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Investigating Propellers for Drone Applications: Analyzing Varied Designs and Characteristics

Jithin Krishna[*], NV Chidvilas[†]

Department of Aerospace Engineering, Hindustan Institute of Technology and Science, Chennai

G Dinesh Kumar[‡], K Arulmozhi[§]

Assistant Professor (S.G), Department of Aeronautical Engineering, Hindustan Institute of Technology and Science, Chennai

Abstract: The importance of drones has evidently increased in various aspects of daily life, such as defense, agriculture, disaster management, and more. Drone propellers are crucial for generating the lift and propulsion necessary for steady flight. Efficient propeller design is critical for maximizing flight time and maneuverability in drones. We are currently investigating the impact of different propeller designs on drone performance. Our research focuses on optimizing propeller characteristics to ensure optimal propulsion and overall functionality. By testing three airfoil designs and systematically varying the angle of attack and pitch, we aim to understand how these changes influence the propeller's efficiency and effectiveness. The CFD-based analysis primarily evaluates parameters such as the lift-to-drag ratio and RPM to determine the most suitable design for drone operations. Through extensive analysis and data collection, the study seeks to identify settings that balance performance metrics, ultimately enhancing the drone's functionality. Based on insights from the analysis, various iterations and refinements have been carried out to draw informed conclusions about the most effective propeller design for drone applications.

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1. Introduction

Propeller design plays a crucial role in enhancing the efficiency, performance, and sustainability of aerial propulsion systems within the dynamic realm of aerospace engineering [1]. Understanding the intricate details of aerofoil profiles, which shape the aerodynamic properties of propellers, forms the basis for advancements in propeller technology. Researchers delve into the behaviours of aerofoils across various operational scenarios through detailed computational fluid dynamics (CFD) simulations [2]. Our research endeavours to contribute to this ongoing exploration by meticulously evaluating the aerodynamic effectiveness of carefully selected aerofoil designs [3]. Drawing insights from aerospace engineering literature [4], we aim to identify and analyse aerofoil profiles with optimal performance attributes. Employing advanced tools and methodologies, our focus is on exploring the nuances of aerofoil behaviour to illuminate their practical applications in propeller technology [5]. Through examination and validation processes, we seek to deepen our understanding of fundamental aerodynamic principles while fostering innovative advancements in propeller technology. Our objective is to uncover insights that will steer the design and refinement of propellers tailored for modern aerospace needs as we navigate the

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[*] UG Research Scholar, Department of Aerospace Engineering, Hindustan Institute of Technology and Science, Chennai. **Corresponding Author: jithinkrishna2102@gmail.com.**
[†] UG Research Scholar, Department of Aerospace Engineering, Hindustan Institute of Technology and Science, Chennai. **Contact: nvchidvilas1308@gmail.com.**
[‡] Assistant Professor (S.G), Department of Aeronautical Engineering, Hindustan Institute of Technology and Science, Chennai. **Contact: gdineshk@hindustanuniv.ac.in.**
[§] Assistant Professor (S.G), Department of Aeronautical Engineering, Hindustan Institute of Technology and Science, Chennai. **Contact: karulmozhi@hindustanuniv.ac.in**
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complexities of aerofoil analysis. To enhance propeller efficiency, performance, and sustainability, we aim to understand the performance attributes of aerofoils in various scenarios. Through collaboration and interdisciplinary studies, we seek to propel aerospace engineering into new frontiers [6].

2. Materials and Methods

The study began with an extensive review of relevant literature to identify aerofoils suitable for propeller applications. The criteria for selection included demonstrated performance in aerospace applications and potential for optimizing drone propulsion systems.

2.1 Aerofoil Selection

Four aerofoil shapes were carefully selected for their performance and suitability in aviation and propeller uses. The selection process involved examining published works and real-world data to identify wing shapes that provide aerodynamic efficiency and stability across different flight scenarios. The selected aerofoils are:

- SG6041
- NLF (1)-0215F
- S809
- SD7080

A system was established to analyze aerodynamics using Computational Fluid Dynamics (CFD) simulations. This setup included defining the analysis domains, specifying boundary conditions, and adjusting parameters to accurately simulate airflow around aerofoil and propeller shapes.

2.1.1 Simulation Setup

We used the ANSYS Student Version 2024 software for our Computational Fluid Dynamics (CFD) simulations. Our process began with preparing the aerofoil shape, ensuring it was scaled and aligned correctly. Next, we created a mesh to effectively capture flow details. We then set conditions by defining parameters such as air velocity and angle of attack. After selecting solver settings, including turbulence models, we conducted the simulation using ANSYS Fluent. The post-processing step involved analyzing data on pressure, velocity, and flow paths. Finally, we calculated both lift (Cl) and drag (Cd) forces, along with measuring the generated acoustic noise level.

