Chapter 19

AeroFeathers: Biomimetic Propellers with 3D-printed Flexible Fibres for Quieter Drones

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Abstract

Excessive noise generated by drone propellers remains a major barrier to the widespread acceptance of unmanned aerial vehicles (UAVs), especially in urban and noise-sensitive environments. Traditional approaches to mitigating propeller noise typically replicate bioinspired features such as rigid leading-edge serrations, which only partially capture the complex mechanisms underlying the exceptionally quiet flight of owls. In contrast, this research introduces AeroFeathers, a novel additive manufacturing (AM) technique that enables the direct 3D printing of thin, flexible, hair-like fibres onto propeller surfaces, closely mimicking the compliant, fringe-like structures found in owl feathers. Using low-cost, consumer-grade material extrusion printers combined with customised G-code, we precisely control fibre characteristics including thickness, flexibility, and density—achieving microstructures previously unattainable through conventional manufacturing. Experimental validation in Michigan Tech's anechoic chamber demonstrates significant aeroacoustic improvements, with reductions of up to 5 dB in overall sound pressure level while maintaining comparable thrust performance to unmodified propellers. By uniquely leveraging flexible fibres rather than rigid serrations, AeroFeathers unlocks a new capability for noise suppression in UAVs. This innovation offers a scalable, accessible pathway toward quieter drones, addressing a critical societal need for reduced environmental noise—with direct benefits for public well-being and health futures—and paving the way for sustainable, resilient infrastructure through a new era of quiet, community-friendly mobility and transportation.

Keywords: *Additive Manufacturing, Biomimetic Propellers, Aeroacoustics, Noise Reduction, Unmanned Aerial Vehicles (UAVs)*

Introduction

Small unmanned aerial vehicles (UAVs) have rapidly proliferated in applications ranging from delivery to surveillance, but their high-pitched noise has emerged as a key barrier to public acceptance[1]. The characteristic whining sound of drone propellers can cause community disturbance and trigger strict noise regulations, especially in urban environments. Conventional propellers are typically designed for aerodynamic performance rather than low noise[2], leaving an unmet need for noise-reducing designs

[1] Ning Wang, Nico Mutzner and Karl Blanchet, "Societal acceptance of urban drones: A scoping literature review." *Technology in Society* 75 (2023): 102377.

[2] Randolph Cabell, Ferdinand Grosveld, and Robert McSwain, "Measured noise from small unmanned aerial vehicles." In *Inter-Noise and Noise-Con Congress and Conference Proceedings*, vol. 252, no. 2, pp. 345-354. Institute of Noise Control Engineering, 2016.

that do not compromise thrust. Reducing the acoustic signature of UAVs would not only improve the quality of life in populated areas but also enable drones to be used more freely in noise-sensitive applications such as wildlife monitoring and urban delivery operations.

Nature offers inspiration for quiet flight: owls, for example, are renowned for near-silent flight due to unique feather adaptations[3]. Researchers have identified three key owl wing features responsible for noise suppression[4]: comb-like serrations along the leading edge, a flexible trailing-edge fringe on the feathers, and a soft downy coating on the wing surface. These structures alter airflow in ways that dampen turbulence and reduce the generation and propagation of sound.

While these principles are well-understood, translating them into effective engineered solutions has been hindered by a persistent and critical barrier: manufacturability. Previous bio-inspired attempts have largely focused on replicating single features, such as rigid, sawtooth-like serrations on the trailing edge[5,6]. These designs, often fabricated as simple two-dimensional add-ons, only partially capture the owl's complex acoustic mechanisms and can introduce aerodynamic penalties. The most challenging and potentially most effective features—the flexible trailing-edge fringe and the three-dimensional downy coating—have remained largely inaccessible to conventional manufacturing workflows[7].

This paper introduces AeroFeathers, a novel approach that overcomes this fabrication barrier, enabling the complete suite of an owl's acoustic features to be realised on a propeller in a single, integrated process. The core innovation of this work is a new additive manufacturing technique that creates complex, multi-scale, flexible bio-inspired structures directly on a propeller blade. Our approach moves beyond simple geometric modifications and treats the propeller surface as a functional, designable acoustic material rather than a rigid body.

Fabrication of Biomimetic Propeller Features

We developed a custom algorithm and slicing strategy for Fused Deposition Modelling (FDM) 3D printing that allows us to fabricate not only rigid serrations but also features previously considered too fine and complex for this process. The key breakthrough is our ability to print a high-density array of thin, flexible, hair-like microfibres that closely mimic the downy feathers of an owl. This "fur-like" surface is generated by programming a standard FDM printer to extrude molten thermoplastic filament at exceptionally high travel speeds, causing the material to stretch into fine, compliant hairs[8].

