Tow-out of A Semi-submersible Floating Offshore Wind Turbine

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SINTEF Ocean

Trondheim, 19 January 2024

Source: EDP Renewables

Technology for a better society

Background

- By 2050, floating wind energy grows to 300 GW[1,2]
- 56-fold increase (compared to 2020).
- Around 15000 wind turbines.
- LCOE for floating offshore wind from USD 270/MWh to USD 67/MWh, 75% reduction[3]

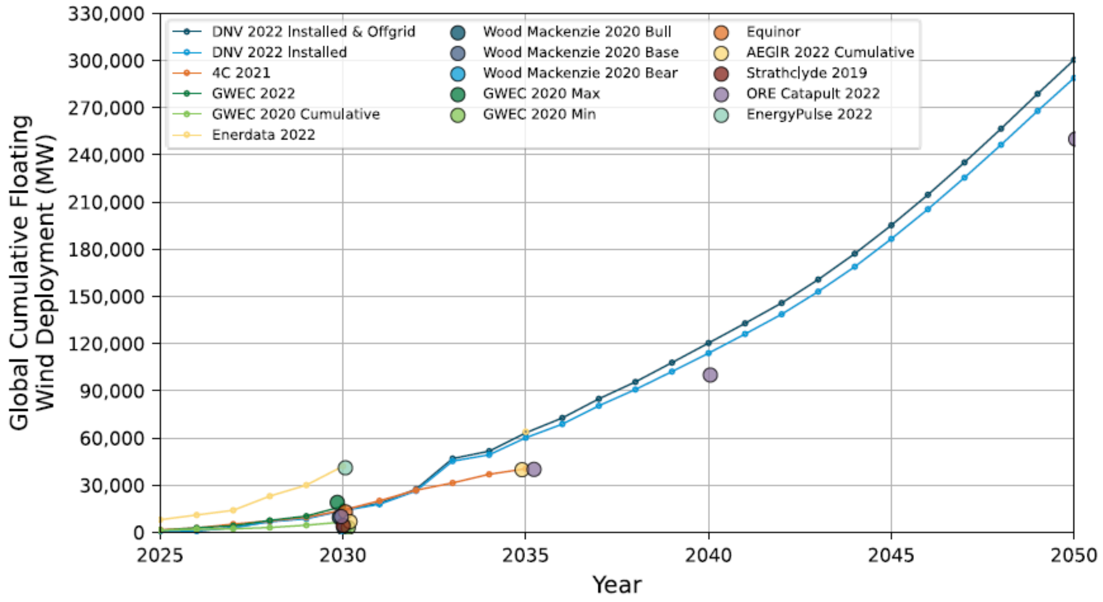


Figure 27. Long-term cumulative floating offshore wind energy deployment projections.

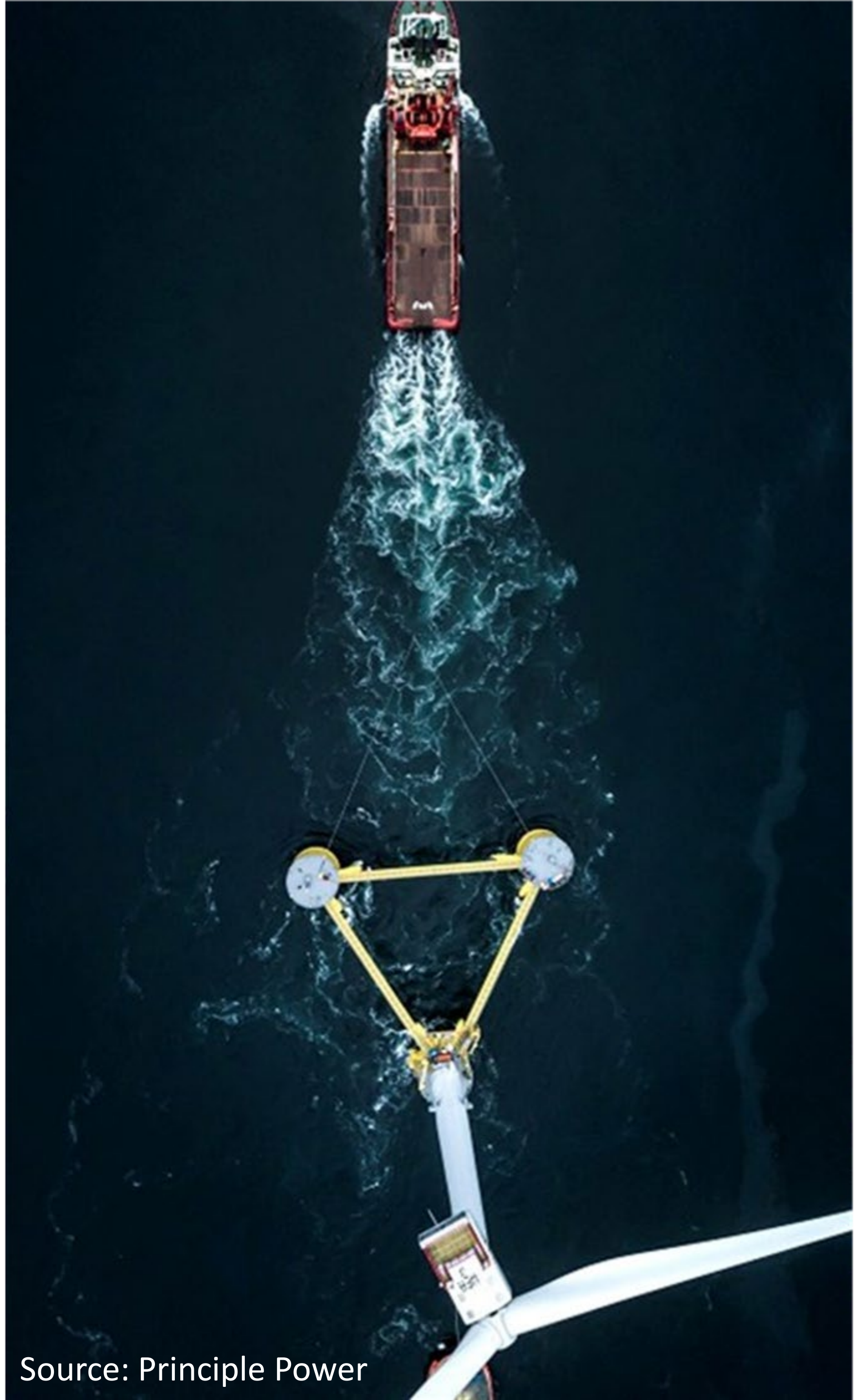
GWEC: Global Wind Energy Council

1) DNV 2022a. *Floating Offshore Wind: The next five years.*
2) DNV 2022b. *Floating Wind: The power to commercialize.*
3) DNV 2023. *Energy Transition Outlook 2023.*
4) US Dep. of Energy, *Offshore Wind Market Report, 2023 Edition*

Motivation

Some facts

- Need to reduce LCOE significantly.
- Large number of towing operations:
  - A 1 GW floating wind farm estimated to have a minimum of 7 tow-back per year (Brown, J., 2022. Solving the tow-back challenge in floating wind).
- Towing speed is very low (~ 2-3 kn).
- Towing under mild sea-states only (limiting Hs ~ 1.0 - 2.5 m).
- Limited number of port infrastructures fitted for the purpose (probably implying weather unrestricted operations).



Source: Principle Power

Potential & solutions

- Potential to reduce the cost / improve the efficiency of transportation to site location.
- Potential to reduce the cost of heave maintenance operations requiring tow-back.

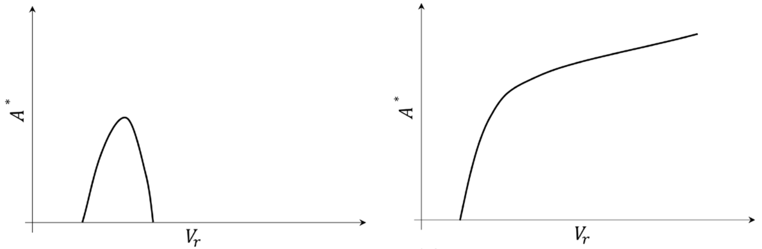
By:

- Increasing the towing speed.
- Expanding the operational criteria / weather windows.

