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VAMOS

Validation of a panel method with full-scale FOWT measurements and verification with engineering models

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Fluid Dynamics and Ship Theory

Maritime Systems

- Methods
- Verification
- Validation
- Summary

Verification models

OpenFAST + Orcaflex

- OpenFAST coupled with

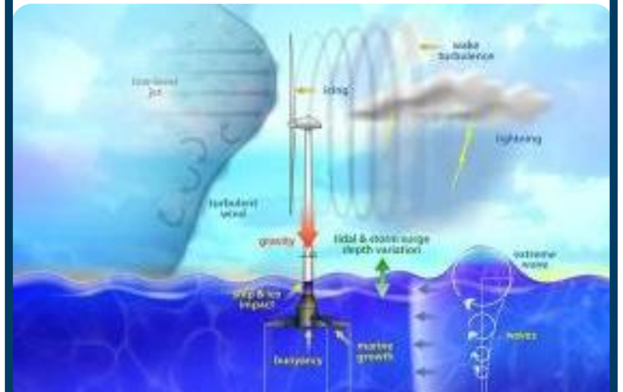
orcaflex

- Validated with measurement data (conservative)

BW Ideol

OpenFAST

- OpenFAST modules
- Coefficients from BW Ideol's model

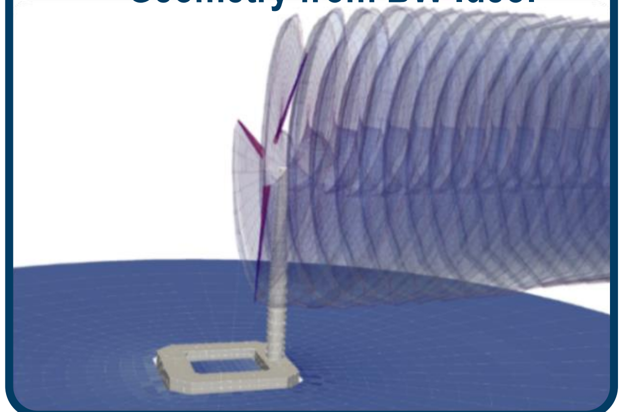


NREL, https://openfast.readthedocs.io

USTUTT

panMARE

- First order panel method
  - for aerodynamics
  - for hydrodynamics
- Geometry from BW Ideol



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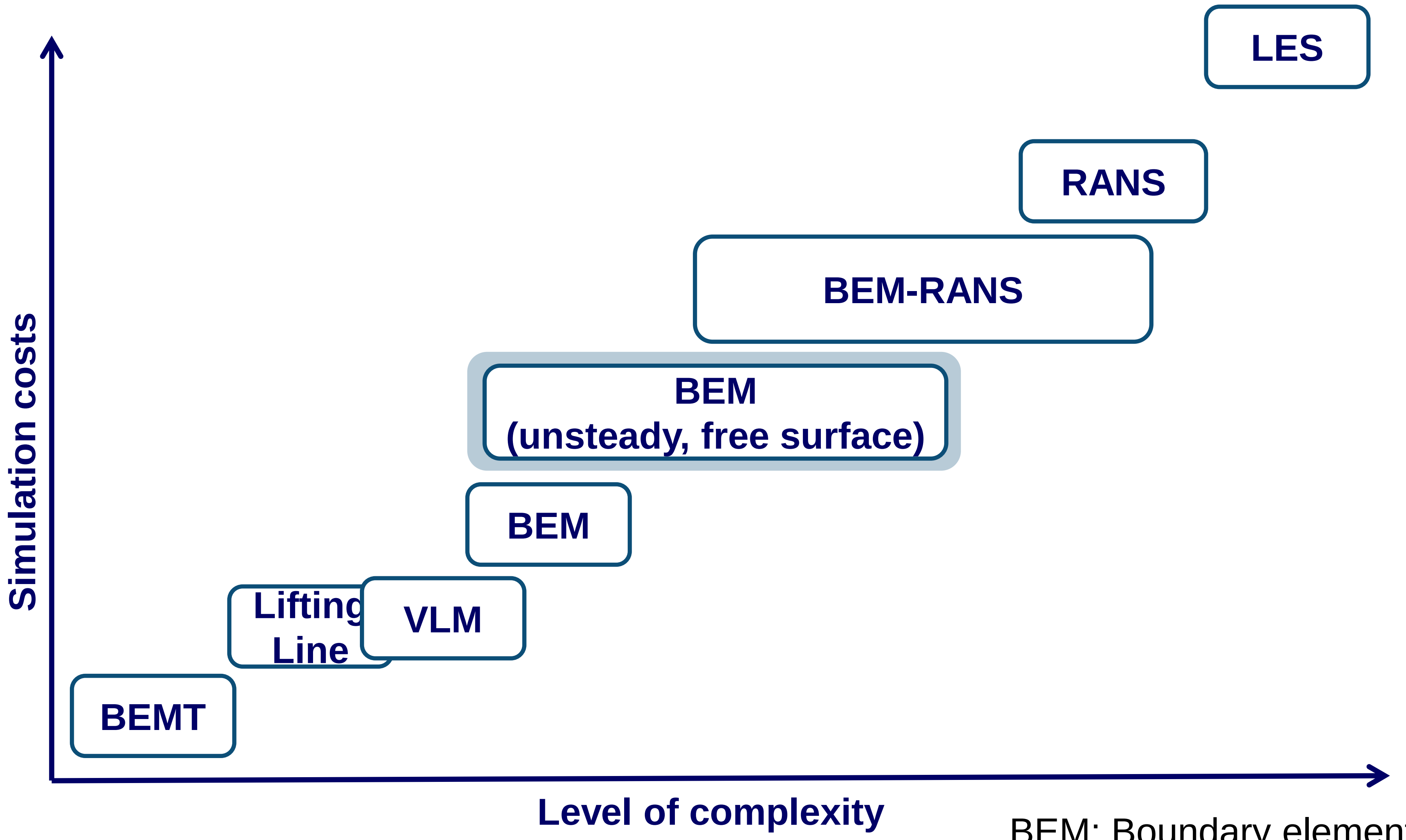
Engineering methods (BEMT + frequency-based BEM)

High fidelity method (fully BEM)



BEM: Boundary element method
BEMT: Blade element momentum theory

*pan*MARE – Panel code for maritime applications and research

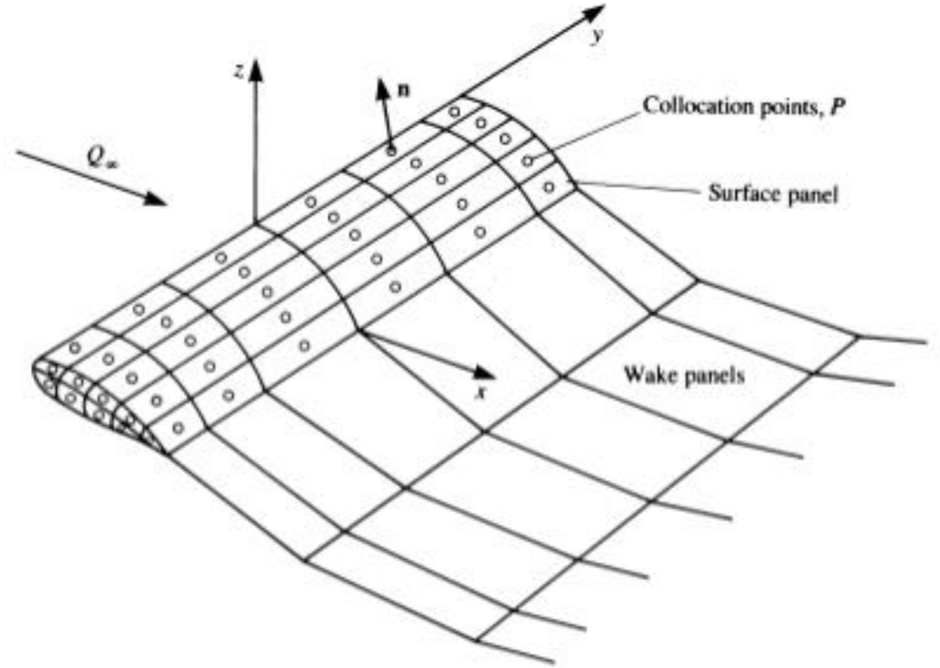
- Boundary element method (BEM)
- Three-dimensional
- Low-order panels
- Potential theory (inviscid, irrotational and incompressible)
- Superposition principle