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[3]R. R. Graham, "The silent flight of owls." *The Aeronautical Journal* 38, no. 286 (1934): 837-843.
[4]Justin W. Jaworski and Nigel Peake, "Aeroacoustics of silent owl flight." *Annual Review of Fluid Mechanics* 52, no. 1 (2020): 395-420.
[5]Chen Rao et al., "Owl-inspired leading-edge serrations play a crucial role in aerodynamic force production and sound suppression." *Bioinspiration & biomimetics* 12, no. 4 (2017): 046008.
[6]Dian Li et al., "Effect of trailing-edge serrations on noise reduction in a coupled bionic aerofoil inspired by barn owls." *Bioinspiration & biomimetics* 15, no. 1 (2019): 016009.
[7]Hermann Wagner et al., "Features of owl wings that promote silent flight." *Interface focus* 7, no. 1 (2017): 20160078.
[8]William Johnston and Bhisham Sharma, "Additive manufacturing of fibrous sound absorbers." *Additive Manufacturing* 41 (2021): 101984.

This technique provides precise control over the placement, density, thickness, and flexibility of these fibrous structures, allowing us to create a toolkit of owl-inspired aerodynamic noise treatments:

1. Leading-Edge Serrations: Stiff, comb-like protrusions along the leading edge to break up large-scale inflow turbulence before it impinges on the blade.
2. Trailing-Edge Fringe: A row of fine, flexible serrations along the trailing edge to disrupt and scatter the vortex shedding responsible for broadband noise.
3. Fur-Like Surface Coating: A dense carpet of minute, compliant fibres on the blade's surface designed to dampen small-scale turbulent eddies directly at the source.

Crucially, all of these features can be fabricated in a single, integrated workflow on a low-cost FDM printer using standard materials like PLA thermoplastic. This eliminates the need for complex multi-part assembly, adhesives, or secondary processing steps. The result is a scalable and accessible pathway to produce propellers with a full suite of bio-inspired acoustic treatments. Figure **1** illustrates the owl-inspired micro-structures fabricated on our prototype propellers.

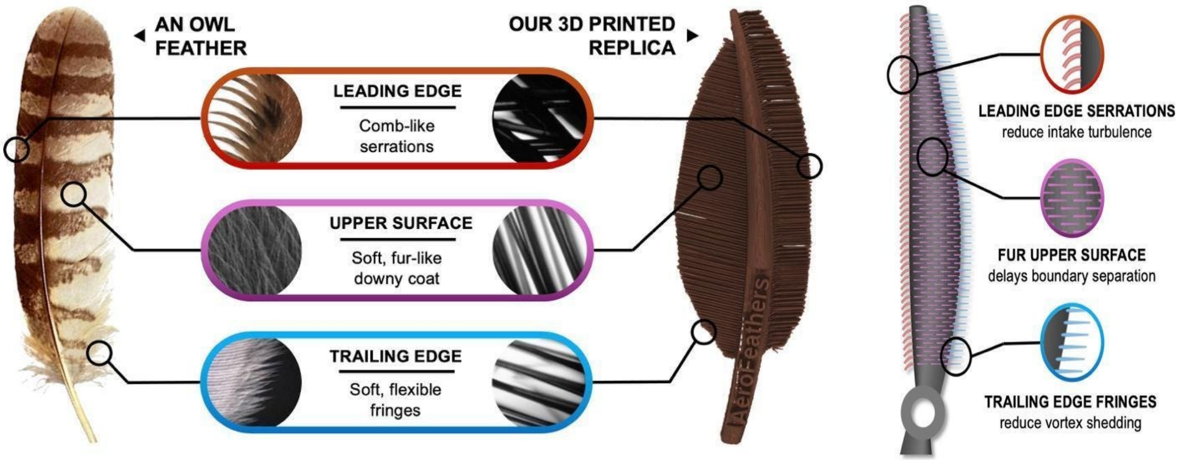


Figure 1: (Left) Our 3D printed replica closely resembles a natural owl feather's three components; (right) the three components are implemented onto a drone propeller blade as a target application.

Experimental Validation

To validate the effectiveness of our fabrication method, we designed and tested several propeller prototypes (Figure **2**), each incorporating different combinations of owl-inspired features, and compared them against an unmodified baseline propeller of the same size and planform. The prototypes included configurations with individual features implemented in isolation (e.g. only leading-edge serrations, only a trailing-edge fringe, or only the fur-like coating) as well as a combined design integrating all three features.

