



# Uncertainty evaluation of BEM approaches for offshore wind turbine design

Maria Laura Mayol, Pierre-Antoine Joulin, N. K. Dimitrov, A. Lovera, S. Eldevik, Alexis Cousin, Martin Guiton

## ► To cite this version:

Maria Laura Mayol, Pierre-Antoine Joulin, N. K. Dimitrov, A. Lovera, S. Eldevik, et al.. Uncertainty evaluation of BEM approaches for offshore wind turbine design. EmrSim22: Simulation et Optimisation pour les Énergies Marines Renouvelables, May 2022, Roscoff (FR), France. hal-03890887

**HAL Id: hal-03890887**

**<https://ifp.hal.science/hal-03890887>**

Submitted on 8 Dec 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Uncertainty evaluation of BEM approaches for offshore wind turbine design



M. Laura Mayol<sup>1</sup>, [maria-laura.mayol@ifpen.fr](mailto:maria-laura.mayol@ifpen.fr)

P. A. Joulin<sup>1</sup>, N. K. Dimitrov<sup>2</sup>, A. Lovera<sup>3</sup>, S. Eldevik<sup>4</sup>, A. Cousin<sup>1</sup>, and M. Guiton<sup>5</sup>

<sup>1</sup> IFP Energies nouvelles, Rueil-Malmaison, France.

<sup>2</sup> Denmark Technical University, DTU, Lyngby, Denmark

<sup>3</sup> EDF R&D, EDF Lab. Saclay, France

<sup>4</sup> DNV Group Research and Development, Høvik, Norway

<sup>5</sup> IFP Energies nouvelles, Solaize, France



*Highly advanced Probabilistic design and Enhanced Reliability methods for high-value, cost-efficient offshore WIND*

**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



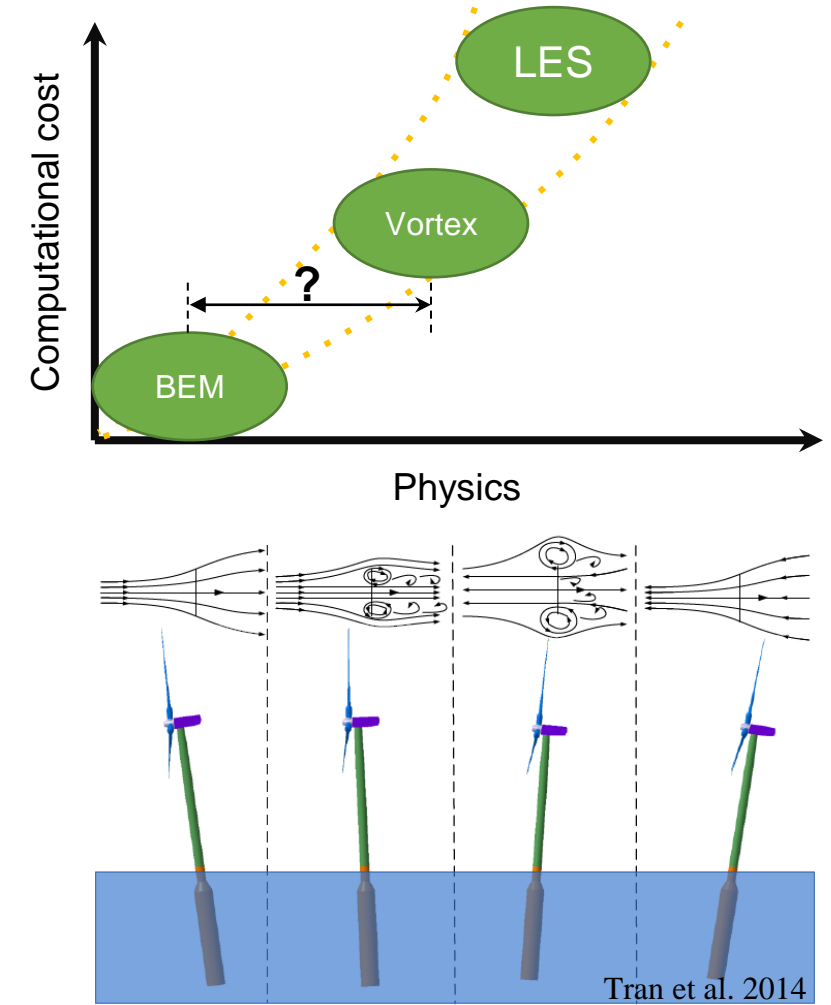
**Main goal:** to evaluate the uncertainty of Blade Element momentum approaches, by comparing them with a high fidelity model

