Initial Design of a 12 MW Floating Offshore Wind turbine

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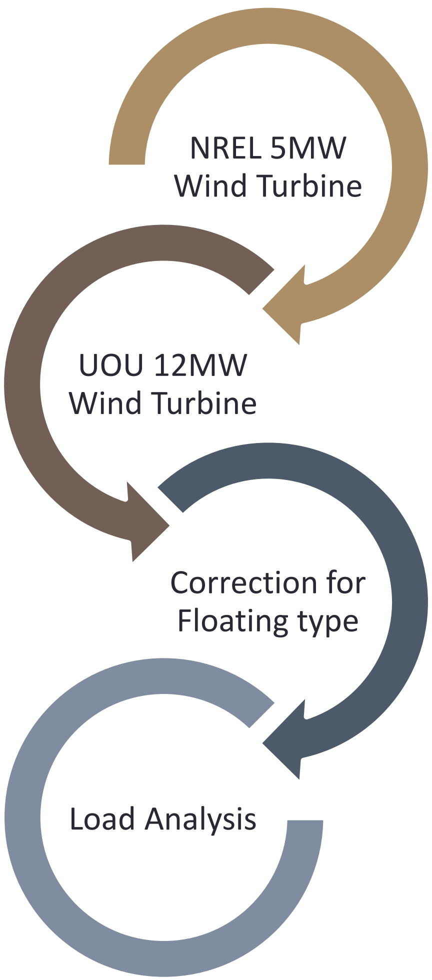
Outline

- 12MW FOWT design
- Numerical Simulation
- Design Load Cases
- Results
- Conclusion

12MW FOWT Design

UOU 12MW Wind Turbine Model

Design Process

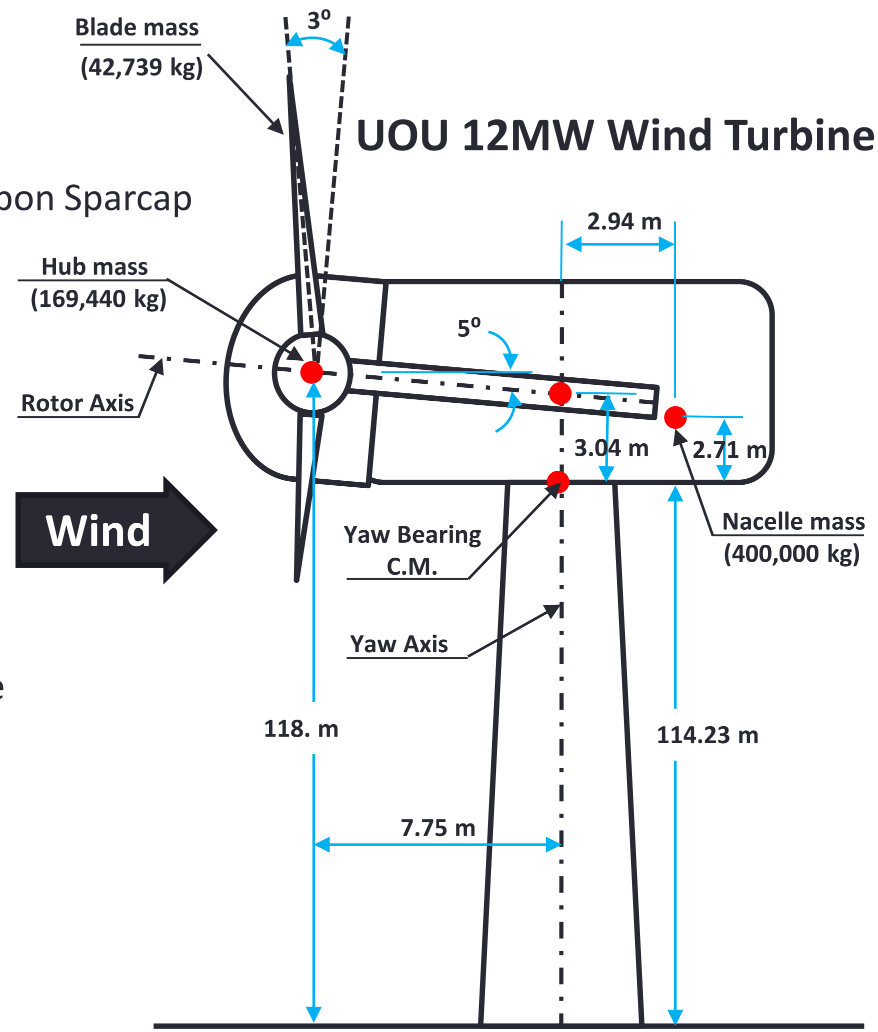


- Upscaling process
  SCSG/Flexible Shaft/Carbon Sparcap

- Blade (CFRP)
- Tower
- Control
- Platform

- Optimized platform
- Negative damping issue
- Tower 3P issue

- IEC61400-1
- IEC61400-3
- IEC61400-3-2



12MW Blade Scale ratio

- $P = C_p * \frac{1}{2} \rho A V^3$
- $\lambda_{Blade} = \sqrt{\frac{P_{12MW}}{P_{5MW}}} = 1.549$

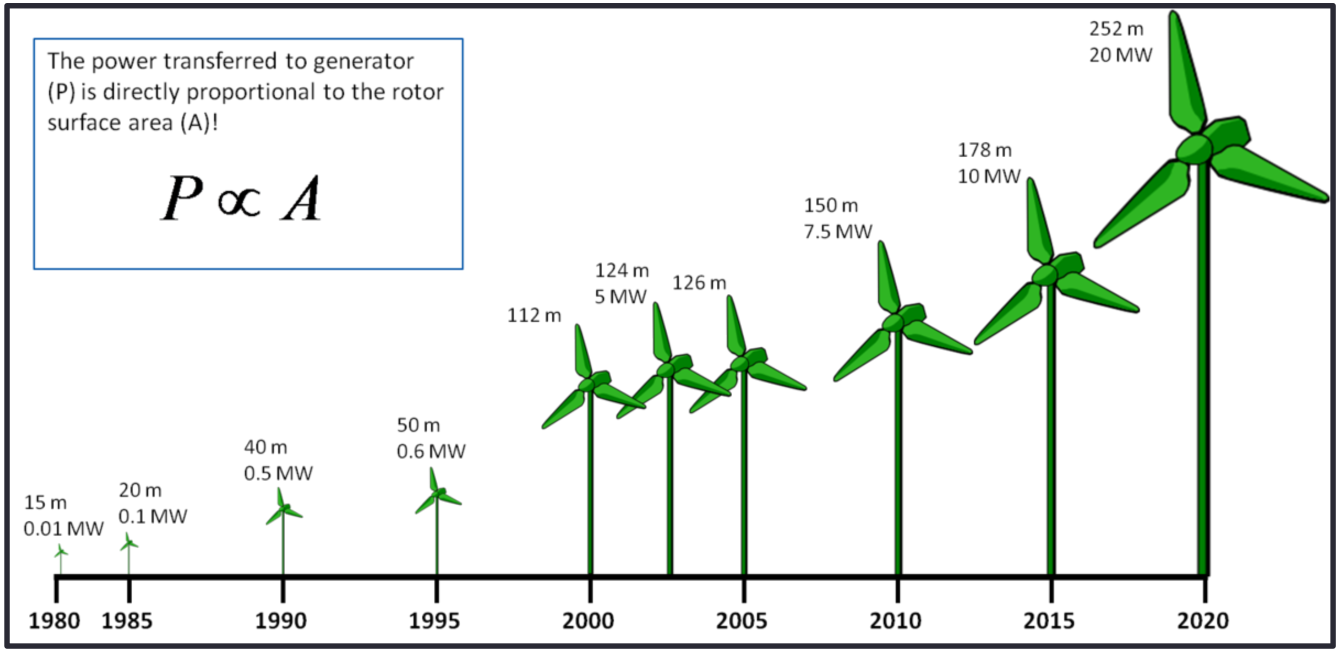
P : Rotor power (kW)

ρ : Air density $(1.225\ kg/m^3)$

A : Rotor swept area (m^3)

V : Wind speed (m/s)

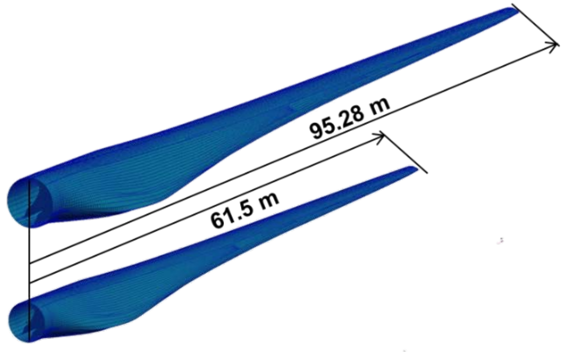
λ_{Blade} : Blade Scale Ratio



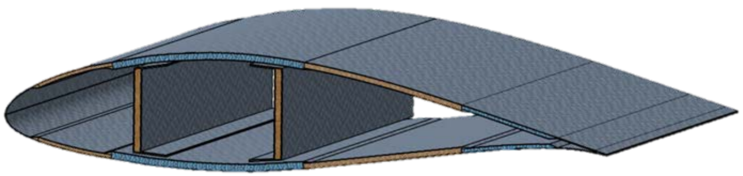
Source : EWEA, Wind energy—the facts: a guide to the technology, economics and future of wind power, 2009.

12MW Carbon blades

- **61.5 (m) 5MW glass blade : 17.7 ton**
  - **→ 95.28 (m) 12MW glass blade : 62.6 ton (Too heavy)**
  - **→ 95.28 (m) 12MW carbon (sparcap) blade : 42.7 ton**



Sparcap
(43% of the total weight – 5MW class IIA)



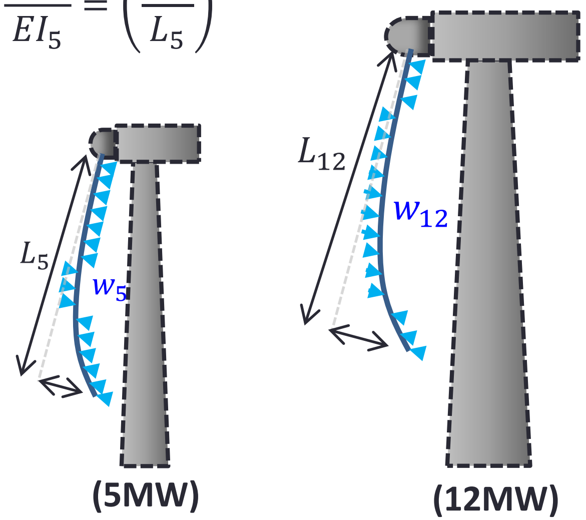
	0^o Stiffness [Gpa]	Density [kg/m^3]	Blade Weight [ton]	Center of Gravity [m]
CFRP	130	1572	42.7 (Carbon Sparcap)	31.8
GFRP	41.5	1920	62.6	31.8

Source : H. G. Lee, Korea Institute of Materials Science(KIMS)

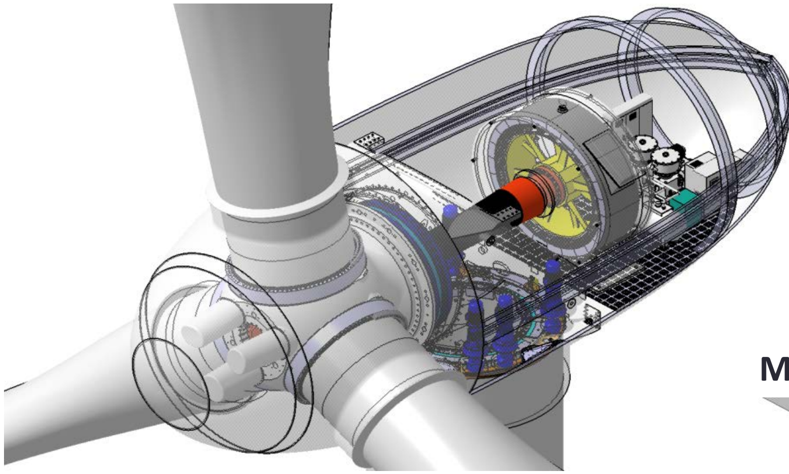
N.F. [Hz]	1st Flapwise	2nd Flapwise	1st Edgewise	2nd Edgewise
12MW Blade	0.5770	1.6254	0.8920	3.2676

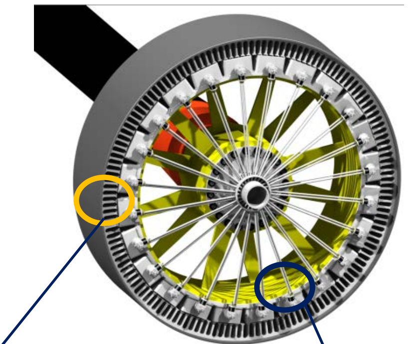
- Scale-up blade properties(deflection)

$$\frac{EI_{12}}{EI_5} = \left(\frac{L_{12}}{L_5}\right)^4$$

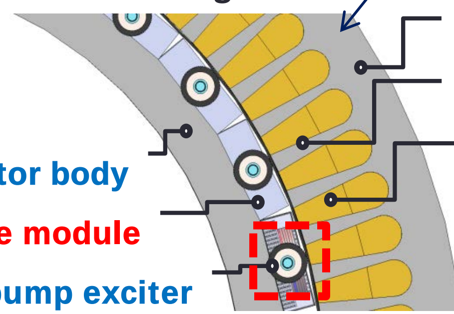


12MW Super conductor synchronous generator

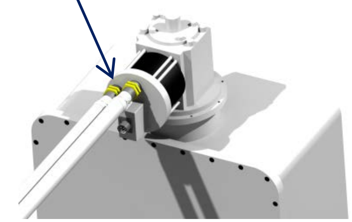




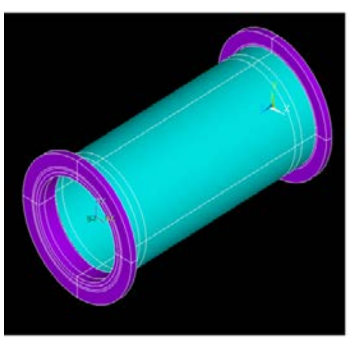
Modularized generator

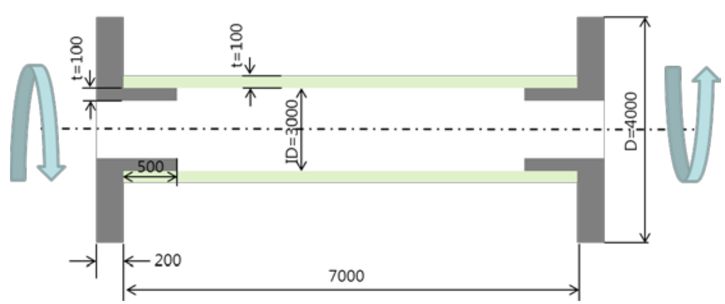


Cooling pipes



Flexible shaft

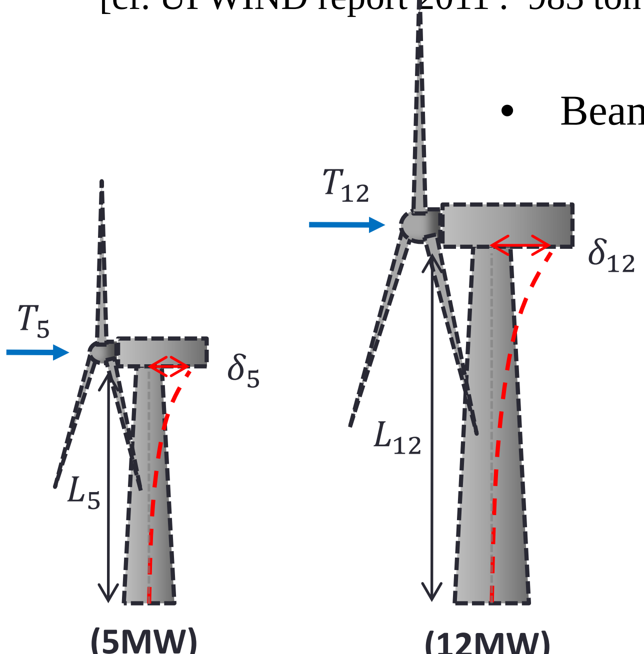




12MW Tower properties

▣ Scale up using <u>offshore tower</u> from OC4 definition

▣ 12MW “Material : steel, Height : 110.88 m, Weight : <u>781.964 ton</u> (scale-up)”
[cf. UPWIND report 2011 : 983 ton (10MW), 2,780 ton (20MW)]