$$\Phi = \Phi_{induced} + \Phi_{wave}$$

- Fluid velocity is given by gradient of velocity potential

$$\nabla\Phi = \vec{v}$$

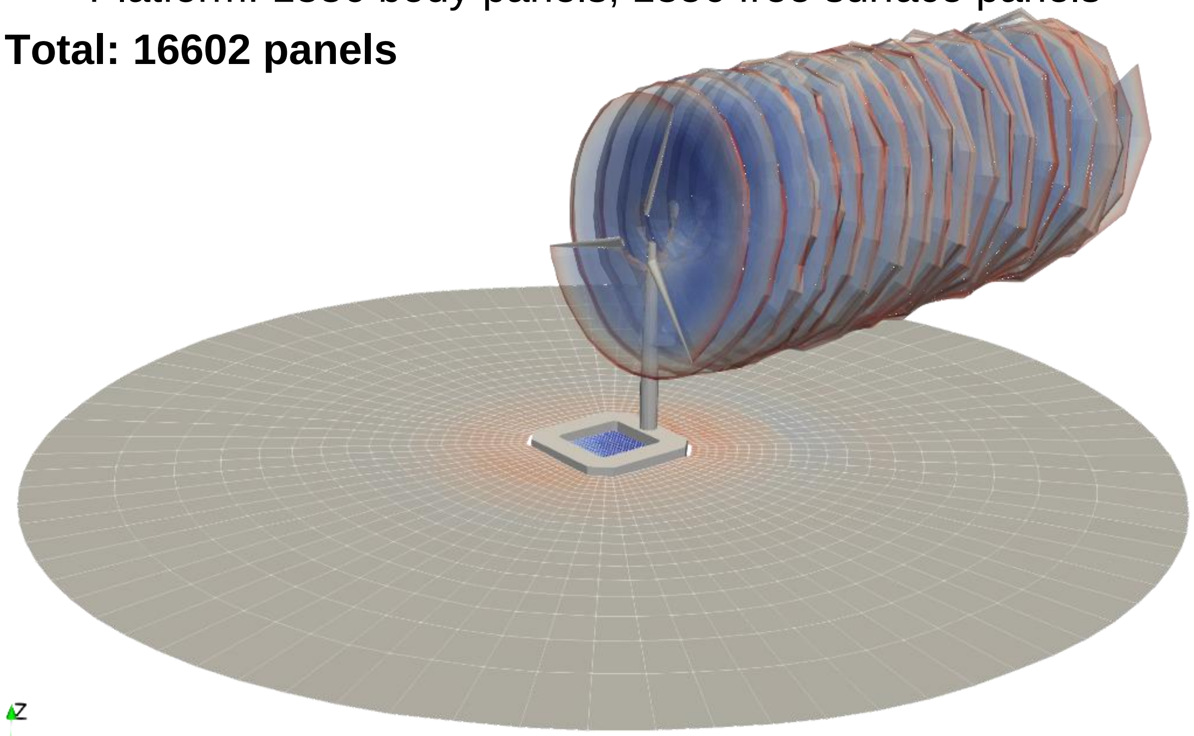
- Bodies: source and doublet panels, Dirichlet boundary condition
- Rotor wake: free vortex wake, doublet panels, iterative deformation
- Platform: instantaneous wetted surface
- Free surface: semi-Lagrange, Dirichlet, kinematic and dynamic boundary condition

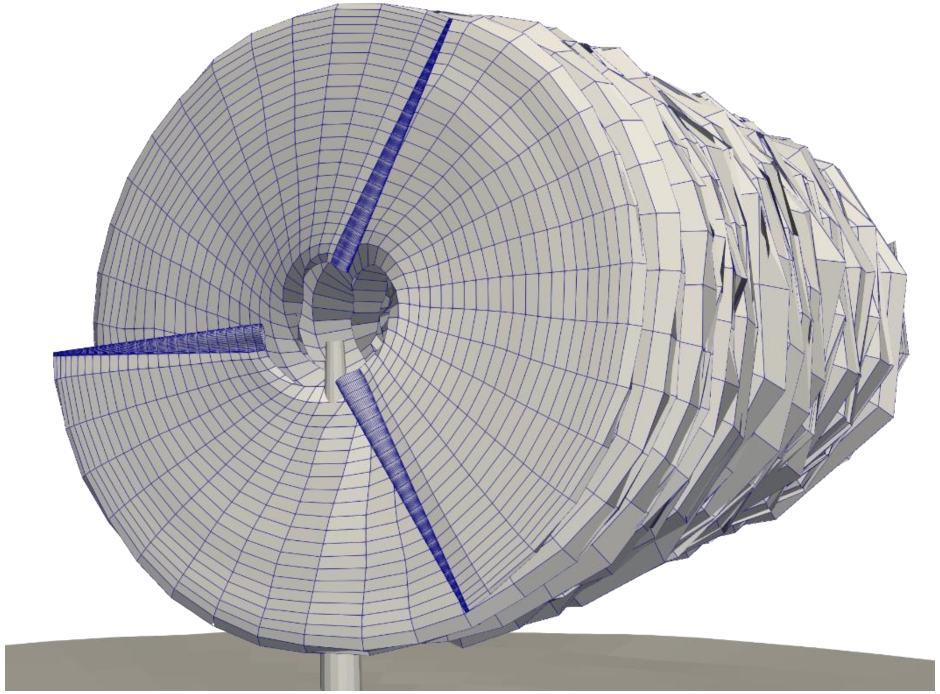


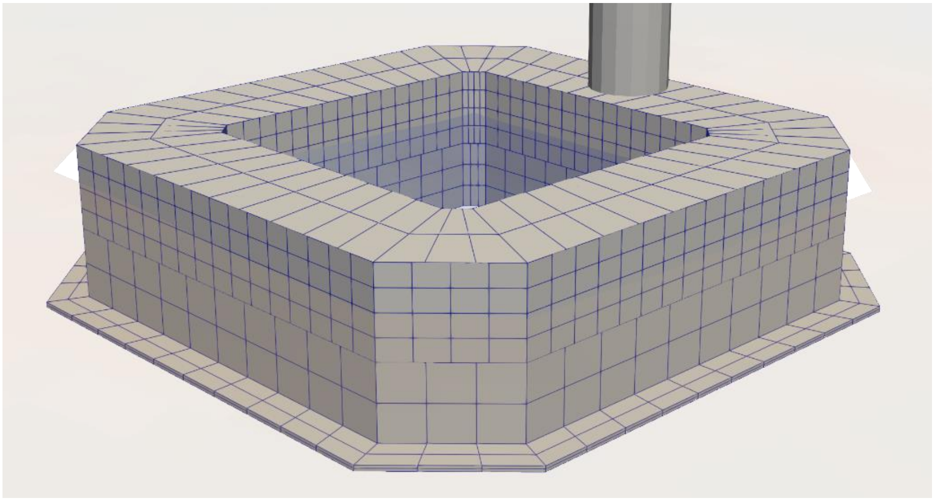
Joseph Katz and Allen Plotkin. Low-Speed Aerodynamics. Cambridge University Press, Cambridge [u.a.], second edition, 2001.

BEM

- **Aerodynamic domain**
  - Rotor: 3900 body panels, 8850 wake panels
  - Tower: 160 body panels
- **Hydrodynamic domain**
  - Platform: 1836 body panels, 1856 free surface panels
- **Total: 16602 panels**

