Physical model testing of the TetraSpar floater in two configurations

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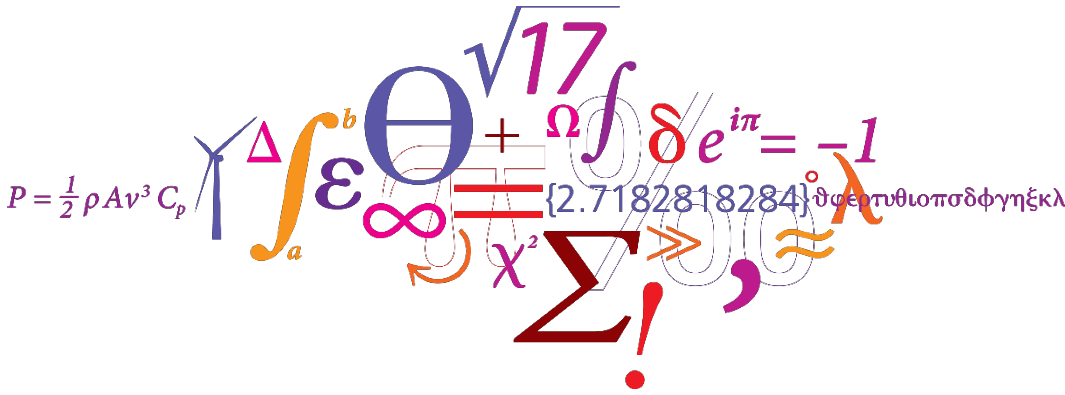
Trondheim, Norway



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DHI

Outline

- Introduction
- TetraSpar concept
- Experimental setup
- Example Results
- Conclusions

Introduction

Scientific ambitions

Improving SoA wind-wave testing

Detailed hydrodynamic testing

Fault & transient conditions

Tech. development ambitions

Proof-of-concept

De-risk concept

DTU Wind Energy
Department of Wind Energy

Stiesdal

Collaborative research project

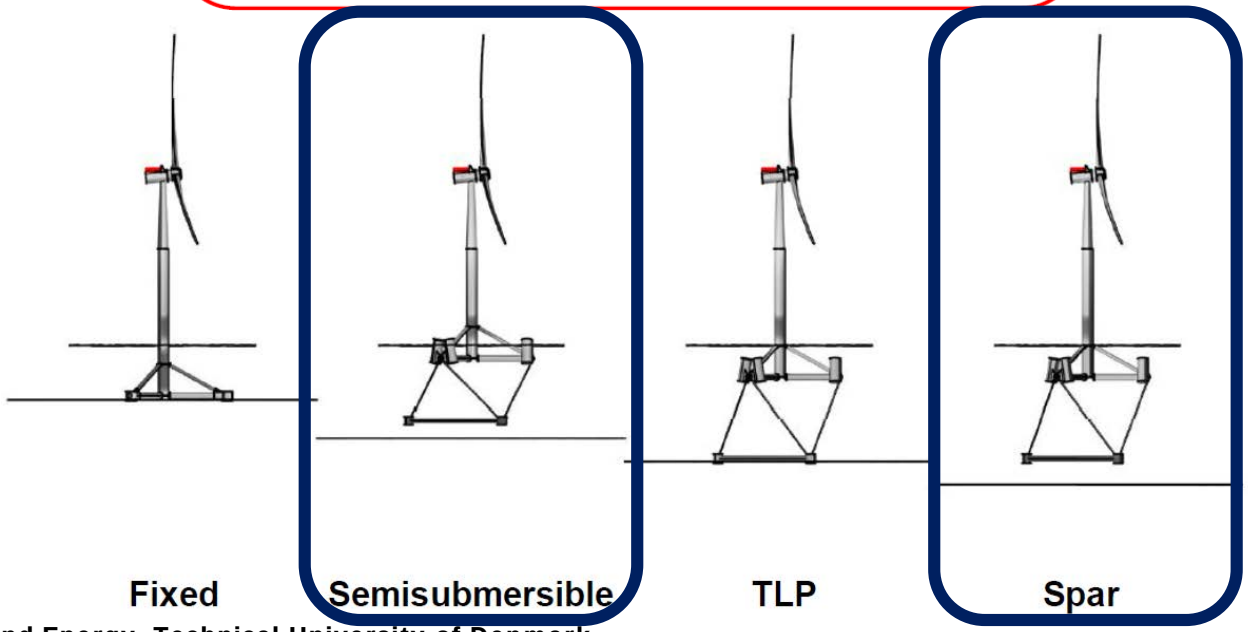
DHI

The TetraSpar concept

- Concept developed by Stiesdal Offshore Technologies
- Rationale:

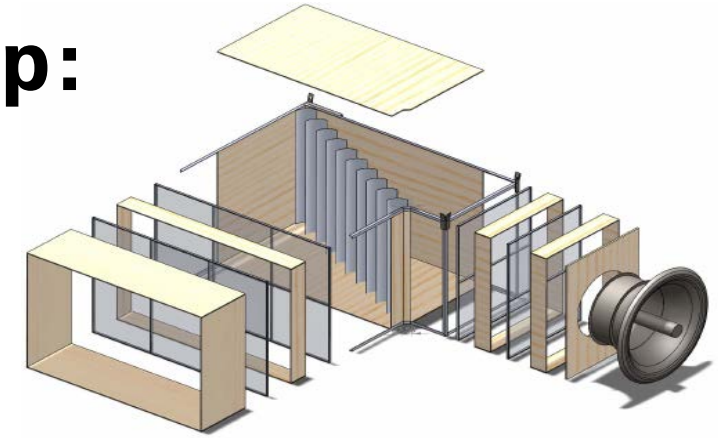
Mindset

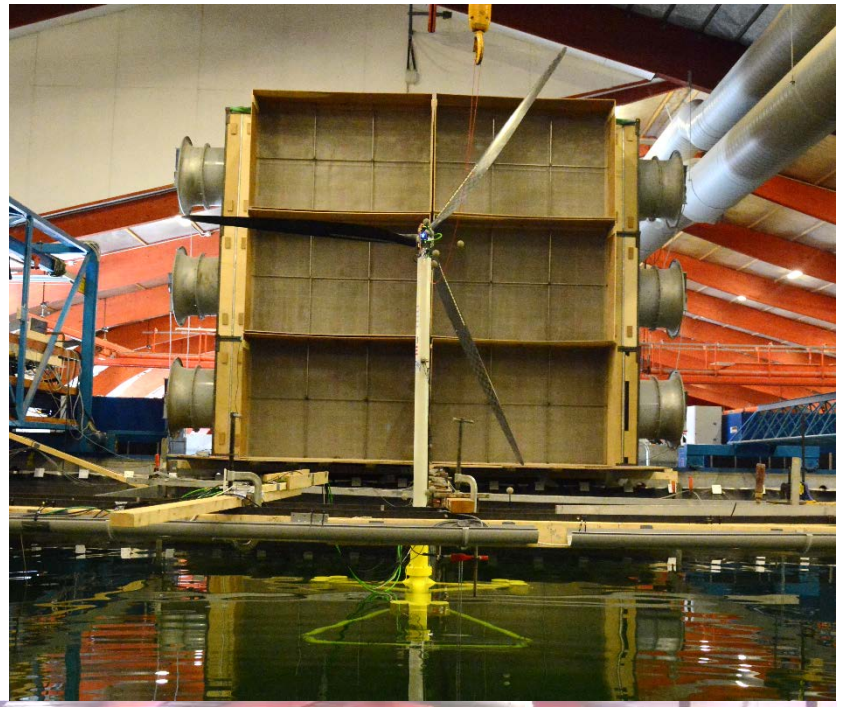
- Conventional thinking
  - We have designed this structure – now, how do we build it?
- TetraSpar thinking
  - We need to manufacture this way – now, how do we design it?

