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An experimental study on investigation of noise and thrust performance for trailing-edge modified propellers

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Abstract: This study investigates the aerodynamic and aeroacoustic effects of biomimetic-inspired trailing-edge modifications on propeller performance. A half-hexagon serration model was applied to the trailing edge of a propeller, and a series of experimental tests were conducted to assess its impact on thrust generation and noise characteristics. In this experimental study, thrust tests and noise measurements were conducted on 15 different models at different propeller speeds. The results indicate that while all modified models exhibited lower thrust performance compared to the base model at higher Kv values (400 to 1200), some half-modified configurations (M02, M03, M06) demonstrated improved noise reduction capabilities. The M06 model achieved the highest noise reduction, approximately 11.75% at 50% RPM. Fully serrated models, on the other hand, had a limited effect on thrust but did not yield significant noise reduction benefits.

Keywords: Thrust Enhancement, Noise Reduction, Biomimetic Design, Propeller, Passive Flow Control

1. Introduction

Ensuring performance efficiency through flow control methods is a widely adopted approach in the aviation industry, particularly in applications aimed at improving aerodynamic performance. Flow control is employed for various purposes, such as enhancing lift, reducing drag, increasing thrust, and minimizing noise pollution [1–3]. Numerous flow control techniques have been introduced in the literature, which are generally categorized into two main types: active and passive control methods. Active flow control techniques function by modifying certain parameters during operation, thereby influencing the experimental setup and directing it toward the desired outcomes. In contrast, passive flow control techniques operate without external intervention during operation, relying on inherent design features to achieve control effects naturally [1]. Both types of flow control techniques influence aerodynamic profiles. However, passive methods often offer advantages in terms of simplicity and cost-effectiveness [4]. There are numerous examples of passive flow control applications tested on airfoils [5, 6], wind turbines [7], axial fans [8], ducts [9], and propellers [10]. In particular, propeller studies involving trailing-edge (TE) serrations demonstrate biomimetic modifications tailored to specific aerodynamic requirements. These applications involve the addition or removal of geometrical variations at different chordwise positions along the propeller blade [11].

▶**Table 1** presents the findings from recent modification studies conducted in the past few years. As can be clearly seen, these studies predominantly focus on modifications of two-bladed propeller types, featuring serrated, sinusoidal, rectangular, and flipper-shaped geometries. Biomimetic modifications involving the addition or removal of features on the propeller blade geometry have demonstrated improvements in both aerodynamic and aeroacoustic performance. These enhancements are typically observed in terms of increased thrust, reduced structural failures, and lower noise levels. Furthermore, the effectiveness of these modifications depends not only on the shape itself but also on the location along the blade where the modification is applied. Results from these studies indicate that a half-hexagon geometry—both wide and narrow—represents an untested configuration, depending on its position. Propeller modification studies have generally concentrated on noise reduction and thrust enhancement. Various bio-inspired geometrical configurations have been explored to improve thrust generation by incorporating their

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Table 1. Propeller Modification by Biomimetic

Ref.	Addition/ Extract	Material	Geometric properties	Propeller Type	Position	Effect
[12]	Addition	Aluminium Plate	10 mm × 20 mm With a Thickness of 1 mm	Phantom3	Trailing Edge	Reduction in noise
[13]	Extract		-	2 Blades	Tip	Reduction in Noise and thrust performance
[14]	Addition	Composite Material	Diameter 0.254 m	2 blades	From the center to the tail edge	Reducing structural failures and increasing durability in low temperature conditions
[15]	Addition	Carbon Fiber	P17 × 5.8 carbon fiber, diameter of 431.2 mm and a pitch of 147.3 mm	2 blades	5 mm from the wing tip (3/4 distribution length, 120 mm)	Noise reduction, increase in thrust
[16]	Extract		radius (R) of 241.3 mm	2 blades	Starting from 0.5R (R=241.3 mm) on TE to the tip of the wing	Noise Reduction
[17]	Addition	Vero white	10 x 3 x 0.3 inches	DJI 9450S 2 blades		Noise reduction and acceleration of vortex breakup and dissipation process
[18]	Addition		Radius 0.103m, radial position 0.0163 m	2 blades	At Trailing edge	Noise reduction and reduction in drag forces.
Present Study	Extract	ABS Plastic	Length: 15.24 cm (6 in) Center hole diameter: 5mm	KingKong 6040R 2 Blade	0.008R and 0.011R position at TE	Thrust improvement