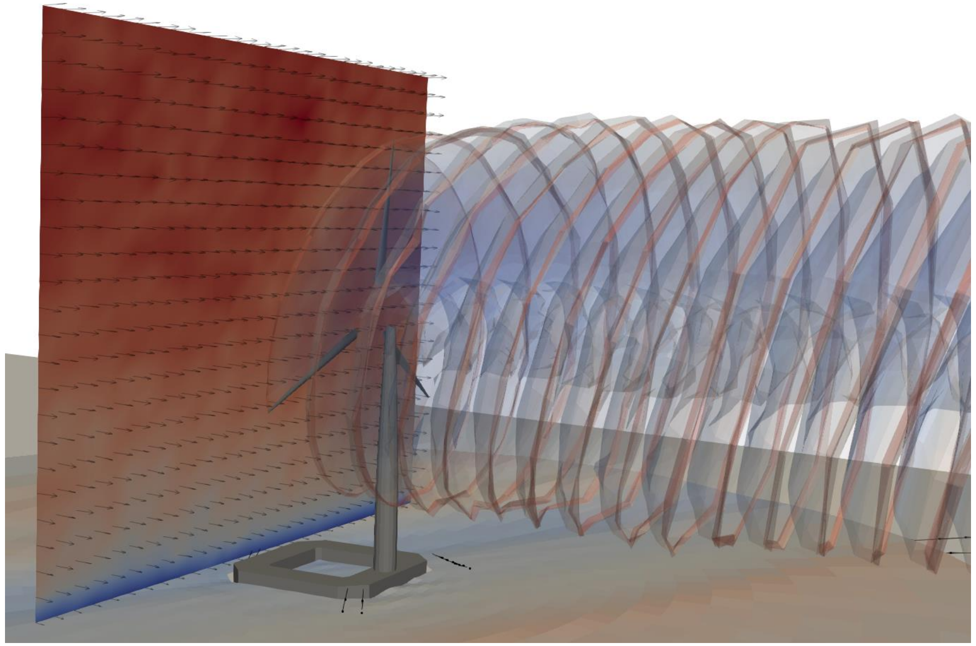


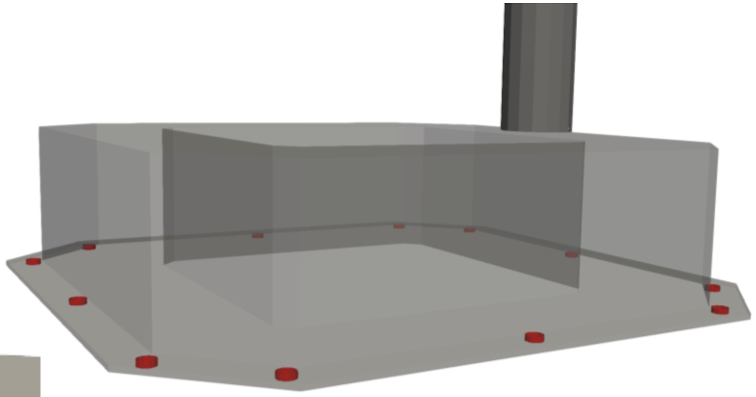


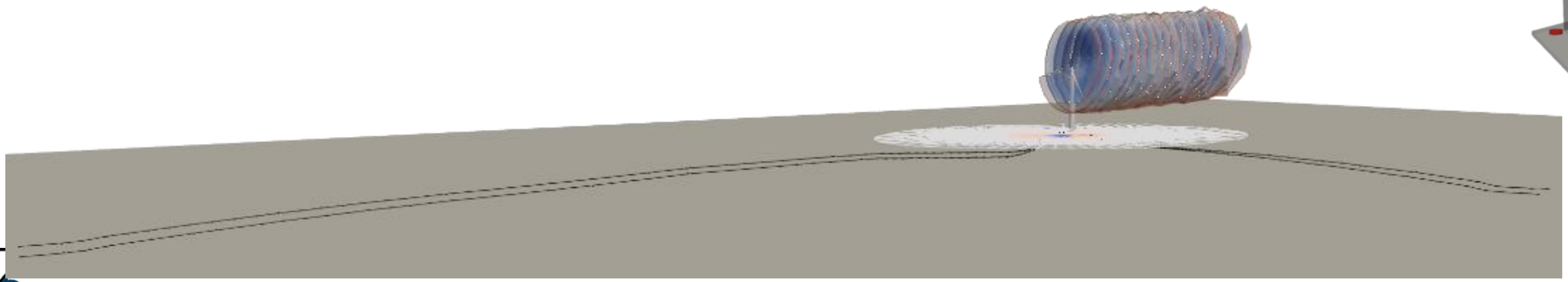


Additional techniques

- **Mooring: Lumped mass model**
  - 318 nodes
  - Synthetic fiber ropes (static-dynamic stiffness)
- **Additional heave drag elements (Morison drag)**
- **Rigid model**
- **6+1 DOF (6 platform, 1 rotor)**
- **Turbulent wind field based on TurbSim scheme**
- **Integrated controller Bladed DISCON interface**
  - Simulation controller differs from real turbine