- Beam deflection $\delta = \dfrac{TL^3}{3EI}$ $\qquad \dfrac{\delta_{12}}{\delta_5} = \dfrac{L_{12}}{L_5}$ $\qquad \dfrac{T_{12}}{T_5} = \dfrac{12\text{ MW}}{5\text{ MW}}$

- Scale-up tower properties $\qquad T = C_t * \dfrac{1}{2}\rho A V^2$

$$\boxed{\dfrac{EI_{12}}{EI_5} = \dfrac{12L_{12}^2}{5L_5^2}}$$

(Beam deflection)

- Tower scale ratio

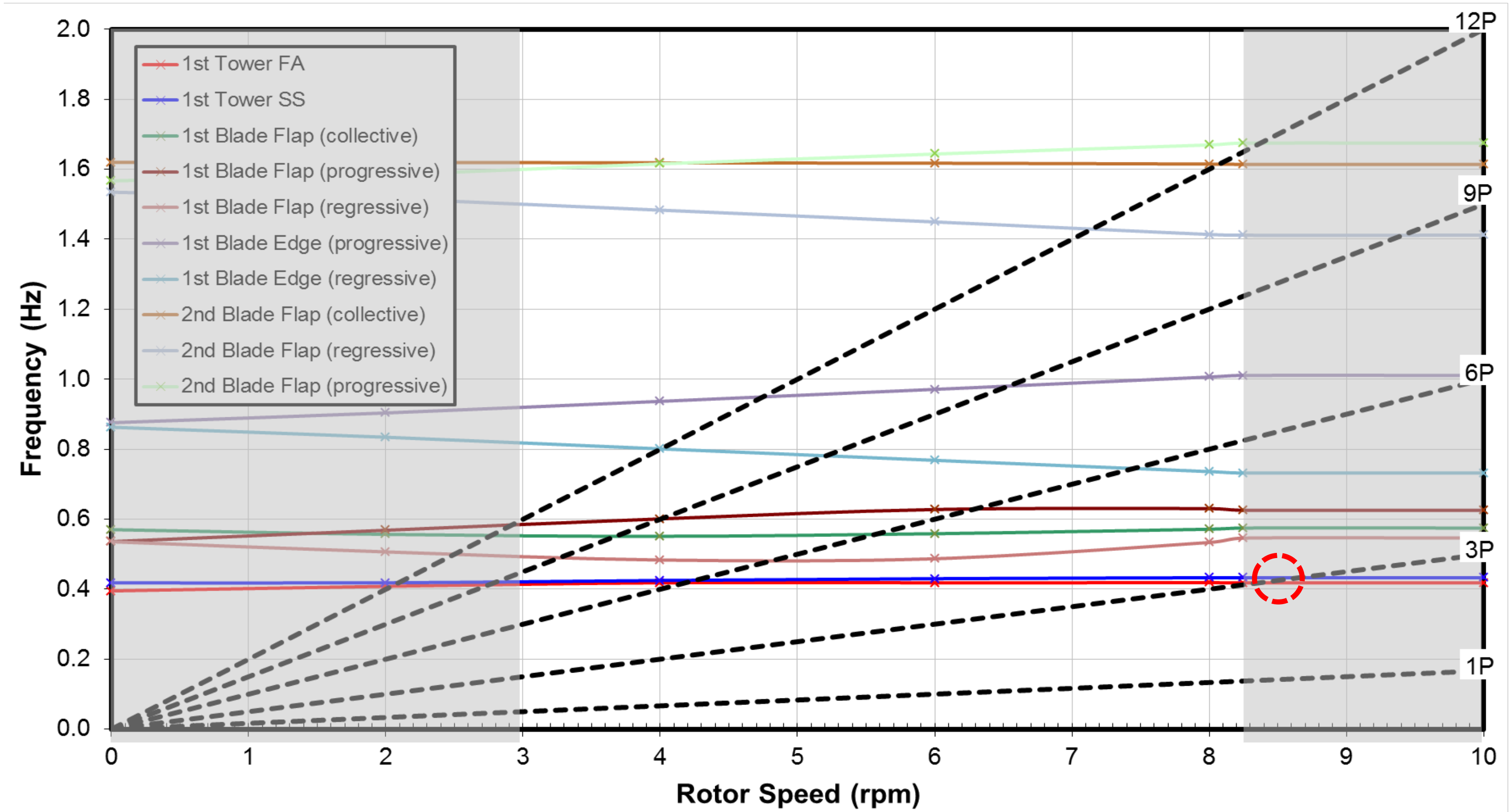
$$\lambda_T = \sqrt[4]{\frac{EI_{12}}{EI_5}} = \sqrt[4]{\frac{12L_{12}^2}{5L_5^2}} = 1.482$$

	Tower height	Tower-base diameter	Tower-base thickness	Tower-top diameter	Tower-top thickness	Tower mass
5MW	77.6 m	6.5 m	0.027 m	3.87 m	0.019 m	249,718 kg
12MW	110.88 m	9.634 m	0.040 m	5.736 m	0.028 m	781,964 kg
12MW R1	104.23 m	9.634 m	0.040 m	5.736 m	0.028 m	735,066 kg

12MW Campbell diagram (Tower Redesign)

- ▣ **Tower Length : 104.23 m**
- ▣ **Tower Mass : 735,066 kg**

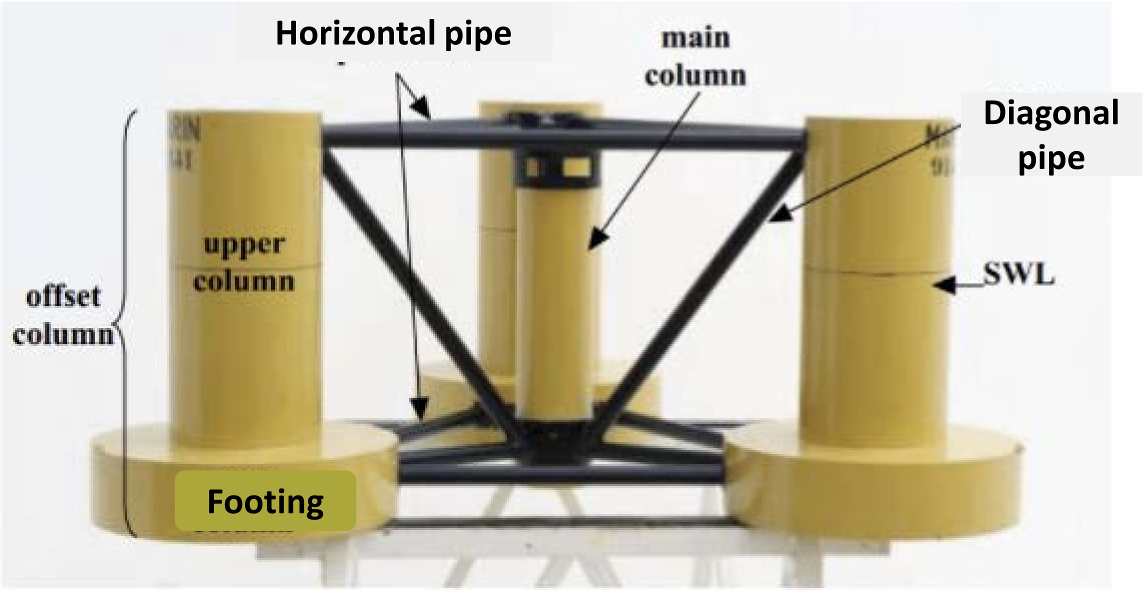
- ▣ **Rotor speed : 8.25 rpm**
  - ➢ Rotor 3P-Excitation : 0.4125
  - ➢ Tower 1st Side to Side Natural Frequency : 0.4337



Design Summary

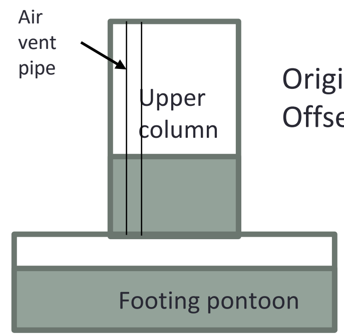
Rating	5 MW	12 MW
Rotor Orientation	Upwind, 3 Blades	Upwind, 3 Blades
Control	Variable Speed, Collective Pitch	Variable Speed, Collective Pitch
Drivetrain	High Speed, Multiple-Stage Gearbox	Low Speed, Direct Drive(gearless)
Rotor, Hub Diameter	126 m, 3 m	195.2 m, 4.64 m
Hub Height	90 m	118 m
Cut-In, Rated, Cut-Out Wind Speed	3 m/s, 11.4 m/s, 25 m/s	3 m/s, 11.2 m/s, 25 m/s
Cut-In, Rated Rotor Speed	6.9 rpm, 12.1 rpm	3.03 rpm, 8.25 rpm
Overhang, Shaft Tilt, Pre-cone	5 m, 5°, 2.5°	7.78 m, 5°, 3°
Rotor Mass	110,000 kg	297,660 kg
Nacelle Mass	240,000 kg	400,000 kg (*Target*)
Tower Mass (for offshore)	249,718 kg	735,066 kg

OC4 semi-submersible models

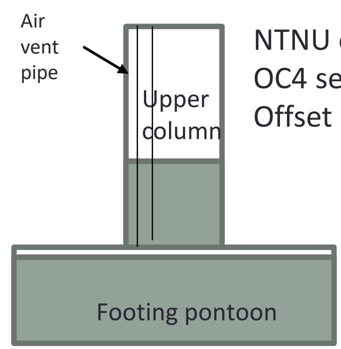


OC4 semi-submersible models

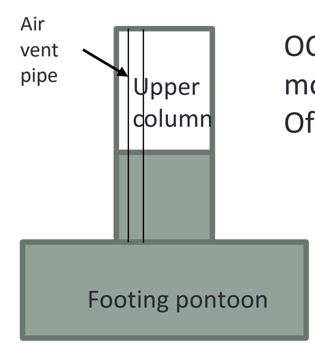
Elements	Parameters	Unit	OC4 semi Original	OC4 semi NTNU Optimal (*)	OC4 semi UOU-modified
Main column	Diameter	m	6.5	6.5	6.500
	Wall thickness	m	0.03	0.030	0.030
	Elevation above SWL	m	10	10.000	10.000
	Depth of base below SWL	m	20	20.000	20.000
Offset Column	Wall thickness	m	0.06	0.060	0.060
	Elevation above SWL	m	12	12.000	12.000
	Spacing between OCs	m	50	50.000	50.000
	Depth of base below SWL	m	20	20.000	20.000
Upper Column	Diameter	m	12	9.900	9.900
	Length	m	26	26.000	26.000
	Height of Ballast (water)	m	7.83	2.630	1.390
Footing Pontoon	Diameter	m	24	24.000	**23.500**
	Length	m	6	6.000	6.000
	Height of Ballast (water)	m	5.0478	5.625	5.880
Mass	Platform steel	kg	3,852,000	3,567,000	3,502,000
	Platform ballast	kg	9,620,820	8,350,000	8,068,000
	Platform total	kg	13,472,820	11,917,000	11,570,000
	Total system	kg	14,072,538	12,516,718	12,169,718
Bouyancy	Volume	m3	13,917	12,402	12,054
	CB below SWL	m	-13.15	-13.93	-13.48



Original OC4 Semi Offset column



NTNU optimal OC4 semi Offset column



OC4 semi UOU modified Offset column

Fulfill ballast water in base column tanks (water level is on the top of air vent pipe) will reduce the difference of pressure between inside and outside footing ballast tank

(*) Leimeister,NTNU 2016 ,Rational Upscaling and Modelling of a Semi-Submersible Floating Offshore Wind Turbine