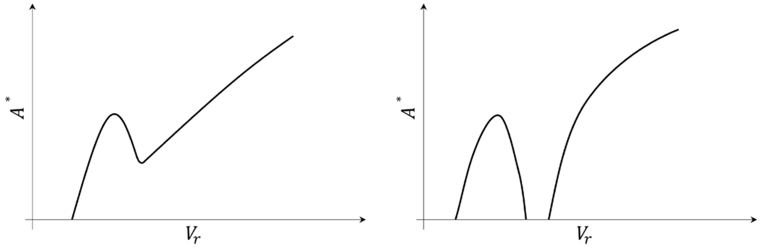
FIM of semi-submersible FOWT

Vortex-induced motion

- Self-limited dynamic response
- Vortex shedding force
- Multi-DOF rigid-body motion



(a) Vortex resonance (b) Galloping



(c) Combined vortex resonance and galloping (d) Separated vortex resonance and galloping

Galloping

- Dynamic instability
- Low frequency
- Non-circular cross-sections

- Wake interference
- End effects
- Shielding effects
- Surface effects

Figure 12 Maximum Y-Response for 0 deg tow direction

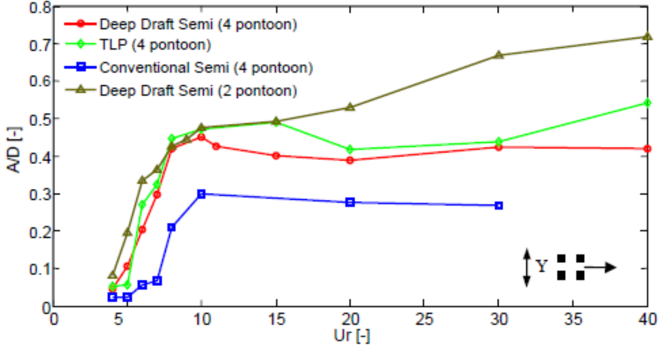
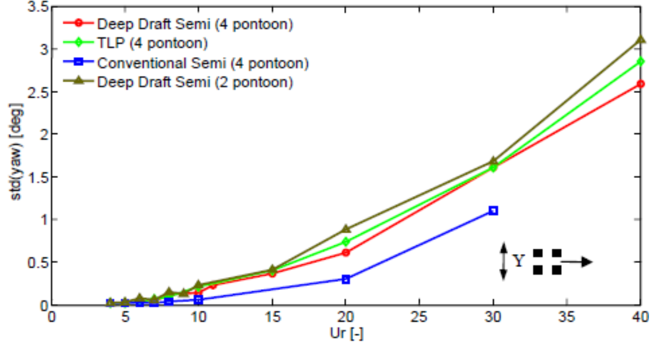
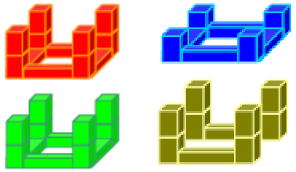


Figure 13 Nominal Yaw-Response for 0 deg tow direction



Waals et al. (2007) OMAE2007-29539



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INO WINDMOOR FOWT

Scale 1:40

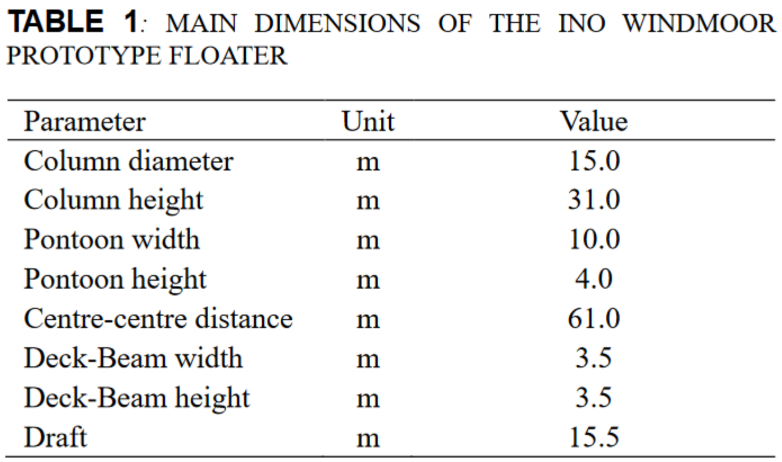


TABLE 1: MAIN DIMENSIONS OF THE INO WINDMOOR PROTOTYPE FLOATER

Parameter	Unit	Value
Column diameter	m	15.0
Column height	m	31.0
Pontoon width	m	10.0
Pontoon height	m	4.0
Centre-centre distance	m	61.0
Deck-Beam width	m	3.5
Deck-Beam height	m	3.5
Draft	m	15.5

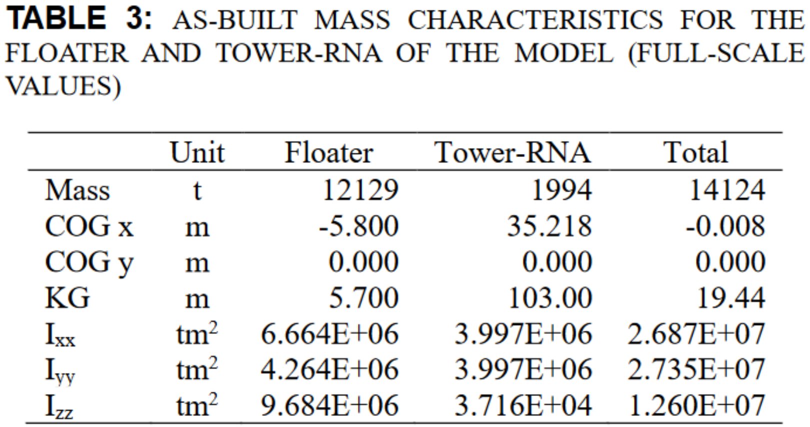
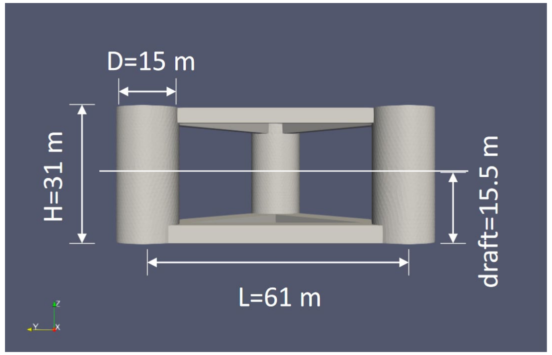
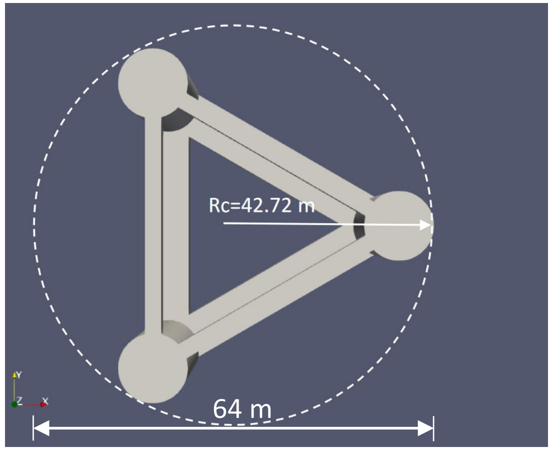


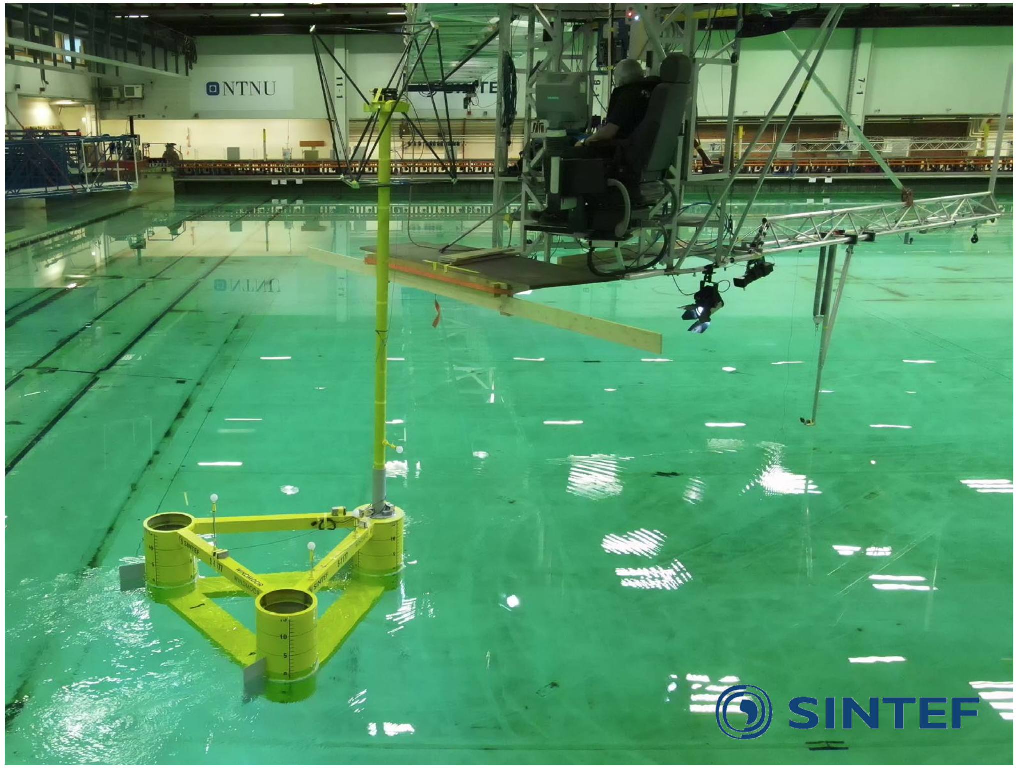
TABLE 3: AS-BUILT MASS CHARACTERISTICS FOR THE FLOATER AND TOWER-RNA OF THE MODEL (FULL-SCALE VALUES)

