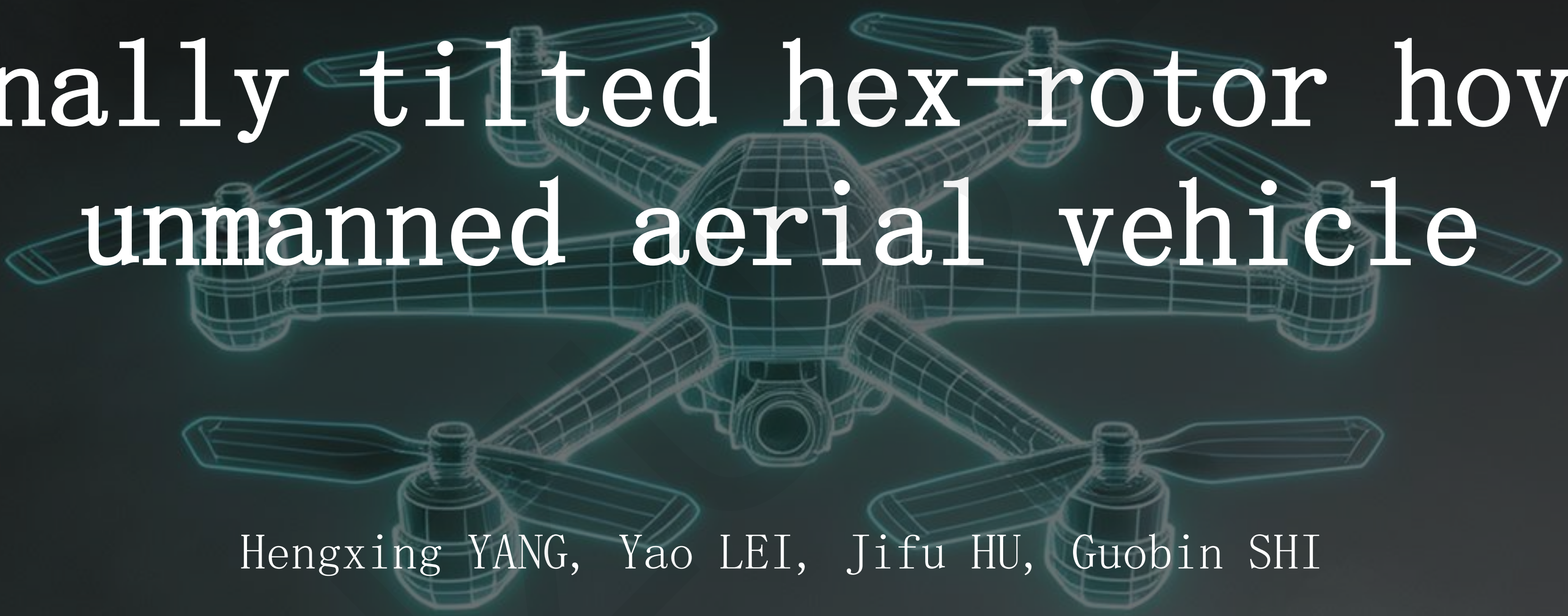
Journal of Zhejiang University-SCIENCE A

Aerodynamic optimization of an externally tilted hex-rotor hovering unmanned aerial vehicle



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Enhancing Hover Efficiency: A Critical Need for Next-Gen UAVs

Widespread Applications & Growing Demands

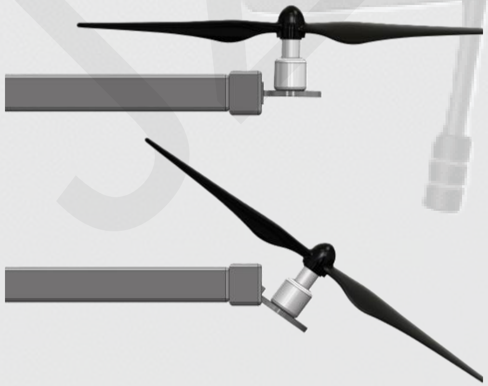
UAVs are now integral to agriculture, commerce, and defense sectors. The industry demands continuous improvements in payload capacity and aerodynamic efficiency to unlock new operational potentials.

The Challenge of Conventional Planar Designs

Traditional multi-rotors face **unregulated inter-rotor flow interference**, causing turbulent mixing and vortex disruption. This leads to significant energy loss and suboptimal aerodynamic efficiency during hover.

Our Research Objective: Transforming Interference

We aim to overcome planar limitations by investigating a novel **externally tilted hex-rotor design**. This innovative configuration actively controls and leverages rotor flow interactions, transforming detrimental interference into **beneficial aerodynamic synergy**. The ultimate goal is to achieve a substantial improvement in hovering efficiency, addressing a key pain point for next-generation UAVs.



Design Comparison: Planar vs. Tilted Configuration

The visual model contrasts conventional planar rotor dynamics with our proposed externally tilted hex-rotor design. The tilted approach strategically manipulates inflow/outflow patterns to mitigate vortex disruption and enhance lift generation through synergistic airflow management.

