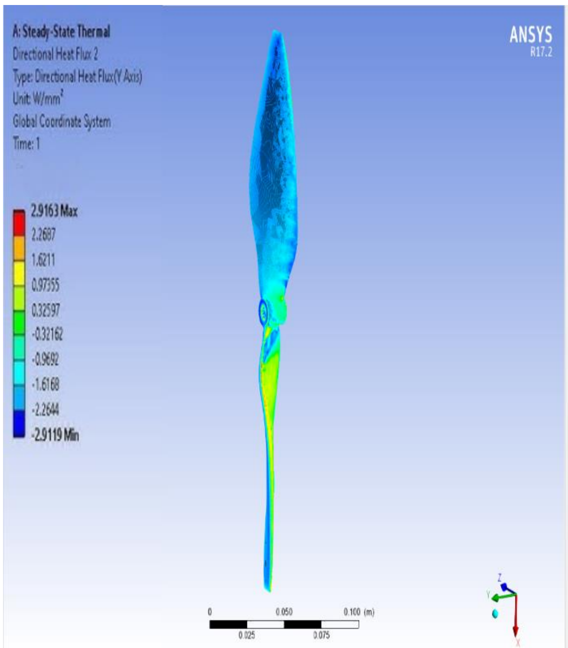


Figure 33. Analysis of heat flux of carbon fiber at 4000 rpm

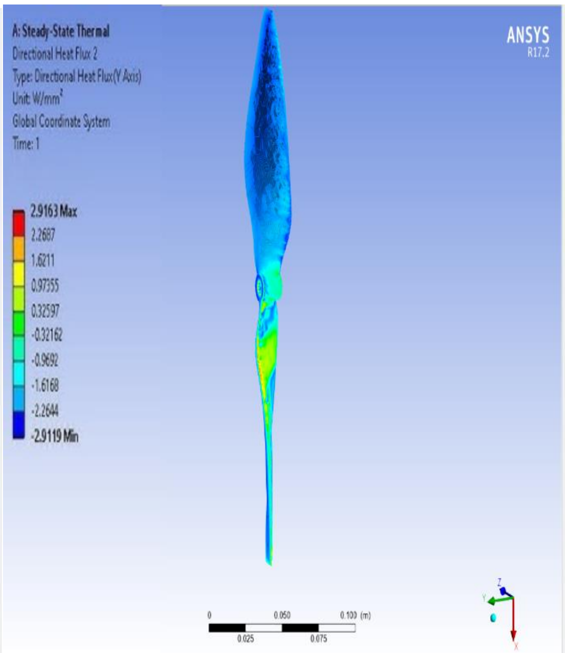


Figure 34. Analysis of heat flux of carbon fiber at 6000 rpm

 doi:10.1088/1742-6596/2925/1/012002

The figure 29,30,31,32,33, and 34 are the heat flux of nylon and carbon fiber at 2000, 4000, and 6000 RPM respectively.

Table 2. The thermal stress and heat flux of carbon fiber and nylon at 2000 rpm, 4000 rpm, & 6000 rpm

Property	Materials	2000 RPM	4000 RPM	6000 RPM
Thermal Stress(Pa)	Carbon Fiber	0.0493	0.0527	0.0566
	Nylon	0.0513	0.0587	0.0596
Heat flux(W/mm2)	Carbon Fiber	0.969	0.323	0.973
	Nylon	0.321	1.621	1.618