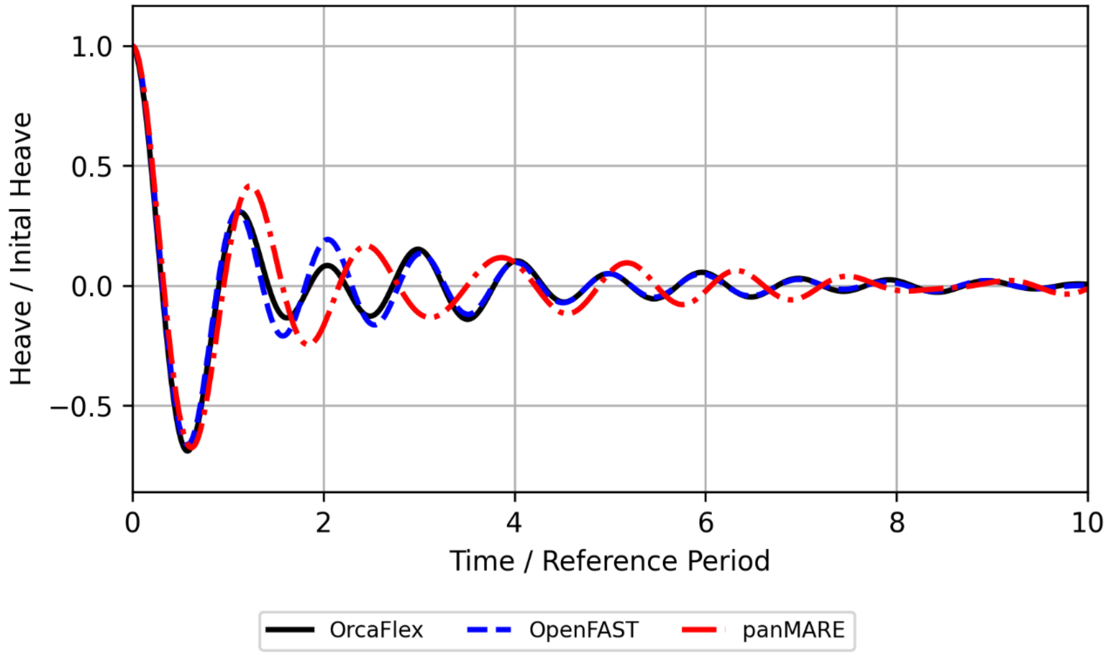




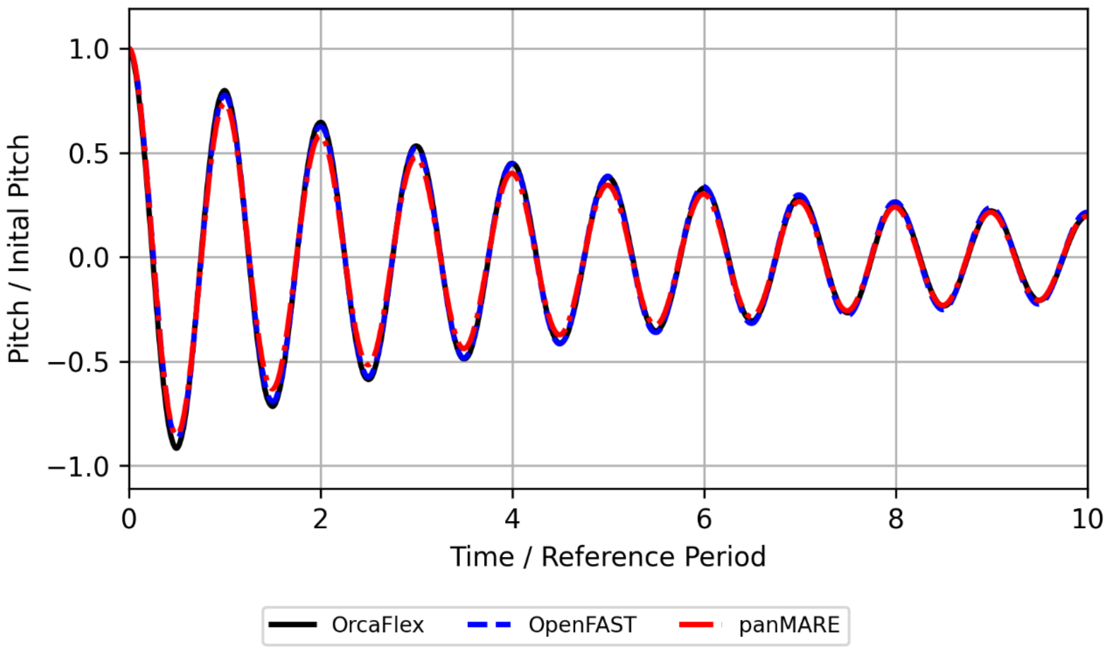
Verification

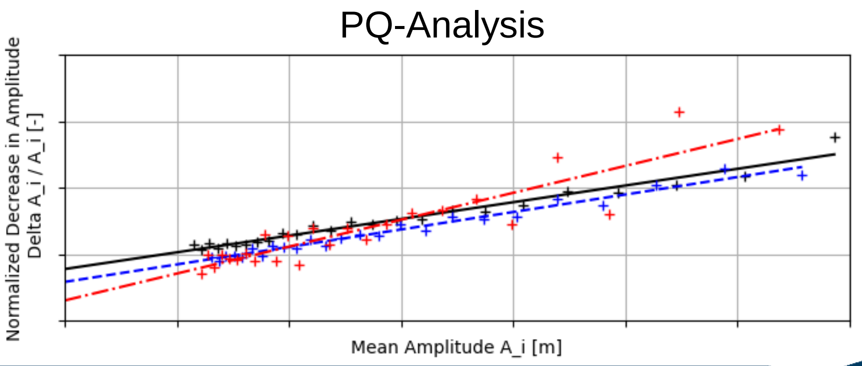
Decays, RAO and random seaway

Heave decay



Pitch decay

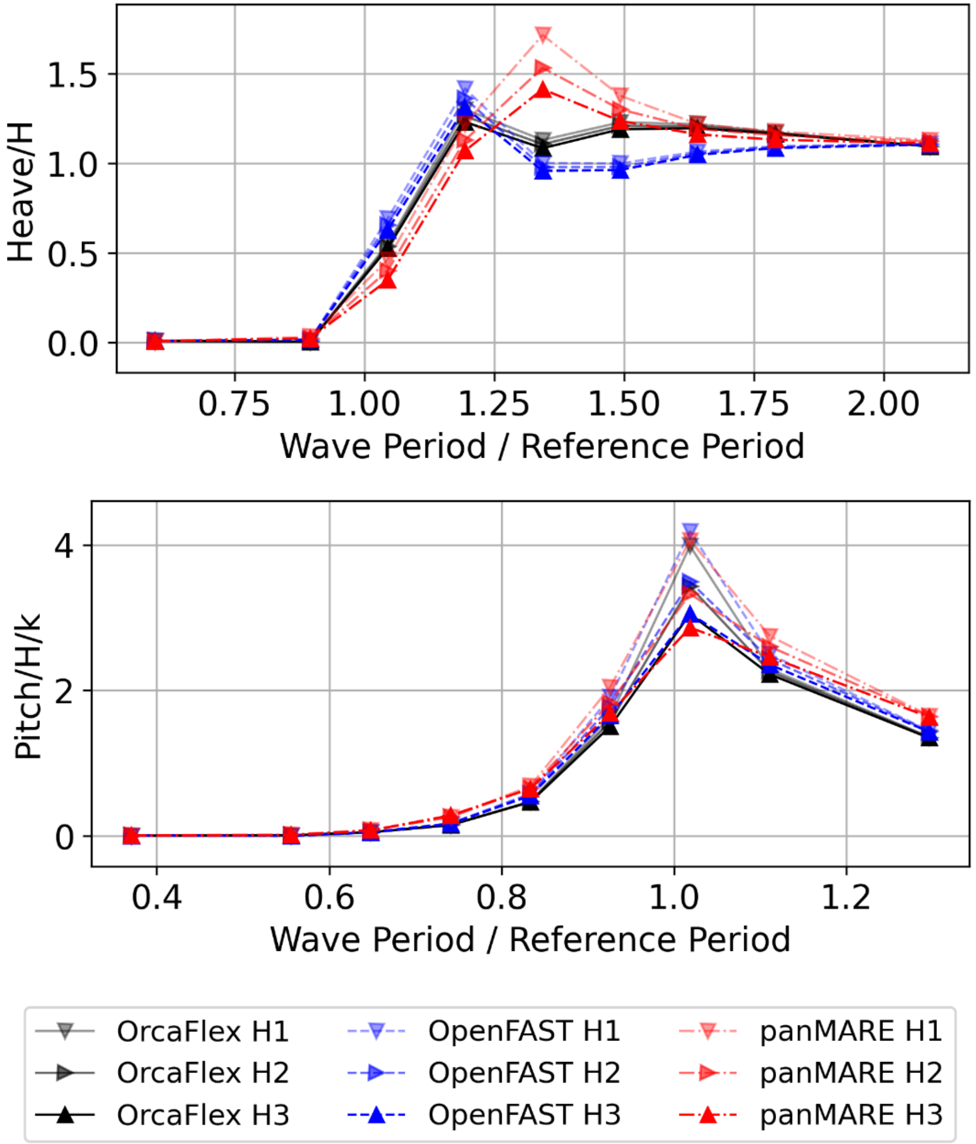


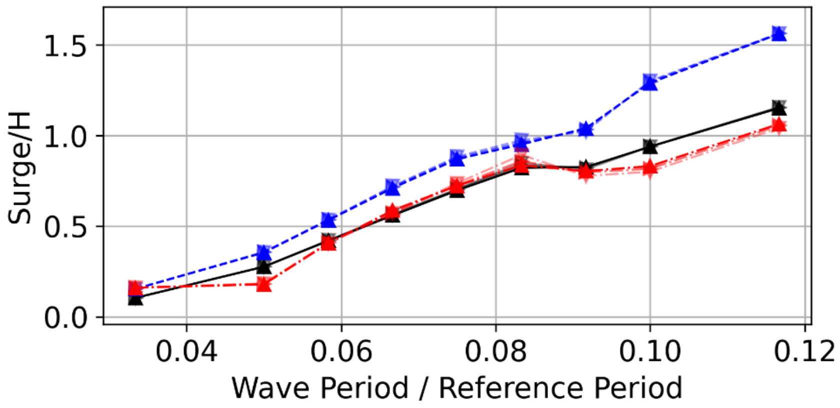


- **Reference period from OrcaFlex results**
- **Initial heave equal in all cases**

RAO

- Regular waves
- Different wave heights (H1<H2<H3)
- Reference periods from free decay
- Heave: Dependent on free surface parameters in *pan*MARE and treatment in OrcaFlex / HydroDyn



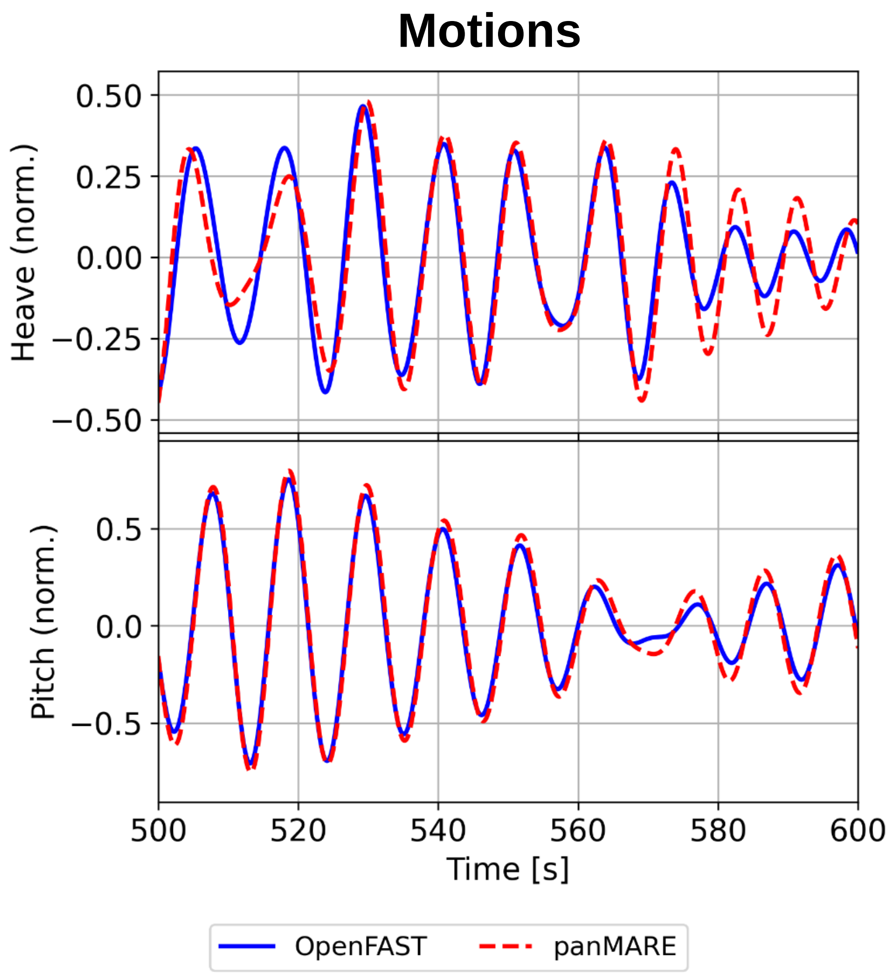


Coupled simulation

- **wind speed: 11 m/s**
- **significant wave height: 1.5 m**
- **Identical random seaway**
- **Identical turbulent wind field**

- **Results**
  - Deviations in heave motion
  - Good agreement of pitch motion

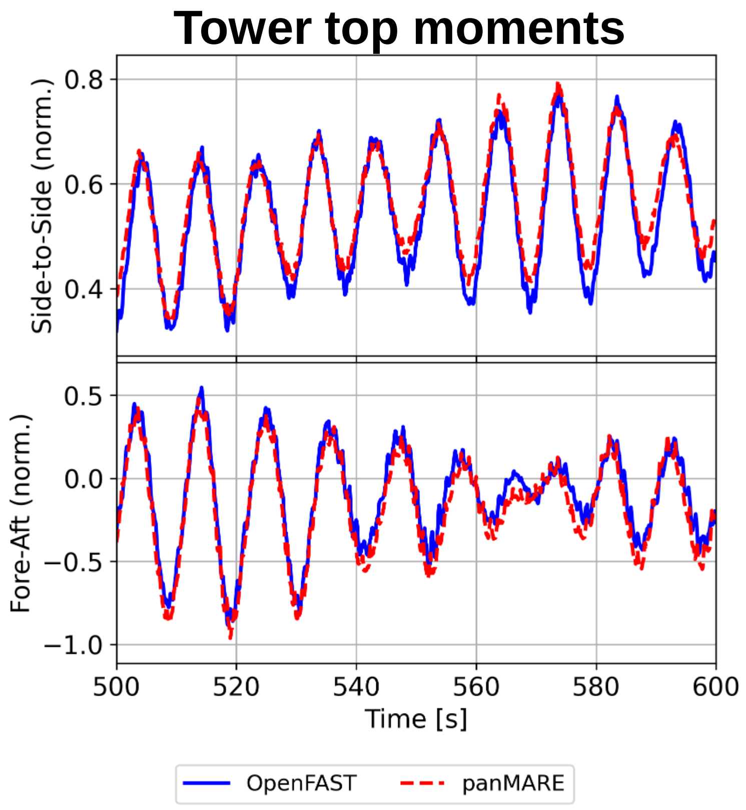
  - Consistent with decay and regular wave RAOs