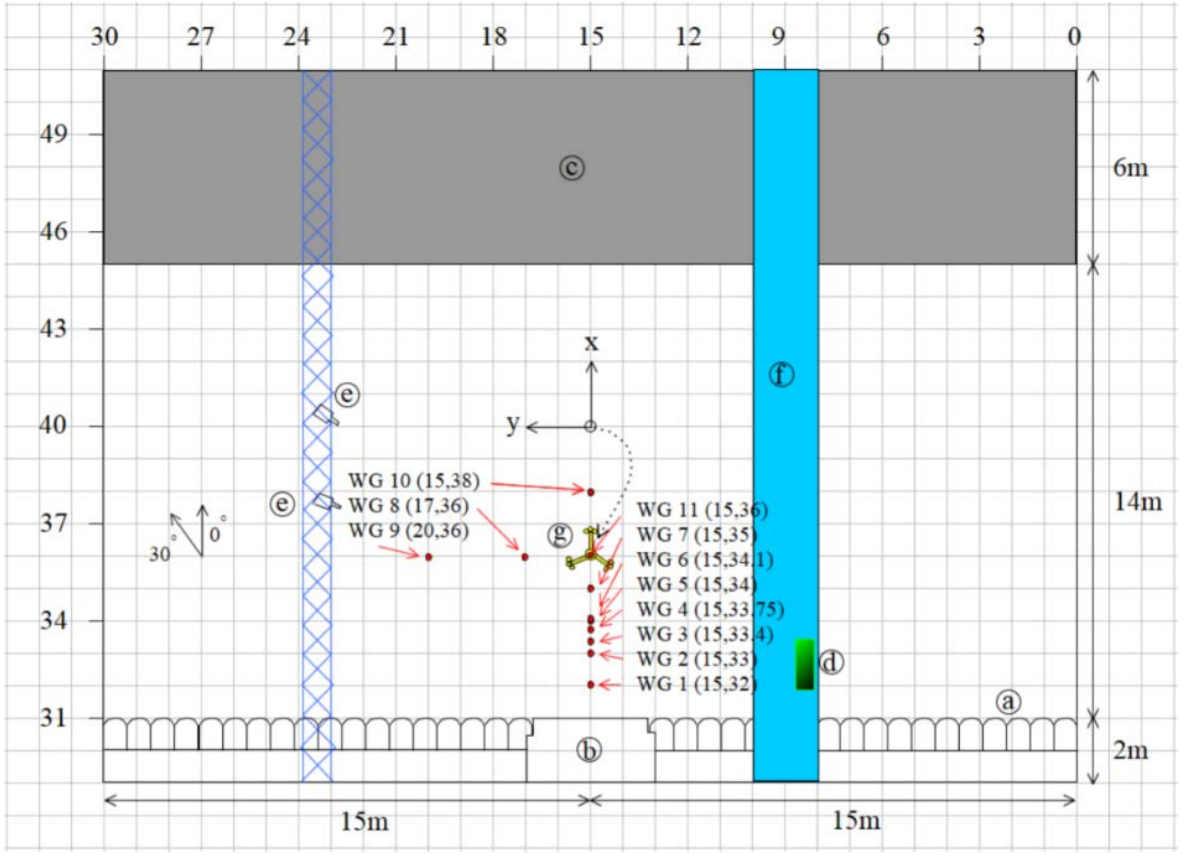


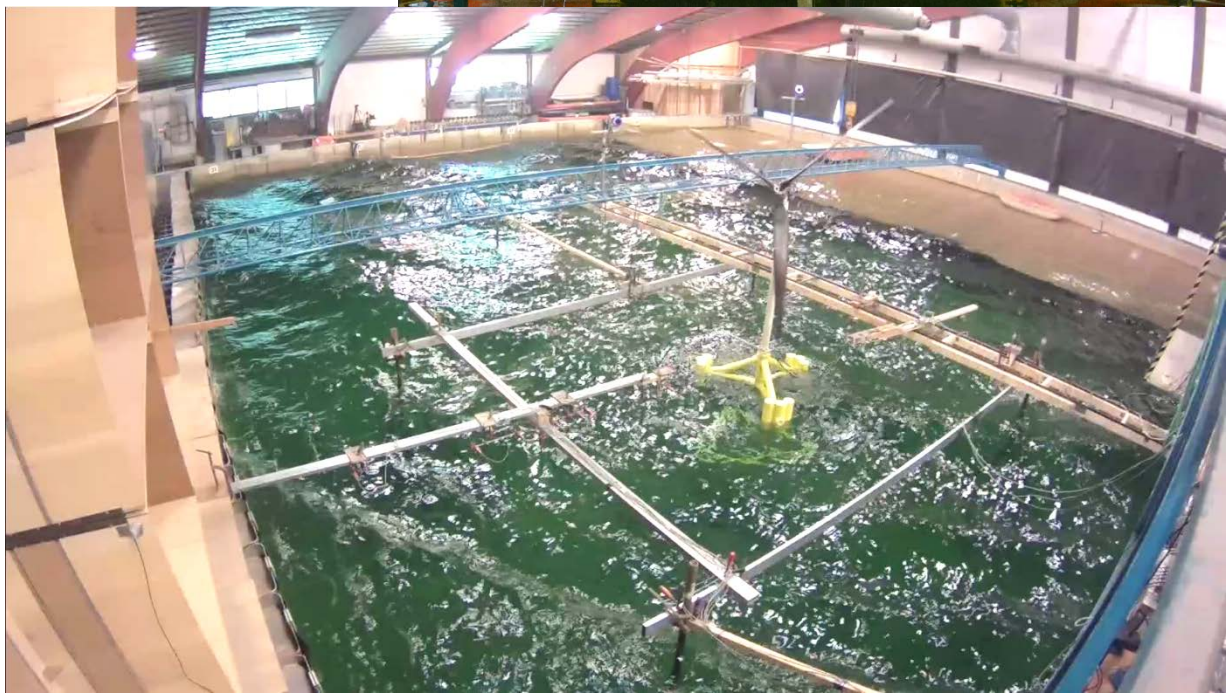
Experimental setup: wave basin

- DHI deep-water wave basin with 4 x 4 m2 wind generator

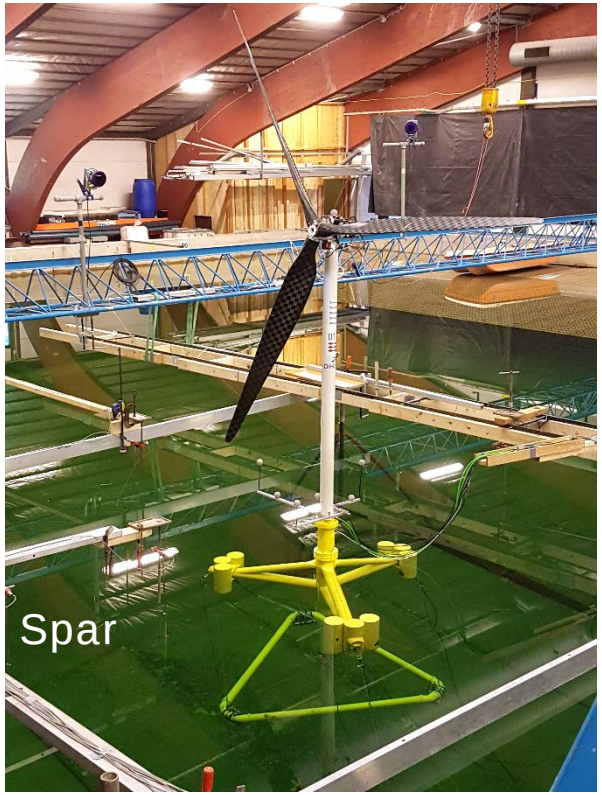


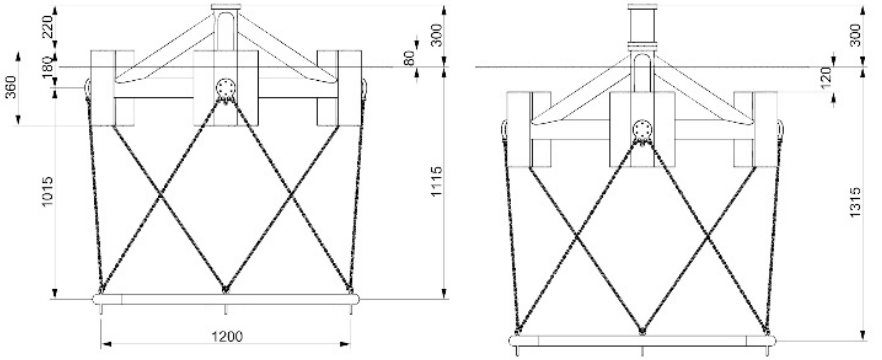


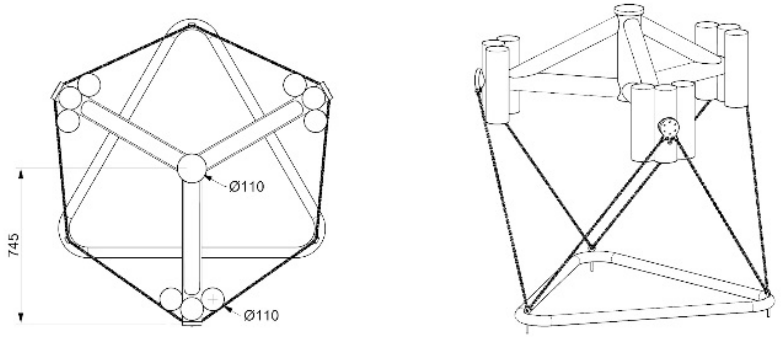




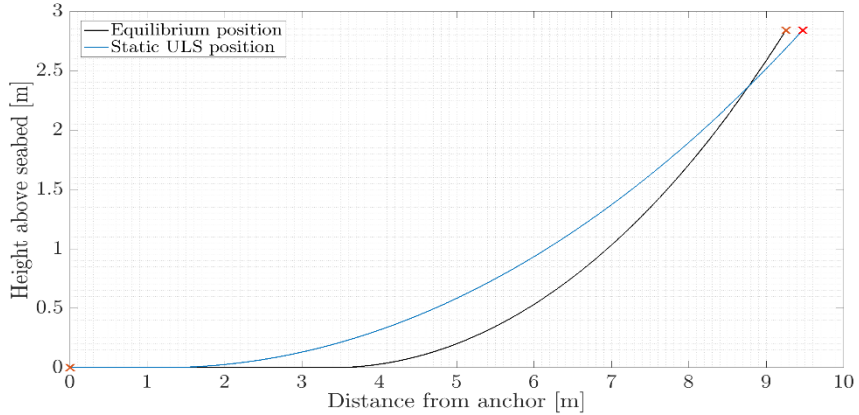
Experimental setup: floater configurations





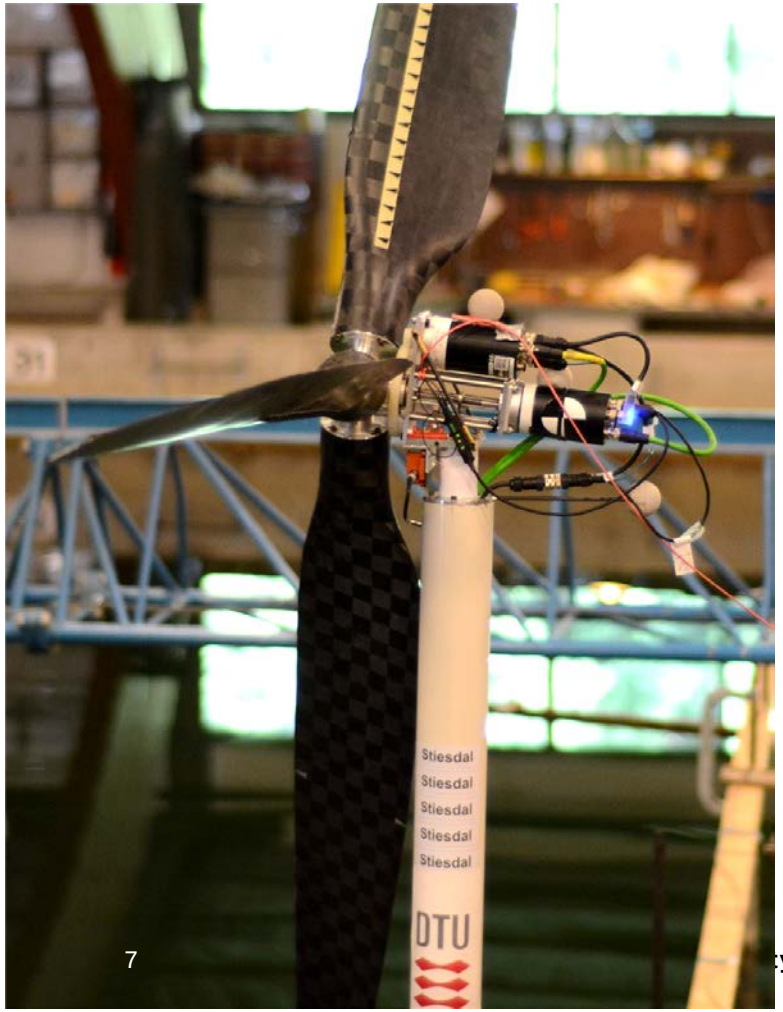


Item	1:60 Model scale	Prototype scale
Floater mass (incl. instrumentation)	15.66 kg	3383 t
Floater vertical centre of gravity below MSL	0.231 m	13.9 m
Water depth	3 m	180 m
Draft, semi configuration	1.12 m	67.2 m
Draft, spar configuration	1.32 m	79.2 m
Transition piece mass	1.08 kg	233 t
Counterweight mass, semi configuration	20.98 kg	4532 t
Counterweight mass, spar configuration	35.66 kg	7703 t



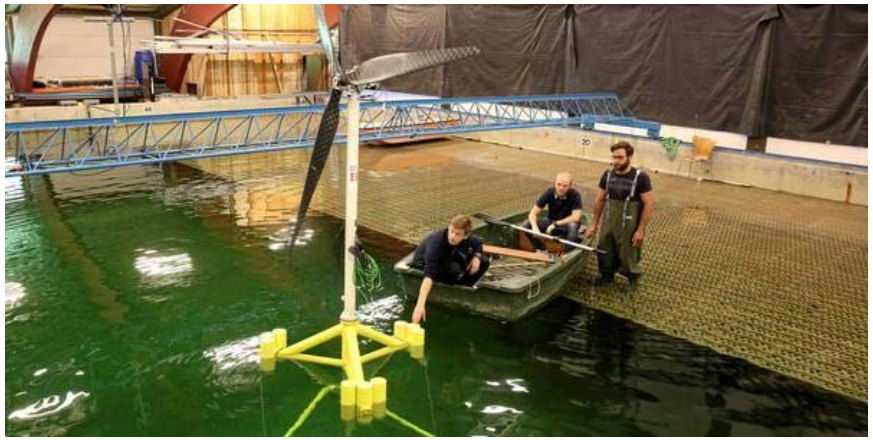
Experimental setup: wind turbine model

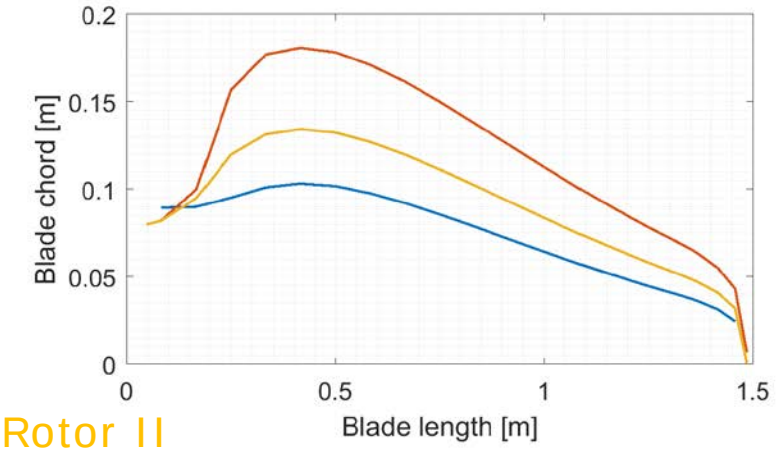
- DTU 10MW RWT 1:60 scale model from previous campaigns [1-3]
  - Match steady thrust curve – 75% increased chord → Rotor I
  - Collective blade pitch control