All propellers were evaluated under identical conditions in a certified anechoic chamber to ensure that acoustic measurements were free from environmental reflections. Each propeller was mounted on a test stand equipped with a calibrated microphone to capture its full acoustic signature, and on a high-precision load-cell thrust stand (Tyto Robotics RCbenchmark Series 1580) to measure aerodynamic performance. This dual measurement setup allowed us to verify that any noise reduction did not come at the expense of thrust or efficiency. We focused our tests on rotational speeds representative of a small quadcopter's typical hover and cruise conditions.

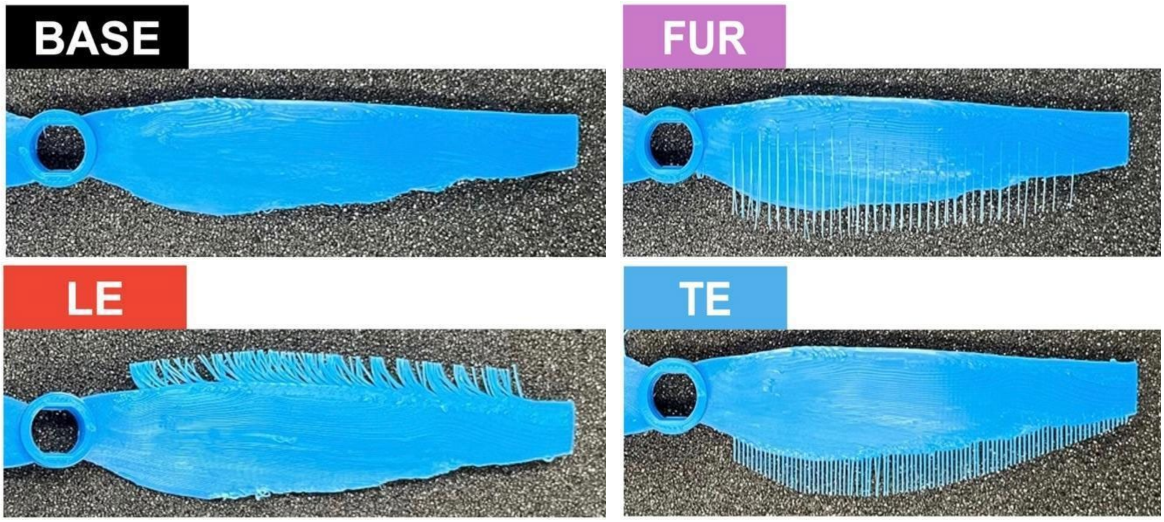
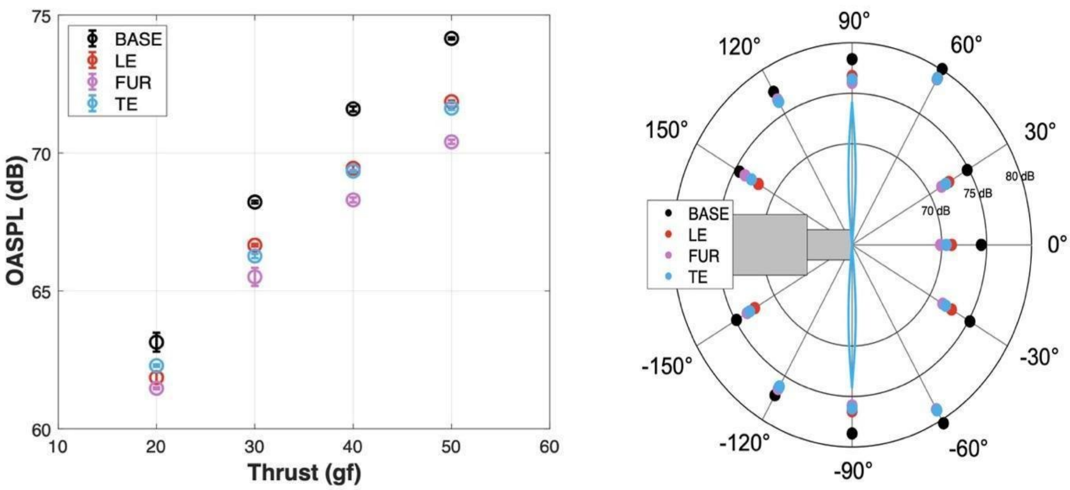


Figure 2: Photos of printed AeroFeather propeller blades compared to a clean BASE blade without any modifications.