	Unit	Floater	Tower-RNA	Total
Mass	t	12129	1994	14124
COG x	m	-5.800	35.218	-0.008
COG y	m	0.000	0.000	0.000
KG	m	5.700	103.00	19.44
I_{xx}	tm^2	6.664E+06	3.997E+06	2.687E+07
I_{yy}	tm^2	4.264E+06	3.997E+06	2.735E+07
I_{zz}	tm^2	9.684E+06	3.716E+04	1.260E+07

Thys et al. (2021) OMAE2021-62980

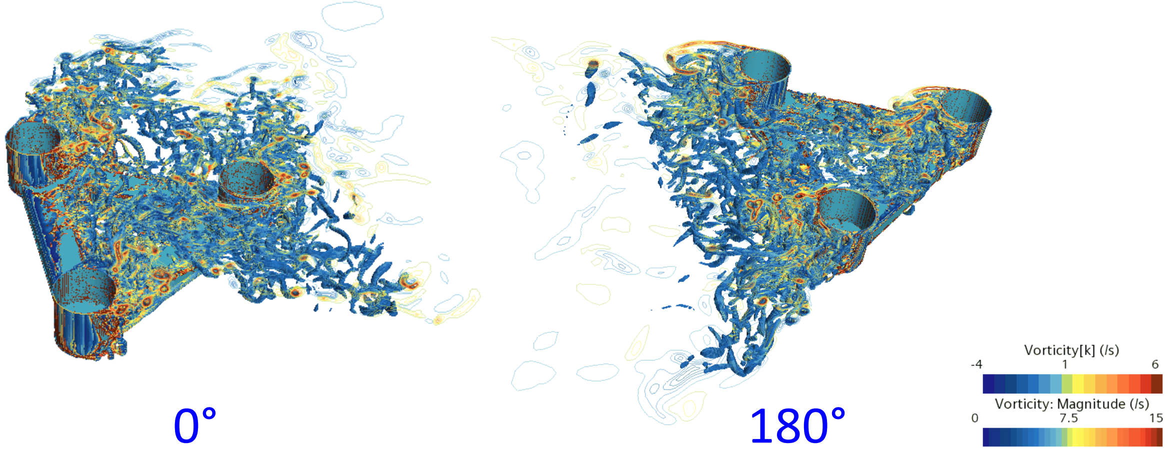


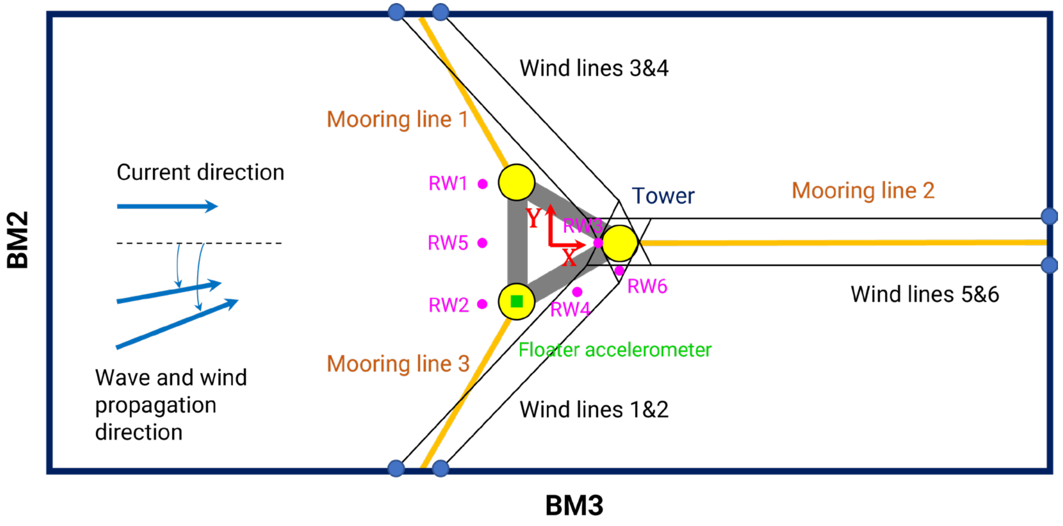




INO WINDMOOR VIM CFD study

- Simplified horizontal mooring system
- Delayed Detached Eddy Simulation (DDES)
- $V_R = UT_n/D = 8$





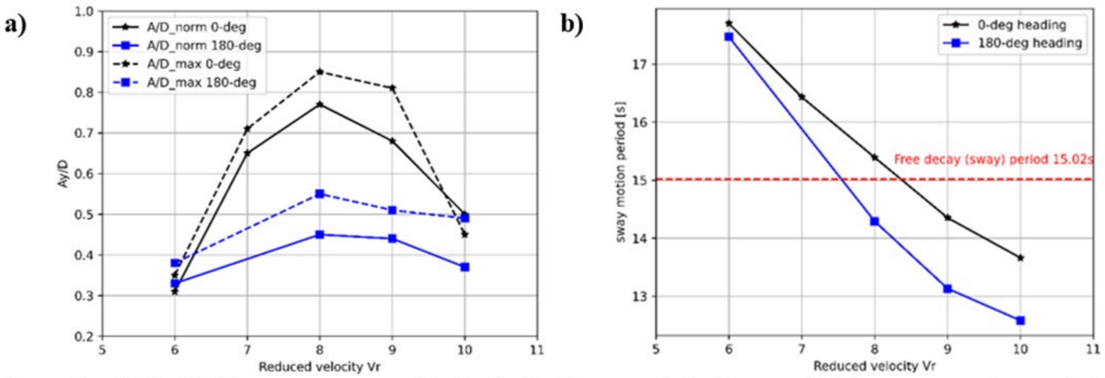
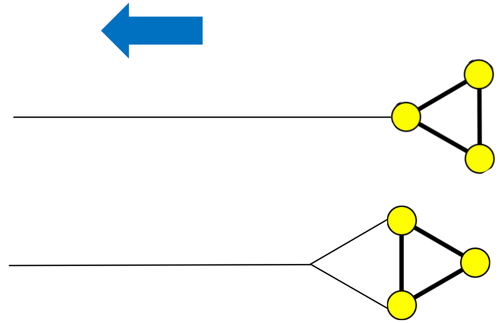


