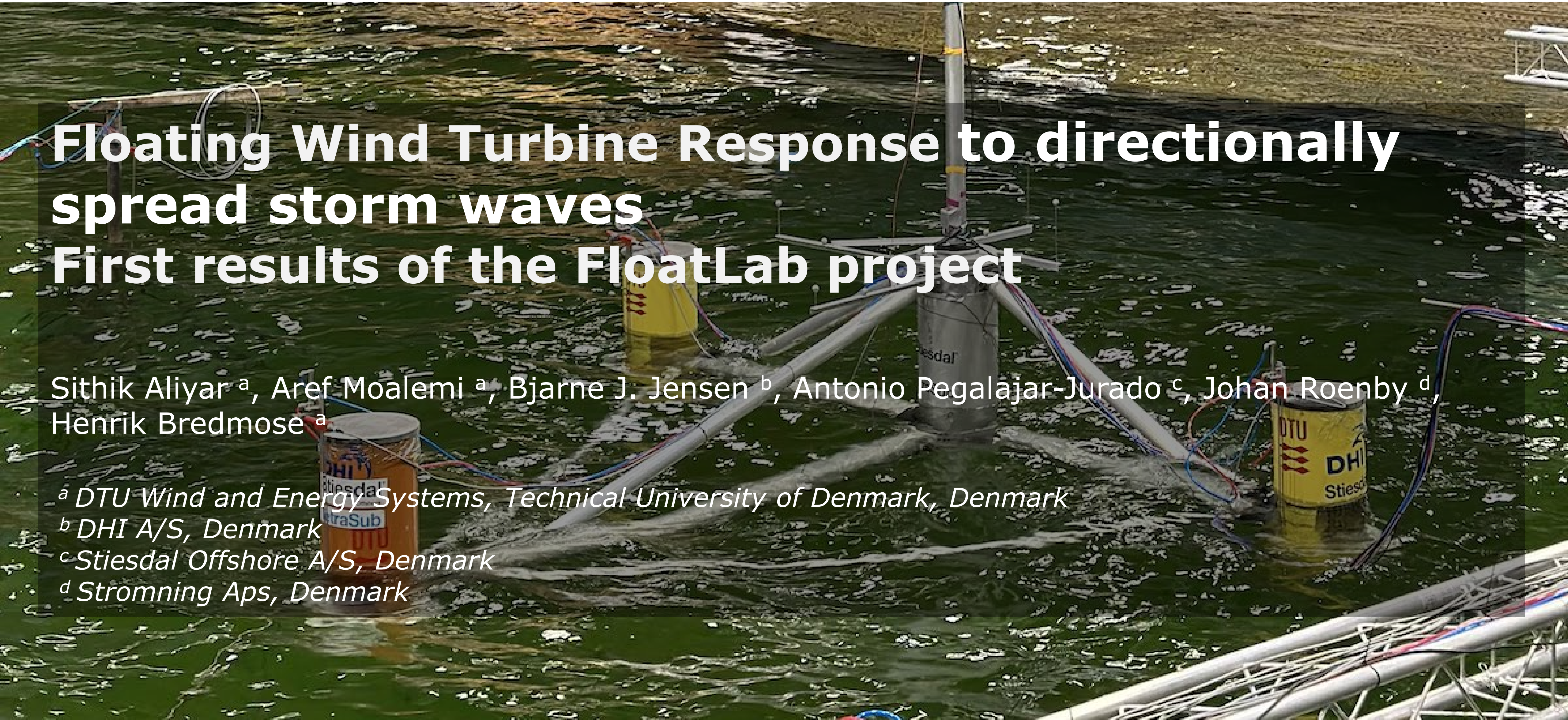

Floating Wind Turbine Response to directionally spread storm waves
First results of the FloatLab project

Sithik Aliyar [a], Aref Moalemi [a], Bjarne J. Jensen [b], Antonio Pegalajar-Jurado [c], Johan Roenby [d], Henrik Bredmose [a]

[a] *DTU Wind and Energy Systems, Technical University of Denmark, Denmark*
[b] *DHI A/S, Denmark*
[c] *Stiesdal Offshore A/S, Denmark*
[d] *Stromning Aps, Denmark*

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FloatLab (2023-2027)
20 MW Floating Wind Innovation

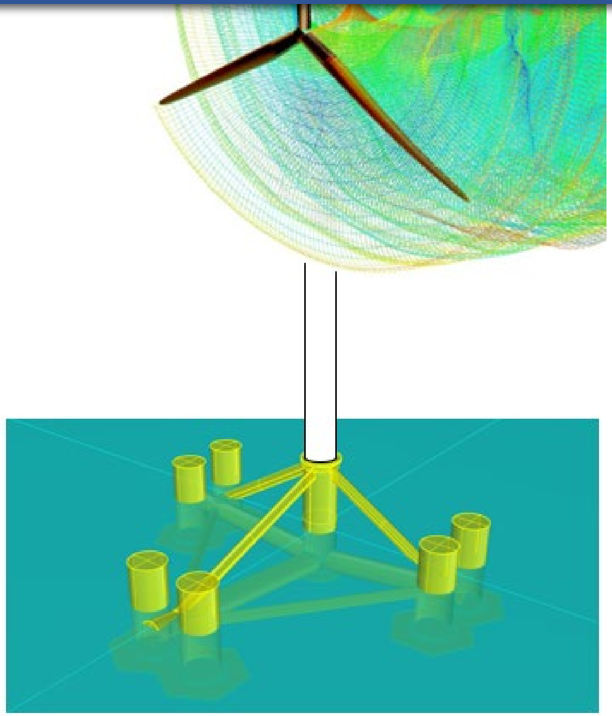

Photo credit: Stiesdal Offshore

DTU

DHI

SIEMENS Gamesa RENEWABLE ENERGY

Stiesdal Offshore

Ørsted

STROMNING

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FloatLab (2023-2027)

- **Digital twin physics for 20 MW turbines**
- **Improved design and less materials**
- **Four test campaigns planned**

Ørsted

SIEMENS Gamesa RENEWABLE ENERGY

Stiesdal Offshore

DHI

STROMNING

DTU

FloatLab

The 6 Key Innovations of FloatLab

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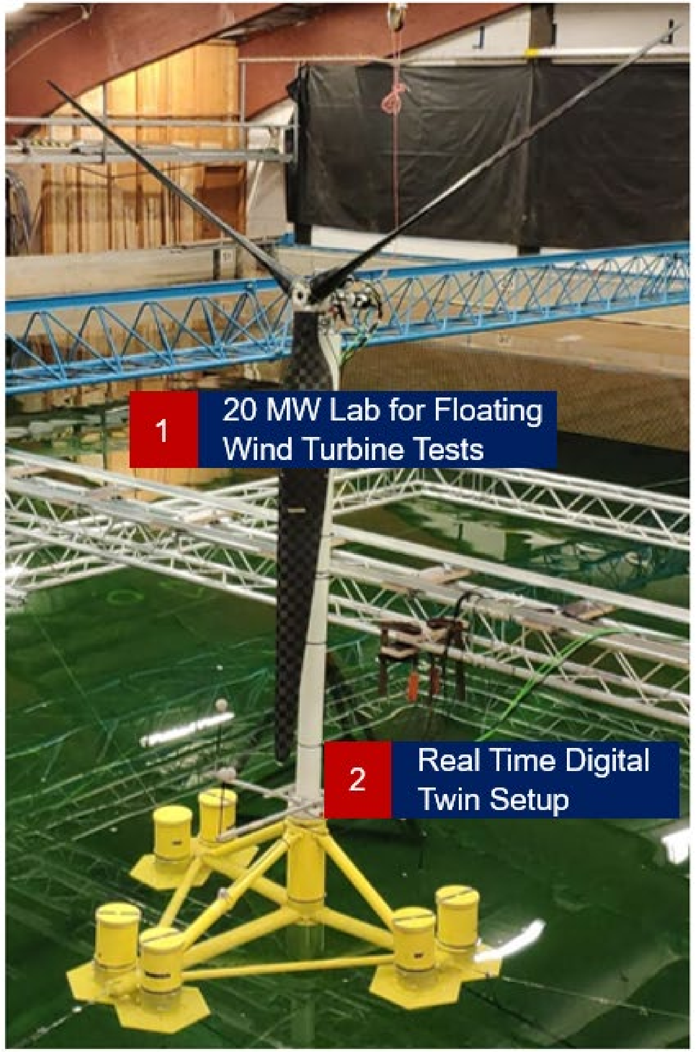

