THERMAL PERFORMANCE ANALYSIS OF INTERNALLY HEATED WIND TURBINE BLADES USING CFD AND EXPERIMENTAL VALIDATION FOR ANTI-ICING SYSTEMS

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Introduction

Wind energy is one of the fastest-growing renewable energy sources due to its environmental benefits and relatively low operating costs [1]. However, wind turbines operating in cold climates face a significant challenge: ice formation on blade surfaces, which reduces aerodynamic efficiency, increases structural vibrations, and decreases power output [2].Various anti-icing technologies have been developed for aircraft and wind turbines [3]. In this study, a thermal protection method based on natural ventilation of internal blade cavities is proposed to prevent snow accumulation and icing. The object of this research is a vertical-axis wind turbine based on the Georges Darrieus rotor design [5]. The aim of this work is to investigate the heat transfer characteristics of a wind turbine blade using computational fluid dynamics (CFD) and to evaluate the effectiveness of an internal heating system for icing prevention.

Experimental setup

An experimental setup was designed to study heat transfer in a symmetrical NASA-0021 airfoil with internal heating. The model was installed in front of a wind tunnel with adjustable angle of attack. Heated air was supplied into the internal cavity through a muffle furnace and pump system. Experimental parameters included external airflow velocity from 4 to 38 m/s, angle of attack from 0° to ±16°, and four internal airflow rates (0.00103–0.00253 m³/s). Temperature measurements were performed using copper–constantan thermocouples installed at the inlet and outlet of the airfoil channel. The collected data were used to determine the heat transfer coefficient and evaluate the effect of airflow conditions on blade thermal protection against icing.

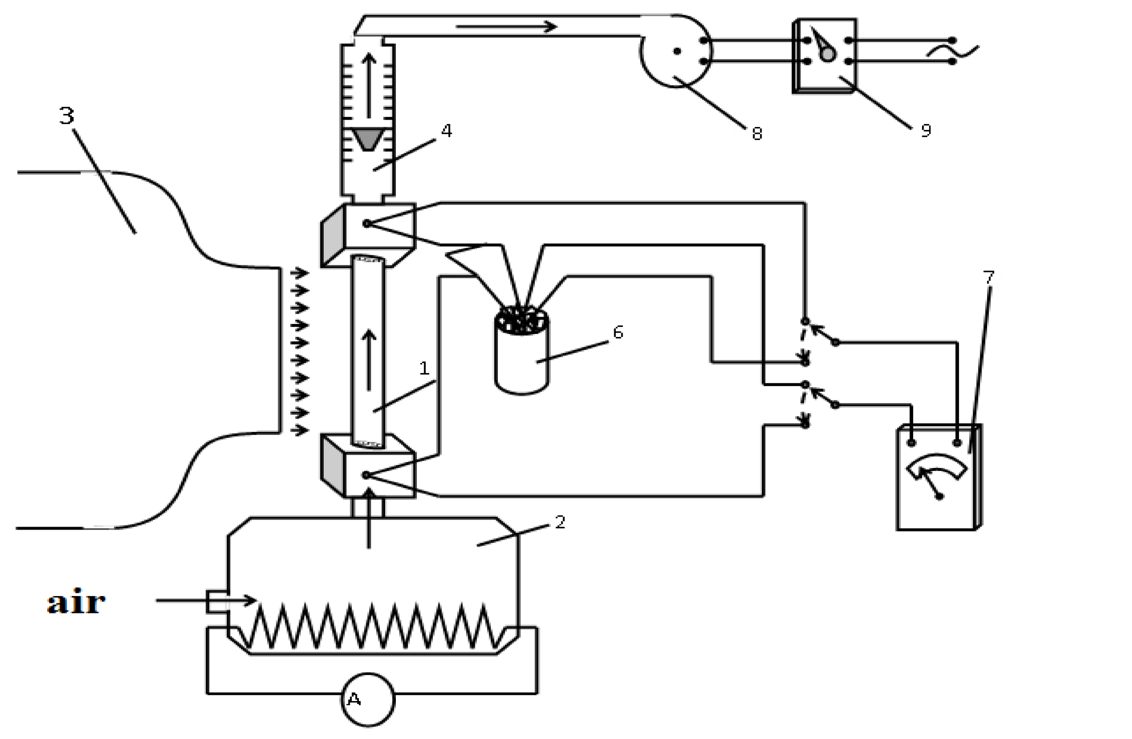

Fig. 1. The experimental setup for determining the heat transfer coefficient from the airfoil NASA-0021 to external flow