# Introduction



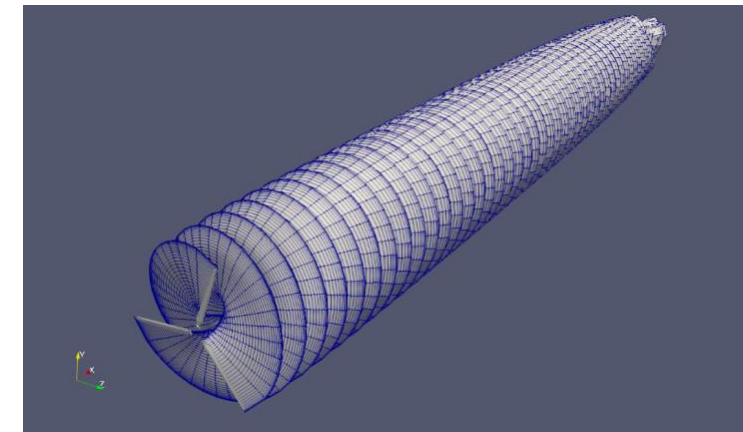
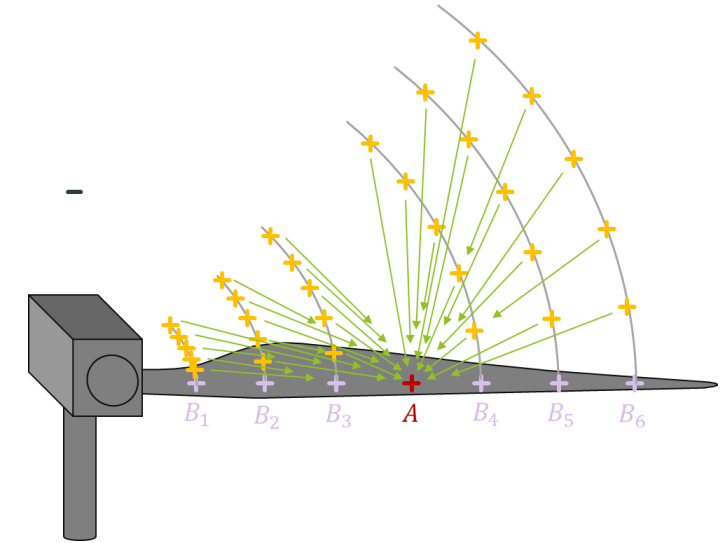
# Aerodynamic approaches

