

Double-Helix Propeller Design: aerodynamic Efficiency Optimisation

An Investigative Research Paper on the Aerodynamics of Looped-Blade Rotors

Atharva Chhalotre

Class XII (Science Stream) - Physics, Chemistry & Mathematics MKH

Sancheti School, Wardha Road, Nagpur, India

Abstract - Propellers have kept more or less the same shape for over a hundred years: two or more flat blades spinning around a central hub. Recently, engineers at MIT Lincoln Laboratory introduced a "toroidal" propeller — two blades that loop back into each other, forming a closed double-helix shape. The design was made mainly to reduce noise, but it raised an interesting question for me: can this unusual geometry also be made aerodynamically efficient, or does the strange shape always cost performance? In this paper I study the physics behind the double-helix (toroidal) propeller using blade element momentum theory, compare published experimental and simulation data from conventional and toroidal propellers, and analyse which design parameters (number of loops, pitch distribution, tip closure, and manufacturing method) most affect efficiency. My analysis shows that the double-helix design pays a small efficiency penalty at low speeds because of added wetted area and induced interference between the two loops, but that careful optimisation of pitch and loop radius can recover most of the lost efficiency while keeping the big noise advantage. I end by proposing a simple, low-cost experimental procedure that a student could actually perform with 3D-printed prototypes and a basic thrust stand.

Keywords: toroidal propeller, double-helix rotor, blade element momentum theory, aerodynamic efficiency, tip vortices, drone propulsion

1. INTRODUCTION

When I first saw a video of a drone flying with propellers that looked like twisted loops of ribbon, I honestly thought it was a computer-generated animation. The propeller had no sharp tips at all — the two blades curved around and joined each other, making a shape that reminded me of the double helix of DNA, which we study in biology. It turned out to be a real invention: the toroidal propeller, developed by Dr. Thomas Sebastian and his team at MIT Lincoln Laboratory, which won an R&D 100 Award in 2022 and is covered under U.S. Patent 10,836,466 [1].

The main motivation behind the design was noise. Anyone who has heard a drone up close knows the annoying, high-pitched buzzing it makes. A lot of that noise comes from the vortices (tiny tornadoes of air) that spin off the tips of normal propeller blades. The toroidal design removes the free blade tip entirely — each blade tip curves back and merges into the other blade — so the strong tip vortex is largely cancelled. According to MIT Lincoln Laboratory, tests on commercial quadcopters showed thrust levels comparable to conventional propellers at similar power, while the reduced sound allowed the drone to operate at half the distance before it became annoying to human hearing [1].

But noise was never my only interest. As a physics student who wants to study aerospace engineering, I kept asking a different question: what happens to efficiency? A propeller that is quiet but wasteful would be useless for delivery drones that need long flight times. In this paper I therefore focus on the aerodynamic efficiency of the double-helix design — how much useful thrust it produces for a given amount of shaft power — and on how its geometry could be optimised.

The paper is organised as follows. Section 2 reviews the basic aerodynamics of propellers and the theoretical tool I use (blade element momentum theory). Section 3 summarises what published studies have found about toroidal and contra-rotating propellers. Section 4 describes my method of analysis. Section 5 presents the analysis itself, including a simple parametric comparison. Section 6 discusses the results and their limitations, and Section 7 concludes with suggestions for future work

— including experiments I hope to carry out myself.

closed structure. MIT Lincoln Laboratory reports that this closed form minimises the drag effects of the swirling vortices created at blade tips and also stiffens the whole propeller, reducing its acoustic signature [1]. Importantly for my question, they also report that prototype toroidal propellers on commercial quadcopters achieved thrust comparable to conventional propellers at similar power levels — in other words, the design did not obviously destroy efficiency [1].



Figure 2. A toroidal (double-helix) propeller. Note the absence of free blade tips — each blade loops into the other (image: MIT Lincoln Laboratory).

The most useful independent study I found is by Alm and co-workers at Oral Roberts University, published by the American Society for Engineering Education in 2024 [2]. They tested six propellers — conventional 2-blade, 3-blade, and toroidal designs in both 3D-printed resin and injection-moulded versions — on a Tyto Robotics Series 1585 thrust stand inside a safety cage, measuring thrust, torque, RPM, power and sound level, and they cross-checked results with Ansys Fluent CFD simulations. Their findings are nuanced: the traditional 2-blade propeller produced the highest thrust overall, but the 2-blade injection-moulded toroidal propeller was a strong performer and clearly quieter than the others. Interestingly, the 3-blade and 4-blade 3D-printed toroidal propellers had both lower thrust and higher sound than the 2-blade toroidal, which tells us that simply adding more loops is not automatically better [2].

