



# Experimental Comparison of Conventional and Toroidal Propellers for UAV Applications

Aatif Muneer

Department of Aerospace Engineering, JAIN (Deemed-to-be University), Bangalore, India

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Unmanned Aerial Vehicles (UAVs) demand continuous improvements in propulsion efficiency, acoustic performance, and manufacturability. Conventional propellers, while well-optimized for thrust, contribute significantly to noise pollution and offer limited scope for rapid design customization. Recently, toroidal propellers—characterized by closed-loop blade tips—have gained attention for their potential to reduce noise by mitigating tip vortices.

This study presents an experimental comparison between a conventional three-bladed propeller and a three-loop toroidal propeller of identical diameter (5.5 inches). Both propellers were manufactured using additive manufacturing techniques and tested under controlled laboratory conditions using an industrial thrust bench and acoustic measurement setup. Thrust output and noise levels were measured across a wide range of rotational speeds.

Results indicate that while the conventional propeller produces significantly higher thrust at all RPM levels, the toroidal propeller demonstrates consistently lower noise emissions, particularly at low-to-medium rotational speeds. The findings highlight the trade-off between thrust performance and acoustic benefits, suggesting that toroidal propellers may be better suited for noise-sensitive UAV applications

where absolute thrust is not the primary requirement.



## Introduction

Unmanned Aerial Vehicles (UAVs) have become integral to modern aerospace applications including surveillance, agriculture, logistics, environmental monitoring, and research. As UAV deployment increases in urban and noise-sensitive environments, propulsion system optimization—particularly propeller design—has emerged as a critical research area.

Propellers are responsible not only for thrust generation but also for a substantial portion of UAV acoustic emissions. Conventional propellers generate strong tip vortices that contribute to aerodynamic losses and noise. In contrast, toroidal propellers employ a closed-loop geometry that connects blade tips, theoretically reducing vortex strength and redistributing aerodynamic loading.

In parallel, additive manufacturing (3D printing) has enabled rapid prototyping of complex propeller geometries that are difficult or costly to produce using traditional injection molding. This study experimentally evaluates the aerodynamic and acoustic performance of a 3D-printed toroidal propeller relative to a conventional propeller of identical size.

## Literature Review

Previous research has focused extensively on optimizing conventional propeller blade geometry and materials using computational methods. Krmela et al. demonstrated that material optimization can improve thrust efficiency and durability of standard UAV propellers.

Ion et al. investigated the feasibility of 3D-printed conventional and toroidal propellers for small multirotor drones, reporting reduced noise levels for toroidal designs but at the expense of thrust. However, comprehensive experimental datasets comparing thrust and noise across wide RPM ranges remain limited.

This study builds upon existing work by providing experimentally validated thrust and acoustic comparisons using identical propeller diameters, controlled test conditions, and industrial-grade measurement system.

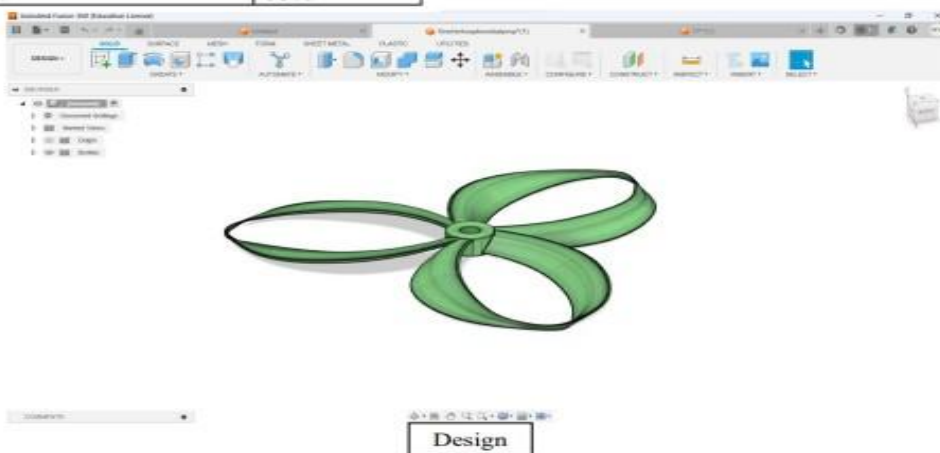
## Proposed Design

Parameters used for printing the conventional propeller

Parameter	Value
Layer height	0.15mm
Extruder temperature	250 ° Celsius
Infill density	10%
Bed temperature	90° Celsius
Print speed	40mm/s
Cooling	20%
Support	Grid
Build plate adhesion type	Brim
Draft Shield	On
Coasting	On
Retraction distance	5mm
Flow	95%

Parameters used for printing the toroidal propeller.

