WAKE DEVELOPMENT AND INTERACTIONS WITHIN AN ARRAY OF LARGE WIND TURBINES

SUPERGEN WIND
EPSRC
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INTRODUCTION

The investigation of wake development and wake interactions within an array of wind turbines is a key objective in the EnFlo wind tunnel laboratory contribution to the EPSRC funded **SUPERGEN V - WIND ENERGY TECHNOLOGIES** project. The turbine wake is generally characterised by reduced wind speeds and increased levels of turbulence. Within a wind farm array, the effects of several wakes interact. Thus, the turbines produce less energy and stand greater structural loads than a single turbine. Current prediction models need improving for these large machines - 5MW.

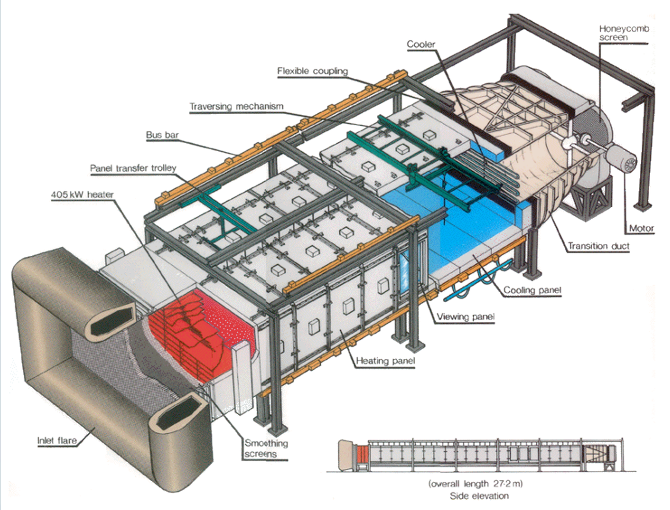


Fig 1: EnFlo ABL wind tunnel.

EXPERIMENTAL SET-UP AND PLANNED CASE STUDIES

Wake characteristics, development and interactions are being studied in the large EnFlo atmospheric boundary layer wind tunnel shown in Figure 1 (working section: 22m x 3.5m x 1.5m) for a 5MW machine (rotor diameter: 126m; hub height: 90m). A model scale of 1:300 has been chosen to ensure sufficient spatial resolution for the wake measurements. Allowing for reasonable longitudinal spacing of 6-8 rotor diameters D, up to five rotating, speed controlled scale model wind turbines will be arranged successively in the test section. Wake interactions of two parallel turbines with a lateral spacing of 3-4D will also be studied.

The planned case studies comprise off-shore ABLs for neutral and non-neutral conditions as well as a rural neutrally-stratified ABL over different terrain. Wake measurements are made using LDA, including phase-locked measurements to separate ordered motion from ABL and blade generated turbulence.

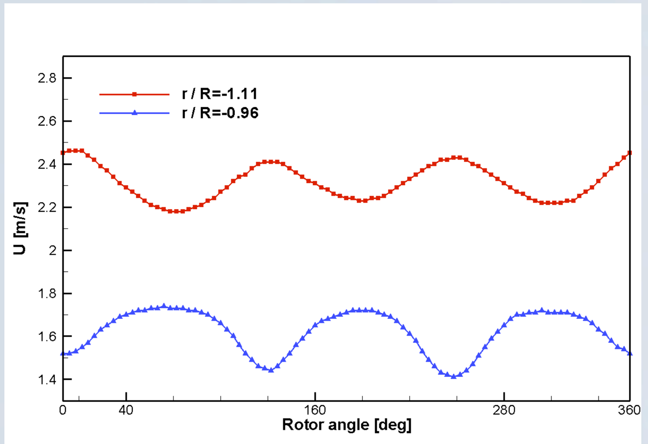


Fig 2: phase-locked wake measurements (low turbulence flow).