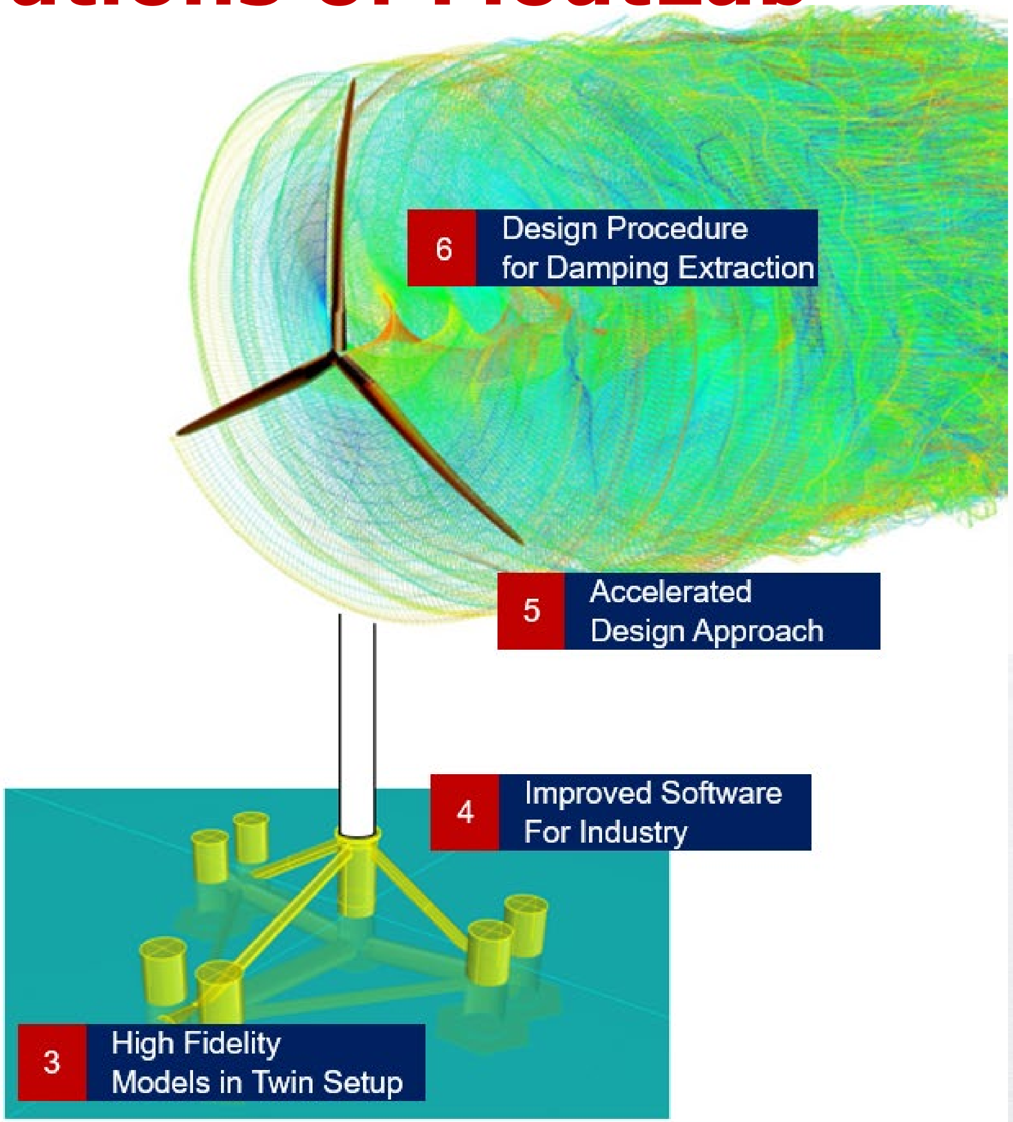

MIKE Powered by DHI

HAWC2

BHAWC

OpenFOAM®

DHI Stiesdal Offshore STROMNING

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Floating Wind Turbine Response to directionally spread storm waves
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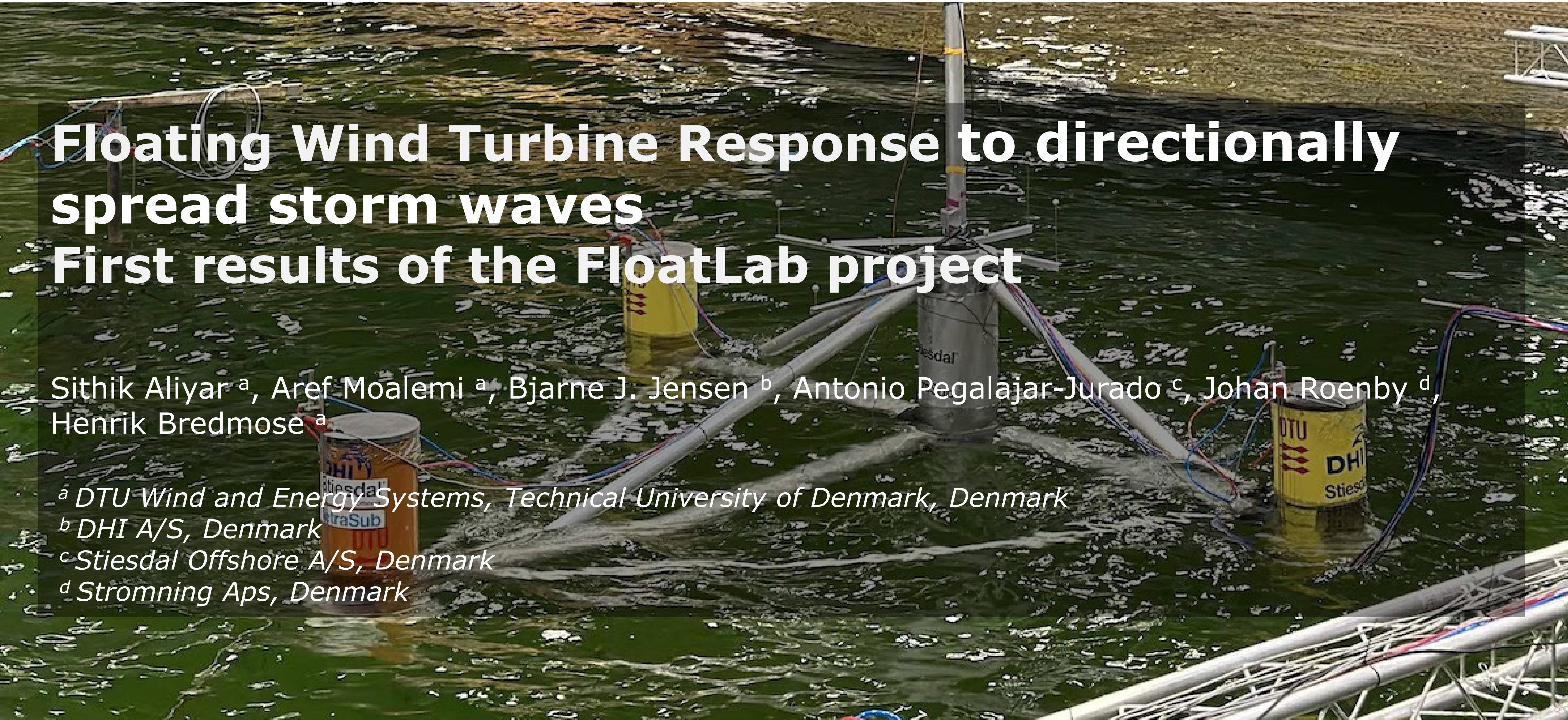

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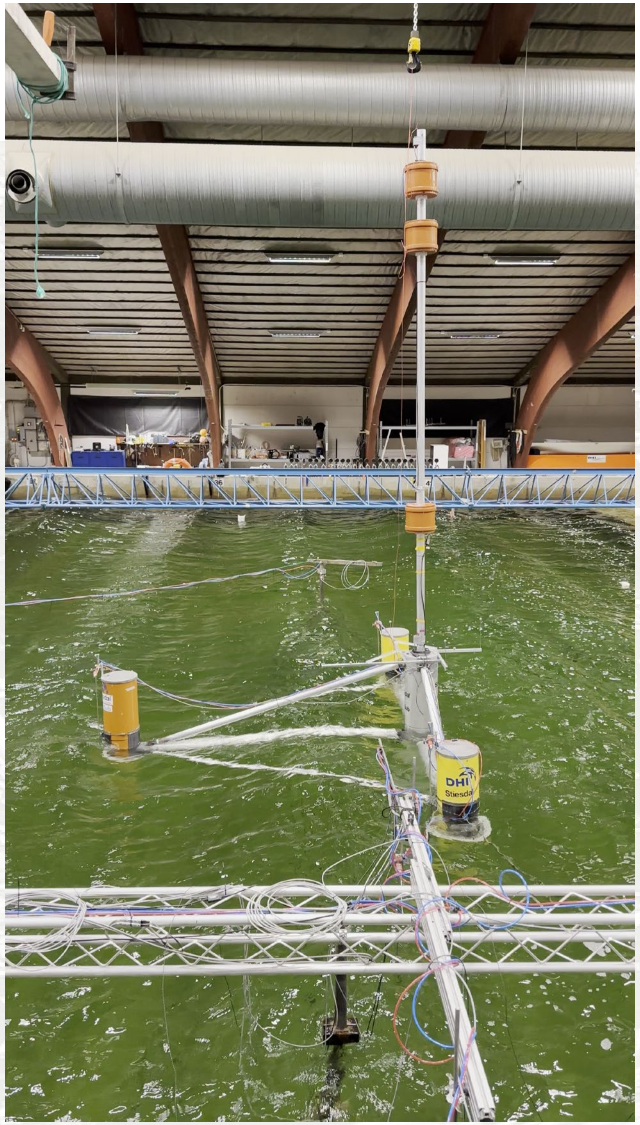
Experimental Setup

- *Scale*: 1 : 40
- *Floater* : Design variant of the TetraSub floater of Stiesdal Offshore
- Configuration : Three Tanks (2 at rear and 1 at the front) and one center column
- *Mass* : 150kg (Including RNA, Tower mass, Ballast)
- *Mooring system* : Inclined Taut Mooring system

Experimental setup

- DHI deep water basin : 30m X 20m X 3m
- Multidirectional wave maker: Sixty hinged wave paddles
- *Absorber*: Porous beach at last 6m of wave basin
- *Floater location*: Central column of the floater was 7.73m from the wavemaker
- *Equipment*: 1 Qualisys motion tracking system, 4 Mooring (1-DoF tension force gauges), 10 resistance-type wave gauges



Video : Floater wave interaction for irregular sea state

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Test Matrix

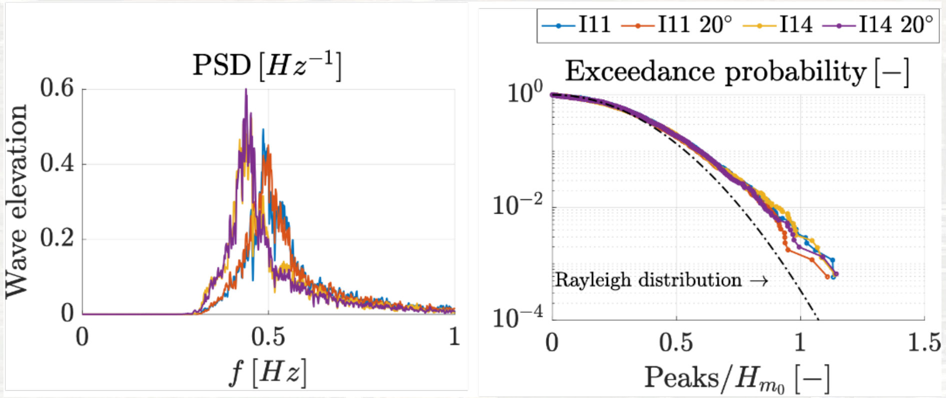
Label	H_{m0} [m]	T_p [s]	Spreading s [°]	Phase shift
R11	0.165	2.024	0	0
I8	0.1	1.597	[0,20]	0,180
I11/F11	0.165	2.024	[0,20]	0,180
I14/F14	0.218	2.245	[0,20]	0,180
S2	0.08	2.21	25 dir	0

