Tank Testing of Floating Offshore Wind Turbines: How complex does it need to be?

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Background and Proposal

- To test the design of floating wind turbines (FWT), a scaled model must be built and tested in wave basins and wind tunnels;
- Model testing of these structures is challenging due to the presence of aerodynamic and hydrodynamic loads;
- For testing facilities, as FloWave, understanding how complex the system setup needs to be according to the development stage of the model being tested is important.

It is then proposed that the testing of FOWT should be based on the design TRL

Test Feature	TRL Level	
	Concept Model (Stage 1)	Design Model (Stage 2)
Wind Loading Application	Static Weight /Constant Thrust Winch System	Performance scaled/ Hybrid Approach
Control	No controller	Control methodologies can be applied
DoF	1	≥1
Environmental Parameters	Long-crested waves and/or uniform wind; regular waves with/without regular wind; irregular waves with/without turbulent wind	Misalignment of wind and wave directions/ short-crested irregular waves

How to demonstrate it

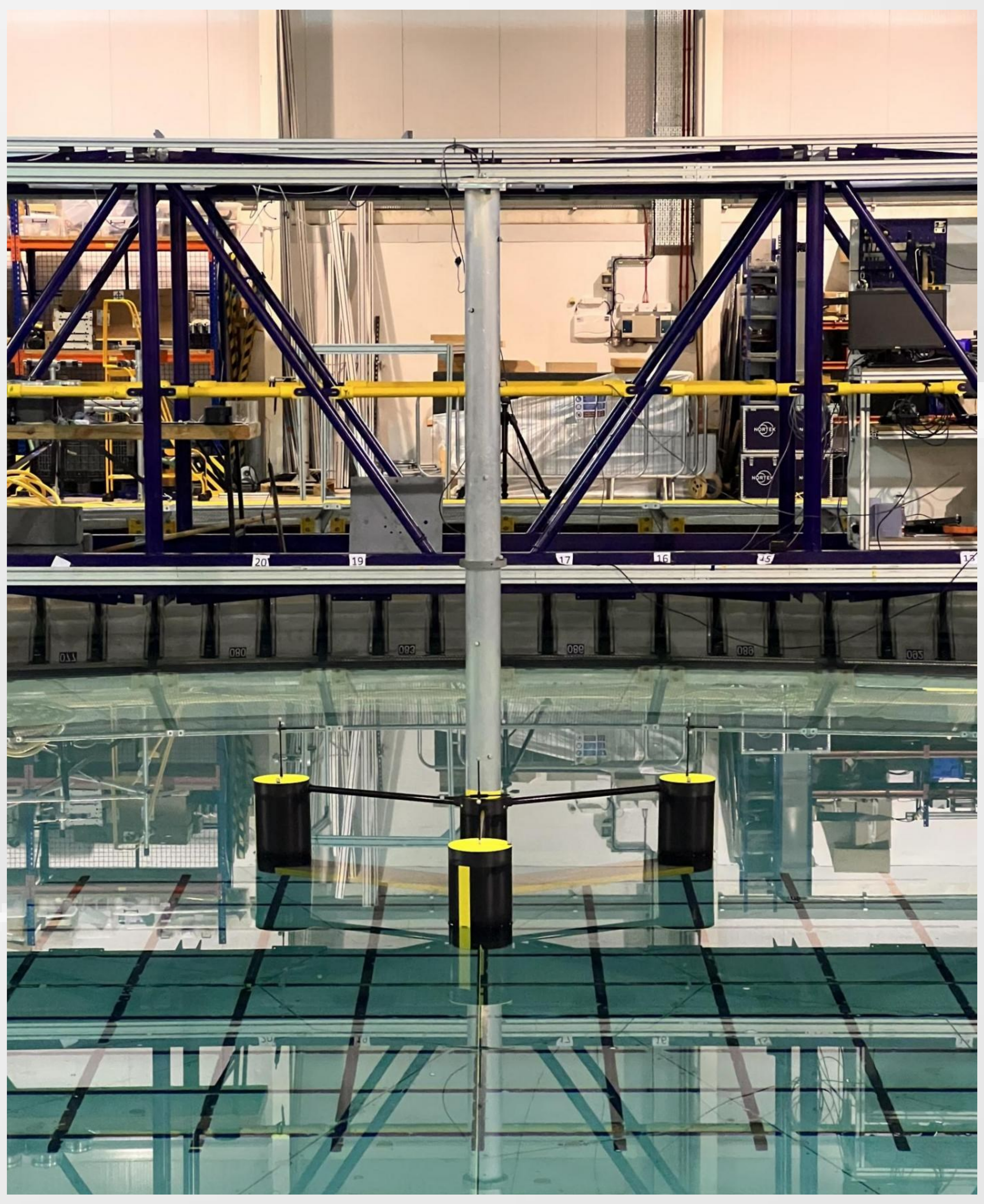

Fig.1: 50th scale model of VolturnUS-S [2] built and tested at FloWave.

3 tank testing campaigns at FloWave:

- Simulate wind thrust using a **static weight** *(most simple)*: It comprises of a calibration weight which weight matches the required wind thrust force.;
- Simulate wind thrust using a **PI controlled winch**: the winch system used is shown in Figure 2 and it is composed by an EC motor and encoder. The motor is controlled by a PI force control loop;
- Simulate wind thrust using **Software-in-the-loop** *(most complex)*.
  ↳ Comparison with OpenFast [1] simulations

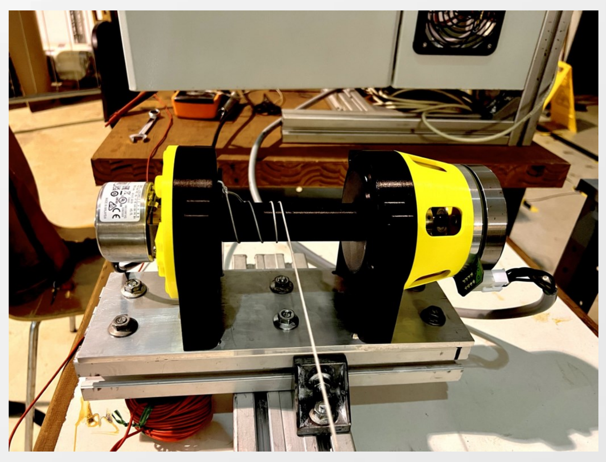

Fig.2: PI controlled winch system.

Results until now...

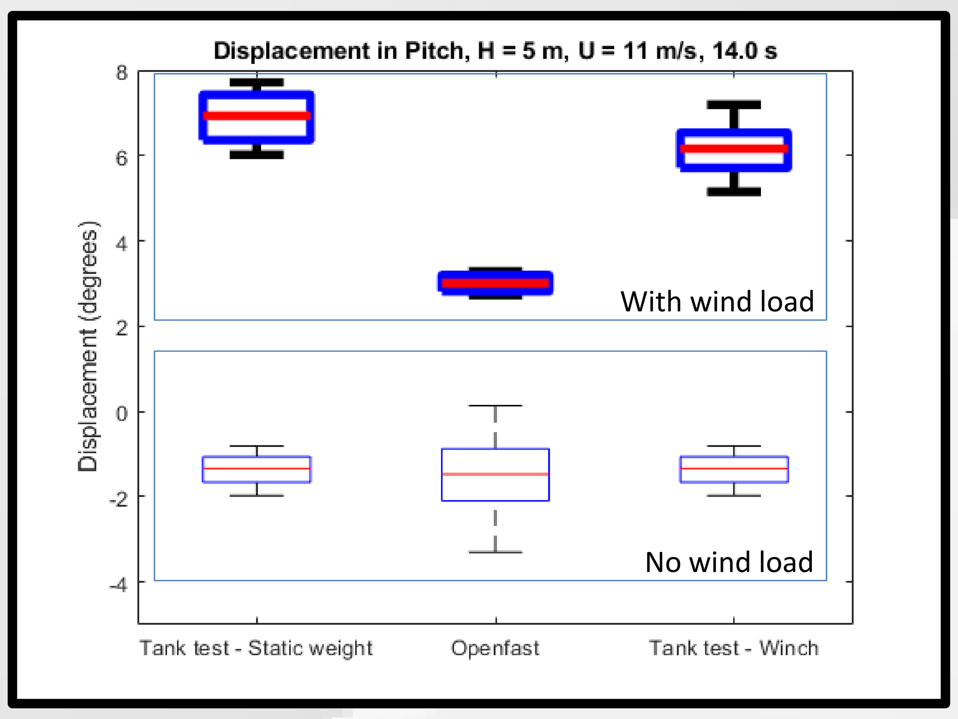

Fig.4: Comparison of pitch displacement for 'static weight' and 'PI controlled Winch' with OpenFast simulation.

