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Formation and Fabrication of A 3D- Printed Polymer Propeller for Improved Propulsion and Minimal Acoustic Emission: A Comparative Study for Small Unmanned Vehicles

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Abstract

The current research focuses on a comparative analysis of propeller designs to identify an option that enhances thrust efficiency while minimizing acoustic noise. The study evaluates three distinct types of propellers: the traditional three-blade propeller, the Sharrow propeller, and a novel aero propeller featuring an air foil-shaped cross-section. To facilitate a hands-on analysis, these propellers were produced using 3D printing technology, specifically employing ABS filament through a Fused Deposition Modelling (FDM) process. Each propeller design was subjected to a thorough evaluation to understand its capabilities and limitations. Traditional three-blade propellers have approached their maximum potential in terms of thrust and noise reduction, prompting the need for innovative alternatives. The Sharrow propeller stands out as a promising design, providing improved efficiency and reduced noise levels when compared to conventional models. However, this study introduces the aero propeller—a refined version of the Sharrow design—engineered to further enhance thrust capabilities and reduce acoustic noise. Experimental methods, including smoke flow visualization, thrust generation tests, and noise emission analysis, were employed to gauge the performance of each propeller. The findings revealed that the aero propeller not only performed better in generating thrust but also emitted less noise than the other designs. Additionally, the ABS polymer material used in the 3D printing process demonstrated excellent durability and stability, even under high rotational speeds. The overall results indicate that the aero propeller excels in achieving both higher thrust efficiency and lower noise emissions, making it a superior choice for applications in small unmanned vehicles that require optimized performance. This advancement in propeller design signifies a meaningful progression toward more efficient and quieter propulsion systems.ABS filament material was found to be the most suitable for experimenting all three different propellers.

Keywords: Sharrow propeller, aero propeller, flow visualization; acoustic noise emission; thrust

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INTRODUCTION

In the dynamic spheres of aeronautics and naval architecture, the relentless pursuit of propulsion efficiency, minimized environmental impact, and heightened operational versatility has spurred a wave of groundbreaking advancements. At the forefront of this technological surge, the Sharrow propeller emerges as a pinnacle of ingenuity, poised to revolutionize both aerial and maritime engineering applications. At the same time research gives an opportunity to explore and come out with a better solution and for varied engineering applications and in the process from sharrow propeller concept a new propeller took birth coined aero propeller that was realized to have better propulsive efficiency and reduced acoustic noise.

The sharrow propeller is targeted to obtain the listed objected such as Optimize sharrow propeller design, noise reduction, Tip vortex elimination. The state-of-the-art technology available till date pertaining to propeller is that the design parameters and propeller testing methods to increase the delivered power and materials for the same has been discussed [1]. A further extended study include design and testing of an optimized propeller with reduced noise characteristics [2]. In order to eliminate the tip vortices, impact of blade twist angles on the aerodynamic performance and acoustic signature of multirotor propellers was studied and experimented [3]. Innovative design and analysis of a twinpropeller UAV with a duct, emphasizing its ability to complete missions with a single engine in case of failure was performed the advantages include enhanced flight resilience, allowing the UAV to continue operations with a single functioning engine, and a well-distributed weight load for increased equipment-carrying capacity [4]. An investigation on marine propellers, emphasizing their application for increased propulsive thrust was performed [5]. For a UAV or Drone a new propeller for a groundbreaking advancement offering a quieter alternative to conventional propeller designs was experimented [6]. For the marine applications the sharrow propeller was designed using a 3D printer for addressing issues like tip cavitation and vortices [7]. In order to cover the diverse flight conditions that range from sea level to high altitude specialized propeller design and analysis methodology has been tailored [8]. Improving the aerodynamic performance for an multirotor unmanned aerial vehicle through blade element momentum theory was performed [9]. Propeller performance in calm waters and evaluating their efficiency behind hulls was experimented [10]. Improving of the propeller efficiency through tip loading through potential flow simulations, Reynolds-Averaged Navier-Stokes (RANS) viscous flow simulations, and experiments was performed [11]. Modelling and a detail analysis for the structural strength pertaining to propeller was performed [12]. Optimized design of a composite propeller was also studied [13]. Tests related to propeller efficiency through different airfoils was discussed [14]. Acoustic emission for three different cases that include fixed pitch propeller at speed reduction (case 1), controllable pitch propeller with a negative angle of attack (case 2), and an inverted, backward-running propeller (case 3) the setting angle significantly influenced acoustics in the first case [15].

