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Characterization of the near-wake flow downwind of a horizontal axis wind turbine using PIV

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Wind turbines operate in the surface layer of the atmospheric boundary layer, where they are subjected to strong wind shear and relatively high turbulence levels as well as significant variability in wind speed, direction and daily and seasonal cycles of thermal stability. While the far wake is usually assumed to be axisymmetric and is analytically modeled having a self-similar form, the near wake is characterized by a coupled vortex system, unsteadiness and strong turbulence heterogeneity. Limited information about the spatial distribution of turbulence in the near wake, the vortex behavior and downwind development hinders our capability to predict wind turbine power production and design efficient wind energy projects. This calls for a better understanding of the spatial distribution of the 3-D flow and organized turbulence structures in the near wake.

Particle Image Velocimetry (PIV) measurements were employed to quantify the vortical flow in the near wake of a model wind turbine in the Saint Anthony Falls Laboratory atmospheric boundary-layer wind tunnel. The miniature wind turbine model consists of a three-blade GWS/EP-6030$\times$3 rotor attached to a small DC generator. The rotor diameter is 13 cm and the hub height is 10.5 cm such that the rotor swept area is within the lowest one third of the boundary layer. The measurements cover multiple vertical stream-wise planes (x-z) and vertical span-wise planes (y-z) planes, allowing for a complete description of the near wake turbulent structure. In particular, PIV data clearly visualized the signature of tip-vortices and revealed a highly non-axisymmetric spatial distribution of the mean flow and turbulence. The experimental results provide new insight into the physical mechanism that governs development of the turbulence in the near wake of a wind turbine, and also are important data sets for the development and validation of numerical models such as Large Eddy Simulations.