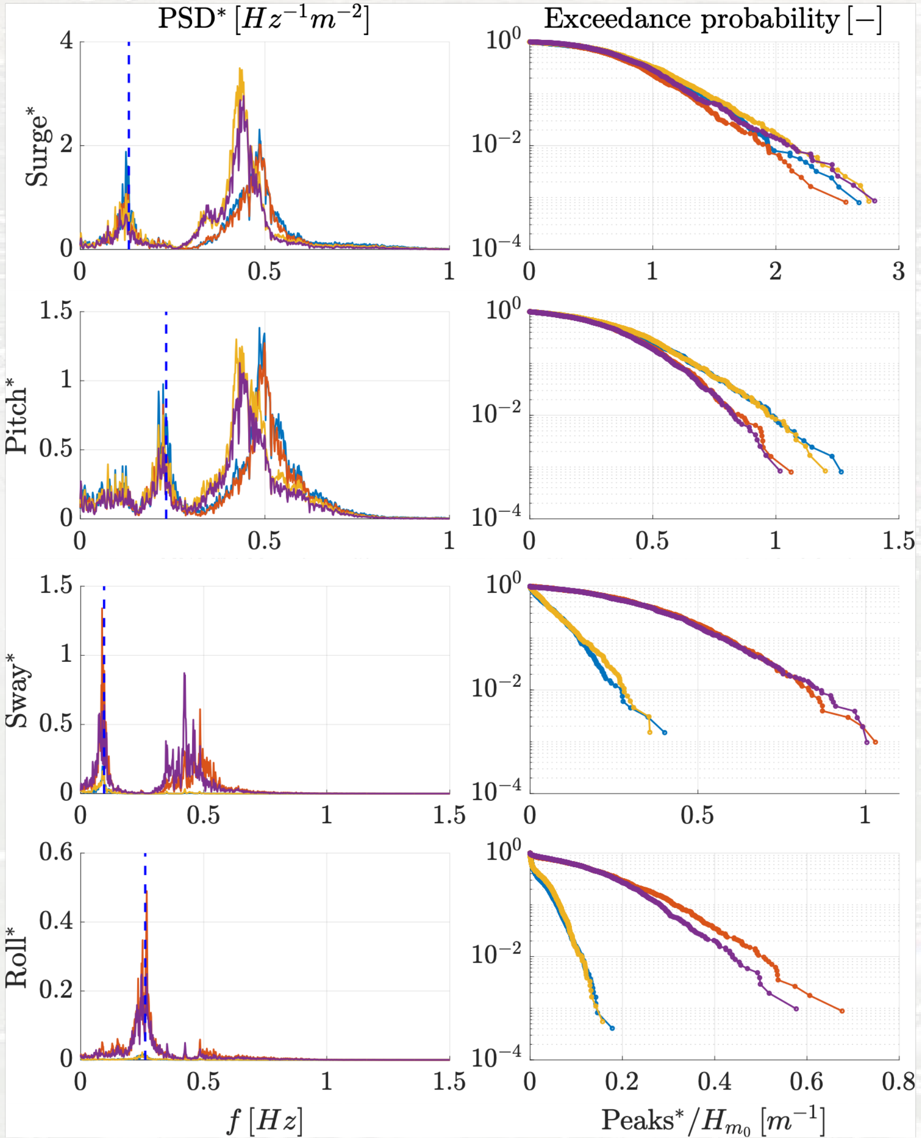
Table : Subset of Test matrix from the Experimental campaign for the presentation
I: Irregular waves, S: Swell, R: Regular waves, F: Focusing waves

- Duration of Testing : 45 minutes
- Tests:
  - Only waves
  - Wave + Floater
- Wave gauge arrangement : 7 gauge arrangement to characterize the directional waves

Due to the proprietary nature of the floating foundation design variant, all the responses and mooring line tensions are normalized (Surge*, Heave* ML* ..)

Summary 1 : Inline Vs Transverse Response





Notable observations

- Wave crest heights are smaller in the spread sea than in the non-spread sea.
- Inline responses in spread seas are smaller than those in non-spread seas (on the order of $H_{m_0} cos\sigma_\theta$)
- Transverse responses in spread seas are significantly larger than those in the non-spread seas (on the order of $H_{m_0}\ sin\ \sigma_\theta$)

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Summary 2: Harmonic Separation

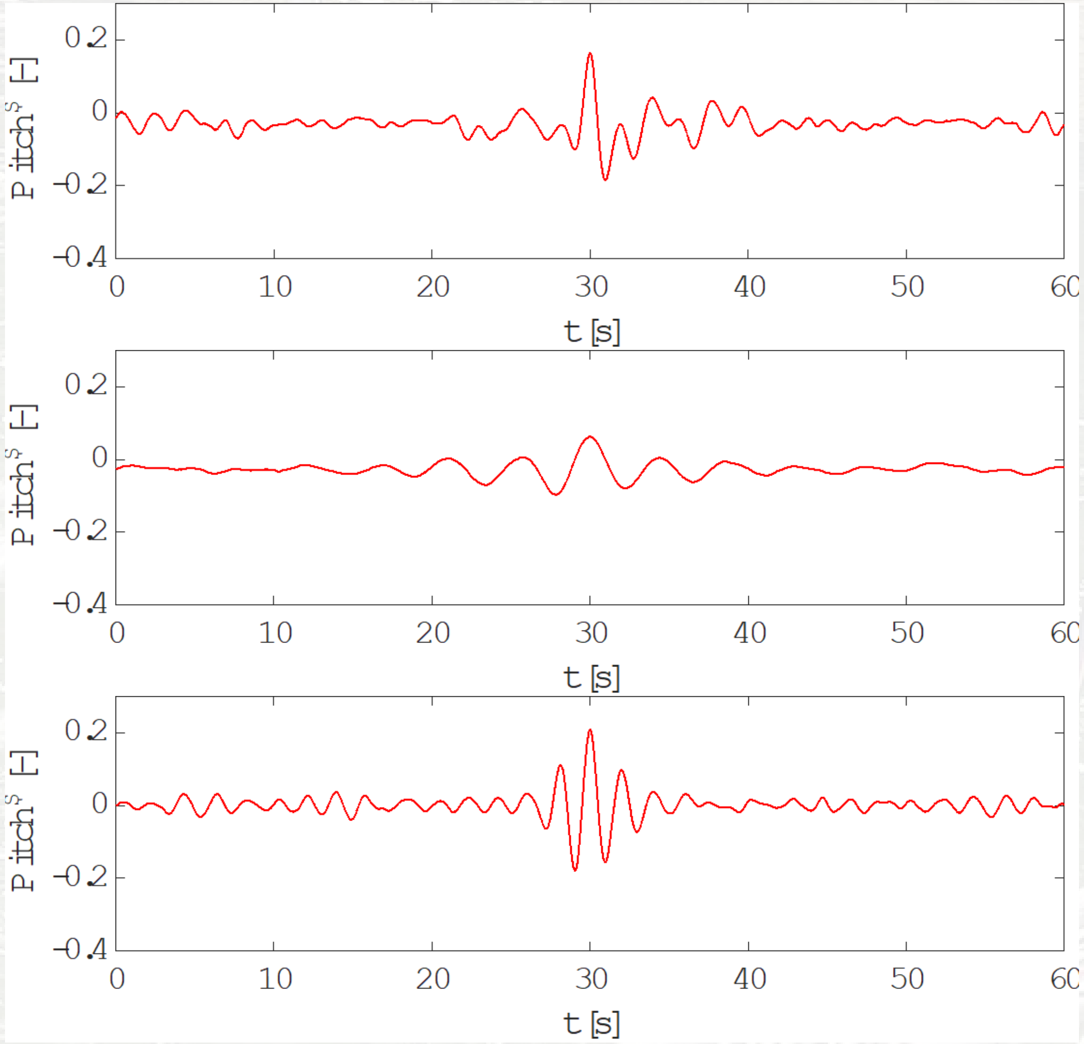
$$Even = \frac{1}{2}(X_0 + X_{180})$$

$$Odd = \frac{1}{2}(X_0 - X_{180})$$

Total response

Even response

Odd response



Jonathan & Taylor (1997)
Walker, Taylor & Eatock Taylor (2004)
Madsen et al (2021)
Orszaghova et al (2021)

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Summary 2

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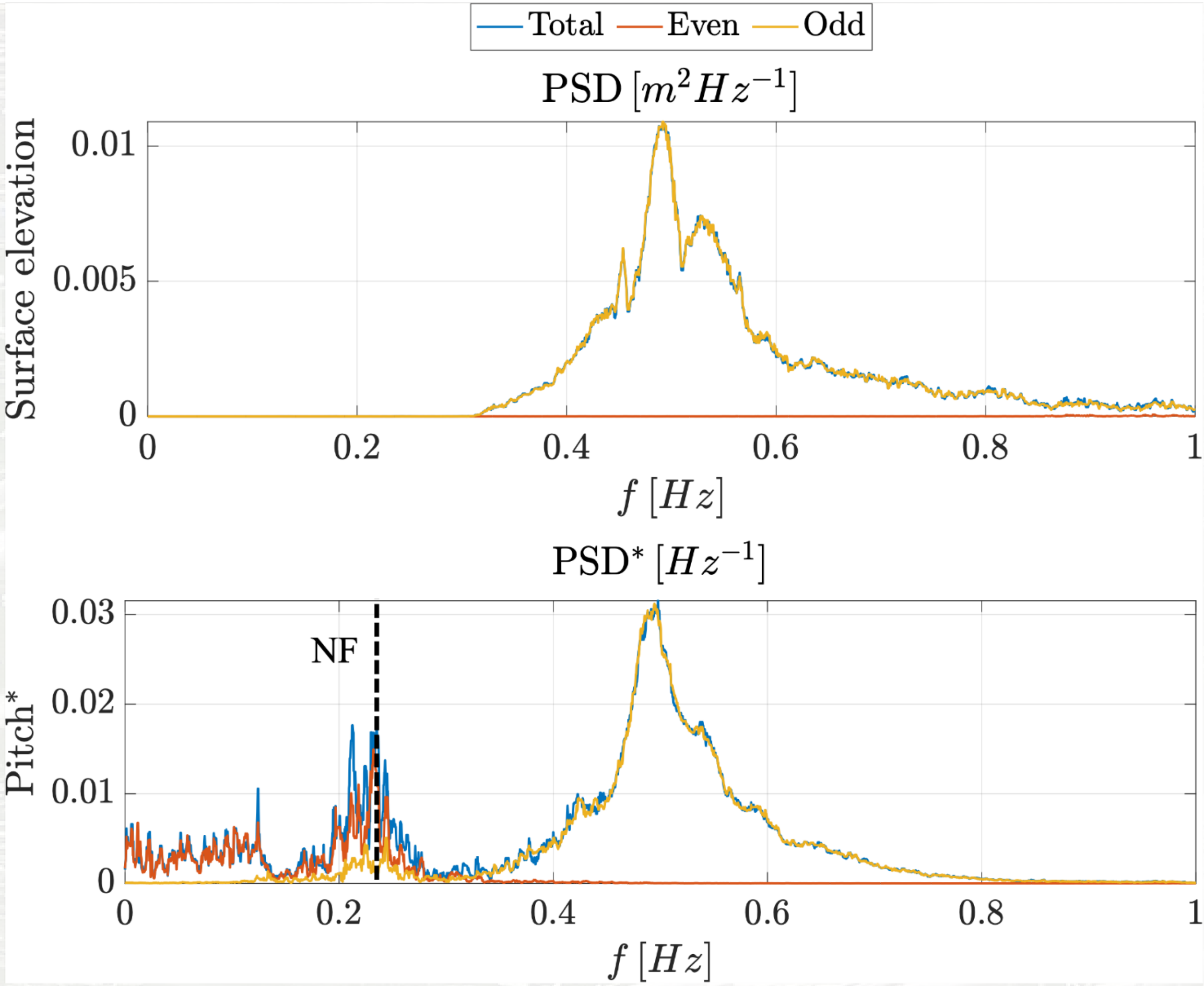
$$Even = \frac{1}{2}(X_0 + X_{180})$$

$$Odd = \frac{1}{2}(X_0 - X_{180})$$

- The linear (odd) response is in the wave frequency range
- The second-order difference forcing (even) is around the pitch natural frequency of the floater.



