

A Simple Nonlinear Eddy Viscosity Model applied to a Wind Turbine Wake in Atmospheric Turbulence

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Traditional Indonesian wedding reception



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Introduction: Wakes in Computational Fluid Dynamics (CFD)

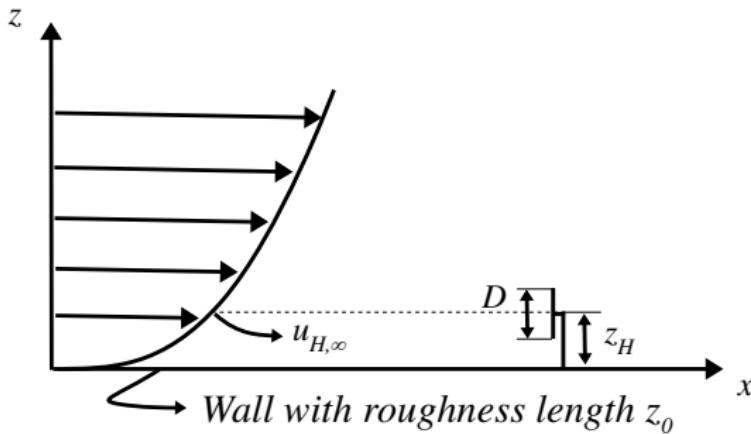
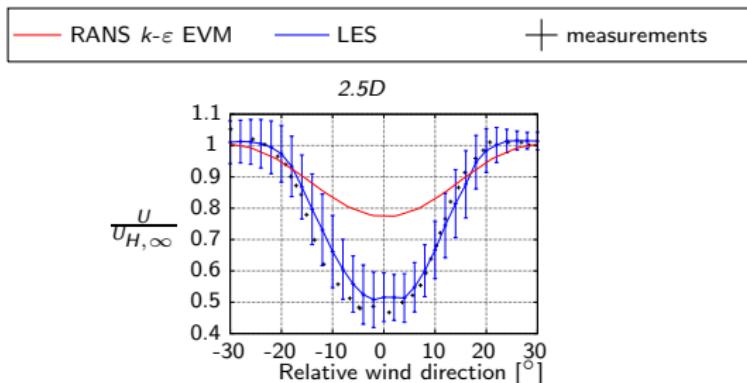


Figure: Sketch of wind turbine in neutral atmospheric boundary layer.

- ▶ The rotor forces are modeled with an actuator disk.
- ▶ The flow is resolved with EllipSys.

Introduction: Wakes in CFD

- ▶ Resolving turbulence (large scale):
 - ▶ Large Eddy Simulation (LES) can predict wind turbine wakes comparable to measured wakes.
 - ▶ High computational costs.
- ▶ Modelling turbulence:
 - ▶ A Reynold Averaged Navier-Stokes method (RANS) with a popular turbulence model, i.e $k - \varepsilon$ eddy viscosity model, fails to predict wake deficit.
 - ▶ Three orders lower computational costs with respect to LES.



- ▶ Goal: RANS turbulence model that can predict the wake flow.

Why $k - \varepsilon$ turbulence model fails

- ▶ Only one scale of turbulence is modelled.
- ▶ A linear stress-strain relationship:

$$\overline{u'_i u'_j} = \frac{2}{3} k \delta_{ij} - \nu_T \left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i} \right) \quad (1)$$

with the eddy viscosity defined as:

$$\nu_T = C_\mu \frac{k^2}{\varepsilon} \quad (2)$$

Consequence \Rightarrow only isotropic turbulence can be modeled.