- 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



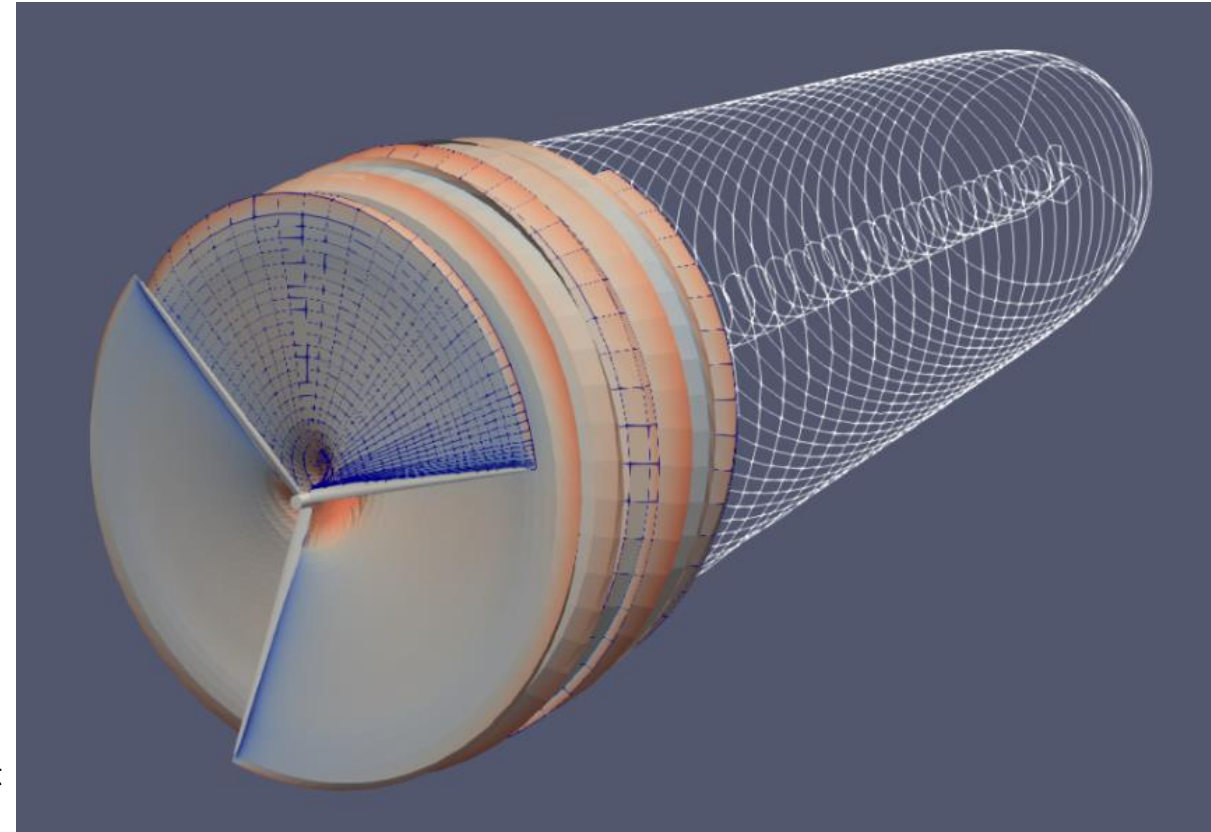
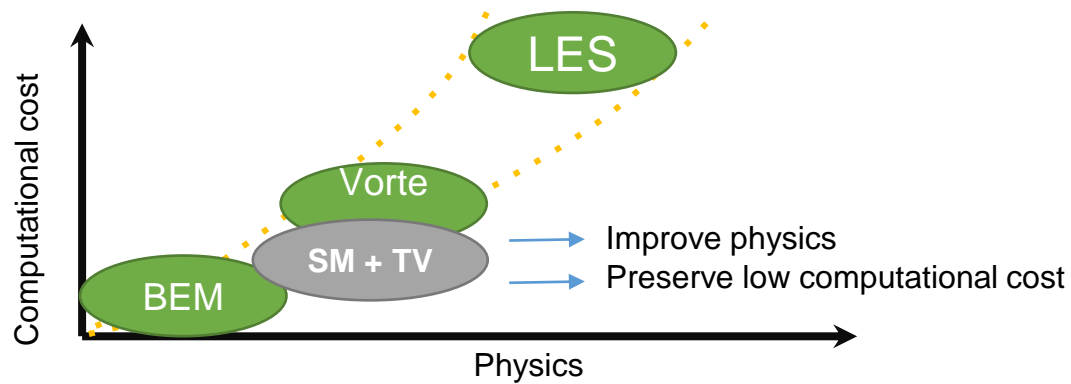
# Aerodynamic approaches

- 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  $\rightarrow$  very high number of vortex elements
  - $\rightarrow$  Time-consuming routines ported to GPU (CUDA)
  - $\rightarrow$  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



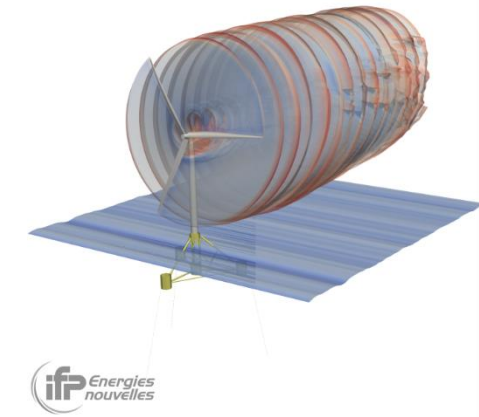
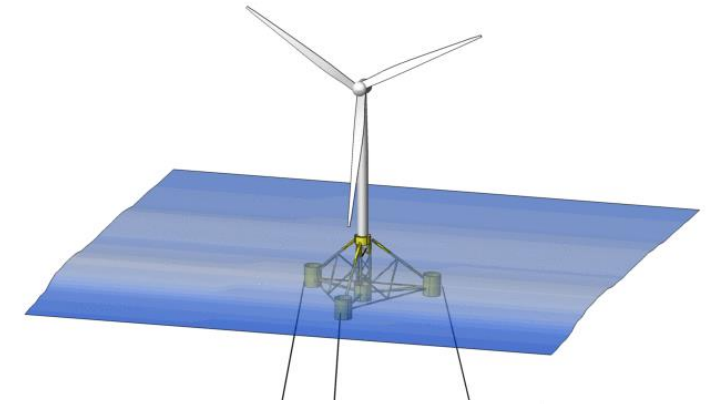


