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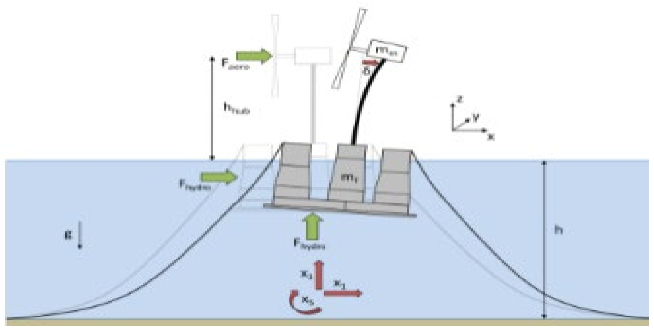
From pre-design to operation:
Outlook and first results of the FloatStep project



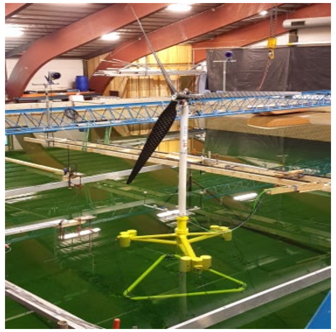



Image: Bourbon Offshore

Henrik Bredmose[1], Mathias Stolpe[1], Antonio Pegalajar-Jurado[1], Kasper Laugesen[2], Bjarne Jensen[3], Michael Borg[4], Johan Rønby[5], Jana Orszaghova[6]

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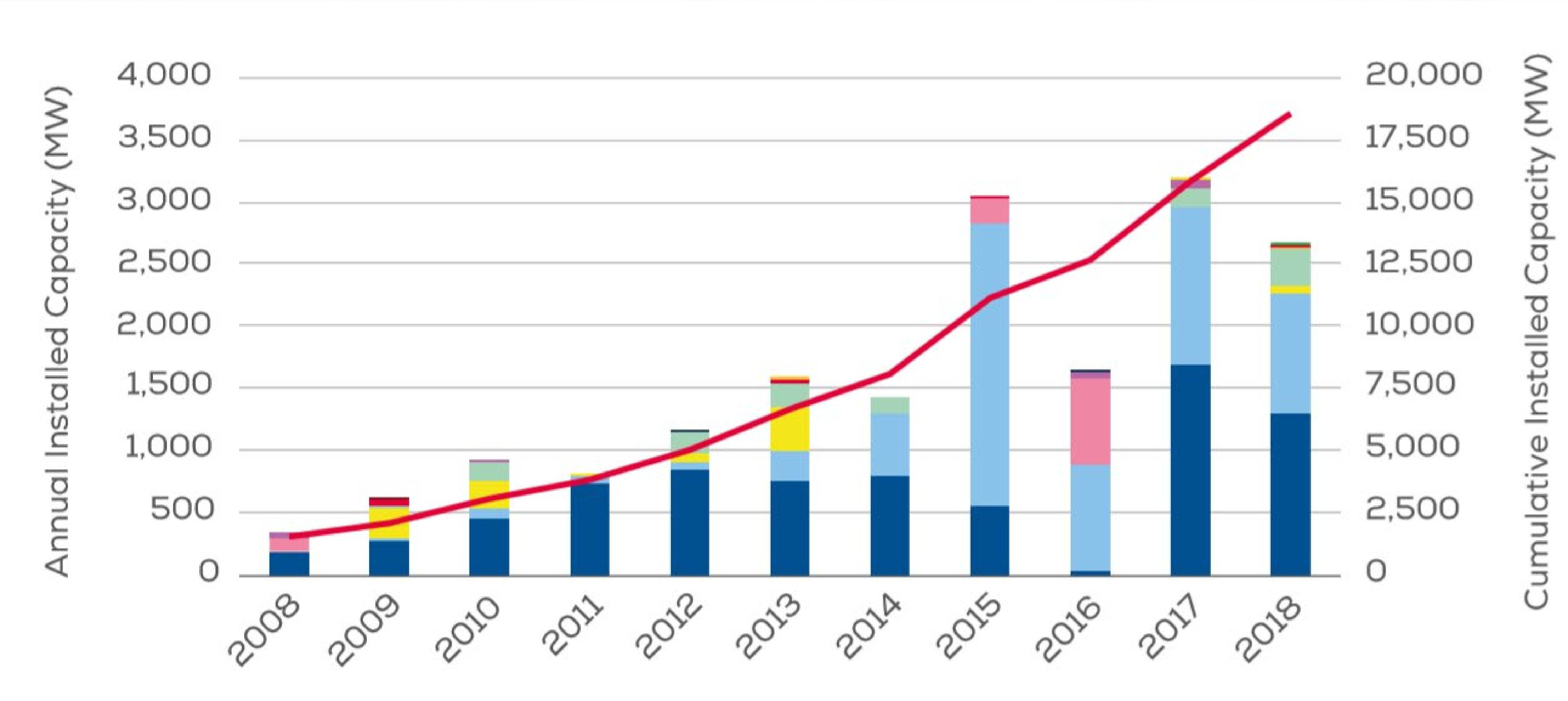
Growth of offshore wind energy in Europe



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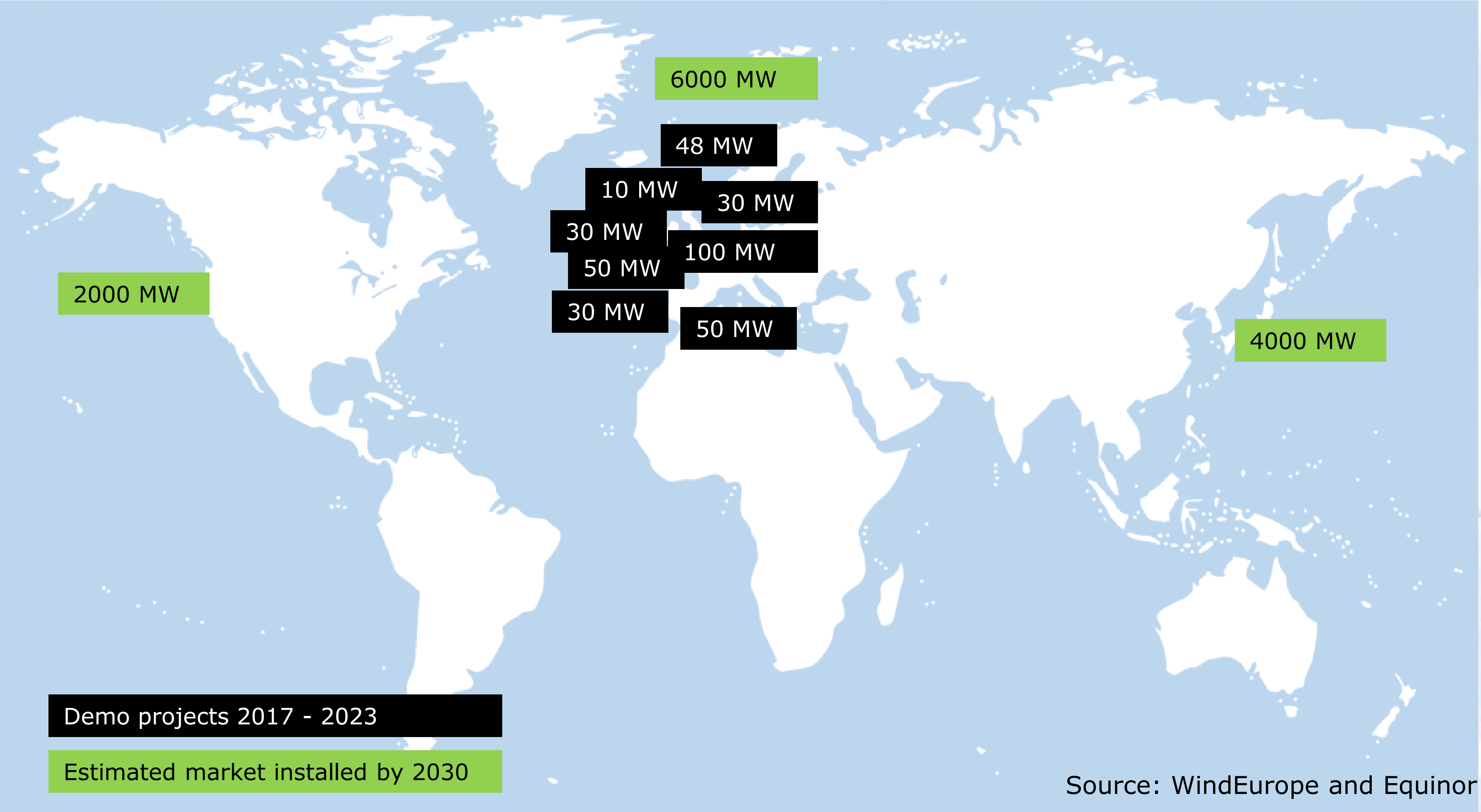
Floating offshore wind is next market



Source: WindEurope and Equinor

IEA: +150 GW offshore wind outside Europe by 2040.

IEA October 2019

A large share can be expected to be floating.