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Summary 3 : Mooring line Failure

Video: Representation of floater motions after mooring line released for I8 wave case

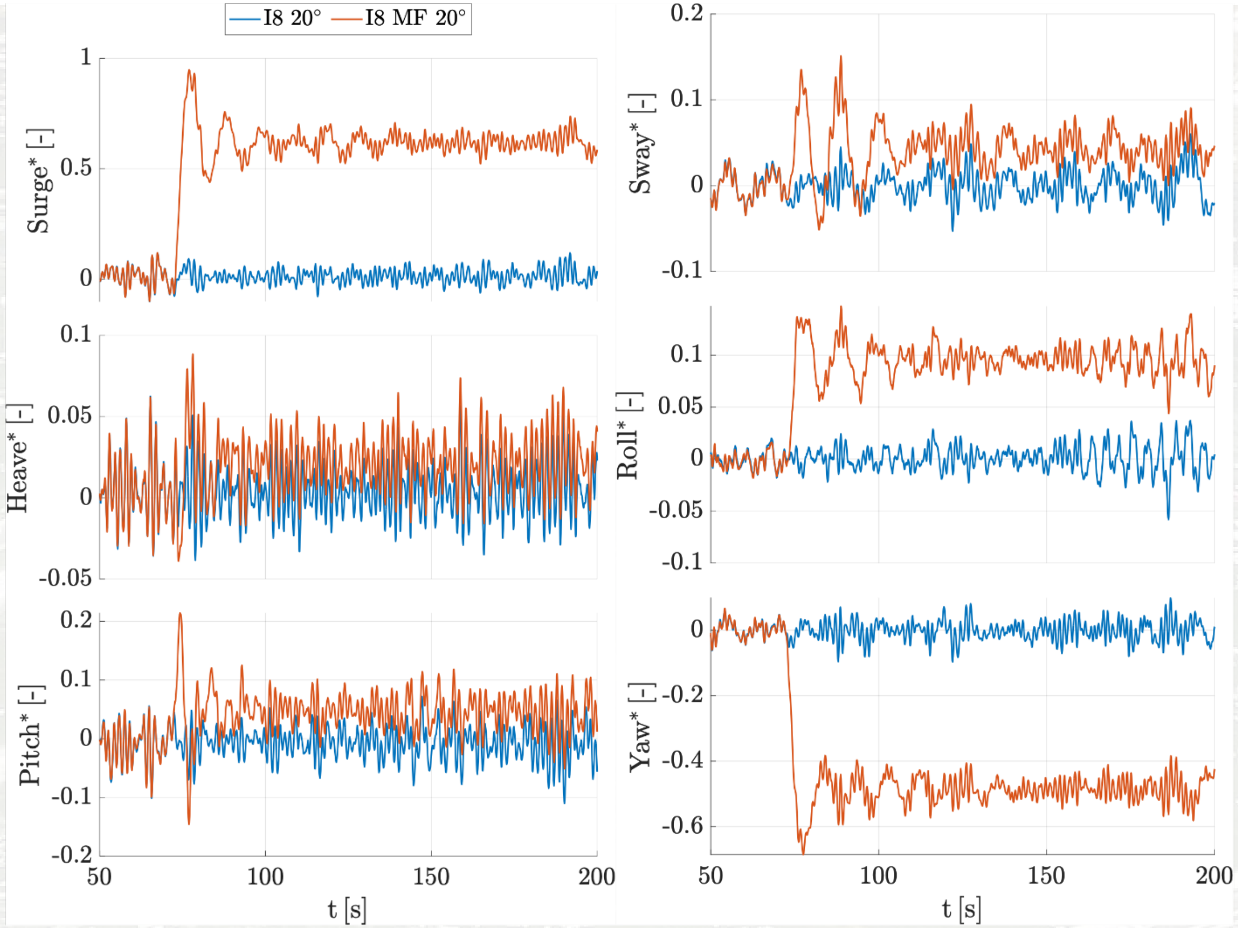

Figure: Floater response with and without mooring line failure for same sea state

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Summary of Experiment findings

- Inline response contains energy content in both the wave frequency range and the natural frequencies of the floater.
- Inline response is slightly reduced in spread seas compared to that in non-spread seas, on the order of $H_{m_0} cos\sigma_\theta$.
- The floater shows a small but non-zero transverse response in sea states with a 0-degree target spreading, mainly in the low-frequency range.
- Transverse motion increases as expected when spreading is introduced.
- Motion response can be separated into linear (odd) response in the wave frequency range and second-order difference forcing (even) around the natural frequency of the floater.

Numerical reproduction

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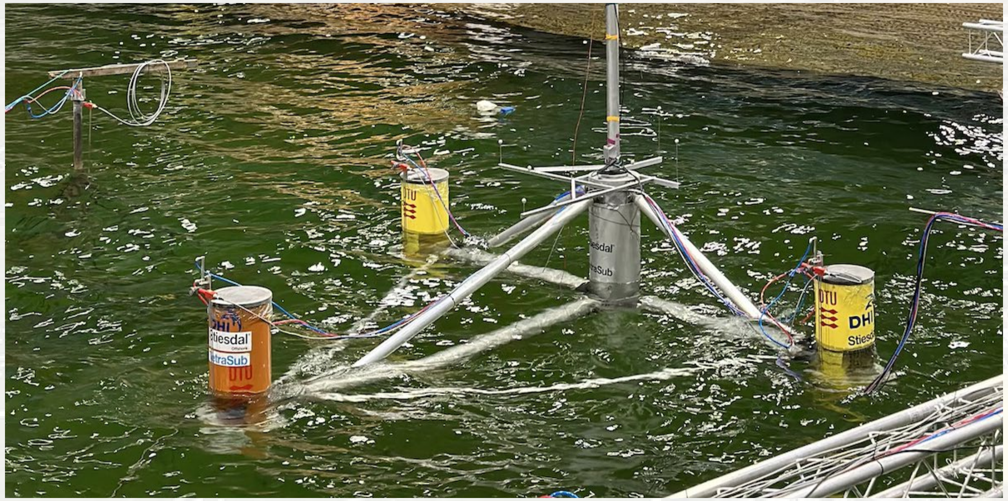

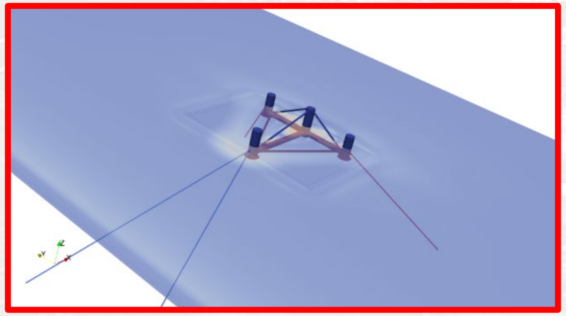

Level 3 Models	**CFD in 2D and 3D**
Level 2 Models	HAWC2 in 2D Fully non linear potential flow modelling in 2D and 3D
Level 1 Models	Linear remodelling in 2D and 3D Second-order remodelling in 2D and 3D

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FloatStepper

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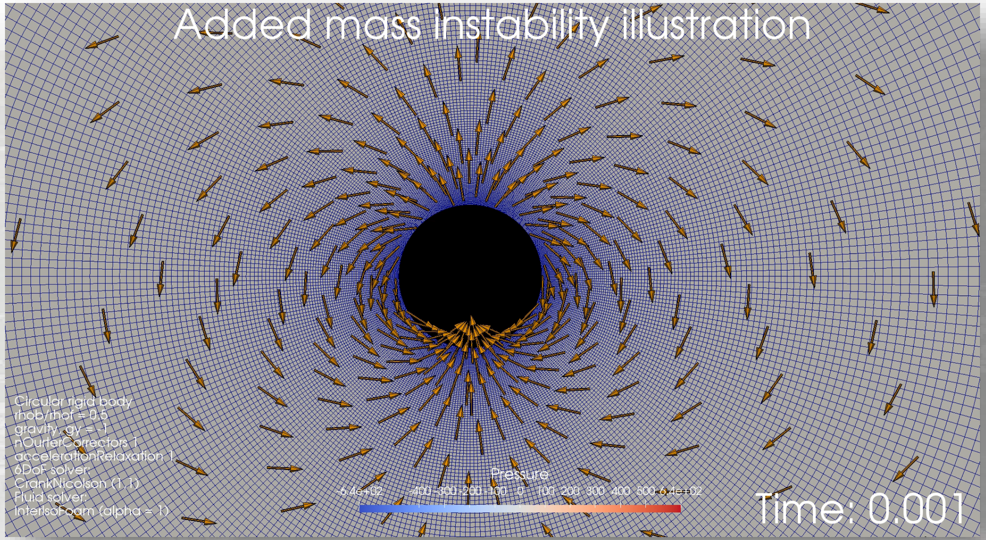
☐ FloatStepper (Open-source solver) , a non-iterative algorithm for coupling rigid body and incompressible fluid in CFD

☐ Purpose : Added mass instability problem, which may arise when a light floating body interacts with a heavy fluid

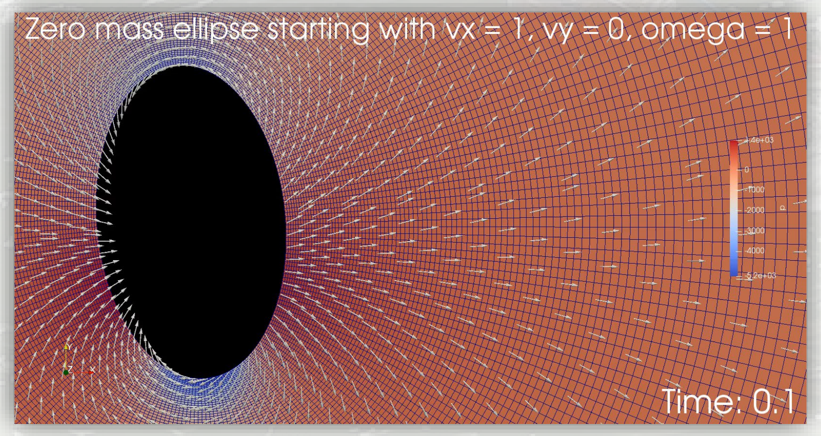
☐ Detailed Discussion : ‘Roenby et al, *A robust algorithm for computational floating body dynamics*’, Royal Society of Open Science, 2024.

