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STUDY OF LARGE-SCALE VERTICAL AXIS WIND TURBINE WAKE THROUGH NUMERICAL MODELLING AND FULL-SCALE EXPERIMENTS

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1. Introduction

Offshore wind capacity is increasing exponentially over the years in Europe, taking advantage of the strong winds available over the ocean and of the political incentives to reduce greenhouse gases. The technology is however not yet competitive when compared to fossil fuels or onshore wind. One key improvement that could make offshore wind more attractive is the reduction of the wake effect [1]. The latter corresponds to the velocity deficit generated by each wind turbine wake which affects the production of the others. This effect accounts for approximately 10% of the energy losses for a typical horizontal axis wind turbine wind farm.

Vertical-Axis-Wind-Turbines (VAWTs) offer great perspectives to solve this issue as they are known to have a less stable wake [2]. The turbulences generated behind a VAWT dissipate therefore more quickly than behind a Horizontal-Axis-Wind-Turbine (HAWT). Modelling of the wake is however a great challenge for scientists and engineers, especially regarding VAWTs where the aerodynamics is highly unsteady and has significant 3D effects [3].

2. Wake study through high fidelity modelling and full-scale experiments

To study the 3D wake structures observed behind an operating VAWT, vortex models (ARDEMA) and a CFD (Computational Fluid Dynamics) modelling strategy have been developed by ADWEN OFFSHORE, NENUPHAR with subcontracting to DELFT University and the CORIA inside the MADRILLET Technopole. ARDEMA is a set of a two dimensional (ARDEMA 2DS) and a three dimensional unsteady vortex code (ARDEMA 3DS). CFD simulations are run with a software using a URANS (Unsteady Reynolds Averaged Navier Stokes) formulation.

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The main difference between the two types of calculation is the modelling of the viscous effects. They are inherently calculated in CFD but are calculated using a semi-empirical model in the vortex codes. For the latter, a Beddoes-Leishman type dynamic stall model [4] is coupled with the inviscid flow solver to correct the local forces and the induced wind speed for flow separation. There is however no correction applied to take into account the viscous dissipation of the wake. In CFD simulations, the SST (Menter's Shear Stress Transport) k-ω turbulence model is used to compute viscous effects including flow separation and viscous dissipation. For this purpose, two partial differential equations are solved for the turbulence kinetic energy and the dissipation rate.

Nenuphar and Risoe DTU collaborated in acquiring unique 3D wind field measurements around an onshore prototype of an offshore floating VAWT concept. The mobile 3D remote-sensing laser-based WindScanner facility www.windscanner.dk provided 3D wake measurements around the large-scale onshore prototype of NENUPHAR operated at an onshore test site well-exposed to the strong Mistral winds near Fos-sur-Mer, Southern France. The WindScanners measured the mean and turbulence flow fields within and behind the 42 m tall and 51.5 m wide VAWT. The campaign resulted in a total of 37 wind field runs.

Fig. 1 Short-range WindScanners in operation around the Nenuphar VAWT at Fos-sur-Mer, Fr.

The three space and time synchronized short-range WindScanners R2D1, R2D2 and R2D3 in operation at the Nenuphar test site at Fos-sur-Mer. The wake influenced mean and turbulent wind fields were scanned in both horizontal and vertical planes through the running rotor and in the wake behind the 51.5 m Ø, 42 m tall Nenuphar VAWT.

3. Comparison between numerical and experimental results of the VAWT wake

Figure 2 shows a comparison of the induced wind speed along the blades path of the wind turbine, simulated by ARDEMA 2DS and measured by the WindScanner. The inflow comes from the azimuth -90°. We observe a good agreement of the model with the experimental results. It predicts correctly the high induction when the blade is perpendicular to the infinite wind upwind and downwind as well as the low induction when the blade is parallel to the unperturbed free wind. The interaction between the upwind part of the rotor and its downwind part is also well modelled.