3.2 Related idea: contra-rotating propellers

The double-helix idea is related to a much older concept: contra-rotating propellers, where two propellers spin in opposite directions on the same axis. A study in the Chinese Journal of Mechanical Engineering showed that a contra-rotating system improves propulsion efficiency by recovering part of the energy normally lost in the rotational (swirl) component of the slipstream [4]. More recently, SINTEF reported that contra-rotating propellers can make ships more than ten percent more energy efficient than conventional propellers [5]. The connection to the toroidal design is the theme of this paper: clever blade arrangements can reclaim energy that a simple open blade wastes at its tips and in its wake — but they add mechanical complexity, which is why contra-rotating propellers never became common on aircraft [6].

3.3 Propeller optimisation studies

There is a healthy body of work on optimising propeller geometry. Peixun and co-workers (2020) optimised a propeller for both aerodynamic and acoustic performance and reduced the maximum total sound pressure level by about 5 dB [10]. Nabid (2023) studied small propellers and found that blade twist angle distribution is one of the most important parameters for small-scale efficiency [11]. Clarke and colleagues at Stanford demonstrated aerodynamic optimisation of wing-mounted multi-propeller systems in the SUAVE design environment [12], and Popișter et al. (2025) showed that 3D-printed propellers in PETG and other materials, while convenient, generally cannot yet match conventionally manufactured propellers in performance — a practical point that matters for any student-built experiment [13].

What I did not find in the open literature is a systematic, efficiency-first optimisation of the double-helix geometry itself — most work treats it as a noise device. That gap is what this paper tries to address, at least in a preliminary, analysis-based way.

4. METHODOLOGY

Because I do not have access to a wind tunnel or a professional thrust stand, this paper is an analytical and comparative study rather than a purely experimental one. My method has three parts:

- (a) Theoretical modelling. I applied blade element momentum reasoning to both a conventional two-blade propeller and a double-helix (two-loop toroidal) propeller of the same diameter and disk area, to identify where the two geometries should differ physically. The key quantities I tracked were induced velocity, blade loading distribution, and tip-region losses.
- (b) Data comparison. I collected published experimental data from the ASEE study by Alm et al. [2] and the performance claims of MIT Lincoln Laboratory [1], plus community 3D-printed toroidal propeller tests [14], and compared thrust-per-watt (a practical efficiency measure for hovering rotors) across designs.
- (c) Parametric reasoning. I identified four design variables — number of loops, pitch distribution along the loop, loop (annular) radius versus inner clearance, and manufacturing method — and reasoned about how each affects efficiency, using the published data as anchors.

This mixed approach is honestly a limitation, which I discuss in Section 6. But it is also realistic: comparing published measurements with theory is how a lot of early-stage engineering judgement is built, and it lets me define exactly what a future experiment should measure.

5. ANALYSIS: WHERE THE DOUBLE HELIX GAINS AND LOSES EFFICIENCY

5.1 The efficiency budget

A propeller’s losses come from three main places: induced loss (the kinetic energy left in the slipstream, which momentum theory shows is unavoidable but decreases with disk area), profile loss (skin friction and pressure drag of the blade sections), and tip loss (the vortex energy at the blade ends). The double-helix design changes all three:

- Tip loss decreases. Closing the loop removes the free tip, so the concentrated tip vortex is replaced by a much weaker, distributed vortex sheet along the loop. This is the design’s biggest win — it is also why the noise drops, since tip vortices are the dominant noise source [1].
- Profile loss increases. A toroidal propeller has more total blade surface (wetted area) than a two-blade propeller of the same disk area, because each blade now travels around a loop. More wetted area means more skin-friction drag, which costs efficiency, especially at the lower Reynolds numbers of small drones [2][13].
- Induced loss is roughly unchanged at the same disk loading, since momentum theory cares mainly about disk area and thrust, not blade shape — but the two loops slightly interfere with each other’s inflow, which adds a small penalty similar to what coaxial rotors experience [4][6].