# Methodology



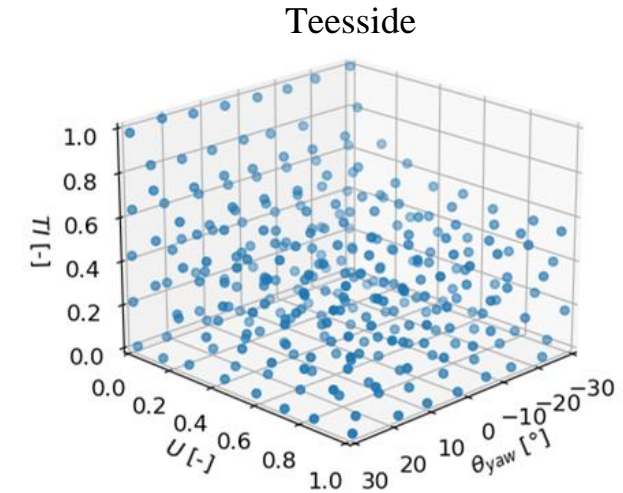
# Aerodynamic approaches

- 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

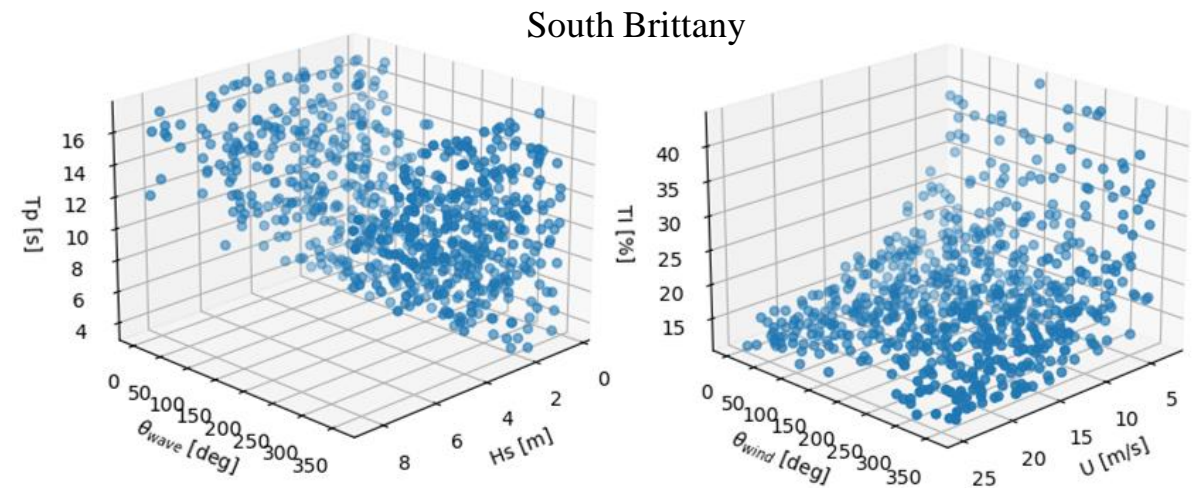


# Study cases

- 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)

