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Energy

CFD Modelling of Wind Turbine Wakes in Complex Terrain

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Summary

Wind turbine (WT) wakes are responsible for a reduction of a wind farm power output and increase of its dynamic loads due to the velocity deficit and increased turbulence levels they induce. In this work, the commercial CFD software Fluent 6.3 is used to model wakes of large rotating WTs operating in complex terrain under neutral conditions. The approach is then applied to cases of real wind farms.

Objectives

1. Model the wake of 1 WT on flat terrain and on a Gaussian hill (H=700m, 0.4 mean slope)
2. Model wakes of 2 WTs and examine wake interaction
3. Apply the model in real complex terrain wind farm cases and compare with measurements and results from simple models (ex. WAsP)

CFD approach

- Meshing:
  - Structured + Unstructured in rotor vicinity
- Turbulence models:
  - k-ω SST
  - Reynolds Stress Model (RSM)
- Fluent's Virtual Blade Model
  - Based on Blade Element Theory
  - Momentum sinks on an actuator disk
  - No need for meshing rotor blades
  - Use of airfoil tables (cl, cd vs. angle of attack)
  - Rotor rotation, varying twist, chord, airfoil types
- Inlet conditions:
  - Logarithmic velocity profile: $U(z) = \frac{u^*}{\kappa} \cdot \ln\left(\frac{z}{z_o}\right)$
  - Turbulence profiles:
    - k-ω SST

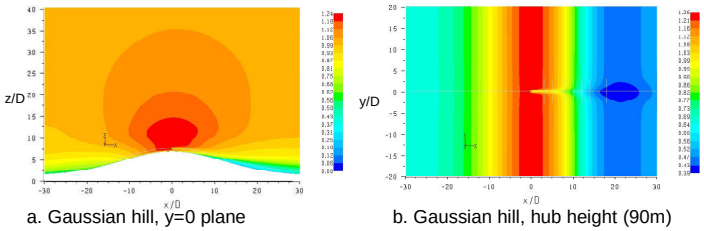
      $k(z) = \frac{u^{*2}}{\sqrt{\beta^*}}, \quad \omega(z) = \frac{u^*}{\sqrt{\beta^*} \cdot \kappa \cdot z}$
    - RSM (accounts for anisotropy)

      $k(z) = 0.5 \cdot (\sigma_u^2 + \sigma_v^2 + \sigma_w^2), \quad \varepsilon(z) = \frac{u^{*3}}{\kappa \cdot z}$

$\frac{\sigma_u}{u_*} = 2.4, \quad \frac{\sigma_v}{u_*} = 1.9, \quad \frac{\sigma_w}{u_*} = 1.25, \quad \overline{u'w'} = -u^{*2}\left(1 - \frac{z}{z_h}\right)^2, \quad \overline{u'v'} = \overline{v'w'} = 0$

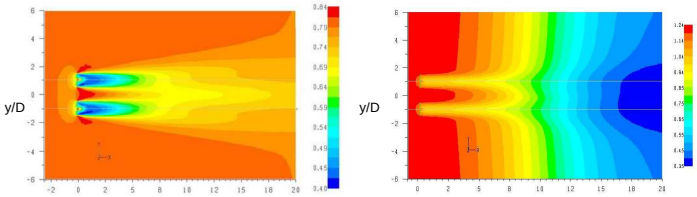
Results

- Normalized velocity $Ux = U_x / U_\infty$



a. Gaussian hill, y=0 plane b. Gaussian hill, hub height (90m)

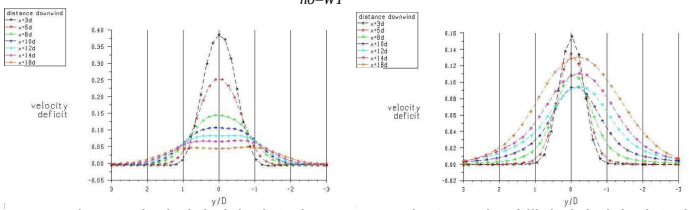
Fig 1. Normalized velocity contours (1 WT), RSM



a. Flat terrain, hub height (90m) b. Gaussian hill, hub height (90m)

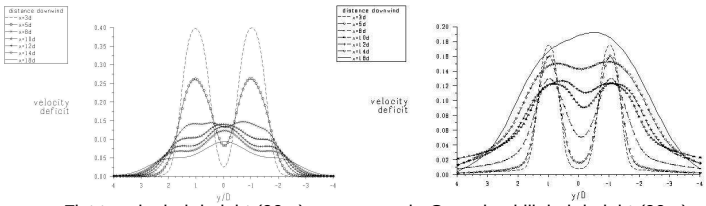
Fig 2. Normalized velocity contours (2 WTs), RSM

- *Velocity* $deficit = \frac{U_{no-WT} - U_{wake}}{U_{no-WT}}$



a. Flat terrain, hub height (90m) b. Gaussian hill, hub height (90m)

Fig 3. Velocity deficit (1 WT), RSM



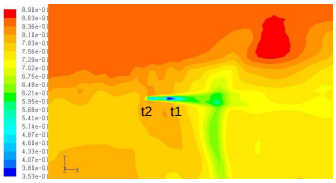
a. Flat terrain, hub height (90m) b. Gaussian hill, hub height (90m)

Fig 4. Velocity deficit (2 WTs), RSM

Latest Work

- Real complex terrain wind farm

Image generated in Google Earth



Contours of normalized velocity

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