Simulating Turbulent Inflow and Wind Tunnel Experiments: Reproducing TKE Decay and Developing a Digital Twin for a Wind tunnel

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Wind energy systems, such as horizontal-axis and vertical-axis wind turbines, operate in a turbulent atmospheric boundary layer, which significantly affects their efficiency. Therefore, it is essential to study the turbulent inflow that they encounter. The Turbulent Kinetic Energy (TKE) and length scales in the wind are important statistical quantities that considerably affect the aerodynamic performance of a rotor blade. To study their effects, experiments can be conducted in a wind tunnel by subjecting a Reynolds-scaled wind turbine rotor or a blade section from a real wind turbine blade to turbulent inflow under different inflow conditions, such as homogeneous inflow or gust inflows.

However, experiments are limited by Reynolds numbers (Re) and turbulence intensities (TI). Therefore, validated simulations of a wind tunnel setup, known as a digital twin, are essential to extend the experiments, where a large number of test cases can be performed. It is crucial to mimic the same turbulence properties in simulations as in experiments to ensure that the test subject is observing similar turbulent inflows in both cases. Large Eddy Simulations (LES) are useful for performing such simulations as they can resolve energy-containing bigger turbulent structures. However, LES is time-consuming and has a high computational cost. If only statistical moments of the velocity fluctuations are to be considered, then Reynolds Averaged Navier-Stokes (RANS) simulations driven by two-equation eddy viscosity-based turbulence models, such as k-omega SST Menter 1994 and 2003, are a good alternative to LES.

The main challenge in RANS simulations is finding the correct boundary conditions and closure model. Although Torrano et al. (2015) [1] used two-equation eddy viscosity models (TEM) to simulate the evolution of the TKE in the wake of a grid, a comparison with experimental results showed large deviations. In the current study, we were able to replicate the TKE decay behind a homogeneous grid observed in experiments using RANS simulations. Additionally, we developed a digital twin of our wind tunnel that accurately matched the force coefficients obtained from the experiments and simulations. Future works will include other grid configurations as well. The results produced in this study can be used to generate turbulence perturbations to study control strategies in a simulation environment.

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[1] Torrano et al., *Journal of Fluids Engineering* **137**, 6 (2015).