MATERIALS AND METHODS

All the three geometries were modelled in FUSION 360 and SLA 3D printer was used to make the physical models. A total of 32 hours was taken to print all the three models. The minimum thickness of the models was kept at 1.1mm. The diameter in all the cases was 112mm. The CAD models are as shown in Figure 1 -2.

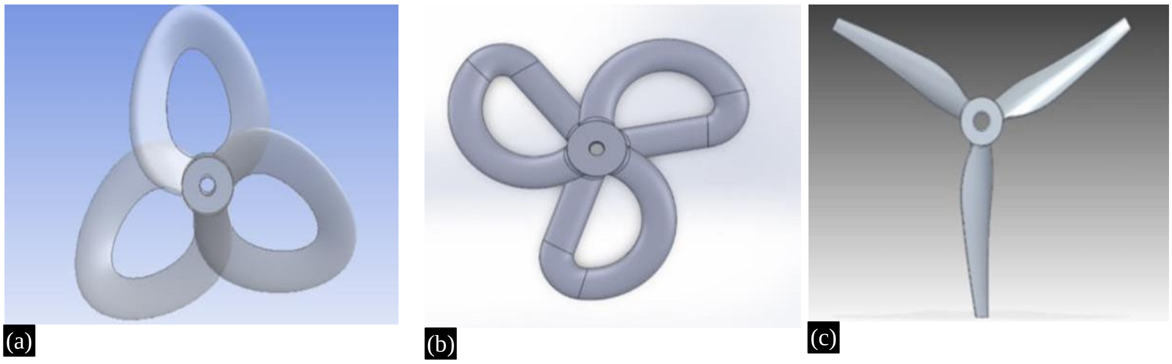

Figure 1. CAD model of (a) Aero propeller (b) Sharrow propeller and (c) Traditional propeller.

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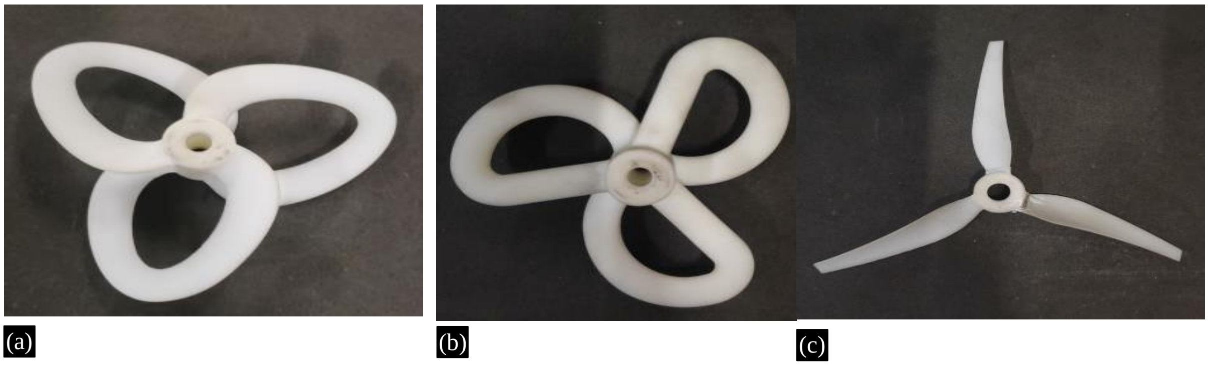

Figure 2. 3D printed models using SLA 3D printer for (a) aero propeller (b) sharrow propeller (c) traditional propeller.

In the case of the aero propeller the cross section was NACA 2412 airfoil with 14mm width. The airfoil shape was so chosen for its simple structure and readily available data for aerodynamic characteristics. The Sharrow propel ler has a width of 12mm and 4mm in height (minor axis) which is of elliptical cross section. And for traditional propeller it is 4mm width of the tip and root at 9mm width.

Design of the Aero Propeller

The Aero Propeller is a three-bladed propeller designed for small UAVs with the following specifications:

- *Diameter*: 112 mm
- *Propeller hub diameter*: 20 mm
- *Blade thickness*: 30 mm
- *Pitch*: 35.35 mm (This value refers to the theoretical axial distance a propeller travels in one revolution, assuming 100% efficiency)
- *Number of blades*: 3
- *Blade shape*: NACA 2412 Airfoil (This is a specific airfoil profile designed for efficient lift generation)

This design procedure outlines the steps for creating a customized propeller in software like Fusion 360. It focuses on achieving the desired specifications and incorporating blade twist for optimal performance.

