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CFD Analysis of Quad-Copter Propeller by Changing the Geometry, Number of Blades, and Materials

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Abstract

It is undeniable fact that the importance of drones has increased in every aspect of the daily life such as Defense, Military, Agriculture, Film shooting, Disaster management and many more Good Design of a propeller plays a crucial part in efficiency, vibration and stability of drone in mid-air. With advancements in design, manufacturing technologies and techniques, it is lot easier to manufacture complex design. One such complex design in drone propeller is its blade. The main objective of this paper is to analyses thrust forces, pressure distribution, viscous coefficient and pressure coefficient by considering various aero foil shapes for the blades in addition to changing the number of blades. Also, material used for the blade is changed. CATIA V5 Modelling Software is used for creating geometric models of drone propeller. Ansys fluent is used for CFD analysis of drone propeller in Ansys 19.2 software version. Aluminum and Carbon Fiber material is used. Finally, after performing CFD analysis Aluminum material has obtained more thrust force than carbon fiber material. Irrespective of material used, the maximum pressure obtained is less than their material strength.

1. Introduction

Drone propellers, also known as rotors or blades, are the essential wings that allow drones to defy gravity and take flight. These spinning marvels of engineering generate lift and thrust, enabling drones to hover, soar, zip, and manoeuvre with impressive agility [1]. As the blades rotate, they push air downwards, creating an upward force called lift. This lift counteracts the drone's weight, allowing it to stay airborne. Additionally, by tilting the blades slightly (changing their pitch), the drone can control its direction and movement [2]. Tilting one blade forward while tilting the opposite one backward makes the drone move forward. Similarly, tilting all blades in the same direction makes it ascend, and Tilting them in the opposite direction makes it descend [3]. Drone propellers come in various sizes, shapes, and materials, each affecting performance. Larger propellers generate more lift but are less efficient at high speeds. Conversely, smaller propellers are more efficient at high speeds but produce less lift [4]. The material also plays a role. Plastic propellers are common due to their affordability, but they can be fragile. Carbon fibre propellers are lighter and more durable but come at a higher cost [5]. The number of propellers on a drone also impacts its capabilities. Most hobbyist drones have four propellers (quad copters), offering a good balance of stability and manoeuvrability.

However, drones with six or eight propellers are becoming increasingly popular, especially for heavy-lift applications or those requiring extra stability in windy conditions. Drone propellers come in various designs, including two-blade, three-blade, and even four-blade configurations. Each design offers a unique balance between efficiency, stability, and agility. The choice of design is influenced by the drone's intended purpose, size, and payload [6]. Table 1 shows the properties of materials.

2. Literature Review

Adams, K., Broad, A., Ruiz-García, D., & Davis, A. R. The authors demonstrate the effectiveness of blimp-mounted cameras in observing marine megafauna like stingrays, seals, and sharks. The continuous coverage provided valuable insights into their foraging behaviour, highlighting the potential of this new technique for research and safety.

Bisio, I., Garibotto, C., Lavagetto, F., Sciarrone, A., & Zappatore, S. The paper proposes a Wi-Fi statistical fingerprint-based approach to identify nearby drones, even in the presence of malicious attacks. This approach analyses the statistical characteristics of Wi-Fi signals to distinguish drones from other devices.

Y. Bühler, M. S. Adams, A. Stoffel, and R. Boesch Operating drone systems to record imagery of alpine snow cover for photogrammetric applications in topographic and meteorological conditions.

Dinesh, M., Santhosh, K., Sanath, J., Akarsh, K., & Manoj Gowda, K. This paper proposes the development of a sophisticated military surveillance drone capable of autonomously detecting and identifying soldiers based on their uniforms.

C. De Michele, F. Avanzi, D. Passoni et al This paper proposes the capabilities of photogrammetry-based surveys with Unmanned Aerial Systems (U.A.S.) to retrieve the snow depth distribution at cm resolution over a small alpine area (~300 000 m2).

Ganesh, M., & Kumara, S. This research demonstrates the successful design and development of a multi-purpose airship with promising applications in aerial survey and communication relay.

3. Methodology

The general purpose of this study is to examine the performance of a propeller used in unmanned aerial vehicles by considering the computational fluid dynamics. Fluid simulations of the propeller is carried out in the fluent module. Ansys 19.2 software version is used for CFD analysis of propeller in Ansys Fluent where geometry is imported from design software. Air is used as fluid in CFD analysis with default values such as density as 1.225 Kg/m3 and Viscosity as 1.7894×10-5 Kg/m-s provided in Ansys fluent. Figure 1, 2, 3 & 4 shows domain rotation of blade propeller and unstructured mesh domain rotation and static domain rotation.

