Prediction of wake effects on wind farm power production using a RANS approach. Part II. Offshore: Case studies from the UPWIND project

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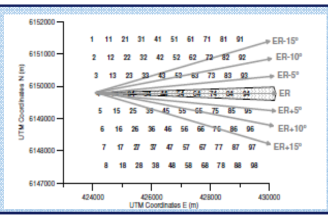
Abstract summary

The estimation of power losses due to wind turbine wakes is crucial to understanding overall wind farm economics. This is especially true for large offshore wind farms, as it represents the primary source of losses in available power, given the regular arrangement of rotors, their generally larger diameter and the lower ambient turbulence level, all of which conspire to dramatically affect wake expansion and, consequently, the power deficit.

Simulation of wake effects in offshore wind farms (in reasonable computational time) is currently feasible using CFD tools. An elliptic CFD model based on the actuator disk method and various RANS turbulence closure schemes is tested and validated using power ratios extracted from Horns Rev and Nysted wind farms, collected as part of the EU-funded UPWIND project. The primary focus of the present work is on turbulence modeling, as turbulent mixing is the main mechanism for flow recovery inside wind farms. A higher-order approach, based on the anisotropic RSM model, is tested to better take into account the imbalance in the length scales inside and outside of the wake, not well reproduced by current two-equation closure schemes.

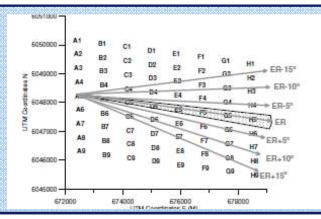
HORNS REV WIND FARM

Wind farm	Horns Rev
Nr turbines	80
Turbine	Vestas 2MW
Diameter (m)	80
Hub height (m)	70
Array	10 x 8
Separation (E-W)	7D



NYSTED WIND FARM

Wind farm	Nysted
Nr turbines	72
Turbine	Siemens2.3MW
Diameter (m)	82.4
Hub height (m)	69
Array	8 x 9
Separation (E-W)	10.3D



NUMERICAL MODEL

SURFACE BOUNDARY LAYER MODEL

A non-uniform flow is modelled in a computational domain representing the surface boundary layer in which the Monin-Obukov theory is solved from the Reynolds Average Navier Stokes equations and the turbulent transport terms from the k-ε method and the RSM model

FREESTREAM WIND SPEED	8±0.5 m/s
ROUGHNESS LENGHT	0.2mm
ATMOSPHERIC STABILITY	Neutral

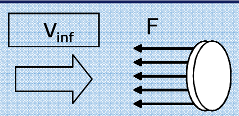
WIND DIRECTION	
HORNS REV	270º±2.5º
NYSTED	278º±2.5º

ACTUATOR DISK MODEL

Each wind turbine is considered as an actuator disk upon which uniformly distributed forces, defined as axial negative momentum sources, are applied.

$$F = -\tfrac{1}{2}\,\rho \cdot A \cdot C_t \cdot V_{inf}^2$$

A = Rotor Diameter (m^2)
V_{inf} = 2D upstream wind speed (m/s)
C_t = Thrust coefficient $C_t\,(V_{inf})$

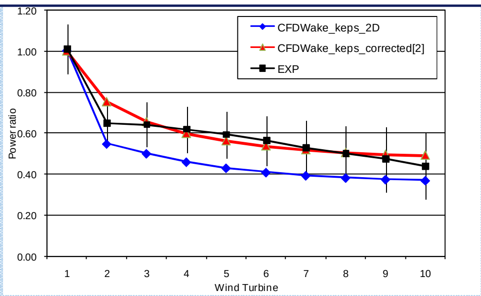


MESH	Structured - ICEM CFD (Ansys Inc)
DOMAIN SIZE	94D x 35D x 12D (1.5 Million hexaedral cells)
RESOLUTION	Axial = 0.4D Transversal = 0.4D First cell height = 0.5m
BOUNDARY CONDITIONS	Inlet: Velocity inlet / Outlet: Pressure Outlet Lateral & Top : Symmetry / Ground: Wall functions
DISCRETIZATION	2nd order upwind
SOLVER	FLUENT 12.0 (Ansys Inc) (+ OpenFOAM 1.7 soon)

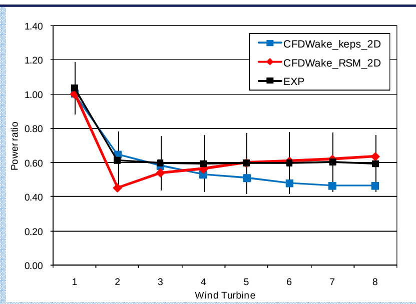
TURBULENCE MODEL. SET OF CONSTANTS

	C_μ	$C_{1\varepsilon}$	$C_{2\varepsilon}$	σ_k	σ_ε
kε Standard (Launder & Spalding)	0.033	1.17	1.92	1	1.3
RSM - Reynolds Stress Model (Gibson&Launder)	0.09	1.44	1.92	1	1.3
	C_{1PS}	$C_{1'PS}$	C_{2PS}		
	1.8	0.5	0.6		

RESULTS FOR HORNS REV: Analysis on V_{inf} estimation



RESULTS FOR NYSTED: Analysis on turbulence modeling



CONCLUSIONS

Two critical aspects for the simulation of big offshore wind farms based on RANS models coupled to the actuator disk technique have been assessed: the method to estimate the reference wind speed and turbulence modeling. For the case run at Horns Rev, the method proposed by [2] for the estimation of the reference wind speed improves the results in comparison to the standard procedure of selecting the value 2D upstream of each rotor disk. For the case run at Nysted, the use of a higher order turbulence closure scheme also improves the results making this option a promising alternative. Further work will consist of generating a parabolic solver based on the open CFD code OpenFOAM for offshore wind farms, combining both methods and validating the model for more cases.

References

1. Vermeer L.J. et. al., 2003, Wind turbine wake aerodynamics. Prog. Aerosp. Sci. 39, 467-510
2. Prospathopoulos J., Cabezón D., Politis E.S., Chaviaropoulos P.,K., Rados K.,G., Schepers J.,G., Hansen K., Barthelmie R.J., Simulation of wind farms in flat and complex terrain using CFD, Proc. of 'The Science of Making Torque form Wind' Conference, Athens (Greece), June 2010
3. Barthelmie, R.J., Hansen, K, Frandsen, S.T., Rathmann, O., et.al., "Modelling and measuring flow and wind turbine wakes in large wind farms offshore", Wind Energy, Vol. 12, No. 5, pp. 431-444, 2009
4. Gibson M.M. and Launder B. E. "Ground Effects on Pressure Fluctuations in the Atmospheric Boundary Layer" J. Fluid Mech., 86:491–511, 1978
5. Crespo A., Manuel F., and Hernández J., Numerical modelling of wind turbine wakes. European Community Wind Energy Conference Proceedings, Madrid, September 1990
6. Réthoré P., Sørensen N., Zahle F., Bechmann A., Study of the wake turbulence of a CFD actuator disk model compared with a full rotor CFD model, Proceedings of the European Wind Energy Conference 2009, Marseille (France)
7. Politis E., Rados K., et. al., CFD modeling issues of wind turbine wakes under stable atmospheric conditions, Proceedings of the European Wind Energy Conference 2009, Marseille (France)
8. Cabezón D., Sanz J., Martí I., Crespo A., "CFD modelling of the interaction between the Surface Boundary Layer and rotor wake. Comparison of results obtained with different turbulence models and mesh strategies". EWEC 2009, Marseille (France)

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