Design Steps

Propeller base and hub

- Begin by creating a new sketch on a plane. Draw a regular polygon with a total diameter of 112 mm. This polygon will serve as the base for the propeller.
- Inside the polygon, create a circle with a diameter of 20 mm centered on the polygon. This circle represents the propeller hub, which houses the motor shaft.
- Extrude the hub to a desired height, keeping in mind factors like the motor shaft length and desired propeller depth.

Airfoil selection and placement

- The propeller blades will utilize the NACA 2412 airfoil profile as their base shape. This specific airfoil is known for its efficient lift generation characteristics.
- We will create five separate sketches on different planes perpendicular to the propeller's axis of rotation. Each sketch will represent a different section of a single propeller blade.
    - *Sketch 1:* This sketch will be located at the base of the hub, representing the root section of the blade.
    - *Sketch 2:* This sketch will be positioned at 2/3rd of the propeller radius measured from the hub center. This section experiences the maximum curvature of the blade.

- *Sketch 3:* This sketch will be located at the tip of the propeller blade.
- *Sketch 4 & 5:* These sketches will be mirror images of Sketches 1 & 2 on the opposite side of the propeller hub. They are necessary to create a complete blade with symmetrical properties.

Airfoil twist and blade profiles

- To achieve blade twist, each airfoil sketch (1-5) will have a different angle of attack relative to the propeller's rotation plane. This twist is crucial for efficient thrust generation as the propeller rotates. Here's an example twist distribution for this design:
  - *Sketch 1:* +30° (This section experiences the highest angle of attack)
  - *Sketch 2:* +15°
  - *Sketch 3:* 0° (This section has no twist)
  - *Sketch 4:* -15°
  - *Sketch 5:* -30° (This section experiences the lowest angle of attack)

- Utilize the specific airfoil coordinates for the NACA 2412 profile to create the precise shape for each sketch. These coordinates define the curvature and thickness of the airfoil at various points along its length. Remember to account for the desired 30 mm blade thickness when defining the airfoil profiles in the sketches.

Loft and blade creation

- Disable any unnecessary sketches that are no longer required for the propeller design.
- Create a 3D sketch by meticulously connecting corresponding points from each of the five airfoil sketches. This 3D sketch essentially serves as a roadmap for defining the propeller blade's overall shape.
- Utilize the loft function within the chosen software (e.g., Fusion 360) to create a solid body for each propeller blade. The loft function essentially extrudes the 3D sketch along a defined path, resulting in the final blade geometry.

Final touches

- Once you have created individual solid bodies for each propeller blade, combine them into a single propeller model. This will result in the complete propeller with three blades.
- Create a sketch on the face of the hub and extrude a cylinder with a diameter slightly smaller than the motor shaft. This extruded cylinder will create a hole in the hub for the motor shaft to seamlessly connect with the propeller.

Finally, export the completed propeller model as a 3D printable file format, such as STL, which is compatible with most 3D printing software

Flow Visualization

A smoke flow visualization technique is used to analyze the flow aft of the propeller for all the cases under study. The propeller motor has the following specifications Model: 6T, A221, Motor KV (rpm/v): 2200, Shaft Diameter: 3.17mm, Weight: 60g, Current Handling Capacity: 12A, Efficiency: 80%. As shown in Figure 3.

ANSYS FLOW FLUENT was used to simulate the flow and understand the flow dynamics and later was compared with experiments. It was found that the experiments and the flow dynamics in ANSYS was almost similar and showed similar trends. Two domains were made inner fine domain and outer coarse domain. In all the cases same mesh elements 232200 were maintained. The mesh over different propeller models are shown in the Figures 4-6. For all the simulations ANSYS student version was used (2022 R1).

Figure 3. Propeller motor.