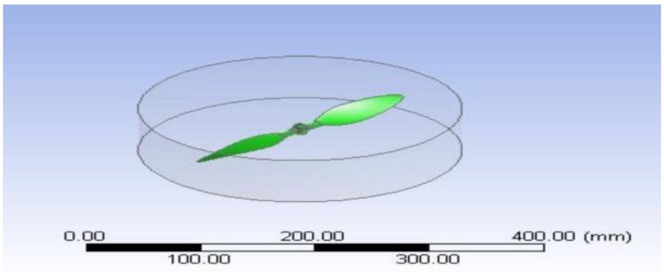

Figure 1 Rotate Domain with 2 Blade Propeller

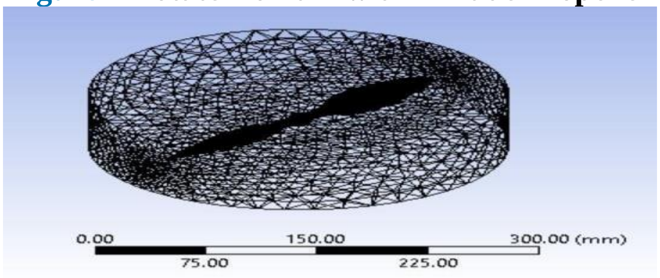

Figure 2 Unstructured Mesh of Rotate Domain

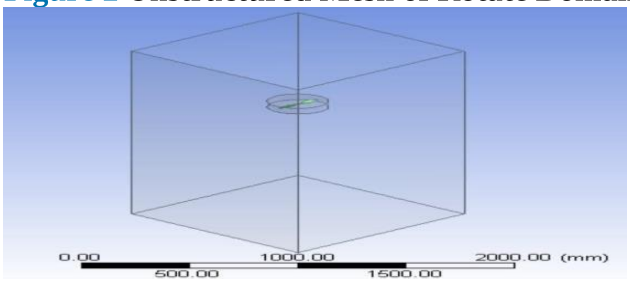

Figure 3 Static Domain with Rotate Domain Inside

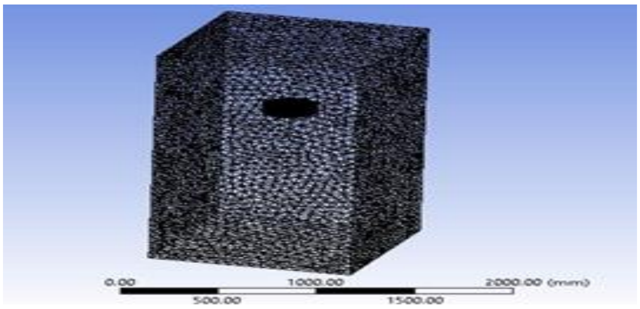

Figure 4 Unstructured Mesh of Static Domain

Table 1 Material Properties

Material	Material strength (MPa)	Density (Kg/m3)
Aluminium	90	2719
Carbon Fibre	3000	1750

4. Results and Discussion

4.1 Two Blade Propeller

4.1.1 Using Aluminum Material

Figure 5 & 6 shows the two blade pressure distribution view. Pressure distribution and thrust force is obtained through ANSYS fluent for two blade drone propeller made up of Aluminium material shown in Table 2. The maximum pressure and minimum pressure obtained is 0.002954 MPa and -0.006385 MPa respectively and the thrust force obtained is 13.5676 N.