Principle of platform upscaling

Main column	Diameter	K1	Ratio tower base diameter upscale/original
	Wall thickness	K1	Ratio tower base diameter upscale/original
	Elevation above SWL	K	Ratio WT mass Upscale/original
	Depth of base below SWL	K	Ratio WT mass Upscale/original
Offset Columns	Wall thickness	K	Ratio WT mass Upscale/original
	Elevation above SWL	K	Ratio WT mass Upscale/original
	Spacing between OCs	K	Ratio WT mass Upscale/original
	Depth of base below SWL	K	Ratio WT mass Upscale/original
Upper Columns	Diameter	K	Ratio WT mass Upscale/original
	Length	K	Ratio WT mass Upscale/original
	Heigh of Ballast (water)	K	Ratio WT mass Upscale/original
Footing Pontoons	Diameter	K	Ratio WT mass Upscale/original
	Length	K	Ratio WT mass Upscale/original
	Heigh of Ballast (water)	K	Ratio WT mass Upscale/original
Pipes	Diameter	K	Ratio WT mass Upscale/original
	Wall thickness	K	Ratio WT mass Upscale/original

$$K = \sqrt[3]{\frac{12MW\_WT\_mass}{5MW\_WT\_mass}}$$

$$K_1 = \frac{Tower\_base\_diameter_{12MW}}{Towe\_base\_diameter_{5MW}}$$

WT_mass includes: Rotor (blades and hub) mass, nacelle mass and tower mass

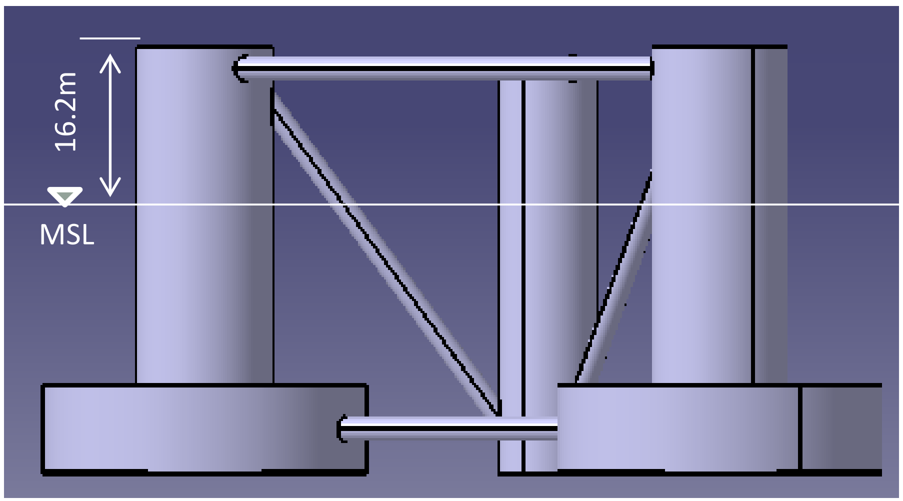
12 MW platform upscaling

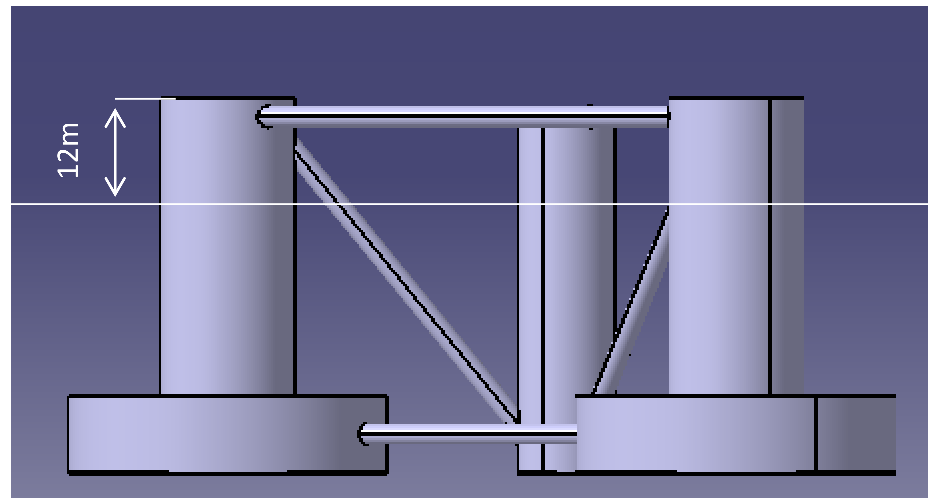
Elements	Parameters	Unit	12MW scaled up OC4 Original	12MW scaled up OC4 NTNU Optimize	12MW scaled up OC4 UOU modified	12MW final
Main column	Diameter	m	8.782	8.782	**8.782**	**9.634**
	Wall thickness	m	0.041	0.041	0.041	0.041
	Elevation above SWL	m	13.510	13.510	13.510	10.000
	Depth of base below SWL	m	27.020	27.020	27.020	27.020
Offset Column	Wall thickness	m	0.081	0.081	0.081	0.081
	Elevation above SWL	m	16.212	16.212	**16.212**	**12.000**
	Spacing between OCs	m	67.550	67.550	67.550	67.550
	Depth of base below SWL	m	27.020	27.020	27.020	27.020
Upper Column	Diameter	m	16.212	13.375	13.375	13.375
	Length	m	35.126	35.126	**35.126**	**30.914**
	Height of Ballast (water)	m	10.410	10.410	1.878	3.600
Footing Pontoon	Diameter	m	32.424	**32.424**	**31.716**	31.716
	Length	m	8.106	8.106	8.106	8.106
	Height of Ballast (water)	m	6.820	7.599	7.944	7.944
Mass	Platform steel	kg	9,501,600	8,798,600	8,638,267	8,168,000
	Platform ballast	kg	23,731,356	20,596,667	19,901,067	20,855,000
	Platform total	kg	33,232,956	29,395,267	28,539,333	28,978,000
	Total system	kg	34,712,260	30,874,571	30,018,638	30,457,418
Bouyancy	Volume	m3	34,329	30,592	30,049	30,049
	CB below SWL	m	-17.77	-18.81943	-18.21	-18.21

12 MW platform upscaling

OC4 semi UOU-modified scaled up
for 12 MW FOWT

12 MW FOWT platform - final



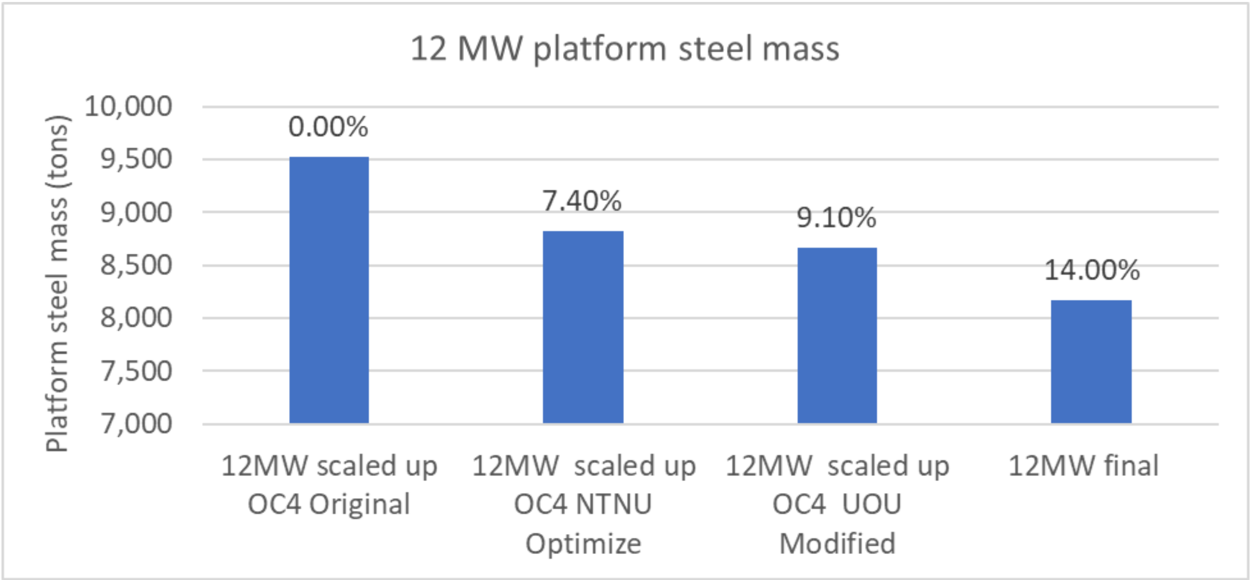


12 MW FOWT Platform modification based on:

- Reduced main column elevation above MSL to 10 m
- Reduced offset column elevation above MSL to 12 m

(the same as OC4 semi-submersible model)

Platform steel mass reduction



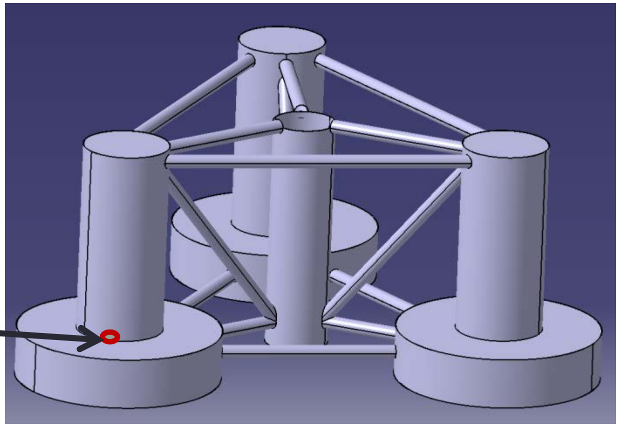
Parameters	Unit	12MW scaled up OC4 Original	12MW scaled up OC4 NTNU Optimize	12MW scaled up OC4 UOU Modified	12MW final
Platform steel	ton	9,525	8,822	8,661	8,168
Difference	%	0.0%	7.4%	9.1%	14.0%

Checking structure strength

Calculate equivalence stress for the inner wall of bottom point of upper column

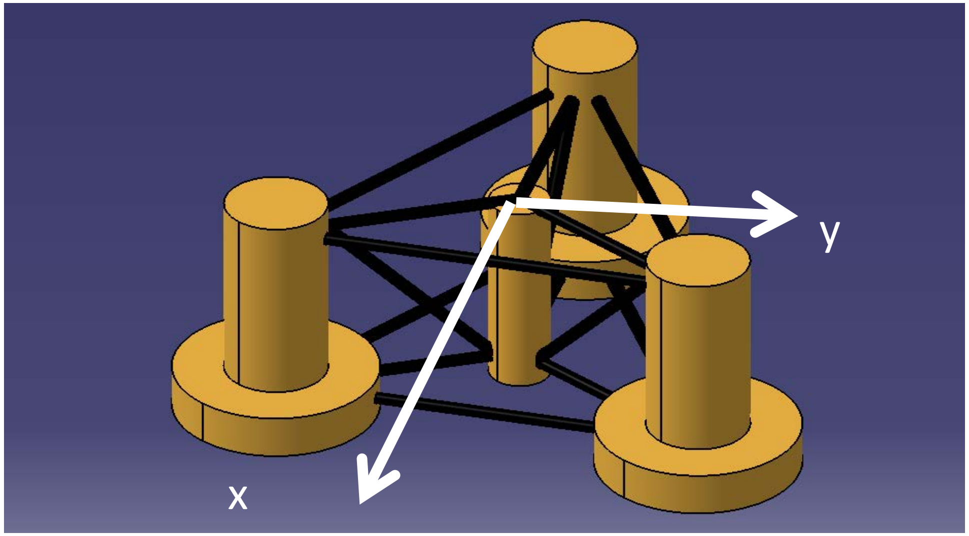
$$\sigma_{\mathrm{equ}} = \sqrt{\sigma_{\mathrm{t}}^2 + \sigma_{\mathrm{r}}^2 + \sigma_{\mathrm{ax}}^2 - \sigma_{\mathrm{t}}\sigma_{\mathrm{r}} - \sigma_{\mathrm{t}}\sigma_{\mathrm{ax}} - \sigma_{\mathrm{r}}\sigma_{\mathrm{ax}}}$$

Pressure checking point: inner wall of upper column at lowest position

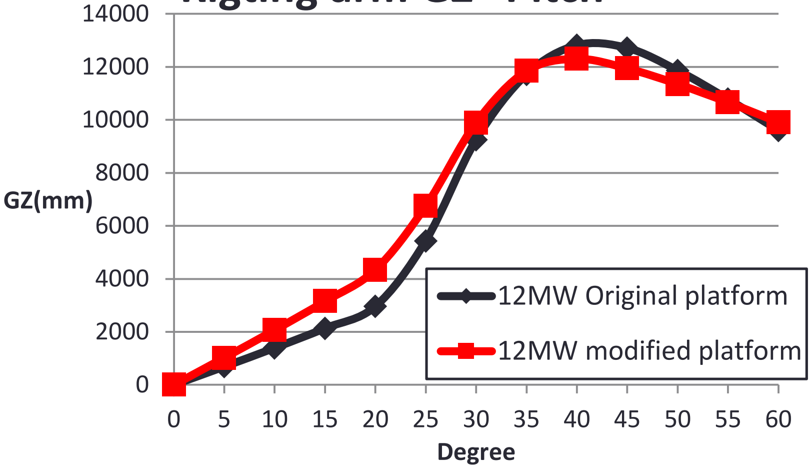


Elements	Parameters	Unit	5MW OC4 Original	12MW scaled up OC4 Original	OC4 NTNU Optimal	12MW scaled up OC4 NTNU Optimize	OC4 UOU-modified	12MW scaled up UOU OC4 modified	12MW final
Ptank min, Pwater max	σ_eq	Mpa	47.50	60.17	39.25	49.73	39.25	49.73	49.76
Steel AH36 (t~80mm)	Yield stress	Mpa	325	325	325	325	325	325	325
Steel SS400 (t~80mm)	Yield stress	Mpa	245	245	245	245	245	245	245

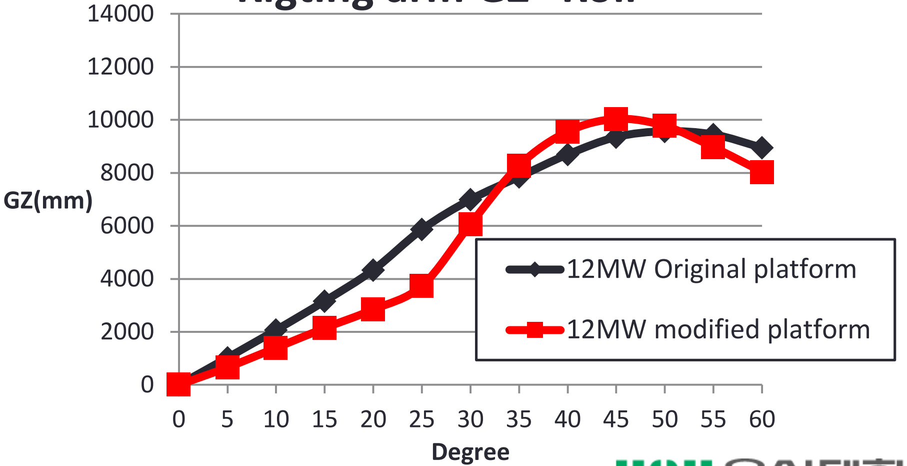
12MW Stability analysis



Rigting arm GZ "Pitch"

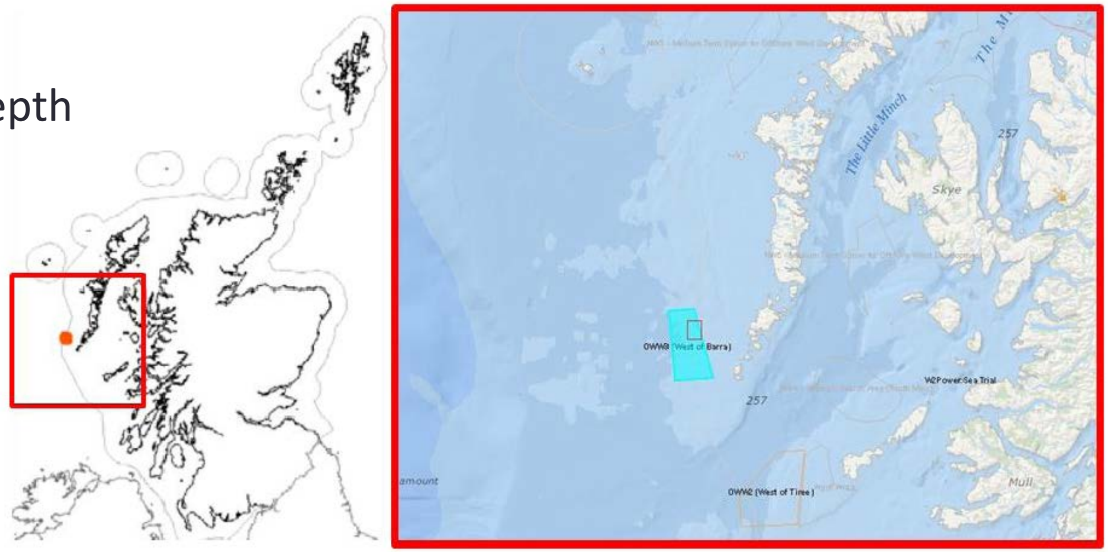


Rigting arm GZ "Roll"



