Improving Vertical Axis Wind Turbine Efficiency by Integrating Hammerhead Shark Hydrodynamic Features Into the NACA0015 Blade Design

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Wind energy is projected to contribute 35% of total energy production in USA by the year 2050. Vertical axis wind turbines (VAWTs) have gained prominence due to their distinct advantages, i.e., their omnidirectionality and enhanced performance in turbulent and variable wind conditions. This inherent resilience makes them particularly well-suited for diverse geographical locations, thereby contributing to the reliability and stability of wind energy systems, but their energy capture efficiency is low. The hammerhead shark's distinctive cephalofoil, with its tubercle-covered ridges, exemplifies nature's hydrodynamic optimization. These tubercles reduce drag and improve swimming efficiency by generating controlled turbulence, delaying flow separation, and decreasing resistance. This research applies the tubercle morphology along the entire chord length of the wind turbine blades, creating constrained flow channels. This modification reduces drag, accelerates airflow, and enhances lift, thereby demonstrating the potential of bio-inspired designs to improve the efficiency of wind energy capture. 3D models of the bio-inspired blade and baseline smooth blade were created using OnShape and analyzed in SimScale. Simulations showed how tubercle modifications influence lift, drag, and overall aerodynamics. Further, these designs were 3D-printed and tested on a fully operational wind turbine model. Key performance metrics, including generated voltage and rotational speed (RPM), were measured during testing. The CFD simulations produced a 67% improved lift-to-drag ratio for the tubercle inspired blade, while physical experiments in real world operations showcased a 12% RPM gain and a 20% improvement in generated voltage over a statistically significant sample.

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