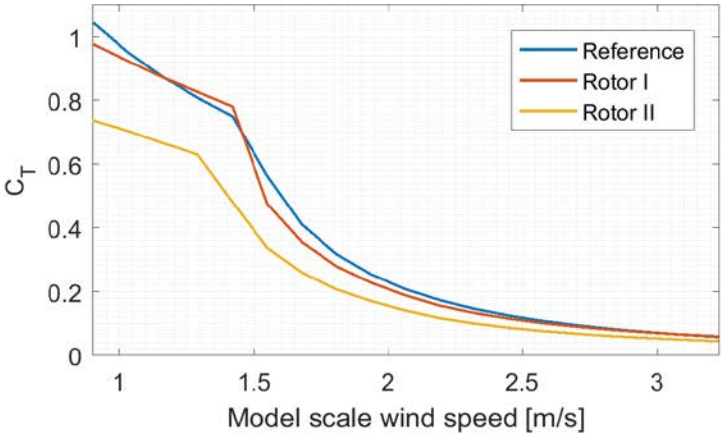


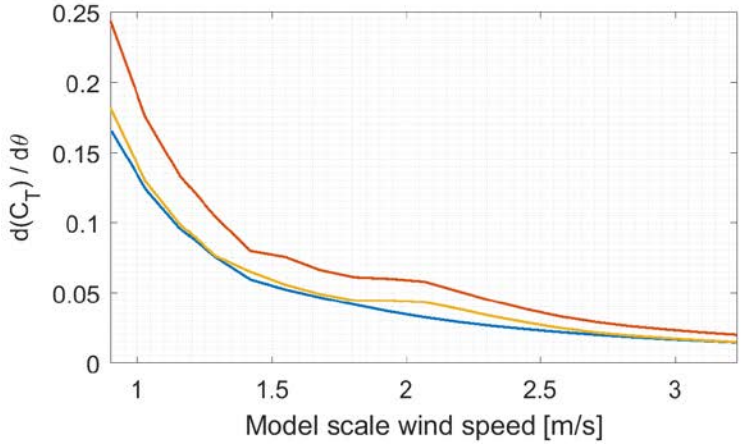
- New rotor design
  - Match $d(C_T)/d\theta$ – 30% increased chord → Rotor II
  - Steady thrust mismatch
  - ***Improve aerodynamic damping***

Dimension	Prototype Scale	Froude Model Scale	Actual Model Scale (incl. instrumentation)	
Tower			**Rotor I**	**Rotor II**
Diameter	7.82m-5.50m	130mm-92mm	80mm	80mm
Tower length	95.6m	1594mm	1682mm	1682mm
Hub height above MSL	119m	1983mm	2070mm	2070mm
Mass	469t	2.12kg	2.250kg	2.250kg
Nacelle and rotor			**Rotor I**	**Rotor II**
Rotor diameter	178.3m	2972mm	2972mm	2972mm
Blade Length	86.5m	1440mm	1440mm	1440mm
Blade mass	41.7t	0.188kg	0.198kg	0.192kg
Nacelle+hub mass	552t	2.49kg	2.896kg	2.896kg
Nacelle+hub+rotor mass	677t	3.06kg	3.490kg	3.472kg

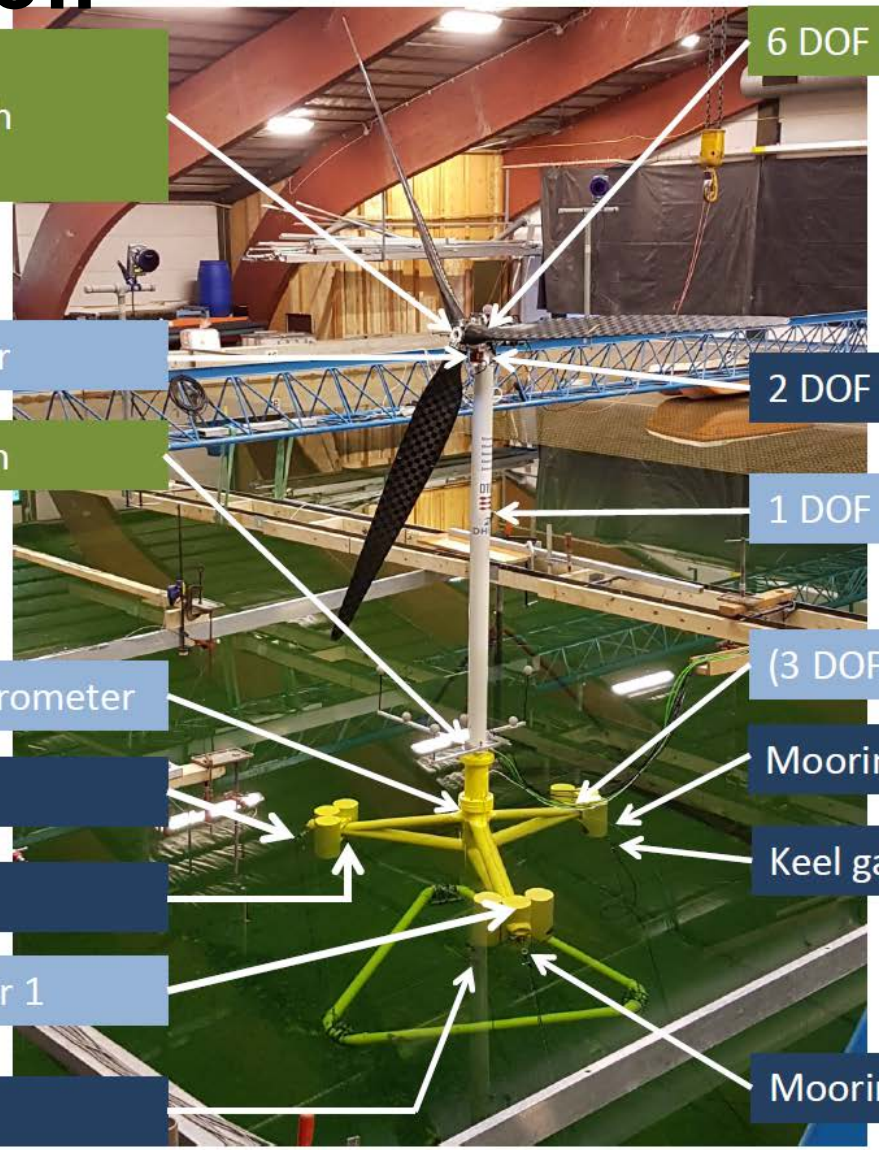








Experimental setup - instrumentation



Experimental program

Test matrix

Type	Direction [deg]	Duration [full scale minutes]	No wind	With wind
Free decays	-	variable (10 repetitions)	x	semisub only
Wind only	-	190		x
2D regular	0	20	x	x
2D irregular	0	190	x	x
2D focused	0	100 (8 repetitions)	x	x
2D regular	30	20	x	x
2D irregular	30	190	x	x
White noise	0	190	x	x
Start-up/shut-down	0	100 (5 repetitions)		x
Start-up/shut-down	30	100 (5 repetitions)		semisub only
Skewed inflow condition - semisub only				
2D regular	0	20	x	x
2D irregular	0	190	x	x
2D focused	0	100 (8 repetitions)	x	x
2D regular	30	20	x	x
2D irregular	30	190	x	x

Environmental conditions

		Full scale			Model scale			
EC	**Type**	**U_{hub}** [m/s]	**H,H_s** [m]	**T,T_p** [s]	**U_{hub}** [m/s]	**H,H_s** [m]	**T,T_p** [s]	**Turbine operation**
3	below-rated	8.5	3.3	6.5	1.10	0.055	0.839	yes
5	rated	11.4	4.16	7.3	1.47	0.069	0.942	yes
6	above rated	18.0	6.18	8.9	2.32	0.103	1.149	yes
64	above rated	18.0	6.18	18.0	2.32	0.103	2.324	yes
11	ULS	18.0	10.5	14.2	2.32	0.175	1.833	idling
12	ULS	18.0	10.5	14.2	2.32	0.175	1.833	yes
W03	white noise	0.0	3.3	n/a	1.10	0.055	n/a	idling

Experimental program – selected results

Test matrix

Type	Direction [deg]	Duration [full scale minutes]	No wind	With wind
Free decays	-	variable (10 repetitions)	x	semisub only
Wind only	-	190		x
2D regular	0	20	x	x
2D irregular	0	190	x	x
2D focused	0	100 (8 repetitions)	x	x
2D regular	30	20	x	x
2D irregular	30	190	x	x
White noise	0	190	x	x
Start-up/shut-down	0	100 (5 repetitions)		x
Start-up/shut-down	30	100 (5 repetitions)		semisub only
Skewed inflow condition - semisub only				
2D regular	0	20	x	x
2D irregular	0	190	x	x
2D focused	0	100 (8 repetitions)	x	x
2D regular	30	20	x	x
2D irregular	30	190	x	x

Environmental conditions

		Full scale			Model scale			
EC	**Type**	**U_{hub}** [m/s]	**H,H_s** [m]	**T,T_p** [s]	**U_{hub}** [m/s]	**H,H_s** [m]	**T,T_p** [s]	**Turbine operation**
3	below-rated	8.5	3.3	6.5	1.10	0.055	0.839	yes
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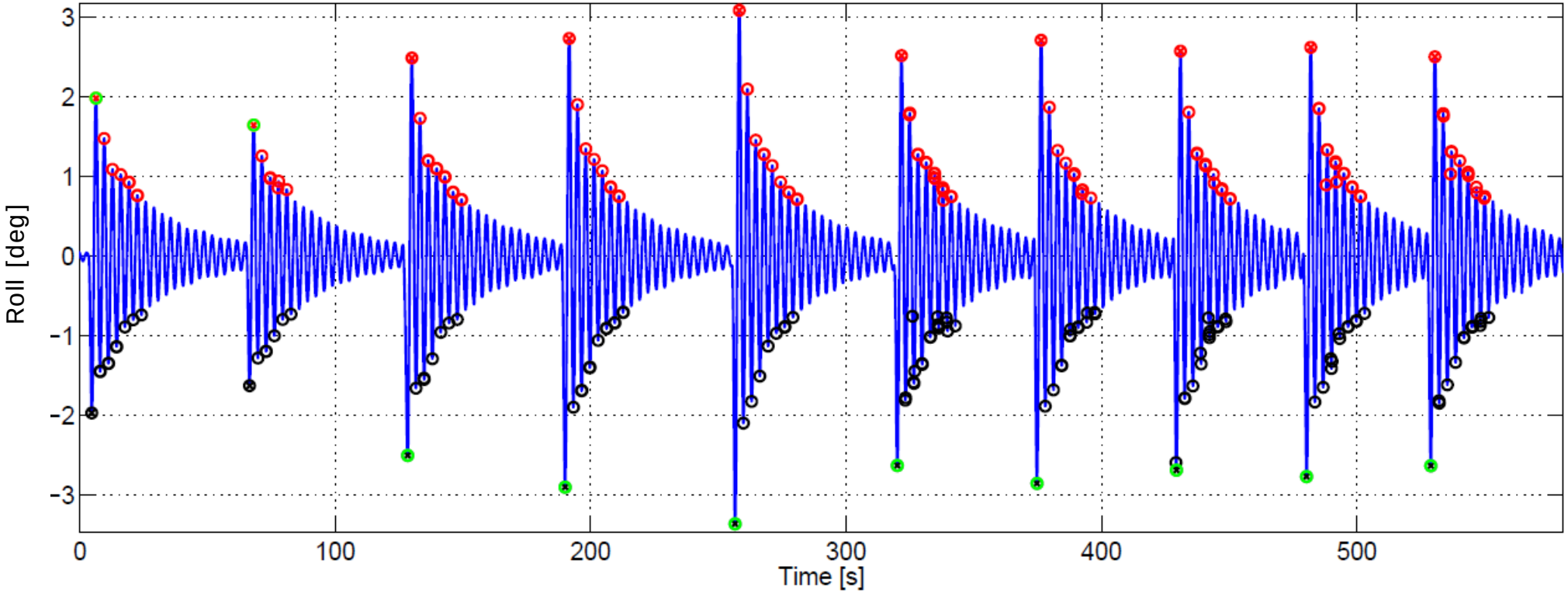
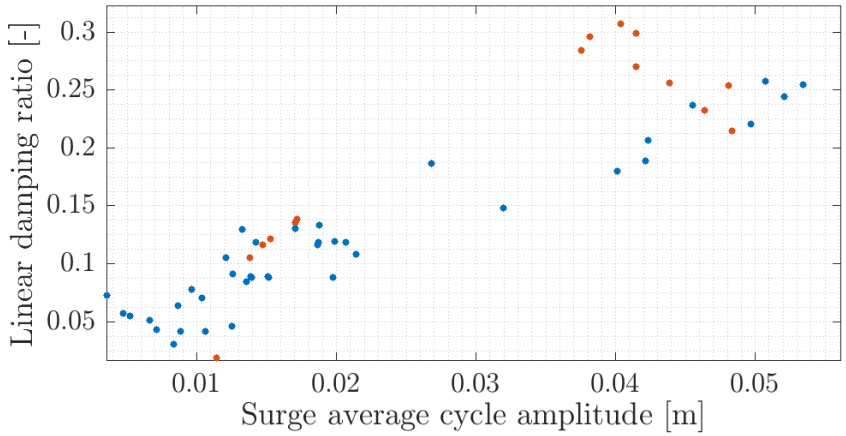
W03	white noise	0.0	3.3	n/a	1.10	0.055	n/a	idling