structural characteristics into propeller blade design [19]. Özyurt and Akbıyık (2025) examined the impact of biomimetic-inspired grooves on drone propellers and their effect on thrust performance [20]. In their study, Ning and Hu (2016) demonstrated that varying the width-to-height ratios in UAV propellers alters the aerodynamic forces and aeroacoustic characteristics generated by the propeller [21]. Butt and Talha (2019) investigated the addition of leading-edge (LE) tubercles on propellers, examining the effects of changes in wavelength and amplitude. Their findings showed delayed flow separation, reduced tip vortices, and modified flow fields around the blade [22]. A study by Yang and Wang et al. (2020) focused on trailing-edge (TE) modifications through both addition and removal methods, targeting noise reduction and aerodynamic performance enhancement [11]. Inspired by the serrated structure of owl wings, Wei and Xu et al. (2020) integrated this design into the LE of propellers, leveraging the owl's silent flight capabilities. Their study tested five different geometries—hook, flaplet, wave, sawtooth, and plate—and compared thrust force and aeroacoustic performance against analytical results [23]. Wei and Qian et al. (2021) selected three modification types and compared their thrust and noise performance using experimental data obtained at high Reynolds numbers [15]. Santamaria et al. (2025) calculated noise reductions resulting from trailing-edge serrations applied to several representative UAV propellers using a low-order methodology [24]. Finally, Chen et al. studied the effects of half-flat-tip trailing-edge serrations on rotating blades. Their design, featuring both wide and narrow configurations, was applied to the propeller, and both models were found to be effective in noise reduction [16].

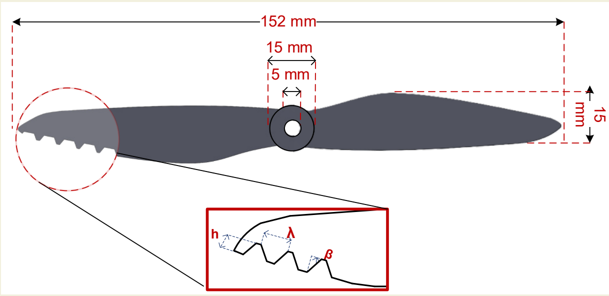

Figure 1. Propeller modification design

In this study, the half-hexagon model, as illustrated in ▶**Figure 1**, is employed. Modifications involving slope angle, amplitude, and chordwise location are applied in various combinations to investigate their effects on thrust performance. While many previous studies have explored similar modifications individually, none have examined all of these parameters collectively. This paper aims to address this gap by systematically evaluating the combined effects of these configurations. Accordingly, the primary objective of this research is to analyze the influence of biomimetic-inspired passive flow control modifications on both thrust performance and acoustic emissions, thereby providing valuable insights into the effectiveness of passive techniques in aerodynamic applications.

2. Materials and Method

In this study, the aerodynamic performance of the KingKong6040 propeller—self-tightening and made of ABS plastic—is experimentally evaluated across a range of RPM values. The propeller has a length of 6 inches, a pitch of 4 inches, and a center hole diameter of 5 mm. As illustrated in ▶**Figure 1**, a half-hexagon modification has been applied to the trailing edge of the selected propeller blade. These modifications were created using a laser cutter (model name to be specified). The primary parameters investigated in this study are the slope angle, amplitude, and chordwise location, as detailed in ▶**Table 2**. The slope angle (β) is set to 15°, 30°, and 45°, based on the findings of Howe (1991), which indicate that maximum efficiency is achieved when the slope angle does not exceed 45° [25]. Additionally, modifications are applied at chordwise positions ranging from 0.5R to the trailing edge, as well as at the full chord length. The wavelength (λ) of the half-hexagon geometry is set to 0.025R and 0.0125, based on the chord length. The modification height (h) is kept constant, while different λ/h ratios are investigated. According to Howe (1991), configurations with λ/h ratios smaller than 4 yield better aerodynamic performance. Therefore, λ/h ratios of 1 and 2 are selected for this study [25].