2.1.2 Geometry Preparation

The design of the aerofoil shape was carefully planned to fit into the CFD software. This step was crucial to ensure the setup was correct for accurate analysis. Particular attention was given to the aerofoil's size and shape, which were vital for obtaining realistic simulation results.

2.1.3 Mesh Generation

After setting up the geometry, the next important step was creating a high-quality mesh around the aerofoil shape. It was crucial to have a detailed mesh to accurately represent the flow patterns near the aerofoil surface and in its surrounding airflow. Using ANSYS Student Version 2024, meshes of varying densities were generated, ranging from fine to coarse grid spacings. After conducting convergence analysis, a grid spacing of 74 mm was found to strike the balance between computational efficiency and solution accuracy. This choice ensured that the mesh resolution effectively captured all flow intricacies while keeping computational requirements in check.

Table 1. Grid Independence

Mesh Size	Cl/Cd
80	14.37604
78	14.80662
76	14.2656
74	14.34325
72	14.34037
70	14.29319
68	14.03126
66	14.1741

2.1.4 Simulation Parameter Setup

A detailed examination of the selected propeller was conducted using two-dimensional Computational Fluid Dynamics (CFD). The study involved testing angles of attack ranging from 0 to 30 degrees, with increments of 2 degrees. An analysis mode was used, applying a velocity of 50 m/s at the inlet to effectively mimic flow conditions. Table 2 provides a summary of the parameters used in the simulation process, ensuring proper record-keeping and replicability of the results.

Table 2. Setup for Simulation

Parameter	Values
Time	Transient
Viscous model	k-omega
Near wall treatment	Scalable wall function Flying medium
Density of air (ρ)	1.225 kg/m^3 Velocity inlet (V)
Viscosity of fluid (μ)	1.7894e-05 Type of air flow
Time	Transient
Viscous model	k-omega
Near wall treatment	Scalable wall function Flying medium

Lift and drag analyses were conducted using CFD simulations at varying angles of attack to comprehensively evaluate the aerodynamic performance of each selected aerofoil. Parameters such as the lift-to-drag ratio and stall behavior were scrutinized to assess the suitability of the aerofoils for propeller applications.

2.2 Propeller Design Development

After analyzing the findings from the aerofoil study, we began developing two propeller designs. We focused on performance, shaping these designs based on operational conditions and specific design requirements for maximum effectiveness. Subsequently, CFD analysis was used to validate the aerodynamic characteristics of these propellers against established standards. Each propeller's design was adjusted according to changes in angle of attack and twisting, informed by the results from these assessments.

Table 3. Propeller Parameter

Propellers	Aerofoil	Angle of Attack	Twisting
1	SG6041	4° at root, 20° at mid, 7° at tip	No
2	SD7080	8° at root, 17° at mid, 6° at tip	Yes

Figure 1. Propeller 1

Figure 2. Propeller 2

2.2.1 Meshing

The quality of the mesh plays a crucial role, as it directly impacts the accuracy of calculations and the speed at which computations converge. Initially, the computational domain was meshed following a sequence, starting from the line surface and moving to the body. The large size of the propeller surface, due to its curvature, necessitated actions to reduce this curvature through splitting and merging surfaces. The computational domain and meshing results are illustrated in Figure 3. The size of elements and nodes varied by adjusting the mesh diameter. A naming convention was established based on selecting the component to configure conditions. The mesh consisted of 119,723 nodes and 665,718 elements.