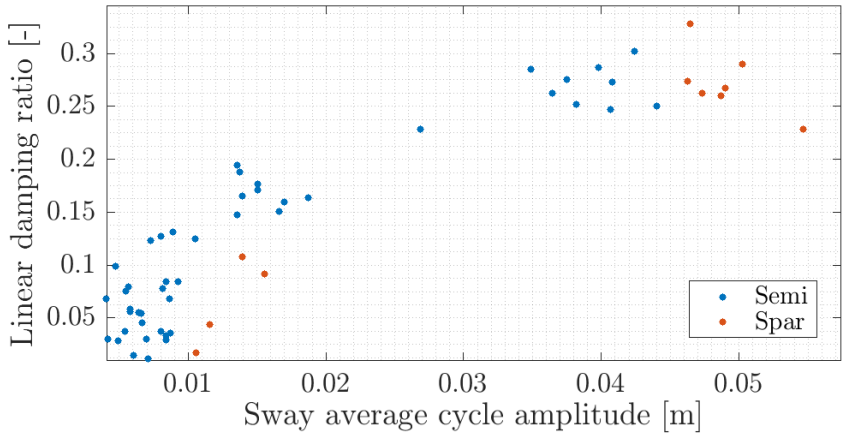
- System damping
- Dynamic response of both configurations in ULS condition (EC11)
- Dynamic response of spar in focused wave group

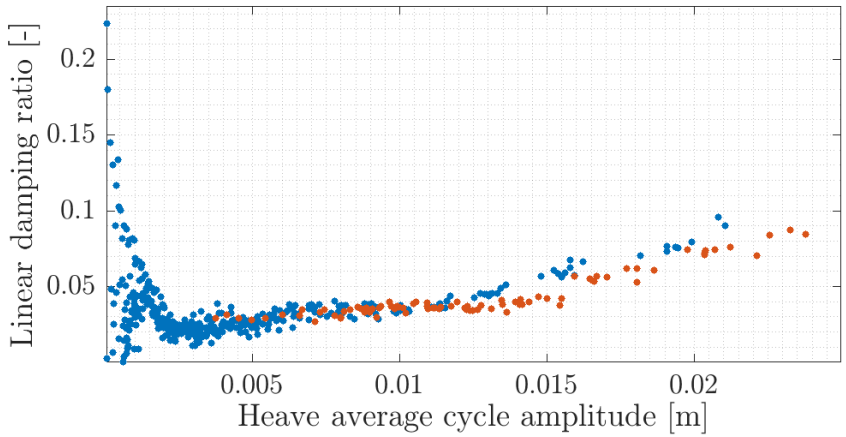
Results – system damping

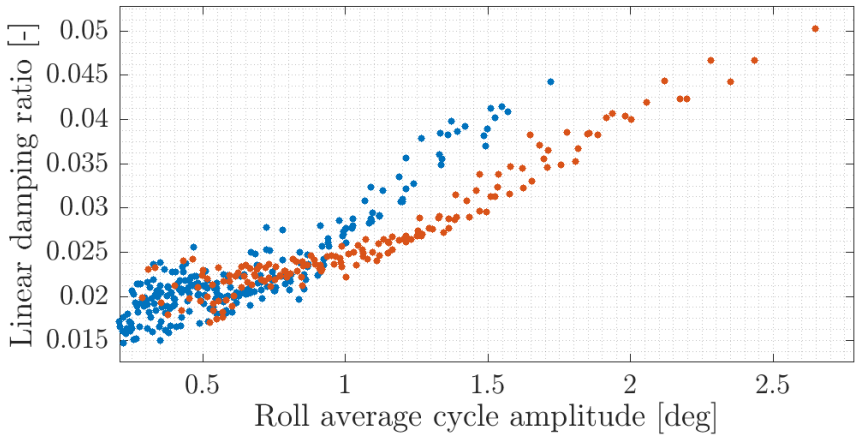
- Identification of system damping – free decay tests in 6 DOF, 10 repetitions
- Roll example:

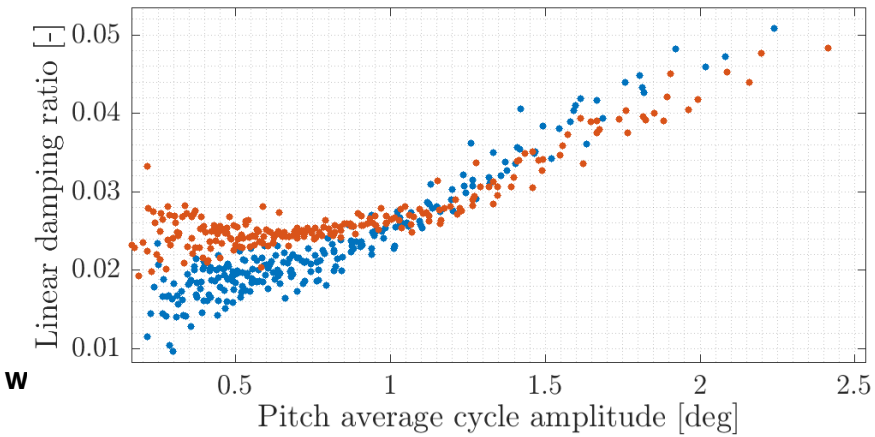


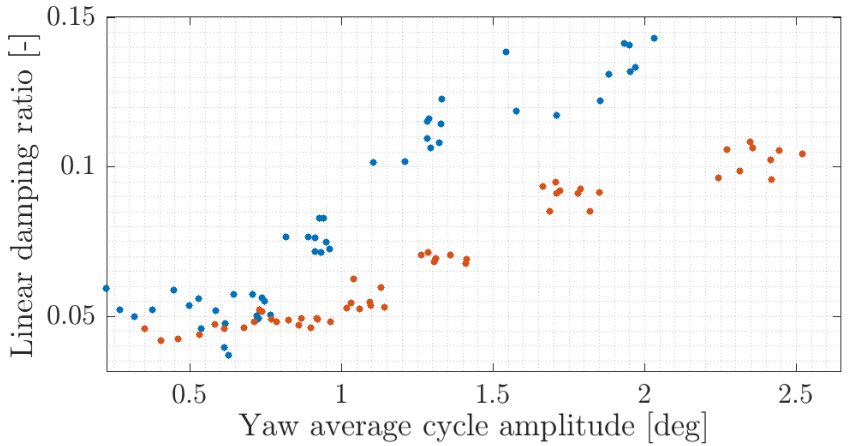

Linear damping ratio [-]
0.3
0.25
0.2
0.15
0.1
0.05
0.01
0.02
0.03
0.04
0.05
Surge average cycle amplitude [m]


Linear damping ratio [-]
0.3
0.25
0.2
0.15
0.1
0.05
0.01
0.02
0.03
0.04
0.05
Sway average cycle amplitude [m]
Semi
Spar

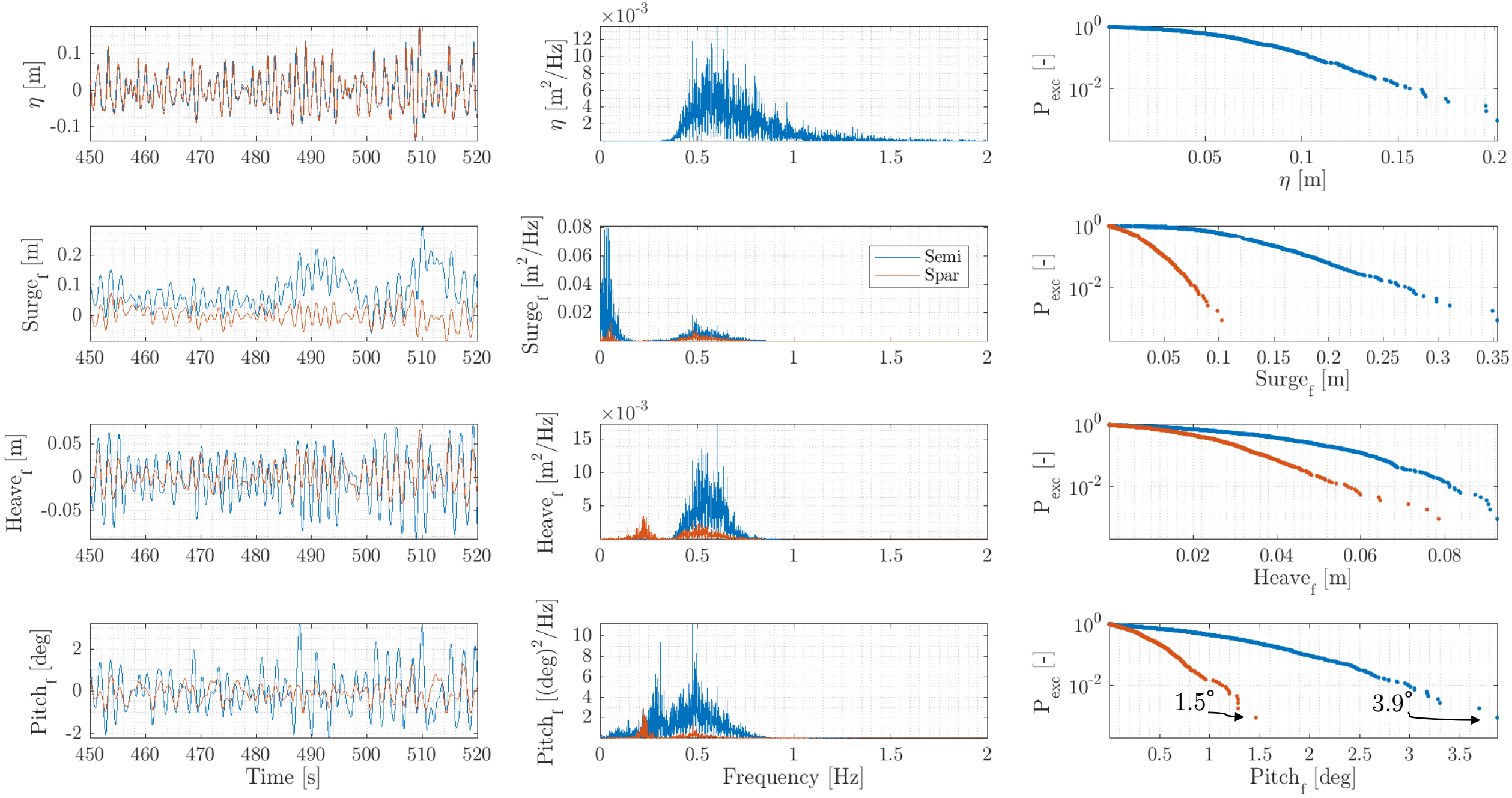

Linear damping ratio [-]
0.2
0.15
0.1
0.05
0.005
0.01
0.015
0.02
Heave average cycle amplitude [m]