Table 2. Parameters of the present study.

Parameters	Values
Position	From TE to 0.5R, Full of chord
β (degree)	15°, 30°, 45°
λ (mm)	0.02R, 0.014R
h (mm)	1, Constant
λ/h	2, 3

In addition to the base propeller, half-chord cut propeller, and fully chord cut propeller, 12 additional propellers with variations in length, number, and aspect ratio are used, bringing the total to 15 propellers. The details of the modification parameters are presented in ▶**Table 3**.

The thrust measurement system utilized in this study is illustrated in ▶**Figure 2**. It comprises a Honeywell Model-41 series load cell, an RW-ST01A signal amplifier, a CCPM Servo Consistency Master (functioning as a servo tester), a brushless motor, an ESC, a propeller, and power supplies. The motor–ESC pair consists of the A2212 brushless motor and a 30A ESC, which are commonly used for thrust force measurements. The servo tester is used to adjust the RPM range, while power is supplied by an AA-Tech ADC-3050DD unit. The propeller rotates counterclockwise, and the resulting thrust force is directed upward, as established in the literature [26]. The experimental environment is maintained at a constant room temperature of 24 °C, with atmospheric pressure held at approximately 101.3 kPa. According to Coleman and Steele (1995) [27], the uncertainty of the thrust measurement system is estimated at approximately 1.433%, considering factors such as load cell accuracy, the manufacturing quality of connecting components, and the use of laser-cut propellers.

Table 3. Specification of the models

#	Modified Models	Design Parameters			
		h (mm)	λ (mm)	λ/h	β (°)
BM		-	-	-	-
HCC		-	-	-	-
FCC		-	-	-	-
M01		1	0.75	2	15°
M02		1	0.4	2	30°
M03		1	0.07	2	45°
M04		1	1.25	3	15°
M05		1	0.9	3	30°
M06		1	0.5	3	45°
M07		1	0.75	2	15°
M08		1	0.4	2	30°
M09		1	0.07	2	45°
M10		1	1.25	3	15°
M11		1	0.9	3	30°
M12		1	0.5	3	45°

▶**Figure 3** shows the noise measurement system for the motor-propeller system. The HyperX QuadCast S microphone is used to measure the noise level in the system. The microphone is positioned perpendicular to the motor-propeller system. It has four selectable polar pattern settings. For this study, the omnidirectional

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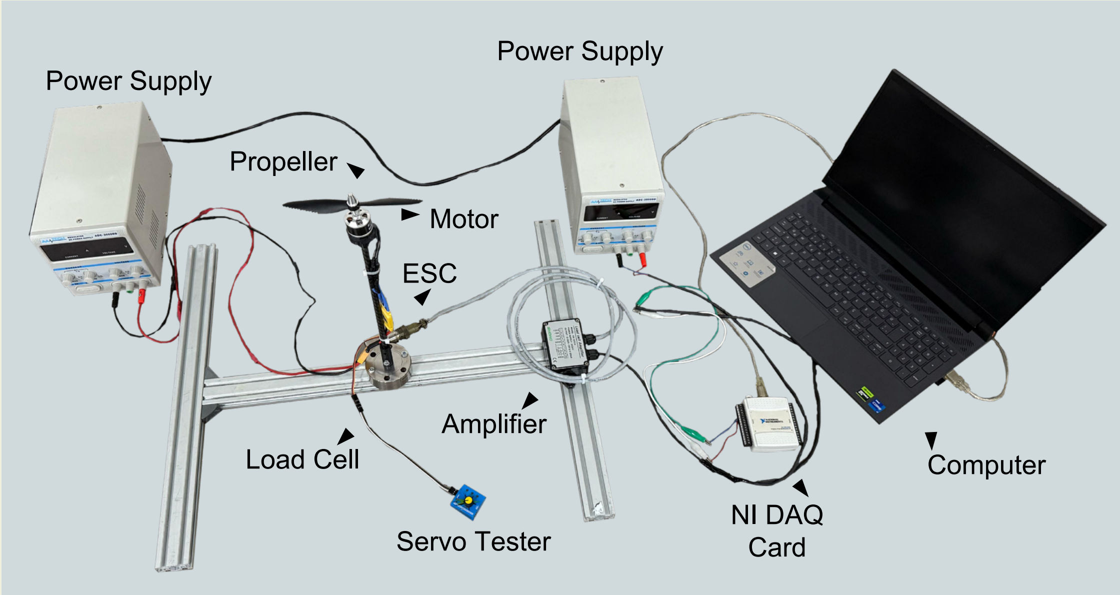