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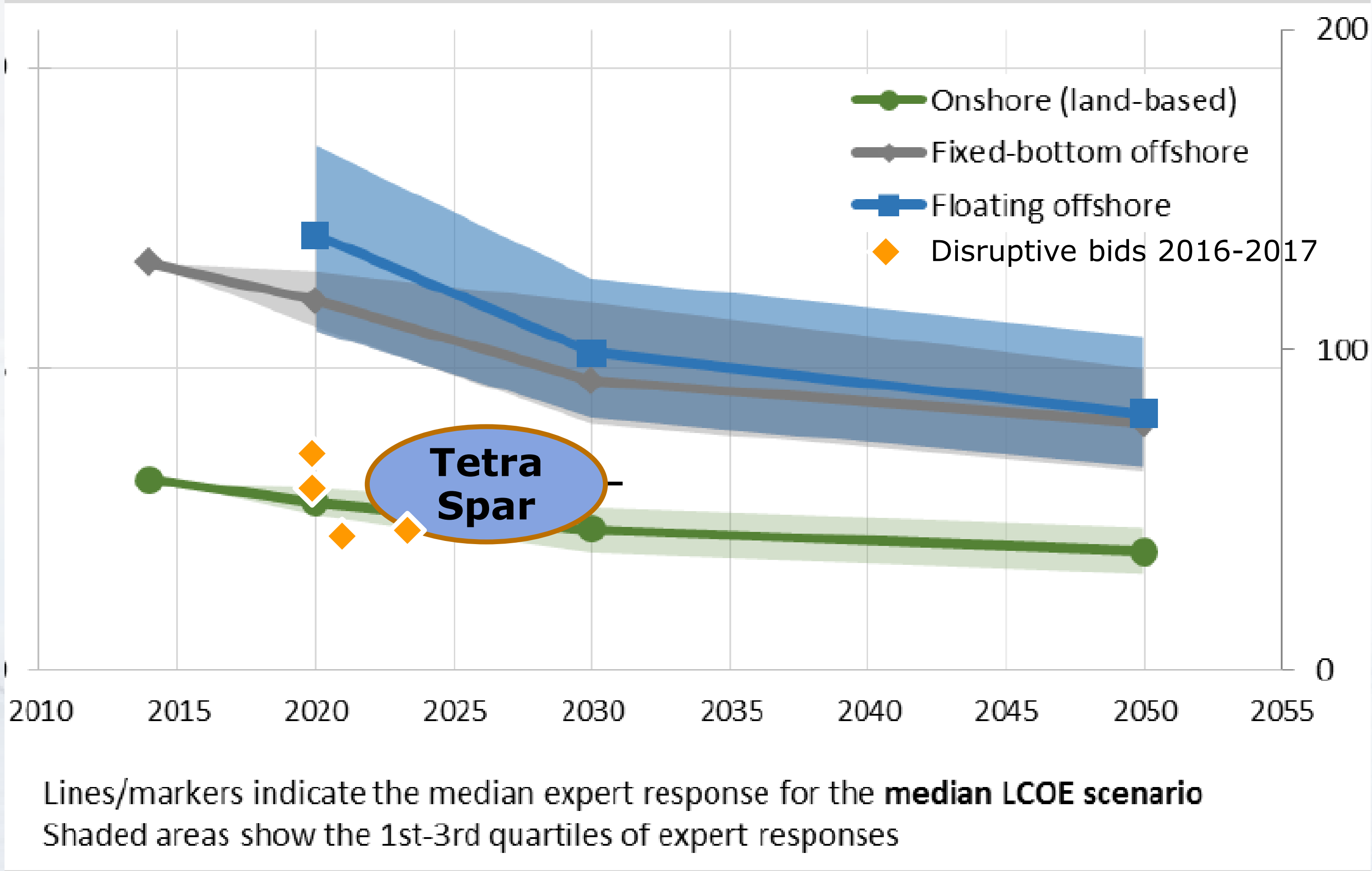
Floating offshore wind is next market



Source: DoE, NREL, IEA

Levelized Cost of Energy €/MWh

The TetraSpar concept

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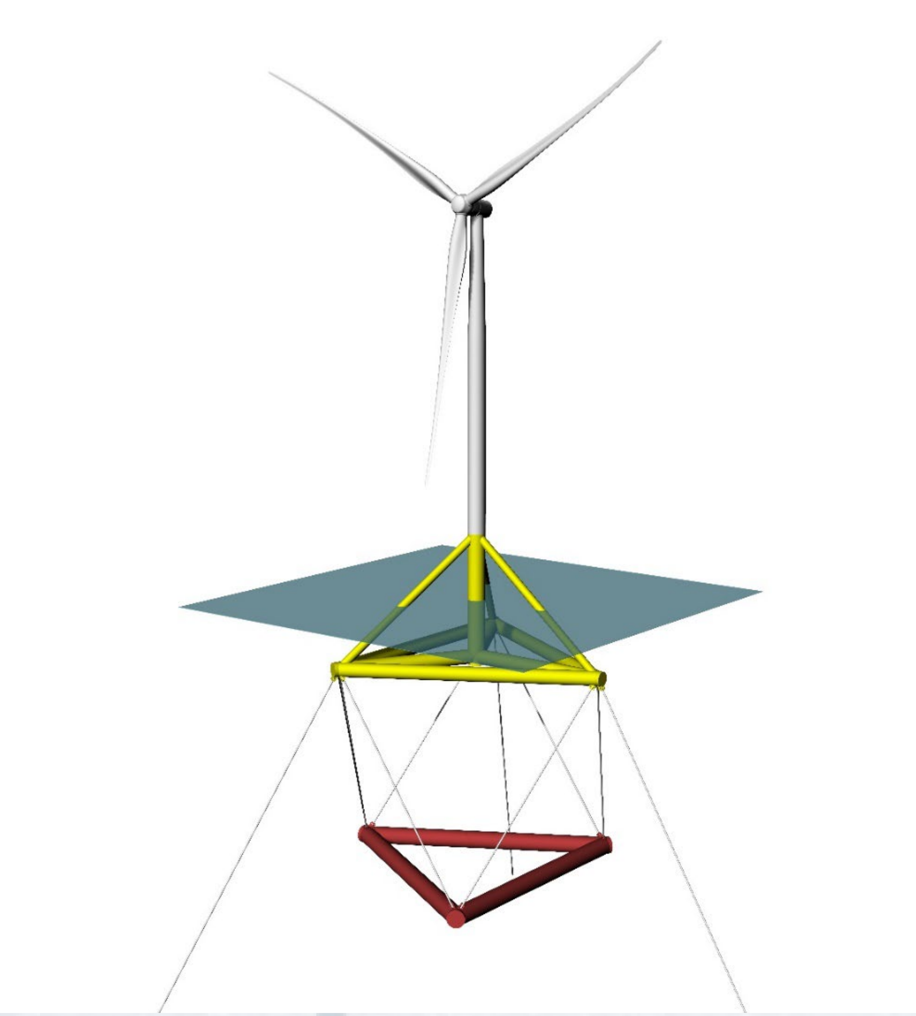

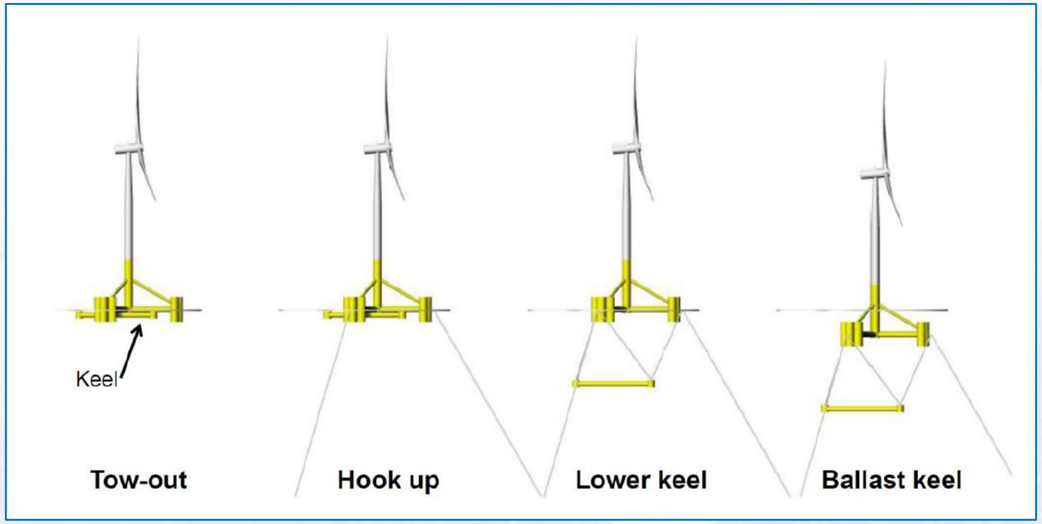

The TetraSpar concept

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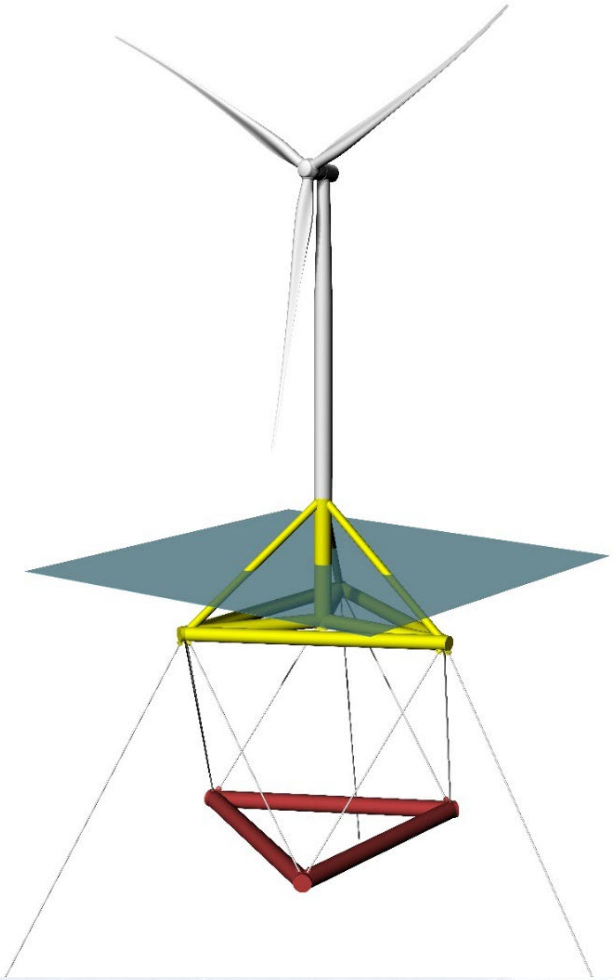
Mindset

- 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?

Concept

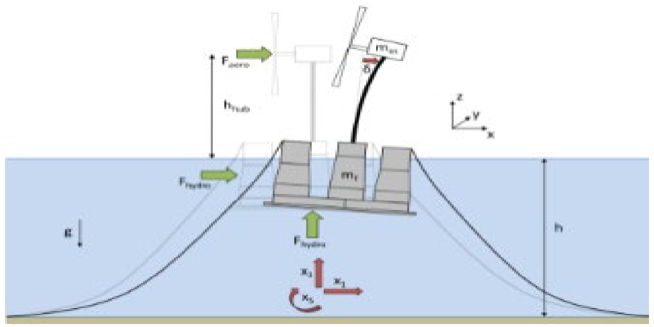
- Modular – all components factory-made, transported by road
- Components assembled at quayside with bolts (not exposed to sea water)
- Turbine mounted in harbor and towed to site, no installation vessels
- Weight 1000-1500 t for 6 MW turbine

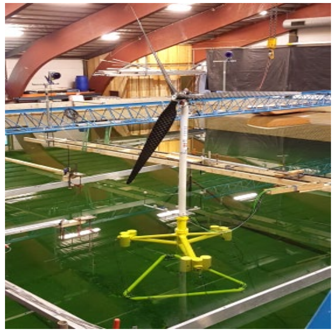


Risks in design and deployment

The FloatStep project

2018-2022





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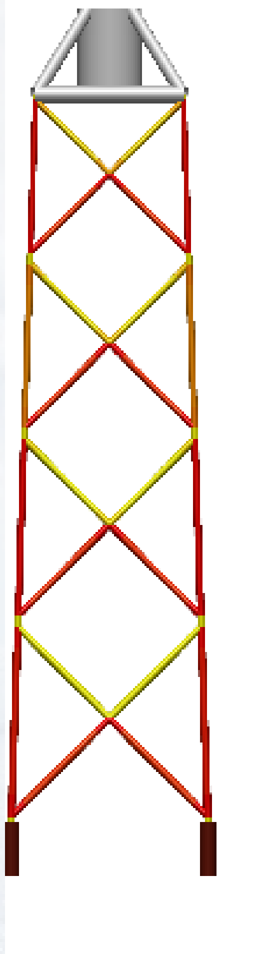
Key innovations in FloatStep