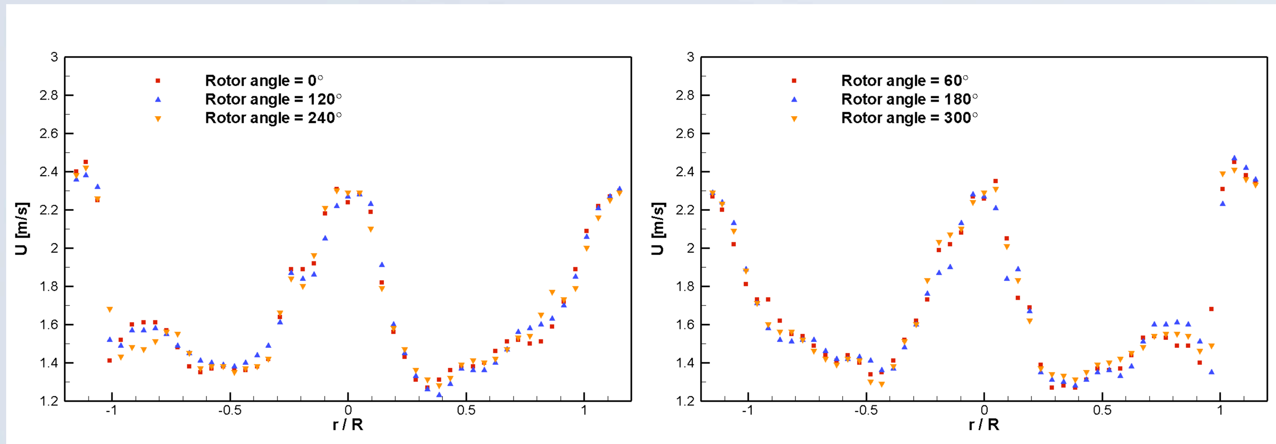


Fig 3: phase-locked wake velocity profiles (low turbulence flow).

WORK PROGRESS

Up to now, initial wind tunnel experiments were conducted to generate neutrally stratified on-shore and off-shore model boundary layers with characteristic mean and turbulent properties at the appropriate scale.

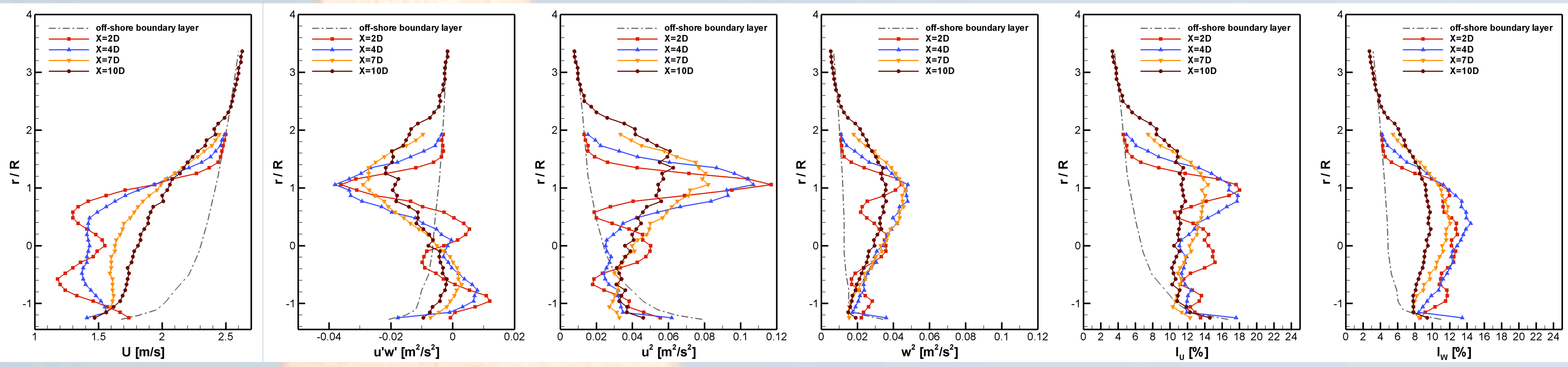


Fig 4: Vertical profiles of velocity, turbulent fluxes and turbulence intensity in the wake of a single turbine (off-shore ABL).