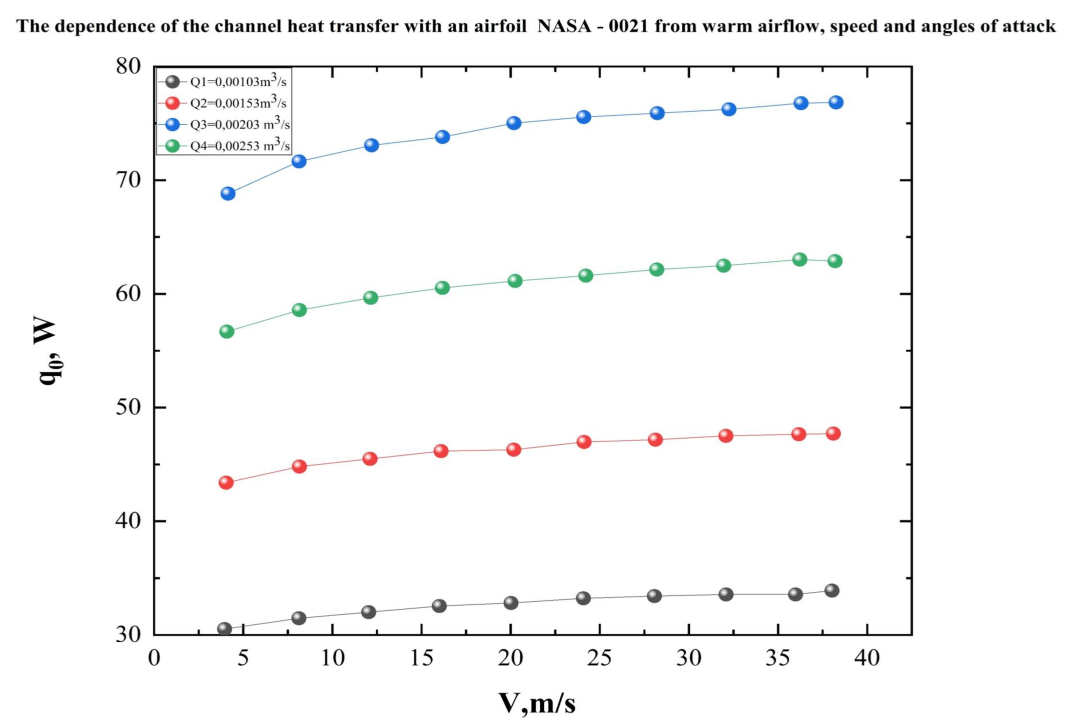

Fig. 2. The dependence of the channel heat transfer with an airfoil NASA - 0021 from warm airflow, speed and angles of attack

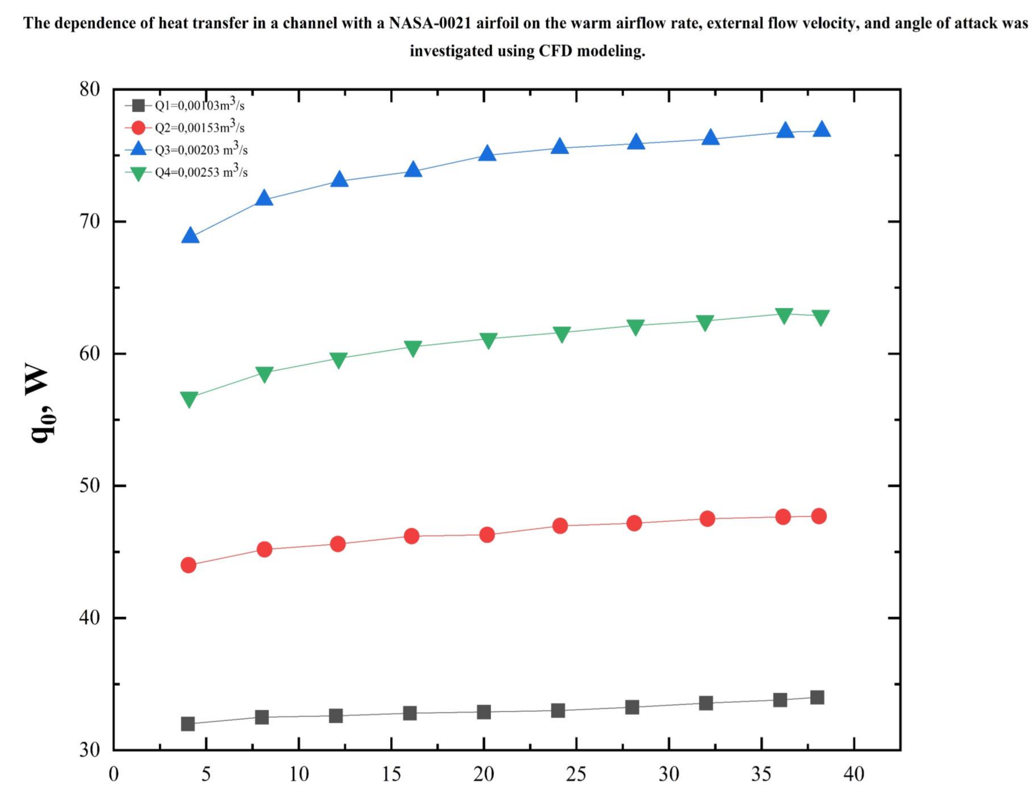

Fig. 3. CFD heat transfer results of NASA-0021 airfoil under different flow conditions