Nonlinear eddy viscosity model (NLEVM)

- ▶ The form of a NLEVM:

$$\overline{u'_i u'_j} = \frac{2}{3} k \delta_{ij} - \nu_T \left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i} \right) + f^{NL}() \quad (3)$$

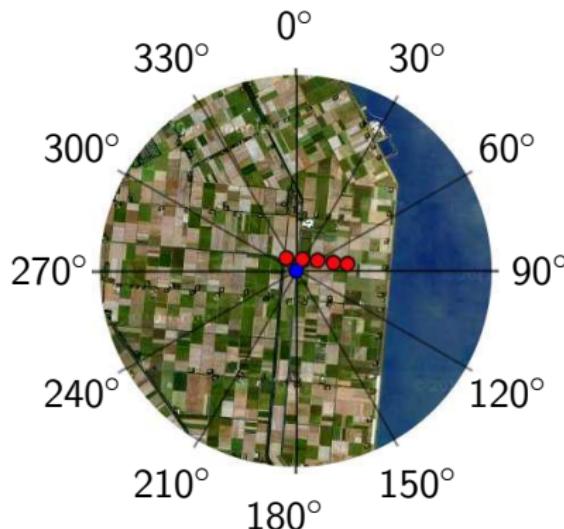
$$\nu_T = C_\mu \frac{k^2}{\varepsilon} \quad (4)$$

with $f^{NL}()$ as a nonlinear function of products of velocity gradients, e.g.: $\frac{\partial U_i}{\partial x_k} \frac{\partial U_k}{\partial x_j}$ or $\frac{\partial U_i}{\partial x_k} \frac{\partial U_k}{\partial x_l} \frac{\partial U_l}{\partial x_j}$, etc.

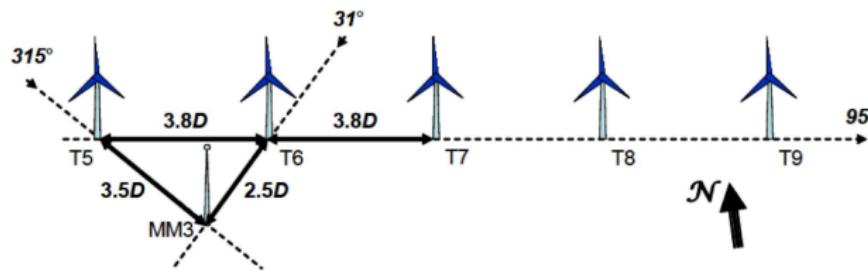
- ▶ Proposed simple NLEVM includes only one extra quadratic term and a flow-dependent C_μ .

Test case I: Wieringermeer

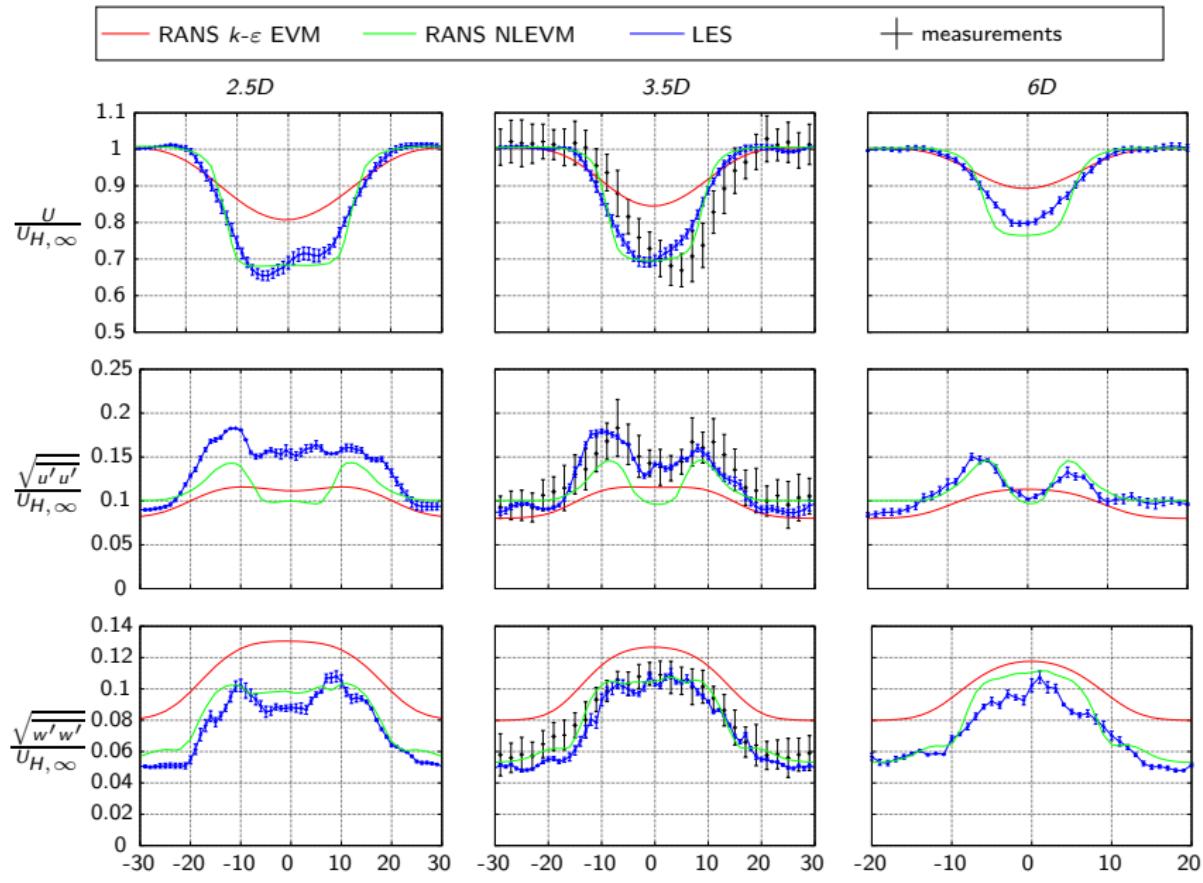
The NLEVM has been tested and compared with wake measurements from ECN (Wieringermeer).