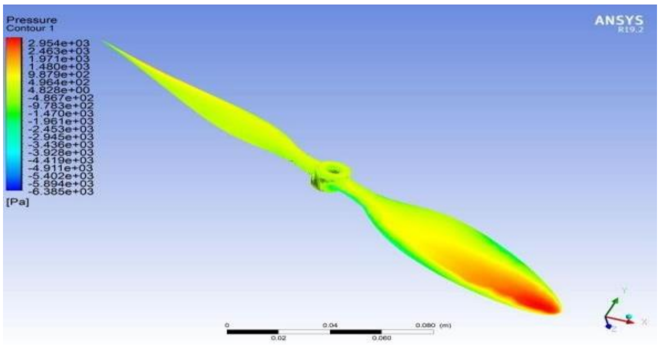

Figure 5 Pressure Distribution in Isometric View

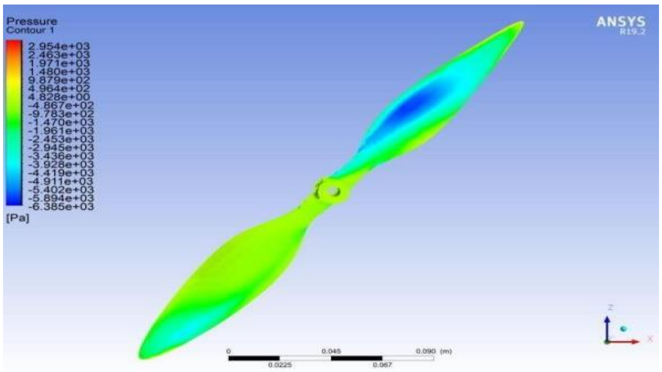

Figure 6 Pressure Distribution in Bottom View

Table 2 Thrust Force

Zone	Propeller	
Forces (N)	Pressure	-13.564
	Viscous	-0.003
	Total	-13.567
Coefficients	Pressure	-22.14
	Viscous	-0.004
	Total	-22.15

4.1.2 Using Carbon Fiber Material

Pressure distribution and thrust force is obtained through ANSYS fluent for two blade drone propeller made up of Carbon Fibre material is shown in Table 3. The maximum pressure and minimum pressure obtained is 0.00101 MPa and -0.002956 MPa respectively and the thrust force obtained is 3.0810 N. Pressure distribution of carbon fibre view is shown in Figure 7 & 8.

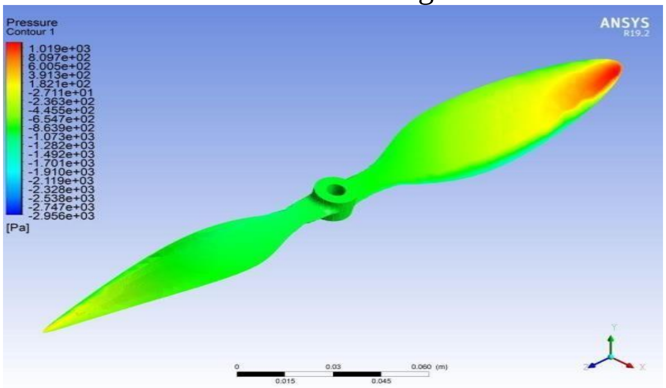

Figure 7 Pressure Distribution in Isometric View

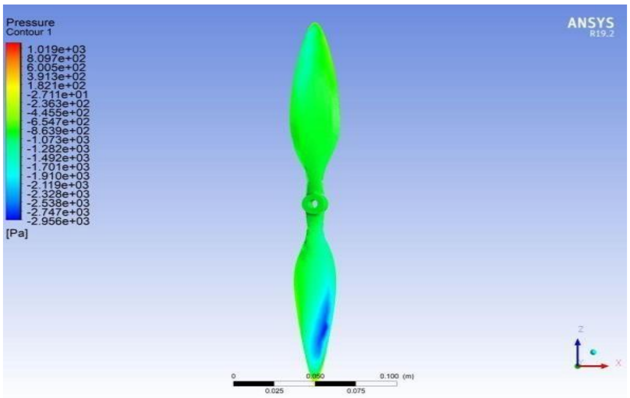

Figure 8 Pressure Distribution in Bottom View

Table 3 Thrust Force

Zone	Propeller	
Forces (N)	Pressure	-3.087
	Viscous	0.006
	Total	-3.081
Coefficients	Pressure	-5.04
	Viscous	0.01
	Total	-5.03

4.2 Three Blade Propeller

4.2.1 Using Aluminum Material

Pressure distribution and thrust force is obtained through ANSYS fluent for three blade drone propeller made up of Aluminium material are shown in Table 4. The maximum pressure and minimum pressure obtained is 0.004365 MPa and -0.01628 MPa respectively and the thrust force obtained is 25.0215 N. Figure 9 & 10 shows the three blade aluminium pressure distribution view.