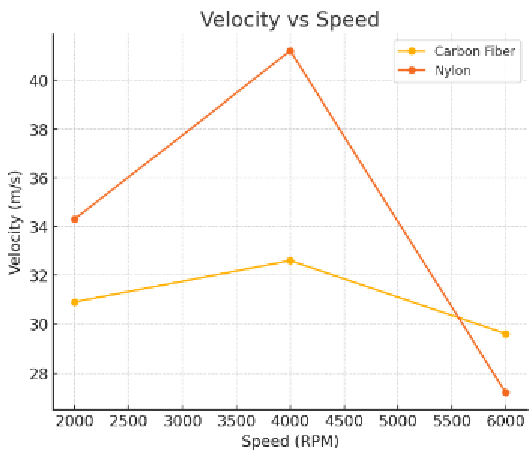
7. RESULT AND DISCUSSION

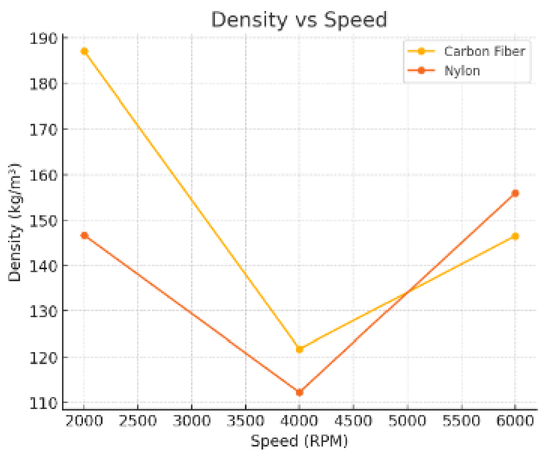
Data Analysis by ANSYS R17.2 software

Table 3. The result of the analysis using ANSYS R17.2 software

Properties	At 2000 RPM	At 6000 RPM
Structural	Nylon	Carbon fiber
Thermal	Carbon fiber	Carbon fiber

STRUCTURAL ANALYSIS:





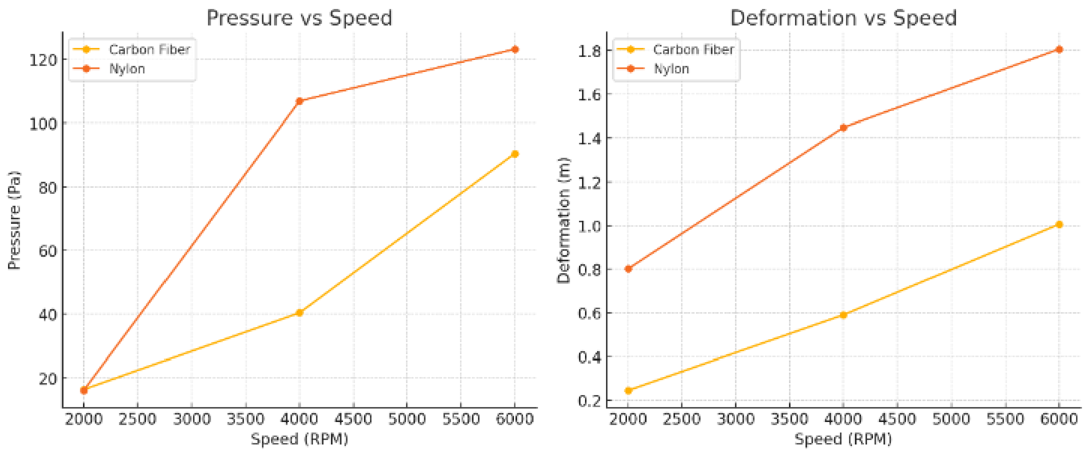


Figure 35. Structural graphical representation

- Nylon shows a higher velocity at 4000 RPM (41.2 m/s), whereas Carbon Fiber remains relatively steady across the RPM range.
- Carbon Fiber has a higher density at lower RPM, but Nylon surpasses it at 6000 RPM.
- Nylon exhibits a sharp increase in pressure, reaching 123.2 Pa at 6000 RPM, while Carbon Fiber increases more gradually.
- Nylon deforms significantly more than Carbon Fiber, especially at higher RPM.

