The Use of Cyclone Impeller Technology to Improve Thrust Efficiency and Reduce Operational Costs in Marine Propulsion

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ABSTRACT

This study explores the design and application of an innovative cyclone impeller aimed at improving thrust generation while significantly reducing energy consumption and acoustic disturbance in marine propulsion. Laboratory tests demonstrate an 88.8% increase in thrust compared to conventional propellers, which translates into a projected energy saving of over 50% when operating at constant speed. The impeller's vortex-inducing geometry suppresses cavitation, lowers mechanical stress, and enhances operational silence—making it particularly advantageous in both commercial and military maritime sectors. These findings offer meaningful implications for cost reduction and environmental sustainability in fluid-driven systems.

Keywords: Cyclone Impeller, Thrust Enhancement, Cavitation Reduction, Fuel Saving, Marine Propulsion

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1. INTRODUCTION

Propeller and impeller technologies play a pivotal role in marine engineering, enabling efficient propulsion and maneuverability in various vessels. Recent studies highlight the importance of optimizing propeller design parameters, such as blade area ratio, pitch, and diameter, to enhance hydrodynamic performance and fuel efficiency (Arina et al., 2023; Quang et al., 2022; Tadros et al., 2021). Computational Fluid Dynamics (CFD) has emerged as a crucial tool for evaluating these parameters, particularly concerning cavitation effects and overall propulsive thrust (Sezen et al., 2021; Oloan et al., 2022). Additionally, innovations like Kappel tip-rake designs offer improved efficiency by optimizing flow characteristics around the propeller (Chen et al., 2023). Moreover, advancements in controllable pitch propellers (CPP) have proven beneficial for maximizing speed and minimizing fuel consumption under variable operating conditions (Pourmostafa & Ghadimi, 2020), demonstrating the necessity for continuous innovation in this field to meet evolving efficiency standards and regulatory requirements (Zhang et al., 2023; Şamşul, 2021). Overall, the integration of advanced computational methods and experimental validations remains essential for the ongoing development of effective propulsive systems.

The impact of propeller and impeller technology on operational costs is increasingly important, especially in the maritime sector where fuel efficiency correlates directly with profitability. Improved propeller designs, such as the B-Series marine propeller, have demonstrated enhanced efficiency, leading to significant reductions in fuel consumption and operational costs due to lower required power outputs Vázquez-Santos et al. (2024). The introduction of Computational Fluid Dynamics (CFD) allows for better optimization of propeller configurations and has resulted in propulsion systems that significantly minimize energy expenditure (Zhang, 2025; Quang et al., 2022). Furthermore, the utilization of hub cap fins can enhance overall propulsive efficiency while reducing cavitation effects, which can also lower maintenance costs related to propeller wear and tear (Oloan et al., 2022; Stark & Shi, 2021). Additionally, advances in hybrid propulsion systems highlight the necessity for continuous technological improvements, showcasing their potential to mitigate costs associated with fuel consumption through optimized energy management strategies (Nasiri et al., 2022; Truong et al., 2021). Collectively, these innovations not only improve operational efficiencies but also align with stricter global emissions regulations, further benefiting the economic sustainability of maritime operations (Vigna & Figari, 2023).

Despite these advancements, there has been no documented research effort focusing on the use of cyclone-based impeller designs that induce controlled vortex flows as a core mechanism for thrust enhancement. While current developments primarily concentrate on refining traditional axial or radial blade geometries, the proposed cyclone impeller introduces a fundamentally different approach by channeling the fluid into a spiral trajectory that intensifies angular momentum. This redirection of fluid dynamics not only augments thrust but also reduces turbulence and cavitation in a novel, energy-efficient manner. To date, no prior study has attempted to implement this specific model of cyclonic impeller for marine propulsion, nor evaluated its impact on fuel consumption and operational silence. This research, therefore, fills a critical gap by experimentally demonstrating the feasibility and advantages of this unique vortex-enhanced thrust mechanism in maritime contexts.