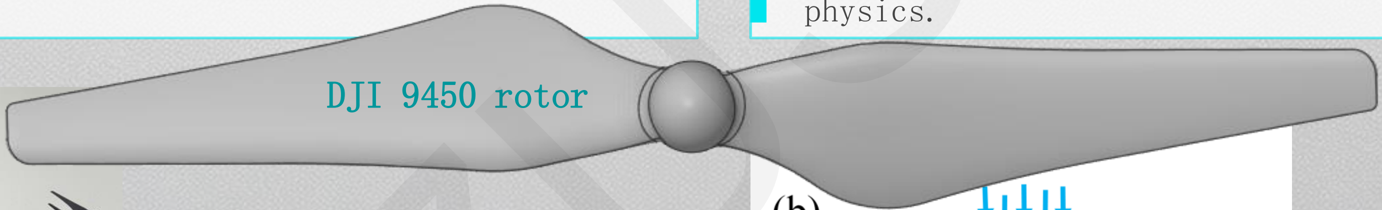
The Externally Tilted Hex-rotor: A New Paradigm for Flow Control

01. Core Innovation: The Externally Tilted Configuration

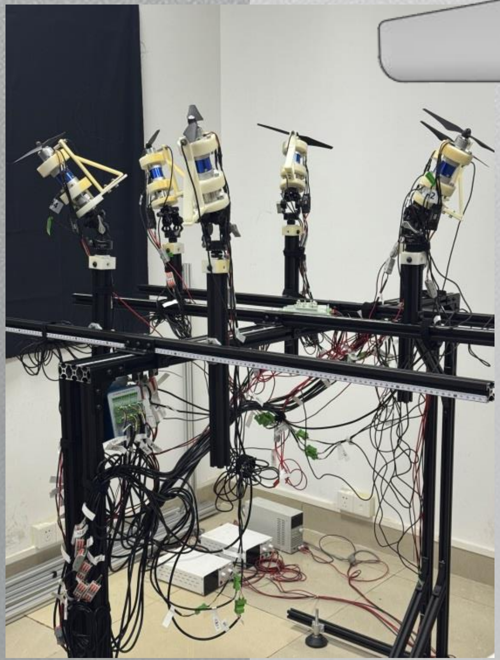
Each rotor is tilted outward by an angle ***θ*** (0° to 40°), enhancing downwash convergence and vortex coupling. The adjacent rotor spacing is governed by the rotor spacing ratio *i* (0.50 to 0.83), a key parameter for flow optimization.

02. Research Methodology: A Dual, Complementary Approach

Experimental: A custom-built test bench quantifies thrust, power, and efficiency metrics.
CFD Simulations: High-fidelity computational models visualize complex flow field mechanisms, validating the experimental data and revealing underlying aerodynamic physics.

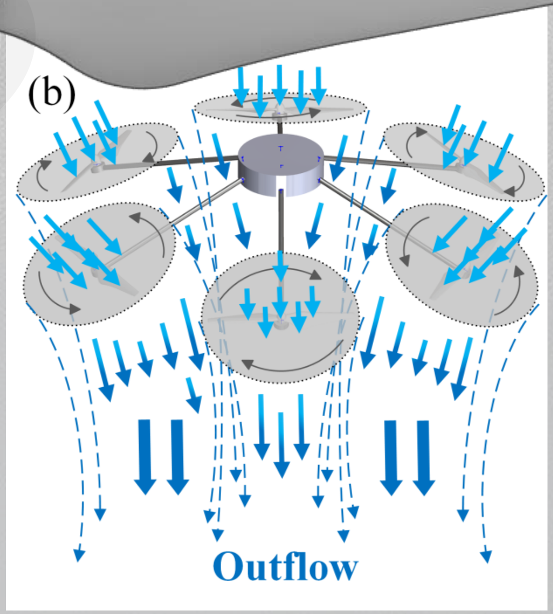


DJI 9450 rotor



Experimental Validation

A modular test bench was constructed to measure the performance of the tilted hex-rotor system under controlled conditions, integrating sensors for thrust, torque, and power consumption.



CFD Flow Field Analysis

The computational domain captures the full extent of the rotor downwash, resolving the complex interactions between individual rotor wakes and the resulting vorticity structures in the flow field.

