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Uncertainty evaluation of BEM approaches for offshore wind turbine design

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**Main objective**: reduce the Levelized Cost Of Energy (LCOE) by reducing the uncertainty in the complete chain of modeling OWTs in a wind farm
Uncertainty evaluation of BEM approaches for offshore wind turbine design

Main goal: to evaluate the uncertainty of Blade Element momentum approaches, by comparing them with a high fidelity model
Introduction
Aerodynamic approaches

• Aerodynamic methods
  • Different levels of complexity

• **Blade Element Momentum (BEM):**
  • Widely used for design
  • Steady conditions, empirical corrections
  • Low computational cost
  • Limitations for large/floating wind turbines

• **Vortex method:**
  • State of the art
  • Free vortex wake model based on lifting line theory
  • Unsteady, less empirical corrections
  • Higher computational cost

Tran et al. 2014
Aerodynamic approaches

• Calculation cost:
  • Larger than BEM
  • N-body problem
  • Ideal time step: equivalent to $\Delta \theta \in [5^\circ; 10^\circ]$
  • Wake length: $\theta \geq 2\pi N_{rot}$ with $N_{rot} \in [15; 25]$

• Aero-elastic simulations constraints:
  • Time step often driven by the controller: $\Delta \theta \approx 0.1^\circ$
  • Low time step → very high number of vortex elements
  → Time-consuming routines ported to GPU (CUDA)
  → Still not enough: the number of filaments must be reduced
Aerodynamic approaches

• Reducing vortex sheet:
  • Shed Merging:
    • Shed filaments are progressively merged
  • Tip Vortex:
    • Filaments are conserved in the near wake. Then, a transition to “Tip Vortex” is applied
Methodology
Aerodynamic approaches

• BEM (DTU, EDF, IFPEN):
  • HAWC2 / DIEGO / DeepLines Wind™ (DLW)
  • Coupled with servo-hydro-elastic models

• Vortex Method (IFPEN)
  • CASTOR + DLW
  • Coupled with servo-hydro-elastic models
Study cases

- 2 wind turbines:
  - **Teesside**
    - Monopile 2.3MW
    - DoE: $U, TI, \theta_{yaw}$
    - 300 BEM, 30 Vortex (iterative GP)
  - **South Brittany**
    - Floating (UMaine) 15MW
    - DoE: $U, TI, \theta_{wind}, H_s, T_p, \theta_{wave}$
    - 700 BEM, 60 Vortex (iterative GP)
Results
Several GP models have been trained based on different relevant responses in the simulation results from both the BEM and Vortex simulations.

Output: **metamodels** for BEM and Vortex
- For several variables and inputs parameters
  - Integrated forces on the rotor (Thrust, Power, Torque)
  - Aerodynamic forces along the blades (over 5 points)
  - Damage at the blade root
Results

- 3 software:
  - HAWC2, DIEGO, DLW

Teesside

Mean Power, fixed $T_l$, Yaw=0°

```
- DLW
- Diego
- Hawc2
- 95% CI DLW
- 95% CI Diego
- 95% CI Hawc2
```

Mean Thrust, fixed $T_l$, Yaw=0°

```
- DLW
- Diego
- Hawc2
- 95% CI DLW
- 95% CI Diego
- 95% CI Hawc2
```

Max DEL flap, rated, Yaw=0°

```
- DLW
- Diego
- Hawc2
- 95% CI DLW
- 95% CI Diego
- 95% CI Hawc2
```
Results

Mean Power, fixed TI, Yaw=0°

Teesside

Power ave [W]

U [-]

Vortex
BEMs
95% CI Vortex
95% CI BEMs

1e7 Mean Power, TI = 14%, Hs = 2m, Tp = 6s

South Brittany

Power ave [W]

U [m/s]

Vortex
DLW
95% CI Vortex
95% CI DLW
Results

Mean Thrust, fixed $T_l$, $\text{Yaw}=0^\circ$

- **Teesside**
  - Vortex
  - BEMs
  - 95% CI Vortex
  - 95% CI BEMs

Mean Thrust, $T_l = 14\%$, $H_s = 2\text{ m}$, $T_p = 6\text{ s}$

- **South Brittany**
  - Vortex
  - DLW
  - 95% CI Vortex
  - 95% CI DLW
Uncertainties

➢ relative discrepancy between the BEM and Vortex GPs

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</tbody>
</table>

• Teesside:

• South Brittany:
Conclusions
Summary, Conclusions and future work

• Comparison between BEM and Vortex models for two different offshore technologies:
  • BEM models, using different ASHE tools (Diego, Hawc2, and DLW)
  • Vortex model, Castor + DLW
  • Several GP models have been trained based on results from both the BEM and Vortex simulations.
  • Benchmark, overall good agreement between BEM codes.
  • BEM vs Vortex differences are higher for the floating wind turbine.
• GPs or metamodells can be used in two different ways:
  • either to select a conservative response with a specified confidence level for all relevant input scenarios
  • or to fully quantify the uncertainties between both approaches.

Future work
• Estimate the model uncertainty by comparing engineering models with high fidelity LES simulations.
Acknowledgements

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