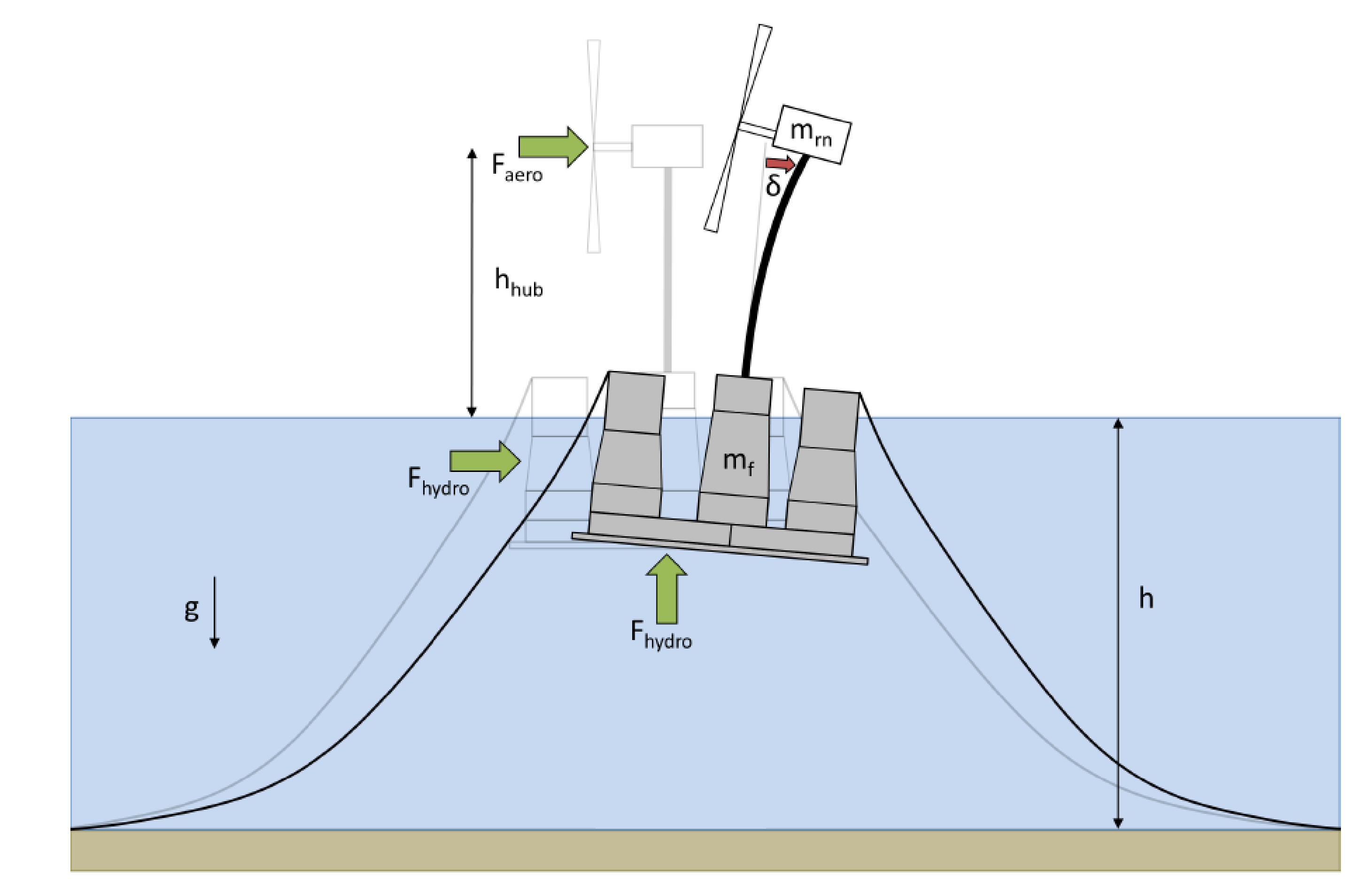
In FloatStep we

1. Reduce cost by structural optimization
2. Enable accurate design by validated engineering models
3. Reduce risk from extreme waves by detailed flow simulations
4. De-risk installation and operation by lab tests and full scale data

1 Reduce cost by structural optimization

- Automated optimal floater design
- LOW-dimensional models
- Frequency domain
- Include mooring and control
- 15 MW floater design





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1 Reduce cost by structural optimization

Automated optimal floater design

LOW-dimensional models

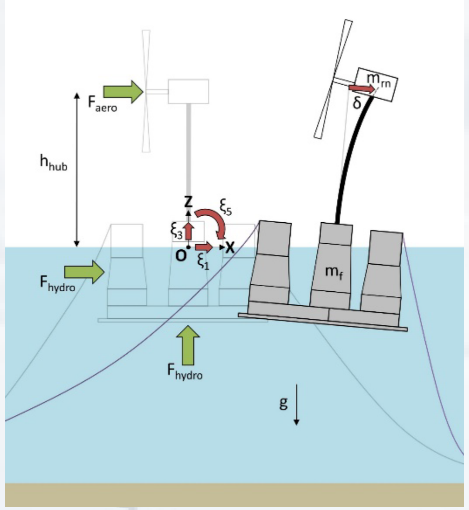
Frequency domain

Include mooring and control

15 MW floater design

The QuLAF model

LIFES50+



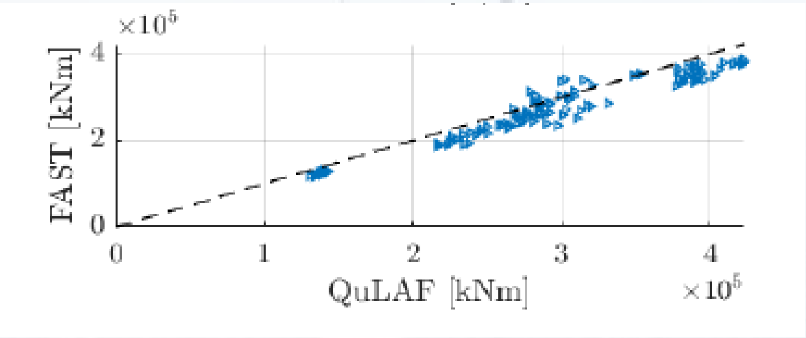
Precompute rotor loads and aero damping

3 floater DOFs
1 tower DOF

WAMIT data for hydro
Linearized mooring

Pegalajar-Jurado et al (2018)

Validation study
Tower bottom moment



Madsen et al (2019)

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1 Reduce cost by structural optimization

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- LOW-dimensional models
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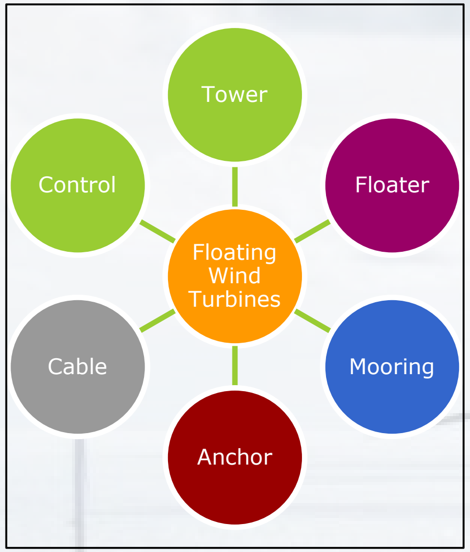
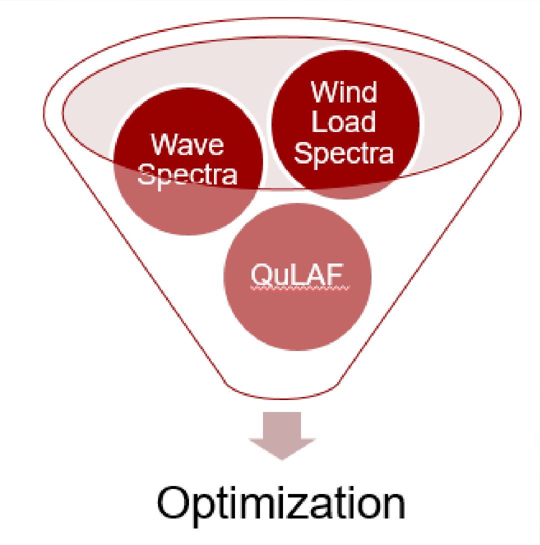
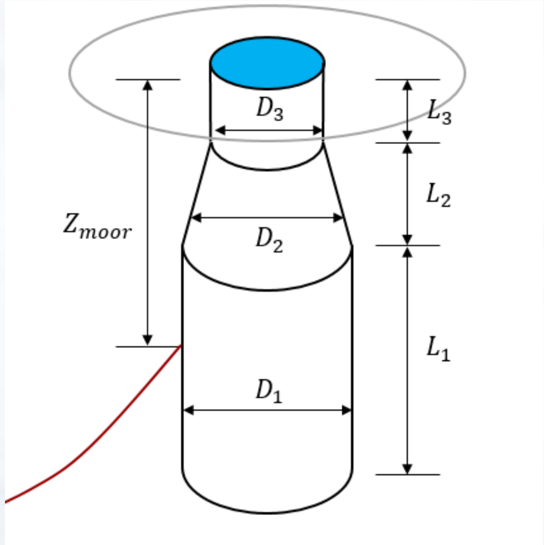
Optimization for floater and tower design



Aspects



Approach



Attack

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1 Reduce cost by structural optimization

