Offshore Wind Farm Optimisation

Ninth Deep Sea Offshore Wind R&D Seminar
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Outline

- WP4 in NORCOWE
- Vision for WP4
- Challenges
- Modelling
- FLACS-Wind
- Activities 2012
- Reflections
- Questions?
NORCOWE WP4

Wind farm optimisation
NORCOWE: WP4 and other WPs

WP1
- Meso scale modelling
- Marine boundary layer
- Long-term forecasting
- Short-term forecasting

WP2
- Dynamic response
- Innovative concepts

WP3
- Single turbine control

WP5
- Test facilities and infrastructure

WP4
Wind farm optimization
- WP4.1 Nowcasting
- WP4.2 Power system integration
- WP4.3 Wind farm modelling

On-going coupling
Initiated
Initiated
Soon
Vision NORCOWE WP4

- Develop a fully integrated model system for optimising the layout of (offshore) wind farms!
  - CFD code(s) with subgrid models validated against experiments and/or more detailed CFD simulations!
  - One-way coupling to relevant meso-scale models (from WP1)!
  - Run manager that can incorporate weather and wave statistics, as well as other site-specific constraints: depth, bottom conditions, shipping lanes, environmental constraints, ...
  - Models for electrical system and network integration: cable length, AC vs. DC, transformers, ...
  - Integrated optimisation scheme for farm layout that takes advantage of parameter reduction and/or artificial neural networks (ANN)
  - Updated documentation to support users and investment decisions!
Vision

• Establish integrated model system:
  – Layout
  – Operation
  – Short-term forecasting?

• Validation
• Improvements
• Validation
• Improvements
• …

Illustration from the «KULING» proposal – FP7 Energy 2011.
The main challenge

Turbulence

“My favourite definition of turbulence is that it is the general solution of the Navier-Stokes equations.”

“Turbulence: The Chief Outstanding Difficulty of our Subject”
Governing equations

Conservation of Mass:
\[
\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j} (\rho u_j) = 0
\]

Conservation of Momentum:
\[
\frac{\partial}{\partial t} (\rho u_i) + \frac{\partial}{\partial x_j} (\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left( \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right) + \left( \mu_B - \frac{2}{3} \mu \right) \frac{\partial u_k}{\partial x_k} \delta_{ij} + \rho a_i
\]

Conservation of Energy:
\[
\frac{\partial}{\partial t} (\rho h) + \frac{\partial}{\partial x_j} (\rho h u_j) = \frac{\partial p}{\partial t} + u_j \frac{\partial p}{\partial x_j} + \frac{\partial}{\partial x_j} \left( J_{h,j} \right) + S_h
\]
Modelling approach
Unfortunately

\[ N_{grid, DNS} \sim Re^{\frac{9}{4}} \sim \left( \frac{UL}{\nu} \right)^{\frac{9}{4}} \sim \left( \frac{100 \text{ m s}^{-1} \cdot 1 \text{ m}}{10^{-5} \text{ m}^2 \text{ s}^{-1}} \right)^{\frac{9}{4}} \sim \left( 10^7 \right)^{\frac{9}{4}} \sim 5.6 \cdot 10^{15} = 5.6 \text{ quadrillion} \]

\[ \ell_{\eta, DNS} \sim \frac{L}{Re^{\frac{3}{4}}} \sim \frac{1 \text{ m}}{\left( 10^7 \right)^{\frac{3}{4}}} \approx 5.6 \mu \text{m} \]
Consequently

- We have to resort to ‘modelling’: LES, RANS, ...
or: “get our hands dirty”!
- ... and we run into questions such as:
  - Required spatial and temporal resolution for CFD?
  - Validating subgrid models?
  - Measuring turbulence?
  - Processing simulated data?
  - Processing experimental data?
  - Comparing experimental and simulated data?
  - How far can we extrapolate results from the model?
Modelling
Modelling in NORCOWE WP4

- **Prototech:**
  - Relatively detailed wake modelling with a $k-\omega$ Shear Stress Transport (SST) formulation in the commercial CFD solver **STAR-CCM** from CD-Adapco.

- **StormGeo/UiS & Uni Research:**
  - RANS / LES modelling in the open source CFD solver **OpenFOAM** (GNU GPL), with focus on turbulent wakes, coupling, effect of swell on MBL, etc.

- **GexCon:**
  - RANS modelling in the commercial CFD solver **FLACS-Wind**

- **CMR Computing**
  - Model reduction techniques in combination with CFD, in order to reduce calculation time ...

- **Uni Research**
  - Artificial intelligence (AI) and Artificial Neural Networks (ANN), in order to avoid solving the Navier Stokes equations ...
Turbulent wake simulated by Thomas Hansen (Prototech) with STAR-CCM+ (CD-Adapco)
Manhattan in FLACS-Dispersion
FLACS-Wind Prototype

Not connected to database!

Grid: direction X, region 1 - 2 (count=1), 0.000 - 10.000 (size=10.000), Units: METERS

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Third Joint NOWITECH / NORCOWE Workshop on

Wind & Wake Modelling

This autumn!
IEA Wind Task 31 WakeBench

www.ieawind.org/Summary_Page_31.html
Reflections

• Approach to research / engineering
  – Blade ⇔ Turbine ⇔ Near Wake ⇔ Far wake ⇔ Wind farm ⇔
  – … or jump to full scale wind farm and tune the model?

• Urgent need for validation data
  – Limited access to data from full-scale wind farms!
  – Uncertainty / variation in site-specific data?

• Sources of uncertainty
  – Model uncertainties vs. weather predictions!
  – Downscaling from meso scale: 3-30 km ⇔ 1-10 m
  – Marine boundary layer: wind-wave interactions!

• Importance vs. urgency
  – It takes time to develop a complex model system!
  – Attempts at boosting the funding for the modelling work have thus far proven unsuccessful.
Questions?