THERMAL ANALYSIS:

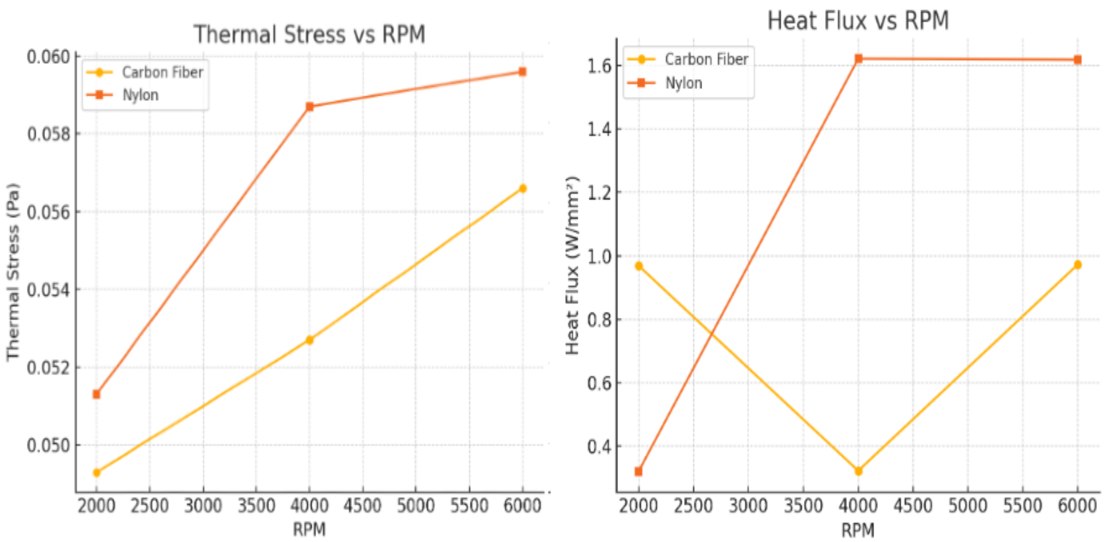


Figure 36. Thermal graphical representation

- The thermal stress for both carbon fiber and nylon increase with RPM.
- Nylon exhibits higher thermal stress compared to carbon fiber at all RPMs.
- For carbon fiber, heat flux decreases significantly at 4000 RPM but increases again at 6000 RPM.
- Nylon, on the other hand, shows a sharp increase in heat flux from 2000 to 4000 RPM and remains almost constant at 6000 RPM.

Carbon fiber's structural qualities are less impacted by speed and it has a very high thermal resistance, making it a better option for high-speed drones like racing and surveillance drones, according to data analysed using the ANSYS R17.2 software and graph. Furthermore, carbon fiber deforms less than nylon, meaning that for low- to medium-weight drones, it will function more efficiently than a nylon propeller. Drones operating at a slow or medium pace can also use it. Furthermore, because its structural qualities are less compromised at low and medium speeds and because it has less thermal resistance than carbon fiber, nylon is a better material choice for low- to medium-speed drones, such as commercial drones. Thus, increased speed will result in increased heat generation, which could harm the drone propeller. Thus, carbon fiber works better than nylon for creating drone propellers.

7.1. ASHBY METHOD:

The Ashby Method is a systematic material selection process based on the relationship between material properties and the design's objectives. For an amphibious drone, you'd use the Ashby Method to evaluate the materials that will balance the various performance demands such as weight, strength, corrosion resistance, and cost. By using this method to conform the data's analysed using the ANSYS R17.2 software for material selection of drone propeller.