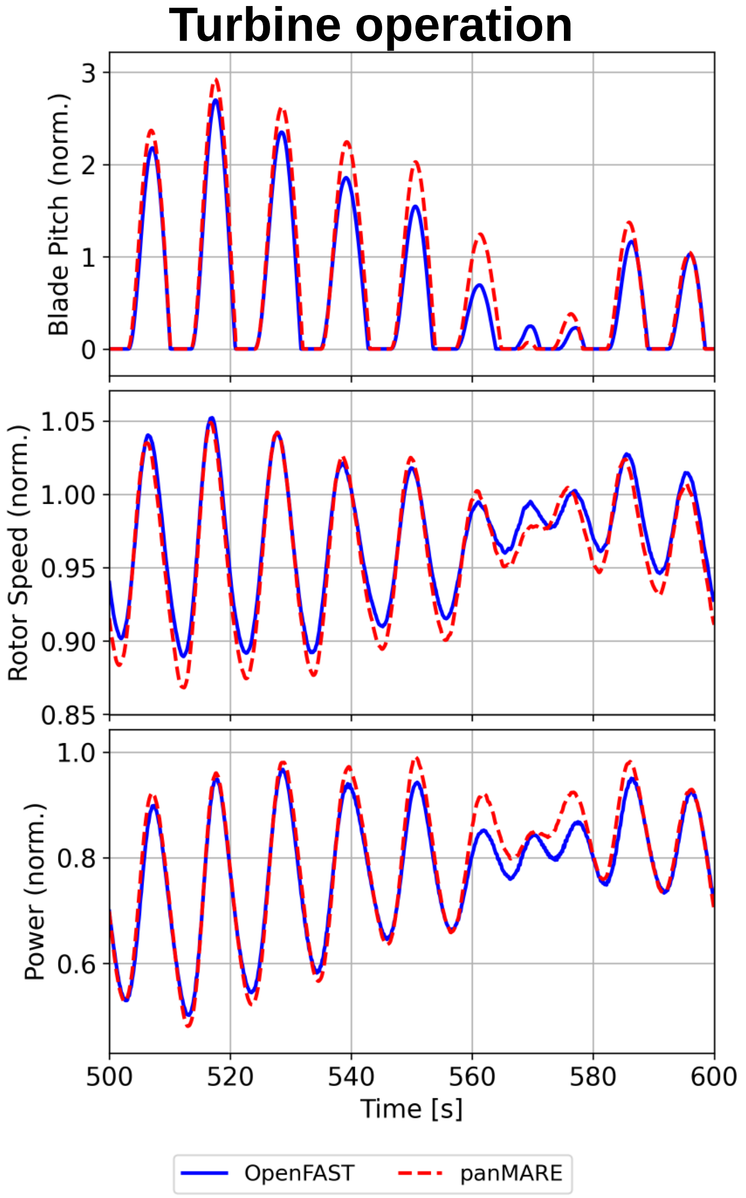


Coupled simulation

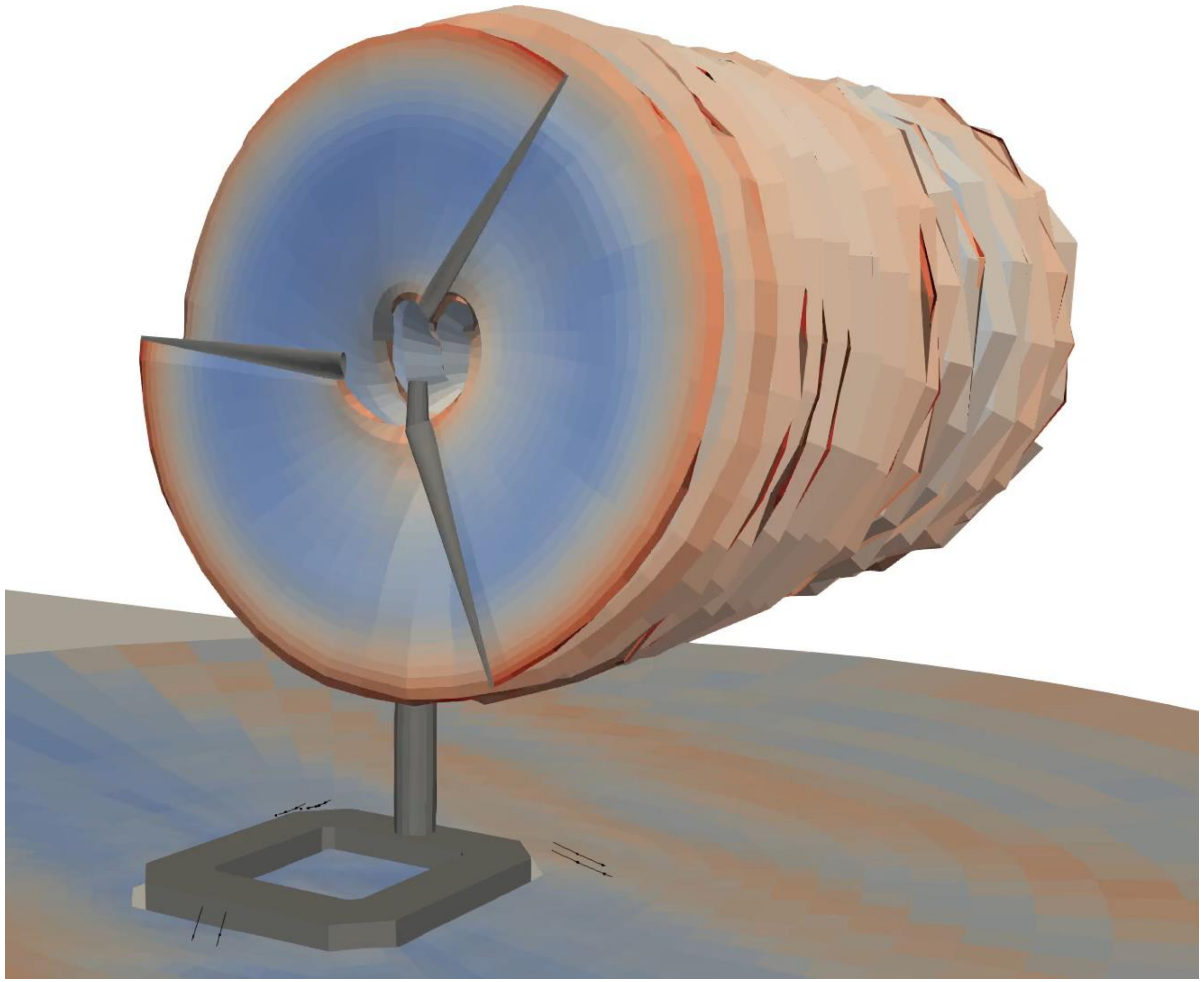
- **Good agreement of tower top bending moments and power**
  - Differences due to neglected structural deformations of tower and blades
- **Differences in rotor speed due to different aerodynamic modelling**

