Analytical Analysis of Propellers Using MATLAB

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Abstract

A propeller converts rotational motion from an engine or motor into thrust, propelling a vehicle. Efficient propeller design is crucial for optimizing vehicle performance, from drones to airplanes. This study develops a computational tool to analyze various propeller geometries at a constant rotational speed across a range of advance ratios. The tool uses Blade Element Momentum Theory (BEMT) and MATLAB to simulate performance metrics, validated with empirical data from wind tunnel tests on the APC 10x7 Thin Electric propeller. Our tool provides valuable insights into how geometric parameters influence performance, paving the way for enhanced propeller design. This approach aids in understanding propeller aerodynamics and enhances design and optimization processes by offering deeper insight into the influence of different geometric parameters on propeller performance.

Introduction

In the quest for more efficient propulsion systems, understanding propeller performance is paramount. Propellers convert rotational motion into thrust, directly impacting a vehicle's efficiency and performance. This study employs Blade Element Momentum Theory (BEMT) to create a computational tool that simulates and analyzes propeller performance[1]. Leveraging MATLAB, we aim to provide a detailed analysis of the propeller's aerodynamic characteristics and optimize its design. The study includes empirical data from wind tunnel tests using the APC 10x7 Thin Electric propeller as a test subject, validating the computational model and offering insights into the influence of geometric parameters on efficiency[3].

Background

Blade Element Momentum Theory (BEMT) integrates Blade Element Theory (BET) and Momentum Theory for propeller analysis. Momentum Theory takes a macroscopic view, assuming homogeneous, incompressible fluid flow with no frictional drag. BET provides a detailed perspective by examining each element of the propeller blade, accounting for variations in blade geometry[1].

However, BEMT assumes steady-state, axisymmetric flow and does not fully consider complex phenomena such as wake rotation and blade-vortex interactions[2].

This study enhances BEMT by developing a MATLAB-based tool that incorporates axial and rotational induction factors, Prandtl's Tip Loss Factor, and friction effects through experimentally obtained drag (Cd) and lift (Cl) coefficients. The tool is validated through wind tunnel tests on the APC 10x7 Thin Electric propeller, aiming to improve propeller design and optimization across various sectors[3].

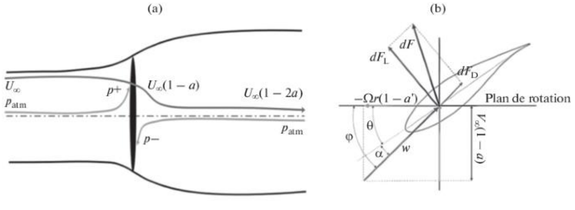

Figure 1: Flow dynamics and force distribution of a propeller blade. Source: Debbache et al. (2018).

Problem

The project aims to develop a reliable and user-friendly computational tool for propeller performance analysis that provides fast results. The primary problem addressed is the accurate prediction of thrust and efficiency across various operational conditions, bridging the gap between theoretical models and practical applications.

Methodology

To address the problem of accurately predicting thrust and efficiency across various operational conditions, the following methodology is employed. The flowchart outlines a systematic approach to propeller performance analysis, starting from the selection of flight conditions to the final computation of efficiency. Each step involves critical calculations and iterative processes to ensure the reliability and accuracy of the predictions. This structured method bridges the gap between theoretical models and practical applications, providing a robust framework for the development of the computational tool.

