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Numerical Simulation and Aerodynamic Performance Investigation of Insect-inspired Propellers

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Abstract

Current research focuses on the improvement of the aerodynamic performance of small commercial multi-rotor propellers by inspired drawing of the wing shapes from different species of animals. The study specifically examines insect-inspired propellers and their impact on the performance parameters such as thrust, torque, and efficiency. By mimicking the wing shapes of three species of insects, Hemiptera, Neuroptera, and Orthoptera, the numerical simulations were conducted to evaluate the performance of the insect-inspired propellers at the hover condition. The results showed that these insect-inspired propellers exhibit higher thrust and require lower rotational speeds compared to conventional propellers. Additionally, these propellers demonstrate a 6.74% improvement in efficiency over than traditional models. Validation against experimental data confirms the effectiveness of this approach.

Keywords: Bio-inspired, insect-inspired, Propeller aerodynamics, Commercial multirotor, Propeller performance, Numerical simulation.

1. Introduction

The concept of smart cities is rapidly evolving with the increasing use of new technologies, particularly the commercial drones. These unmanned aerial vehicles have diverse commercial applications, from environmental inspections to delivery of goods [1]. Multi-rotor drones are revolutionizing transportation, however, face challenges such as limited performance at low Reynolds numbers [2]. The Optimization of the propellers for small drones is vital to enhance efficiency and effectiveness in various industries. The use of lithium batteries can also help reduce noise levels generated by these drones [3]. Several studies have explored the impact of propeller design on UAV performance. Brandt and Selig [4], found that choosing the right propeller size significantly affects performance. Gomez et al. [5], demonstrated that nature-inspired propellers, like those modeled after cicada wings, can create weaker vortices and improve rotorcraft efficiency. Ning and Hu [6], showed that propellers inspired by natural shapes, such as cicada wings and maple seeds, can match conventional propellers in thrust production with lower rotations. Deters et al. [7], confirmed manufacturer flight time claims through investigations on small UAV propellers and motors. Hintz et al. [8], found that cicada wing-inspired propellers offer better efficiency. Moslem et al. [9], demonstrated better thrust and rotation efficiency with lower noise levels in propellers inspired by insect wings and plant seeds. Finally, Mozafari and Masdari [10], highlighted the benefits of owl-inspired characteristics in reducing aerodynamic and aeroacoustics costs. Despite the limited research on insect-inspired propellers, a new study delves deeper into the aerodynamic performance of propellers by examining a larger number of insect wings through numerical simulation. The goal is to enhance propeller efficiency and explore the possibilities of nature-inspired design in aircraft technology.

2. Methodology

In the research, the DJI Phantom-3 propeller is selected as the base propeller. It is a well-known propeller in small commercial multi-rotor categories. Considering comparison possibility condition, all insect inspired propellers are modeled and design based on geometric characteristic of this propeller. The base propeller diameter is 0.24. The wings of Hemiptera (He.), Orthoptera (Or.), Neuroptera (Ne.) were selected. Geometric parameters such as chord distribution, airfoil, and twist distribution were used to create three-dimensional geometries of the propellers. After verification of the base propeller, simulations were conducted for other propellers using the k-ω SST model in ANSYS Fluent with the MRF technique for incompressible and turbulent flow. The propeller efficiency was then calculated based on thrust and torque obtained from the numerical simulation, and comparisons were made to select the optimal propeller.

3. Verification

The results of a numerical simulation were compared with the experimental studies of Deters and Selig [12] to validate the thrust produced by insect-inspired propellers at different rotation speeds. Despite slight differences in parameter values, the numerical method achieved acceptable accuracy with an error percentage of 5% or less. These differences were attributed to factors such as the existence of inevitable inaccuracies in propeller morphology and its modeling process.

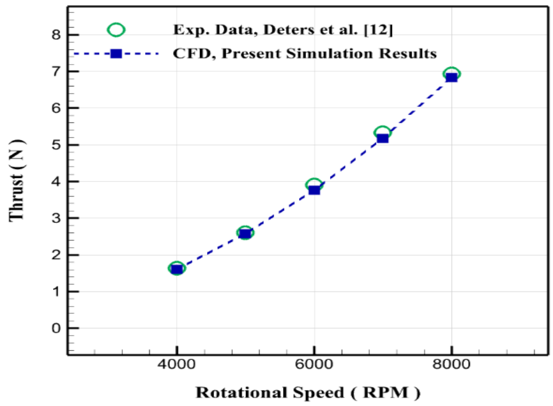

Figure 1. Verification of numerical method

4. Results and Discussion

The figure 2 shows the increase in thrust of each propeller as the rotational speed goes from 4000 to 8000 rpm. As is evident, the wider propellers generate the higher thrust, with the rate of change depending on the propeller's shape. Insect-inspired propellers generally have higher levels of thrust and torque compared to the DJI Phantom-3 propeller. The Hemiptera propeller has the largest difference in thrust and torque, being 36.21% and 66.66% higher than the DJI Phantom-3 propeller at 8000 rpm. Also, the insect-inspired propellers, such as the Hemiptera propeller, outperform traditional propellers like the DJI Phantom-3 in terms of thrust and torque coefficients. However, as rotational speed and torque are increased, the demand for mechanical power also rises, resulting in a decrease in propeller efficiency.

