Experimental setup design for validation of a theoretical model for wind turbine performance under confinement

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Wind turbines experience confinement (blockage) effects depending on the atmospheric boundary layer height and density of wind farm arrays, leading to deviations from expected performance levels. Furthermore, confinement effects on wind turbine performance are ever-present in typical experimental facilities due to finite test section size. Rotor confinement induces a streamwise pressure gradient that modifies induction, thrust, and power. Although these can be corrected via blockage models, most existing models are limited to flow-aligned, low thrust rotors, creating uncertainty in wind turbine performance predictions using these theoretical models, for both in-field and laboratory settings. To address this limitation, a unified rotor model that is fully predictive of wind turbine performance under confinement and yaw-misalignment for both low and high thrust rotor was developed and presented in Upfal *et al.,*(JFM, under consideration)[1]. In this work, a fully predictive model for a given blade, blockage, and yaw-misalignment combination is developed by coupling an actuator disk model and blade element momentum model. This unified rotor model demonstrates excellent agreement with blade-resolved simulations, however, previous experimental wind turbine performance results suffer from Reynolds number dependency of blade loading, creating notable disagreement between existing experimental results and the unified rotor model predictions. Thus, there is a need to obtain experimental results under different blockage ratios while maintaining Reynolds number independency of blade loading in order to verify the unified rotor model. To this end, we present an overview of an experimental campaign planned at the water towing tank at Queen's University using newly designed rotors and actuator disks with varying blockage levels. In addition, novel scaling laws combining blade thrust, blockage, and yaw-misalignment, along with useful heuristic guidelines for experimentalists are developed. A validated model along with the proposed blockage correction methods is an extremely useful tool facilitating accurate wind turbine performance prediction in untested blockage ratios and rotor design optimization under confinement.

[1] Upfal, McClure, Heck, Pieris, Kurelek, Hultmark, & Howland An analytical model for rotors in confined flow across operating regimes. *J. Fluid Mech.*, **Under consideration**. Preprint available at arXiv preprint arXiv:2603.06895 (2026)

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