- **All results normalized (norm.), divided by constant reference**

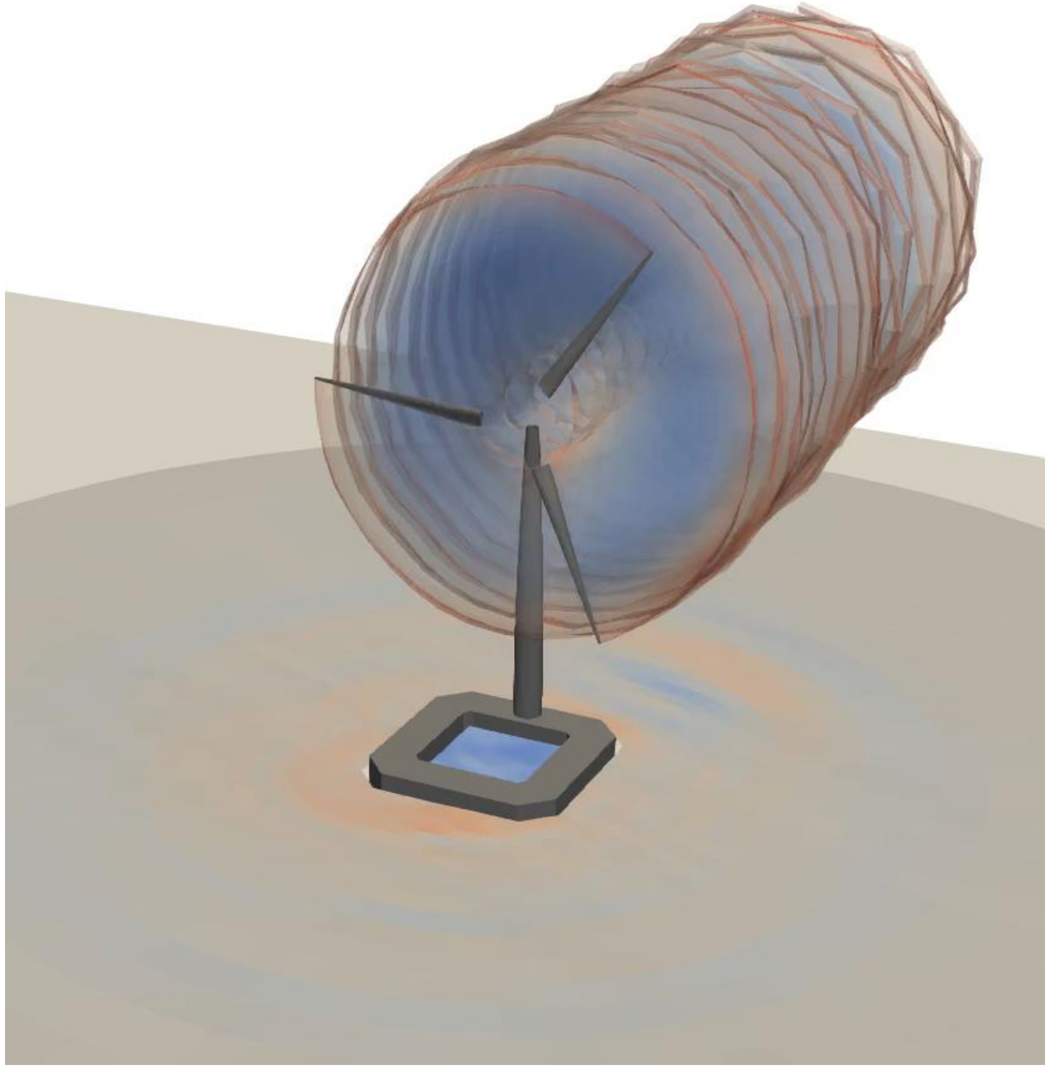




Wake – Doublet strength



Free surface – Induced elevation



Hybrid Simulations

Prescribed motion and constraint wind field

Validation in time-domain using full-scale data

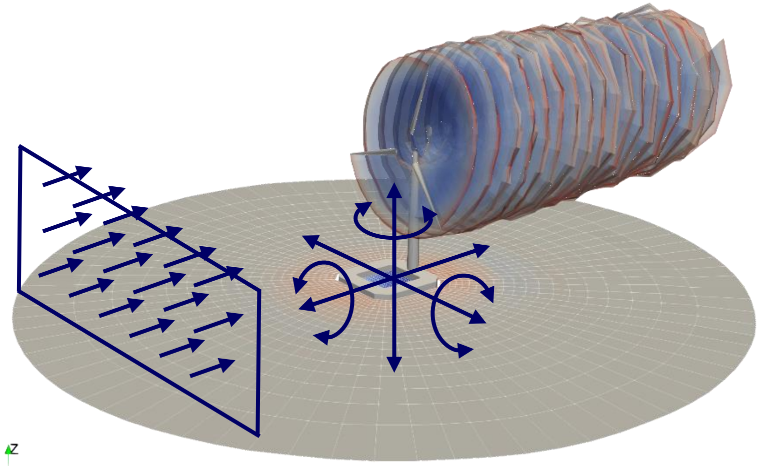
Problem

- Wave elevation at platform unknown
- Waves dominate the platform motions

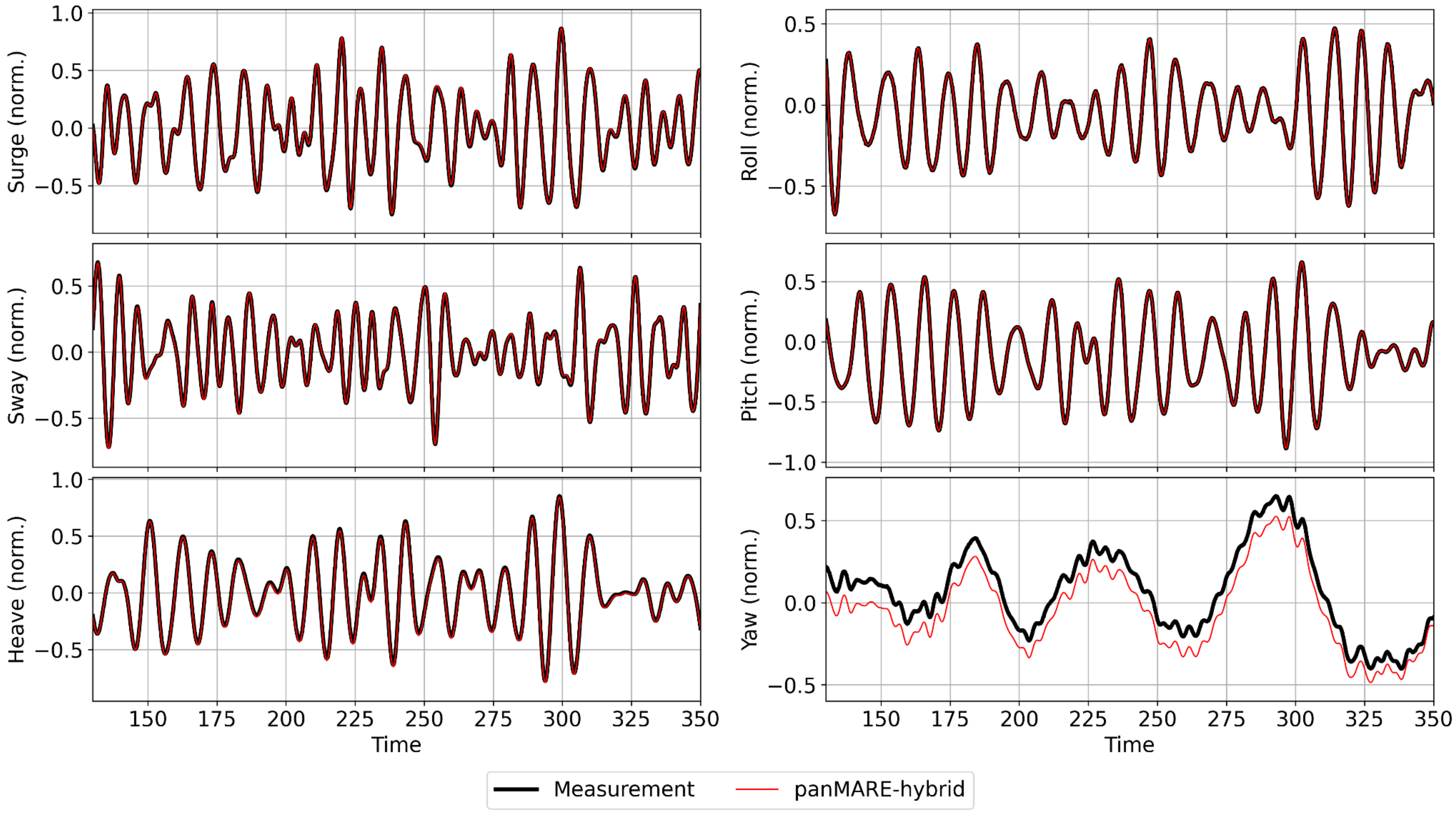
Approach

- Prescribe motion of the simulation model with measurement data
- Wind field reconstructed from LIDAR measurement (low frequency coherence)
- Hydrodynamic simulation is suppressed