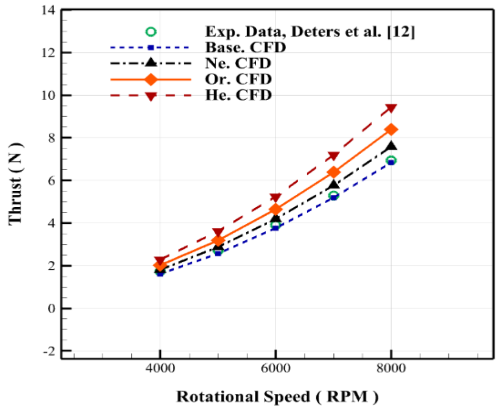

Figure 2. Thrust Vs RPM

This article explores the importance of generating enough thrust force for multi-rotor drones to overcome their weight during takeoff. It compares the performance of insect-inspired propellers by analyzing the hovering rotational speed, the required power, and the propeller efficiency. It highlights the superior efficiency of Neuroptera and Orthoptera propellers compared to the DJI Phantom-3 propeller. The study found that the Neuroptera propeller had a 74.6% increase in efficiency compared to the DJI Phantom-3 propeller.

Figure 3 demonstrates the efficiency of insect-inspired propellers in obtaining a thrust to weight ratio of 1:1. The study suggests that the chord width of the propeller significantly impacts the amount of mechanical power required for the rotation. Hemiptera propeller, with wider chord design, demand more mechanical power compared to Neuroptera propeller, which is narrower and require less power. In comparison to the DJI Phantom-3 propeller in figure 4, insect-inspired propellers were able to generate the same thrust force at lower rotational speeds, potentially resulting in reduced noise output. The Hemiptera propeller exhibited the lowest rotational speed, indicating a 13.36% decrease compared to the DJI Phantom-3.

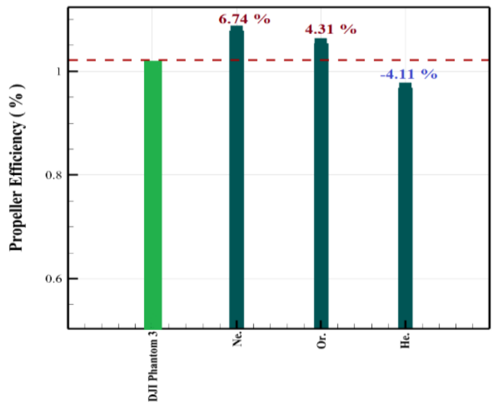

Figure 3. propeller efficiency in thrust to weight ratio of 1:1

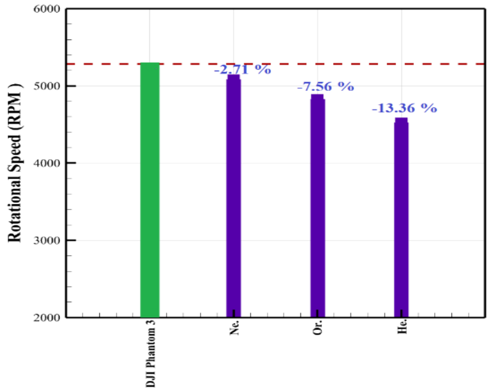

Figure 4. Rotational Speed in thrust to weight ratio of 1:1

5. Conclusions

The present study utilizes the numerical simulation method with ANSYS Fluent software to investigate the aerodynamic performance of propellers inspired by insects. The present insect-inspired propellers are designed by inspiration from the wing of Hemiptera, Neuroptera, and Orthoptera insects. During this study all propellers operating at different rotational speeds are simulated and compared using the MRF method, offering insights into their efficiency.

- Overall, insect-inspired propellers typically outperform the DJI Phantom-3 propeller in terms of thrust and torque. However, as rotational speed and torque increase, the efficiency of these propellers tends to decrease. The Neuroptera propeller stands out as the top performer with a 74.6% improvement in efficiency compared to the DJI Phantom-3 propeller. It also requires 32.6% less mechanical power while the Hemiptera propeller rotates 13.36% slower than the DJI Phantom-3 propeller. The Orthoptera propeller falls between the Neuroptera and Hemiptera propellers in terms of performance, making it a viable option to replace the DJI Phantom-3 propeller.

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