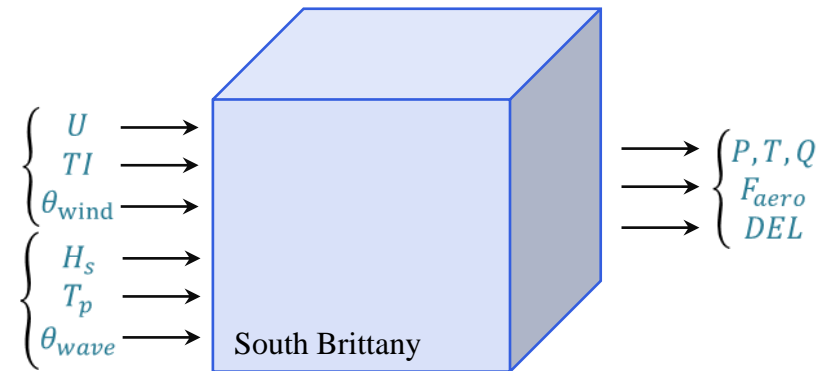
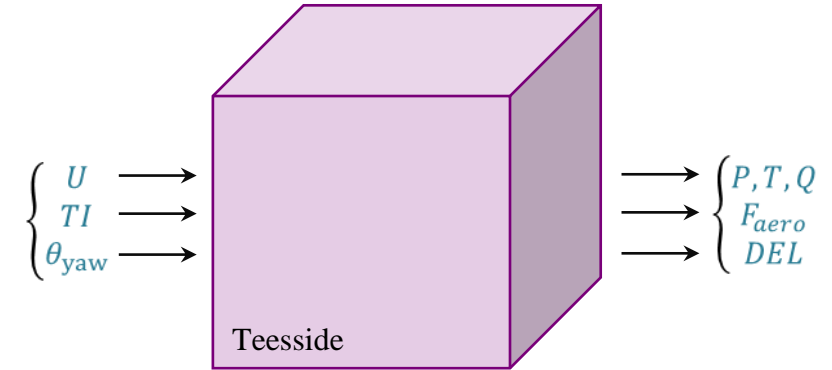


# Results



# Results

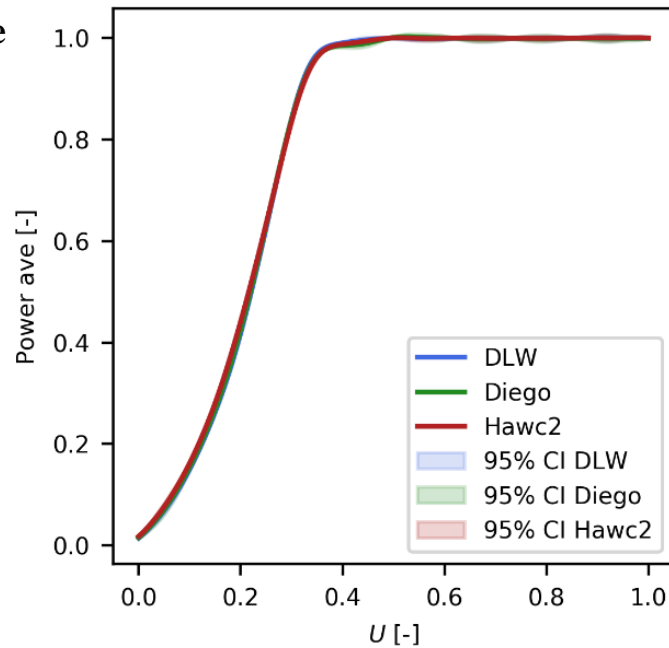
- Several GP models have been trained based on different relevant responses in the simulation results from both the BEM and Vortex simulations.
- Output: **metamodels** for BEM and Vortex
  - For several variables and inputs parameters
    - Integrated forces on the rotor (Thrust, Power, Torque)
    - Aerodynamic forces along the blades (over 5 points)
    - Damage at the blade root