Optimal Configuration Yields Significant Performance Gains

The Optimal Design Parameter Point

Rotor Spacing Ratio (i)
≈ 0.56

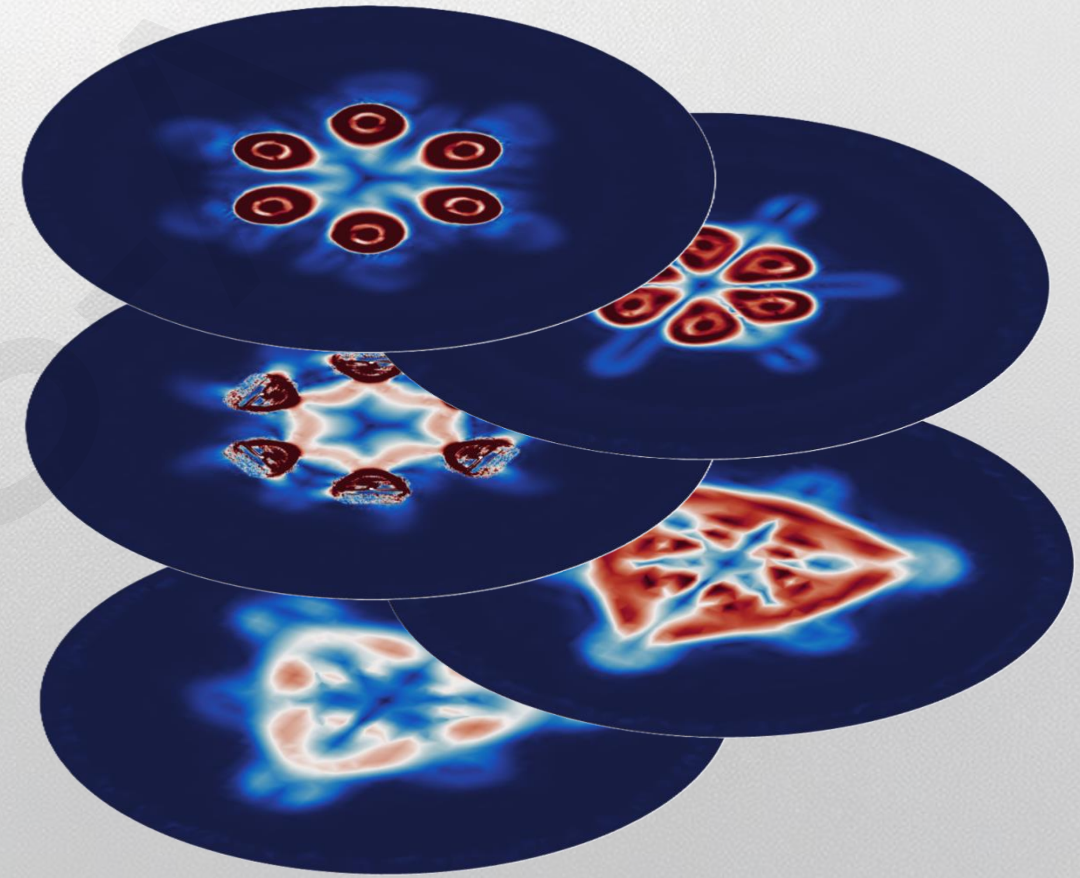
Tilt Angle (θ)
≈ 24°

Thrust Increase
+5.43%

Power Consumption
-2.73%

Figure of Merit (FM)
+11.15%

Power Loading (PL)
+3.77%



CFD simulation results visualize the flow field at the optimal tilt angle (24°). The streamlines show a significantly more organized and converging flow pattern compared to conventional planar designs, directly correlating with the measured performance improvements.

Conclusion: A Framework for Efficient Multi-rotor Design

01. Core Conclusions

Flow Synergy is Key: Moderate tilting ($\theta=24^\circ$) creates beneficial flow interactions (downwash convergence and vortex coupling) that significantly boost aerodynamic efficiency.

Synergistic Geometry: Optimal performance is achieved through a precise balance between rotor spacing ($i=0.56$) and tilt angle ($\theta=24^\circ$).

Proven Configuration: Validated by experiments and simulations, the optimal design excels across all key performance metrics.

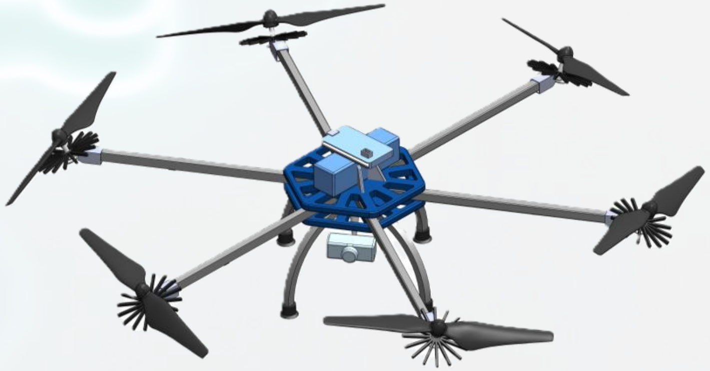
02. Broader Implications

Theoretical Framework: Establishes a foundational understanding of multi-rotor flow dynamics, enabling more informed control strategies for complex aerial systems.

Actionable Design Insights: Provides clear guidance for engineering next-gen UAVs with higher efficiency, greater payload capacity, and extended flight endurance.

Generalizable Methodology: The approach is extensible to diverse rotor configurations and dynamic, real-world flight conditions.

03. System Overview



Schematic of the externally tilted hexarotor system. The integrated design leverages optimized tilt and spacing to minimize induced drag and maximize overall propulsive efficiency.