Linear damping ratio [-]
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.5
1
1.5
2
2.5
Roll average cycle amplitude [deg]

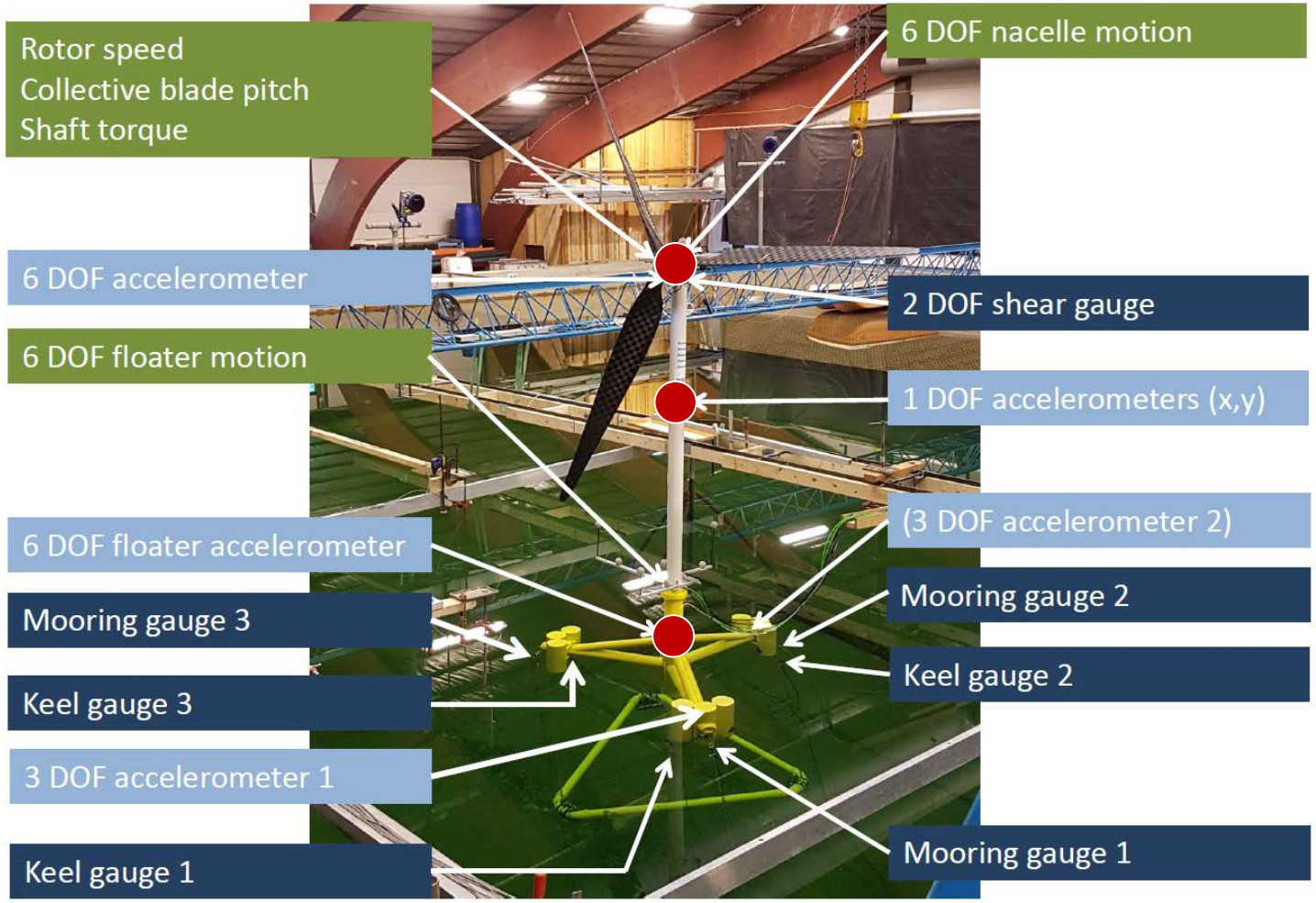

Linear damping ratio [-]
0.05
0.04
0.03
0.02
0.01
0.5
1
1.5
2
2.5
Pitch average cycle amplitude [deg]

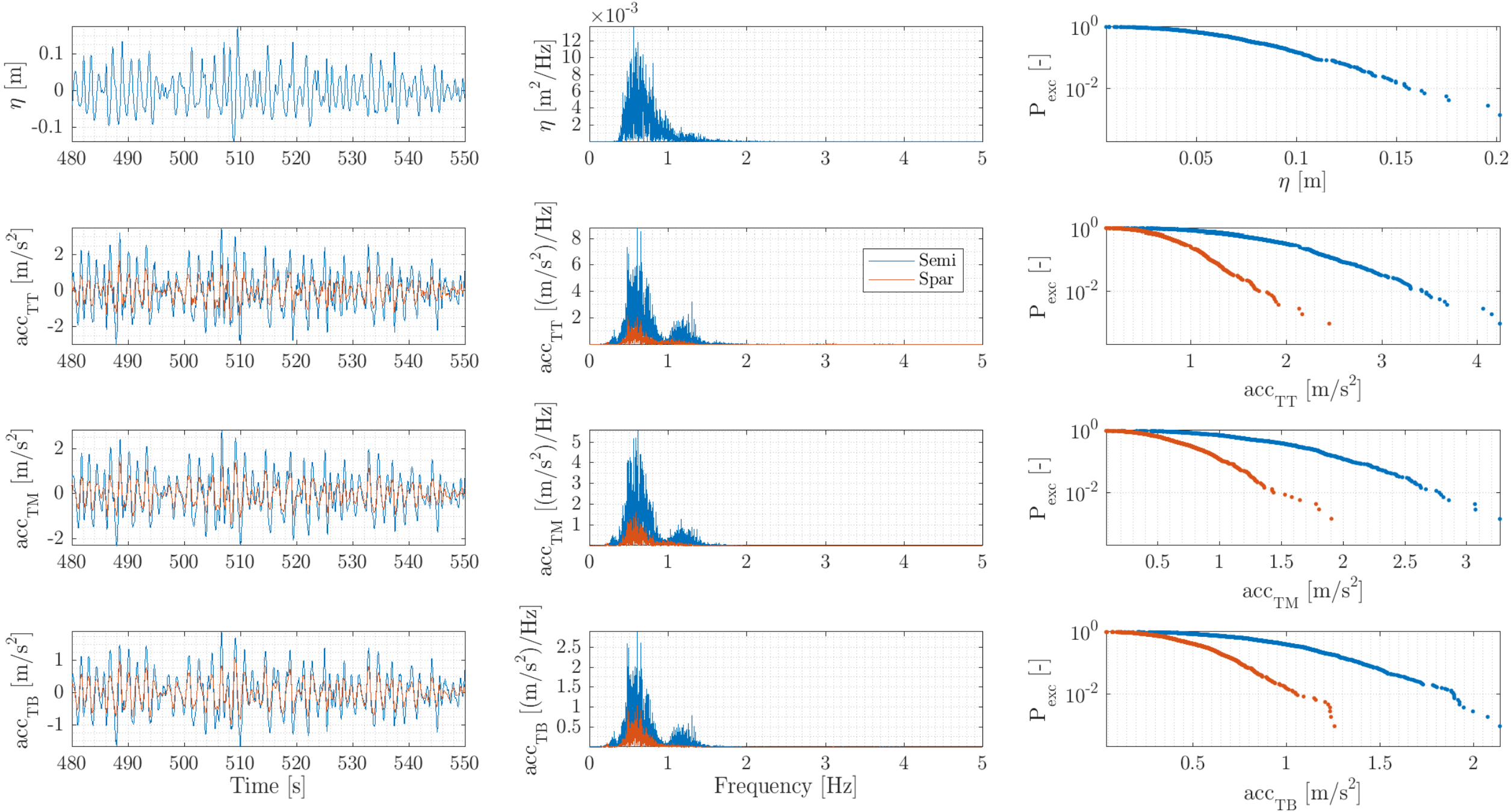

Linear damping ratio [-]
0.15
0.1
0.05
0.5
1
1.5
2
2.5
Yaw average cycle amplitude [deg]