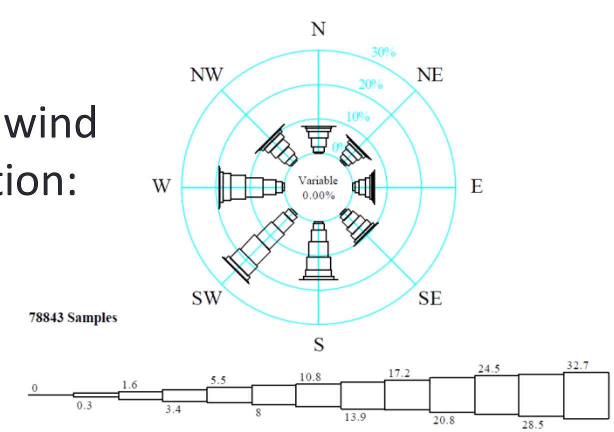
Reference location: West of Barra - Scotland

100m water depth

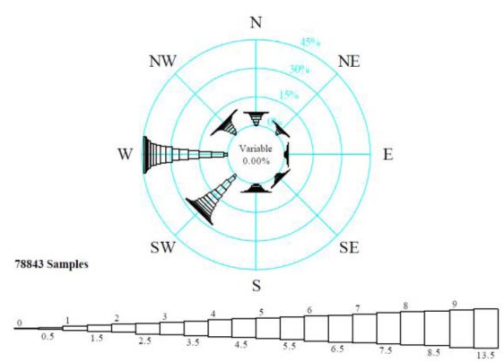


Main wind direction: SW

Mean Wind Direction (direction from)



Dominant Wave Direction (direction from)



울산대학교 공과대학 조선해양공학부

Source: LIFE50+ 'D1.1 Oceanographic and meteorological conditions for the design' 2015

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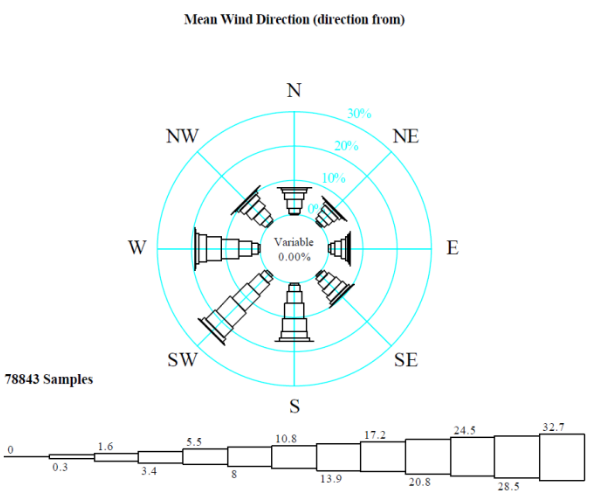
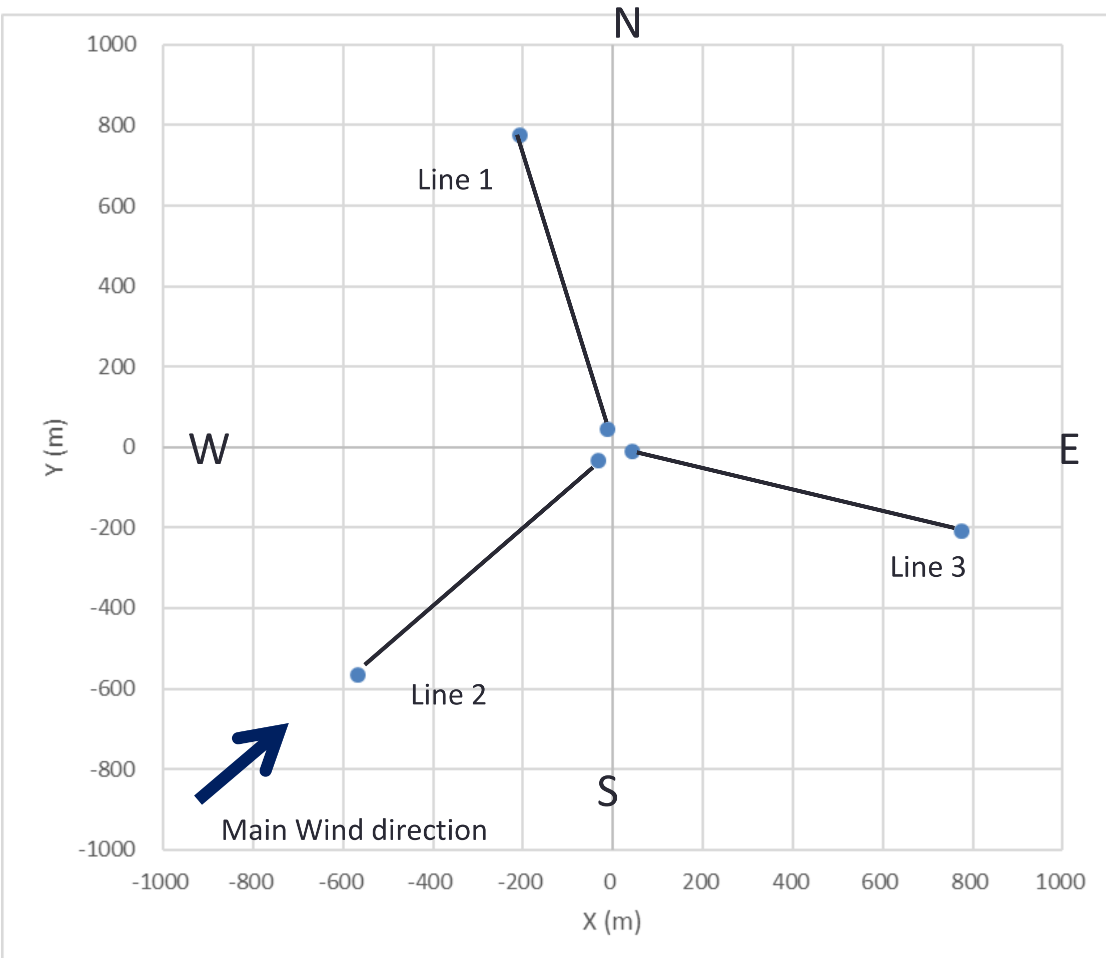
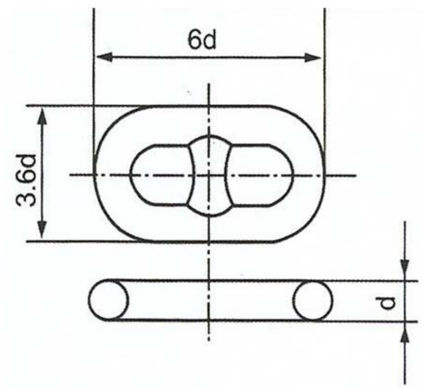
Mooring lines arrangement



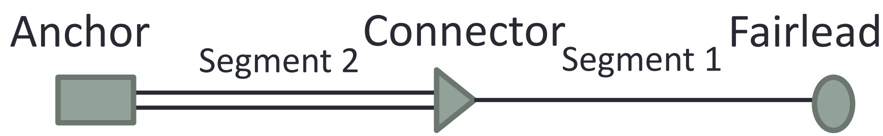


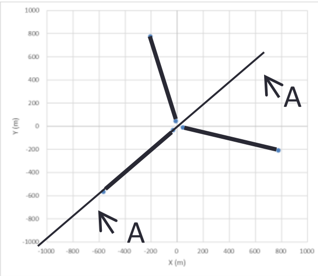
Mooring lines arrangement

Stud common link



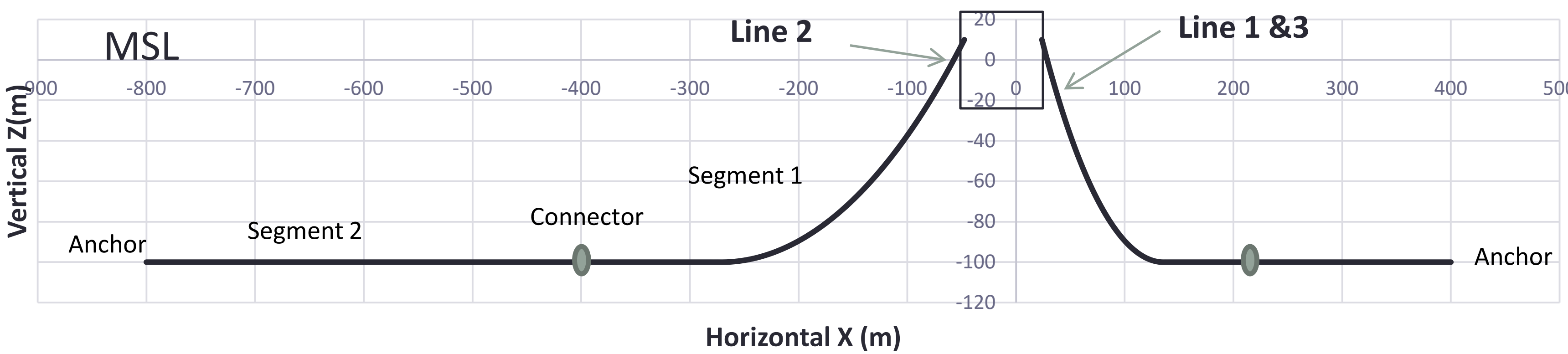
Mooring line components





View A-A

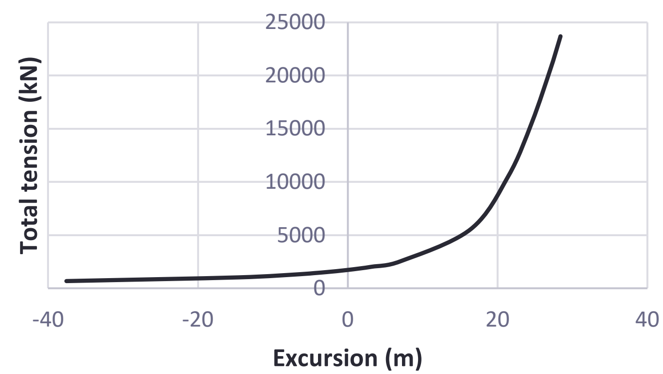
Mooring lines configuration



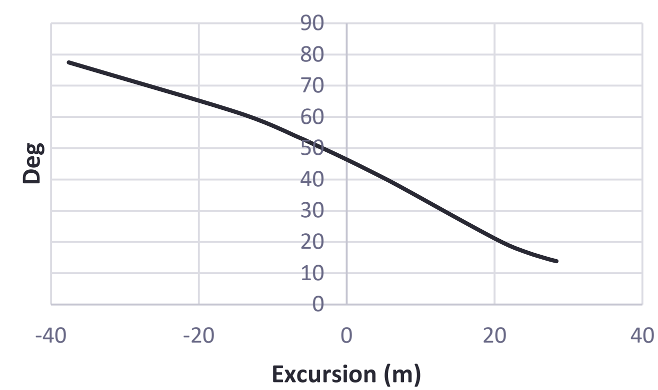
Mooring line properties

Water Depth	m	100
Mooring Line Diameter (d)	mm	162
Number of Mooring Lines	-	3
Angle Between Adjacent Lines	deg	120
Depth to Anchors below SWL	m	100
Fairleads Location above SWL	m	10
Radius to Anchors from Platform Centerline	m	801.5
Radius to Fairleads from Platform Centerline	m	45.7
Equivalent Mooring Line Extensional Stiffness EA	N	2.360E+09
Minimum Breaking Load	N	2.600E+07
Segment 1 (top side) 162mm mooring stud chain, material class R5		
Un-stretched Mooring Line Length	m	385
Equivalent Mooring Line Mass Density	kg/m	522.73
Segment 2 (Anchor side) 2x162mm mooring stud chain, material class R5		
Un-stretched Mooring Line Length	m	400
Equivalent Mooring Line Mass Density	kg/m	1045.46
Equivalent Mooring Line Extensional Stiffness EA	N	2.360E+09
Minimum Breaking Load	N	2.600E+07

