On the Hydrodynamic Analysis of a Vertical Axis MHK Turbine: Investigating Fish Trajectories via large-eddy simulation

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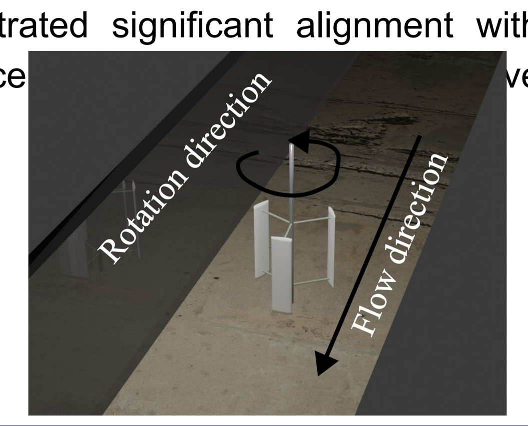
This study demonstrates that LES can effectively capture the hydrodynamics around a vertical axis MHK turbine and correlates these dynamics with fish trajectories. Understanding such relationships is crucial for designing fish-friendly turbines, minimizing ecological impact, and advancing sustainable marine energy solutions.

Introduction and Problem Description

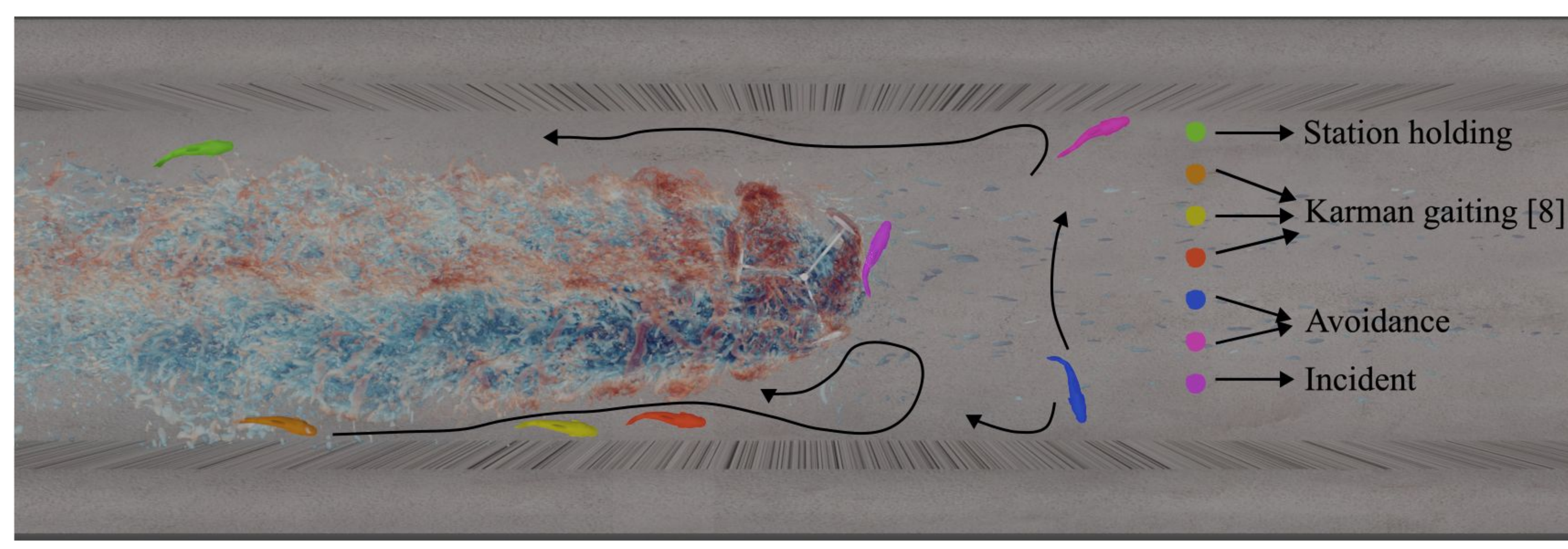
Marine energy as a renewable resource has significant potential due to the vast water coverage on Earth's surface. Vertical axis turbines (VAT) can exploit kinetic energy from flowing water without hydraulic structures. The turbulence generated by these turbines can alter aquatic habitats, affecting fish movement and behavior. This study employs high-fidelity numerical simulations using a turbine geometry-resolving methodology to examine the hydrodynamics of VAT and explore the relationship between turbulent flow dynamics and fish trajectory using large-eddy simulation (LES). The LES results were validated using experimental data obtained at the Hydro-environmental Research Center, Cardiff University. The results demonstrated significant alignment with fish behavior, serving as a reliable turbulence vement trajectories within the flow.