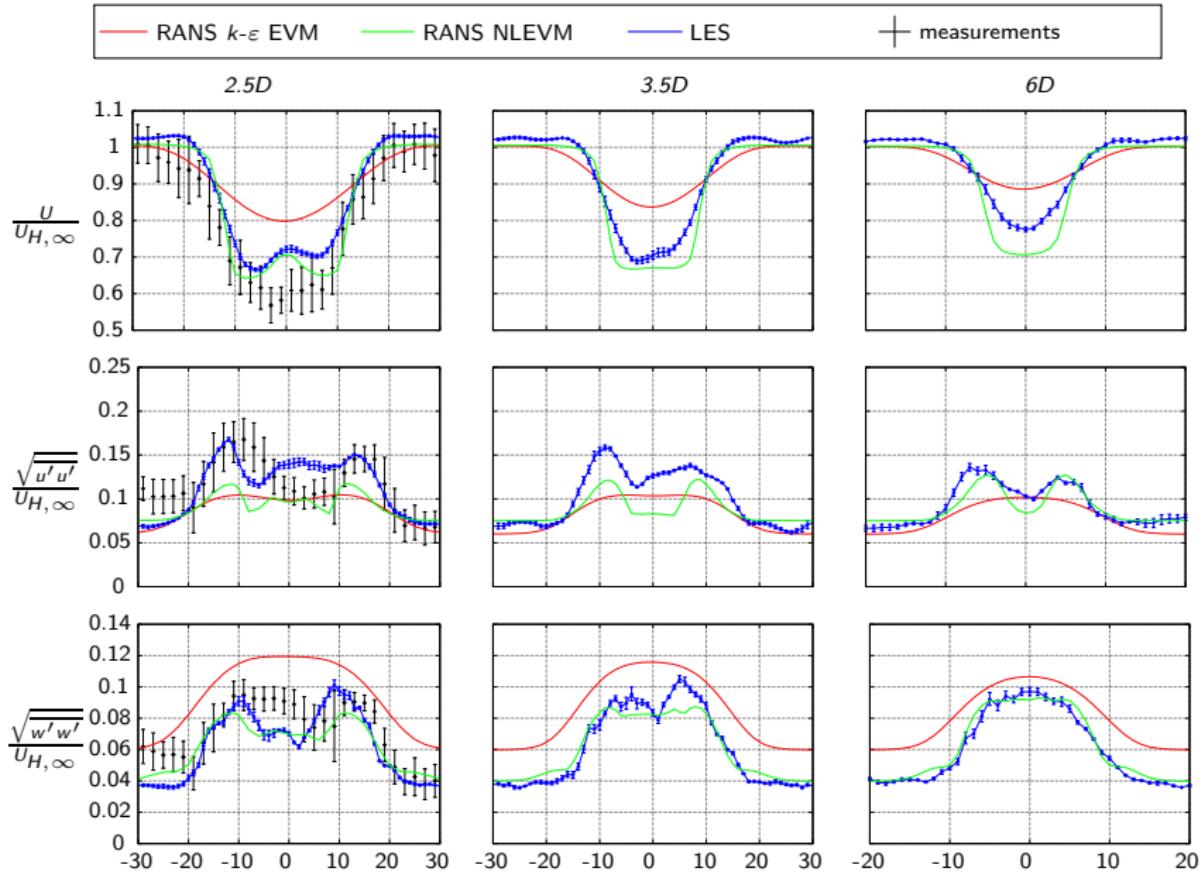
4 km radius around meteorological mast (●),
2.5 MW research wind turbines (●)
with 80 m diameter and hub height.