Mooring line tension excursion



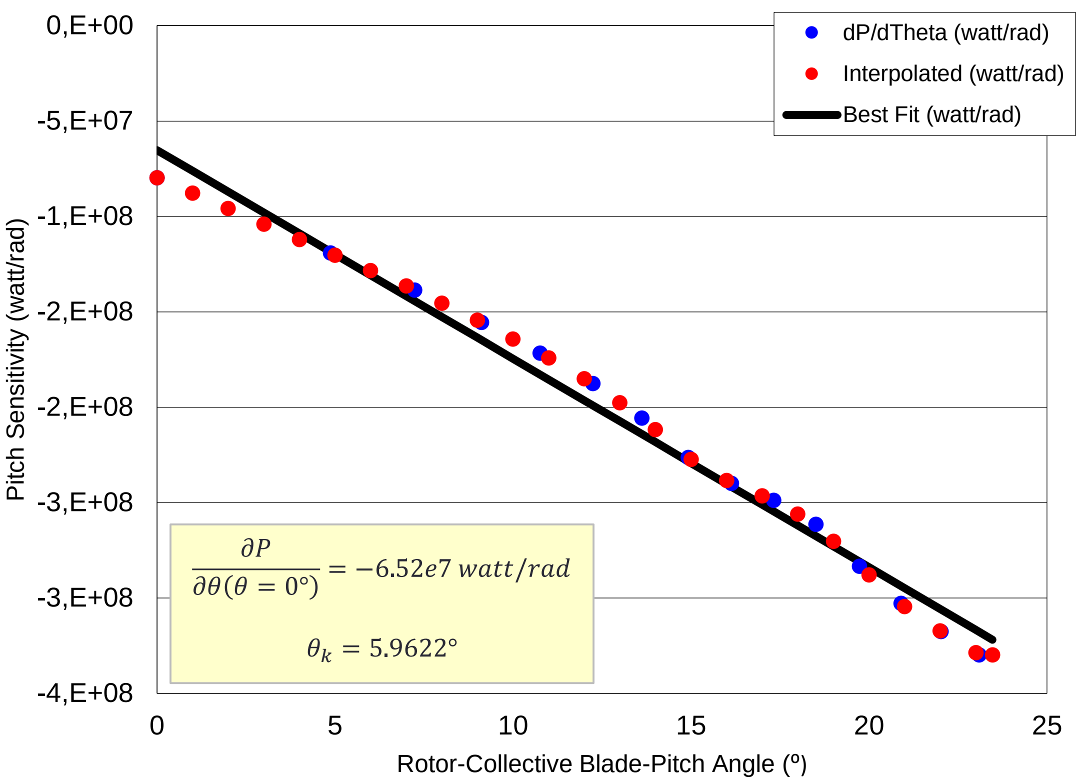
Mooring line angle at fairlead



PI controller

- **Results using FAST Linearization with frozen wake assumption**

12 MW

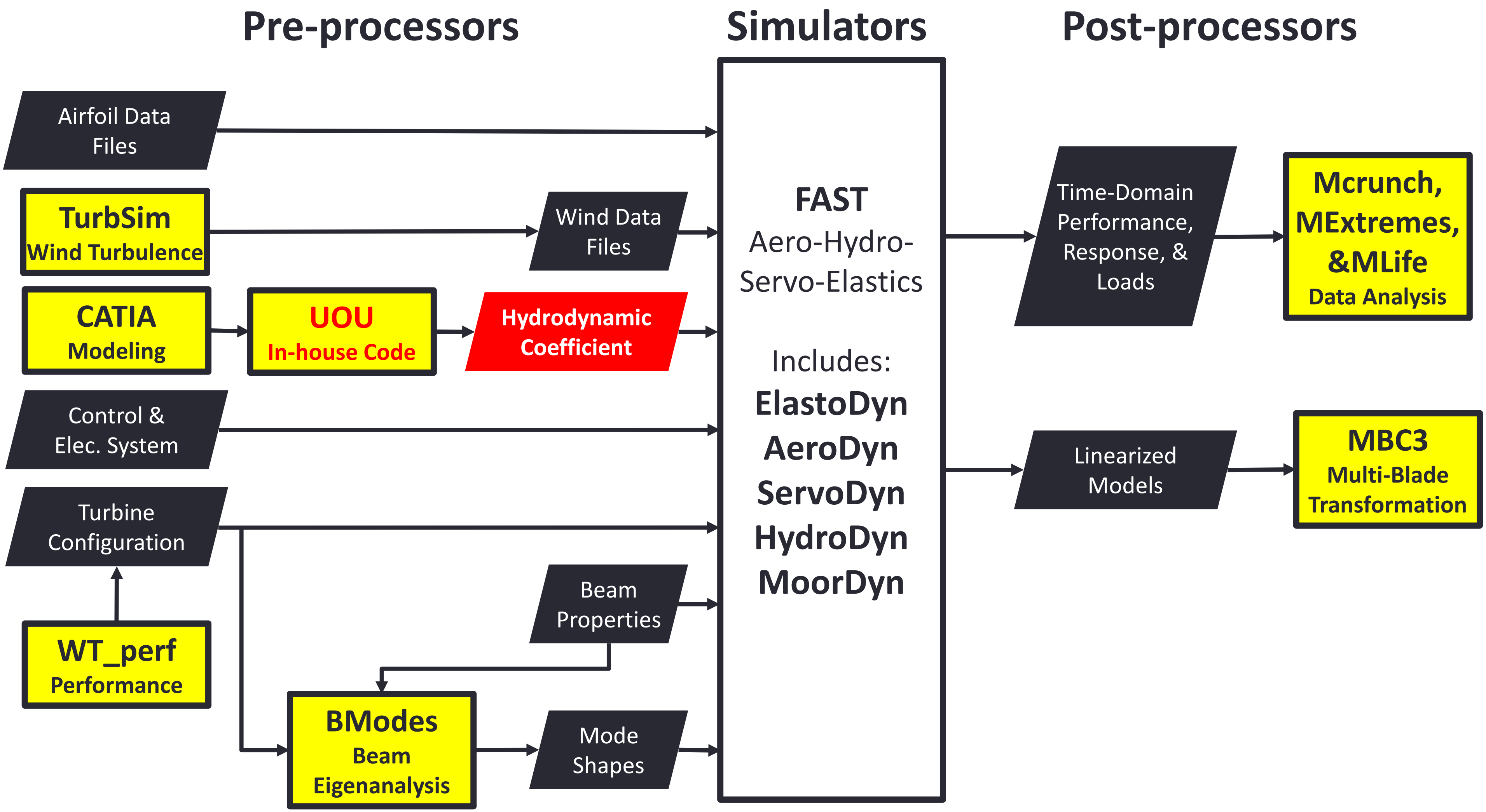


Parameters for pitch and VS control

Parameters	
ConerFreq	1.225221 rad/s
PC_DT	0.00125 s
PC_KI	0.19685052
PC_KK	0.0948646 rad
PC_KP	0.45931788 s
PC_MaxPit	1.5707963 rad
PC_MaxRat	0.139626 rad/s
PC_MinPit	0.0000000 rad
PC_RefSpd	0.8639 rad/s
VS_CtInSp	0.29636 rad/s
VS_DT	0.00125 s
VS_MaxRat	4900000 Nm/s
VS_MaxTq	15511547.75 Nm
VS_Rgn2K	19341827.070932 Nm/(rad/s)^2
VS_Rgn2Sp	0.38537 rad/s
VS_Rgn3MP	0.0174533 rad
VS_RtGnSp	0.83802 rad/s
VS_RtPwr	12182741.1 W
VS_SlPc	15.0 %

Numerical Simulation

Flow Diagram of UOU + FAST v8

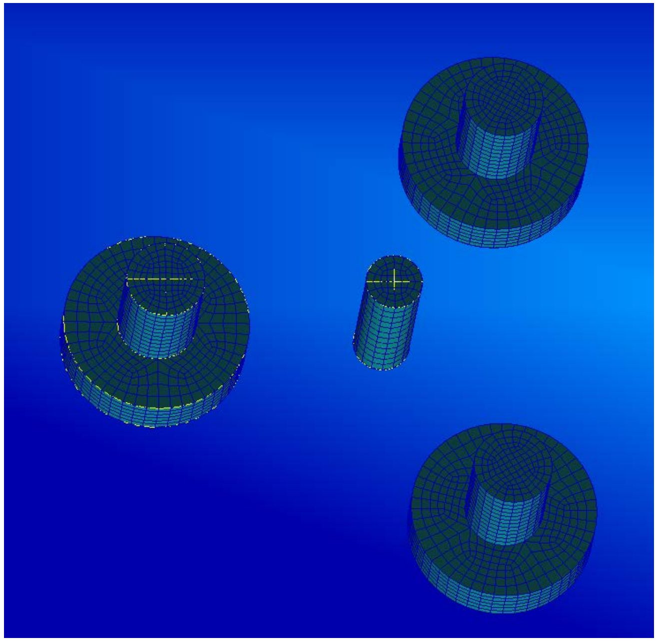


Source : J. Jonkman, FASTWorkshop, NREL

UOU in-house code

➢ **Hydrodynamic coefficients need for numerical simulation in hydro part**

Hydrodynamic in-house code modeling:
- Consider parts under water line
- Neglect pontoons and braces



- **UOU in-house code**

3D panel method(BEM)
Element : 4000

Output
1. Added mass coefficients
2. Radiation Damping coefficients
3. Wave Excitation Forces/Moments

Design Load Cases(DLCs)

Design Load Cases (1/2)

DLC	Winds		Waves			Current	Controls/Events
	Model	Speed	Model	Height	Direction		
1) Power Production							
1.1	NTM	V_in<V_hub<V_out	NSS	Hs = E[Hs/V_hub]	0˚	NCM	Normal operation
1.2	NTM	V_in<V_hub<V_out	NSS	Hs = E[Hs/V_hub]	8 directions	NCM	Normal operation
1.4	EDC	V_hub = V_r, V_r+-2m/s	NSS	Hs = E[Hs/V_hub]	0˚	NCM	Normal operation
1.5	EWS	V_in<V_hub<V_out	NSS	Hs = E[Hs/V_hub]	0˚	NCM	Normal operation
1.6a	NTM	V_in<V_hub<V_out	SSS	Hsss	0˚	NCM	Normal operation
2) Power Production Plus Occurrence of Fault							
2.3	EOG	V_hub = V_r, V_r+-2m/s, V_out		Hs = E[Hs/V_hub]	0˚	NCM	Loss of load -> shutdown
6) Parked							
6.1a	EWM	V_hub = V50	ESS	Hs = Hs50	0˚, +-45˚	ECM	Yaw = 0, +-8 Deg
9) Power production: Transient condition between intact and redundancy check condition: 1 mooring line lost							
9.1	NTM	V_in<V_hub<V_out	NSS		0˚	NCM	Normal operation
10) Parked: Transient condition between intact and redundancy check condition: 1 mooring line lost							
10.1	EWM	V-hub = V_50	ESS	Hs = Hs50	0˚	ECM	

Design Load Cases (2/2)

DLC1.1, DLC1.2, DLC9.1

Wave	NSS		
Current	NCM		
V-hub	Hs	Tp	Current
m/s	m	s	m/s
4	0.35	3.00	0.08
6	0.73	5.77	0.13
8	1.14	7.18	0.17
10	1.60	8.23	0.21
12	2.12	9.11	0.25
14	2.71	9.88	0.29
16	3.39	10.58	0.34
18	4.18	11.24	0.38
20	5.08	11.85	0.42
22	6.12	12.43	0.46
24	7.31	12.99	0.50

DLC1.6

Wind	ETM		
Wave	SSS		
Current	NCM		
V-hub	Hs	Tp	Current
m/s	m	s	m/s
10	11.5	14.4	0.21
11.2	11.5	14.4	0.25
12	15.6	15.2	0.50
24	15.6	15.2	0.50

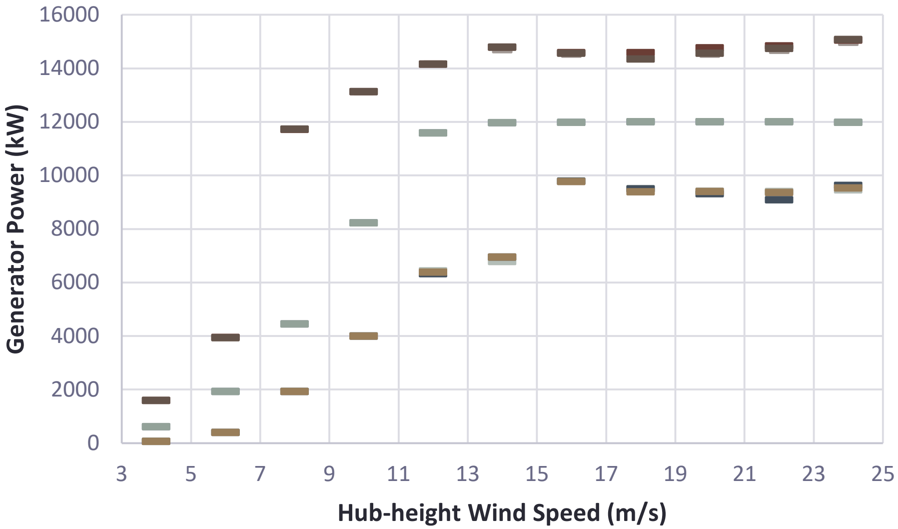
DLC6.1, DLC10.1

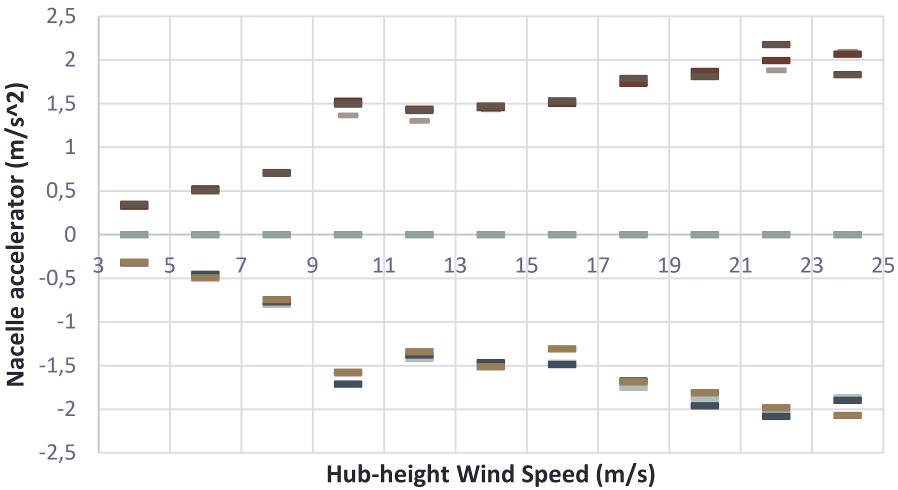
Wind	EWM		
Wave	ESS		
Current	ECM		
V-hub	Hs	Tp	Current
m/s	m	s	m/s
50	15.6	15.2	1.82

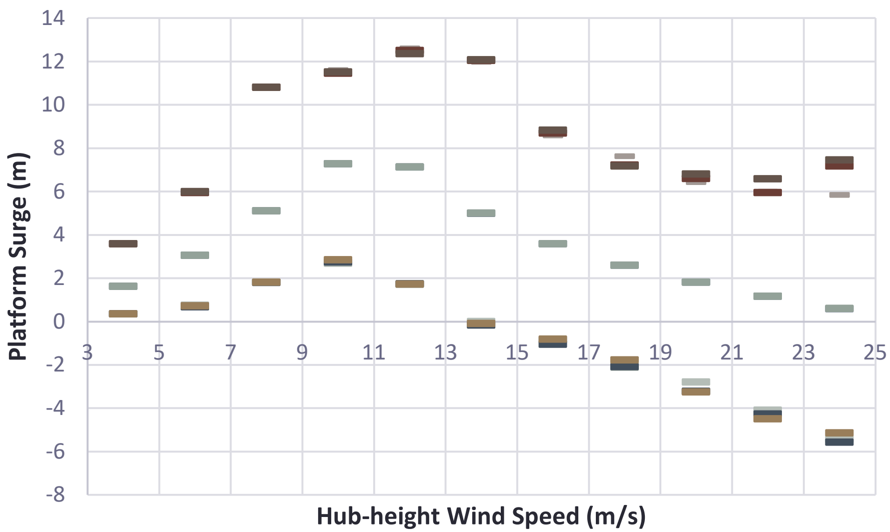
Simulation time:
3 hours irregular waves (1h x 3 wave seed numbers)
DLC1.2: 1 hour simulation