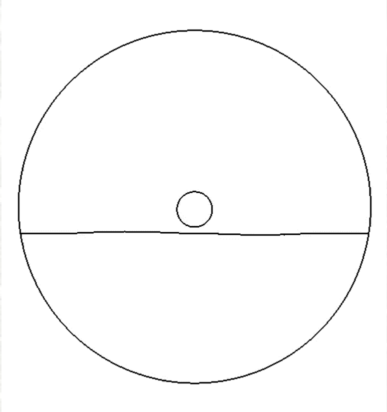
☐ Github : github.com/FloatStepper/FloatStepper

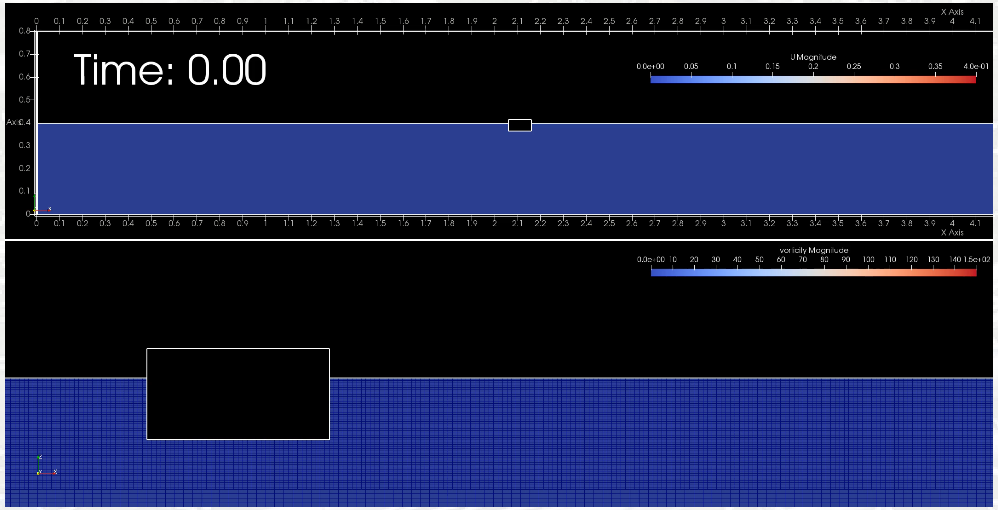


Video : Added mass instability observed ‘Light weight circle rising in ideal fluid’

Some Validation cases:







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FloatStepper : CFD solver in 2D and 3D sea states

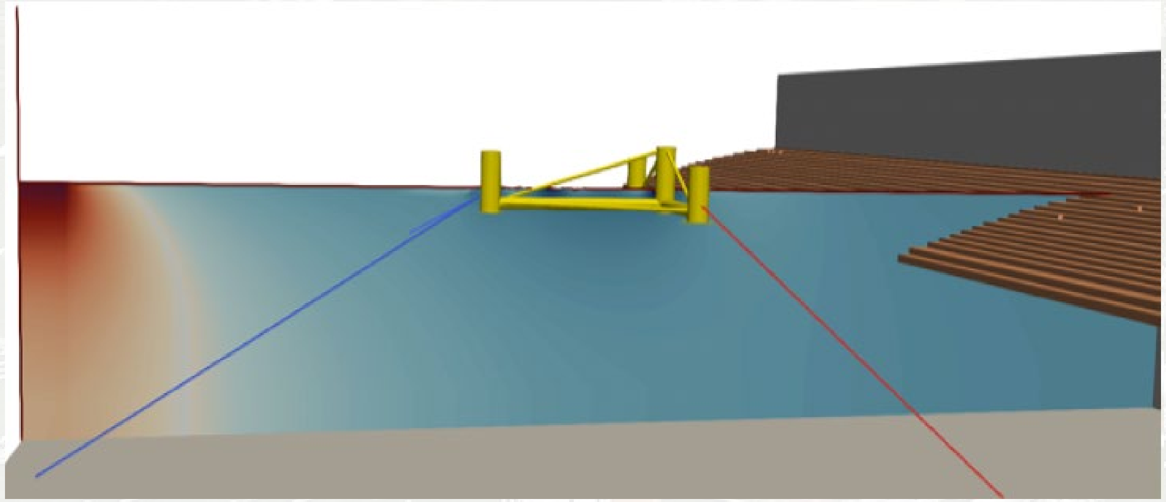

Figure: Typical Computational domain with wavemaker and wave absorption representation

OpenFOAM based Numerical wave tank :

- Wave maker type wave generation
- Active and porous wall based wave absorption
- IsoAdvector based free surface tracking (Geometric Volume of Fluid method)
- FLOATSTEPPER algorithm based six degree of equation solver
- Coupled with MoorDyn (dynamic mooring solver) for mooring evaluation
- Other than considering the mass properties – RNA setup are ignored in the solver

CFD Test Matrix

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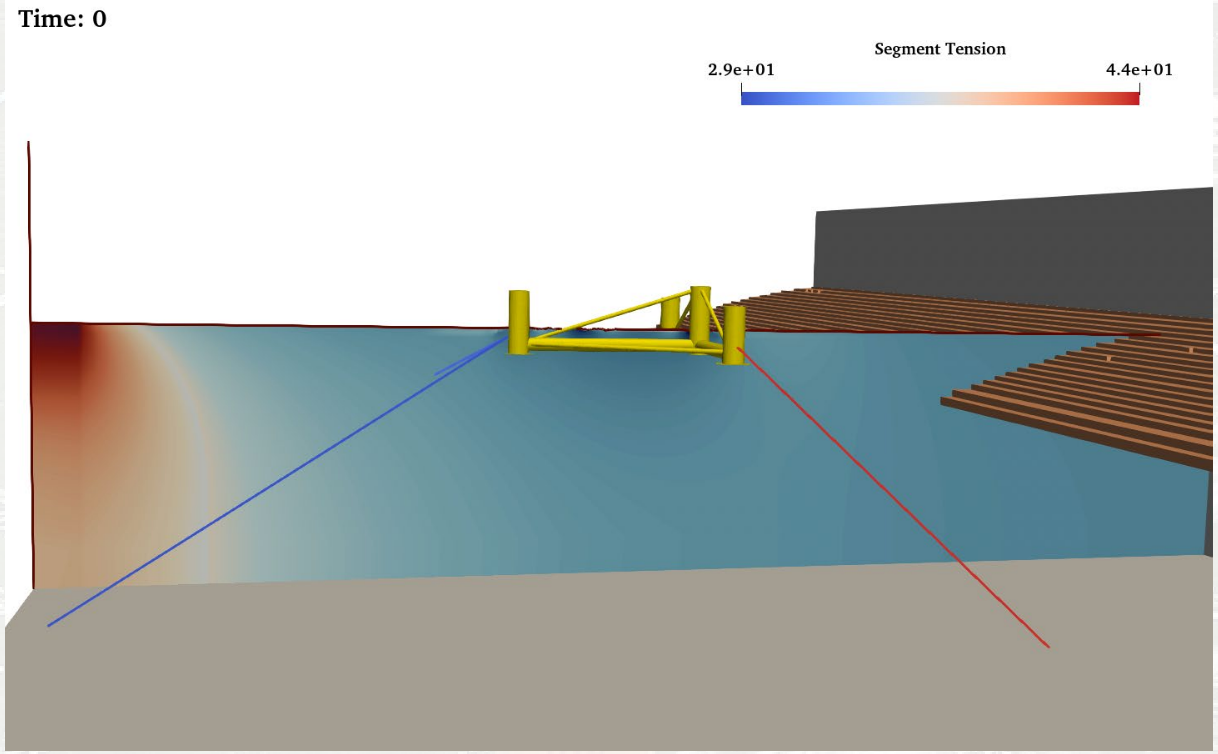
Test Cases	Spreading	Case name	Time period (s)	Wave height (m)
Regular Wave	0	R11	0.165	2.024
Focusing Wave	0	F140deg	2.245	0.218
Focusing Wave	20	F1420deg	2.245	0.218
Focusing Wave	40	Fx40deg	2.245	0.218
Swell Waves	25 (direction)	S2	2.21	0.08

