Validation of a numerical model of the model of a FOWT based on a real-time hybrid test campaign

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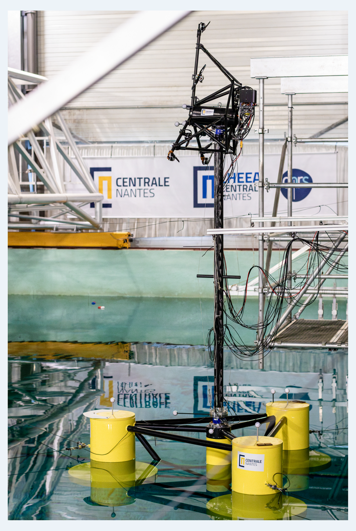
Abstract

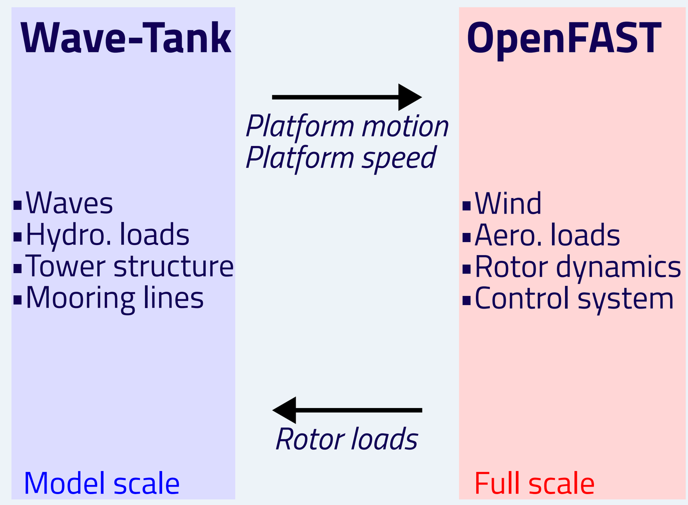


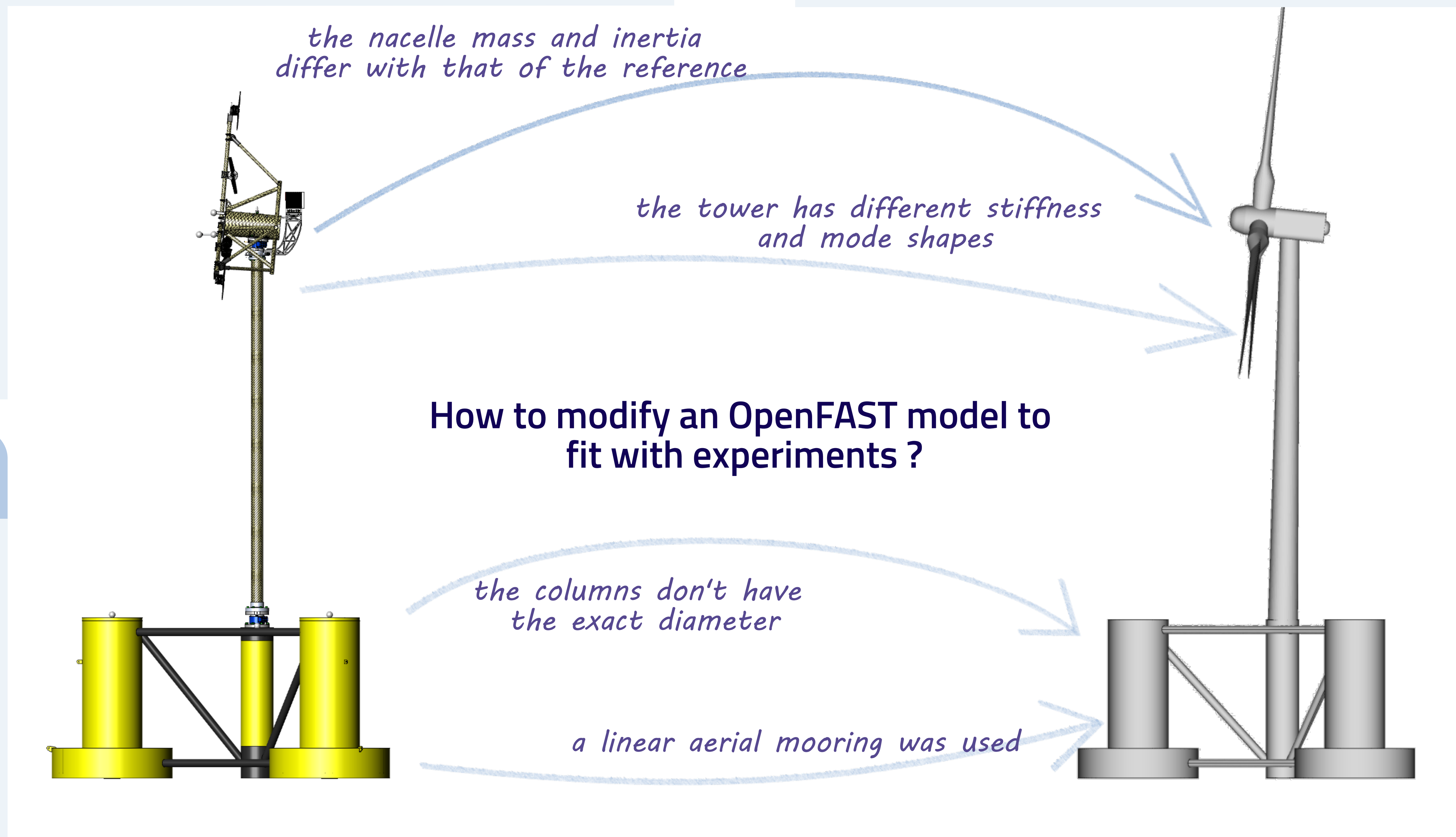
A model of the NREL-5MW wind turbine on the OC4 Semi-Submersible platform [1] was tested in the ECN wave-tank. The goal was to investigate the behaviour of various controllers in realistic conditions, not always well captured by numerical simulations.
A software-in-the-loop method was used, using OpenFAST to compute the aerodynamic loads that are applied on the model via an actuator.