- **Figure 4** shows the comparison between the displacement in Pitch of the tank test results for the 'static weight' method, the OpenFast full-coupled simulation and the tank test results for the 'PI controlled Winch'. The simulated wind corresponds to the rated wind speed of 11 m/s. On the 'static weight' case, it corresponded to a 2 kg weight. On the 'PI controlled Winch', it corresponded to a force of 19 N. The regular wave parameters were 5 m wave height and period of 14.0 s.
- It is visible that both methods don't exactly match the OpenFast results. These methods are simple to apply, however they are only capable of applying a constant wind thrust while the OpenFast simulations include all the coupled effects.

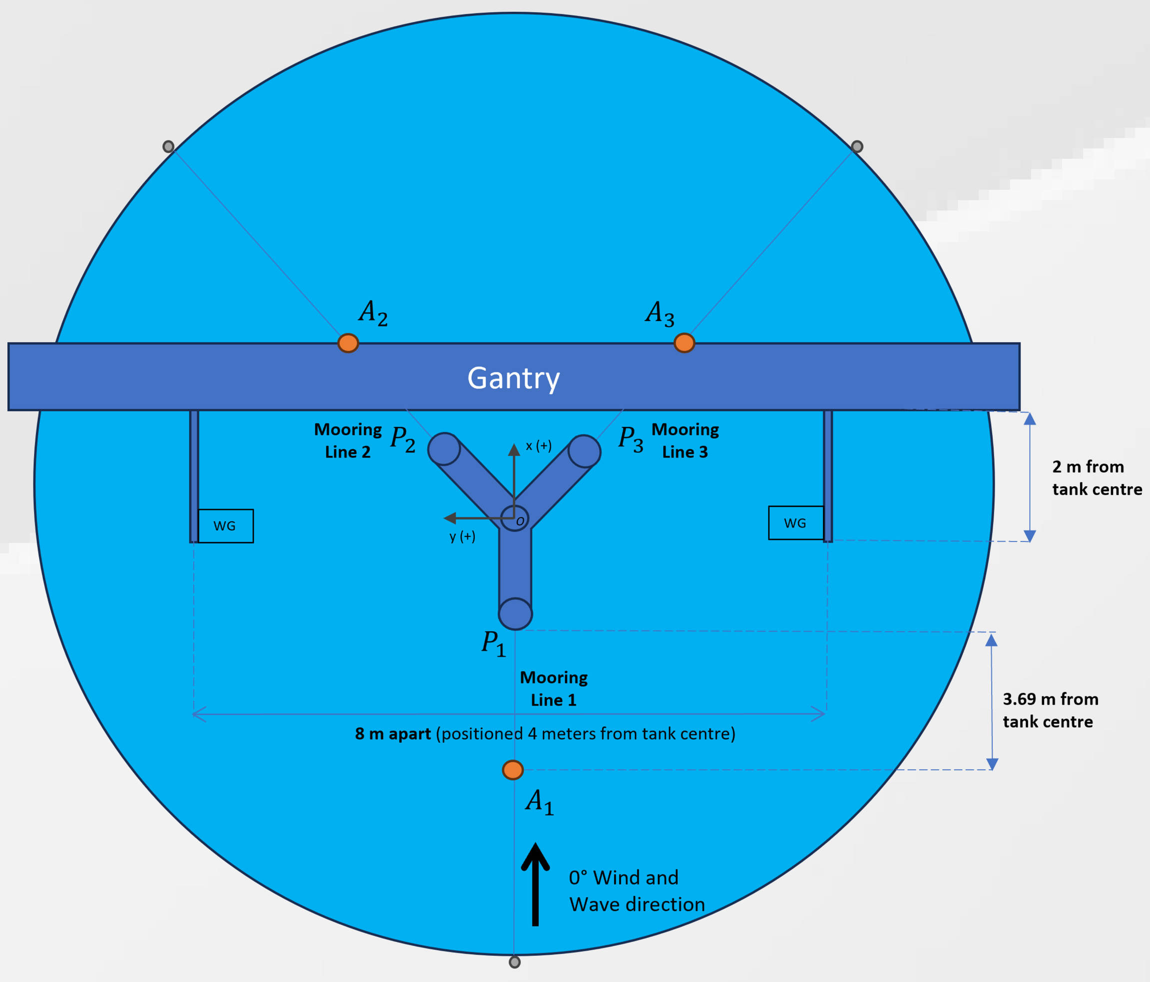

Fig.3: Tank testing layout at FloWave.

- Distinctions emerge when comparing the two methodologies employed for the application of wind thrust. The 'static weight' approach neglects platform responsiveness, whereas the 'PI controlled winch' method measures the force exerted at nacelle height, attempting to sustain a constant value. Nevertheless, this force undergoes variations corresponding to the angular rate of the platform's pitching motion.
- **Table 1** and **2** compare the pitch and surge displacements and the mooring line 1 tension under regular and irregular waves. The mooring line 1 corresponds to the front mooring shown at **Figure 3**. The regular wave parameters are 5 m wave height and period of 14.0 s and for the irregular waves a JONSWAP spectrum $(H_s = 5\,m, T_p = 14.0\,s)$.

Table 1: Comparison of pitch and surge displacement and Mooring line 1 tension results for regular waves test.

Regular Waves						
Test Description	Pitch (deg)		Surge (m)		Line 1 Ten. (kN)	
	mean	std.	mean	std.	mean	std.
No wind - Experimental	-1.36	0.31	0.11	1.03	1063.29	56.10
No wind - OpenFast	-1.49	0.76	0.28	1.17	1161.7	58.99
% Difference	9%	59%	61%	12%	8%	5%
Steady thrust - Experimental 'Static Weight'	6.89	0.55	31.05	1.08	2890.88	51.35