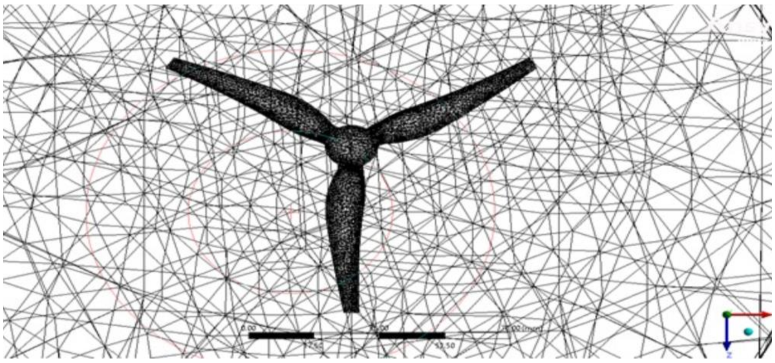
Figure 4. Mesh over the traditional propeller.

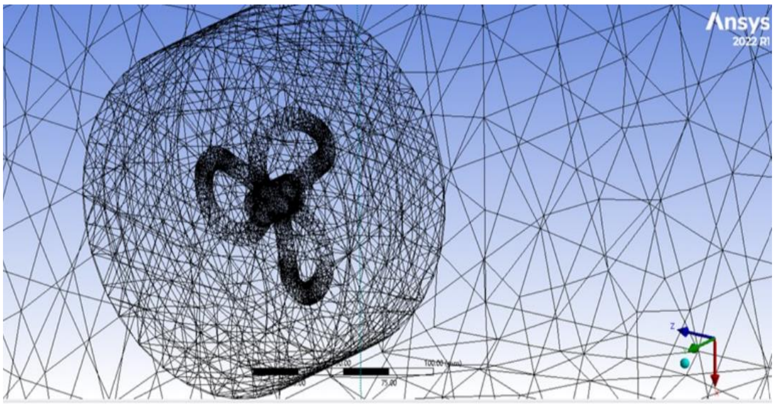

Figure 5. Mesh over the sharrow propeller.

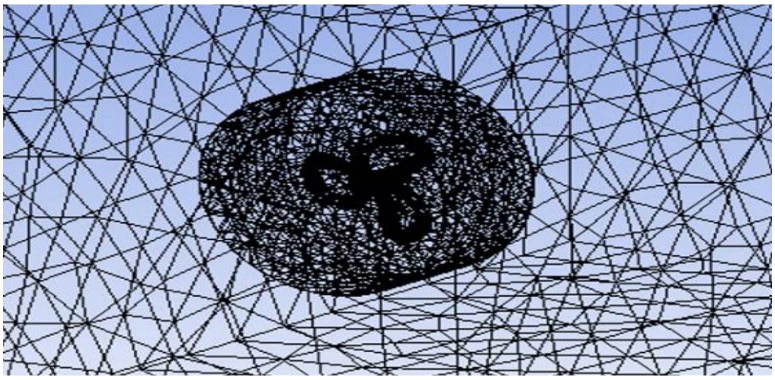
Figure 6. Mesh over the aero propeller.

Acoustic Emission Test

Sound meter mobile application was used to measure the sound in dB. The experiments were performed in isolated conditions and readings obtained accordingly. The setup is as shown in the following Figure 7 and sample reading shown in Figure 8. The set has additional microphone that is connected to the mobile through app and as the propeller is operated the noise emission is known. For all the experiments the rpm was maintained between 2400-2600 and time of running the propeller was about 30secs.

Figure 7. Acoustics noise emission test for the aero propeller using sound meter mobile application.

Figure 8. Sample reading using sound meter mobile application for sharrow propeller.

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Figure 9. Trust experiment setup. The sharrow propeller placed over the digital weighting machine.

Thrust Experiment

For the thrust experiment the propeller is mounted at the center of the digital weighting machine. The settings are adjusted to zero after the engine has been mounted. The engine position is fixed and all the testes performed at isolated conditions as shown in Figure 9.

RESULTS

Smoke Flow Visualization

In the case of the traditional propeller as shown in figure 10 the smoke was initially sucked from tip to the root and resulted in tip vortices. The smoke later was dispersed after pulled by the propeller. This flow phenomenon is clear evidence of large acoustic emission and low efficiency.


Figure 10. Flow visualization for a rotating traditional propeller.

In the case of the sharrow propeller as shown in Figure 11 the smoke was initially pulled as the propeller started rotating. This flow phenomenon is clear evidence of better acoustic emission compared to the traditional and better efficiency as the flow stream aft propeller is restricted within the diameter of the propeller as shown.

For the aero propeller as shown in Figure 12, as the propeller started rotating the flow aft of propeller was found to be straight and not deviated as shown. This phenomenon led to low acoustic emission and good propulsive efficiency.