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- Automated optimal floater design
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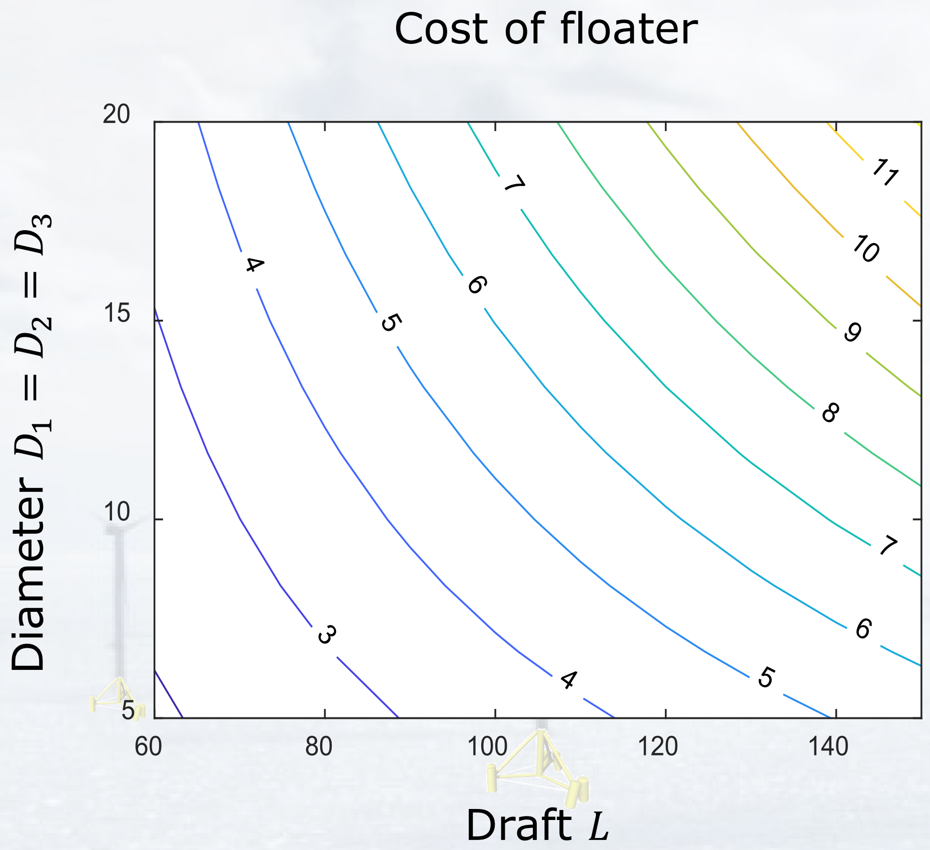
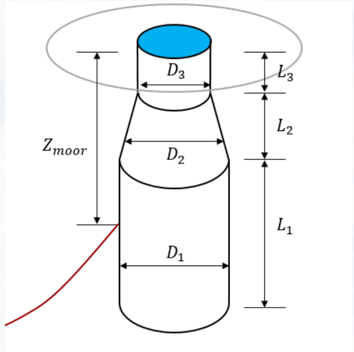
Optimization for floater and tower design





	Initial design	Optimized design
Draft L_1	130 m	80.6 m
Diameter D_1	15 m	20.0 m
Diameter D_3	10 m	10.4 m
Normalized cost	1.00	0.86

Suguang Dou, Shaofeng Wang, M. Stolpe

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2 Enable accurate design by validated engineering models

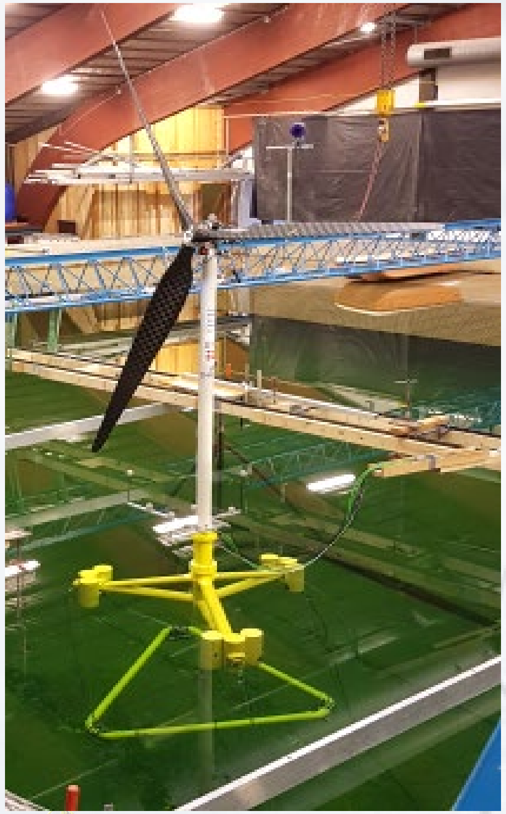
Validation

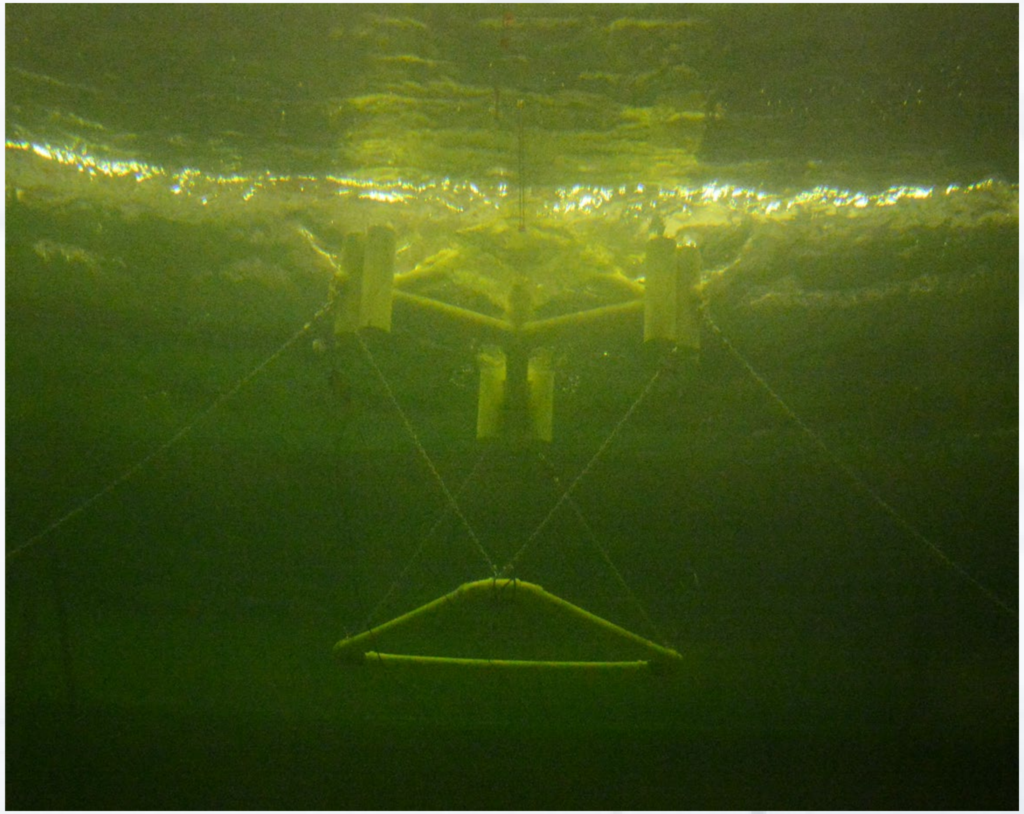
2nd-order waves

Design for flexible floaters

Fast models that enable optimization

HAWC2, BHAWC, Mike21





2 Enable accurate design by validated engineering models

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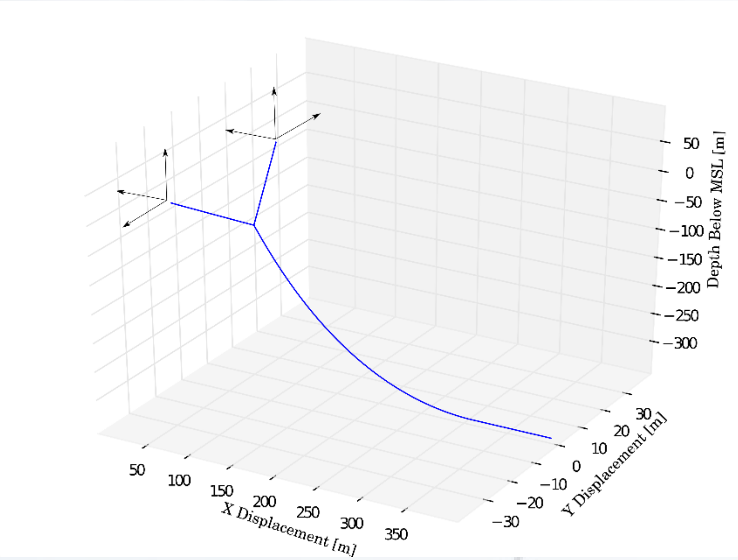
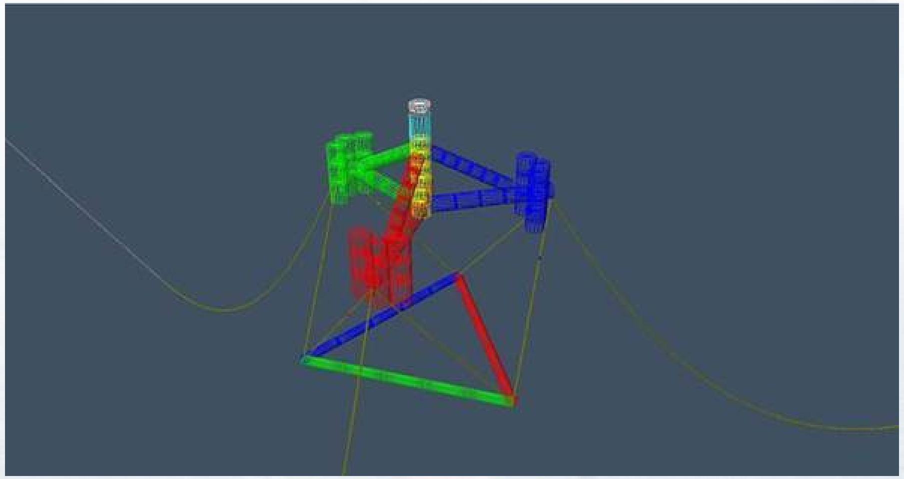
HAWC2, BHAWC, Mike21



Implementing Mooring Lines into BHawC

BHawC/Orcaflex Coupling



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2 Enable accurate design by validated engineering models