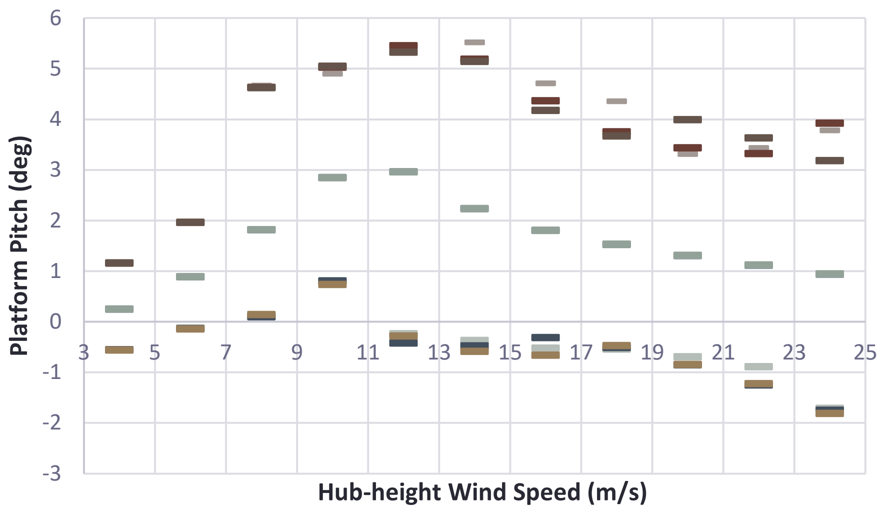
Results

DLC1.1 Minimum, mean, and maximum values

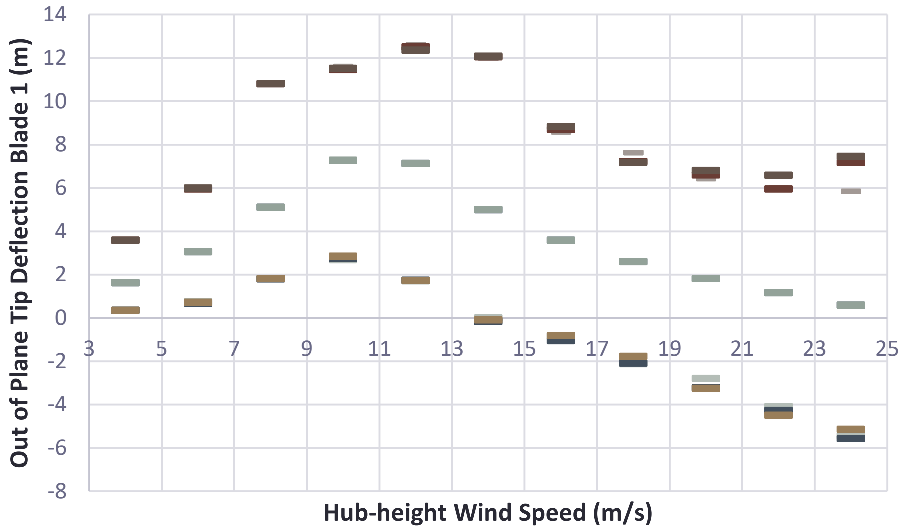


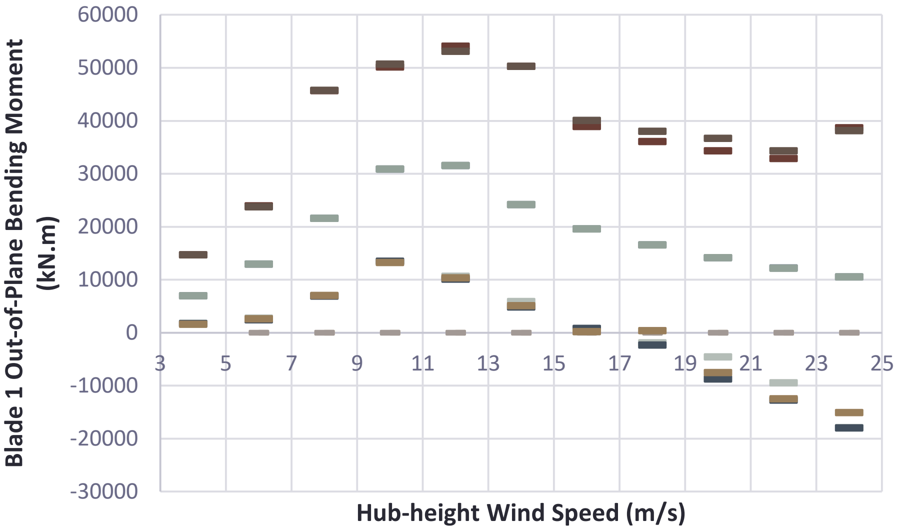


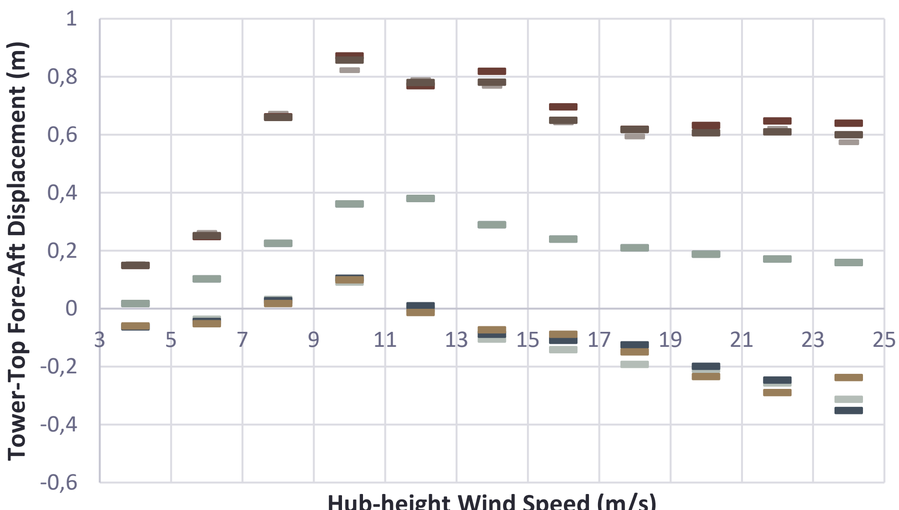


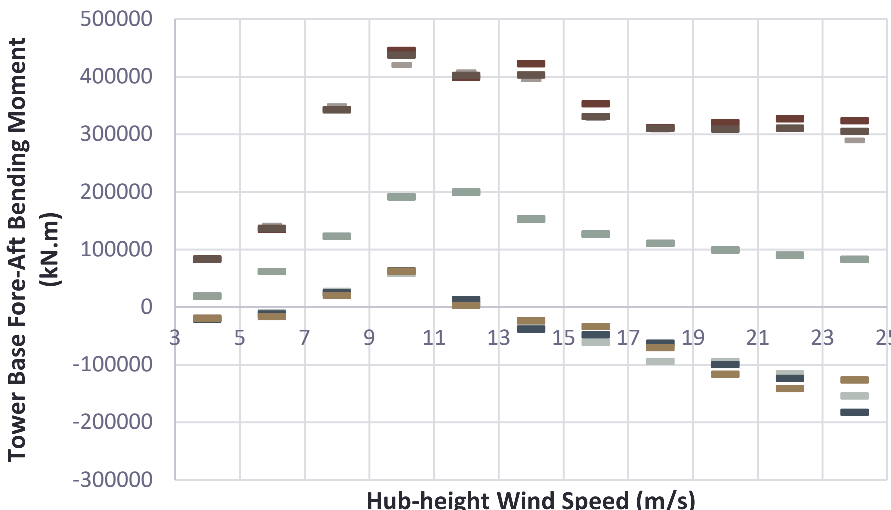


DLC1.1 Minimum, mean, and maximum values









Extreme motions of the FOWT in operation conditions

Serviceability Limit States (SLS) during operational:
Max. tilt: 10 deg.
Nacelle acceleration: 0.3g

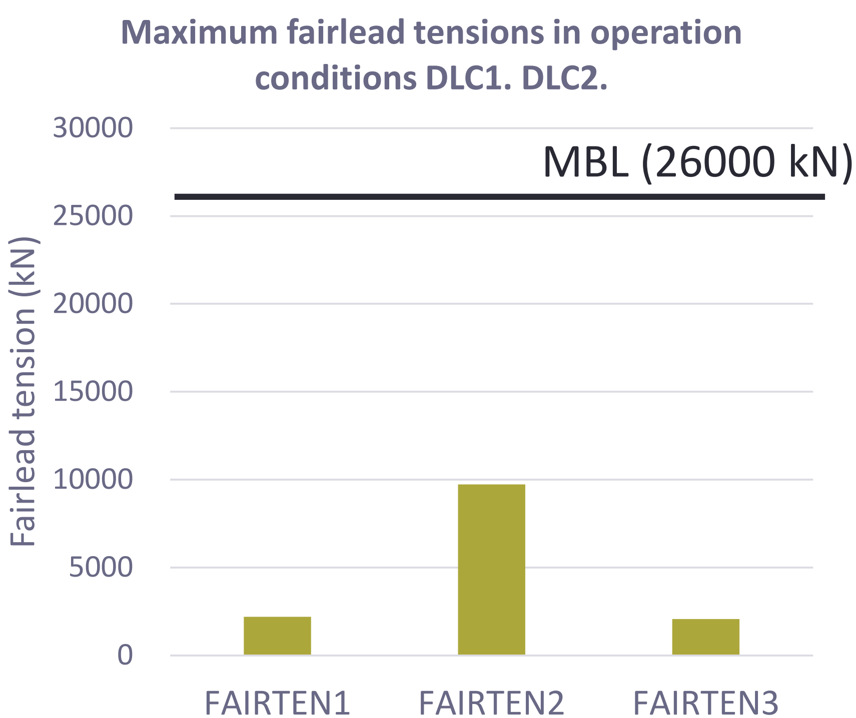
Parameter	Type	File Name	Unit	Calculated Extreme	Time (s)
PtfmSurge	Minimum	DLC1.6-25a.out	m	-1.23	3080.4
PtfmSurge	**Maximum**	**DLC1.6-12a.out**	**m**	**17.91**	761.1
PtfmSway	Minimum	DLC1.1-10c.out	m	-2.18	542.9
PtfmSway	Maximum	DLC1.1-10a.out	m	2.31	826.4
PtfmHeave	Minimum	DLC1.6-12c.out	m	-3.22	1306.2
PtfmHeave	Maximum	DLC1.6-25a.out	m	2.83	773.8
PtfmRoll	Minimum	DLC1.1-12c.out	deg	-0.33	3402.4
PtfmRoll	Maximum	DLC1.6-25a.out	deg	1.43	3504.3
PtfmPitch	Minimum	DLC1.6-25a.out	deg	-5.98	760.5
PtfmPitch	**Maximum**	**DLC1.6-12b.out**	**deg**	**8.69**	3365.5
PtfmYaw	Minimum	DLC1.1-24c.out	deg	-6.83	3548.6
PtfmYaw	Maximum	DLC1.1-12c.out	deg	5.16	3402.1
Nacelle acc. Fore-aft	Minimum	DLC1.6-12c.out	m/s^2	-3.12	1305.1
Nacelle acc. Fore-aft	**Maximum**	**DLC1.6-12b.out**	**m/s^2**	**3.37**	1300.0
Nacelle acc. Side-to-side	Minimum	DLC1.6-25b.out	m/s^2	-1.54	1959.9
Nacelle acc. Side-to-side	Maximum	DLC1.6-25b.out	m/s^2	1.59	1956.5

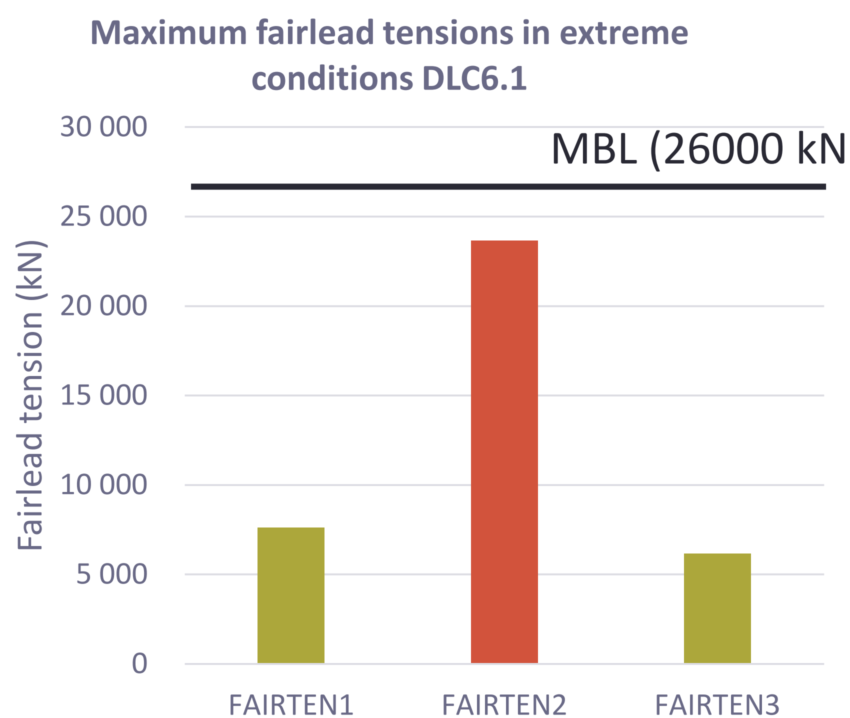
Extreme motions of the FOWT in parked conditions

Serviceability Limit States (SLS) during non-operational:
Max. tilt: 15 deg. (max. value)
Nacelle acceleration: 0.6g

Parameter	Type	File Name	Unit	Extreme Values	Time (s)
PtfmSurge	Minimum	DLC6.1-H0-Y8.out	m	9.40	2242.2
PtfmSurge	**Maximum**	**DLC6.1-H0-Y8.out**	**m**	**26.79**	2329.6
PtfmSway	Minimum	DLC6.1-H-45-Y-8.out	m	-14.28	3490.9
PtfmSway	Maximum	DLC6.1-H45-Y8.out	m	20.51	237.9
PtfmHeave	Minimum	DLC6.1-H45-Y8.out	m	-5.68	3198.4
PtfmHeave	Maximum	DLC6.1-H45-Y8.out	m	4.75	3206.3
PtfmRoll	Minimum	DLC6.1-H-45-Y8.out	deg	-10.27	1408.1
PtfmRoll	Maximum	DLC6.1-H-45-Y-8.out	deg	10.10	3490.5
PtfmPitch	**Minimum**	**DLC6.1-H0-Y8.out**	**deg**	**-11.12**	2559.0
PtfmPitch	Maximum	DLC6.1-H0-Y0.out	deg	0.35	1706.9
PtfmYaw	Minimum	DLC6.1-H45-Y8.out	deg	-3.13	288.6
PtfmYaw	Maximum	DLC6.1-H45-Y-8.out	deg	8.73	3507.4
Nacelle acc. Fore-aft	Minimum	DLC6.1-H0-Y8.out	m/s^2	-2.72	2908.8
Nacelle acc. Fore-aft	Maximum	DLC6.1-H0-Y8.out	m/s^2	2.34	2913.7
Nacelle acc. Side-to-side	**Minimum**	**DLC6.1-H-45-Y-8.out**	**m/s^2**	**-6.33**	3497.2
Nacelle acc. Side-to-side	Maximum	DLC6.1-H45-Y8.out	m/s^2	5.93	3128.1