The goal of this research is to make a **"model-of-the-model" of the SIL experiment in OpenFAST**. A reference model was modified to account for the experimental choices made and the results of the simulations are compared with experimental data.

Software-in-the-loop

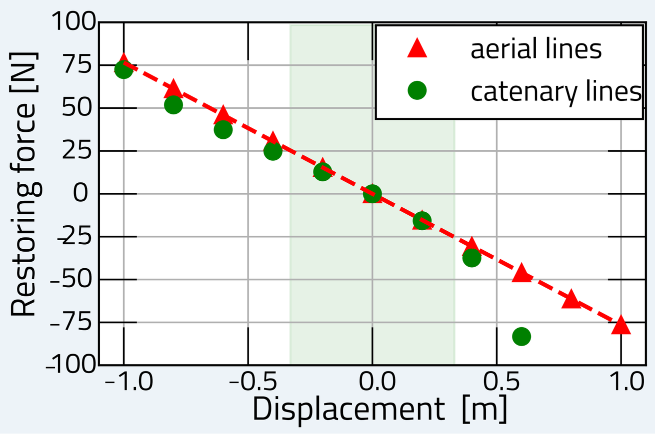
The model undergoes hydrodynamic loading from the wave-tank, but the wind forces are not directly applied to it. Instead, a method called **"Software-In-The-Loop"** was used. The motion of the model in the basin is measured and sent to a numerical counterpart modeled in the **OpenFAST** [2] software which computes and sends back aerodynamic loads which are **applied by an actuator** called the SoftWind nacelle [3], a **5-DOF system using 6 controlled drone propellers.**





Mooring validation

As the experimental model uses **aerial lines**, test simulations where done with both **aerial and catenary lines**. Both have a linear behaviour in the domain where the surge motion does not exceed 30 cm, but this is the case in most of the tested environmental conditions.