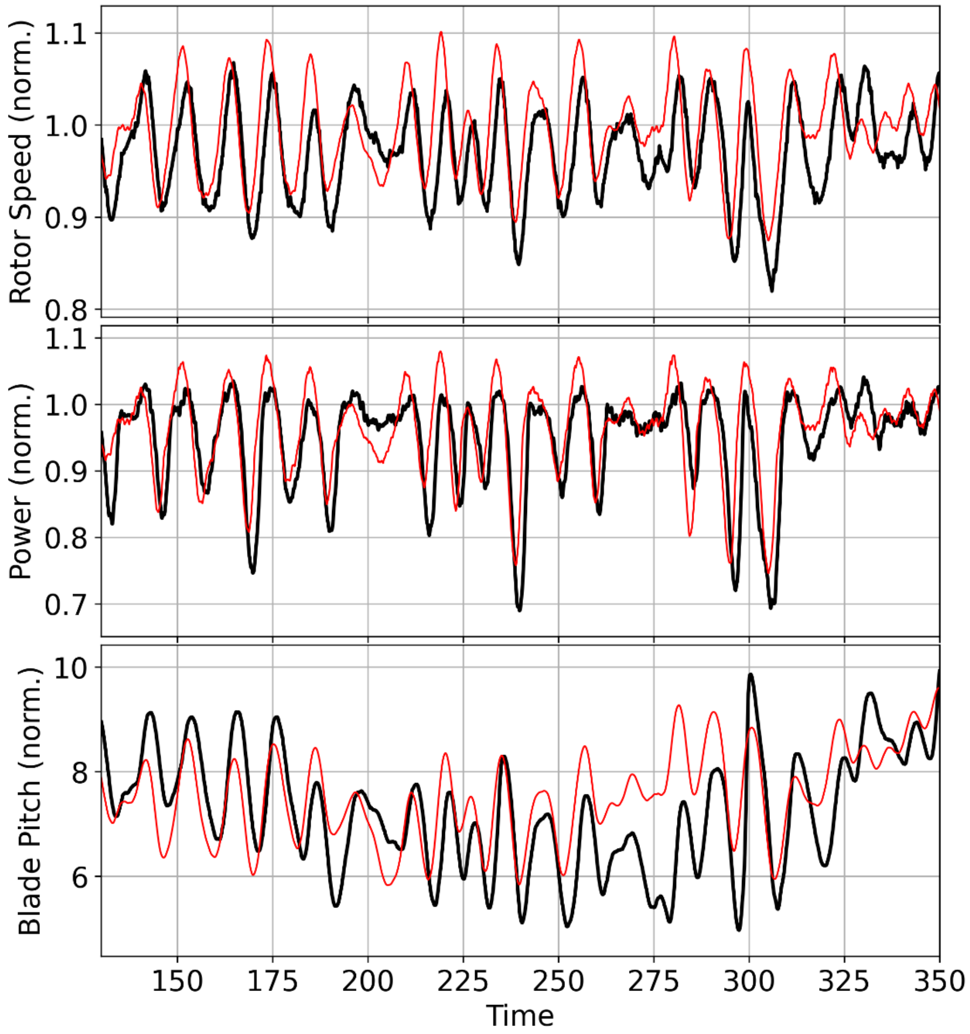
Prescribed motion and constrained wind field



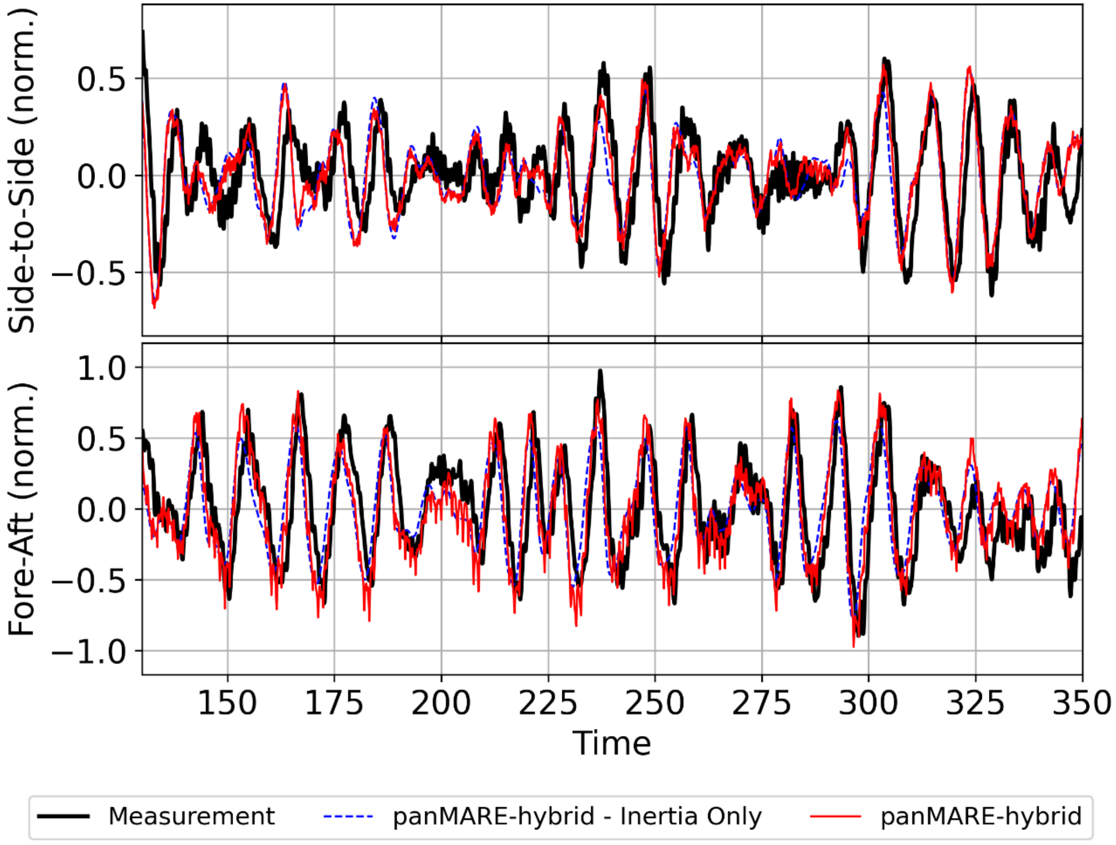
Motions are prescribed based on measurement data, LIDAR reconstructed wind field