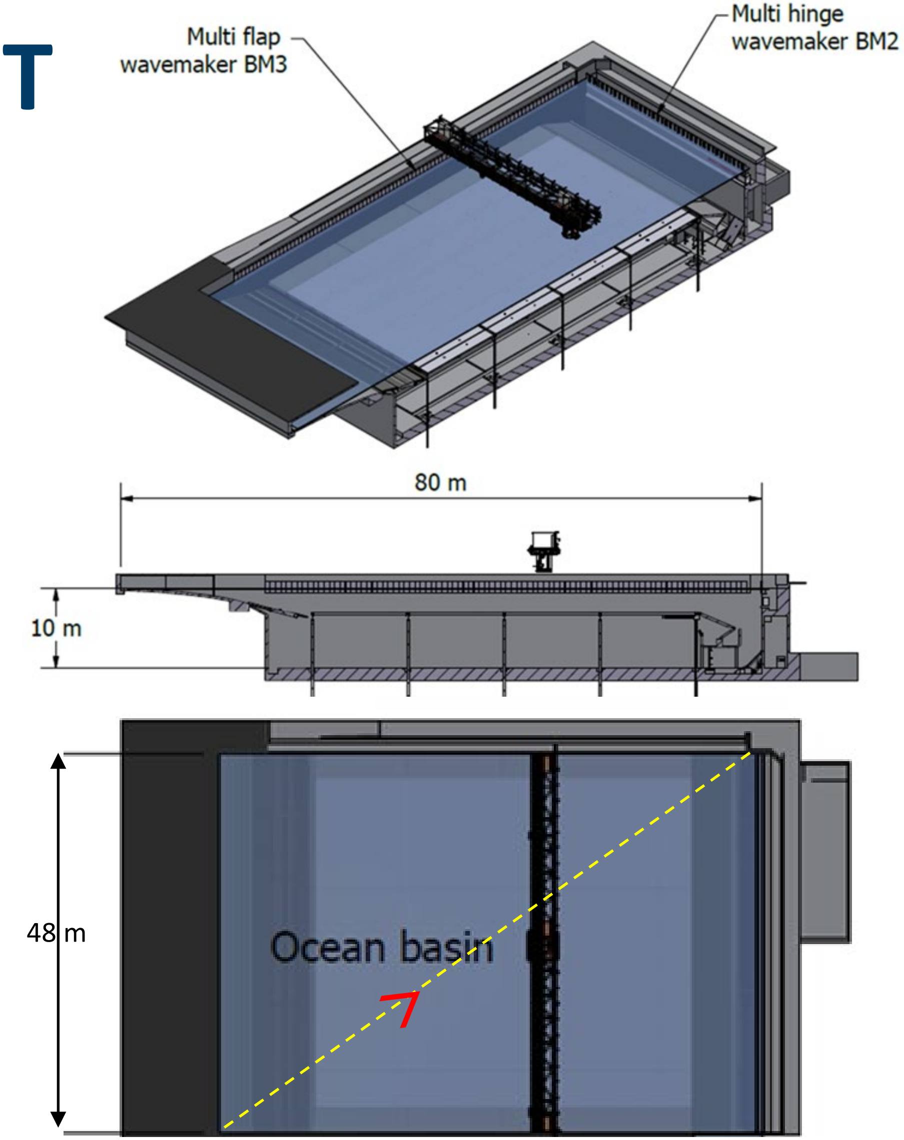
Figure 7. a) The VIM curves measured by both A_y/D_{max} and A_y/D_{norm}; b) The sway motion period. Results from 0° and 180° current headings are plotted together in each sub-plot for direct comparisons.

❑ Jiang, F.; Yin, D.; Califano, A. & Berthelsen, P. A. Application of CFD on VIM of semi-submersible FOWT: A Case Study IOP The Journal of Physics, EERA DeepWind 2023, vol 2626, no. 012041, 2023

Towing of WINDMOOR FOWT

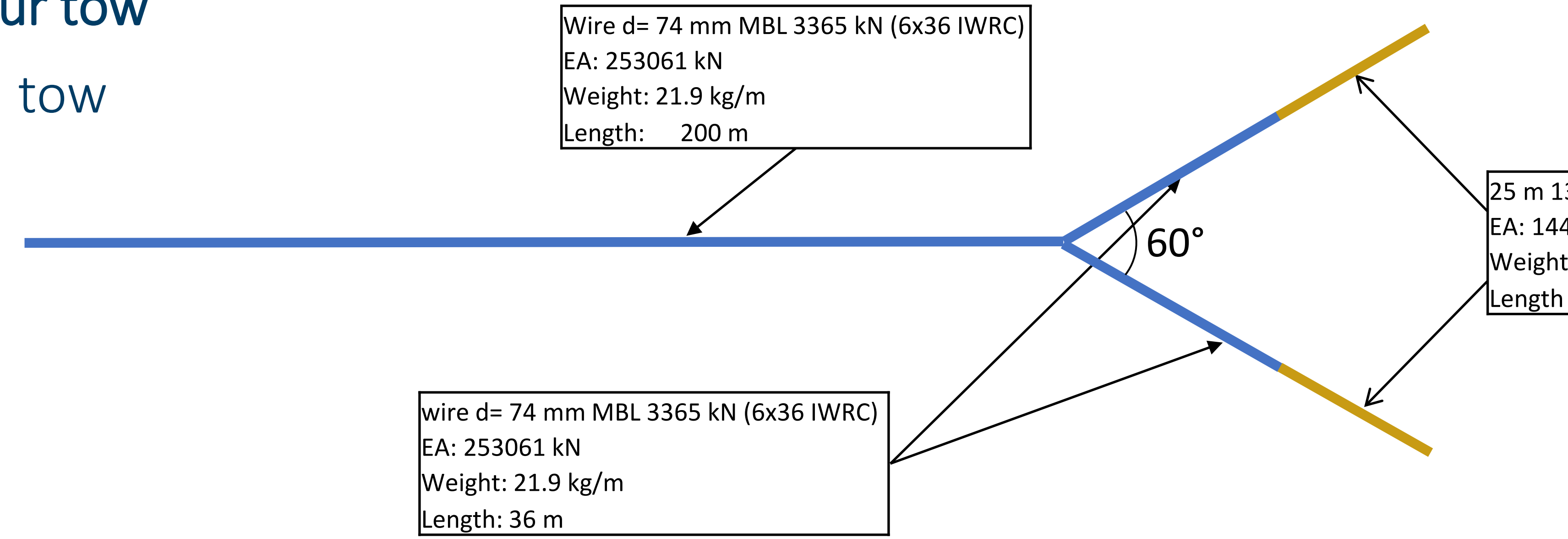
- Towing test
- Ocean Basin
- Two configurations
- VIM mitigation devices





Towline and bridles (FS)

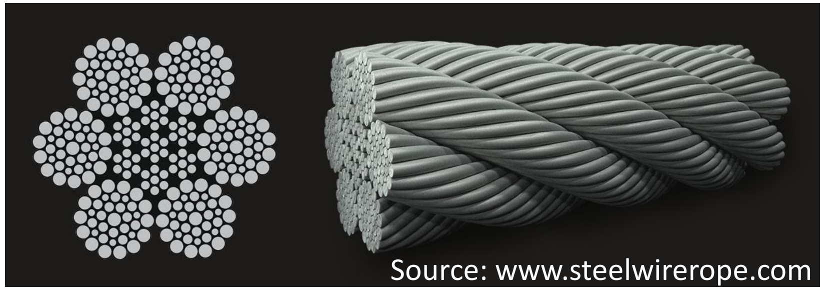
- Harbour tow
- Ocean tow



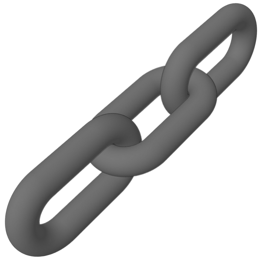
Wire d= 74 mm MBL 3365 kN (6x36 IWRC)
EA: 253061 kN
Weight: 21.9 kg/m
Length: 200 m

25 m 130 mm studless chain
EA: 1443260 kN
Weight: 377.7 kg/m
Length 25m

wire d= 74 mm MBL 3365 kN (6x36 IWRC)
EA: 253061 kN
Weight: 21.9 kg/m
Length: 36 m