Table 4 Thrust Force

Zone	Propeller	
Forces (N)	Pressure	-25.01
	Viscous	-0.006
	Total	-25.02
Coefficients	Pressure	-40.84
	Viscous	-0.01
	Total	-40.85

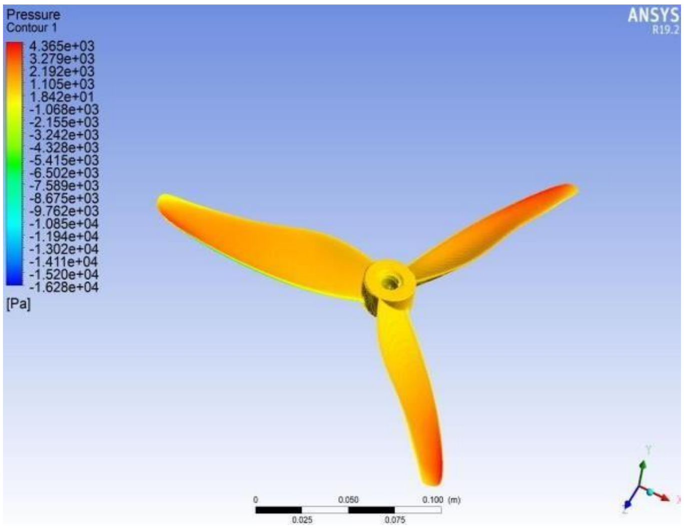

Figure 9 Pressure Distribution in Isometric View

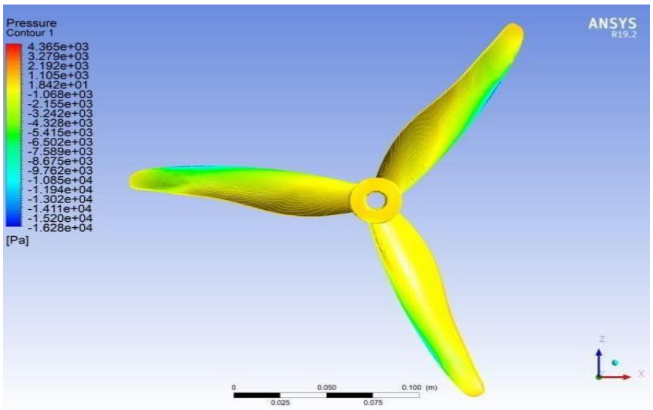

Figure 10 Pressure Distribution in Bottom View

4.2.2 Using Carbon Fibre Material

Pressure distribution and thrust force is obtained through ANSYS fluent for three blade propeller made up of Carbon Fibre material are shown in Table 5. The maximum pressure and minimum pressure obtained is -0.07245 MPa and -14.45 MPa respectively and the thrust force obtained is 4.2603 N. Figure 11& 12 shows carbon fibre pressure distribution in three blade.

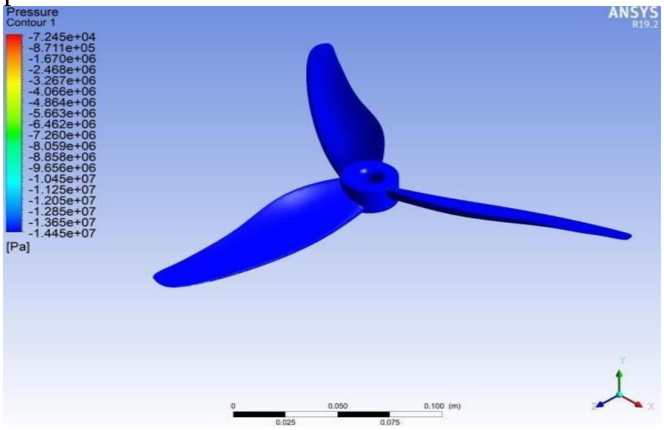

Figure 11 Pressure Distribution in Isometric View

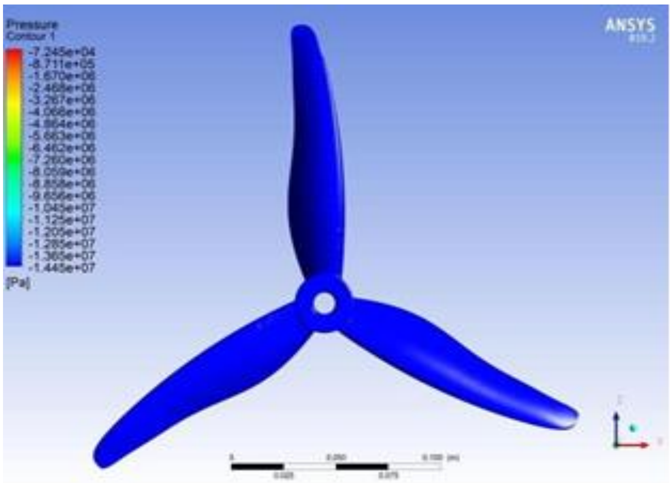

Figure 12 Pressure Distribution in Bottom View

Table 5 Thrust Force

Zone	Propeller	
Forces (N)	Pressure	-4.27
	Viscous	0.01
	Total	-4.26
Coefficients	Pressure	-6.97
	Viscous	0.01
	Total	-6.95