Tensile Strength of Carbon fiber (σ) = 5.96 × 106 Pa
Tensile Strength of Nylon (ρ) = 85 × 106 Pa
Young's Modulus of Carbon fiber (E) = 350 × 109 Pa
Young's Modulus of Nylon (E) = 3 × 109 Pa

Minimizing weight while maintaining strength:

$$(1)\ Material\ Index = \frac{\sigma}{\rho}$$

Carbon fiber at 2000 RPM

$$Material\ Index = \frac{5.96 \times 10^{6}}{187.1}$$

= 31.8 × 103

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Stiffness with minimum weight:

$$(2) Material\ Index = \frac{E}{\rho}$$

Carbon fiber at 2000 RPM

$$Material\ Index = \frac{350 \times 10^9}{187.1}$$

= 18.7 × 108

Thermal Conductivity with minimum Density:

$$(3) Thermal\ Conductivity\ (k) = \frac{Thermal\ Stress}{E\ \times\ \alpha}$$

Coefficient of Thermal Expansion of carbon fiber (α) = 1.5 × 10-6 k-1
Coefficient of Thermal Expansion of nylon (α) = 100 × 10-6 k-1

$$k = \frac{0.0493}{350 \times 10^9 \times 1.5 \times 10^{-8}}$$

= 93.3 × 10-6

K for carbon fiber at 2000 RPM = 93.3 × 10-5 kelvin
K for carbon fiber at 4000 RPM = 10.03 × 10-5 kelvin
K for carbon fiber at 6000 RPM = 10.7 × 10-5 kelvin
K for Nylon at 2000 RPM = 17.1 × 10-6 kelvin
K for Nylon at 4000 RPM = 19.5 × 10-6 kelvin
K for Nylon at 6000 RPM = 19.8 × 10-6 kelvin

$$(4) Material\ Index = \frac{k}{\rho}$$

Carbon fiber at 2000 RPM

$$Material\ Index = \frac{93.3\ \times\ 10^{-6}}{187.1}$$

= 50.1 × 10-1

Table 4. Verified data of drone propeller properties from analysis using ANSYS R17.2 software using the Ashby's method of material selection

Speed	Carbon Fiber			Nylon		
	Strength	Stiffness	Thermal Conductivity	Strength	Stiffness	Thermal Conductivity
2000 RPM	31.8×10^3	18.7×10^8	50.1×10^{-11}	87.9×10^4	20.4×10^6	11.6×10^{-10}
4000 RPM	48.9×10^3	28.7×10^8	82.4×10^{-11}	75.7×10^4	26.7×10^6	17.3×10^{-10}
6000 RMP	40.6×10^3	23.8×10^8	72.9×10^{-11}	54.5×10^4	19.2×10^6	12.7×10^{-10}