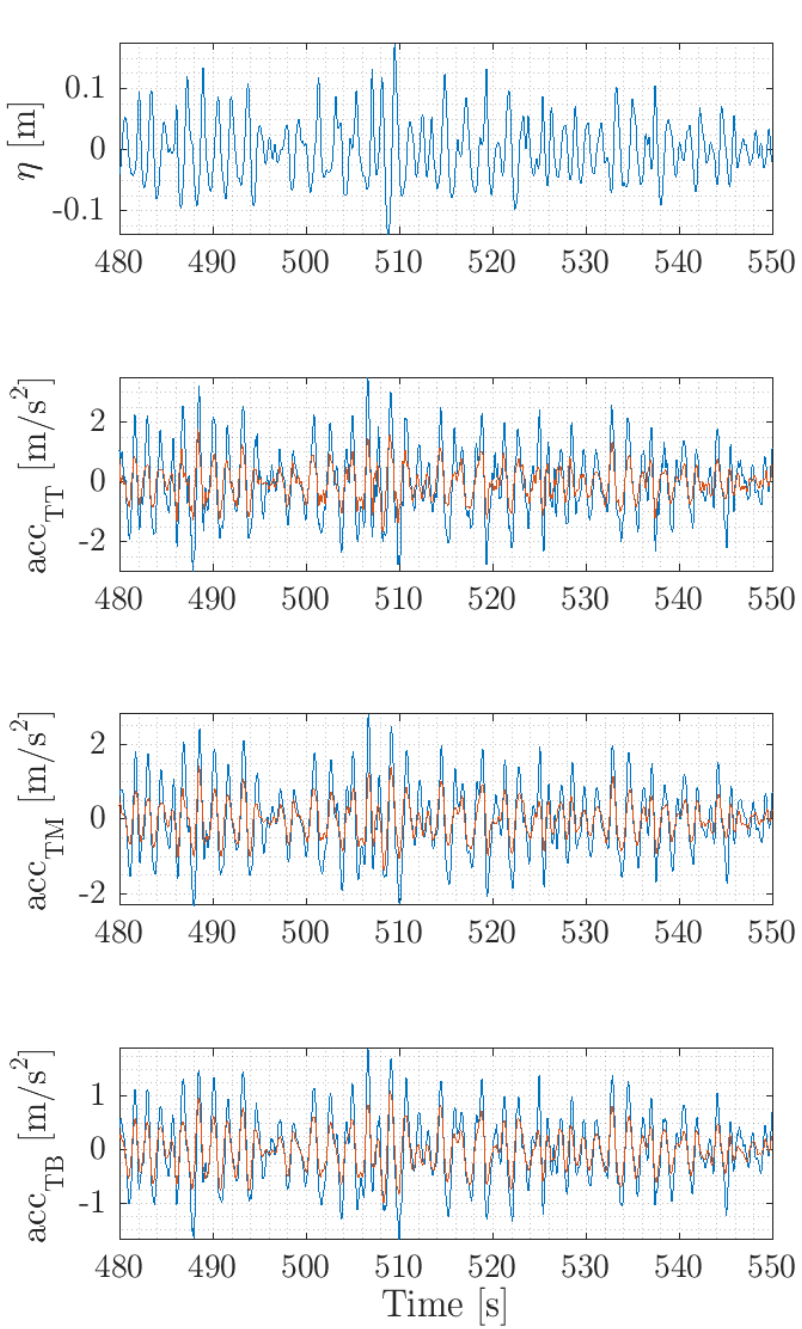
Results
ULS waves only
Motion response

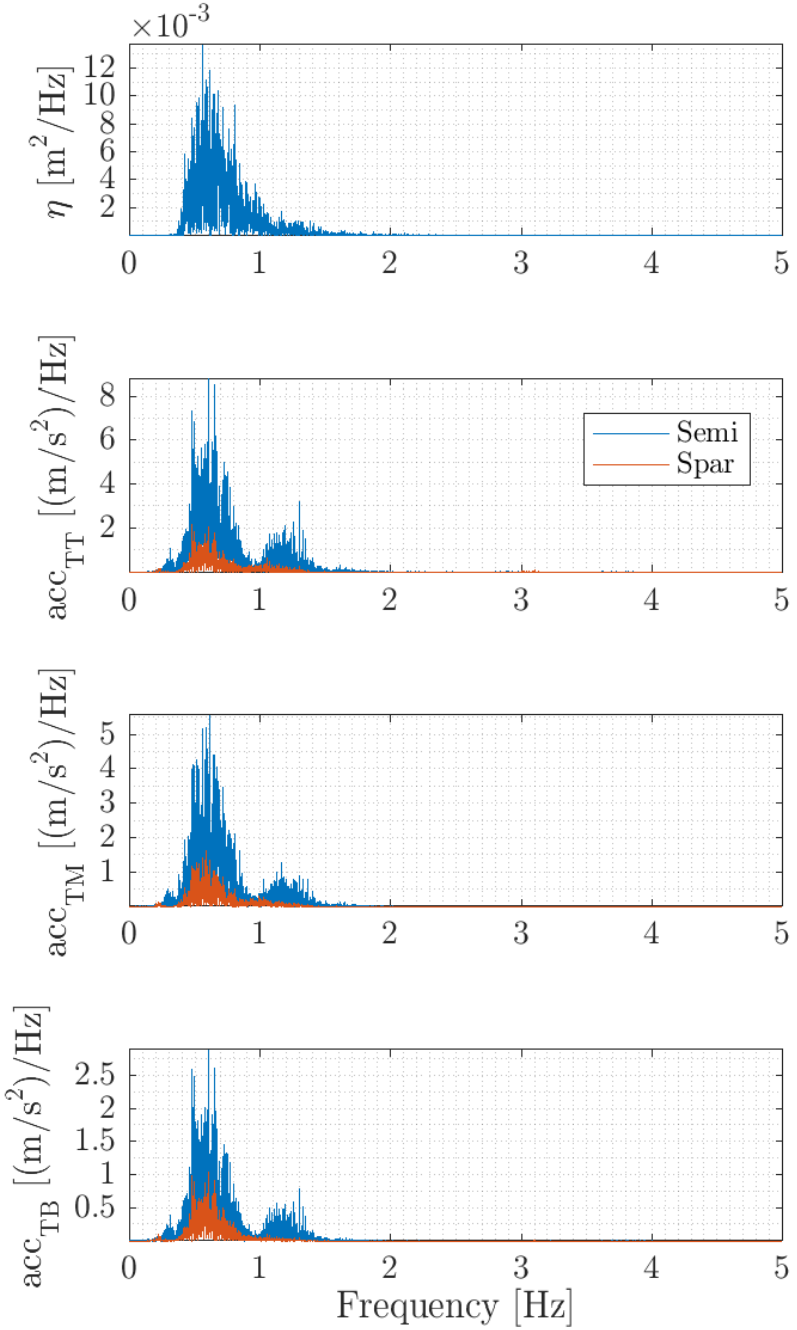

η [m]
Surge_f [m]
Heave_f [m]
Pitch_f [deg]
Time [s]
η [m²/Hz]
Surge_f [m²/Hz]
Heave_f [m²/Hz]
Pitch_f [(deg)²/Hz]
Frequency [Hz]
Semi
Spar
P_exc [-]
η [m]
Surge_f [m]
Heave_f [m]
Pitch_f [deg]
1.5°
3.9°

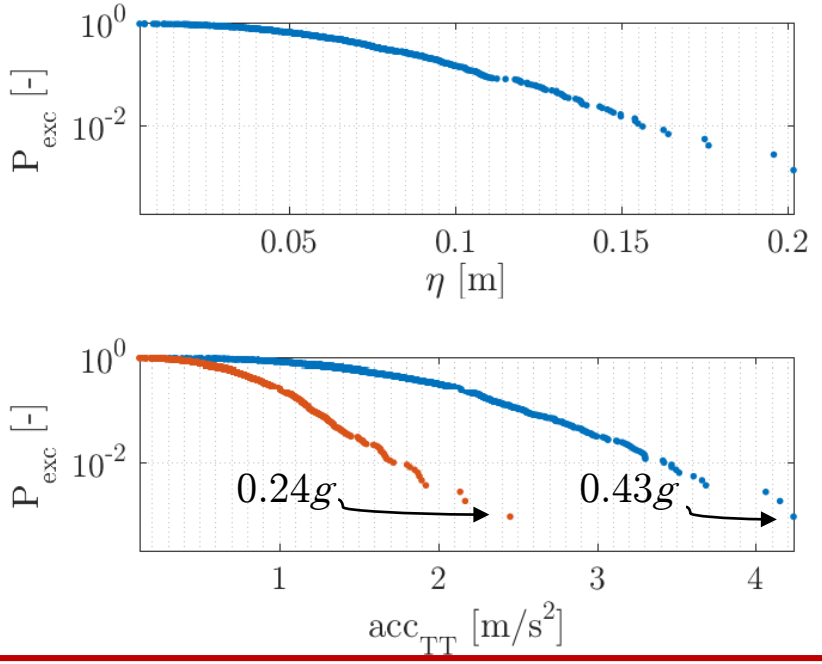
Results
ULS waves only
Acceleration response

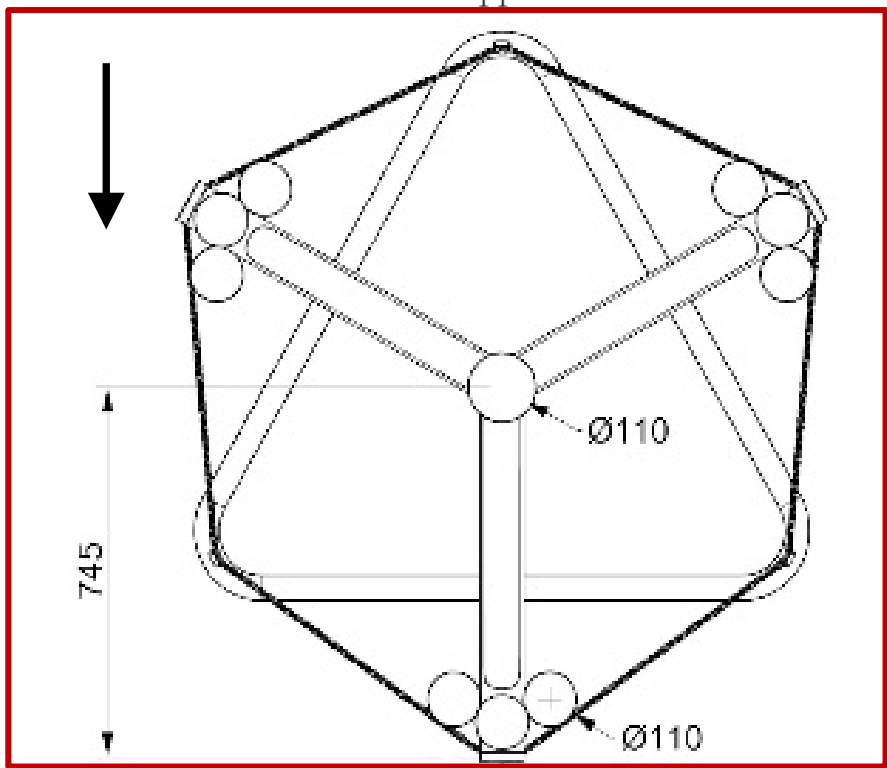



η [m]
η [m²/Hz]
×10⁻³
P exc [-]
η [m]
acc TT [m/s²]
acc TT [(m/s²)²/Hz]
Semi
Spar
acc TT [m/s²]
acc TM [m/s²]
acc TM [(m/s²)²/Hz]
acc TM [m/s²]
acc TB [m/s²]
acc TB [(m/s²)²/Hz]
acc TB [m/s²]
Time [s]
Frequency [Hz]

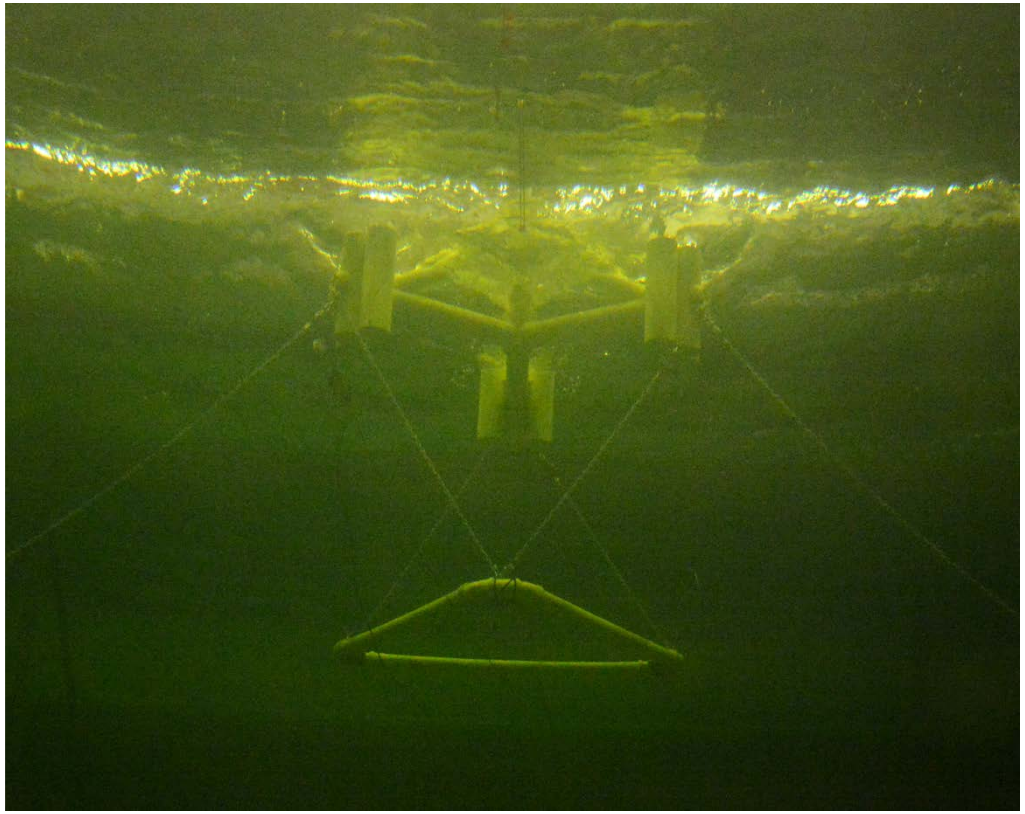

η [m]
acc_TT [m/s²]
acc_TM [m/s²]
acc_TB [m/s²]
Time [s]