Figure 2. Motor-propeller combination stands for thrust measurement

mode was selected in order to capture all possible noise around the entire system. The noise measurements were conducted in an empty room.

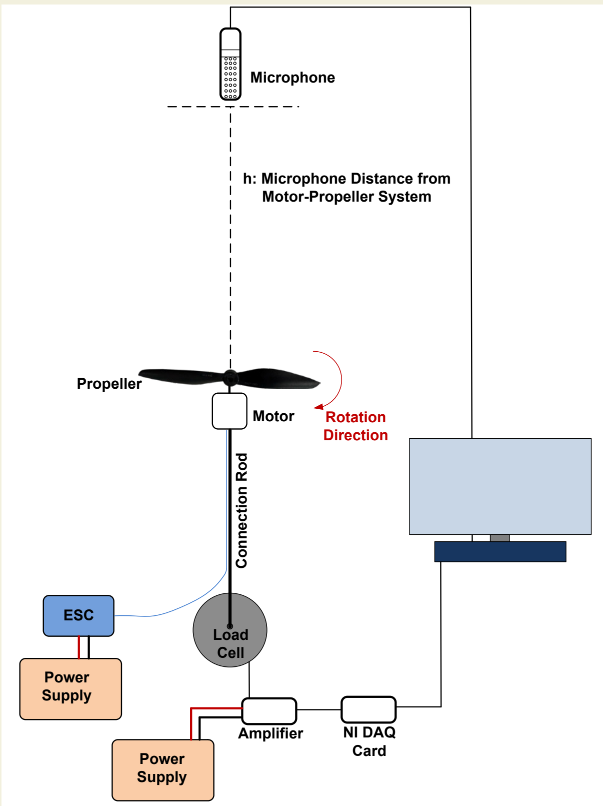

Figure 3. Schematic view of noise measurement system

3. Results and Discussion

►**Figures 4 to 6** illustrate the thrust (in grams) and noise (in decibels) measurements for both the base and modified models. Thrust values were measured across various Kv values (RPM/V), while noise levels were recorded at different rotational speeds (expressed as %RPM). ►**Figure 4** presents a comparative analysis of thrust values for the base model, the half-chord cut (HCC) model, and the full-chord cut (FCC) model. It is observed that the thrust values decrease when the base model is modified by reducing the effective lift area. The variation in thrust reduction is observed to be directly related to the rotational speed (RPM).

►**Figure 5** presents the thrust and noise measurement results for the base and partially modified models. An analysis of the thrust results reveals that the base model achieves higher thrust values compared to all modified configurations. However, noise level measurements indicate that the M06 model exhibits the lowest noise levels at higher rotational speeds. The modifications are observed to contribute to the reduction of vortices formed behind the high-speed rotating propellers. A maximum noise reduction of approximately 11.75% was observed at 50% RPM for the M06 model. Bahrom et al. (2023) demonstrated that the thrust coefficient of propellers with a half-serrated trailing-edge modification decreases compared to the base model [28]. They also reported that as the RPM increases, the thrust force is reduced by nearly 50% or more. Although the geometry used in the present study differs from that in the study by Bahrom et al. (2023), the observed thrust reduction is notably smaller [28]. Gu et al. (2024) conducted another study on half-serration, applying owl-inspired modifications to the trailing edge of the propeller [29].