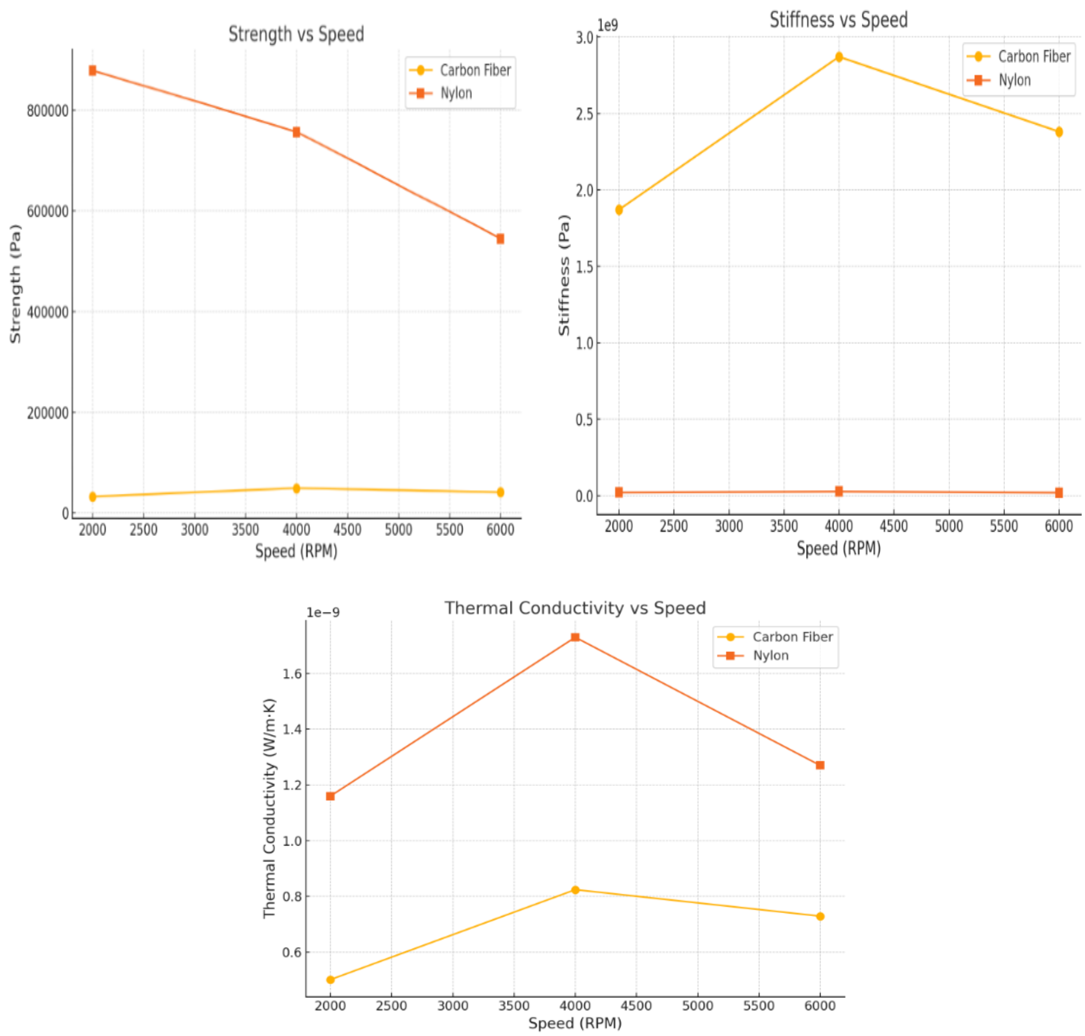

Figure 37. Ashby's method graphical representation

- Nylon demonstrates much higher strength, which decreases as speed increases, while Carbon Fiber shows relatively stable, low strength across the RPM range
- Carbon Fiber has significantly higher stiffness, peaking at 4000 RPM, while Nylon's stiffness is very low and shows little variation.
- Nylon has higher thermal conductivity at all speeds, with a peak at 4000 RPM, whereas Carbon Fiber maintains lower but consistent thermal conductivity.

The data that are obtained by ANSYS R17.2 software are used in Ashby's method [1] of material selection and verified the data to identify the most suitable material for a drone propeller. As the carbon fiber's result value (material index) is higher than the nylon's result value in maintaining strength while minimizing weight, it indicates that stronger the material is relative to its weight, making it more suitable for lightweight, high-strength applications such as flight. Carbon fiber has a higher stiffness with a minimum weight than nylon, which means the material is both stiff and lightweight, which is highly desirable for drone applications where both factors impact efficiency and performance. And the thermal conductivity of nylon is higher than that of carbon fiber, which could potentially cause uneven thermal expansion, which may affect the propeller's balance or shape if subjected to extreme temperature changes, but this is rare in most operational conditions for drones. So the analysed data using the ANSYS software is verified using Ashby's method, and it is proven that carbon fiber is a more suitable material for drone propeller making.

7.2. VALIDATION OF DESIGN OF EXPERIMENT USING PYTHON

RESEARCH OBJECTIVE:

Goal: Using simulation software (ANSYS R17.2), the main goal of this study is to identify the best material for drone propellers by assessing thermal and structural parameters (density, pressure, velocity, and deformation) as well as thermal stress and heat flow.

Materials Studied: Three distinct speeds (2000, 4000, and 6000 RPM) were used to evaluate carbon fiber and nylon, two materials commonly used in the production of drone propellers.