Validation

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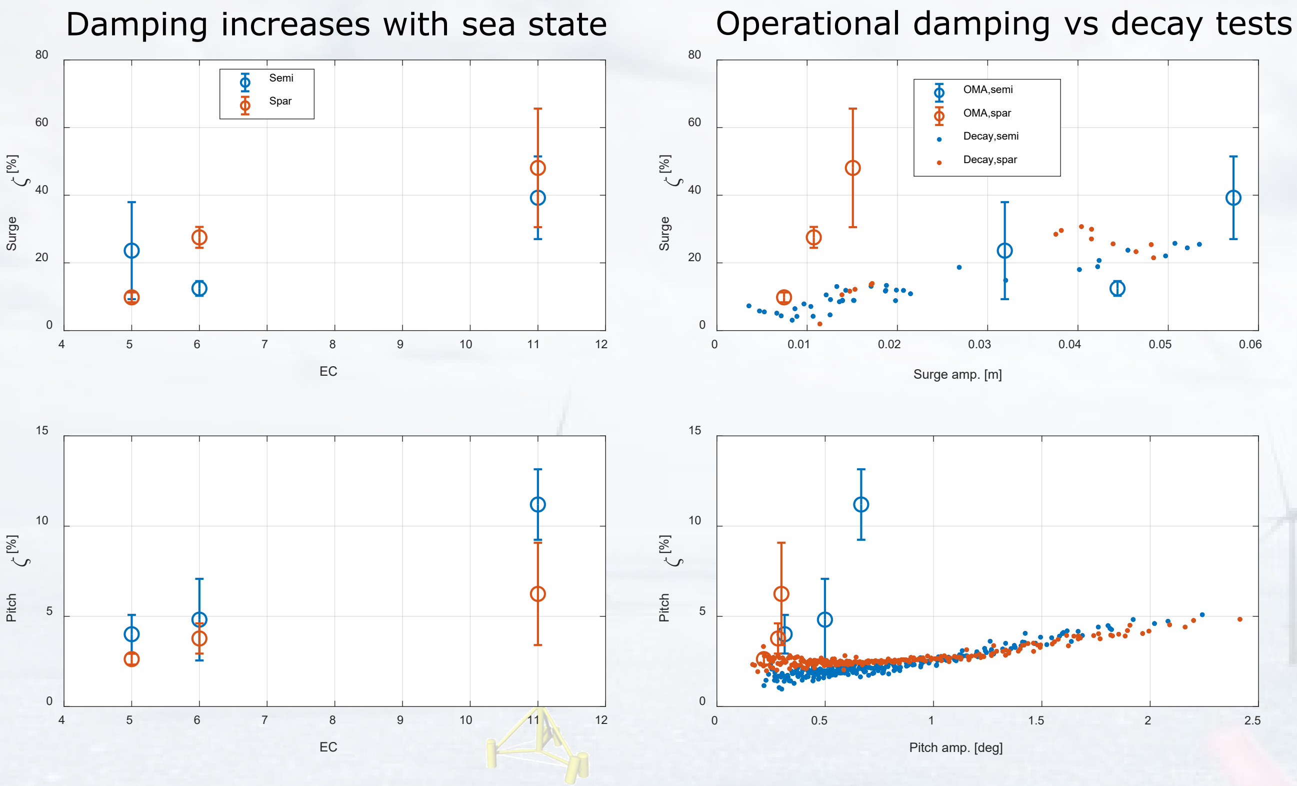
Design for flexible floaters

Fast models that enables optimization

HAWC2, BHAWC, Mike21

Damping identification with Operational Modal Analysis



Pegalajar-Jurado, Madsen and Bredmose (2019)

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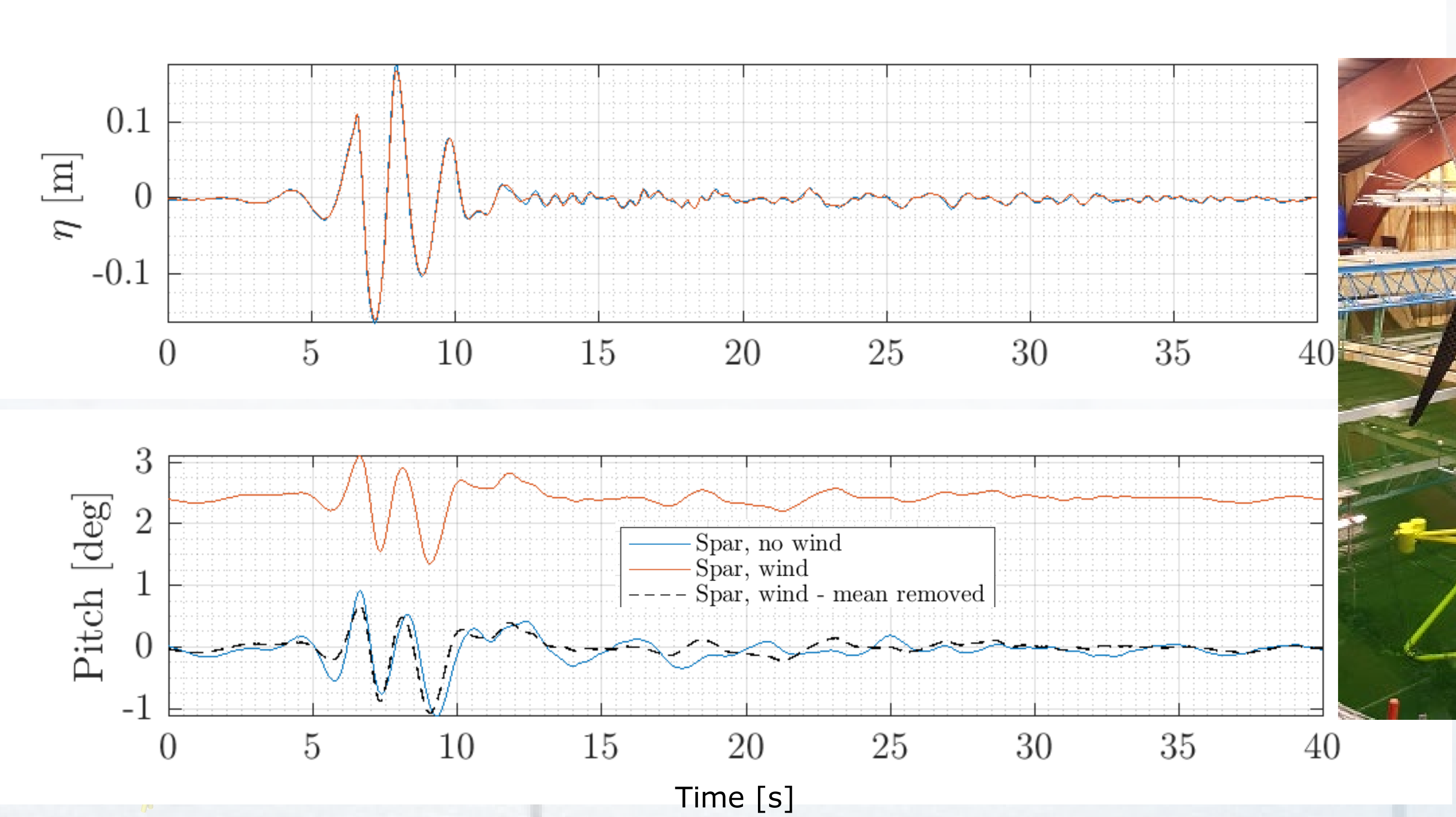

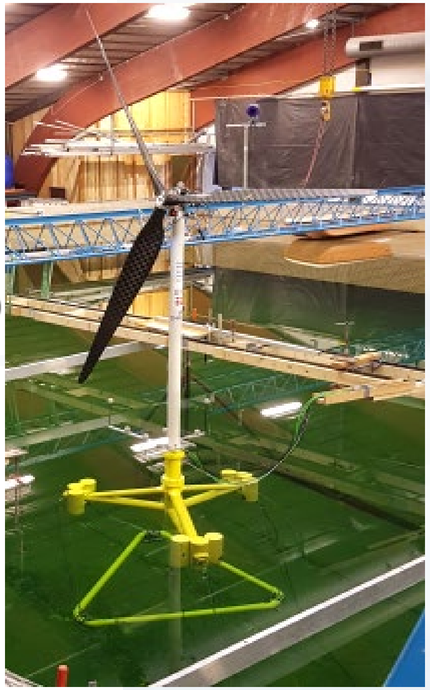

Focused wave group test at DHI (Borg et al EERA DeepWind 2018)

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2 Enable accurate design by validated engineering models

Validation

2nd-order waves

Design for flexible floaters

Fast models that enable optimization

HAWC2, BHAWC, Mike21

HAWC2-recomputation of model tests – waves-only

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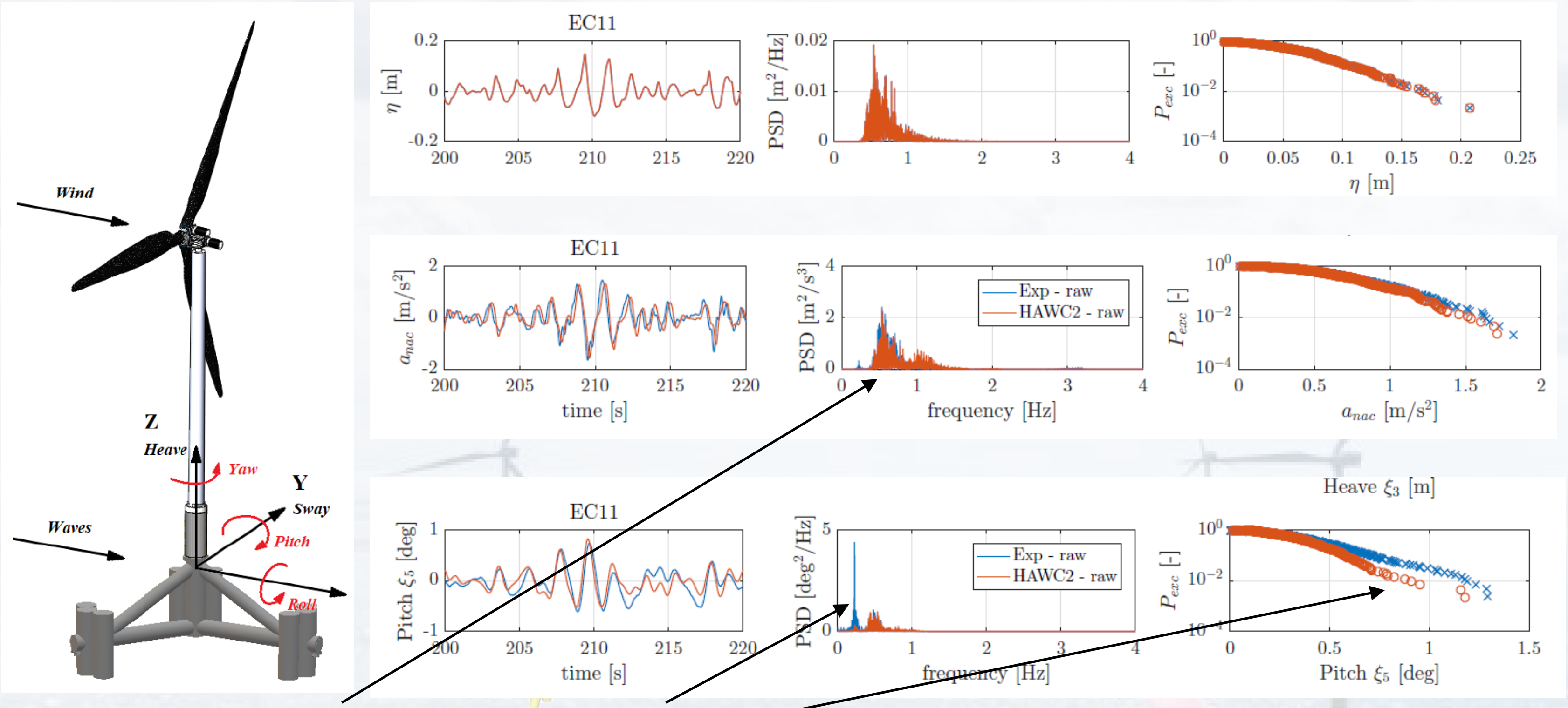