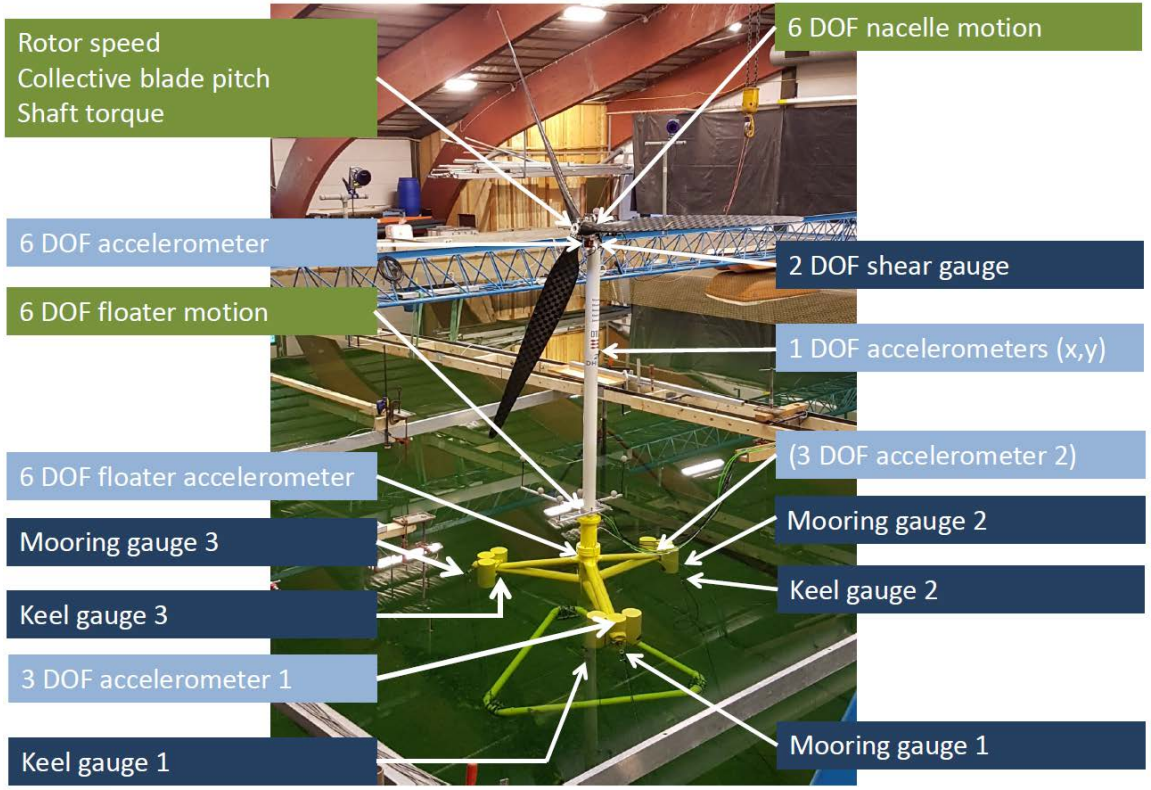

×10⁻³
η [m²/Hz]
acc_TT [(m/s²)²/Hz]
acc_TM [(m/s²)²/Hz]
acc_TB [(m/s²)²/Hz]
Semi
Spar
Frequency [Hz]

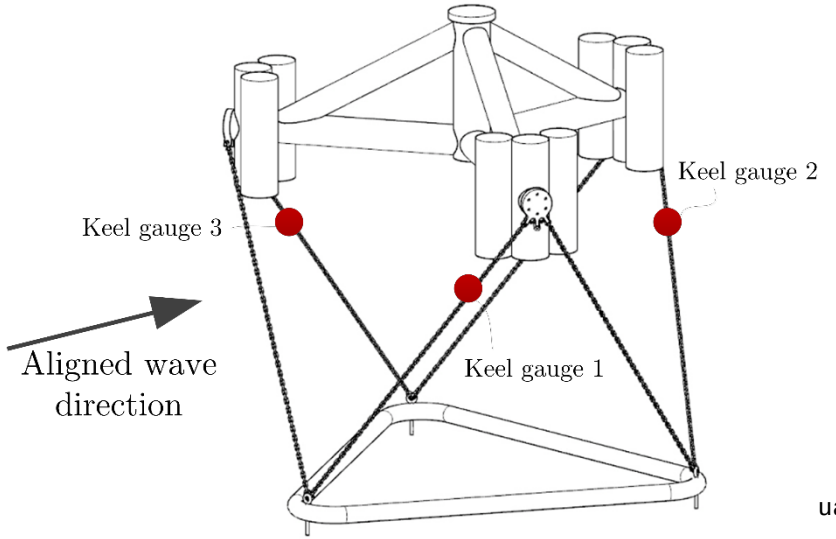

P_exc [-]
η [m]
0.24g
0.43g
acc_TT [m/s²]


745
Ø110
Ø110

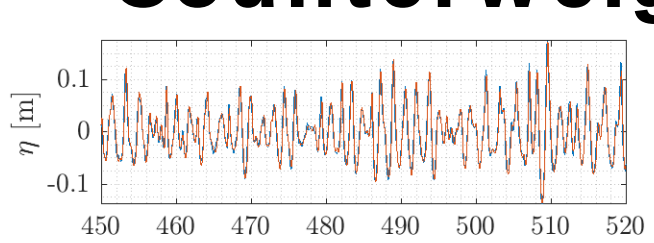
Results
ULS waves only
Counterweight line tensions

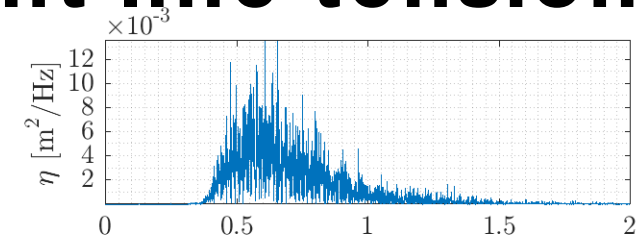


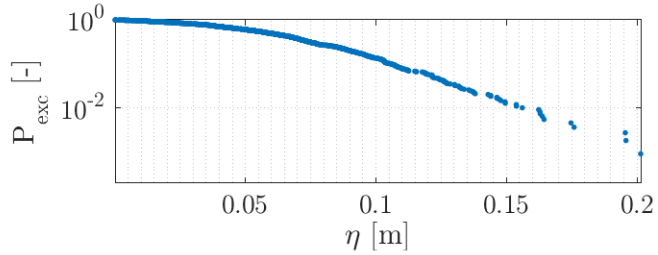


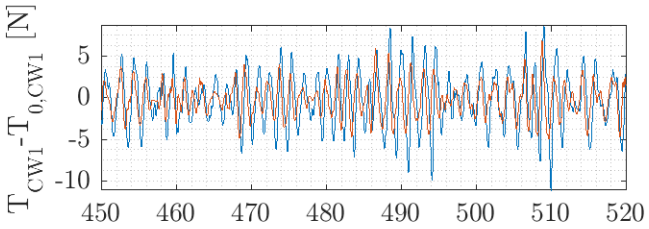


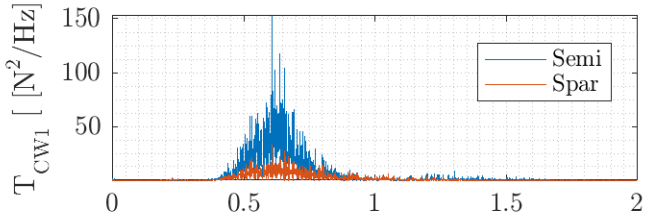
Results
ULS waves only
Counterweight line tensions