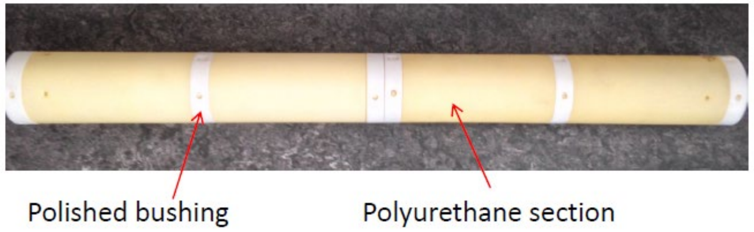
Source: www.steelwirerope.com

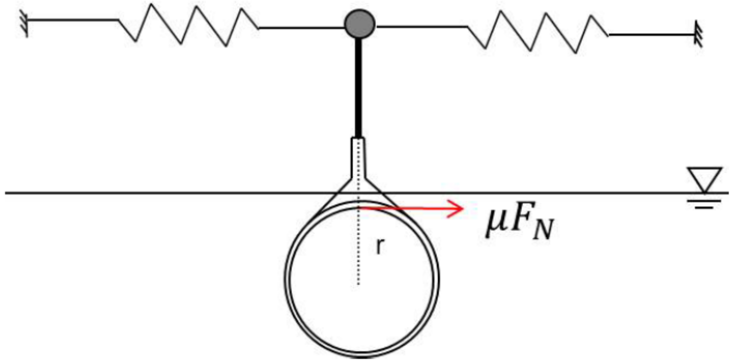


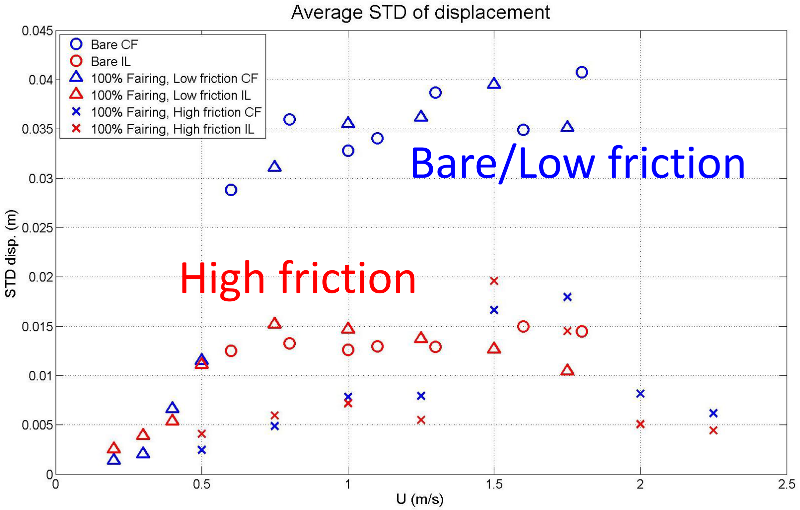
Source: www.damenmc.com

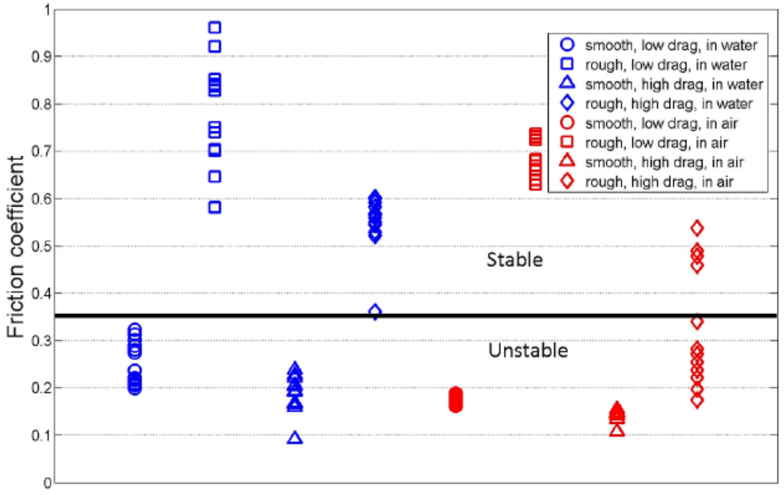
VIM Mitigation – from O&G to Renewable energy

Riser model (pipe3) covered with fairing models

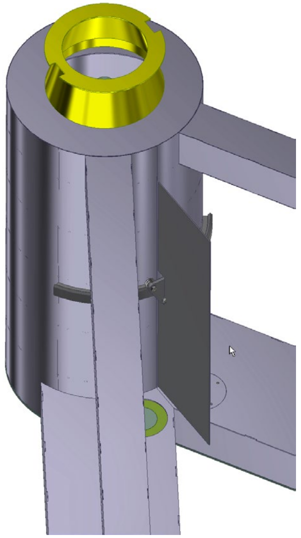








❑ OMAE2014-24591



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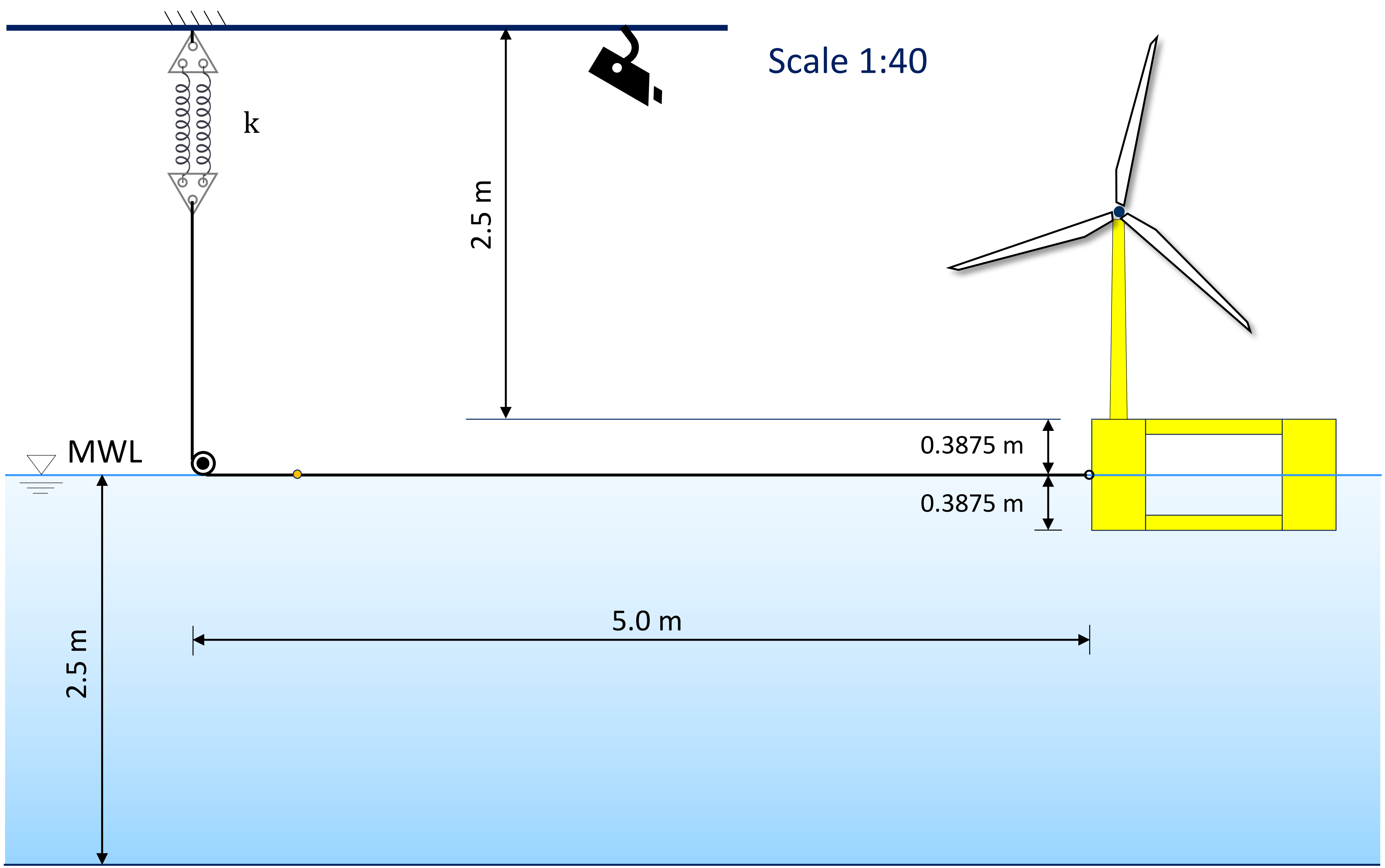
Measurements:

- 6 DOF motions
- Towing force
- Towing speed
- Photo & video



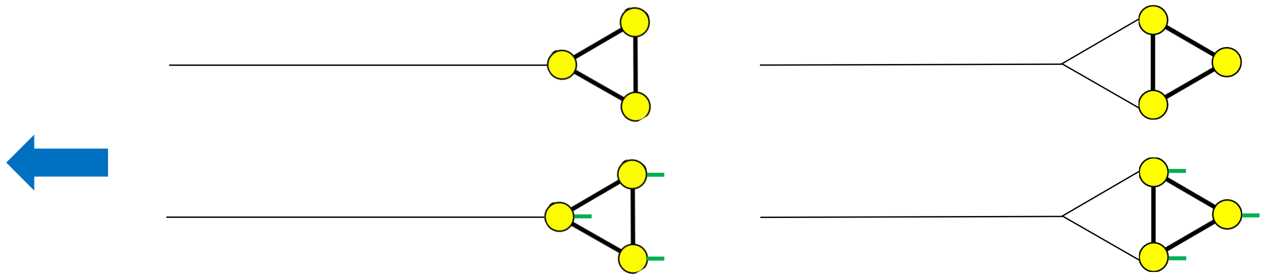
NORTH WIND

Overview video of tow-out tests of FOWT

Test program

- Decay test
  - Roll
  - Pitch
  - Heave
- Pull-out test
  - Surge
- Calm water towing test