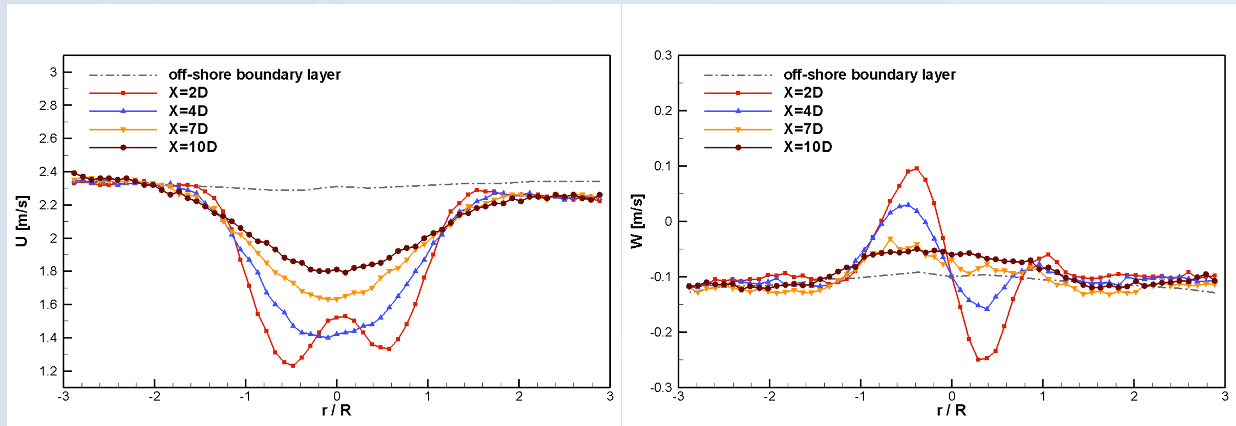


Fig 5: Lateral profiles of stream-wise and vertical velocity in the wake of a single turbine in an off-shore ABL (flow out of paper plane, counter-clockwise blade rotation).