Parameter	Value
Layer height	0.15mm
Extruder temperature	250° Celsius
Infill density	100%
Bed temperature	90° Celsius
Print speed	40mm/s
Cooling	20%
Support	Grid
Build plate adhesion type	Brim
Retraction distance	0.5mm
Flow	110%



The key design specifications of the proposed toroidal propeller are summarized as follows:

- Outer Diameter: 320 mm
- Inner Diameter: 200 mm
- Pitch: 230 mm
- Loop Width: 20 mm
- Loop Spacing: 15 mm

### **Propeller Design and Manufacturing**

#### **Toroidal Propeller Geometry**

The toroidal propeller was designed with the following specifications:

- Diameter: 5.5 inches
- Configuration: Three-loop closed-tip structure.
- Airfoil: NACA 6412

#### **Twist Distribution:**

- Root angle:  $10^\circ$
- Tip angle:  $0^\circ$

#### **Manufacturing Method**

Both propellers were fabricated using 3D printing to enable precise replication of the design geometry and to assess the feasibility of additive manufacturing for UAV propellers. A commercial hub was used to ensure compatibility with standard BLDC motors.



3D Printed Toroidal Propeller

## Thrust Measurement

Thrust testing was conducted using an industrial thrust bench equipped with:

Load cell for direct thrust measurement Electronic Speed Controller (ESC)

BLDC motor

Benchmark data acquisition software

Thrust was measured across RPM values ranging from 1000 to 8000 RPM.

## Noise Measurement

Acoustic measurements were carried out in a controlled environment using calibrated microphones positioned around the propeller. Noise levels were recorded in decibels (dB) at identical RPM settings for both propellers.

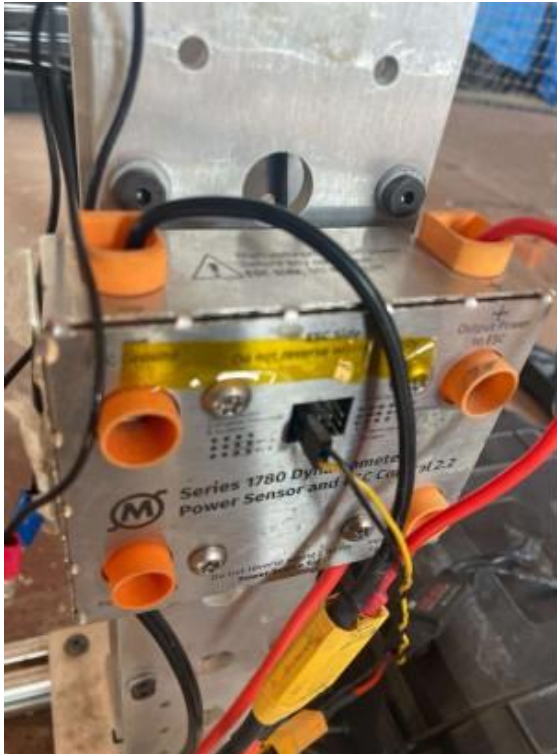
## Results and Discussion Thrust Performance

The conventional propeller consistently outperformed the toroidal propeller in thrust generation across all RPM levels. At 8000 RPM, the conventional propeller produced approximately four times higher thrust than the toroidal propeller.