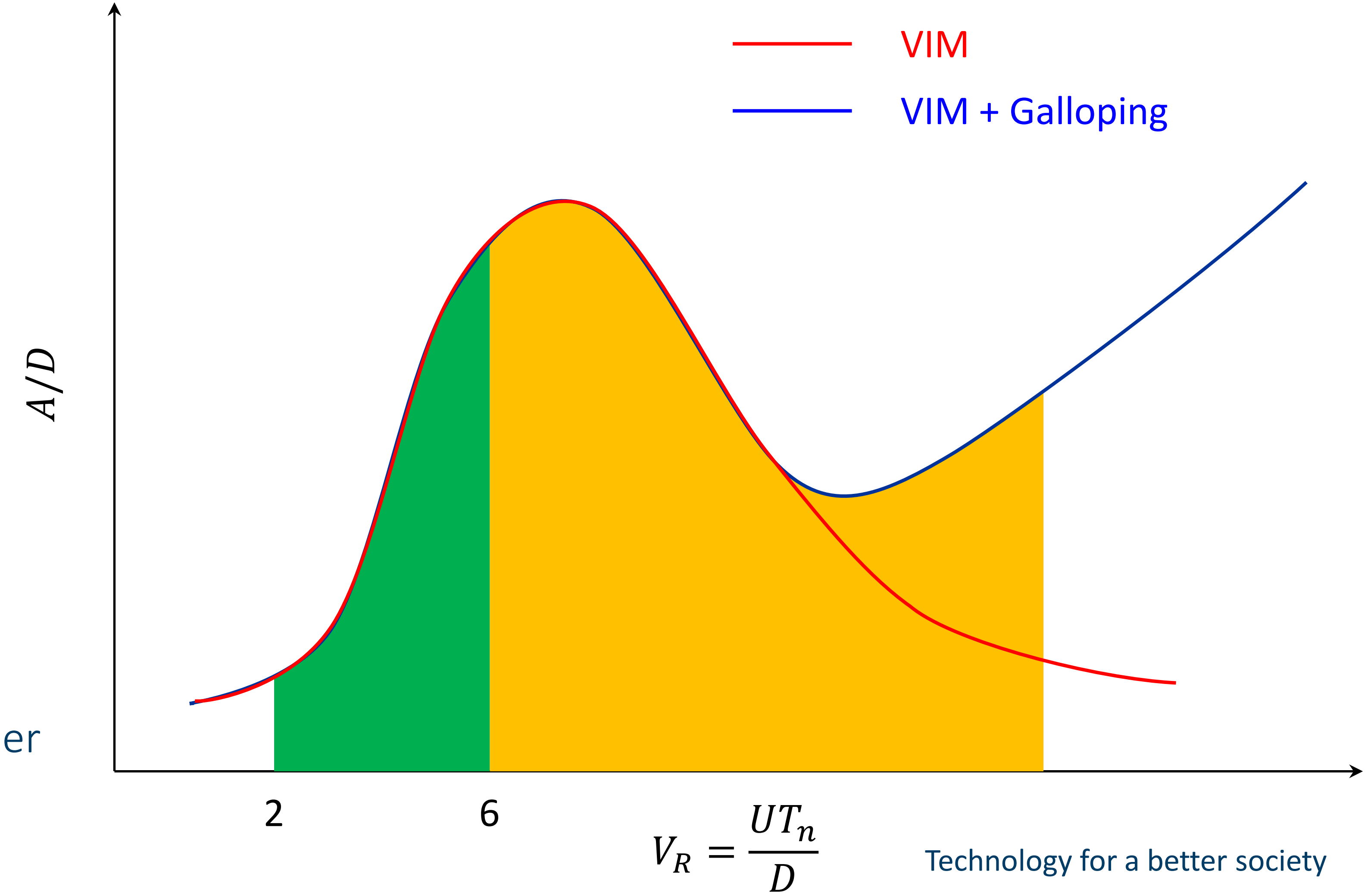
Test series	Description	U_{FS} (m/s)
1xxx	Decay test and pull-out test	-
2xxx	Single tow line	0.9 - 3.0
4xxx	Single tow line + splitters	0.9 - 3.0
3xxx	Single tow line with bridles	0.9 - 3.0
5xxx	Single tow line with bridles + splitters	0.9 - 3.0



Decay test results

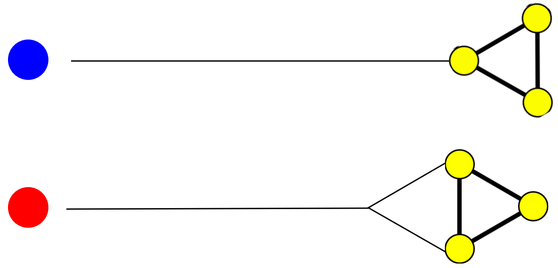
DOF	$T_{p,FS}$ (s)	$T_{p,MS}$ (s)
Surge	31.6	5.0
Sway		
Heave	31.6	5.0
Roll	30.3	4.8
Pitch	31.3	4.95
Yaw		

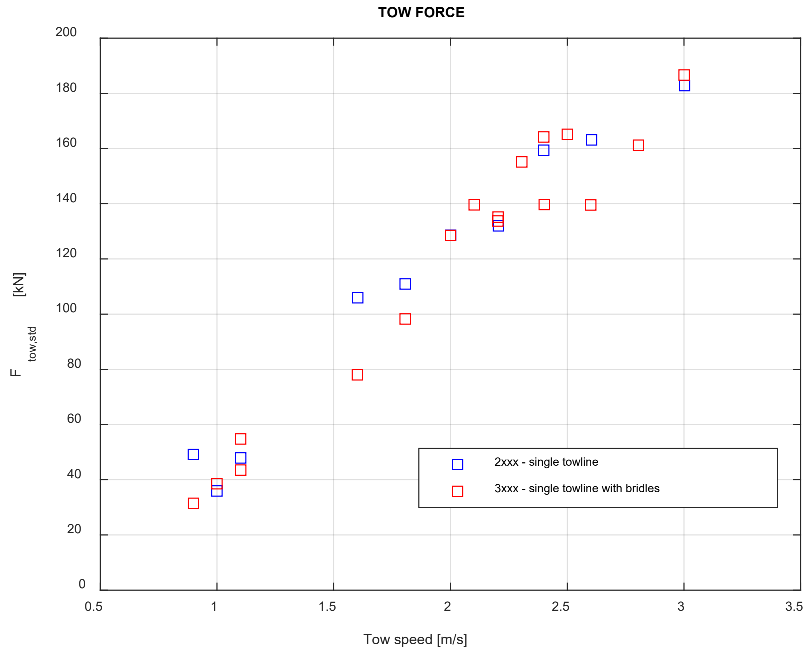
- Eigen periods of sway and yaw depend on the towing speed, significantly higher than the other DOFs