4.3 Four Blade Propeller

4.3.1 Using Aluminum Material

Pressure distribution and thrust force is obtained through ANSYS fluent for four blade drone propeller made up of Aluminium material are shown in Table 6. The maximum pressure and minimum pressure obtained is 0.000253 MPa and -0.001798 MPa respectively and the thrust force obtained is 0.4865 N. Figure 13 &14 shows four blade aluminium pressure distribution.

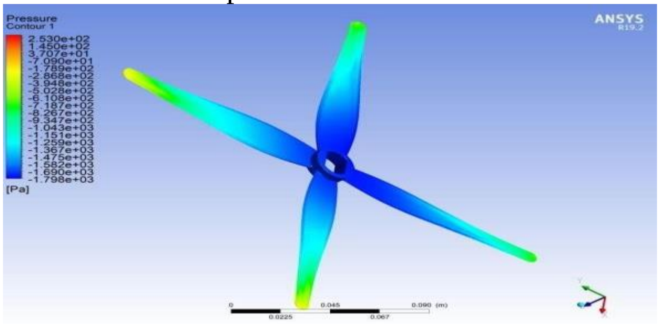

Figure 13 Pressure Distribution in Isometric View

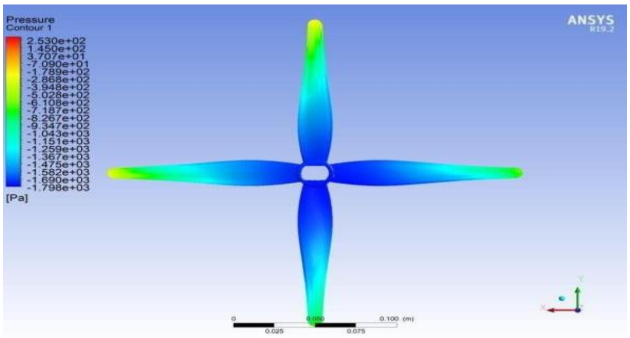

Figure 14 Pressure Distribution in Bottom View

Table 6 Thrust Force

Zone	Propeller	
Forces (N)	Pressure	-0.4896
	Viscous	0.0031
	Total	-0.4865
Coefficients	Pressure	-0.7994
	Viscous	0.0051
	Total	-0.7943

4.3.2 Using Carbon Fiber Material

Pressure distribution and thrust force is obtained through ANSYS fluent for four blade propeller made up of Carbon Fibre material are shown in Table 7. The maximum pressure and minimum pressure obtained is 95.85×10-6 MPa and -0.006908 MPa respectively and the thrust force obtained is 0.4848 N. Figure 15 & 16 shows the four blade carbon fibre pressure distribution view.

Table 7 Thrust Force

Zone	Propeller	
Forces (N)	Pressure	-0.4879
	Viscous	0.0031
	Total	-0.4848
Coefficients	Pressure	-0.7966
	Viscous	0.0051
	Total	-0.7915

