Numerical study of wake flow mixing in turbulence condition

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Abstract
This study discusses the effect of turbulent inflow on wind turbine wake using computational fluid dynamics (CFD). The moving, overlapped-structured, grids-CFD-solver rFlow3D is used for simulating the velocity/vorticity distributions of wind turbine wake. A turbulent inflow condition is generated using a synthetic random Fourier method which uses the Cholesky factorization of a function of spatial correlations. By comparing uniform and turbulent inflow conditions, rFlow3D could capture the diffusion effect of turbulent inflow. The CFD results show the more dynamic breakdown of tip vortices in turbulent inflow condition with rapid velocity recovery in the wake region.

Objectives
- Research on the relation between turbulent inflow and velocity recovery process
- Important information for design of wind farms

Turbulence modeling

- Turbulence generation
  ✓ Using synthetic random Fourier method(2) to generate wind distributions
  ✓ Turbulence intensity $\sigma = 14\%$ of inflow speed $U_{in}$ (IEC Class B(3))
  ✓ Using spatial correlation and power spectrum of Kaimal model(4)
- Validation
  ✓ Turbulence standard deviation are decayed by numerical viscosity of CFD (Table 2)
  ✓ Power spectrum of inflow shows that low-frequency fluctuations are missing in this study
  ⇒ Influenced by grid resolution of the outer grid

Method
- CFD solver rFlow3D(1)
  • Outer grid: holds turbulent inflow
  • Inner grid: resolves wake structures
  • Blade grid: resolves flows around rotor
- Table 1 Grid information
<table>
<thead>
<tr>
<th>Domain (D: diameter)</th>
<th>Outer grid</th>
<th>Inner grid</th>
<th>Blade grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 × 50 + SD</td>
<td>11.5D × 2D</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Partitions</td>
<td>701 × 101</td>
<td>1369 × 249</td>
<td>121 × 121</td>
</tr>
<tr>
<td>Total</td>
<td>7 M</td>
<td>88 M</td>
<td>2.7 M</td>
</tr>
</tbody>
</table>

Results & Discussion

- Wake analysis
  ✓ Visualize distributions of vorticity in wake region
  ✓ Turbulent inflow accelerates interactions between tip vortex sheets ⇒ increase of diffusion effect
- Evaluate the recovery of wake region using rotor equivalent wind speed (REWS)
  REWS(non-dimensional) $U_{REWS}^* = \frac{\int u ds}{U_{ref}S}$
  where, $u$ : wind speed at wake region
  $U_{ref}$ : wind speed of inflow
  $S$ : sweep area of blades
  ✓ In turbulence condition, wind speed in wake tends to recover rapidly

Conclusions

- Due to turbulent inflow, the interaction between tip vortices in wake tends to be more dynamic because of fluctuation of wind
- Dynamic mixing of tip vortices in turbulence flow makes recovery of wind a bit faster and goes back to the inflow speed quickly

References
1. Tanabe Y and Salot S “Significance of all-speed scheme in application to rotorcraft cfd simulations,” The 3rd Int. Basic Research Conf. on Rotorcraft Technology, 2009

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