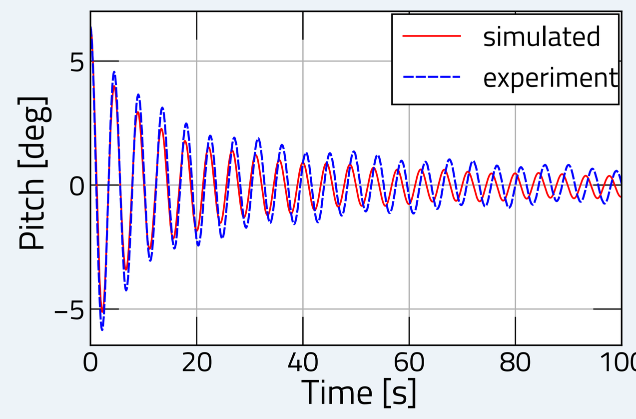


The difference in mooring lines might however impact the dynamics.
The resulting stiffness in the linear region is:
- experimental setup : 78.6 N/m
- numerical aerial lines: 76.6 N/m
- numerical catenary lines: 77.8 N/m

Natural periods

Numerical decay tests were run to investigate the natural frequencies of the system compared with those of the basin model. The tests displayed good agreement between the natural frequencies but also showed a difference in the damping.

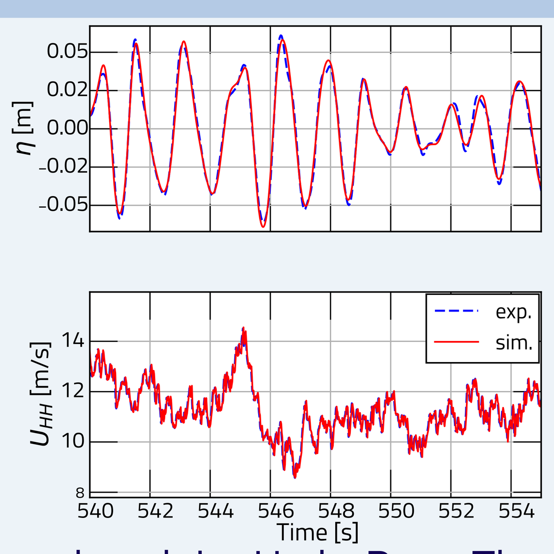
	Heave Period [s]	Surge Period [s]	Pitch Period [s]
Experimental	3.05	18.85	4.43
Numerical	3.08	18.92	4.49
Error	1.16%	0.37%	1.35%