Turbine operation

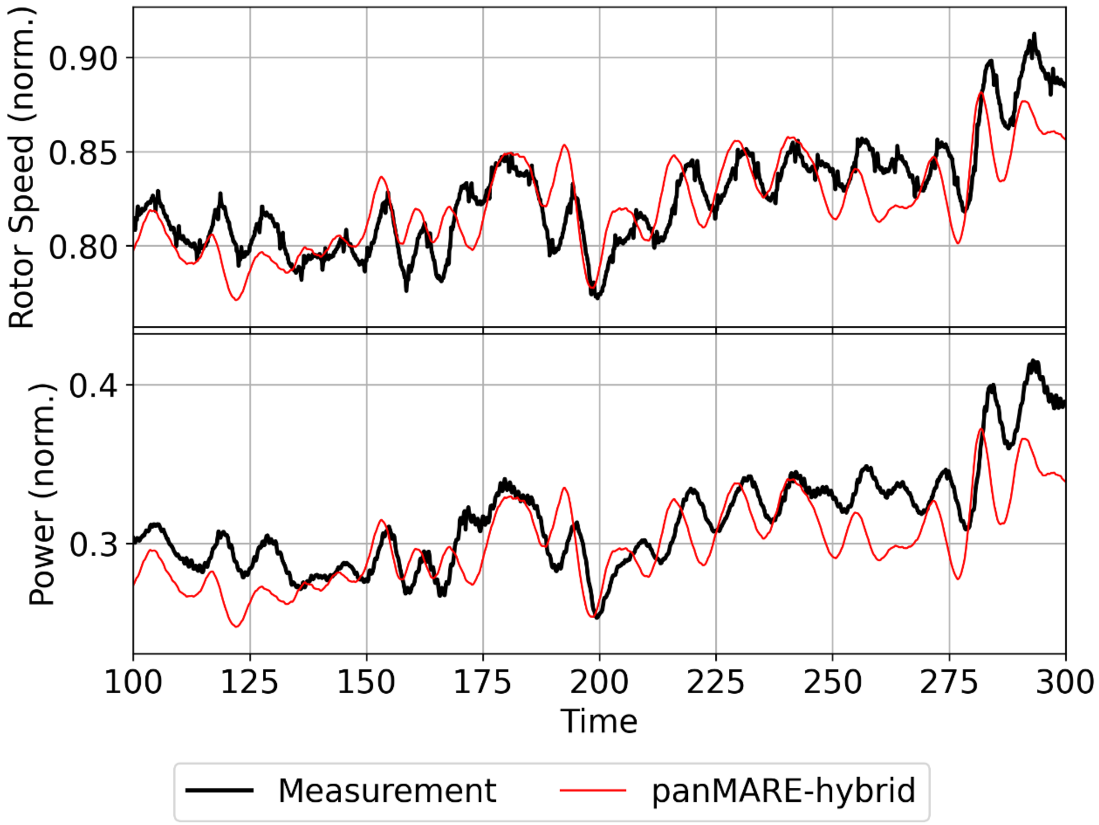


Tower top moments



TUHH Maritime Systems

Turbine operation



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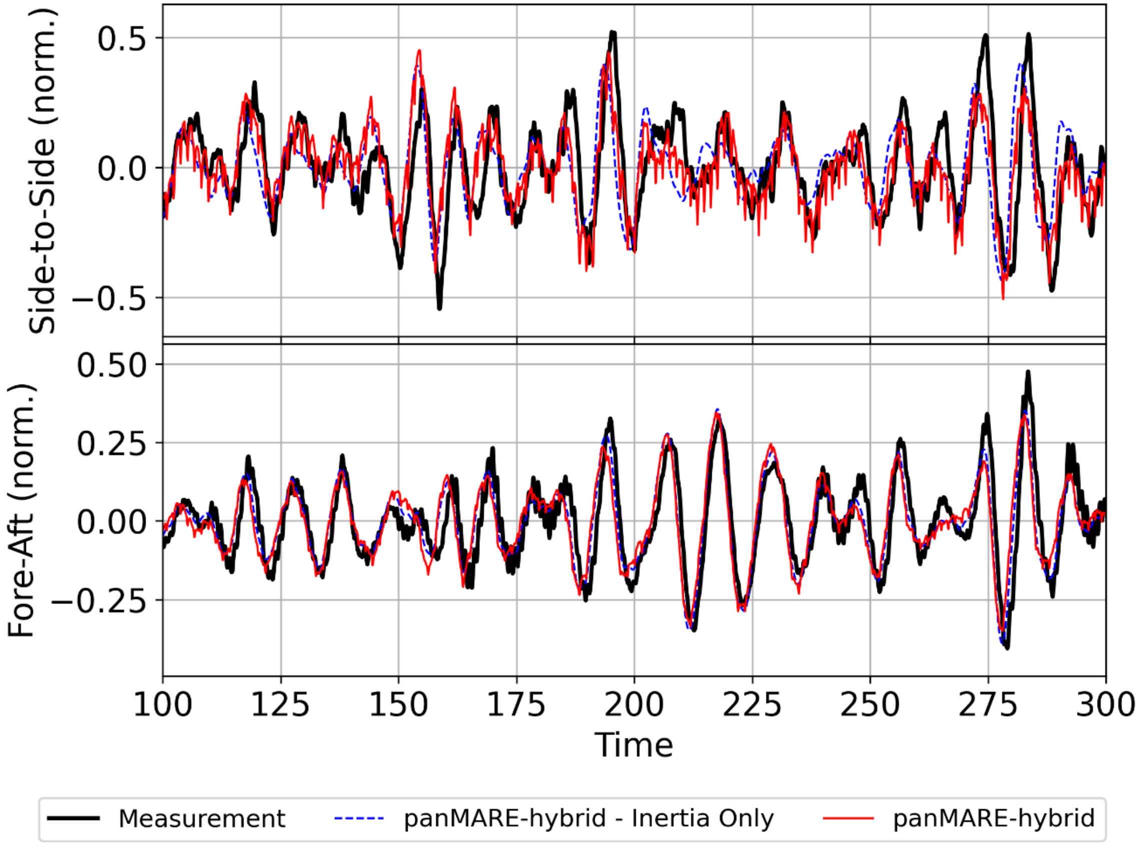
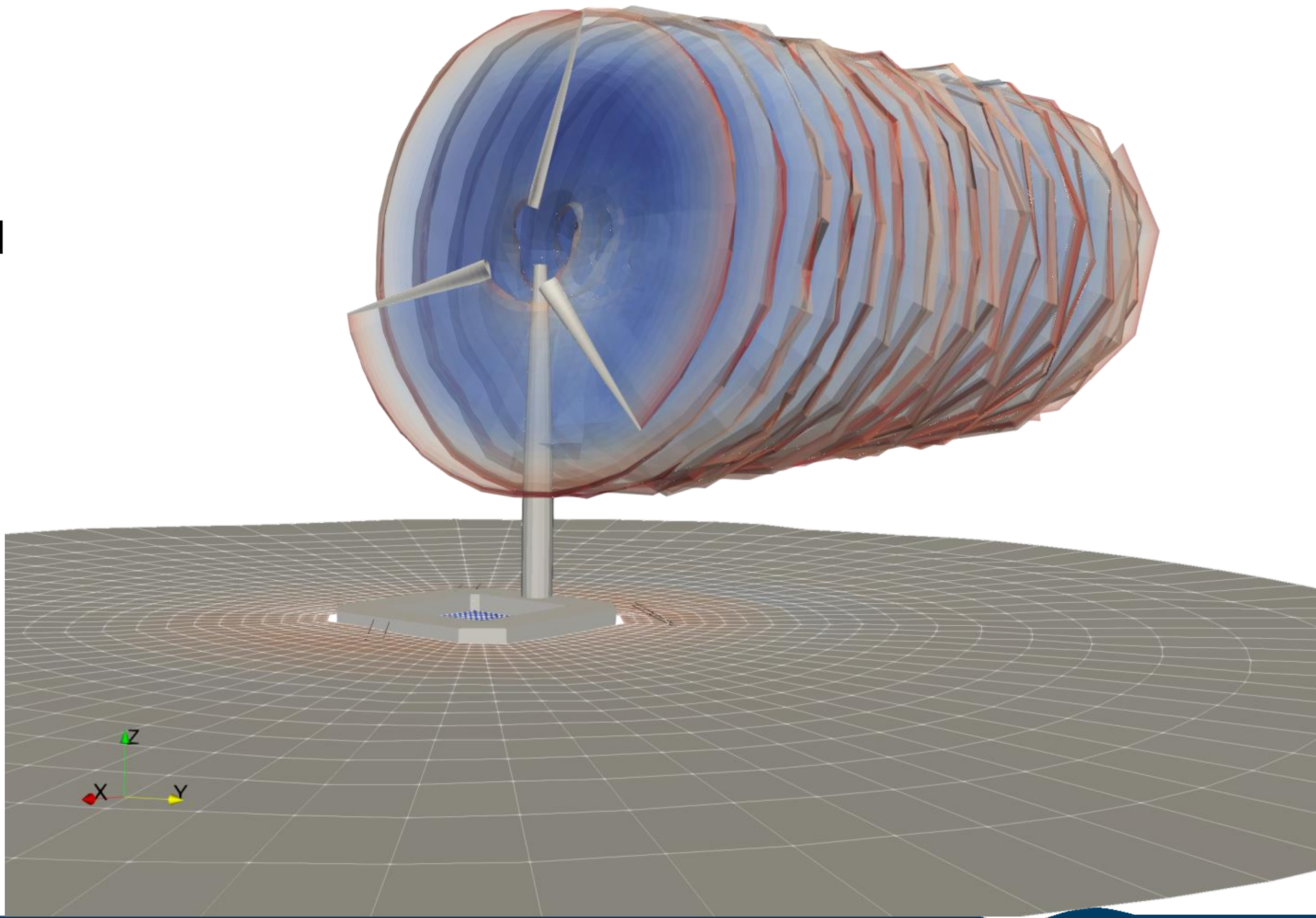


- **Verification**
  - Overall good agreement
  - Heave motion depending on free surface parameters

- **Hybrid simulation**
  - Accurate validation of the aerodynamics and inertia loads
  - Good agreement for turbine operating parameters
  - Blade loads influenced by rigid blade model



Acknowledgements

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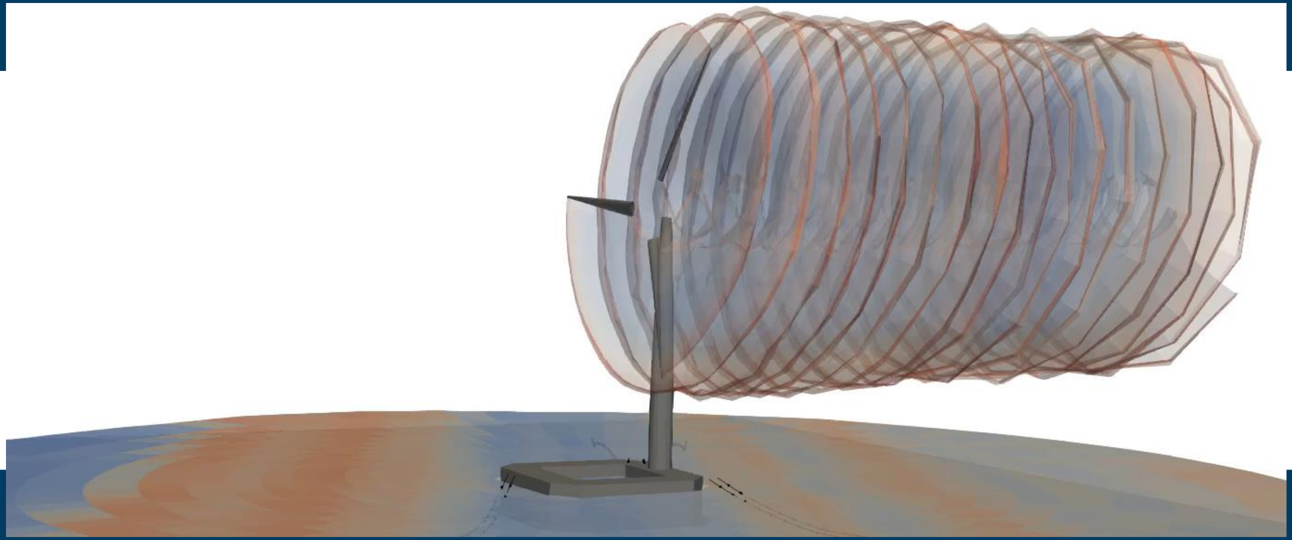

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