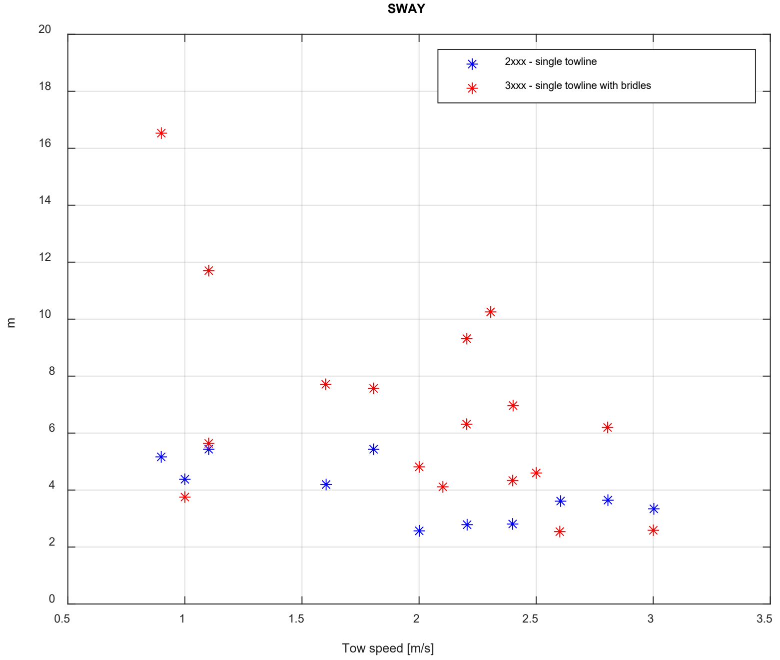


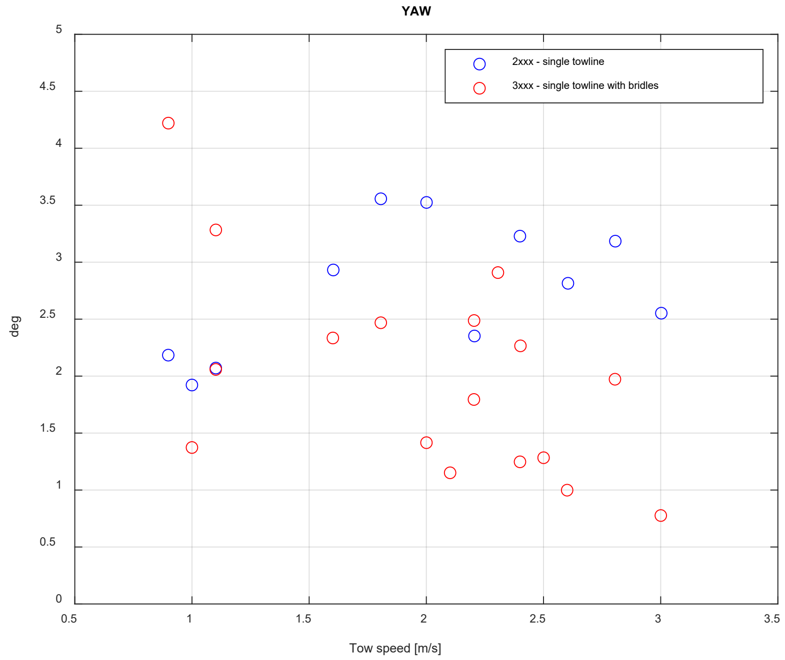
Preliminary results

- Standard deviations
- Tow force increases with tow speed
- Single tow line
  - Sway motion is relatively small
  - Yaw motion not sensitive to the tested tow speeds
- With bridles
  - sway motions larger than single tow line
  - Yaw motion decreases with tow speed




TOW FORCE


SWAY


YAW

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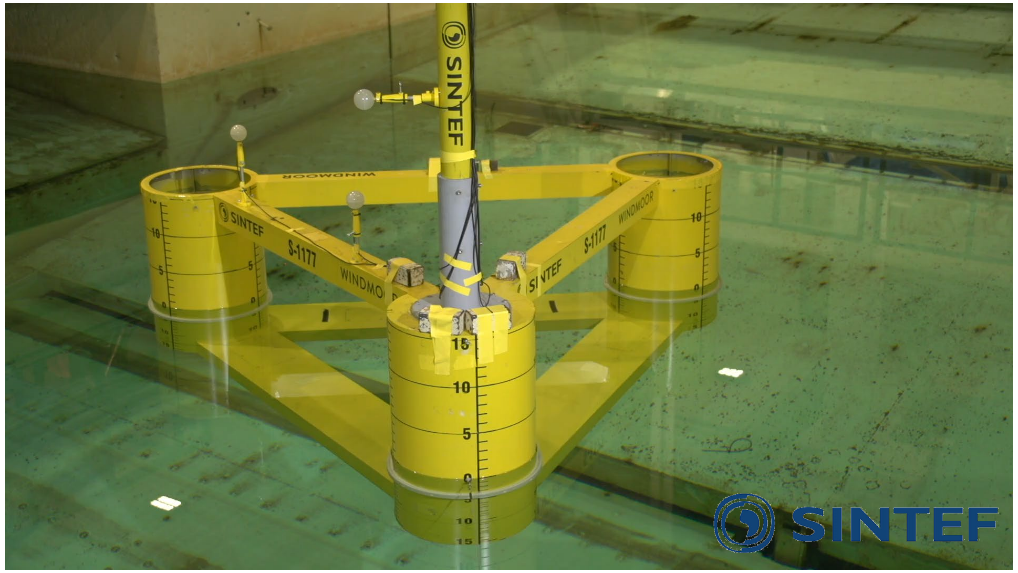
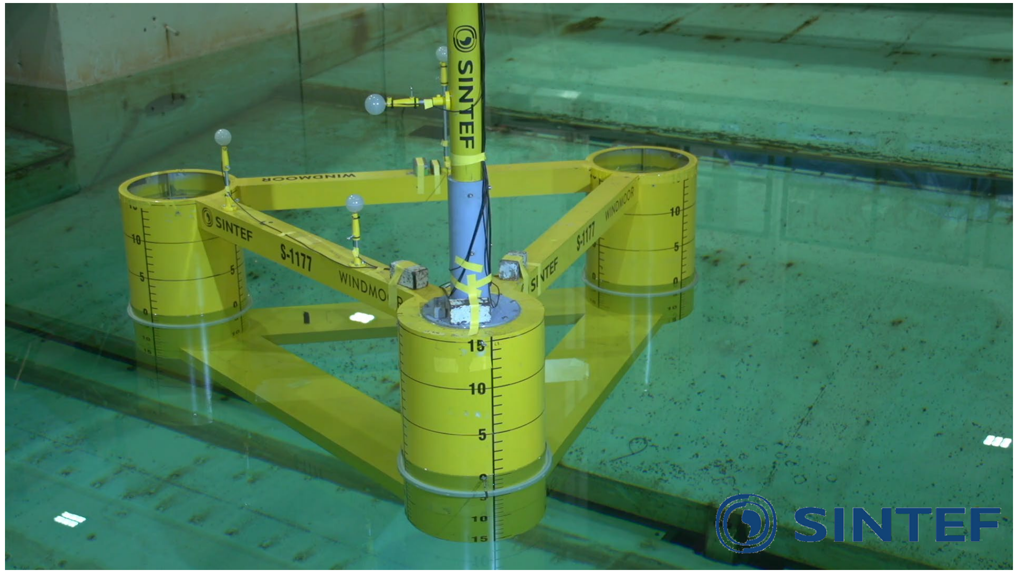
U=3.0 m/s