EXPERIMENTAL DESIGN:

Software Tools Used: ANSYS R17.2 is the software used in the research to simulate the thermal and structural properties of the materials. To confirm the findings and choose the best material for the drone propellers, the Ashby material selection approach is applied.

Control variables: Propeller design, RPM (speeds), and environmental parameters are the same for both materials under the simulation.

KEY PARAMETERS MEASURED

Structural Properties:

At 2000, 4000, and 6000 RPM, velocity, density, pressure, and deformation are measured.

Thermal Properties:

Heat flux and thermal stress.

VALIDITY OF METHODOLOGY:

Simulation Accuracy: It is generally known that using ANSYS software to simulate material properties is a legitimate method for assessing structural and thermal properties, yielding dependable computational outcomes. With three alternative speed options (2000, 4000, and 6000 RPM), the experiment is extensive enough to cover low, medium, and high-speed conditions for various drone applications.

Material Selection using Ashby Method: This technique compares the stiffness, thermal conductivity, and tensile strength of the materials to further validate the findings. The experiment's conclusions are more reliable now that there has been an additional verification.

EXPERIMENTAL SCOPE:

Justification for Material Choice: Since carbon fiber and nylon are widely used in drone manufacturing, these materials are used for the drone propeller. An in-depth knowledge of how each material functions under various operational loads can be gained by comparing these two materials at different speeds

Simulated Speeds: The RPM range of 2000, 4000, and 6000 RPM was selected to ensure that the results are usable in real-world circumstances. This range reflects common drone operation speeds.

DATA INTERPRETATION:

The graphical data, shows the two material's respective characteristics at various RPM levels, include velocity, density, pressure, deformation, thermal stress, and heat flux vs. Speed (RPM). Carbon fiber performs better than nylon in terms of strength-to-weight ratio, rigidity, and thermal characteristics at high speeds, which is important for high-performance drones, according to the results of the Ashby approach (material index for strength, stiffness, and thermal conductivity).

Table 5. Summary of the data of key properties of the drone propeller at different speeds.

Materials	Speed (RPM)	Velocity (ms^{-1})	Density (kgm^{-3})	Pressure (pa)	Deformation (m)	Thermal Stress (Pa)	Heat Flux (W/mm^2)
Carbon Fiber	2000	30.9	187.1	16.4	0.245	0.0493	0.969
	4000	32.6	121.7	40.4	0.590	0.0527	0.323
	6000	29.6	146.5	90.5	1.006	0.0566	0.973
Nylon	2000	34.3	146.7	16.1	0.801	0.0513	0.321
	4000	41.2	112.2	106.9	1.449	0.0587	1.621
	6000	27.2	155.9	123.2	1.807	0.0596	1.618

CONCLUSION VALIDITY:

Results: The data and analysis provide strong support for the conclusion that nylon may be a better material for low- to medium-speed drones, whereas carbon fiber is better suited for high-speed drone applications.

Verification: The experimental results are given more credibility by the use of both the Ashby approach and ANSYS simulation for verification.

STATISTICAL ANALYSIS:

To determine whether the variations between carbon fiber and nylon are statistically significant, we can compare the two materials by running a t-test for each attribute. By using the values of various properties at different speeds.

MEAN AND STANDARD DEVIATION OF KEY PROPERTIES AND t-TEST:

The mean and standard deviation for each attribute (heat flux, density, pressure, deformation, thermal stress, and velocity) are determined for both nylon and carbon fiber at various RPMs. A t-test is used to determine whether the differences in each property between the two materials are statistically significant.

STATISTICAL SIGNIFICANCE LEVEL:

For the purposes of this research, we will use a p-value threshold of 0.05 to assess statistical significance.