Numerical setup

CFD simulations were performed in ANSYS Fluent 2025 R2 using a 3D model of the NASA-0021 airfoil. The computational domain included internal and external flow regions. An unstructured hybrid mesh with 538,447 cells and 15 prism layers ($y^+ < 1$) was generated to accurately capture boundary layer effects. Boundary conditions included velocity inlet for external airflow (4–38 m/s), internal heated airflow supply, and pressure outlet at atmospheric conditions. The blade surface was modeled as a no-slip wall with conjugate heat transfer through a 1 mm copper wall (λ = 385 W/m·K).The k-ω SST turbulence model was used to simulate aerodynamic and thermal behavior and evaluate heat transfer characteristics under different operating conditions.

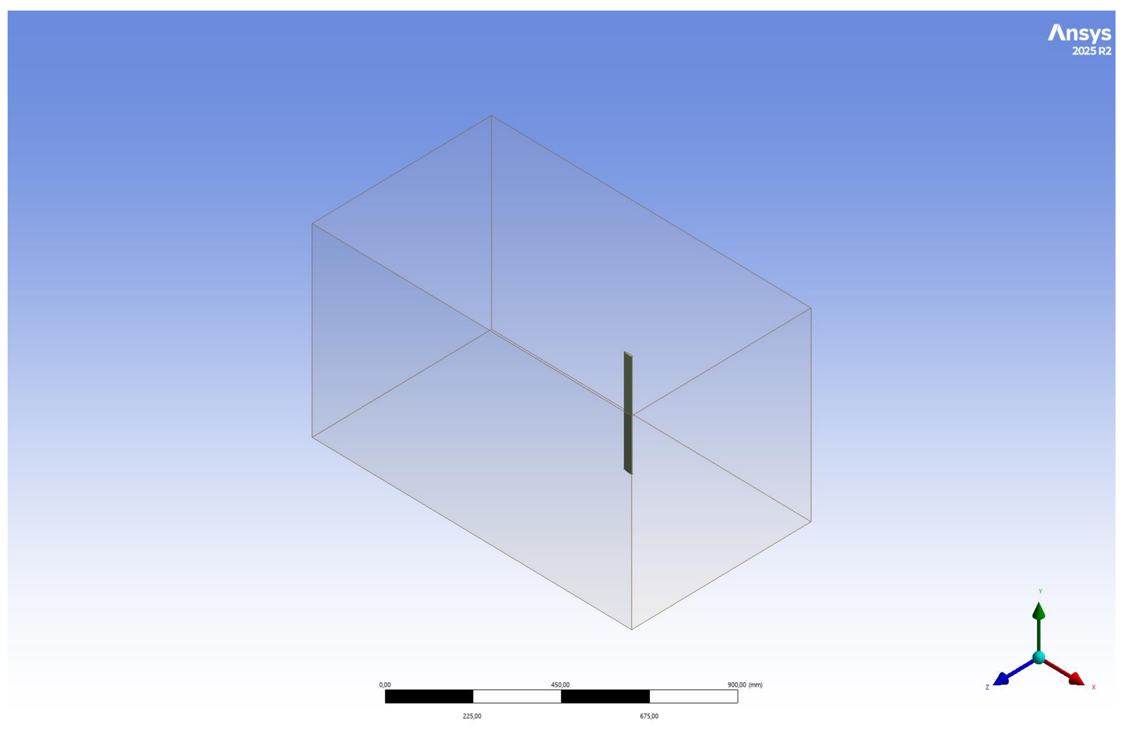

Fig. 4. Geometry of the NASA-0021 airfoil profile used in the numerical simulation.

Conclusions

A combined experimental and CFD study of the NASA-0021 airfoil with internal heating was performed to evaluate an anti-icing method for Darrieus wind turbine blades. The results showed that internal warm airflow significantly improves heat transfer and can effectively reduce icing risk. CFD simulations in ANSYS Fluent 2025 R2 demonstrated good agreement with experimental data for external velocities of 4–38 m/s. The influence of attack angle (0°–16°) on heat transfer was found to be negligible. The proposed thermal protection method based on internal heating and natural ventilation can improve the reliability of wind turbines operating in cold climates.

References

[1] Y. K. Hwang and Á. Sánchez Díez, "Renewable energy transition and green growth nexus in Latin America," *Renewable and Sustainable Energy Reviews*, vol. 198, no. 3, p. 114431, Jul. 2024, doi: 10.1016/j.rser.2024.114431.
[2] R. Rekuviene *et al.*, "A review on passive and active anti-icing and de-icing technologies," *Appl. Therm. Eng.*, vol. 250, p. 123474, Aug. 2024, doi: 10.1016/J.APPLTHERMALENG.2024.123474.
[3] Darrieus G.J.M. Turbine having its rotating shaft traverse to the flow of the current, US Patent No. 1,835,018; 1931.