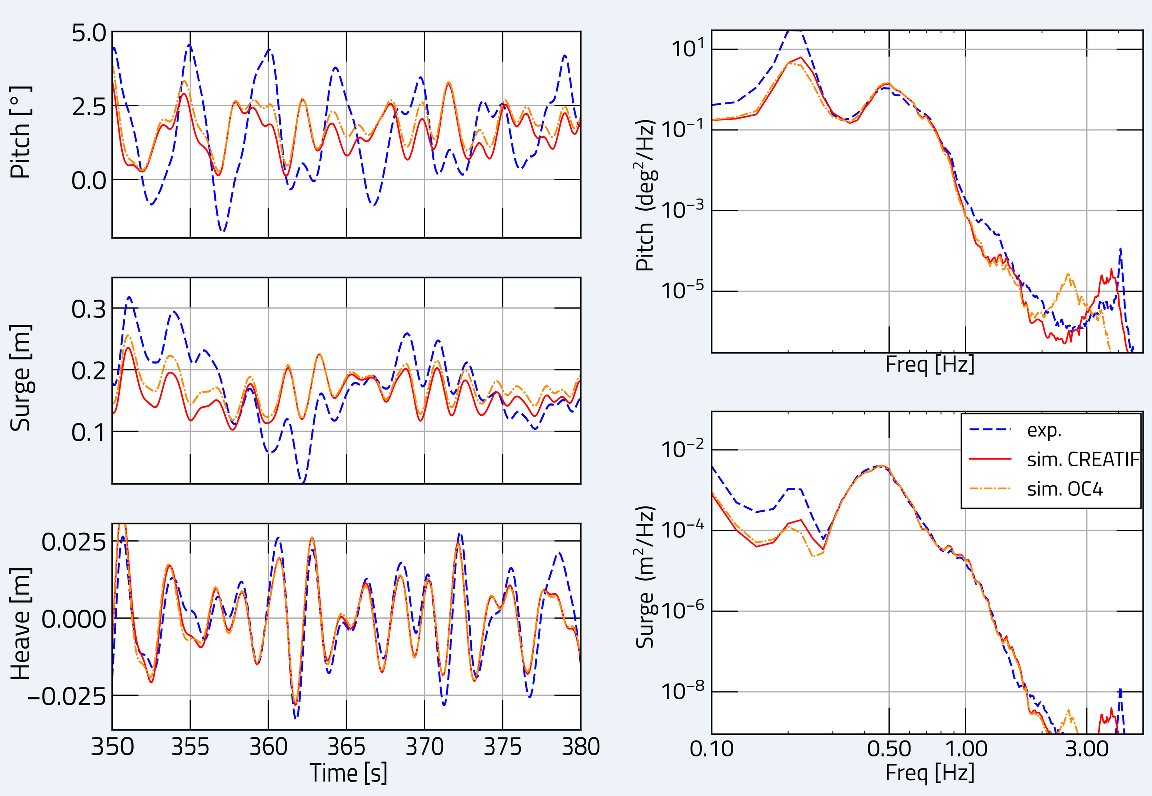
Environmental conditions

In total **15 sets of wind and waves environmental conditions** were used. They were selected to correspond to specific regions to challenge the tested controllers.

	U_{HH} [mps]	Wave height full scale [m]	Wave period full scale [s]	Wave height model scale [m]	Wave period model scale [s]
Region II	8	2	8	0.06	1.41
Region II.½	11.5	3.5	9	0.11	1.59
Region III	20	7	12	0.22	2.12



The water elevation was measured in the basin and reproduced in HydroDyn. The steepest waves are not always well reproduced in Hydrodyn, but overall the time series match very well. For the wind, the time series exactly match because in both the SIL and the simulation the wind is applied via the InflowWind module.