R11 : Regular wave interaction



Video: Regular Wave impact on floater demonstration

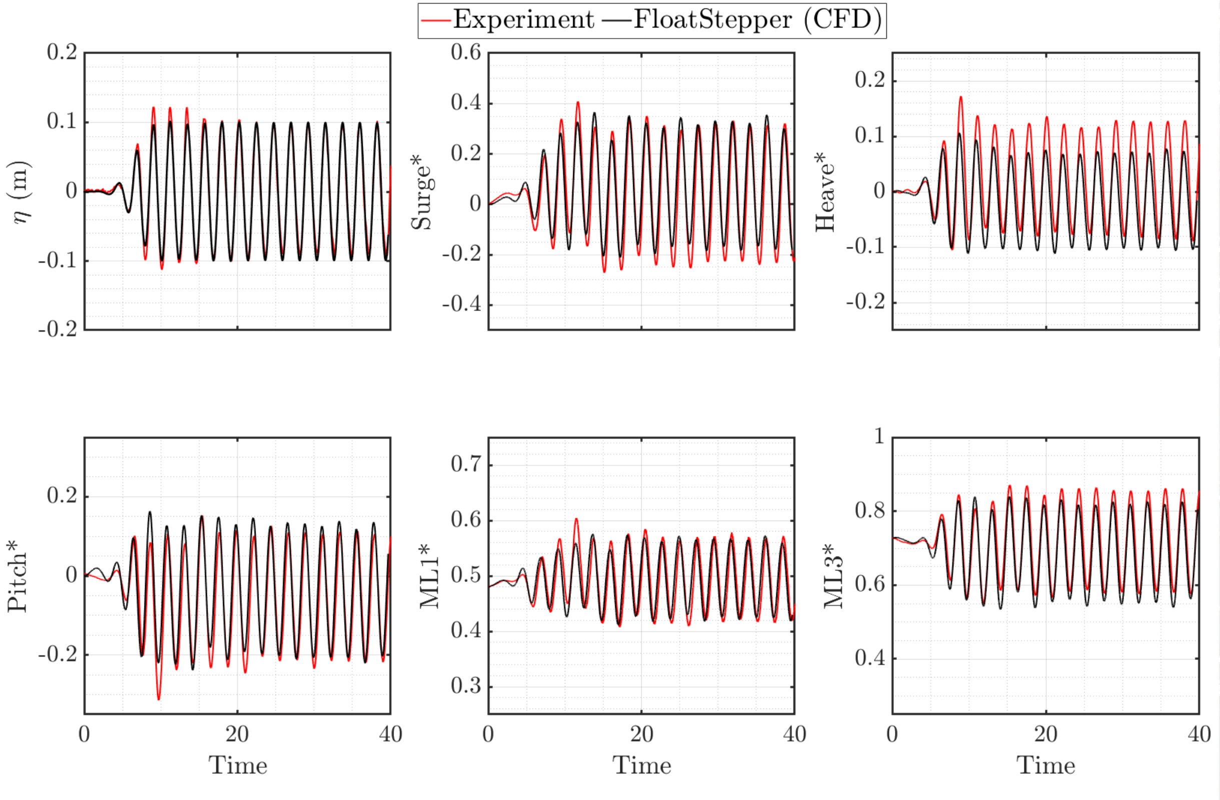


Figure: Non dimensionalised floater responses over regular wave and mooring tension

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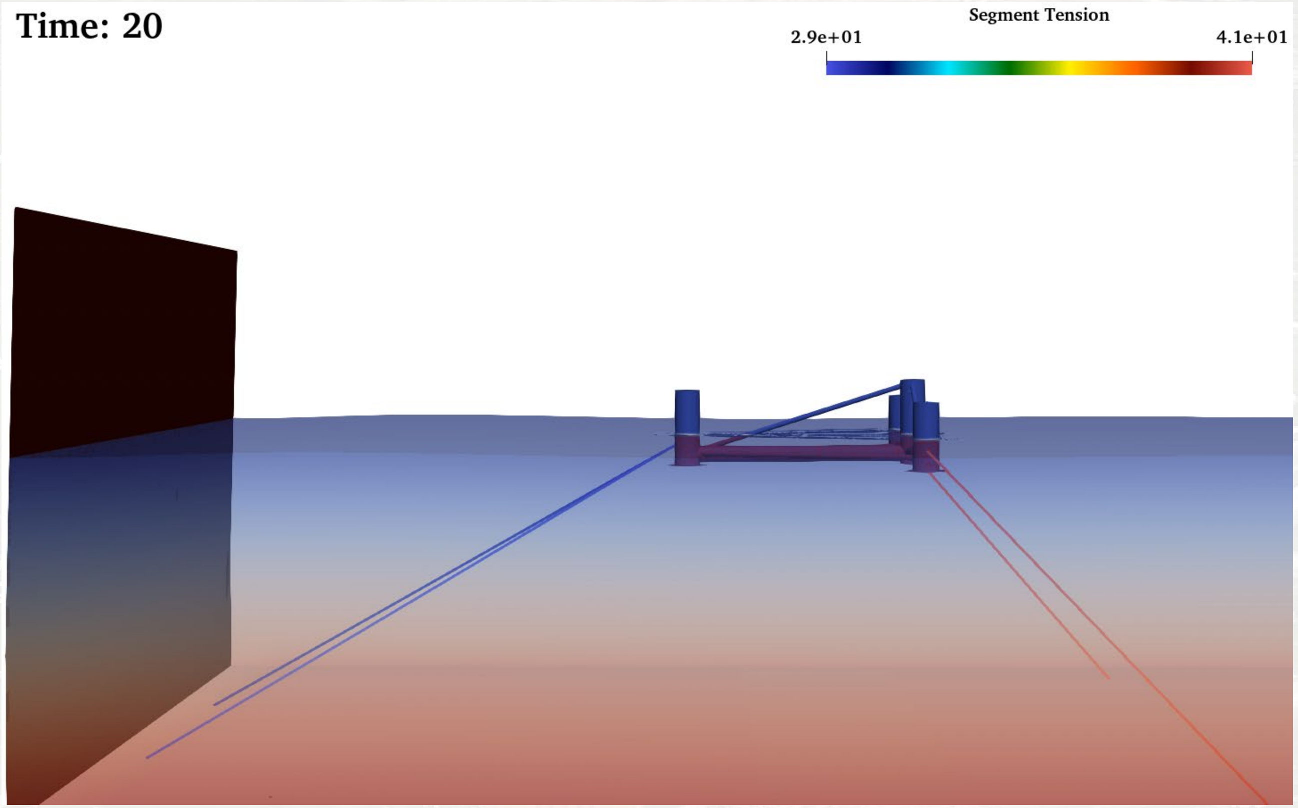
F140deg : Focusing wave interaction



Video: 2D focusing Wave impact on floater demonstration

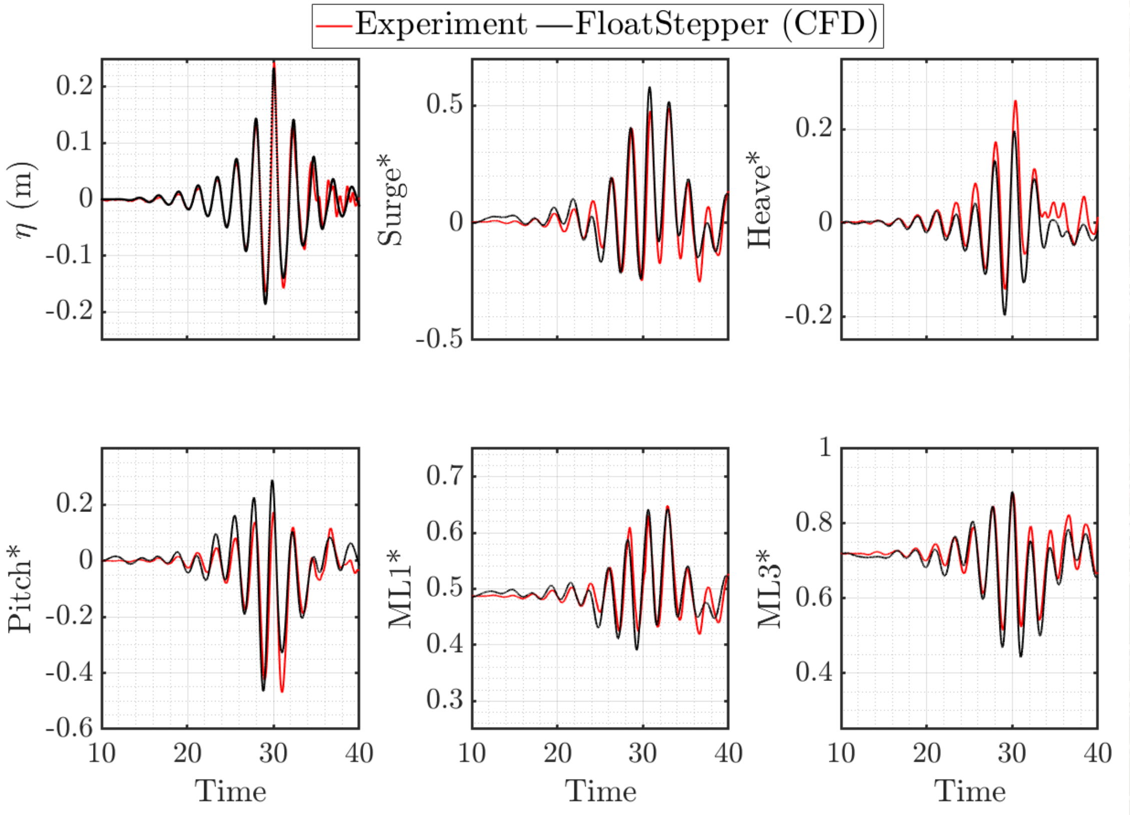


Figure: Non dimensionalised floater responses over non spreaded 2D focused wave impact and mooring tension

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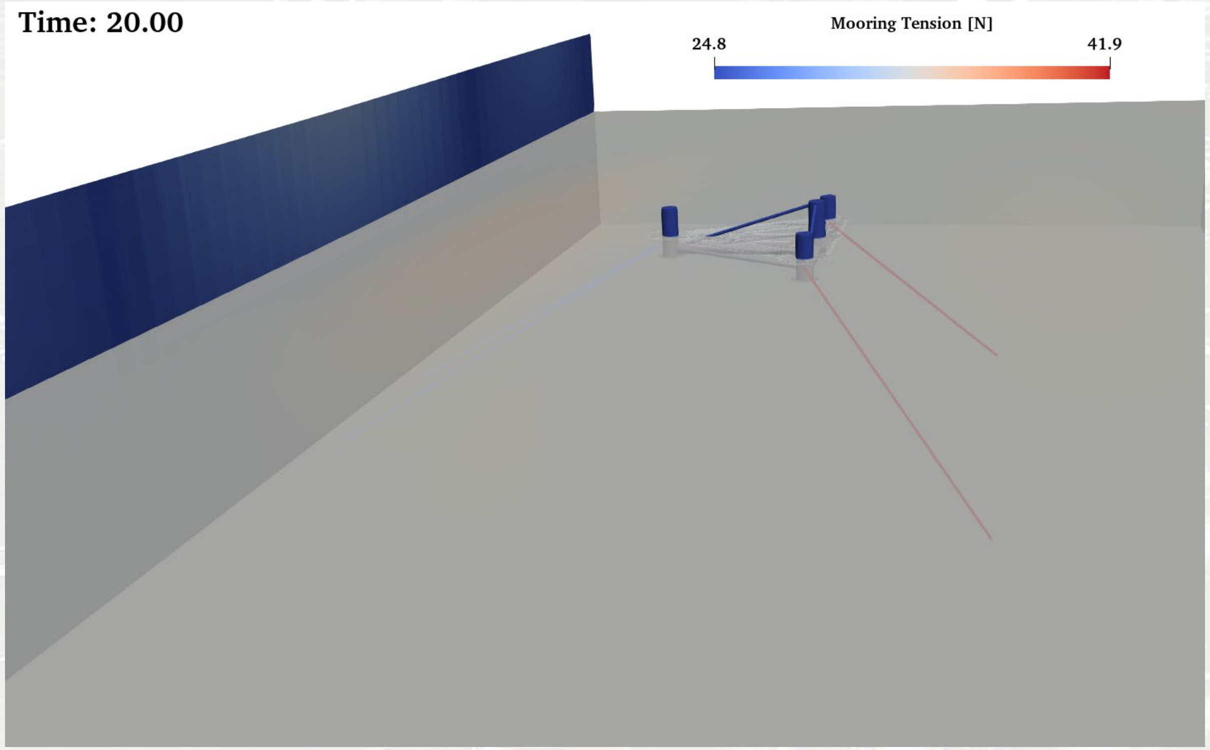
F1420deg : Spreaded Focusing wave interaction