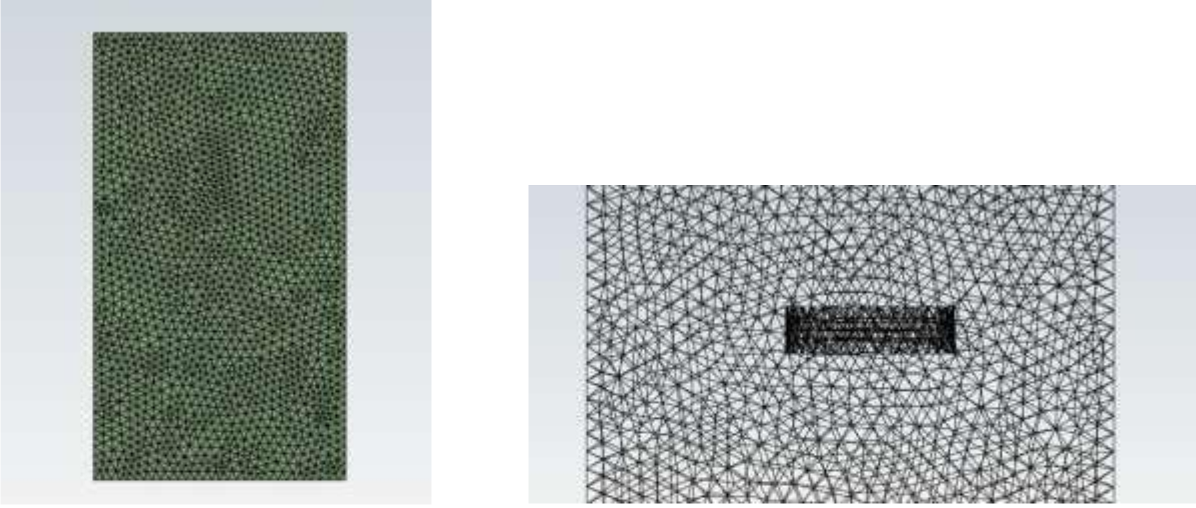
(a) **(b)**

Figure 3. Meshing of Computational domain: (a) computational domain; (b) Propellers meshing

2.2.2 Simulation Parameter Setup

The model used in this research includes a propeller with two different characteristics: angle of attack and blade twist. The model is three-dimensional. The inlet velocity was set at 10 m/s, and each propeller was rotated at 6000 RPM. Table 4 shows the parameters used for the simulation.

Table 4. Simulation Setup

Parameter	Values
Time	Transient
Viscous model	k-epsilon (realizable)
Near wall treatment	Scalable wall function
Flying medium	Air
RPM	6000
Density of air (ρ)	1.225 kg/m³
Velocity inlet (V)	10 m/s
Viscosity of fluid (μ)	1.7894e-05 Pa·s
Type of airflow	Turbulent

3. Results

In this section, we delve into the outcomes of our computational simulations on aerofoils and propellers. Through detailed analysis, we aim to uncover the performance characteristics of these components under various conditions. Starting with aerofoil performance, we then explore propeller behavior. By examining simulation results and discussing significant findings, we seek to enhance our understanding of aerodynamic principles and contribute to the advancement of aerospace engineering.

3.1 Aerofoil Performance Analysis

In this section, we thoroughly examine the performance of the chosen aerofoil shapes. Using Computational Fluid Dynamics (CFD) simulations, we carefully assess factors such as lift, drag, and the distribution of aerodynamic forces across each aerofoil shape. By studying the airflow patterns, we gather valuable insights into the performance of different aerofoil shapes and setups. We also investigate how changes in angle of attack and blade twist impact performance, revealing the intricate relationship between design choices and aerodynamic forces.

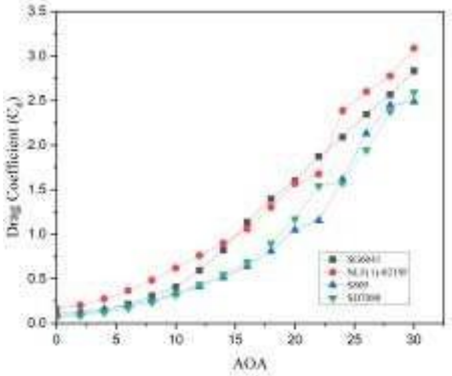

Figure 4. Simulation results for Cd

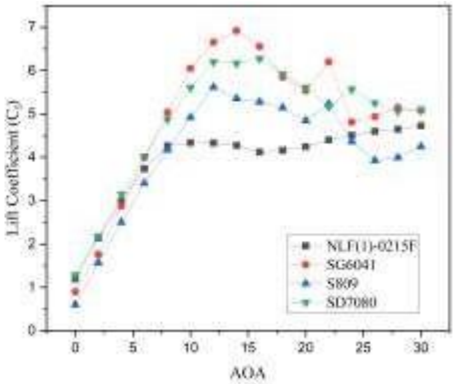

Figure 5. Simulation results for Cl

After studying the aerodynamic performance graphs, we began designing the propellers. Using the features of the SG6041 and SD7080 aerofoil profiles, we carefully created two propellers. Our goal was to enhance efficiency and performance through these designs. We then conducted CFD analysis to assess and confirm the aerodynamic properties of our propeller designs. The analysis results provided information on how the propellers would perform in different scenarios, setting a solid foundation for future improvements and enhancements.

3.2 Thrust Force

The simulation was conducted with a velocity inlet set at 10 m/s to emulate the thrust force exerted on the propeller. Using a 3D model, the simulation aimed to ascertain the thrust force while analyzing the lift and drag coefficients for each propeller design. Notably, the propeller's rotation was tested at a speed of 6000 RPM. Table 5 presents the thrust force values obtained from the simulation.

Table 5. Thrust Force from Propeller

Propeller	Thrust Force (N)
1	154.67
2	81.54

At a rotational speed of 6000 RPM, Propeller 1 demonstrates a significant thrust force of 154.67 N. This indicates that Propeller 1 is efficient in generating lift, making it suitable for applications requiring strong thrust output.