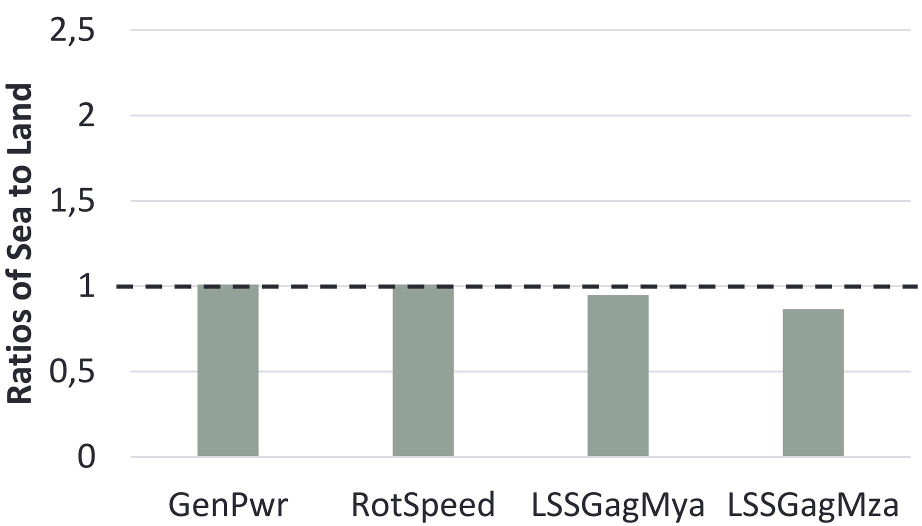
Maximum Mooring line tensions

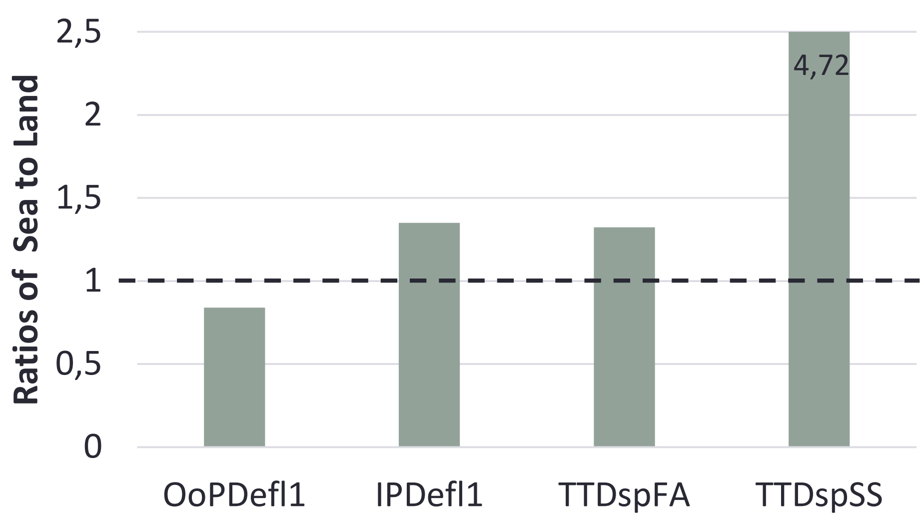




	Operation	Extreme (parked)
Max. Fairlead 2 Tension [kN]	9.727E+03	2.36E+04
Min. Breaking Load MBL [kN]	2.60E+04	2.60E+04
Ratio Max/MBL	0.374	0.908

Ratios of sea to land of absolute extreme values (all DLCs)

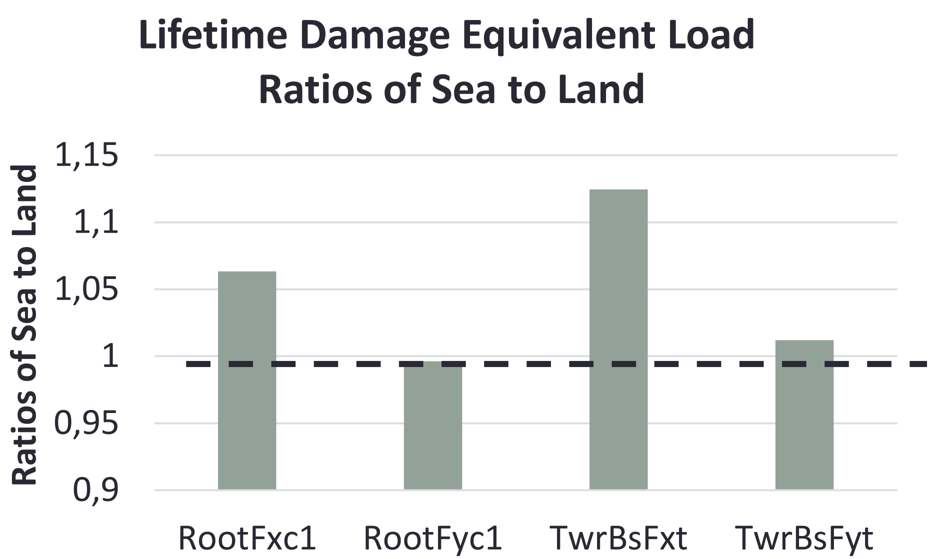




DLC1.2 Fatigue analysis

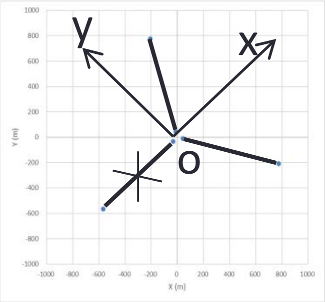
Comparison between sea and land wind turbine based on :

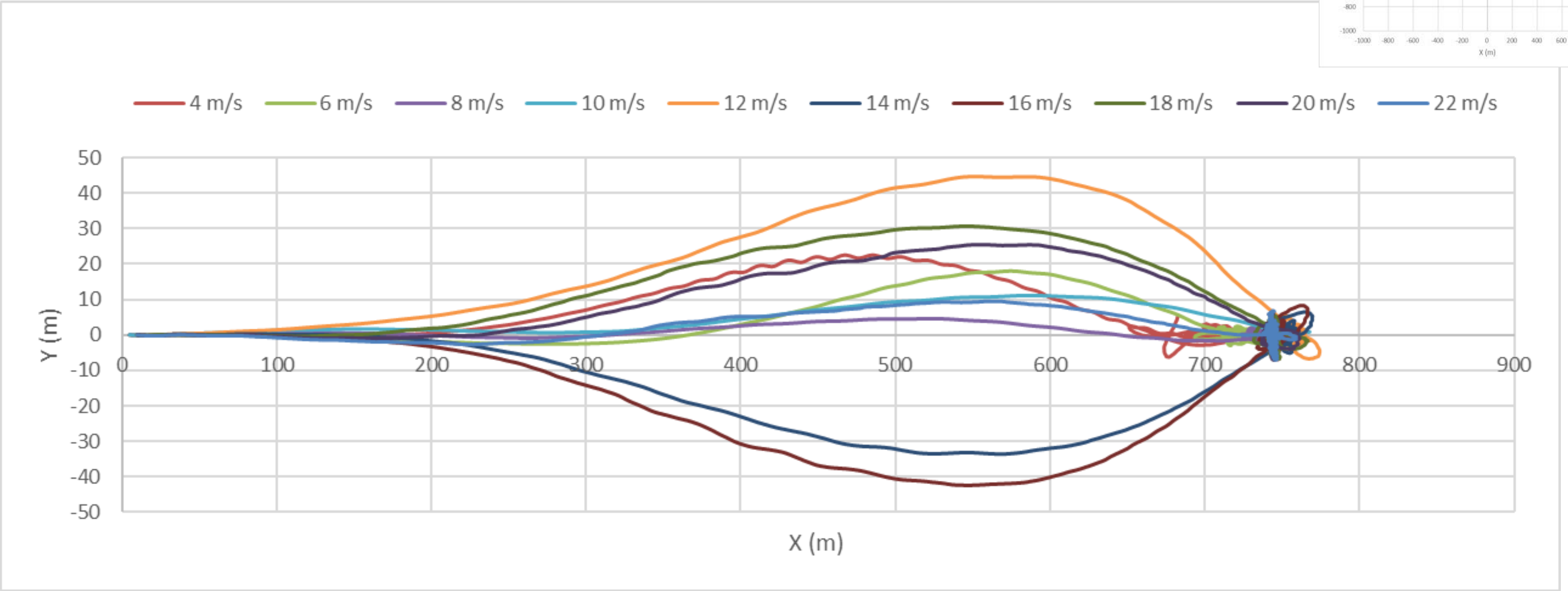
- The same wind conditions
- The same controller
- Root of blade m= 10, ultimate load L_Ult= 4600 kN
- Tower base m=4, ultimate load L_Ult= 8000 kN



DLC9.1 Motions of the FOWT after a mooring line loss

Wind turbine trajectories after mooring line 2 was lost





Conclusion

Conclusion

- A design of the 12 MW FOWT was suggested.
- Lighting wind turbine mass such as super conductor generator, carbon fiber blade, short tower drive a smaller platform scale ratio.
- Strong wave and high current speed has a significant effect to the design of mooring system.
- Mooring line provided in 2 segments with heavier segment at anchor side to avoid the lift up force at the anchor.
- Loads and displacements of blades and tower in sea are higher than those in land
- Wind and wave misalignments have strong effects to nacelle side to side acceleration

Future work

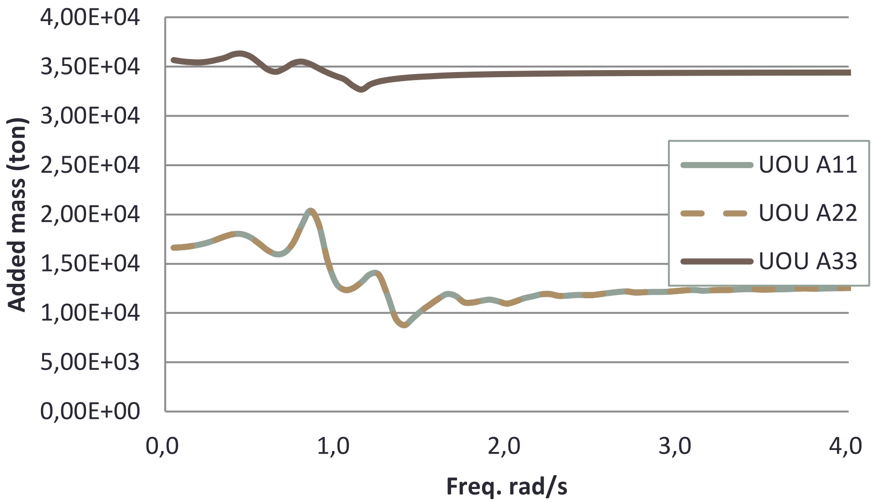
- Consider 2nd order wave loads
- Optimize mooring system

THANK YOU!

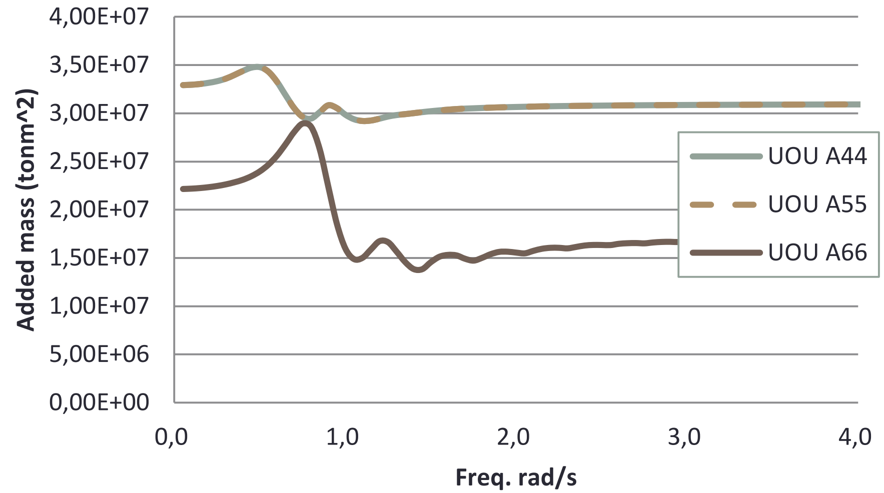
ACKNOWLEDGMENTS

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning(KETEP) and the Ministry of Trade, Industry & Energy(MOTIE) of the Republic of Korea (No. 20154030200970 and No. 20142020103560).