5.2 What the data shows

Putting the published numbers side by side makes the trade-off concrete. In the ASEE tests [2], the ranking for raw thrust was: conventional 2-blade first, then the injection-moulded 2-loop toroidal close behind, with 3D-printed toroidal designs further back. For sound, the order reversed: the 2-loop injection-moulded toroidal was the quietest propeller tested. MIT Lincoln Laboratory’s flight tests report the same pattern in real conditions — comparable thrust at comparable power, with drones tolerable at half the usual distance [1].

Table 1. Summary of published comparisons between conventional and double-helix (toroidal) propellers

Property	Conventional 2-blade	2-loop toroidal (double helix)	Source
Thrust (same diameter, same RPM)	Highest in test	Slightly lower, comparable	Alm et al., 2024 [2]

Thrust at similar power (flight test)	Baseline	Comparable	MIT Lincoln Lab [1]
Noise level	Loudest group	Quietest propeller tested	Alm et al., 2024 [2]
Annoyance distance	Typical	About half the distance	MIT Lincoln Lab [1]
Effect of adding loops (3D-printed)	—	Lower thrust, higher noise	Alm et al., 2024 [2]
Manufacturing effect	Injection-moulded best	Injection-moulded clearly better than resin print	Alm et al. [2]; Popișter et al. [13]

5.3 Which design parameters matter most

From the theory and the data together, four parameters stand out for optimising a double-helix propeller:

- (1) Number of loops. Two loops appear to be the sweet spot. The ASEE data show that going to three or four loops (in 3D-printed form) reduced thrust and increased noise [2] — probably because each extra loop adds wetted area and operates in the disturbed wake of the loop ahead of it, like the rear propeller in a poorly-matched contra-rotating pair [4].
- (2) Pitch distribution. Small-propeller optimisation studies show twist distribution is one of the strongest efficiency levers [11]. On a double helix, the blade element near the outer rim of the loop moves fastest, so pitch should be highest near the hub crossing and decrease outward — just like a normal blade, but applied continuously around the loop so that every section works near its best lift-to-drag ratio.
- (3) Loop radius and inner clearance. A larger loop (more area in the outer, high-velocity annulus) recovers more of the tip-vortex benefit, but if the inner gap between the two loops is too small, their boundary layers and wakes interfere. There should be an optimum gap — wide enough to keep the two inflows separate, narrow enough to keep the structure stiff and compact. This is exactly the kind of parameter BEM-plus-CFD optimisation can pin down [9][12].
- (4) Manufacturing method. Both the ASEE study and the 2025 Polymers study found that injection-moulded or well-made propellers outperform rough 3D prints, because surface roughness at low Reynolds numbers trips the boundary layer and adds drag [2][13]. Any efficiency comparison of double-helix prototypes must therefore control for surface finish, or the geometry's true effect will be hidden by manufacturing noise.

5.4 The efficiency verdict

Combining these pieces, my estimate is that a well-optimised two-loop double-helix propeller sits within roughly 5–10% of a comparable conventional propeller in hover efficiency — a small penalty — while delivering the large noise reduction that motivated the design in the first place. For applications like urban delivery drones, cinematography, and inspection work, that trade looks worthwhile: a few percent of battery life in exchange for being socially acceptable in a neighbourhood is a good bargain. For long-range fixed-wing aircraft, where efficiency is everything and noise matters less, the conventional blade probably still wins.

6. DISCUSSION AND LIMITATIONS

I want to be honest about the limits of this study. First, I could not run my own experiments, so my quantitative claims rest on published data from different laboratories using different propeller sizes, motors, and test stands — never a perfectly clean comparison. Second, blade element momentum theory assumes steady, axisymmetric flow and treats each blade section independently; a double helix is about as non-axisymmetric as a propeller gets, so my theory-based reasoning is qualitatively reliable but not precise. Proper CFD (as Alm et al. did with Ansys Fluent [2]) or wind-tunnel testing would be needed to confirm the 5–10% efficiency estimate.

Third, there is a structural side I have only touched on. The closed loop makes the propeller stiffer and also safer — MIT notes it

is less likely to cut or catch objects [1] — but it also adds weight, and weight matters on a drone. A full optimisation would trade aerodynamic efficiency against structural mass, which is beyond what I could do here but is a natural next step.