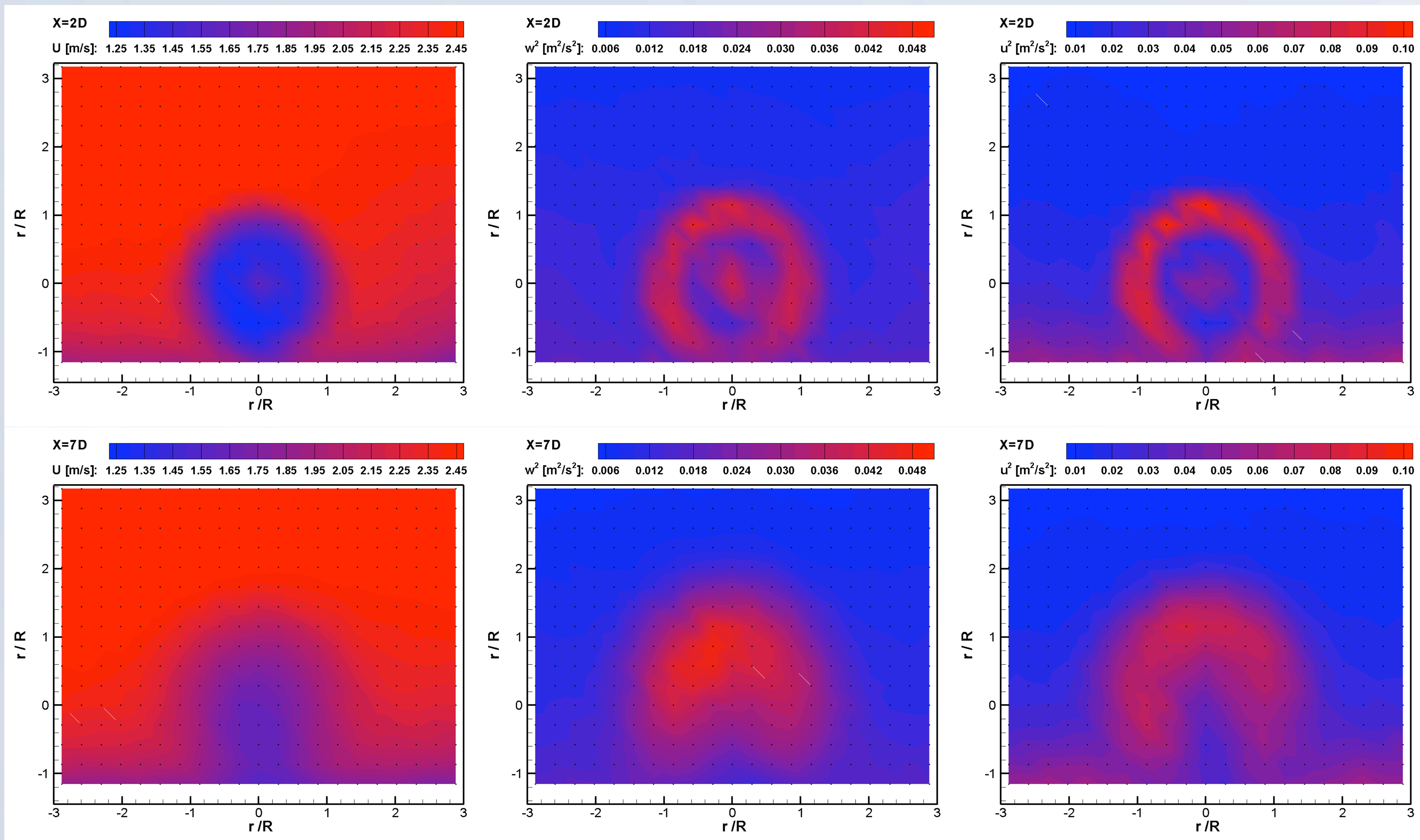
The blade design is based on blade-element theory for low Reynolds number blade aerodynamics (no camber; twist at root: 50.6°; pitch: 2°). The blades are made from thin layers of fibre glass and resin using a custom made former and mounted on a brushed micro motor. The braking voltage speed control is coupled to the signal of a micro-Hall sensor. The Hall sensor signal is furthermore used to phase-lock the measurements.

Pre-tests in an uniform, low turbulence flow have been conducted to compare model turbine performance with the theoretical design case (tip speed rato TSR=6; design lift coefficient C_L=0.6). The measured trust coefficient C_T=0.52 is within about 5% of the predicted value.

Figure 2 shows phase-locked velocity traces at two stations near the blade tip (r/R≈1) taken in the uniform, low turbulence flow at a downstream position of 0.5D. The finding of a 180 ° phase shift coincide with a shed tip vortex. A similar feature is observed near the root. Figure 3 shows phase-locked velocity profiles at hub height.

The development of mean and turbulent wake flow characteristics in a realistic off-shore ABL is shown in Figure 4 (selection of realised downstream positions only). The model results suggest a transition from near to far wake at a downstream distance of approximately 4D. Turbulence levels are still significantly increased 10 diameters downstream of the model turbine (factor of 2). Time averaged flow fields of the mean and turbulent stream-wise and vertical flow components are shown in Figure 6. The mean vertical velocity component in particular illustrate the characteristic swirl generated by the blade rotation, which persists until about a downstream distance of 7D (compare also lateral profile of vertical velocity at hub height shown in Figure 5).

At present, a second blade set with different chord distribution is tested before a decision will be made to which design will be used for the planned turbine arrays. In the presence of ambient turbulence, the present speed control is insufficient to keep the desired TSR constant within reasonable limits of ±2%. Further improvement is needed in order to explore ordered motions in the wake.