STATISTICAL ANALYSIS OF DEFORMATION DATA:

Mean and Standard Deviation:

1. **Carbon Fiber:**
    - Mean Deformation: 0.614 m
    - Standard Deviation: 0.381 m
2. **Nylon:**
    - Mean Deformation: 1.352 m
    - Standard Deviation: 0.510 m

t-Test Results:

- **t-statistic:** -2.01
- **p-value**: 0.115

INTERPRETATION:

The p-value of 0.115, which is more than 0.05, indicates that the deformation difference between carbon fiber and nylon is not statistically significant at the 5% significance level. This indicates that, over a range of RPMs, there is very little difference between the two materials, despite the fact that nylon has a larger mean deformation than carbon fiber.

PROGRAM:

```
import numpy as np

from scipy import stats


# Deformation values for Carbon Fiber and Nylon at different RPMs

deformation_carbon_fiber = [0.245, 0.590, 1.006]   # Deformation at 2000, 4000, 6000 RPM for Carbon Fiber

deformation_nylon = [0.801, 1.449, 1.807]        # Deformation at 2000, 4000, 6000 RPM for Nylon


# Calculate mean and standard deviation for both materials

mean_carbon_fiber = np.mean(deformation_carbon_fiber)

std_carbon_fiber = np.std(deformation_carbon_fiber, ddof=1)


mean_nylon = np.mean(deformation_nylon)

std_nylon = np.std(deformation_nylon, ddof=1)


# Perform an independent t-test between carbon fiber and nylon deformations

t_stat, p_value = stats.ttest_ind(deformation_carbon_fiber, deformation_nylon)


mean_carbon_fiber, std_carbon_fiber, mean_nylon, std_nylon, t_stat, p_value
```

RESULT:

```
(0.6136666666666667,

0.3810516150514695,

1.3523333333333334,

0.509918947807721,

-2.0098560013712796,

0.11481780651188468)
```

In summary, the design of the experiment is sound, flawlessly executed, and supported by techniques for both material selection and simulation. The findings bolster the notion that carbon fiber is the better material for fast-moving drones.

8. CONCLUSION

The analysis of the drone propeller was conducted, and the structural and thermal properties were focused through simulation and analysis using ANSYS R17.2 software. The two most commonly used drone propeller materials, nylon and carbon fiber, were studied, with structural properties such as velocity, density, pressure, and deformation as well as thermal properties like thermal stress and heat flux evaluated under varying speeds. When nylon and carbon fiber are compared in structural properties, it can be shown that nylon deforms (1.807 m at 6000 RPM), experiences higher pressure (123.2 Pa at 6000 RPM), and has a higher velocity (41.2 m/s at 4000 RPM). At 4000 RPM, carbon fiber has a density of 121.7 kg/m^3, which makes it a more stable material in the same circumstances. According to the thermal investigation, carbon fiber demonstrates good thermal performance at 6000 RPM, with thermal stress values of 0.0566 Pa and a heat flow of 0.973 W/mm^2. Conversely, nylon exhibits a somewhat elevated thermal stress (0.0596 Pa) together with a reduced heat flux (1.618 W/mm^2), suggesting disparities in its capacity to regulate thermal expansion.

Based on the data from Ashby's method, carbon fiber performs stronger and stiffer than nylon at every evaluated RPM. At 6000 RPM, the strength and stiffness of carbon fiber are 40.6×10^3 and 23.8×10^4, respectively, while the values for nylon are much lower, at 54.5×10^4 and 19.2×10^4, respectively. Based on the result of the analysis, nylon was found to be optimal for low- or medium-speed drones as it exhibits significant structural changes at high speeds and lower thermal resistance. Carbon fiber is proven to be suitable for all speed ranges, particularly high-speed drones, due to its stability in structural properties and superior thermal resistance. The result is further verified using Ashby's method for material selection, confirming both nylon and carbon fiber's specific structural and thermal properties at varying speeds and proving that carbon fiber is the most appropriate material for drone propellers. Carbon fiber outperforms materials like aluminium, nylon, and fiberglass for drone propellers, offering superior rigidity, strength, and heat resistance. Compared to previous studies, it shows less deformation and stress under high-speed conditions, making it the ideal material for propellers across all speed ranges.

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