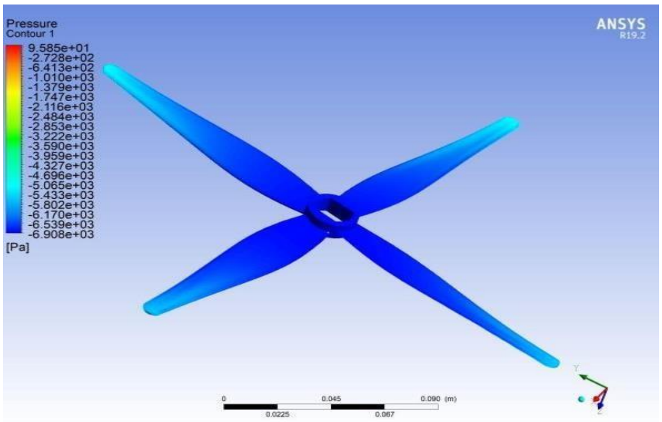

Figure 15 Pressure Distribution in Isometric View

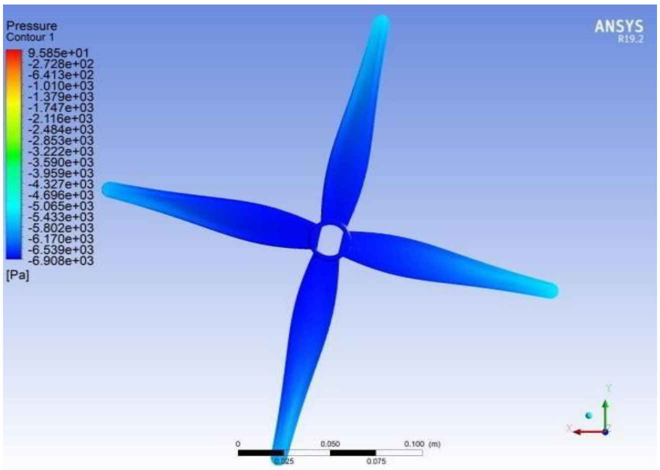

Figure 16 Pressure Distribution in Bottom View

4.4 Graphical Representation of Thrust Force

4.4.1 Two Blade Propeller

Graph is generated between thrust force (N) and flow time (seconds) during simulation of CFD analysis for two blade propeller made up of Aluminium material and carbon fibre in ANSYS fluent as shown in below Figure 17 & 18 respectively. Comparison between Thrust force and maximum pressure shown in Table 8.

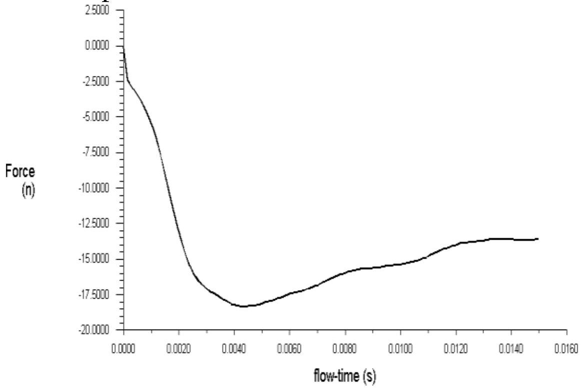

Figure 17 Graph B/W Thrust Force and Flow Time

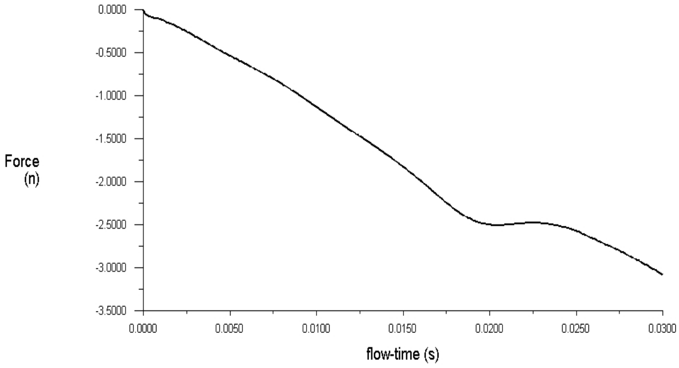

Figure 18 Graph B/W Thrust Force and Flow Time

4.4.2 Three Blade Propeller

Graph is generated between thrust force (N) and flow time (seconds) during simulation of CFD analysis for three blade propeller made up of Aluminium material and carbon fibre in ANSYS fluent as shown in below Figure 19 & 20 respectively.