Test case I: Western wake

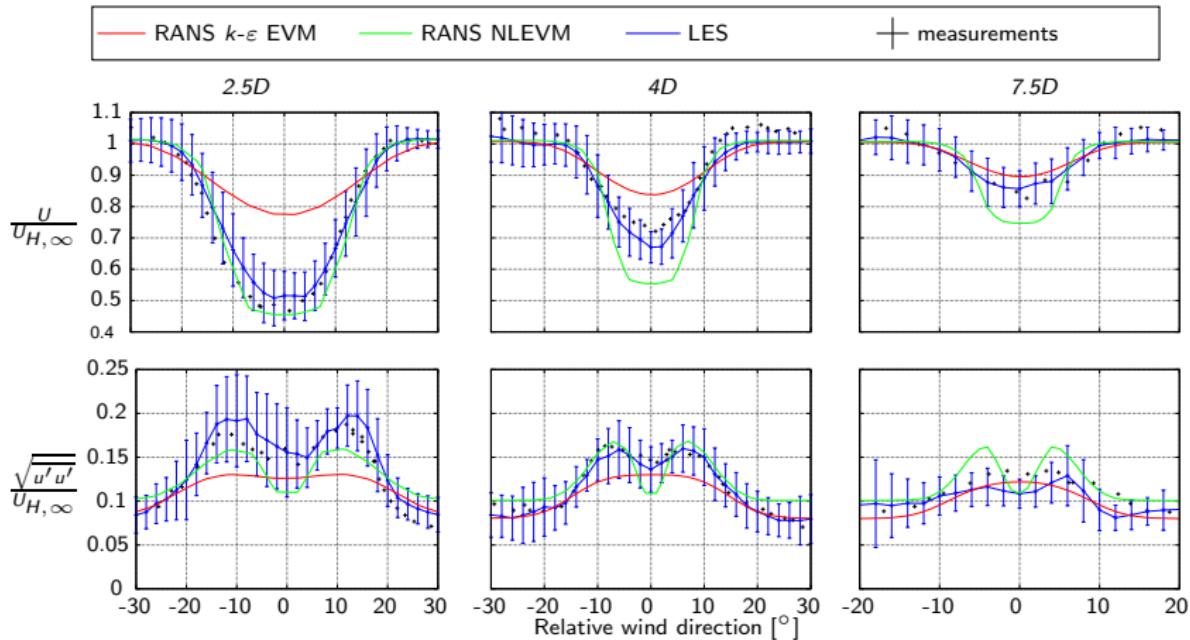


Test case I: Eastern wake



Test case II: Nibe (1990)

- ▶ 630 kW, rotor diameter: 40 m, hub height 45 m.



Conclusion

- ▶ In terms of wake deficits and Reynolds-stresses the NLEVM shows large improvements compared to the linear $k - \varepsilon$ model.
 - ▶ The extra term in the stress-strain relationship models anisotropic turbulence.
 - ▶ The flow-dependent C_μ decreases the eddy viscosity behind the wind turbine and delays the wake recovery.
- ▶ At the far wake the NLEVM behaves incorrect because the wake recovery is too slow.

Future work

- ▶ Investigate alternative flow-dependent C_μ functions.
- ▶ Multi scale turbulence models?