This behavior is attributed to: Higher effective blade area

More efficient airflow acceleration

Lower structural blockage compared to toroidal geometry

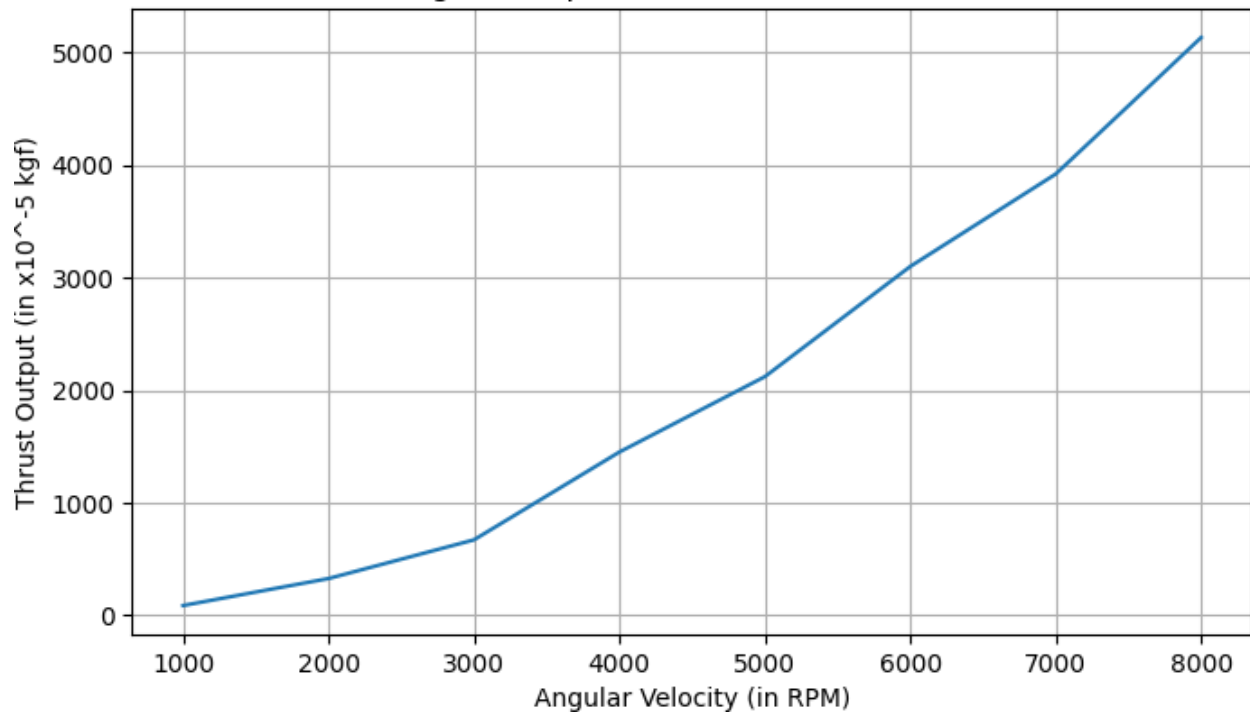


Electronic Speed  
Control Unit of the  
New Set Up (Thrust  
Bench)