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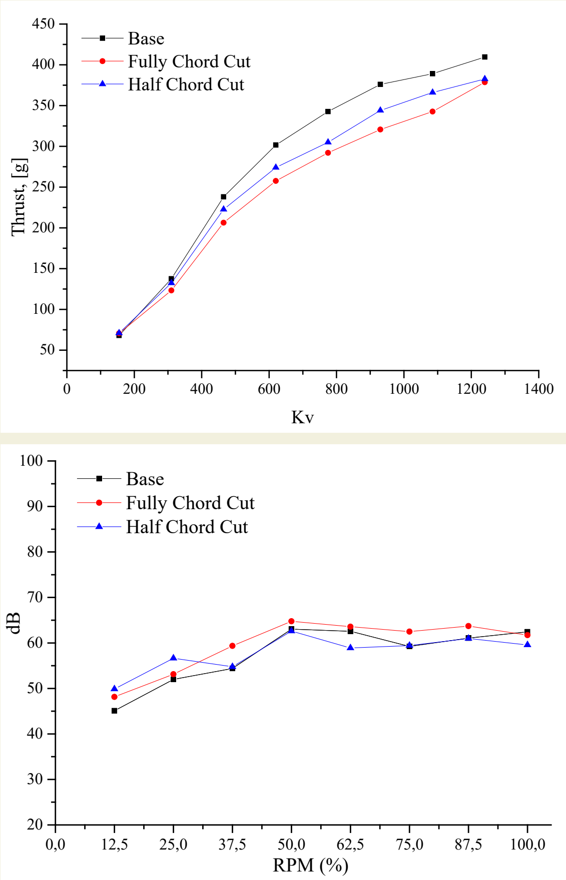

Figure 4. Thrust and noise measurement results for base, HCC and FCC models

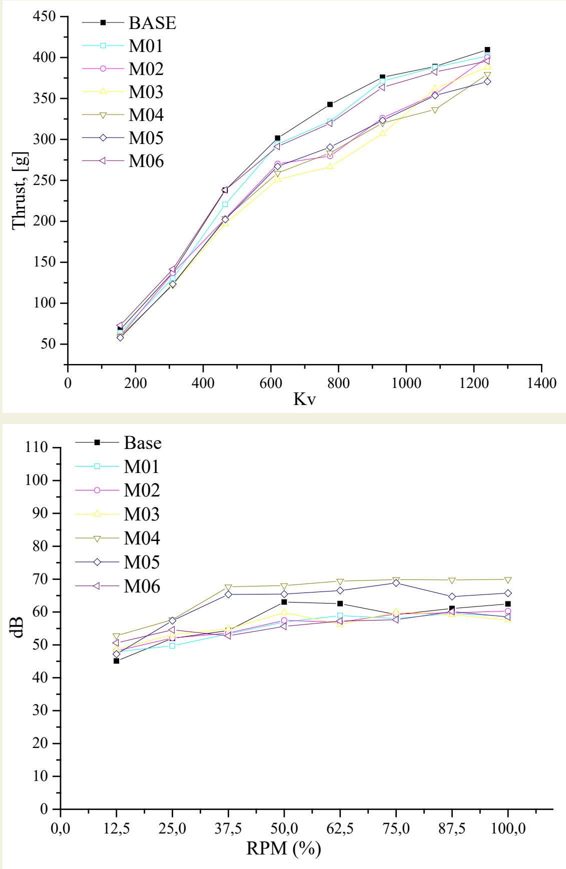

Figure 5. Thrust and noise measurement results for base and half-modified models

They investigated variations in thrust and noise, achieving a noise reduction of up to 60%. This was achieved using both sharp and rounded serrations with varying geometric parameters in the experimental setup. In the present study, the effects of similar design parameters were examined with several variations, yielding promising results. These findings highlight the potential of continued variation-based investigations to yield valuable outcomes in this field.

