Wake Characteristics from Scaled and Full-Scale Wind Turbines Based on Measurements and Simulations

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Abstract
Characteristics of wind turbine wakes are compared for a scaled and a full-scale wind turbine. The wake measurements are performed with nacelle-mounted, rear-facing scanning lidars, and the free stream is characterized with tall, well-equipped meteorological masts. To complement the analysis, large-eddy simulations of both turbines are performed. We focus on mean wake deficit, width, and meandering. The overall objective is to determine how the results obtained at the Scaled Wind Farm Technology (SWiFT) facility can be translated to full-scale scenarios, so that future experiments in wind turbine and wind farm aerodynamics can take advantage of this highly instrumented facility.

Introduction: The Scaled Wind Farm Technology (SWiFT) facility is a highly instrumented site with open source meteorological and wind turbine data, and provides a unique opportunity for field research and testing in the area of wind turbine aerodynamics and design [1]. However, the wind turbines at the site have smaller rotors and shorter hub heights (Table 1) than what is typically found in utility-scale wind farms. Therefore, it is crucial to understand how the results obtained from the scaled field experiments can be carried over to full-scale wind turbines and power plants. With that in mind, this work investigates how rotor size and hub height modulate some properties of wind turbine wakes such as deficit, width, and meandering.

Data: The analysis considers observational and simulated data sets upstream of the wind turbine (i.e. in free stream conditions), at the turbine, and downstream in the wake. To enable a comparison between below-scale and full-scale wind turbine aerodynamics, measurements were collected at SWiFT and at the National Wind Technology Center (NWTC) and the instrumentation used is summarized in Table 1. To complement the analysis of the observational data, high-fidelity simulations were performed using the National Renewable Energy Laboratory (NREL) Simulator for Wind Farm Applications (SOWFA, [2]) Large-Eddy Simulation (LES) tool. Details on model configuration and initialization will be given in the presentation of the work.

Table 1: Information about the sites and instruments used in to collect observations.

Site	Wind Turbine				Upstream Measurements	Downstream Measurements		
	Model	Rotor Diameter	Hub Height	Rated Wind Speed		Instrument	Range	Number of points/ Frequency
SWiFT [1] (Lubbock, TX, USA)	Vestas V27 reconfigured	27 m	32.5 m	14 m/s	200 m met. tower	DTU spinner lidar	1-5 D	984/ 4 s
NWTC [3] (Boulder, CO, USA)	GE 1.5 SLE	77 m	80 m	14 m/s	135 m met. tower	Stuttgart scanning lidar	1-2.8 D	49/ 1 s

Methodology: To enable a comparison between the scaled and the full-scale measurements collected at different sites, the observational data sets are first sorted according to atmospheric inflow conditions. Periods with sufficiently homogeneous mean wind and turbulence intensity are identified, and further reduced according to the magnitude of shear and veer across the rotor. Criteria for homogeneity will be defined based on data availability, and discussed during the conference presentation. Finally, conditions with strong synoptic-scale or meso-scale atmospheric forcing are eliminated, to reduce the level of uncertainty in the analysis related to large-scale differences between the two sites. The remaining data is then used to characterize the measured wakes, providing preliminary results that can be used to determine the configurations of interest for the high-fidelity simulations. More conclusive results are then obtained from the simulation data, which are performed with the two distinct turbines (Table 1) under a set of different atmospheric conditions. Limitations in the analysis of observational data include the different topographic characteristics of the two sites (e.g., roughness and orography) and the differences between the two lidars, as is best illustrated by the scanned area and number of points as shown in Fig. 1. The uncertainty associated with these limitations is not considered in the current work, and is the topic of ongoing research. Moreover, blade-scale differences between the two turbines are not explicitly considered in the present analysis.

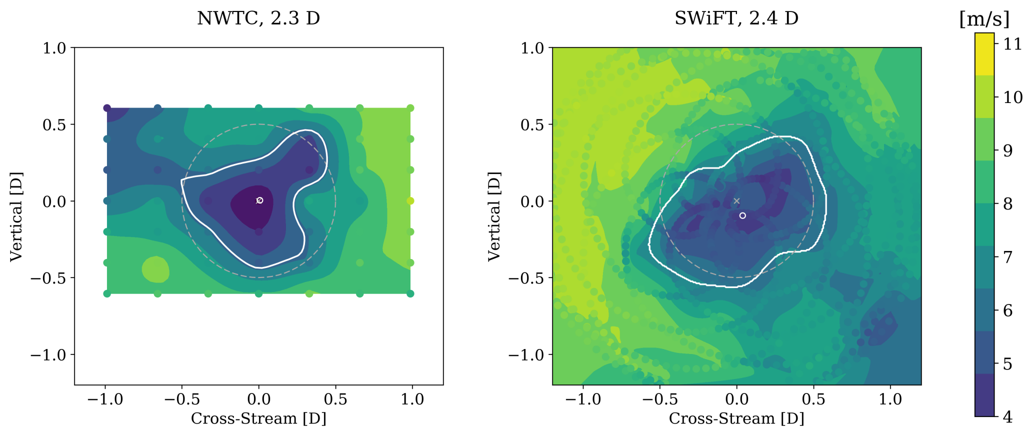

Fig. 1: Example wake measurements at NWTC (2.3 D downstream of wind turbine) and at SWiFT (2.4 D downstream of wind turbine). Data are snapshots, and contour values are consistent for both plots. Dashed gray line indicates rotor area and gray marker the hub location. White solid line indicates wake outline and white circle its center.

Summary: This work is the first effort towards determining whether wind turbine wake metrics can be scaled from smaller to larger rotors, and from lower to higher hub heights. This is of significant interest to the research community in wind farm aerodynamics, which struggles to perform experiments in full-scale operational wind farms due to logistical and economical challenges. In providing guidelines regarding the scaling of these quantities of interest, we enable the larger community to make use of the large open-source data sets available in the Atmosphere to Electrons (A2e) Data Archive and Portal (DAP).

References

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