Video: Spreaded focused Wave impact on floater demonstration

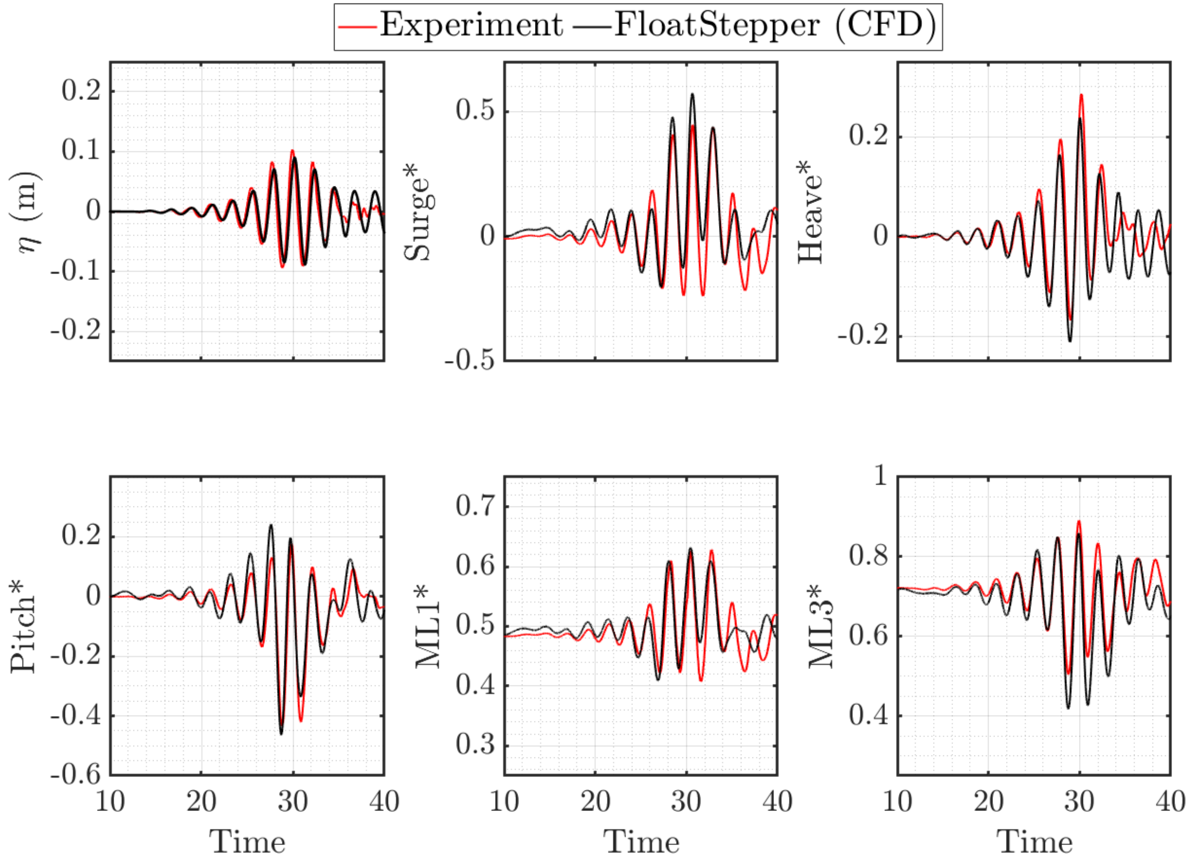


Figure: Non dimensionalised floater responses over spreaded focused wave impact and mooring tension

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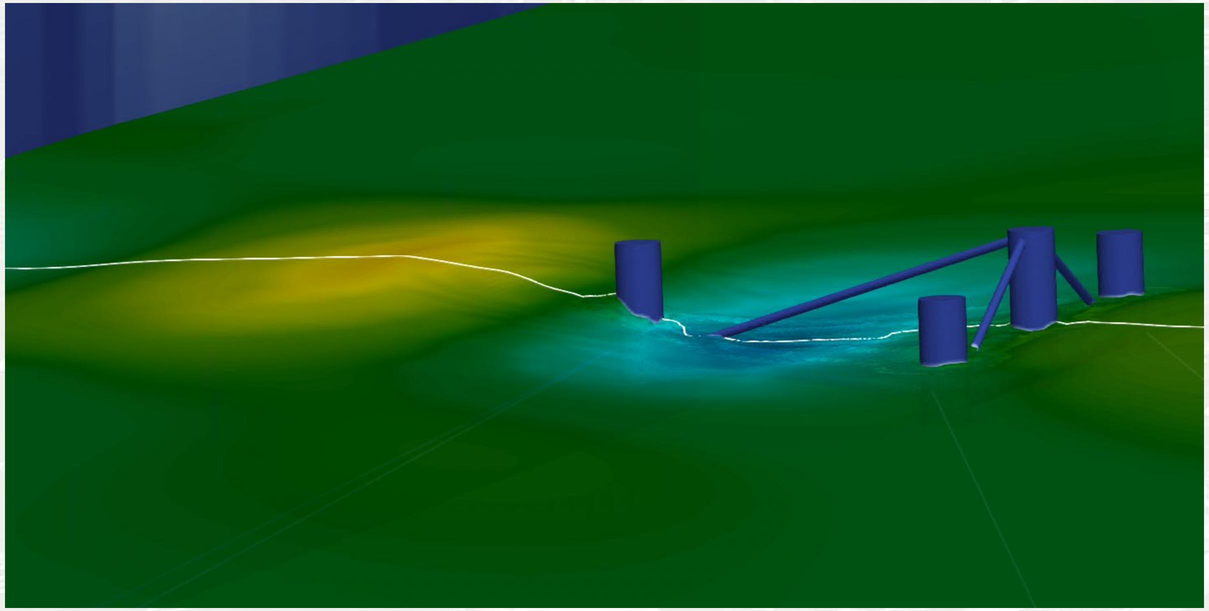
Fx40deg : Focused breaking wave interaction



Video: Focused breaking wave impact on the floater with white line represents the contour of free surface at middle of the tank

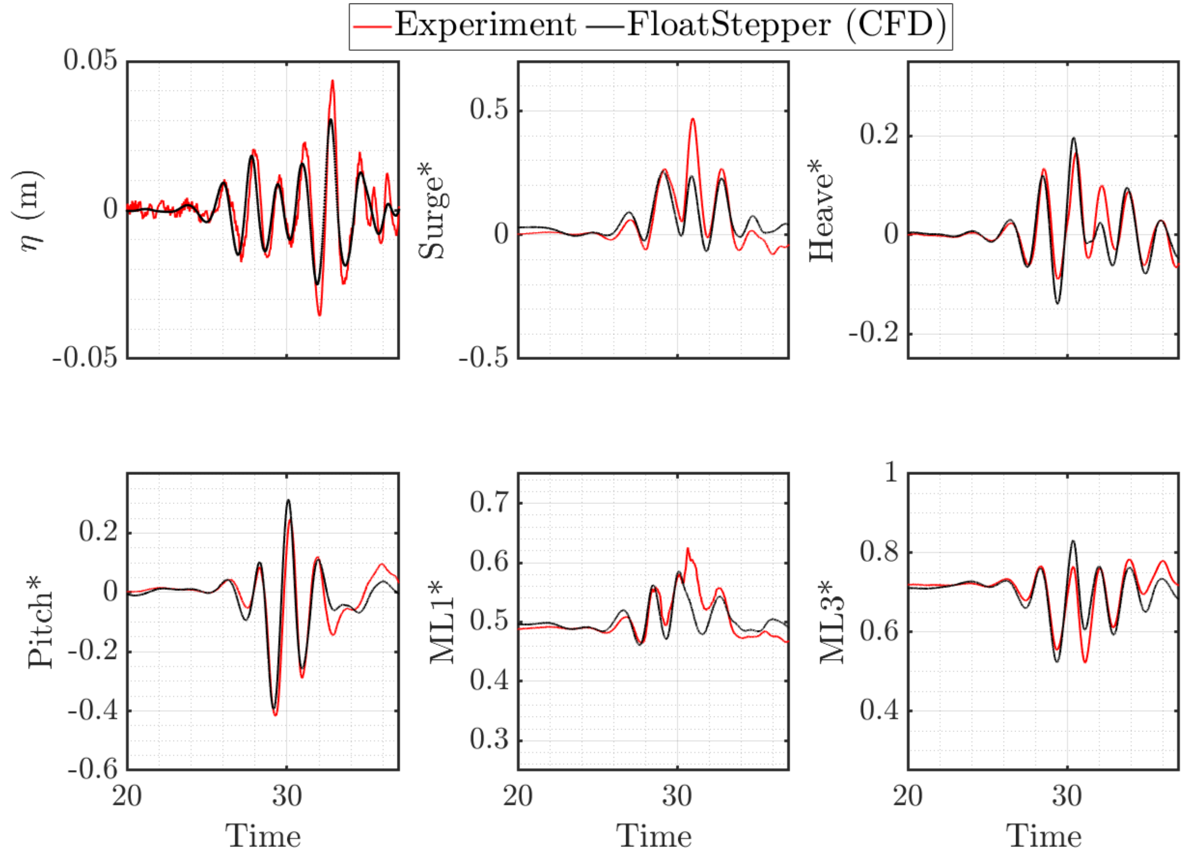


Figure: Non dimensionalised floater responses over focused breaking wave impact and mooring tension