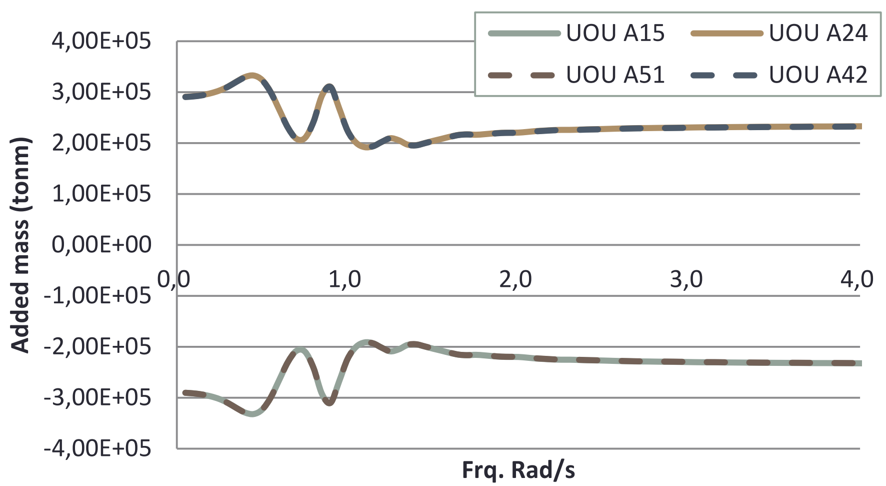
Added mass



4,00E+04
3,50E+04
3,00E+04
2,50E+04
2,00E+04
1,50E+04
1,00E+04
5,00E+03
0,00E+00
0,0
1,0
2,0
3,0
4,0
Added mass (ton)
Freq. rad/s
UOU A11
UOU A22
UOU A33



4,00E+07
3,50E+07
3,00E+07
2,50E+07
2,00E+07
1,50E+07
1,00E+07
5,00E+06
0,00E+00
0,0
1,0
2,0
3,0
4,0
Added mass (tonm^2)
Freq. rad/s
UOU A44
UOU A55
UOU A66



4,00E+05
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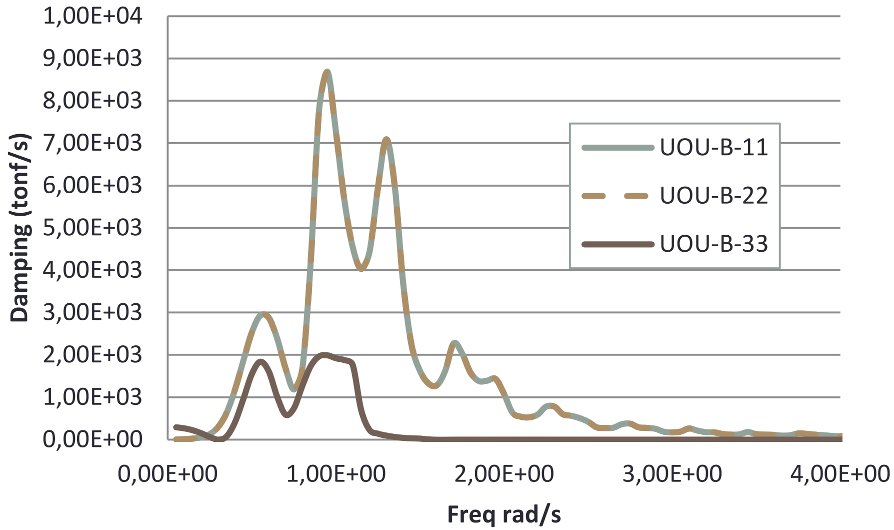
2,00E+05
1,00E+05
0,00E+00
-1,00E+05
-2,00E+05
-3,00E+05
-4,00E+05
0,0
1,0
2,0
3,0
4,0
Added mass (tonm)
Frq. Rad/s
UOU A15
UOU A24
UOU A51
UOU A42

Damping



1,00E+04
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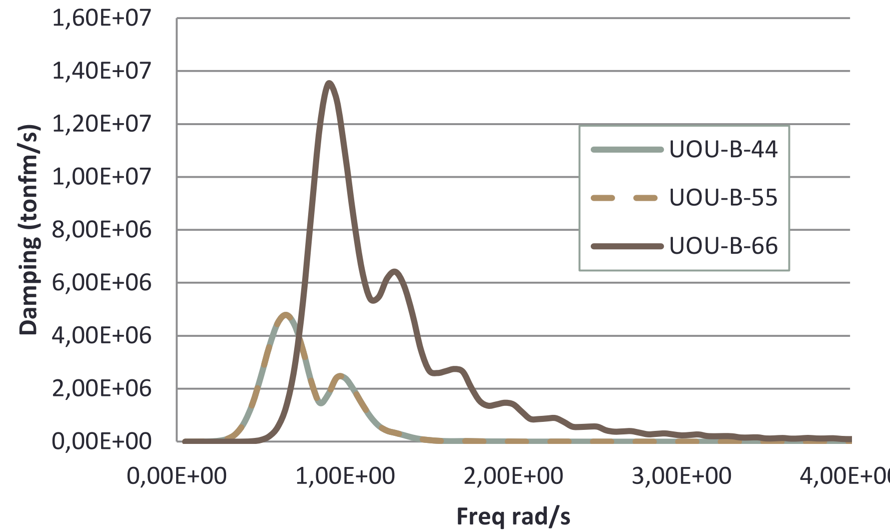
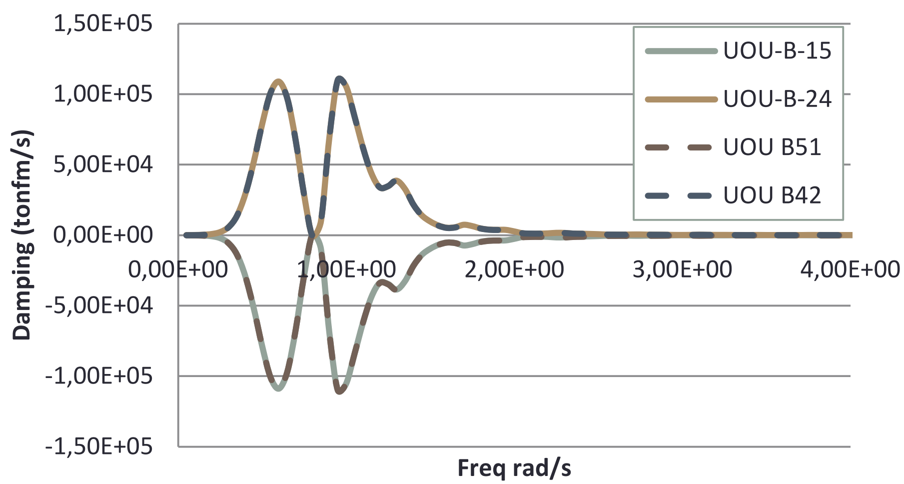
8,00E+03
7,00E+03
6,00E+03
5,00E+03
4,00E+03
3,00E+03
2,00E+03
1,00E+03
0,00E+00
Damping (tonf/s)
0,00E+00
1,00E+00
2,00E+00
3,00E+00
4,00E+00
Freq rad/s
UOU-B-11
UOU-B-22
UOU-B-33

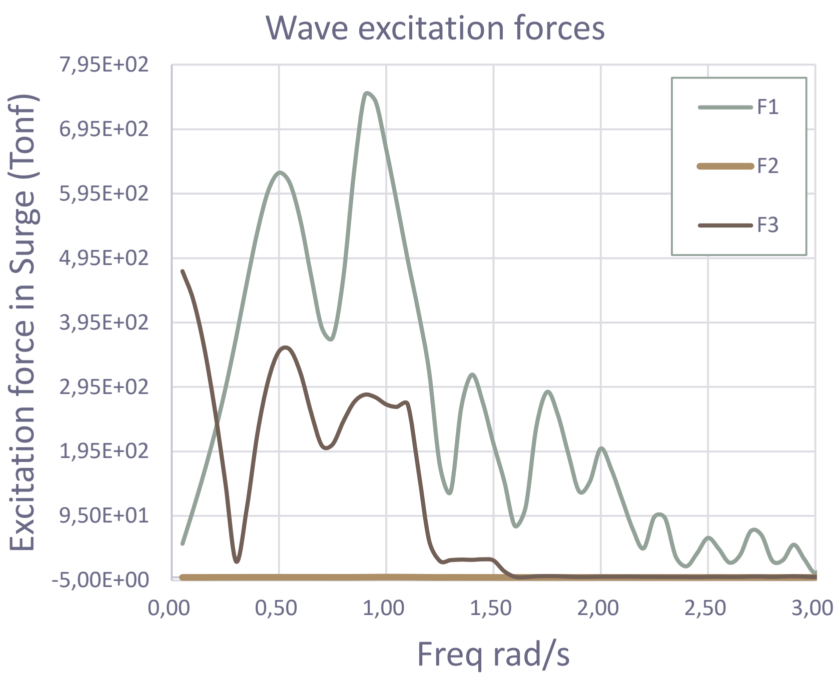


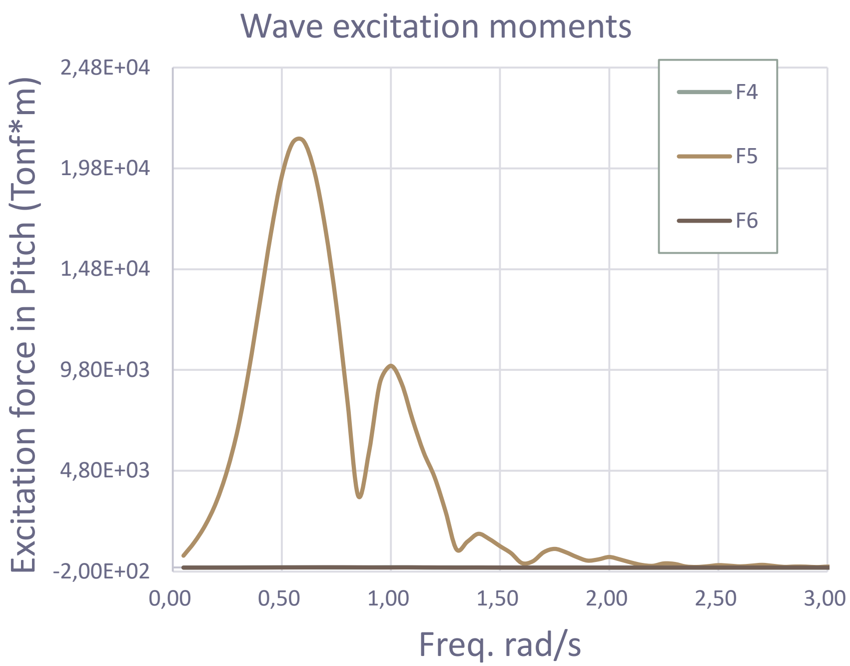
1,60E+07
1,40E+07
1,20E+07
1,00E+07
8,00E+06
6,00E+06
4,00E+06
2,00E+06
0,00E+00
Damping (tonfm/s)
0,00E+00
1,00E+00
2,00E+00
3,00E+00
4,00E+00
Freq rad/s
UOU-B-44
UOU-B-55
UOU-B-66



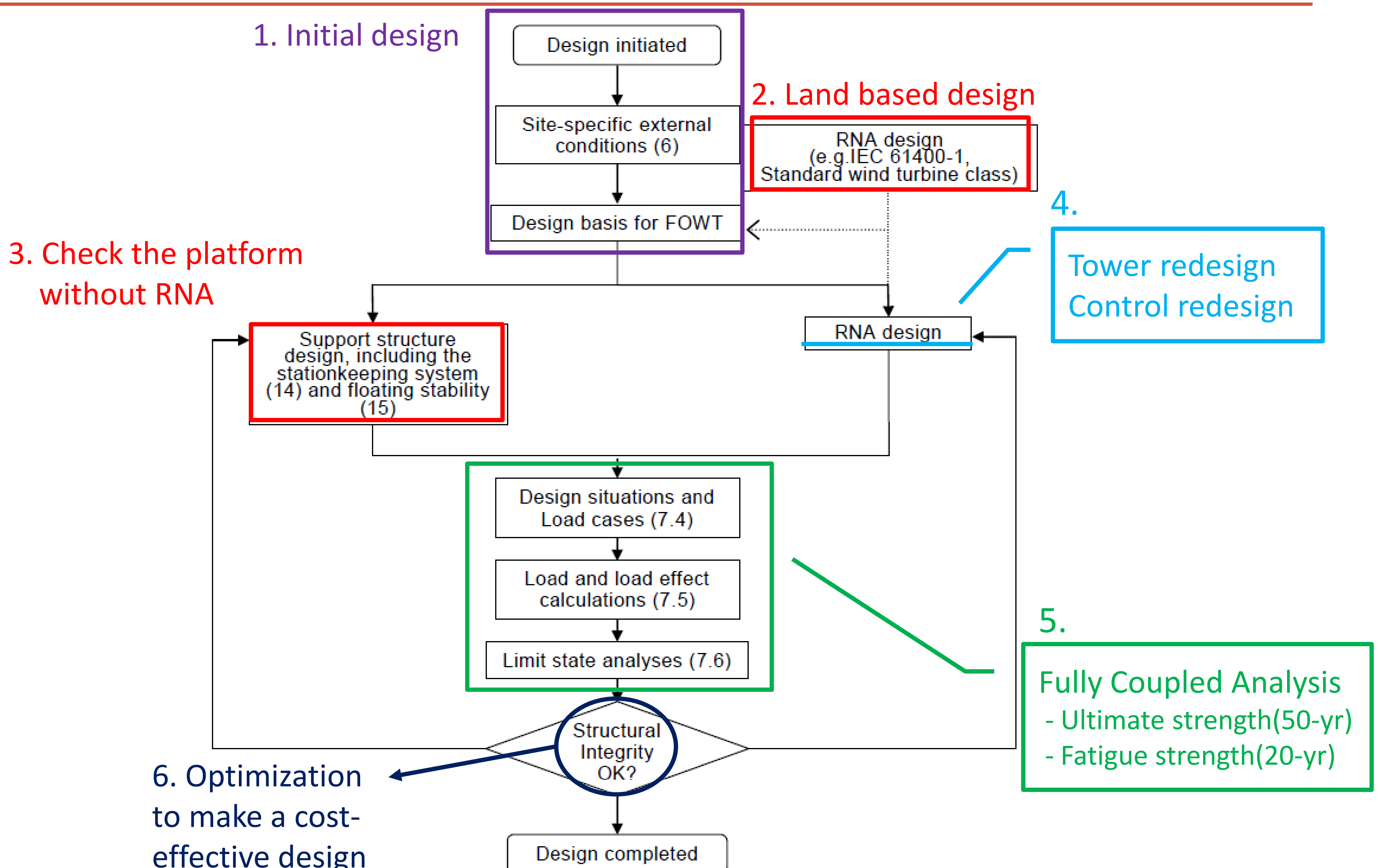
1,50E+05
1,00E+05
5,00E+04
0,00E+00
-5,00E+04
-1,00E+05
-1,50E+05
Damping (tonfm/s)
0,00E+00
1,00E+00
2,00E+00
3,00E+00
4,00E+00
Freq rad/s
UOU-B-15
UOU-B-24
UOU B51
UOU B42

Hydrodynamic coefficients(1/2)

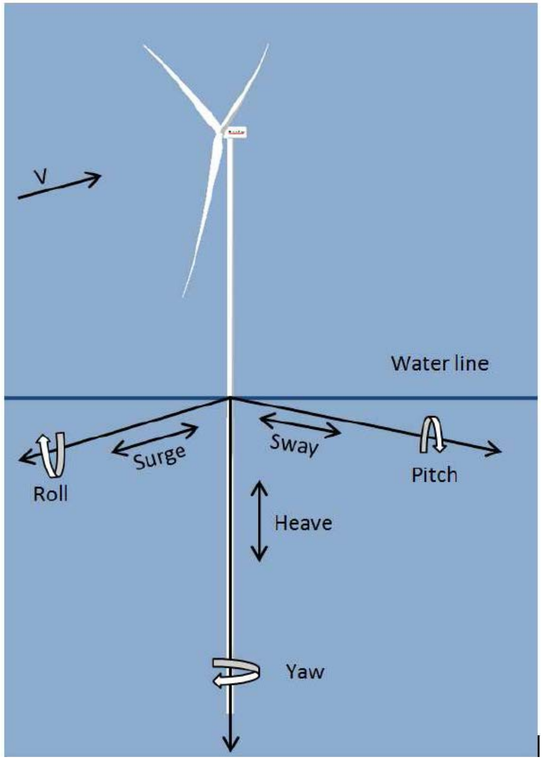




Design process for a floating offshore wind turbine



Source: IEC61400-3-2



Surge	Translation along the longitudinal axis (main wind direction)
Sway	Translation along the lateral axis (transversal to the main wind direction)
Heave	Translation along the vertical axis
Roll	Rotation about the longitudinal axis
Pitch	Rotation about the lateral axis
Yaw	Rotation about the vertical axis

DOFs of a floating wind turbine
(DNV-OS-J103)