▶Figure 6 presents the thrust and noise measurement results for the base and fully modified models. Analysis of the fully modified configurations revealed that the M07 model achieved the greatest noise reduction at higher RPM values. Moreover, the thrust performance of the M7 model was found to be almost identical to that of the base model. Lee et al. (2019) reported a 5.8 dB noise reduction with the use of a TE serrated propeller; however, this also resulted in a 15.3% decrease in aerodynamic performance [13]. Similarly, Ning et al. (2017) investigated fully modified serrated propellers and found localized reductions in noise levels [30]. They also concluded that deformation of the serrations could decrease aerodynamic performance and potentially increase noise levels. It can be concluded that geometrical modifications to the propeller's TE have a limited effect on thrust performance. Furthermore, the experimental

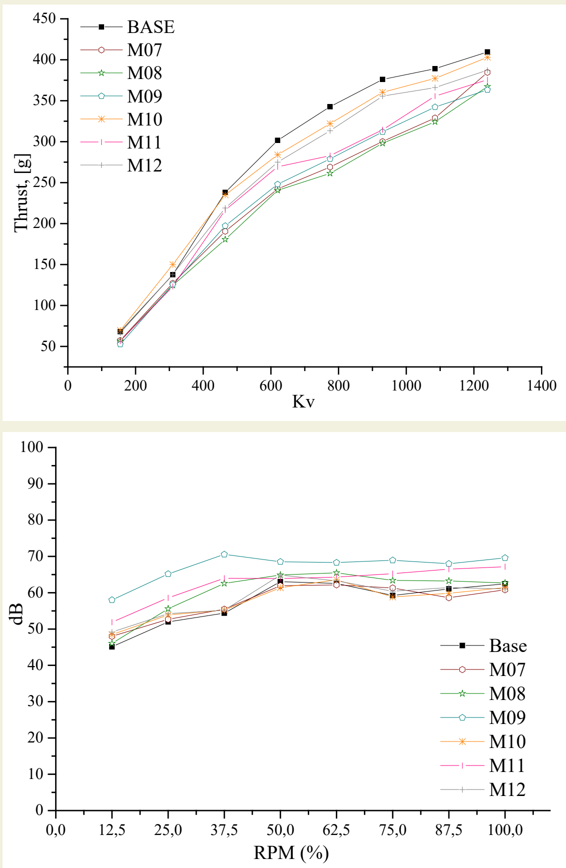

Figure 6. Thrust and noise measurement results for base and fully modified models

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results indicate that further research on these geometric modifications is necessary to fully understand their impact on noise levels.

4. Conclusion

Studies have shown that trailing-edge serrations effectively reduce airfoil self-noise. However, their impact on airfoil aerodynamic performance is not yet fully understood, posing significant challenges for UAV manufacturers in designing serrations. Moreover, most serration implementations are retrofitted as add-ons to the original airfoil geometry. While this approach is acceptable in wind turbine applications, it may negatively affect UAV flight endurance due to increased drag and weight.

This study experimentally investigates the effect of varying half-hexagonal tubercles along the TE of the propeller. A base model, full-chord cut ,half-chord cut, and twelve different configurations were studied. Thrust performance and noise reduction experiments were conducted at eight different rotational speeds. The key findings are summarized as follows:

- All modified models thrust are lower than base model for higher thrust values
- M06 model thrust value are nearly same as the base model for low thrust values (under 50%)
- Both fully cut and half-cut models have no effect on thrust and negatively impact it. The primary reason for this is the reduction in the lifting area as a result of the modification.
- No significant effect on noise reduction has been observed for the half-cut and fully cut models; however, noise reduction has been observed when modifications are applied.
- For more noise reduction half cut models better than fully cut models
- Some half-cut models (M02, M03, M06) performed better than the base model across almost all RPM values
- The maximum noise reduction of approximately 11.75% was observed at 50% RPM for the M06 model

In light of these findings, it is evident that this area holds significant potential for future research. Beyond the geometric modifications applied in this study, further research exploring a broader range of parameters is recommended to gain deeper insights.

Research ethics

Not applicable

Artificial Intelligence Use

The author declares that no generative artificial intelligence (e.g., ChatGPT, Gemini, Copilot, etc.) was used in any part of this study.

Author contributions

The author solely conducted all stages of this research.

Competing interests

The author states no conflict of interest.

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Data availability

The raw data can be obtained on request from the corresponding author

Peer review

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