Steady thrust - Experimental 'PI cont. Winch'	6.13	0.47	28.67	1.19	2897.76	271.16
Steady wind - Openfast	4.62	0.16	27.11	1.23	2528.63	62.45
% Difference 'Static Weight' ' - OpenFast	-49%	-244%	-15%	12%	-14%	18%
% Difference 'PI cont. Winch' - OpenFast	-33%	-194%	-6%	3%	-15%	-334%

Table 2: Comparison of pitch and surge displacement and Mooring line 1 tension results for irregular waves test.

Irregular Waves						
Test Description	Pitch (deg)		Surge (m)		Line 1 Ten. (kN)	
	mean	std.	mean	std.	mean	std.
No wind - Experimental	-1.24	0.32	-0.75	0.85	1111.97	46.95
No wind - OpenFast	-1.51	0.53	0.80	0.90	1185.70	44.63
% Difference	18%	40%	6%	6%	6%	-5%
Steady thrust - Experimental 'PI cont. Winch'	6.21	0.4	29.45	0.85	2933.46	269.24
Steady wind - Openfast	4.67	0.24	27.94	0.86	2569.06	43.23
% Difference 'PI cont. Winch' - OpenFast	-33%	-67%	-5%	1%	-14%	-523%

First Outcome

There is a clear difference regarding the pitch motion, for both methods when compared to the OpenFast results. Under irregular waves, the standard deviation value for the 'PI cont. winch' method is significantly higher for the regular waves. The surge displacement results show good approximation between the 'PI controlled winch' method and the OpenFast results. Regarding the mooring line 1 tension, there is a difference of around 15% for the mean value for both methods, however the standard deviation is much higher for the 'PI controlled winch' method.

References

[1] OpenFAST v3.1.0. Accessed June, 2021. Available at https://github.com/openfast/openfast/.

[2] Allen, Christopher, Viscelli, Anthony, Dagher, Habib, Goupee, Andrew, Gaertner, Evan, Abbas, Nikhar, Hall, Matthew, and Barter, Garrett. 2020. "Definition of the UMaine VolturnUS-S Reference Platform Developed for the IEA Wind 15-Megawatt Offshore Reference Wind Turbine". United States. https://doi.org/10.2172/1660012. https://www.osti.gov/servlets/purl/1660012.

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