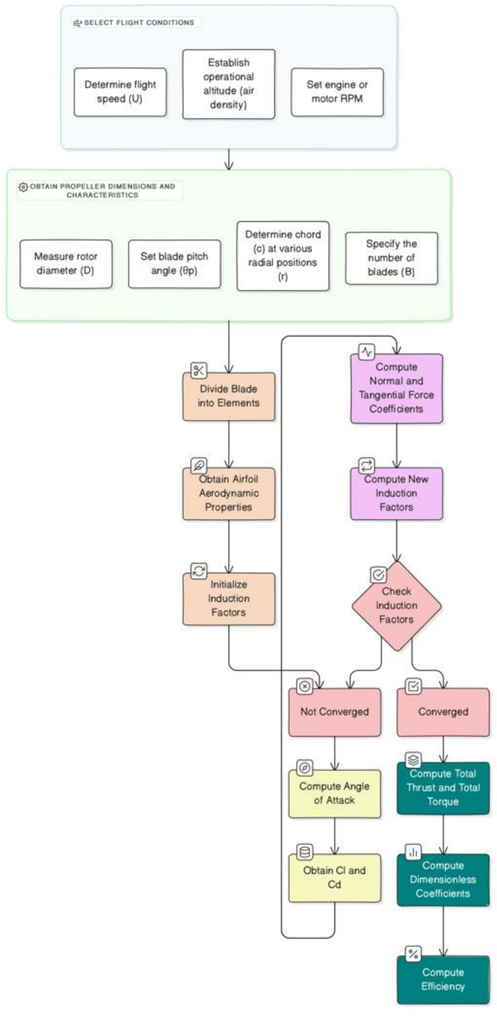

Figure 2: BEMT Propeller Performance Analysis Algorithm

Results and Discussion

This section presents the thrust, torque, and power coefficients, along with propulsive efficiency of the APC 10x7 Thin Electric propeller under various advance ratios. Graphs illustrate observed trends, supported by empirical data[1][3]. Notably, the tool showed exceptional accuracy at higher advance ratios, exceeding our initial expectations and validating its robustness.

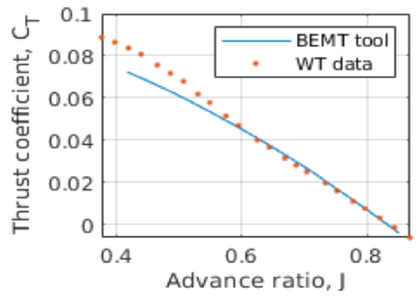

Figure 3: Thrust coefficient vs Advance ratio for APC 10x7 Thin Electric Propeller

This graph shows how the thrust coefficient decreases with increasing advance ratio, indicating the propeller's diminishing ability to generate thrust as the forward speed increases.

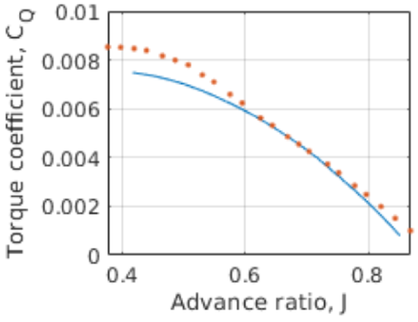

Figure 4: Torque Coefficient vs Advance Ratio for APC 10x7 Thin Electric Propeller

This graph illustrates the parabolic decline in the torque coefficient with increasing advance ratio, highlighting the relationship between the generated torque and the advance ratio.

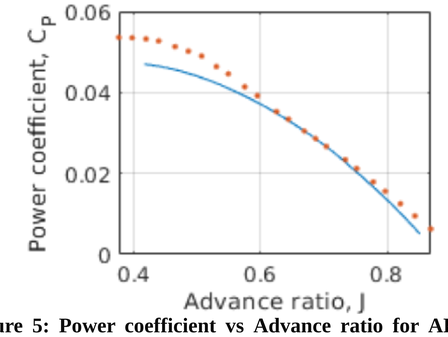

Figure 5: Power coefficient vs Advance ratio for APC 10x7 Thin Electric propeller

This graph depicts the parabolic decrease in the power coefficient, reflecting the combined effects of decreasing thrust and torque as the advance ratio increases.

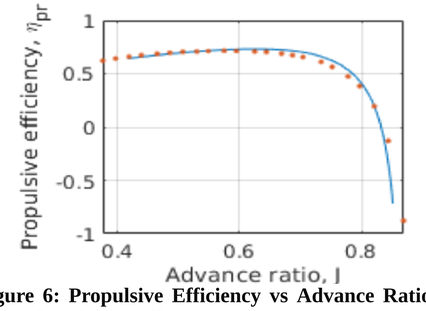

Figure 6: Propulsive Efficiency vs Advance Ratio APC 10x7 Thin Electric Propeller

This graph shows that propulsive efficiency remains stable up to an advance ratio of 0.70, after which it declines abruptly.

Conclusions

A MATLAB tool, using Blade Element Momentum Theory (BEMT), for propeller performance was created and tested on an APC 10x7 Thin Electric propeller. It accurately predicts metrics such as thrust, torque, power coefficients, and propulsive efficiency across different advance ratios. The key findings are that as the advance ratio increases, these coefficients decrease, while efficiency remains stable up to an advance ratio of 0.70, after which it drops abruptly. Predictions align well with wind tunnel data, especially at higher advance ratios, but accuracy lessens at lower ratios due to BEMT's limitations. This study provides a robust basis for future propeller research and optimization.

Future Work

Future work should focus on enhancing the BEMT model to include three-dimensional effects and viscous interactions, thereby improving its accuracy across a broader range of conditions. Potential areas for improvement and extension include:

- Incorporating three-dimensional flow effects to better capture the complex aerodynamics of propellers.
- Accounting for viscous interactions to enhance the model's predictive capability at lower advance ratios.
- Integrating the tool with optimization algorithms to aid in the design of more efficient propellers for various applications in aerospace, marine, and wind energy sectors.

Acknowledgements

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