Wind turbine wakes in stable atmospheric boundary layers

Philip E Hancock, Paul Hayden
University of Surrey, Guildford, UK, +44 1483 689625, p.hancock@surrey.ac.uk;

Summary
Results are presented of a meteorological wind-tunnel simulation of the wake of a wind turbine in two cases of moderately stable flow, and baseline neutral flow, where one case is with an overlying inversion. The wake deficit decreases more slowly in the stable cases, more so when an inversion is present, and the vertical extent of the wake development is also almost entirely inhibited. Reynolds stresses (and other turbulent transfers) are also reduced.

1. Introduction

The wakes of wind turbines, the energy available to downwind turbines, and the associated fatigue loads, are strongly dependent on atmospheric boundary layer (ABL) conditions, which range from strongly convective to strongly stable. Studies have been made via wind tunnel simulations [1, 2] of the wake of a model wind turbine in stable flow. It is commonly supposed that the surface condition (via the Obukhov length) is sufficient to define the degree of stability, but it is not. This paper gives results for a moderately stable boundary layer a) without an overlying inversion [3], b) with an overlying inversion. The height of an ABL can be less than the tip-top height of a large wind turbine.

2. Wind tunnel

The experiments were conducted in the EnFlo meteorological wind tunnel, which is especially designed in order to simulate stratified flows by either cooling (stable) or heating (unstable) the floor, and by heating the inlet flow to provide a rising (stable) or falling (unstable) temperature profile. Specifying the inlet temperature profile shape needs particular care in the case of stable flow. The boundary layer was artificially thickened by means of flow generators that also provide profiles of mean velocity and turbulence quantities that are characteristic of a stable atmosphere. Particular attention was paid to ensuring the flow is closely horizontally homogeneous over the development length of the wake. The turbine was a three-blade rotating model. Measurements were made using two-component LDA and coincident fluctuating temperature measurement to give turbulent heat flux.

3. Results

An introduction to the results is given below [Fig. 1], for three cases: neutral (left); stable no, inversion (middle); stable with inversion (right). The top row shows the mean velocity profiles at three non-dimensional streamwise stations (*X/D* = 1, 6 and 15) together with the undisturbed flow at the same stations. The difference in development is clearly seen; slower reduction of the velocity deficit; reduced vertical development, almost to zero in the inversion case. The middle row shows the corresponding temperature profiles for the two stable cases, where it is seen in this instance that only the profiles in the upper half of the layer are markedly affected. The lower row shows the streamwise Reynolds stress for each of the three cases, and the undisturbed profiles. Even moderate stability leads to a marked reduction, also seen in all the other stresses.

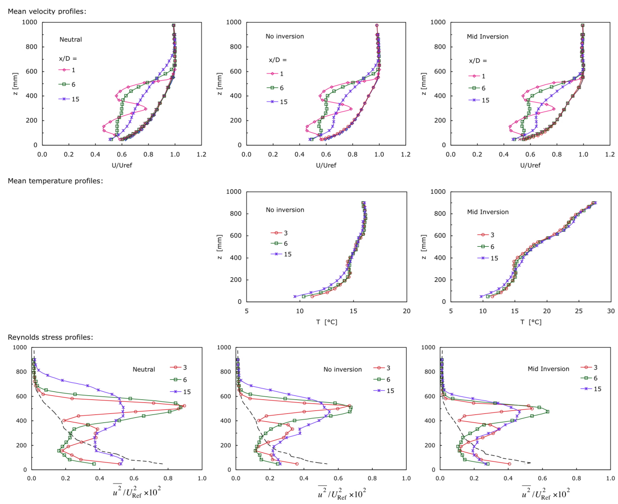

Fig. 1 Wake profiles in neutral and stable conditions.

4. References

[1] Hancock P E, Pasheke F. Boundary-Layer Met. 2014; 151(1), 3-21; 23-37.
[2] Hancock P E, Zhang S. Boundary-Layer Met. 2015; 156(3):395–413.
[3] Hancock P E, Hayden P. Boundary-Layer Met. 2018; doi: 10.1007/s10546-018-0337-7.