3.3 Lift and Drag Coefficient

Below is the table which shows the comparison of the lift and drag coefficients for each simulated propeller.

Table 6. Lift and Drag Coefficient

Propeller	Lift Coefficient	Drag Coefficient
1	0.1291	0.0026
2	1.001	0.0208

The lift and drag coefficients provide information about how the two propellers perform in the air. Propeller 1 has a lift coefficient of 0.1291 and a drag coefficient of 0.0026, indicating that it generates lift while encountering minimal resistance. These values imply that Propeller 1 can efficiently propel forward with minimal energy usage, making it ideal for situations where speed and effectiveness are crucial.

On the other hand, Propeller 2 has a higher lift coefficient of 1.001 and a drag coefficient of 0.0208. While it produces more lift than Propeller 1, it also encounters increased drag, which could lead to higher energy usage for equivalent propulsion levels. This characteristic could be beneficial in scenarios where maximizing lift is crucial, such as lifting loads or performing short takeoff and landing maneuvers, despite consuming more energy and power. When balancing the trade-off between lift and drag, we prefer Propeller 1 due to its lower drag coefficient and high lift. This results in lower energy wastage, leading to fuel efficiency and longer operational endurance. Hence, in situations prioritizing drag reduction and efficiency maximization, Propeller 1 emerges as the better choice.

3.4 Acoustic Performance

The acoustic performance of the propeller designs was evaluated to assess their noise levels during operation. This analysis is crucial for applications where noise reduction is a priority, such as in residential areas or for environmentally sensitive operations.

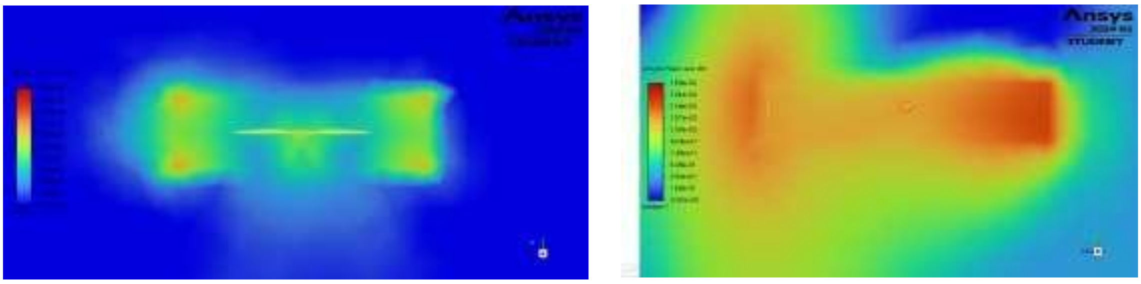

Figure 6. Acoustic contour: (a) Propeller 1 (left); (b) Propeller 2 (right)

The acoustic analysis shows that the first propeller generates a sound level of 60 dB, whereas the second propeller emits a noise level of 80 dB at 6000 RPM. This indicates that the first propeller is quieter under the given operating conditions. Lower noise levels are beneficial for situations where reducing noise is important. Hence, these findings suggest that the first propeller could be better suited for applications where noise reduction is a priority, while additional adjustments might be needed to further decrease the noise from the second propeller.

4. Discussion

In the discussion section, we relate our findings to existing research and explore their implications, while proposing areas for future investigation. By selecting the SG6041 and SD7080 aerofoil profiles, we build upon existing studies on lift-to-drag ratios and stability, thereby deepening our understanding of aerofoil shapes and setups. Through CFD analysis and validation of our propeller designs, we advance knowledge on propeller performance in scenarios emphasizing the importance of balancing efficiency with propulsion capabilities. Our results highlight the benefits of quieter propeller designs in noise-sensitive settings, suggesting that future research could focus on new noise reduction technologies. Overall, our findings offer valuable insights for engineers and researchers in the aerospace field, providing guidance for projects focused on propeller enhancement and sustainability.

5. Conclusion

In summary, this study aims to enhance our understanding of aerofoil and propeller performance through Computational Fluid Dynamics (CFD) analysis. By selecting the aerofoil profiles SG6041 and SD7080 and conducting thorough simulations, we have gained insights into their aerodynamic characteristics and suitability for propeller use. The creation and validation of two different propeller designs further emphasize the importance of maximizing efficiency and performance in aerospace engineering. Additionally, our examination of noise reduction in propeller design highlights the significance of performance and lays the groundwork for future advancements in this field. Overall, this research contributes to the quest for solutions in propeller optimization that can benefit various aerospace applications.

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8. Conflict of Interest

The authors declare no competing conflict of interest.

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