Results and Discussion

Across all tested thrust levels, the bio-inspired prototypes were consistently quieter than the baseline propeller, confirming that the owl-inspired features provide significant acoustic benefits without compromising aerodynamic performance. The most significant result was achieved by the prototype featuring the fur-like surface coating—a feature exceptionally difficult to fabricate by traditional means. As shown in Figure 3a, this configuration achieved a noise reduction of approximately 5 dB (A-weighted) at a thrust of 50 gf, a typical hover condition for a small UAV. A 5 dB reduction corresponds to roughly a 68% decrease in acoustic energy, a substantial and perceptually significant improvement that can transform a drone's intrusive whine into a much softer sound profile. This dramatic noise reduction is directly attributable to our ability to 3D-print a dense, flexible fibre array that effectively damps the small-scale turbulence on the blade's surface—a mechanism central to the owl's silent flight.



(a) (b)

Figure 3: (a) Overall sound pressure level (OASPL) performance at variable thrust levels; (b) directional OASPL plot at constant 50 gf thrust and 0.1 m microphone distance.

Directional measurements (Figure **3**b) confirm that the noise reduction is not confined to a narrow angle but is present across the entire forward hemisphere. The effect is most pronounced directly in front of the propeller's axis of rotation, indicating a genuine reduction in overall acoustic output rather than merely redirecting the noise to a different direction.

Equally important, these acoustic benefits were achieved with no aerodynamic penalty. Figure **4** shows that all AeroFeathers-modified propellers matched or even slightly exceeded the thrust output of the baseline propeller at equivalent rotational speeds. Furthermore, the power required to produce a given thrust was the same as, or slightly lower than, that of the baseline, indicating a minor improvement in propulsive efficiency for the modified blades. This result overcomes a common trade-off in aeroacoustics, where noise reduction often comes at the cost of performance.

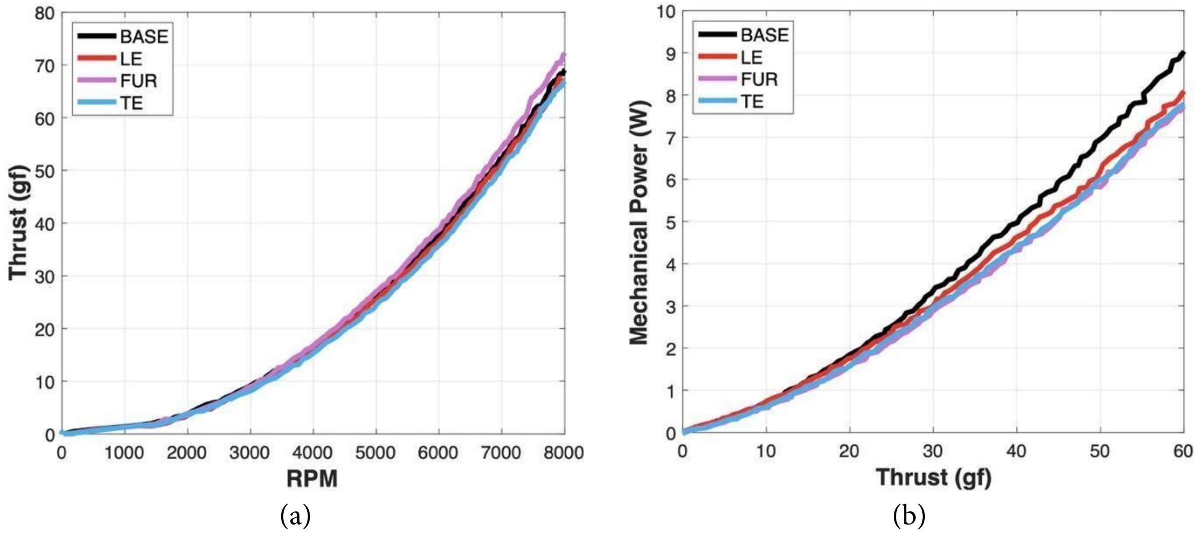


Figure 4: (a) Thrust performance compared to an untreated BASE blade; (b) mechanical power required to produce a given thrust.

Conclusion

We demonstrate a significant step forward in the development of low-noise UAV propellers. The core breakthrough presented here is not merely a new propeller shape, but a novel and accessible additive manufacturing workflow that successfully replicates the complex, multi-scale and flexible acoustic features of an owl's wing. By overcoming the fabrication barriers that have limited previous research, we have shown that features such as a downy, fur-like coating can be applied to a functional propeller in a single manufacturing step.

Our anechoic chamber tests provide clear validation: these 3D-printed biomimetic features can reduce propeller noise by up to 5 dB without any loss of thrust or efficiency. This innovation offers a scalable, cost-effective pathway to mitigate one of the most significant barriers to widespread UAV adoption – their acoustic signature. Quieter UAVs will have profound societal benefits, enabling drone operations in noise-sensitive environments, improving public well-being and acceptance, and paving the way for a future in which drones integrate harmoniously and sustainably into our communities.

Acknowledgements

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