7. CONCLUSIONS AND FUTURE WORK

The double-helix (toroidal) propeller is a genuinely clever idea: by closing the blade loop, it removes the free tip where the most damaging vortex forms, cutting noise dramatically while keeping thrust roughly intact. My analysis suggests its efficiency penalty against a good conventional propeller is small — on the order of 5–10% in hover — and that the penalty can be minimised by sticking to two loops, optimising the pitch distribution around the loop, choosing a sensible inner clearance, and using smooth, high-quality manufacturing.

For future work, I plan to actually build and test prototypes. The procedure would be: 3D-print three double-helix variants (two-loop with different pitches) plus one conventional propeller of the same diameter, all in the same material and printed in the same batch; mount each on a brushless motor with a digital scale as a simple thrust stand and a wattmeter on the supply; record thrust-per-watt across a throttle sweep; and record sound with a phone decibel app at a fixed distance. It is a modest setup — essentially a simplified version of the Tyto Robotics rig used in the ASEE study [2] — but it would turn the estimates in this paper into measurements, which is what engineering is really about.

If the results confirm the analysis, the double helix could be more than a quiet curiosity — it could be the shape that finally lets drones work next door without anyone noticing.

REFERENCES

- [1] MIT Lincoln Laboratory, "Toroidal Propeller," available at: <https://www.ll.mit.edu/partner-us/available-technologies/toroidal-propeller-0> (accessed 2026).
- [2] A. Alm, W. P. Garrison, V. R. C. Gomes, C. H. Harris, G. T. Shrauger, C. Whitacre, and J. E. Matsson, "A Study of the Efficiency of Toroidal Propeller Designs," Proceedings of the ASEE Annual Conference, American Society for Engineering Education, 2024. <https://peer.asee.org/a-study-of-the-efficiency-of-toroidal-propeller-designs.pdf>
- [3] NASA Langley Research Center, "Psychoacoustic experiments on human sensitivity to small multirotor UAS noise," NASA Technical Reports Server, 2017. <https://ntrs.nasa.gov/search?q=20170005870>
- [4] "Study on the Contra-Rotating Propeller System Design and Full-Scale Performance Prediction," Chinese Journal of Mechanical Engineering, 2016. <https://www.sciencedirect.com/science/article/pii/S2092678216303806>
- [5] SINTEF, "This is how two contra-rotating propellers can make ships more energy efficient," 2025. <https://www.sintef.no/en/latest-news/2025/this-is-how-two-contra-rotating-propellers-can-make-ships-more-energy-efficient/>
- [6] "Historical development of the coaxial contra-rotating propeller," ResearchGate, 2022. https://www.researchgate.net/publication/365746220_Historical_development_of_the_coaxial_contra-rotating_propeller
- [7] J. G. Leishman, Principles of Helicopter Aerodynamics, 2nd ed., Cambridge University Press, 2016.
- [8] "Blade Element Theory — an overview," ScienceDirect Topics. <https://www.sciencedirect.com/topics/engineering/blade-element-theory>
- [9] A. Ning, "Using Blade Element Momentum Methods with Gradient-Based Design Optimization," Structural and Multidisciplinary Optimization, Brigham Young University. <https://flowlab.groups.et.byu.net/preprints/Ning2020.pdf>
- [10] Y. Peixun et al., "Aeroacoustic and aerodynamic optimization of propeller blades," Chinese Journal of Aeronautics, 2020. <https://www.sciencedirect.com/science/article/pii/S1000936119304108>
- [11] F. M. Nabid, "An Optimization Study of Small-Scale Propeller Blade," Honors Undergraduate Thesis, University of Central Florida, 2023. <https://stars.library.ucf.edu/cgi/viewcontent.cgi?article=2604&context=honorstheses>
- [12] M. A. Clarke et al., "Aerodynamic Optimization of Wing-Mounted Propeller Configurations in SUAVE," Stanford University, 2021. https://suave.stanford.edu/publications/2021_Aero_Optimization.pdf
- [13] F. Popișter et al., "Experimental Study of Comprehensive Performance Analysis Regarding the Dynamical-Mechanical Aspects of 3D-Printed UAV Propellers and Sound Footprint," Polymers, vol. 17, no. 11, 1466, MDPI, 2025. <https://www.mdpi.com/2073-4360/17/11/1466>
- [14] "Community Toroidal Propeller Tests and Flights," video playlist of independent 3D-printed toroidal propeller thrust and noise tests. https://www.youtube.com/playlist?list=PLYXuRA_sySbwa7FRot80kzEA_j4iqWQ_w