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Wind tunnel simulations of wind turbine wake interactions in neutral and stratified wind flow.

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A second programme of work is about to commence as part of a further four years of funding for the UK-EPSRC SUPERGEN-Wind large-wind-farm consortium. The first part of the initial programme at Surrey was to establish and set up appropriate techniques for both on- and off-shore boundary layers (though with an emphasis on the latter) at a suitable scale, and to build suitable rotating model wind turbines. The EnFlo wind tunnel, a UK-NCAS special facility, is capable of creating scaled neutral, stable and unstable boundary layers in its 20m long working section. The model turbines are 1/300-scale of 5MW-size, speed controlled with phase-lock measurement capability, and the blade design takes into account low Reynolds-number effects. Velocity measurements are primarily made using two-component LDA, combined with a 'cold-wire' probe in order to measure the local turbulent heat flux.

Simulation of off-shore wakes is particularly constrained because i) at wind tunnel scale the inherently low surface roughness can be below that for fully rough conditions, ii) the power required to stratify the flow varies as the square of the flow speed, and could easily be impractically large, iii) low blade Reynolds number. The boundary layer simulations, set up to give near-equilibrium conditions in terms of streamwise development, and the model turbines have been designed against these constraints, but not all constraints can be always met simultaneously in practice.

Most measurements so far have been made behind just one or two turbines in neutral off- and on-shore boundary layers, at stations up to 12 disk diameters downstream. These show how, for example, the wake of a turbine affects the development of the wake of a downwind turbine that is laterally off-set by say half or one diameter, and how the unaffected part from the first turbine merges with the affected wake of the second. As expected a lower level of atmospheric turbulence causes the wakes to develop and fill-in more slowly compared with the on-shore case. A turbine can also suppress the level of atmospheric turbulence below hub height.

In neutral flow, the wakes grow in width and height. However, even in mild stable stratification the vertical development of the wake deficit can be completely inhibited; at least some reduction would be expected arising from the stabilizing influence on vertical fluctuations. The width in contrast develops at about the same rate. As anticipated, the wake development is slower still in the stable case because of the lower level ambient turbulence. The maximum deficit is at a lower height than it is for neutral flow. Various aspects of the turbulence in the wake have been investigated.

Second-phase work will examine a larger number of wake-turbine and wake-wake interactions, make a more detailed study of how turbines alter the atmospheric turbulence, and examine more cases of stratification. Work is also in hand related to turbines in or near forested regions, and it is expected that aspects of the physics will have links with the effect a large wind farm will have on the ABL and on the wind resource for a downwind farm. The work will produce a series of test cases to assist in the development of better wake and wind resource prediction models as well as a better understanding of wake physics.