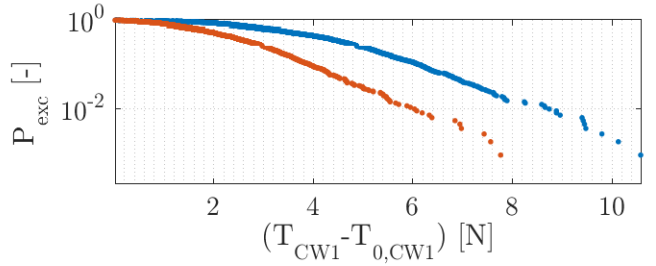


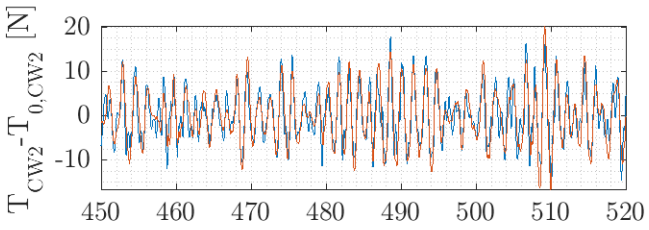


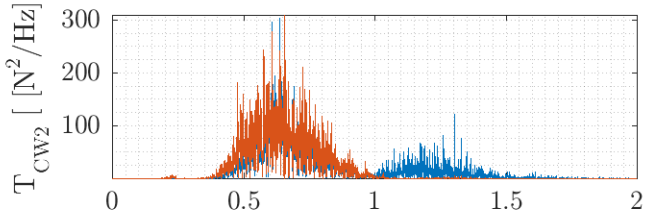


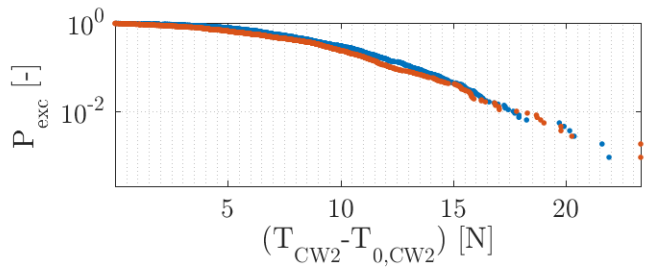


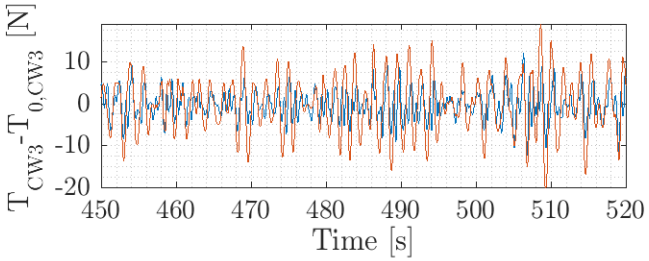


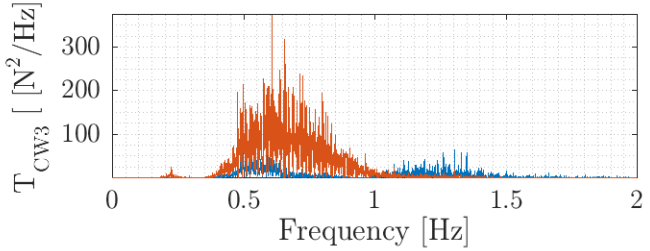


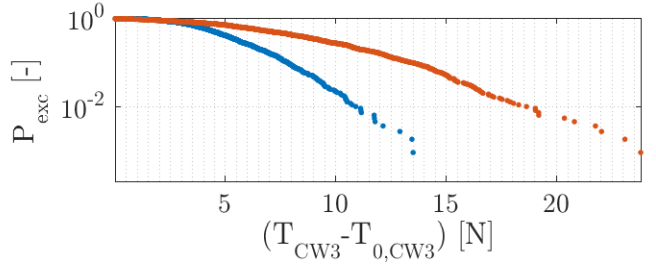


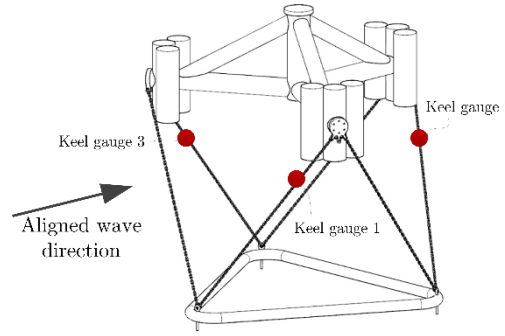


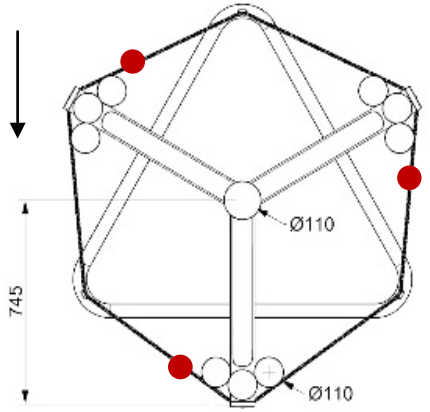




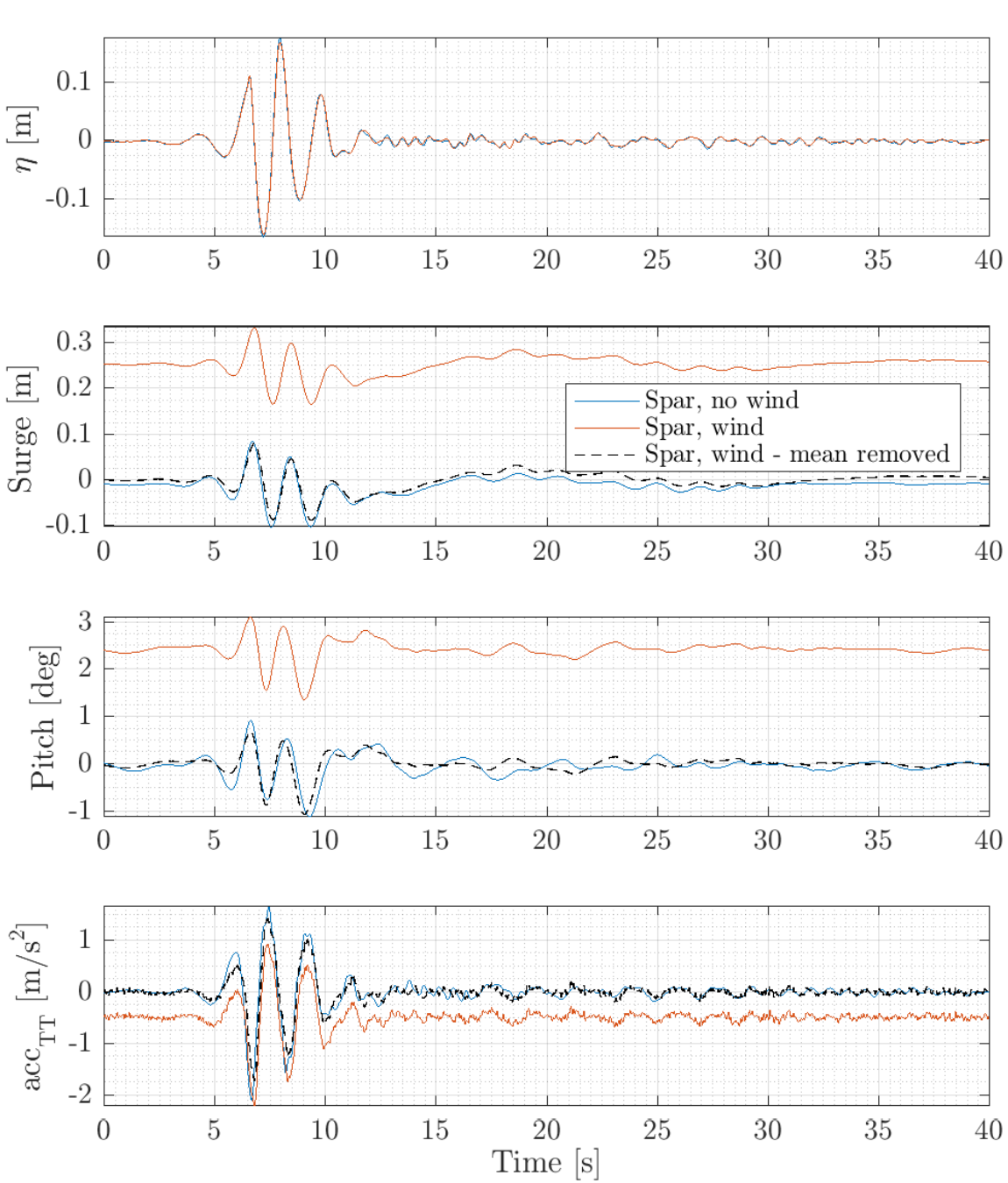


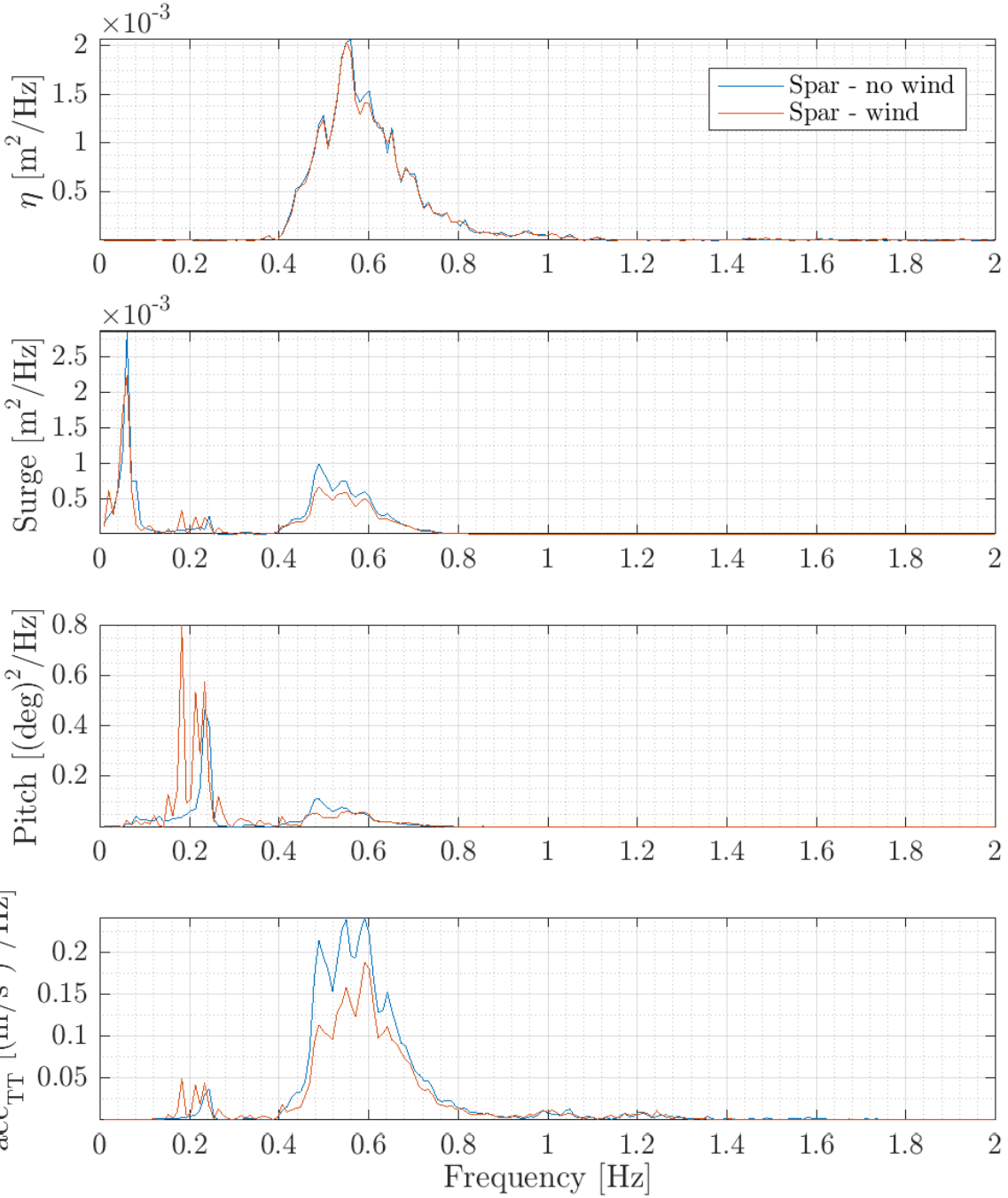






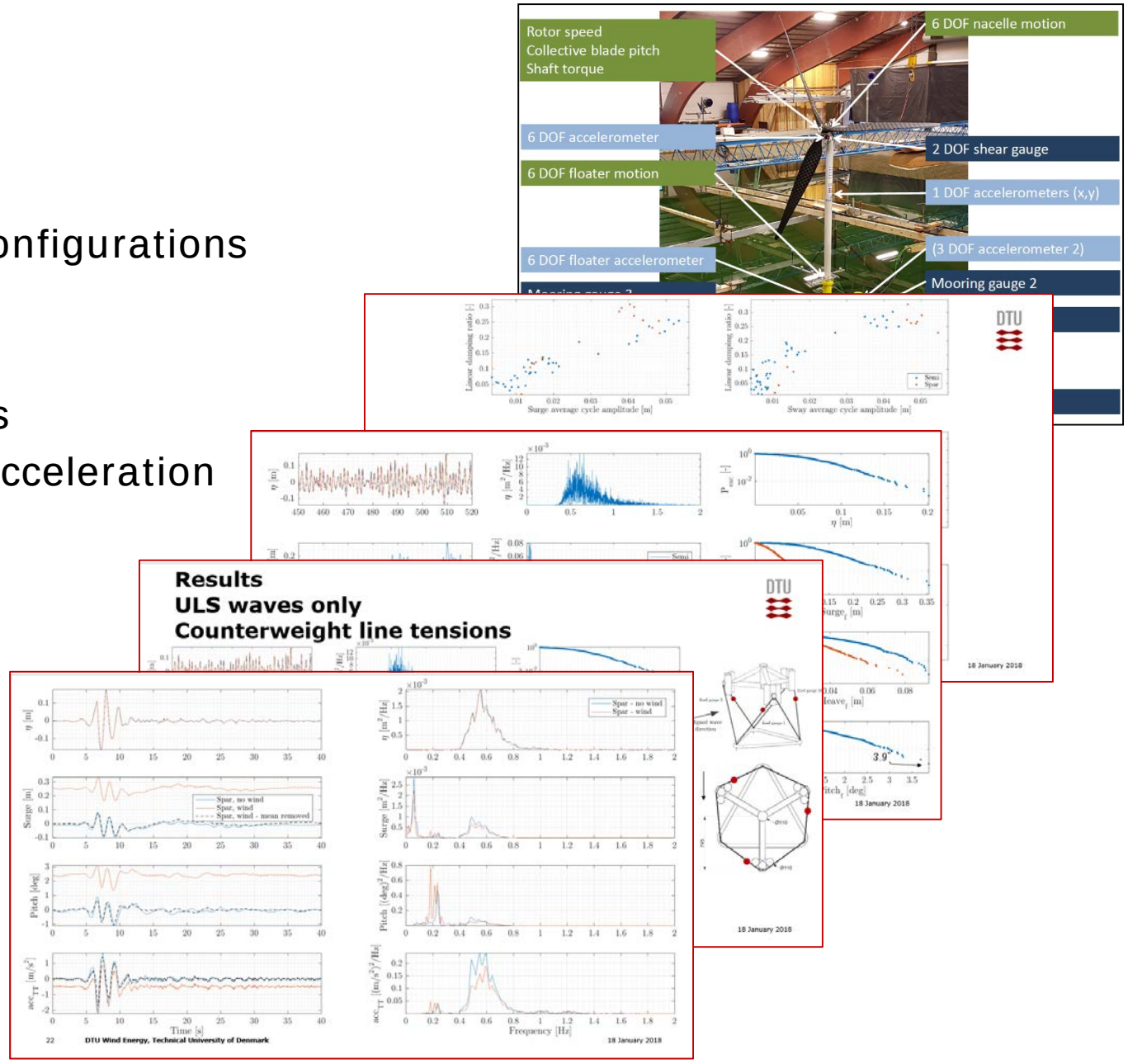
Results
Focused wave group – EC11 – H = 0.33m (19.5m)
Spar response


η [m]
Surge [m]
Spar, no wind
Spar, wind
Spar, wind - mean removed
Pitch [deg]
acc_TT [m/s^2]
Time [s]


×10^-3
η [m^2/Hz]
Spar - no wind
Spar - wind
Surge [m^2/Hz]
Pitch [(deg)^2/Hz]
acc_TT [(m/s^2)^2/Hz]
Frequency [Hz]

Conclusions

- Testing of TetraSpar in semi and spar configurations
- Nonlinear system damping
- Significant subharmonic wave forcing
- C/W tensions dominated by inertia loads
- WT operation observed to reduce max acceleration



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[3] F. J. Madsen, T. R. L. Nielsen, Experimental and numerical study of the scaled DTU 10MW floating wind turbine on a TLP platform, MSc thesis, Department of Wind Energy, Technical University of Denmark, (2017).


Thank you for your attention
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