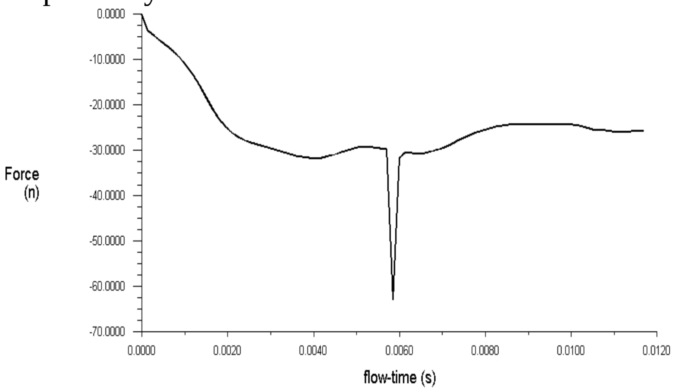

Figure 19 Graph B/W Thrust Force and Flow Time

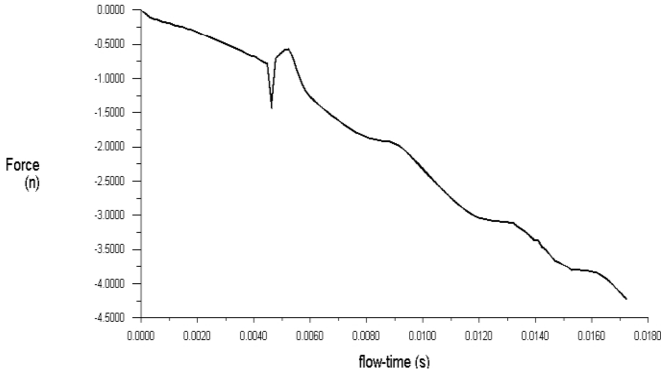

Figure 20 Graph B/W Thrust Force and Flow Time

4.4.3 Four Blade Propeller

Graph is generated between thrust force (N) and flow time (seconds) during simulation of CFD analysis for four blade propeller made up of Aluminium material and carbon fibre in ANSYS fluent as shown in below Figure 21 & 22 respectively. Table 8 shows the comparison of thrust force and maximum pressure.

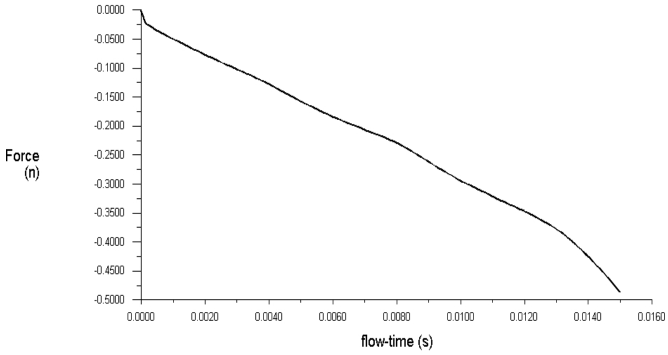

Figure 21 Graph B/W Thrust Force and Flow Time

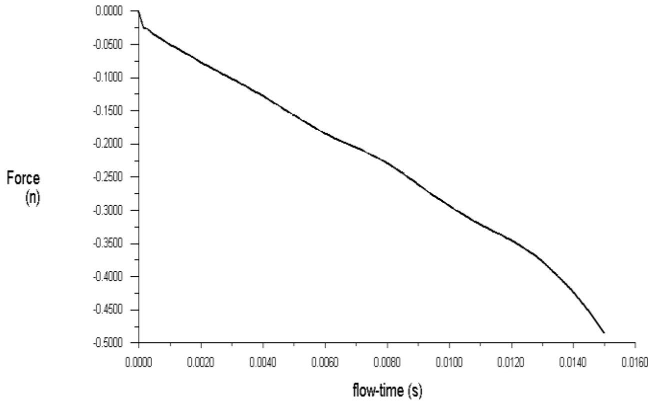

Figure 22 Graph B/W Thrust Force and Flow Time

Table 8 Comparison between Thrust Force and Maximum Pressure

Geometry	Material	Material strength (MPa)	Thrust force (N)	Maximum Pressure (MPa)
Two Blade Propeller	Aluminium	90	13.5676	0.002954
	Carbon Fibre	3000	3.0810	0.00101
Three Blade Propeller	Aluminium	90	25.0215	0.004365
	Carbon Fibre	3000	4.2603	-0.07245
Four Blade propeller	Aluminium	90	0.4865	0.000253
	Carbon Fibre	3000	0.4848	95.85×10^{-6}

Conclusion

1. In all the cases irrespective of geometry we have observed that, Aluminium material maximum pressure is less than its material strength.
2. Similarly for Carbon Fibre material irrespective of geometry the maximum pressure obtained is less than its material strength
3. In all the cases propeller made of Aluminium Material has obtained best results for Thrust force
4. Among 2 blade, 3 blade, 4 blade propellers it is advised to use 3 blade propeller made up

   Aluminum Material as it has obtained more thrust force.
5. In case of Carbon Fibre Material, 3 blade propeller has obtained good thrust force

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