CFD Flow Simulations

The CFD results are in agreement with the experimental findings as shown in the figure where the flow is contained within the diameter of the sharrow propeller, the flow is getting dispersed aft of the traditional propeller and flow is straight and almost laminar for the aero propeller the results shown in Figure 13.

Figure 11. flow visualization for a rotating sharrow propeller.

Figure 12. Flow visualization for a rotating aero propeller.

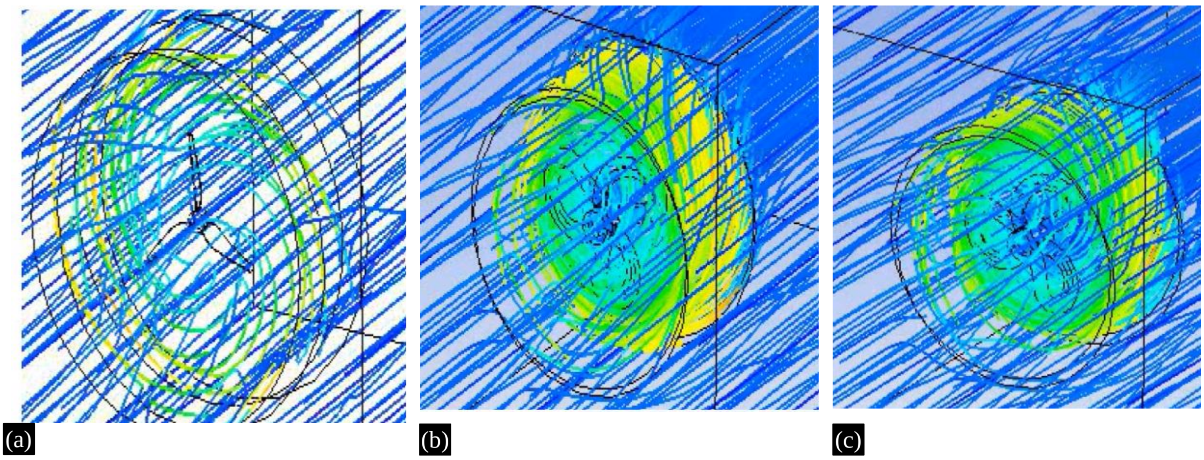

Figure 13. CFD flow simulations for (a) Traditional propeller(b) sharrow propeller and (c) aero propeller.

Table 1. Acoustic emission test for a time of 30 secs.

Name of propeller	Average noise	Max noise
Traditional propeller	68 dB	72.7 dB
Sharrow Propeller	64.3dB	69.4dB
Aero Propeller	65.3dB	67.8dB

Table 2. Generated Thrust.

Name of propeller	Thrust (in grams)
Traditional propeller	55
Sharrow Propeller	67
Aero Propeller	94

The acoustic noise emission test showed better results for the aero propeller compared to the traditional and the sharrow propeller as summarized in the Table 1.

The thrust results for the three propellers at an rpm 2400-2600 for a time of 30secs are as mentioned in Table 2

DISCUSSION

In the present paper three propulsive devices traditional, sharrow and aero propeller performances for small unmanned vehicles are experimentally and computationally analyzed.

It is realized that aero propeller is a new innovative design that is giving a better performance compared to traditional and sharrow propeller. All the results closely align with the computational results. The aero propeller initially whose aero foil cross section was thirty degrees was later aligned to 15 degrees and then brought it to zero. And again, increased to thirty degrees in a step of fifteen in the counter clockwise direction thereby making a complete loop. In total there are three closed loops similar to sharrow propeller and it is realized that three closed loops would guide the flow aft rotating propeller in laminar thereby the efficiency is increased and acoustic noise emission decreased.

For sharrow propeller initial turbulence was detected and later the turbulence was continued but the turbulence was less compared to traditional propeller. As a result, the sharrow propeller acoustic noise emission was more but lesser than traditional propeller.

CONCLUSIONS

Among the three propellers the aero propeller maximum acoustic noise emission was less by 2% as compared with sharrow propeller and less by 6% as compared to the traditional propeller.

The thrust for aero propeller is more than around 41% as compared to traditional and more than 28% as compared to sharrow propeller.

The flow visualization also confirms that the thrust of aero propeller is more than other two propellers.

The ABS polymer material was found to be strong and could withstand high engine rpm.

PATENTS

The authors are planning to file a patent after making some modifications to the working model.

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