Nacelle acceleration good. Platform pitch needs nonlinear wave forcing

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2 Enable accurate design by validated engineering models

Validation

2nd-order waves

Design for flexible floaters

Fast models that enables optimization

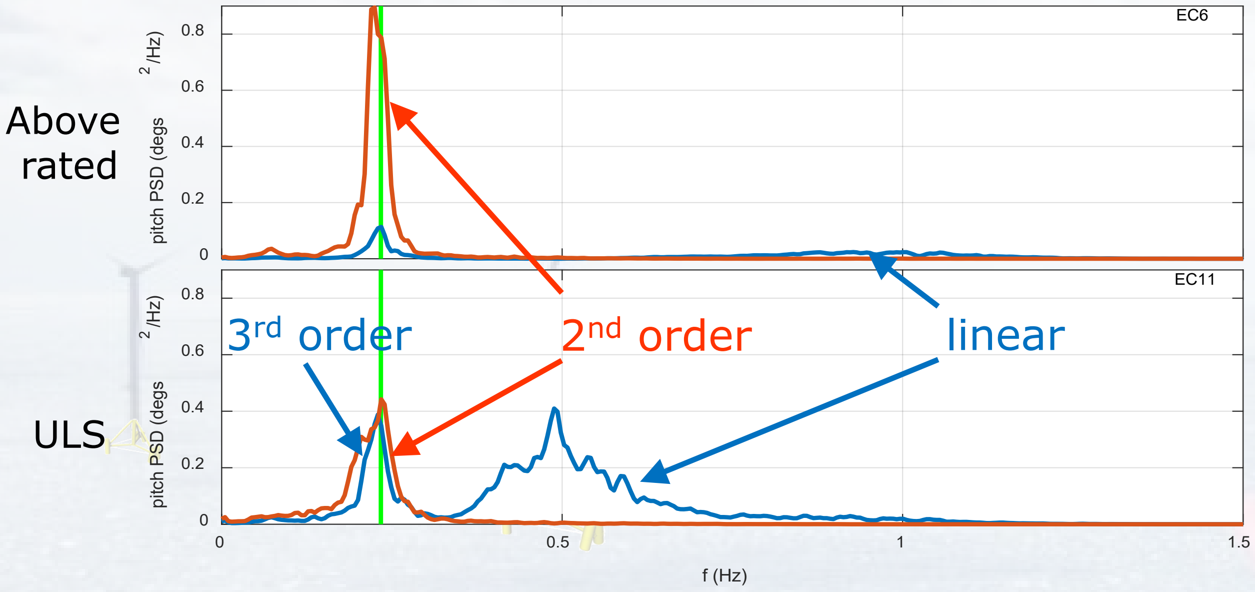
HAWC2, BHAWC, Mike21

Analysis of experimental platform motions

Separation of response to subharmonic wave forcing

Pitch motion - dominated by nonlinear (difference frequency) wave forcing

- primarily 2nd order, but 3rd order important in severe sea states



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2 Enable accurate design by validated engineering models

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2nd-order waves

Design for flexible floaters

Fast models that enable optimization

HAWC2, BHAWC, Mike21

A fast method for second-order wave forcing

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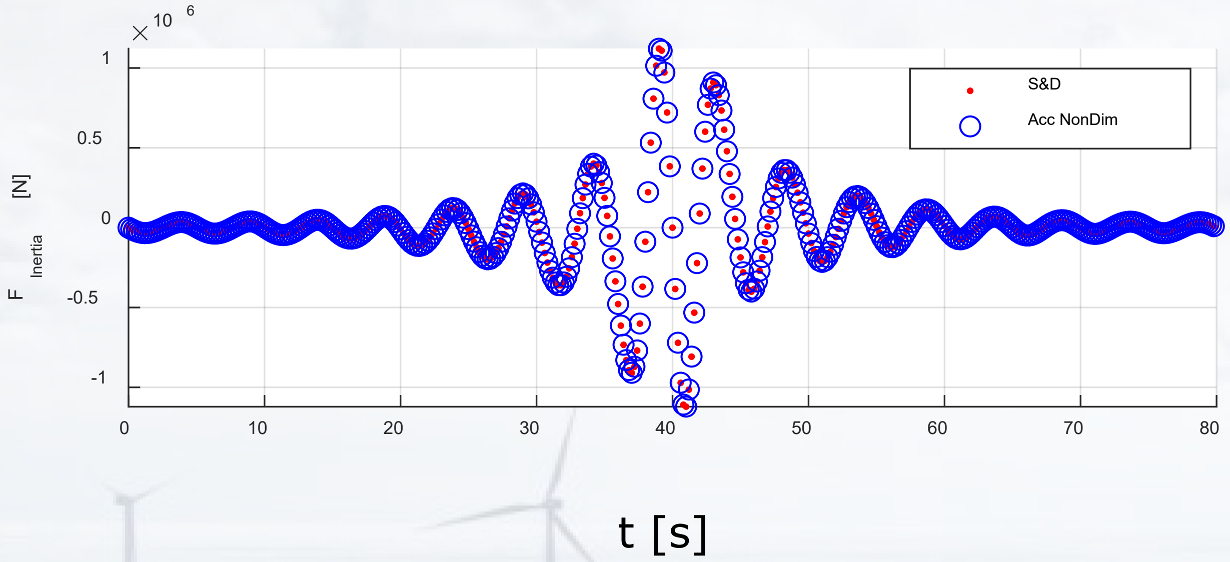


Here: 2nd-order super harmonic monopile force at 33m depth.

Classical Sharma & Dean (1981) method is $O(N^2)$. New method $O(N \log N)$

2 Enable accurate design by validated engineering models

Validation

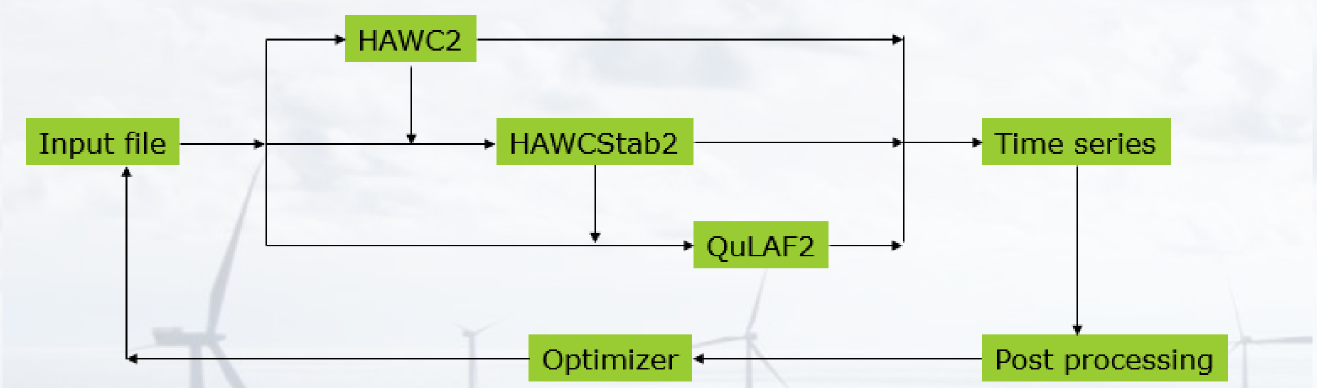
2nd-order waves

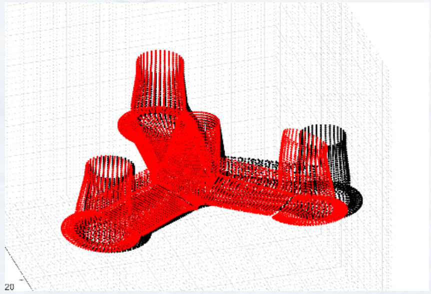
Design for flexible floaters

Fast models that enables optimization

HAWC2, BHAWC, Mike21

Combine QuLAF principles + flexible substructuring in HAWC2





Linearization based on HAWCStab2

Flexible floater modes in HAWC2 (Borg et al 2016, 2017)

2 Enable accurate design by validated engineering models

Validation

2nd-order waves

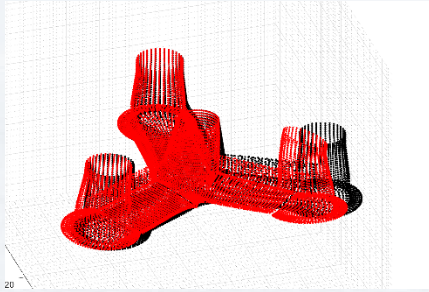
Design for flexible floaters

Fast models that enables optimization

HAWC2, BHAWC, Mike21

Flexible substructuring in HAWC2

Model tests for validation to be conducted at DHI



Flexible floater modes in HAWC2 (Borg et al 2016, 2017)

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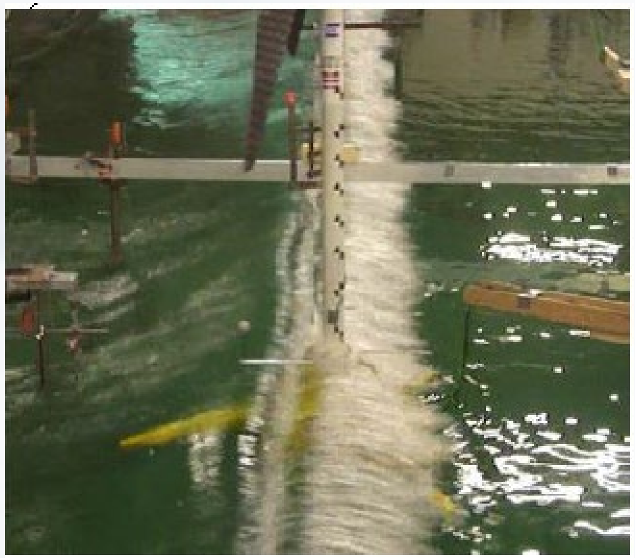
3 Reduce risk from extreme waves by detailed flow simulations