### Regular Propeller Thrust Characteristics

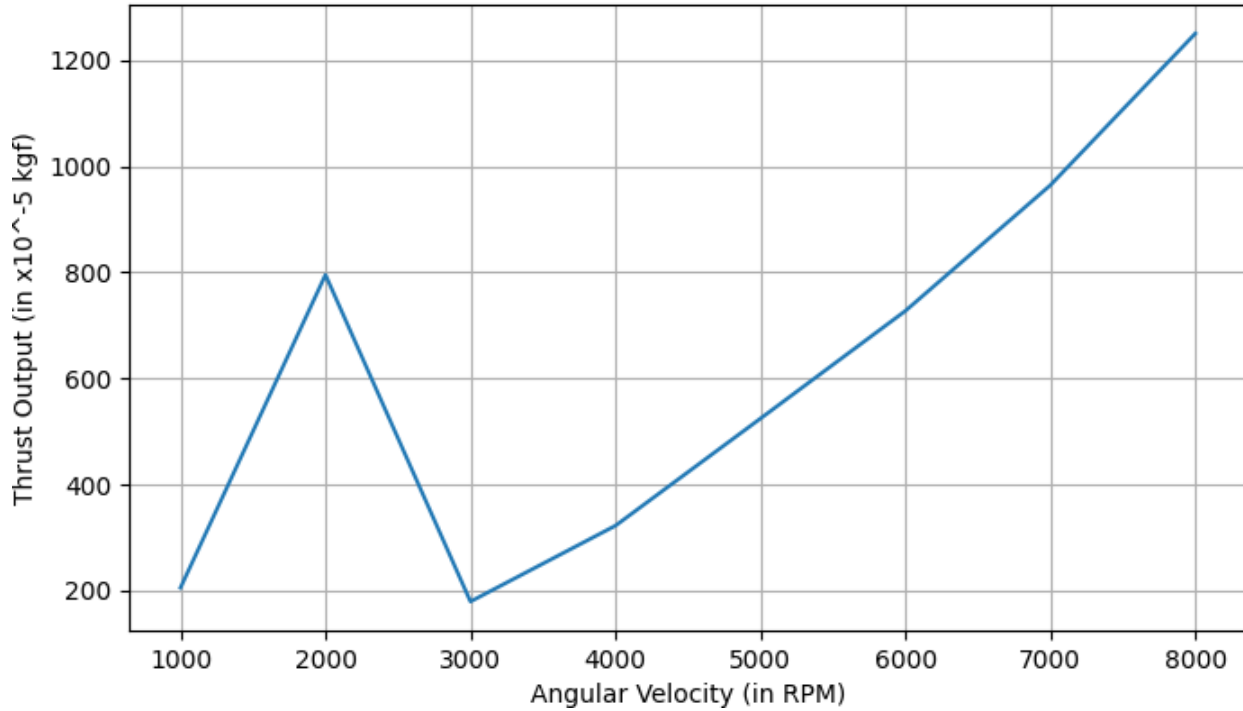


### b) Toroidal Propeller (3-Looped 5.5" Diameter)

RPM	Thrust (in $\times 10^{-5}$ KgF)
1000	205
2000	795
3000	179
4000	322
5000	524
6000	727
7000	964
8000	1250



### Toroidal Propeller Thrust Characteristics



#### Acoustic Performance

The toroidal propeller exhibited lower noise levels at low and medium RPM ranges. At 3000 RPM, noise reduction of approximately 5–6 dB was observed compared to the conventional propeller. At higher RPMs (above 7000 RPM), the noise advantage diminished, indicating increased turbulence and structural interaction within the toroidal loops.

#### Trade-Off Analysis

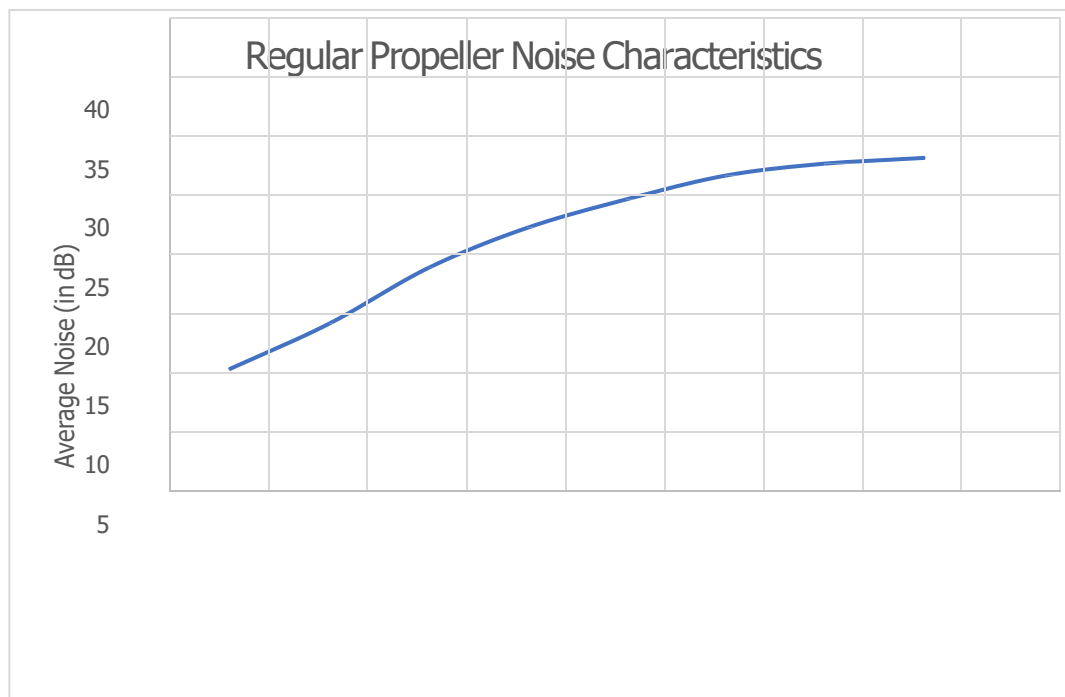
Pa		
Th		
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	endurance	Noise-sensitive missions