Platform motion

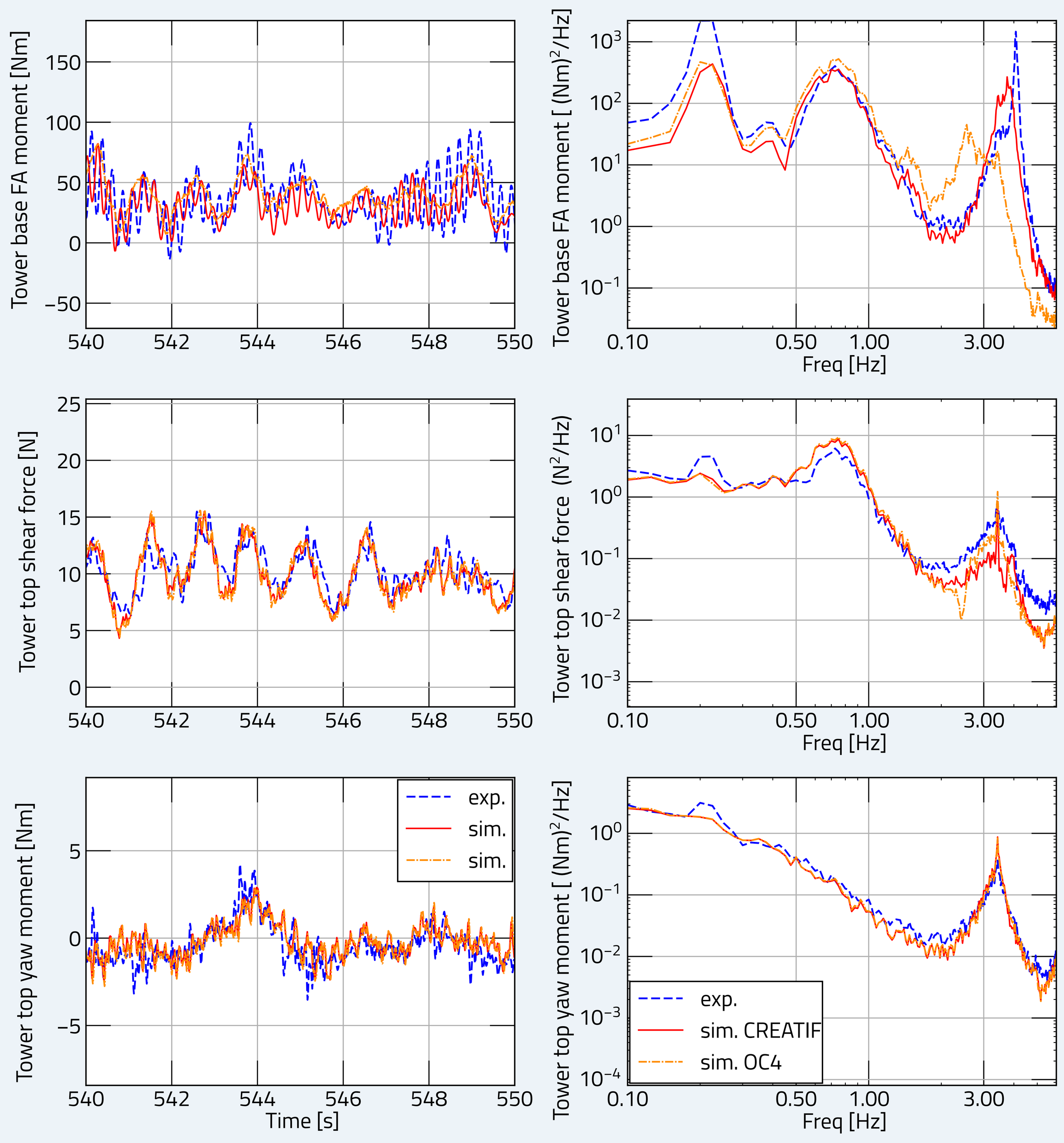
The **heave** motion, dominated by the wave elevation is very similar for all three models.

The **surge** motion matches well at high frequency but the numerical models fail to catch the low frequency phenomena.

The **pitch** and **surge** motion are coupled and both frequencies appear in the power densities.

Comparison with experiments

Comparison of the SIL experiment with numerical model was done. The 3 models are :
- **experimental**: the OC4 platform in the wave tank with the SoftWind nacelle
- **OC4**: the unmodified OpenFAST model of the OC4 semi-sub with the NREL 5MW
- **CREATIF**: the OpenFAST model modified so as to take into account all the differences



Tower loads (base & top)

The tower base and top loads are measured with 6-DOF load cells on the experimental model and compared with OpenFAST outputs.

For the tower base fore-aft moment, the **tower bending mode has a great influence** and a **better agreement is reached with the modified OC4 model**. The loads reproduced by the actuator display a lag of approximately 100 ms.

The **3P frequency** that corresponds to 3 times the rotor frequency can be seen on the power spectrum and is correctly captured by the SIL system.

Takeways

This work showcases useful results both for OpenFAST-Software-In-The-Loop experimental work and numerical modelisation.
- The use of aerial lines to model catenary lines is validated.
- It is possible to apply loads up to the 3P frequency using an actuator like the SoftWind nacelle.
- After tuning of the model, OpenFAST can be used to model the full dynamics of a wind turbine for controller tuning purpose.

References

[1] Robertson, A., Jonkman, J., Masciola, M., Song, H., Goupee, A., Coulling, A., & Luan, C. (2014). *Definition of the semisubmersible floating system for Phase II of OC4 (Technical report)*. National Renewable Energy Laboratory, University of Maine, Norwegian University of Science.

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[3] Bonnefoy F., Leroy V., Mojallizadeh M.R., Delacroix S., Arnal V., Gilloteaux J.C., (2024) Multidimensional hybrid software-in-the-loop modeling approach for experimental analysis of a floating offshore wind turbine in wave tank experiments. *Ocean Engineering*. 309, 118390.

The wave tank picture is credited to Bertrand Malas, ECN.

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