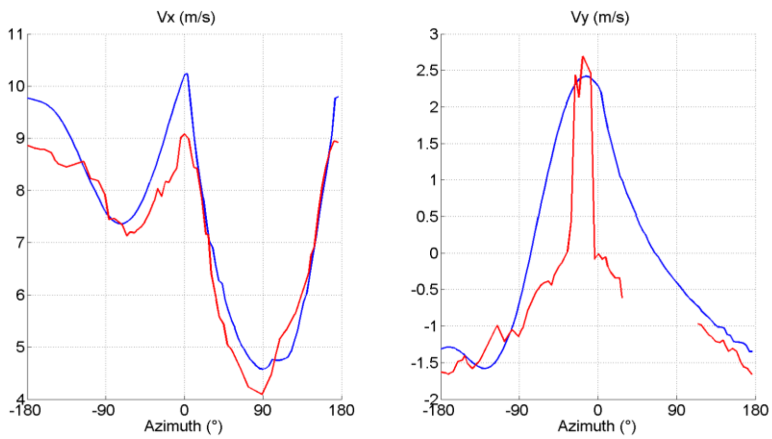

Fig. 2 Induced wind speed along the blades path at hub height 27 m.
Comparison between ARDEMA 2DS (in blue) and the WindScanner measurement (in red). Vx is the wind speed along the free wind direction and Vy is the perpendicular component in the horizontal plane. The free wind comes from azimuth -90°. The measurements of Vy is not valid from 30° to 115° because this region is affected from noise generated by the reflections of the laser light from the wind turbine tower.

Figure 3 shows a comparison of the mean wind field in a horizontal plane at the hub height of 27m between ARDEMA 2DS and the WindScanner measurements. A fairly good agreement is observed as the velocity deficit is of the same magnitude and the asymmetry of the flow around the wake is present in both figures. Far downstream of the rotor, we observe that the wake dissipates more quickly in reality compared to what the model predicts. This can be explained by two assumptions made in the numerical simulations:

- the vortices viscous diffusion is not taken into account.
- steady wind was used as input, which lowers the reenergizing of the wake by the turbulent ambient air.

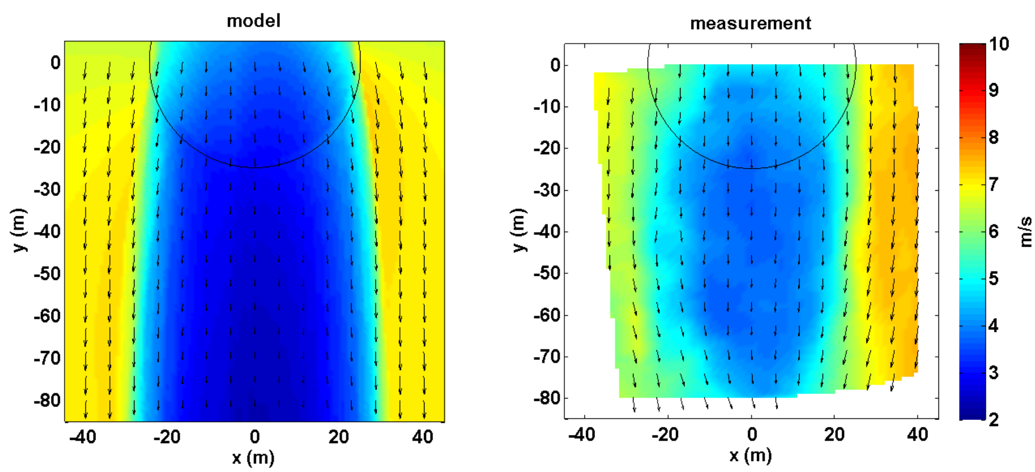

Fig. 3 Horizontal plane mean wind field at hub height 27 m.
Comparison between ARDEMA 2DS (on the left) and the WindScanner measurement (on the right). The rotor consists of three blades turning anticlockwise and the wind is coming from the top.

4. Conclusion

The paper presents the modelling method of the VAWT wake with ARDEMA simulations as well as comparison of the numerical modelling of the near wake of a VAWT with, for the first time, measurements on a large-scale prototype at high Reynolds number. The data, obtained with a new laser-based remote sensing instrument were compared to vortex models and CFD simulations. The comparisons between ARDEMA 2DS and the WindScanner measurements show a satisfying agreement. Comparisons with ARDEMA 3DS and CFD simulations will be presented in the full paper.

5. Learning objectives

The measurements on the Nenuphar full-scale prototype provided valuable information about wake viscous diffusion and tip vortices roll-up [5] at high Reynolds number. These flow mechanisms are of particular importance as they govern the wake shape and expansion of a VAWT. It will therefore be possible to improve the numerical models and predict more precisely the wake losses in a wind farm. It is expected that this work can lead to a significant improvement of a VAWT wind farm efficiency.

Acknowledgments

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