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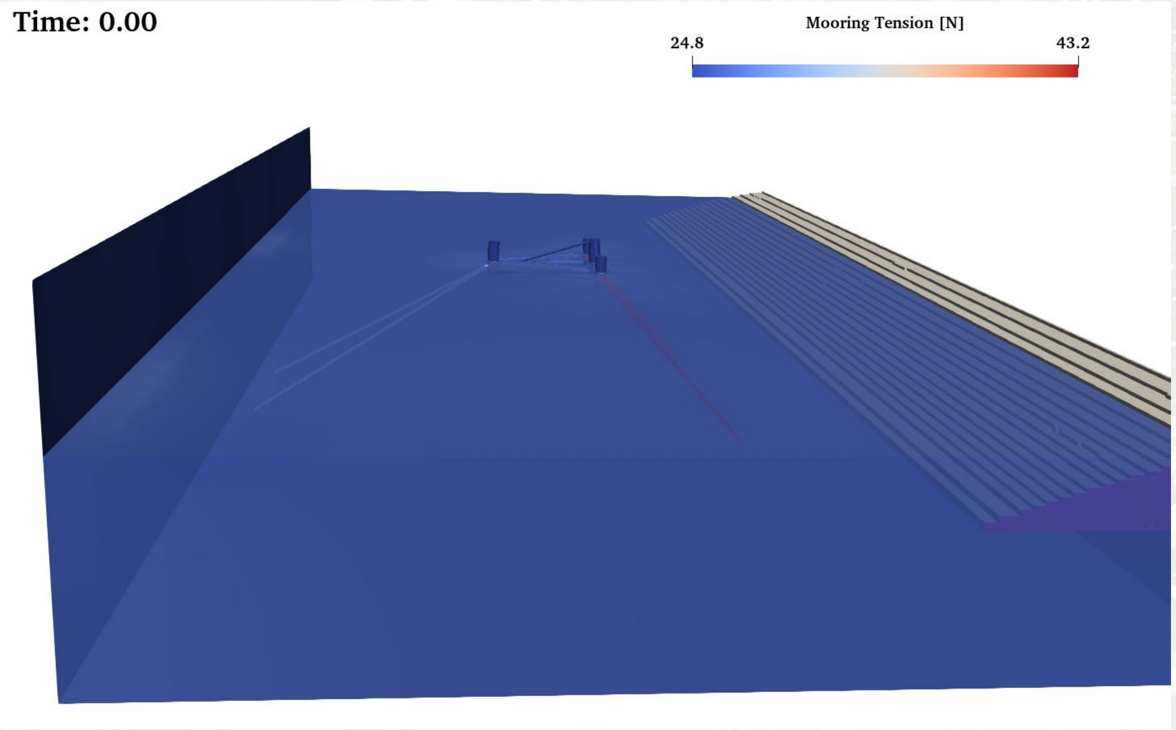
S2 : Swell wave interaction



Video: Representation of Swell wave impact on the floater

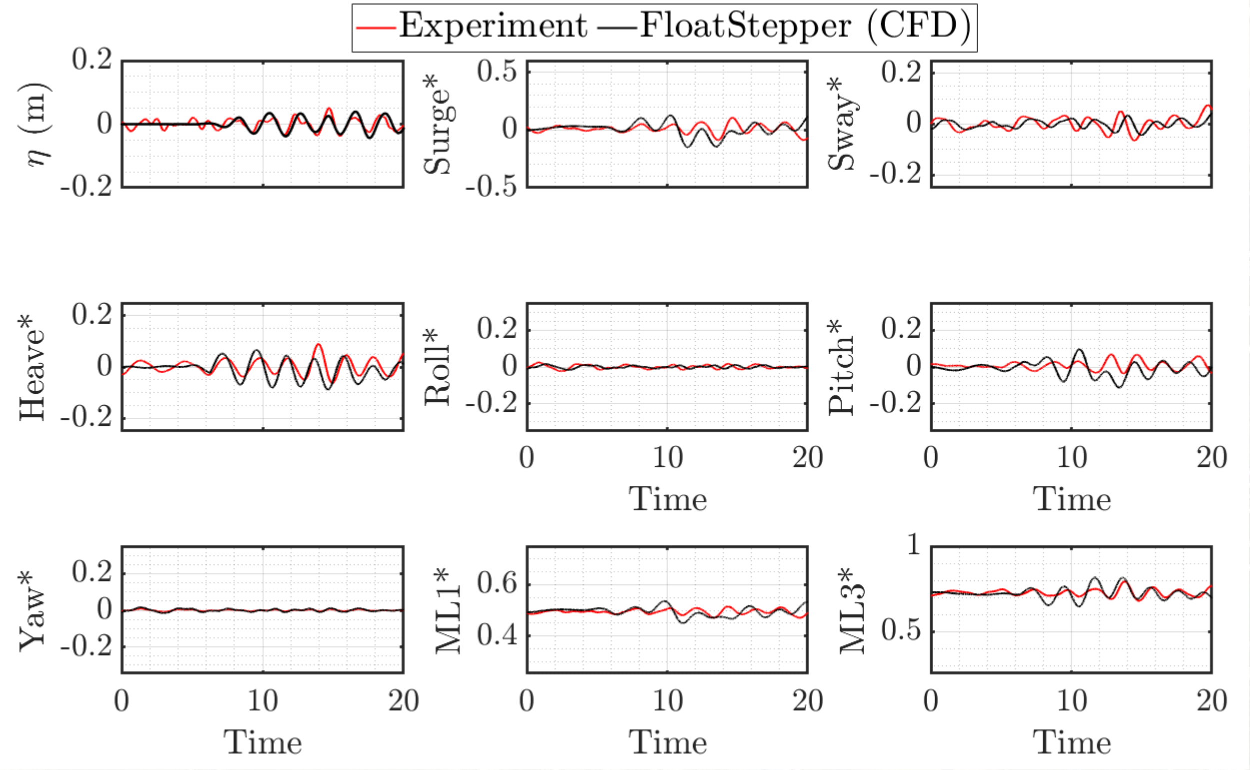


Figure: Non dimensionalised floater responses over swell sea state and corresponding mooring tension

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Summary and Conclusion

☐ Investigated the responses of a 1:40 scale design variant of floating foundation to irregular, swell and bimodal sea states, emphasizing the direction and spreading characteristics of waves

☐ Inline response is slightly reduced, and transverse motion increases as expected when spreading is introduced

☐ Inline response of the floater contains energy content in both the wave frequency range and the natural frequencies of the floater.

☐ FloatStepper (CFD solver): Extended the capabilities of the rigid body solver for simulating directional waves

☐ Present CFD setup has been validated against experimental data, considering regular, focusing (with and without spreading), and swell sea states.

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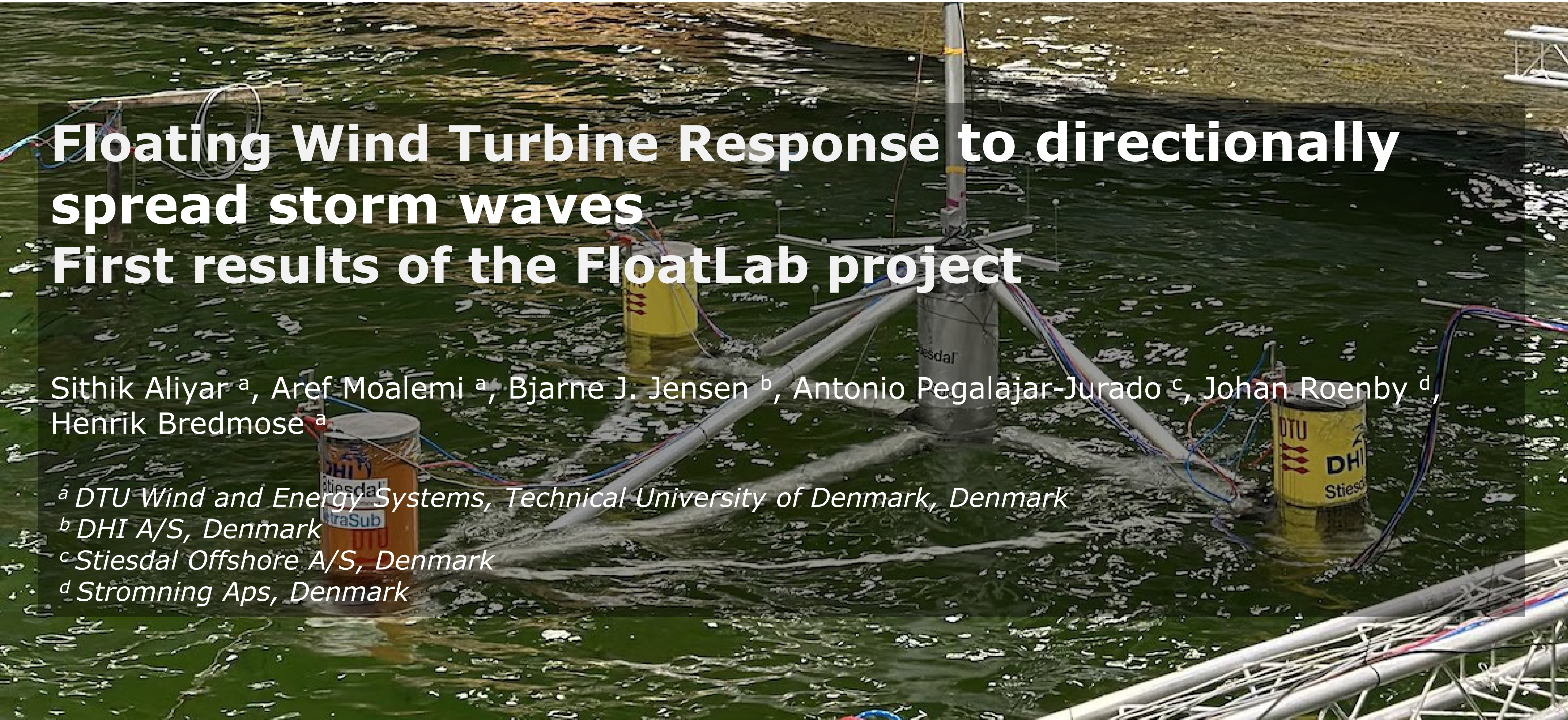

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