

Wind tunnel measurements of the flow upstream a wind turbine: effects on the power production

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Abstract summary

This study presents a wind tunnel measurement campaign which used rotating wind turbine models to investigate the flow field upstream of the rotor. Hot wire measurements were carried out up to several diameters upstream of the rotor. With a PIV system, both the streamwise and radial velocities close to the rotor were measured, as well as the effect of a rotor inclination up to 20 degrees. The results show that the flow is influenced up to more than 3 diameters upstream of the turbine. This is a larger effect on the upstream flow than usually considered, and this should be taken into account when power performance testing and energy production predictions are performed.

Objectives

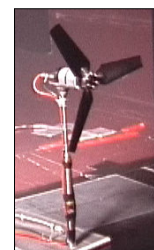
There is a large body of knowledge on wakes, but only a limited number of measurements have been taken on the flow approaching a wind turbine. These studies focussed only on a few points for comparisons with data from meteorological masts, or on the flow close to the blades, such as for the NREL measurements which provided valuable data of the aerodynamic coefficients as a function of the angle of attack.

The current practice for power curve measurements assumes that a turbine, in steady and not-yawed wind conditions, will have a negligible influence on the flow that is 2 rotor diameters upstream. However, any upstream effect caused by the turbine that reaches beyond 2 diameters can have important consequences on the power estimate for a given turbine and, therefore, on the total production of a wind farm.

The objective of this study was to obtain new information on the flow upstream of a turbine under both normal and yawed conditions. Of special interest is to see how far upstream the blockage effect of the turbine has a negligible influence on the wind speed.

Methods

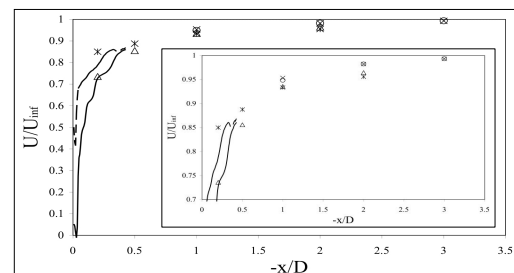
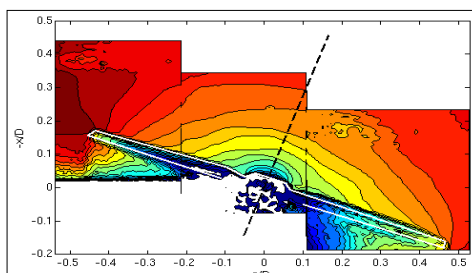
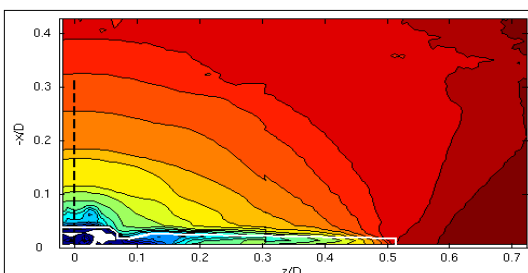
The main part of the data presented here can be found in the doctoral thesis of Medici (2006). These experiments were performed in the MTL (Minimum Turbulence Level) wind tunnel at KTH Mechanics. The PIV data was obtained using a three bladed model shown to the side. The turbine has a diameter of 0.18m and it is positioned on the wind tunnel floor along the centreline, 1.45m from the test section inlet. The blockage of the model is less than 3% of the wind tunnel cross-section. The hub diameter is 25mm and its centre is approximately 1.3 rotor diameters above the wind tunnel floor. The non-twisted blade is based on the Göttingen 417A airfoil where the maximum chord is 27mm at 12% of the radius, and the tip chord is 16mm. Details on the blades and their construction can be found in Medici & Alfredsson (2006). The rotational speed of the turbine was controlled by a loading circuit connected to the turbine generator. The turbine was set at the maximum power coefficient of 0.31, with a thrust coefficient at 0.83 and a tip speed ratio of 2.8.



A two-bladed turbine without nacelle and a diameter of 0.205m was used to see the effect of the nacelle on the upstream flow. In this case the rotor is free-running, i.e. no loading can be applied to the shaft except the friction from the bearings; the tunnel wind speed was set at 6 m/s, the tip-speed ratio was 3.2 and the thrust coefficient estimated to be 0.74. Finally some data published by Alfredsson & Dahlberg (1979) has been used for comparison with the present results.

Results

The first two figures show the PIV measurements upstream of the three-bladed turbine. The contour lines represent the velocity component normal to the rotor disc. In the left diagram, the turbine is positioned normally, the flow is symmetric and only one side of the turbine is shown. In the centre diagram, the turbine is yawed at 20° and, to show the full turbine disc, three images were combined. The colour coding is from zero (dark blue) to the undisturbed velocity (dark red). In the rightmost figure, data are plotted for the two-bladed turbines described above along the centreline (\circ, Δ) and at the 60% radius (\times, \star). The data related to the three-bladed turbine is represented by lines. It is clear that the velocity defect behaves in a similar way in all three cases.



Conclusions

This study has shown, using several data sets, detailed velocity measurements upstream of a rotating wind turbine. Each set of data has shown that, contrary to usual considerations, the wind speed upstream of a turbine is affected beyond 2 diameters upstream of the rotor and that at 2 diameters, the velocity defect for thrust coefficients in the 0.7 to 0.8 range is 2-4 % of the undisturbed free stream velocity. Such large effects should be taken into consideration when determining the turbine characteristics.

References

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