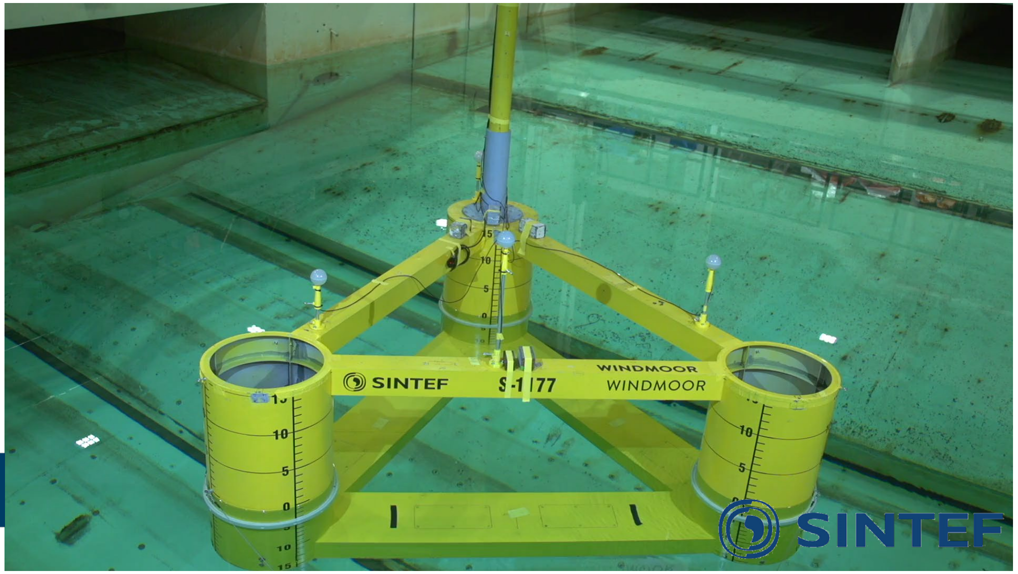
Single tow line



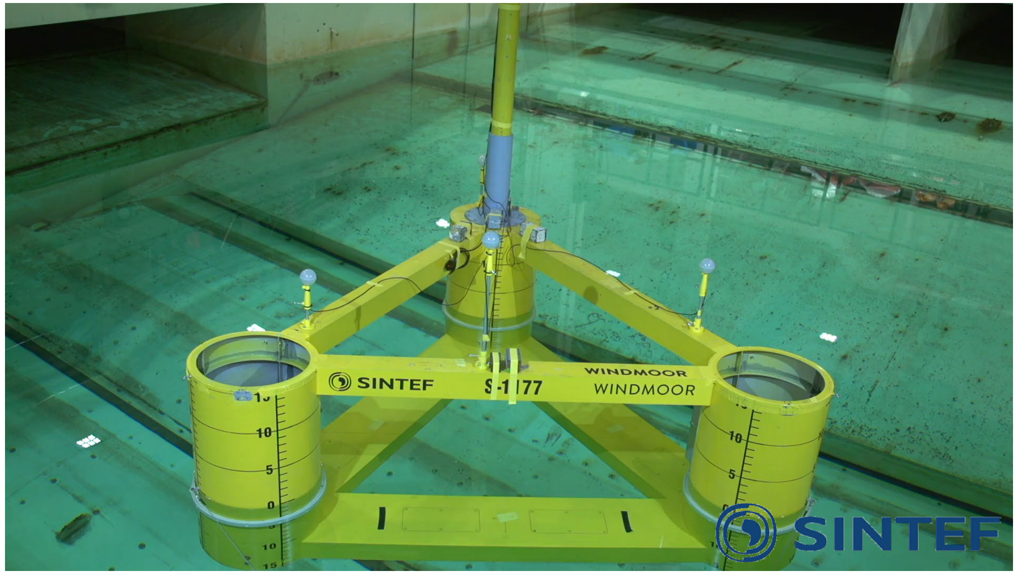
Single tow line + splitters



Single tow line with bridles



Single tow line with bridles + splitters



NORTH WIND

Concluding remarks

- During tow-out, stability and resistance of FOWT are of concern, cost-effective operation is desired.
- FIM – VIM and galloping is an interesting, but complex FSI problem that can cause severe issues/limits during installation, transportation and operation of FOWT.
- Free-to-rotate splitter could be a solution to reduce FIM.
- The industry requires a practical design practice/standard accounting for FIM.
- SINTEF Ocean has various tools, facilities and competences (VIVANA-TD, Towing tanks, Ocean basin, CFD) to study FIM.
- Towing tests with waves in a long towing tank are desired.

SINTEF

TOWIN JIP

TOWIN JIP – FOWT towing resistance and dynamics

Objective

The objective of the TOWIN JIP is to improve the efficiency of the towing operation of floating offshore wind turbines (FOWT) by safely increasing the towing speed and expanding the operational window. Detailed objectives include:

a. Test and validate methods for accurate prediction of towing resistance in calm water and in waves.

b. Improve insight into the physics of VIM, possible galloping and tow stability in calm water, in current and in waves. Propose semi-empirical calculation methods.

c. Test and validate methods for simulation of the towing operation and prediction of related dynamic motions and towing line loads.

d. Use the tools of a., b. and c. to investigate optimum tow arrangements and mitigation solutions.

The focus in on semi-submersible and spar type of substructures.

Background

While the market for offshore floating wind turbines is expected to increase exponentially in the next decade and further on, one challenge to be addressed is the reduction of LCOE to a competitive value. Part of the costs are related to towing of the FOWTs from the manufacturing site to the wind park. Even more significant in terms of cost will be maintenance activities involving replacement of large components, which also require towing to port. Due to limited number of port infrastructures fitted for the purpose, the travelling distance may be quite long for many projects implying operations classified as weather unrestricted (> 72 hours). Altogether, a significant number of towing operations will be needed to install and operate FOWT parks.

The existing procedures and technologies for towing of offshore structures have been developed within the oil and gas sector. While this experience will certainly be transferred to the new offshore wind industry, there are important differences which need to be addressed, namely: the different geometry and mass characteristics of the new structures, the much larger number of structures and required operations and the related economy fundamentals. One expects a stronger need for improved efficiency while keeping the safety of the towing operation. This requires an increased insight into the physics of the problem, validated numerical procedures for design and planning and technical solutions to improve performance.

There are several challenges related to the planning and execution of the tow operation. While these are in fact partly related, or coupled, the challenges can be listed as:

- Estimation of the extreme mooring line tensions, due to uncertainties in prediction of towing resistance and dynamic effects.
- Possibility of flow induced motions (FIM), namely vortex induced motions (VIM) and Galloping (e.g. yaw instabilities).
- Possibility of complex coupled motions trigged by FIM and/or instabilities.
- Limited weather windows complying operational criteria.

Figure 1 Tow-out of WindFloat Atlantic FWT. Source: EDP Renewables [1].

Methods and scope of work

The project objectives will be achieved by combining the existing best knowledge, model testing, field data and numerical modelling.

WP1: Prediction of towing resistance

Towing resistance has two main components which can be estimated independently: calm water resistance and added resistance in waves. FIM may also add to the drag loads. A semi-empirical model will be proposed for the first, based on the cross flow and strip method approach. Added resistance in waves is a 2nd order load with a mean and a slowly varying component. The second is important for the dynamic responses of the tow line [2]. The loads will be based on full QTFs of wave drift forces, with a semi-empirical method for small forward speed effects tested recently in another JIP [3].

WP2: Time domain FIM solver

This WP will establish design method(s) for prediction of VIM and galloping for floating platforms by use of semi-empirical methods. The VIM model will be based on the VIVANA-TD load model [4]-[6], which includes vortex induced force terms. While the model has been validated for VIV responses, the project will generalize it for VIM.

TOWIN JIP – FOWT towing resistance and dynamics

Some initial studies for a spar platform show promising results [7]. A galloping model based on direction-dependent current coefficients and instantaneous relative velocities will be tested.

WP3: Model tests and field data

Model tests with a generic FWT in a wave basin is the main scope of this WP. The purpose is to (a) identify the resistance in calm water and added resistance in waves and (b) the dynamic responses during towing in calm water and in waves, including conditions with FIMs.
Field data is of great value for validation of numerical methods and will be used if made available by some of the Participants.

WP4: Towing studies and recommendations

This WP starts with calibration and validation of the numerical models of WP1 and WP2 based on model tests and field data. The related force models will also be integrated into a simulator of the towing operation (SIMO will be used for demonstration purposes).

Second, the numerical procedures will be demonstrated with a representative case study to investigate optimum tow arrangements and mitigation solutions for excessive dynamic responses.

Finally, the project results will be summarized into a set of recommendations for numerical modelling of the tow operation.

Project Deliverables

The project will have the following deliverables:

- Report with state of the art
- Model tests report
- Report with methods/tools for prediction of: towing resistance, FIM, towing stability and towing line loads.
- Report with optimum tow arrangements for representative scenarios.
- Recommended practice for simulation of the tow operation.

Organization

TOWIN is a Joint Industry Project executed by SINTEF Ocean. A project Steering Committee will be established comprising one member from each Partner and with meeting twice a year.

The TOWIN JIP aims at the following participants:

- Energy companies
- Offshore contractors
- Designers of floating wind turbines
- Wind-park developers
- Classification Societies and regulatory authorities.

The project will tentatively start during Q1 of 2024 and have a duration of 2 years.

Participation fee

- Energy companies: 60 kEUR per year.
- Other: 20 kEUR per year.

Total of two payments corresponding to two years. The tentative total budget is 500 kEUR.

References

[1] EDP Renewables, 'WindFloat Atlantic begins the installation of the first floating wind farm. https://www.edpr.com/en/news/windfloat-atlantic-begins-installation-first-floating-wind-farm (accessed Oct. 24, 2023).

[2] Brun-Lie, Thekla, 2021. Numerical simulations of offshore towing of floating wind turbines. MSc thesis, NTNU.

[3] SINTEF Ocean, 2021. Assessment of the EXWAVE 2 methods to predict low frequency motions of FPSOs. Report no. OC2021 F-068.

[4] M. J. Thorsen, 'Time Domain Analysis of Vortex-Induced Vibrations', PhD Thesis, Norwegian University of Science and Technology, Trondheim, Norway, 2016.

[5] J. V. Ulveseter, 'Advances in semi-empirical time domain modelling of vortex-induced vibrations', PhD Thesis, Norwegian University of Science and Technology, 2018.

[6] S. Kim, 'Non-Linear Time Domain Analysis of Deepwater Riser Vortex-Induced Vibrations', PhD Thesis, Norwegian University of Science and Technology, Trondheim, Norway, 2021.

[7] E. Passano, G. Grytøyr, H. Haslum, H. Lie, and D. Yin, 'Simulation of VIM of an offshore floating wind turbine', in *Proceedings of the ASME 2022 41st International Conference on Ocean, Offshore and Arctic Engineering*, Hamburg, Germany, 2022, no. OMAE2022-79006.

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