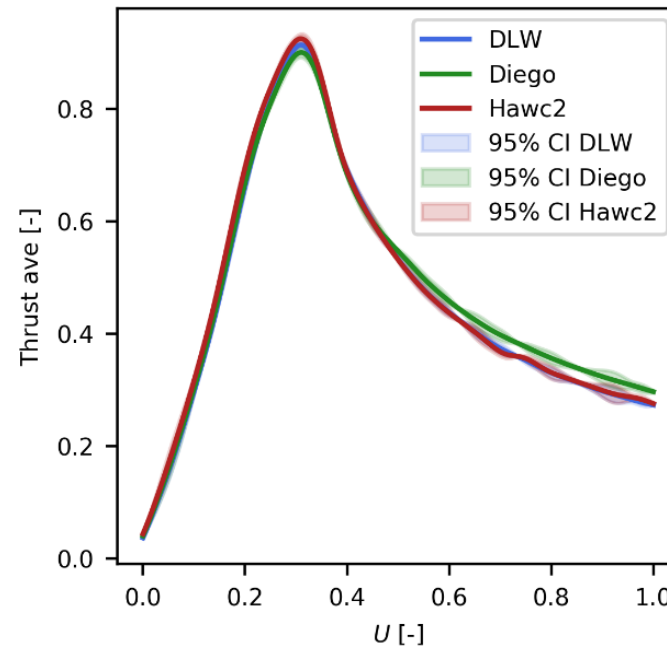
# Results

- 3 software:
  - HAWC2, DIEGO, DLW

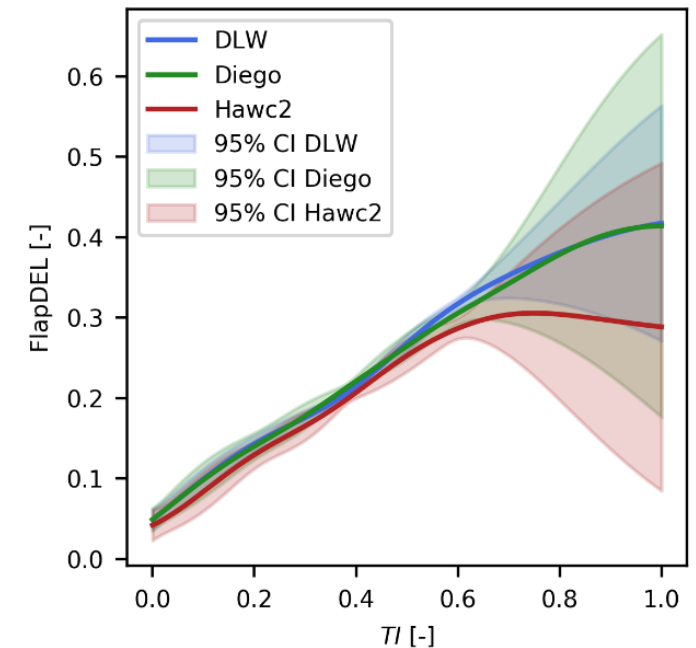