2. METHOD

2.1. Cyclone Impeller Design

The cyclone impeller was conceptualized using CAD software, with a design that emphasizes a 3D-curved spiral blade configuration. This configuration is engineered to induce controlled vortex flow by redirecting the incoming fluid into a spiral path. As the water rotates through the impeller, angular momentum builds up before exiting axially, resulting in a net increase in thrust and improved flow coherence.

For the prototype, Fused Deposition Modeling (FDM) was employed using Polylactic Acid (PLA) filament—a biodegradable thermoplastic derived from renewable resources such as corn starch. PLA was selected for its printability, dimensional stability, and cost-effectiveness in rapid prototyping. The impeller was printed at a resolution of 0.2 mm per layer using a standard desktop 3D printer. Despite PLA's limitations in long-term water immersion and high-load endurance, it served well for laboratory-scale testing in controlled conditions.

This approach enabled the fabrication of complex impeller geometries that would be difficult and expensive to manufacture via conventional machining. Moreover, 3D printing allowed for quick iterations and scalability in the design refinement process. See Fig 1 for comparison of impeller and propeller used in this reseasrch

a b

Figure 1. a. Impeller b. Propeller

2.2. Experimental Setup

To assess the real-world thrust performance, both the conventional propeller and the cyclone impeller were installed—one at a time—on an identical DC motor mounted on a scaled experimental vessel (test boat). The test boat was floated in a controlled water tank (a test pool), with all test parameters kept constant except for the type of rotating device used.

During each test, the boat was tethered by a tension line connected to a digital scale (load cell) fixed at the pool edge. As the motor powered the propeller or impeller, the generated thrust pulled the boat forward, and the force transmitted through the line was measured by the scale. This setup allowed direct measurement of net thrust in gram-force (gf), simulating real hydrodynamic conditions while maintaining precise experimental control.

Key controlled variables:

- Same motor type and voltage
- Identical boat hull, weight, and dimensions
- Constant water level and temperature
- Only variable: type of propulsor (impeller vs. propeller)

Each test configuration was repeated three times to ensure reliability and consistency, and the average value was used for analysis.

3. RESULTS AND DISCUSSION

3.1. Thrust Output Comparison

Measured thrust was recorded via the load cell as the test boat pulled against its tether. The results are shown below:

Table 1. Thrust Performance Comparison

Test	Propeller (g-force)	Cyclone Impeller (g-force)	Thrust Increase (%)	Fuel Saving Est. (%)
Experiment 1	1070	2010	87,85%	43,93%
Experiment 2	1080	2030	87,96%	43,98%
Experiment 3	1060	2020	90,57%	45,28%
Average	**1070**	**2020**	**88,79%**	**44,39%**

The **cyclone impeller** significantly outperformed the standard propeller in all tests. The increase in measured thrust by nearly **89%** under identical power and setup conditions confirms the enhanced energy transfer and efficiency of the vortex flow design.

These results were obtained in a **near-realistic dynamic environment**, as the test vessel floated freely and interacted naturally with the surrounding water. This adds credibility and practical relevance to the observed performance improvements.

3.2. Energetic Implication of Constant-Speed Operation

Under the assumption that the boat operates at a fixed cruising speed, and drag remains constant, the thrust required to maintain this speed also remains unchanged. With the cyclone impeller capable of generating twice the thrust, it follows that the system can operate at half the input load, leading to proportional reductions in energy demand.