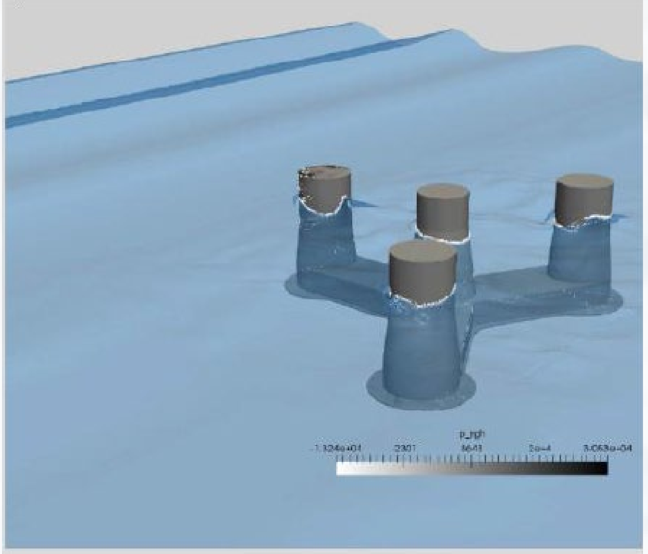
Applicable Computational Fluid Dynamics

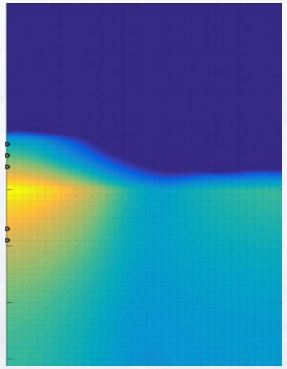
Detailed hydrodynamic loads

Develop and adapt OpenFOAM model

Coupling to engineering models







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3 Reduce risk from extreme waves by detailed flow simulations

Applicable Computational Fluid Dynamics

Detailed hydrodynamic loads

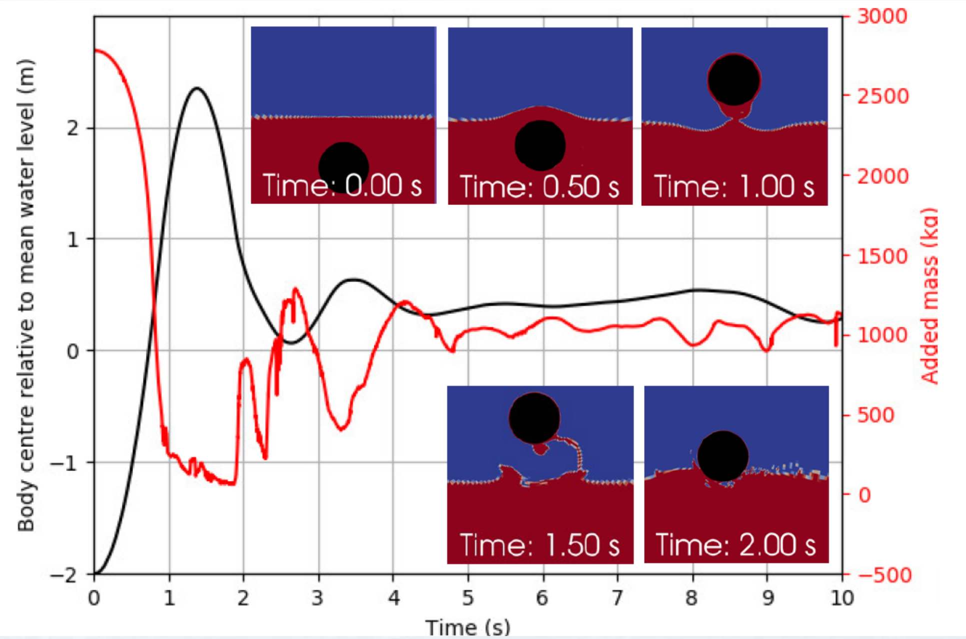
Develop and adapt OpenFOAM model

Coupling to engineering models

Key for stable floater CFD: Added mass

InterFOAM solver of OpenFOAM not stable when added mass larger than structural mass.

New method to overcome this problem developed. Will be released as Open Source.



2D example of circular disk water exit.

3 Reduce risk from extreme waves by detailed flow simulations

Applicable Computational Fluid Dynamics

Detailed hydrodynamic loads

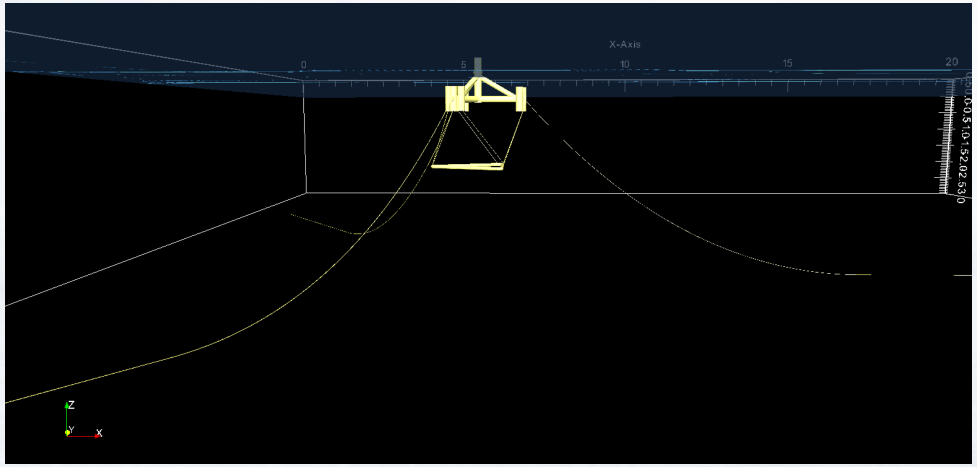
Develop and adapt OpenFOAM model

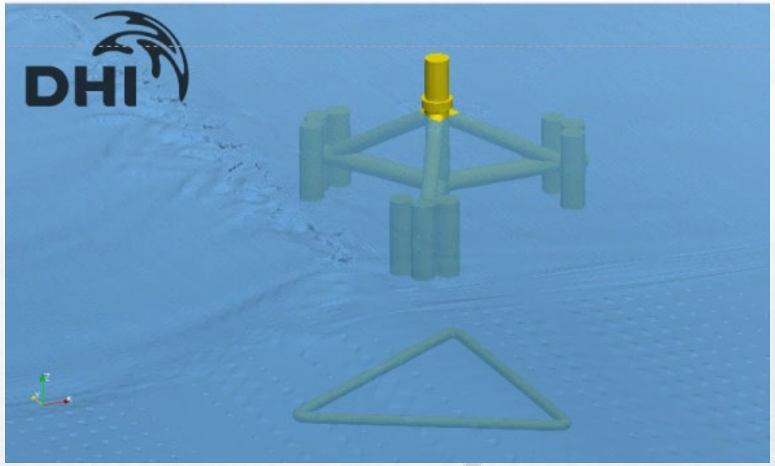
Coupling to engineering models

- OpenFOAM CFD 6DOF-solver with catenary mooring chains
- Validation against experimental tests with TetraSpar floater
- Coupling to MIKE 3 Wave FM model

<u>Presentation on 16^{th} January at 15.45:</u>

"Hybrid Modelling for Engineering Design of Floating Offshore Wind Turbine Foundations - Model Coupling and Validation"





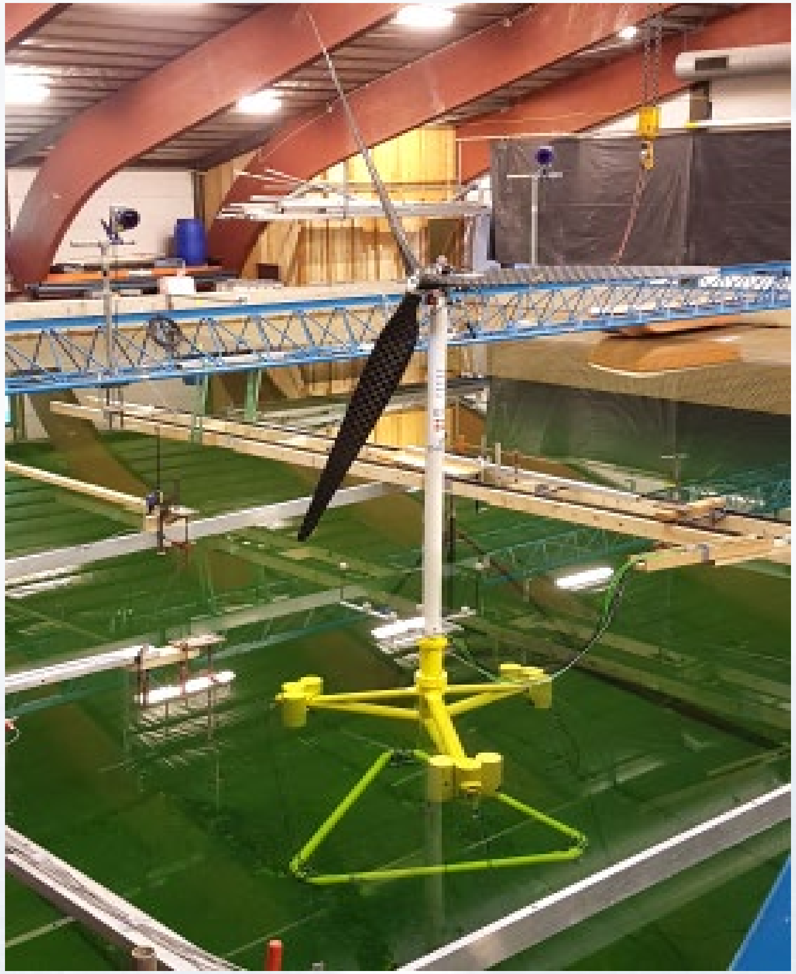
4 De-risk installation and operation by lab tests and full scale data

Model tests for installation

Model tests with control

Analysis of full scale data

Re-modelling and tools validation



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4 De-risk installation and operation by lab tests and full scale data

- **Model tests for installation**
- Model tests with control
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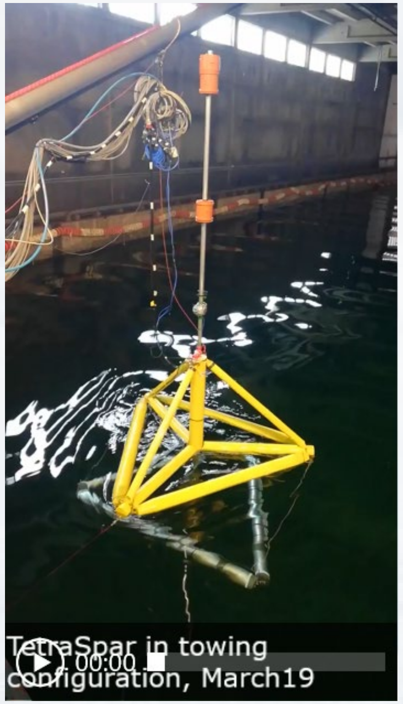
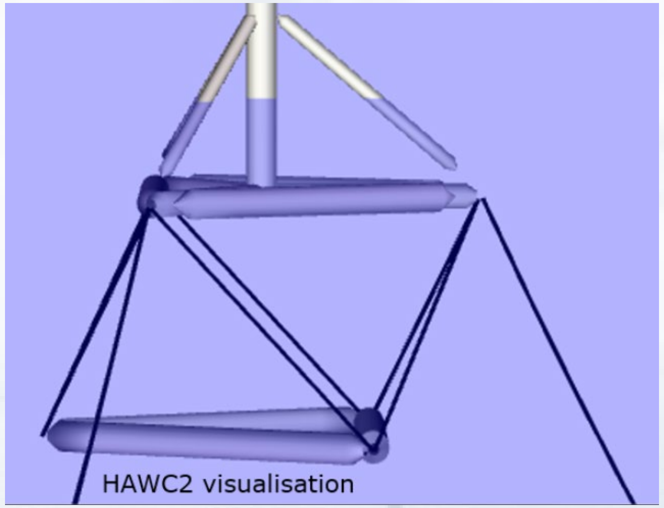
Installation



Towing test by SOT at Force Technology



After installation

Tests in FloatStep at DHI are planned.