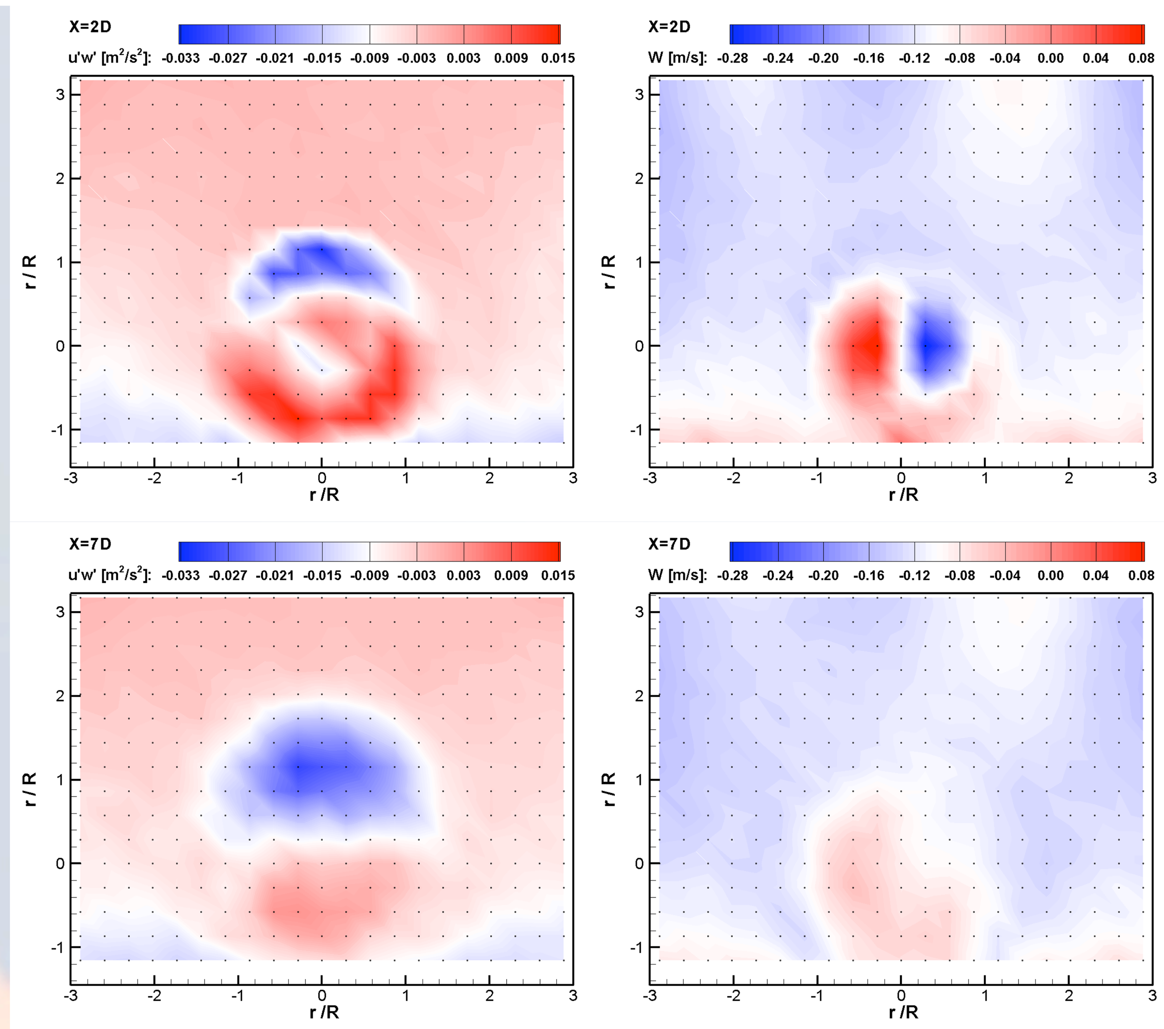


Fig 6: Development of flow characteristics in the wake of a single turbine in an off-shore ABL (flow out of paper plane, counter-clockwise blade rotation).