## Noise Characteristics

### a) Regular Propeller (3-Bladed, 5.5” diameter)

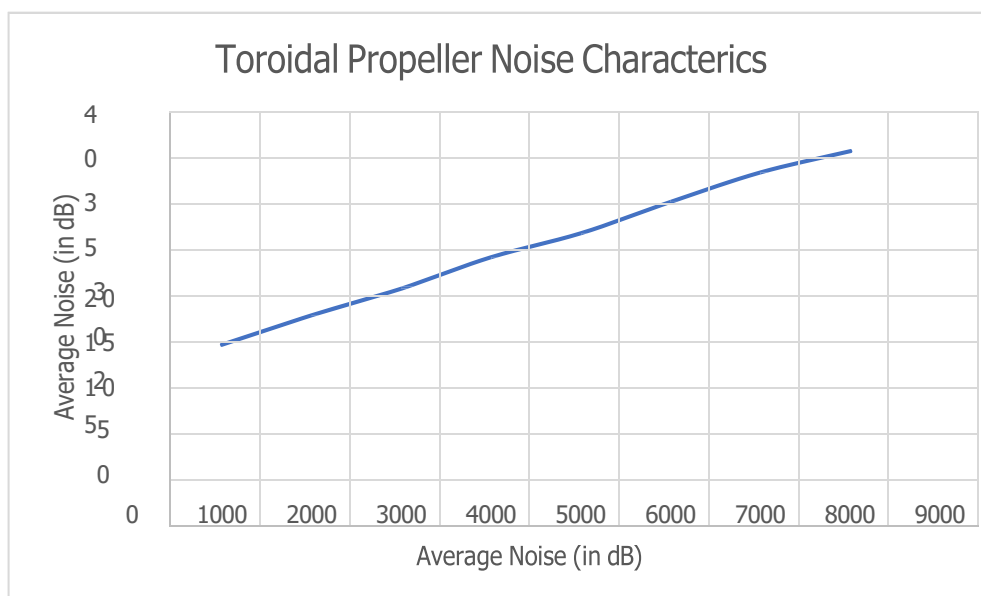
RPM	Average Noise (in dB)
1000	18.2
2000	22.0
3000	26.7
4000	30.1
5000	32.5
6000	34.5
7000	35.5
8000	36.0





### a) Toroidal Propeller (3-Looped, 5.5" diameter)

RPM	Average Noise (in dB)
1000	15.0
2000	18.2
3000	21.1
4000	24.5
5000	27.1
6000	30.5
7000	33.7
8000	36.0



### Conclusion

This study experimentally compared conventional and toroidal UAV propellers of identical size using thrust and noise measurements. The conventional propeller demonstrated superior thrust performance, making it suitable for payload-intensive and endurance-focused UAV missions.

Conversely, the toroidal propeller showed measurable noise reduction, validating its potential for applications such as urban surveillance, indoor UAVs, and research platforms where acoustic signature is critical.

The results confirm that toroidal propellers are not direct replacements for conventional propellers but represent a specialized solution where noise reduction outweighs thrust requirements. Future work may focus on optimizing toroidal geometries and materials to reduce weight penalties and improve thrust efficiency.



## Future Scope

- CFD-based optimization of toroidal propeller geometry
- Hybrid propeller designs combining open and closed tips
- Material strength analysis of 3D-printed propellers Flight testing on multirotor UAV platforms

## References

- Krmela, J. et al., Drone Propeller Blade Material Optimization Using Modern Computational Methods
- Ion, A. et al., Performance of 3D Printed Conventional and Toroidal Propellers for Small Multirotor Drones
- McCormick, B. W., Aerodynamics of V/STOL Flight