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4 De-risk installation and operation by lab tests and full scale data

- Model tests for installation
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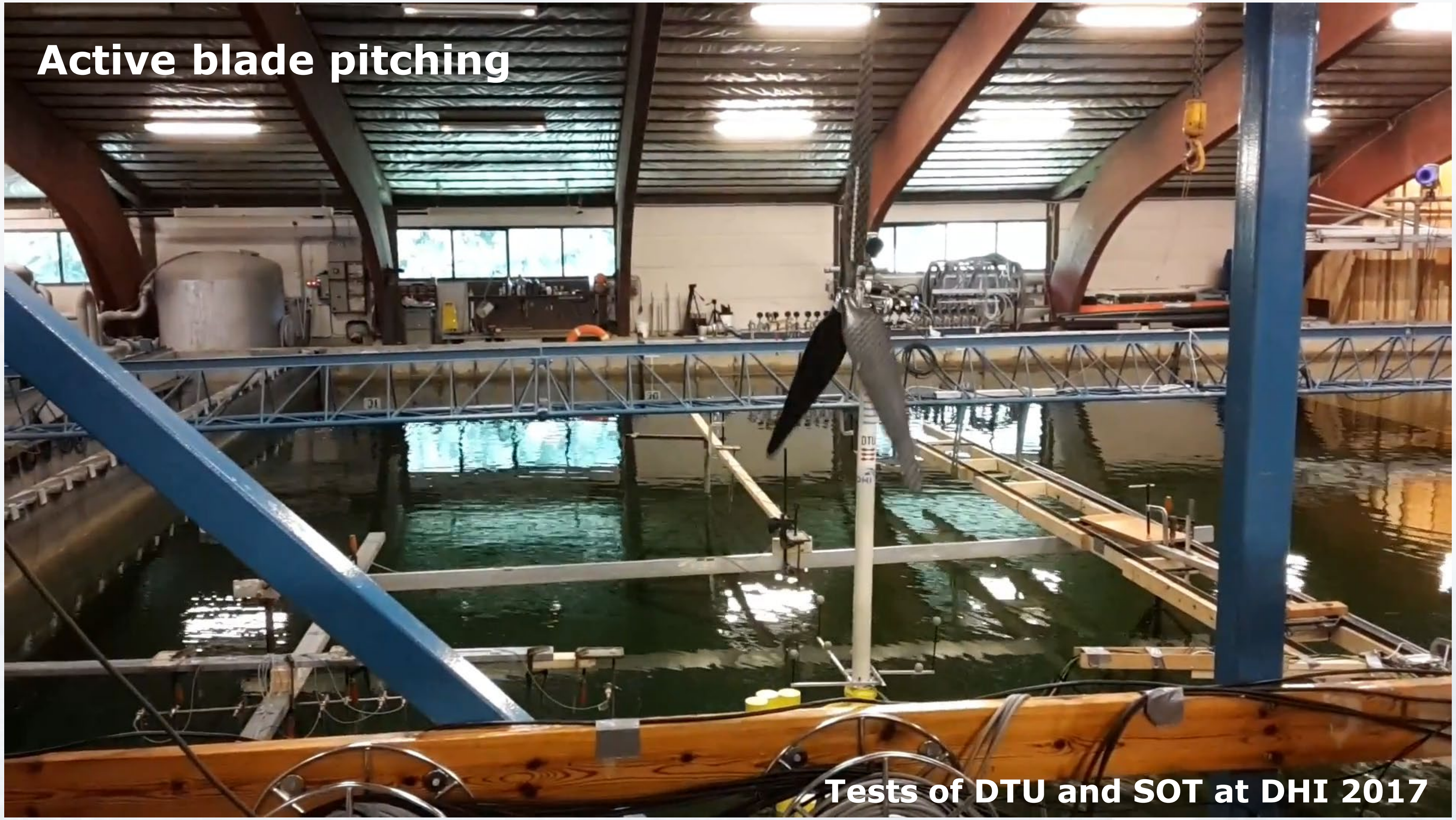


4 De-risk installation and operation by lab tests and full scale data

Model tests for installation

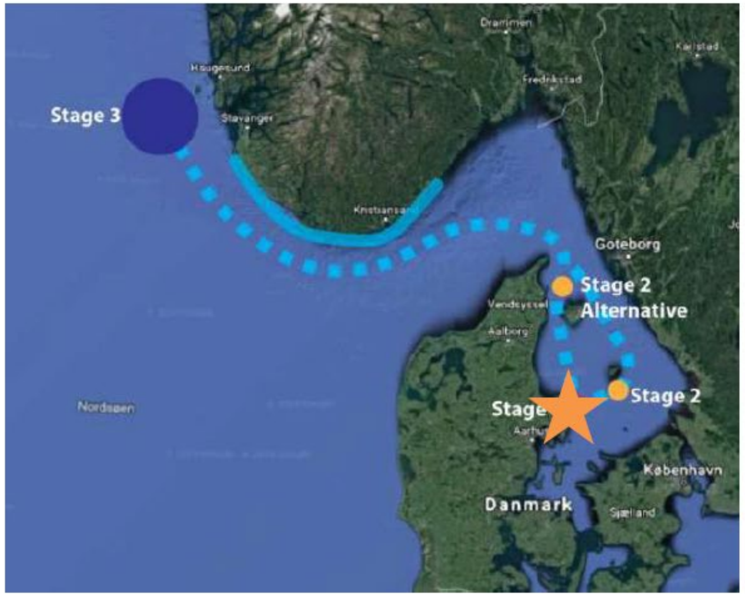
Model tests with control

Analysis of full scale data

Re-modelling and tools validation

Full scale demonstrator of Stiesdal Offshore Technology

Prototype with 3.6 MW SGRE turbine will be installed at the MetCentre, Karmøy, in late summer 2020



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Implementation

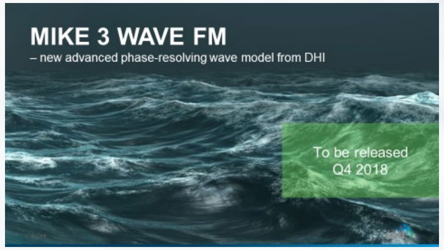
Mike Powered by DHI Software

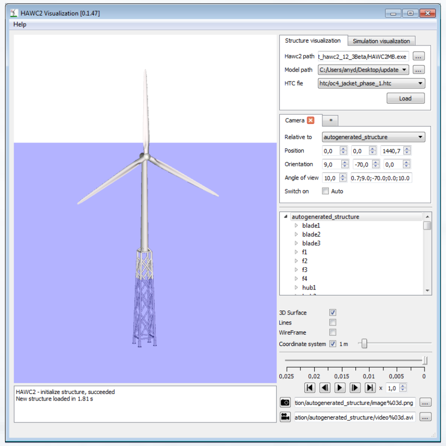
HAWC2 (DTU Wind Energy)

Siemens-Gamesa

OpenFOAM

TetraSpar





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FloatStep – Science and innovation for floating wind technology

First publications of FloatStep

Pegalajar-Jurado, Madsen and Bredmose (2019) ‘Damping identification of the TetraSpar floater in two configurations with Operational Modal Analysis’. 2nd Int Offshore Wind Technical Conference, Malta, November 2019. ASME.

Madsen, Pegalajar-Jurado and Bredmose (2019) ‘Performance study of the QuLAF pre-design model for a 10MW floating wind turbine’, Wind Energy Science (2019). Available online.

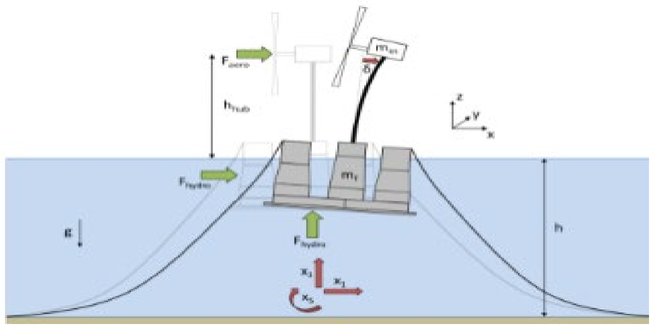
Pegalajar-Jurado, Pisi, Fandino, Madsen and Bredmose (2019) ‘Study on aerodynamic damping for application in frequency-domain models for floating wind turbines’. Poster at WindEurope Offshore, Copenhagen, November 2019

Pirrung et al (2019) ‘Modal reduction in HAWCSTAB2 applied to floating wind turbines.’ Poster at WindEurope Offshore, Copenhagen, November 2019

Papers are planned for Torque 2020, IWWWFB 2020, ICTAM 2020 and OMAE 2020

From pre-design to operation:

Outlook and first results of the FloatStep project



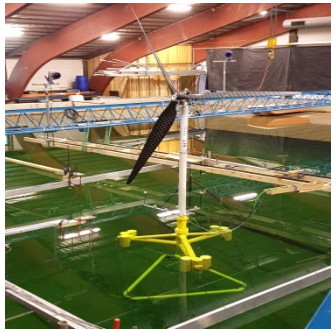


Image: Bourbon Offshore

Henrik Bredmose[1], Mathias Stolpe[1], Antonio Pegalajar-Jurado[1], Kasper Laugesen[2], Bjarne Jensen[3], Michael Borg[4], Johan Rønby[5], Jana Orszaghova[6]

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