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Wake predictions of full HAWT rotor and actuator disk model
CFD simulations using different RANS turbulence models
compared to experimental measurements

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Abstract
The development of large scale wind energy projects created the demand for increasingly accurate and efficient models that limit the project’s uncertainties and risk. Wake effects are of great importance and together with the complex terrain effects are employed to the optimization process of wind farms. Despite the growing body research there are still many open questions and challenges to overcome. To investigate the physics involved in a single wake, full wind turbine rotor simulations are compared with a simplified actuator disk model that is used by the industry for wind farm applications.

The steady state 3-D Reynolds-Averaged Navier Stokes (RANS) equations are solved in the open-source package OpenFOAM [1], using different two equation turbulence models. For the full-rotor computational fluid dynamics (CFD) simulations, the multiple reference frame (MRF) approach was used to model the rotation of the blades and hub geometries. For the simplified cases, the actuator disk model was used with the experimentally measured thrust (Ct) and pressure (Cp) coefficient values. The performance of each modelling approach is compared against wind tunnel wake measurements of the 4th blind test organized by NOWITECH and NORCOWE in 2015 [2, 3].

Computational domain and boundary conditions
The computational mesh was generated with blockMesh and snappyHexMesh. The final grid size was 30Mi cells for the full rotor CFD simulations and 14Mi cells for the ADM cases. A uniform velocity profile of 11.5 m/s has been used in all cases. Turbulence characteristics are based on the experimental measured turbulence intensity and length scale.

Figure 1: Details of the mesh and local refinements

Table 1: Inflow and outflow boundary conditions

<table>
<thead>
<tr>
<th>Dirichlet</th>
<th>von Neumann</th>
<th>Zero gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet</td>
<td>$u$, $k$, $e$, $\omega$</td>
<td>$p$</td>
</tr>
<tr>
<td>Outlet</td>
<td>$p$</td>
<td>$u$, $k$, $e$, $\omega$</td>
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</tbody>
</table>

Table 2: Other boundary conditions

<table>
<thead>
<tr>
<th>Sides, top, bottom</th>
<th>Slip condition</th>
<th>Wall functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blades, hubs</td>
<td>Momentum sinks</td>
<td></td>
</tr>
<tr>
<td>Actuator disks</td>
<td>$\lambda=6$</td>
<td></td>
</tr>
<tr>
<td>Rotating frame WT1</td>
<td>$\lambda=5$</td>
<td></td>
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<tr>
<td>Rotating frame WT2</td>
<td></td>
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</tbody>
</table>

Figure 2: Contours of velocity, TKE and vorticity. From top to bottom: k-e, k-omega, k-omega SST, k-e Realizable, k-e RNG

Wake predictions against measurements

Figure 3: Normalized velocity over three downstream positions.

Left: actuator disk model. Right: full rotor simulations

Conclusions
Results in all wake regions show that both CFD approaches are very sensitive to the choice of turbulence model [4, 5].

On average, the actuator disk models under-predict the velocity deficit in the wake. However, good results are obtained with an appropriate turbulence model: the k-e RNG shows excellent agreement in the mid and far wake (Figure 3).

Full-rotor simulations show very good agreement in the near and mid wake. On the other hand, they all over-estimate the velocity deficit in the far wake, which is related to the severe under-estimation of the turbulence intensity by the full-rotor simulations (Figures 2, 3). Preliminary calculations that we have performed, suggest that including the tower and nacelle might lead to better prediction of the far wake. This topic needs further investigation.

References
[1] OpenFOAM.org. URL: www.openfoam.org