Mean Power, fixed  $Tl$ , Yaw=0°



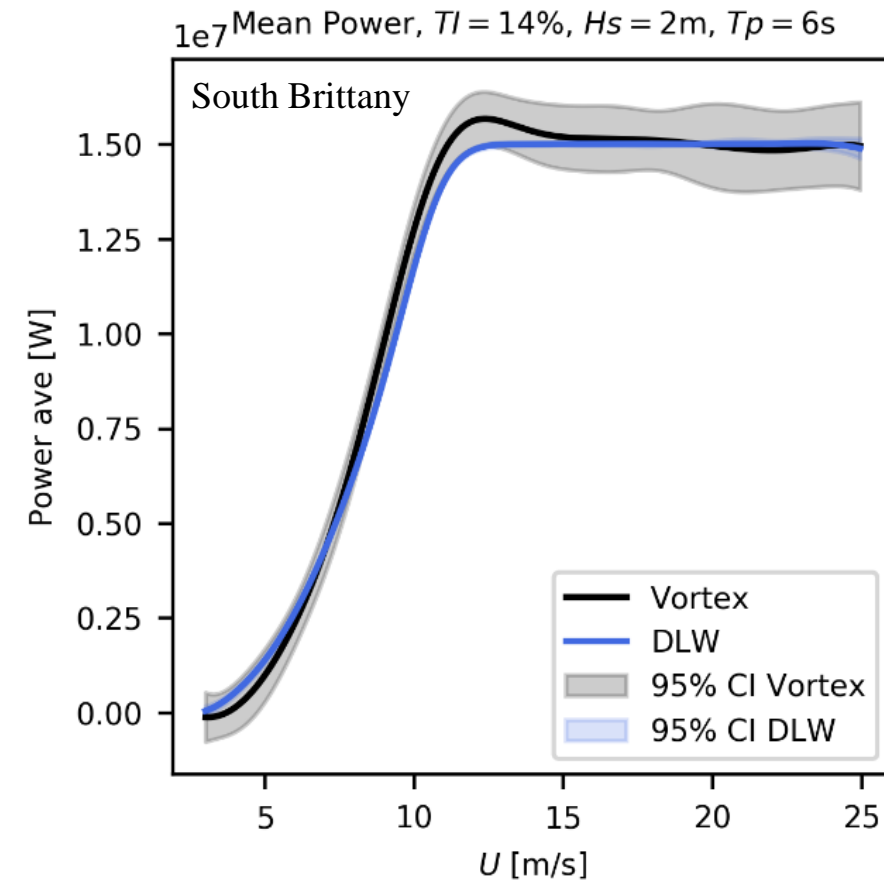
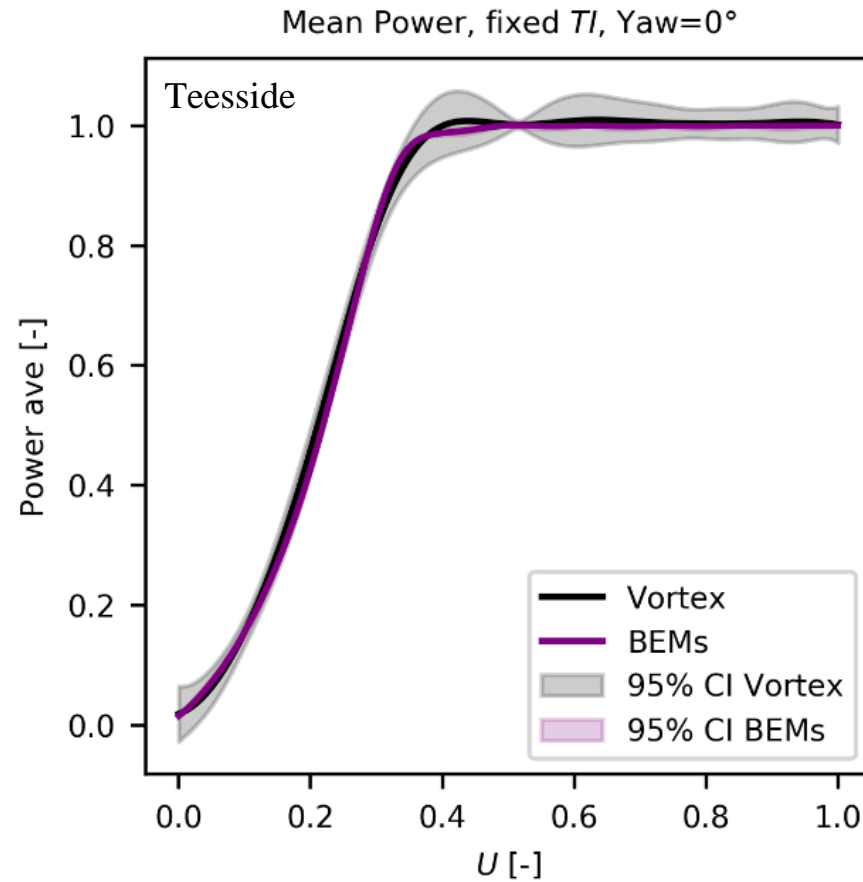
Mean Thrust, fixed  $Tl$ , Yaw=0°