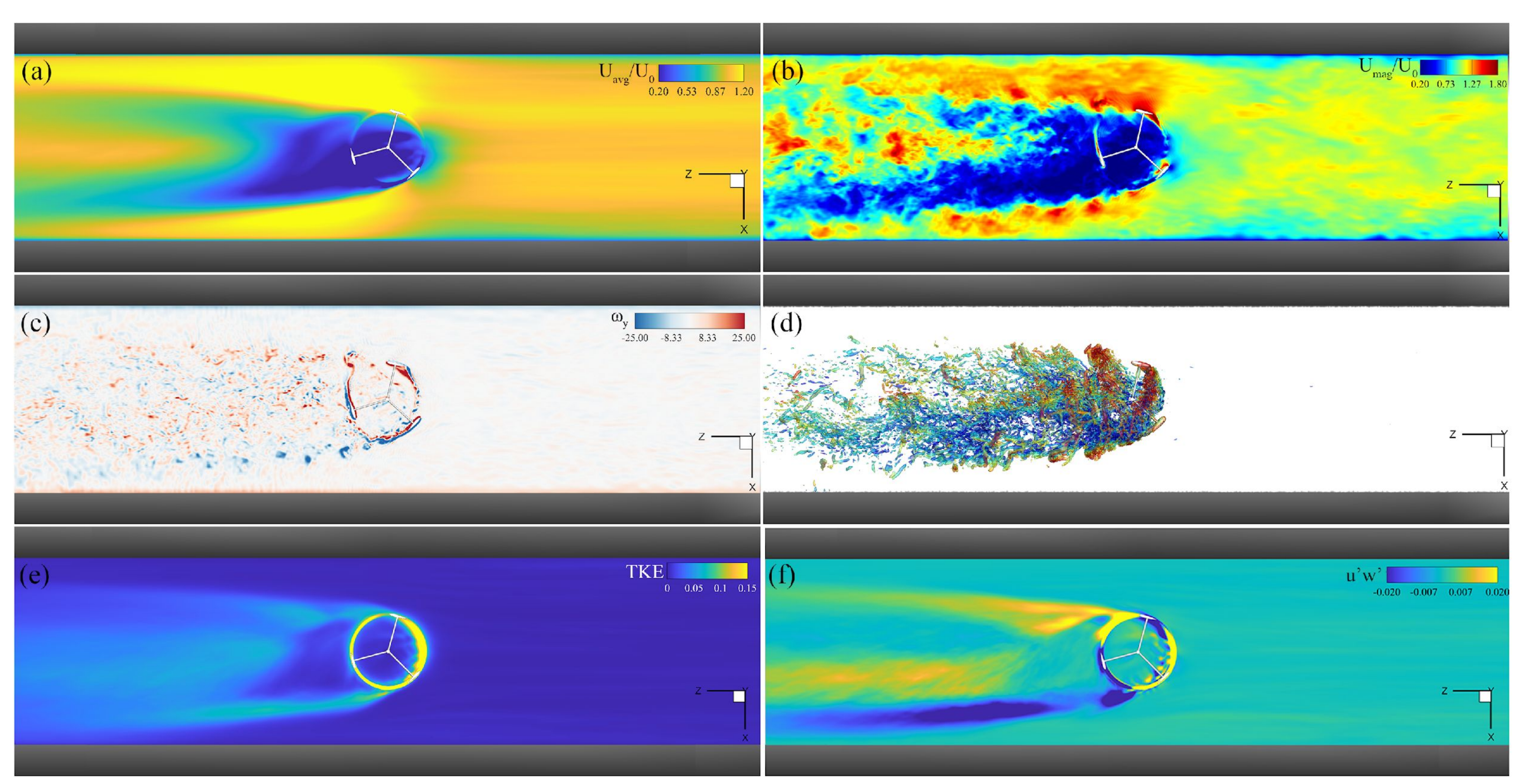


Methodology

The LES was performed on a lab-scale VAT with a rotor diameter of 12 cm. The simulations examined a tip speed ratio of 1.9 in an open channel. The flow depth was 23 cm with a free stream velocity of 0.19 m/s. A computational grid system with 32 million nodes was used to capture turbulence generated by the turbine blades. The spatially filtered Navier-Stokes equations were solved to describe incompressible flows within non-orthogonal generalized curvilinear coordinates. Turbulence is quantified using turbulent kinetic energy (TKE), Reynolds stresses, and iso-surfaces of Q-criteria. Experimental data from Cardiff University are being used as benchmark data to understand and map out the different fish behaviors in relation to the turbulence map obtained from LES results.

RESULTS





Discussion

The LES results indicated that fish tend to avoid areas with significant temporal velocity fluctuations due to high turbulent shear stress. Fish predominantly remained downstream of the channel, exhibiting station-holding behavior and consistent avoidance patterns. The TKE and Reynolds stress identified regions of high mixing and energy dissipation. Fish trajectories, mapped using turbulence data, demonstrated avoidance of the turbine wake, primarily influenced by Magnus effect-induced wake asymmetry. Additionally, while moving upstream, fish employed the Karman gaiting mechanism [8], which led to decreased oxygen consumption. According to experimental results, incidents of fish coming into contact with the turbine were observed a few times but did not result in injuries [1,2]. This is attributed to the lower tip-speed ratio of vertical-axis turbines.

Conclusion

This study revealed that fish behavior is influenced by turbulent flow dynamics. Fish-friendly eddies can create flow conditions that protect fish from injury while navigating areas with potential hazards and save them more energy while moving upstream. The turbulence map obtained from LES is a reliable tool for understanding fish movement near VATs. This study enhances the comprehension of VAT hydrodynamics and highlights the potential of high-fidelity CFD simulations in elucidating the interaction between marine hydrokinetic turbines and aquatic ecosystems.

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