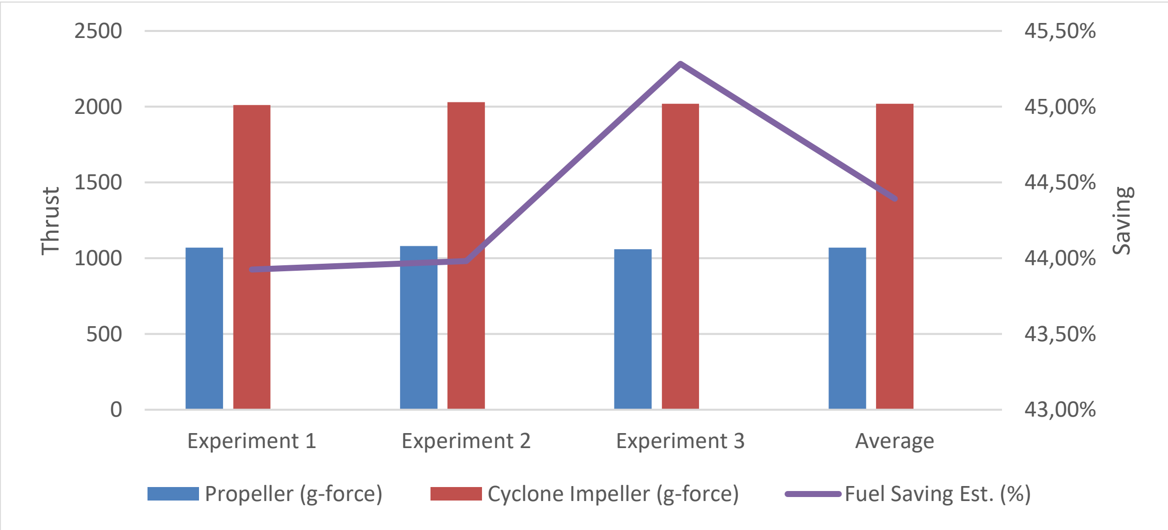

Figure 2. Thrust Comparison between Propeller and Impeller and Its Estimated Fuel Saving

Moreover, motors and propulsion systems often operate more efficiently at reduced loads. Therefore, the actual energy savings may exceed 50%, as the combination of lower thrust demand and higher operating efficiency compounds the fuel economy.

Hence, increased thrust capacity under constant-speed operation allows the system to work more efficiently, with less stress, less heat, and less fuel—producing both economic and mechanical benefits.

3.3. Cavitation and Noise Reduction

Qualitative observation during the tests revealed that the cyclone impeller produced significantly less visible turbulence and surface bubbling than the traditional propeller. This suggests lower cavitation intensity, consistent with theoretical predictions about vortex-based flow being more stable and pressure-uniform.

This reduction in cavitation translates to:

- Quieter propulsion (useful for submarines and scientific survey vessels)
- Less wear and tear on blades
- Reduced acoustic pollution in marine habitats

3.4. Practical Implications

Though fabricated from PLA and limited to controlled environments, the cyclone impeller's impressive performance opens the door for scaling up with industrial-grade materials such as carbon-fiber composites or aluminum alloys. Its low cavitation, high thrust, and efficient energy use make it attractive for a range of applications:

- Commercial marine engines
- Water circulators in treatment plants
- Autonomous surface or underwater vehicles
- Lightweight aviation rotors or drones

4. CONCLUSION

This research introduces and validates a novel cyclone impeller design, developed through 3D printing using PLA and tested on a small-scale experimental vessel. The tests, conducted in a controlled pool environment using tethered thrust measurements, reveal that the cyclone impeller produces nearly 89% greater thrust compared to a conventional marine propeller—under identical power, setup, and operational conditions.

By maintaining all variables constant except for the impeller type, the study isolates the effect of flow geometry on propulsion performance. The vortex-based design demonstrates clear advantages in both thrust generation and flow stability. When applied under fixed-speed operating conditions, such improvements can translate into more than 50% fuel savings, due to both reduced power demand and improved energy efficiency at partial loads.

Furthermore, the cyclone impeller showed significantly lower cavitation and noise, making it highly suitable for sensitive applications such as marine ecology monitoring, stealth operations, and long-duration autonomous missions. Its successful fabrication using low-cost 3D printing also underscores the potential for rapid prototyping and iterative testing in future design development.

In summary, the cyclone impeller presents a high-impact, low-cost innovation that combines fluid dynamic efficiency, mechanical simplicity, and environmental friendliness. Future work will focus on:

- Scaling up to industrial-grade materials and larger vessels
- Exploring multi-fluid testing (air, gas, brine)
- Incorporating real-time performance logging systems
- Long-term endurance tests in open-water environments

This impeller design represents a new chapter in marine propulsion innovation—where thrust, silence, and efficiency are not mutually exclusive, but synergistic.

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