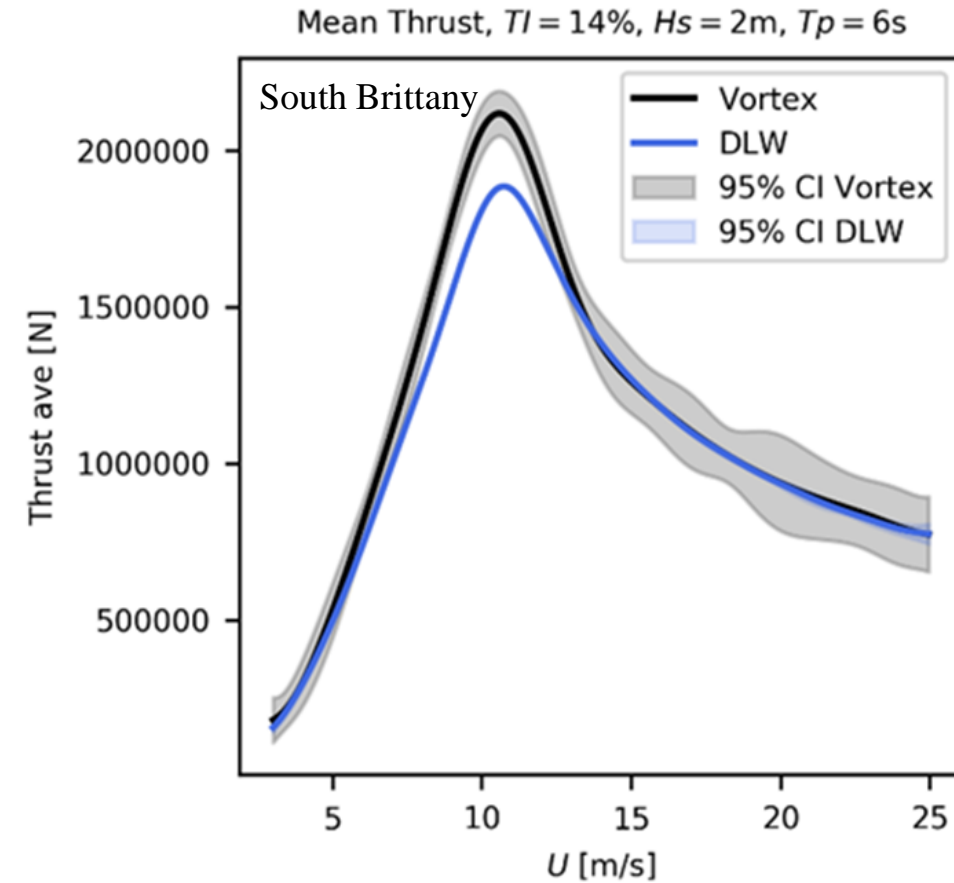
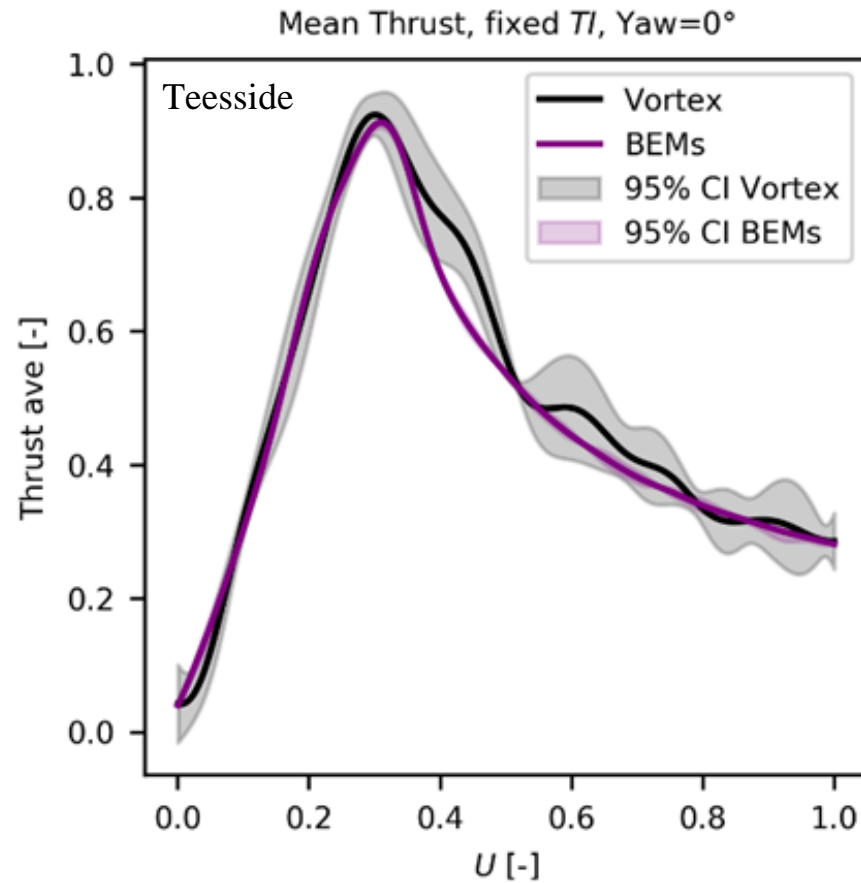
Max DEL flap, rated, Yaw=0°



# Results



# Results





# Uncertainties

➤ relative discrepancy between the BEM and Vortex GPs

- Teesside:

	delFlap	delEdge	Power	Thrust
Min	-9.8%	-15.2%	-8.3%	-12.6%
Max	13.4%	9.7%	14.6%	13.9%
Mean	<b>0.2%</b>	<b>0.2%</b>	<b>2.0%</b>	<b>2.3%</b>
Std	<b>3.0%</b>	<b>2.4%</b>	3.3%	4.2%

- South Brittany:

	delFlap	delEdge	Power	Thrust
Min	-34.0%	-33.5%	-3.3%	-18.6%
Max	9.3%	9.2%	7.2%	27.7%
Mean	<b>-1.8%</b>	<b>-5.2%</b>	<b>1.3%</b>	<b>4.4%</b>
Std	<b>4.2%</b>	<b>4.6%</b>	2.4%	5.9%

# 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 metamodels 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



*This project has received funding from  
the European Union's Horizon 2020  
Research and Innovation Programme  
under Grant Agreement No. 101006689*