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Floating offshore wind – A state of the art review

Rostock | 83rd Annual Meeting of the DPG and DPG-Frühjahrstagung | 13rd of March 2019

Dr.-Ing. Frank Adam

Personal introduction

Dr.-Ing. Frank ADAM (married, 3 children)

- 2009 – Diploma at the excellent Technical University of Dresden
- 2015 – PhD (summa cum laude) at the Technical University Bergakademie Freiberg (Topic: System dynamic of floating offshore wind)
- Since 2015 – group leader offshore wind at the University of Rostock
- Since 2015 – head of R&D offshore wind division at the GICON – Großmann Ingenieur Consult GmbH
- Reviewer for several Journals within the field of Renewable Energy
- Member of: ISSC V.4 committee (2015/2018), IEC61400-3-2 standard committee, ISOPE and ReNew conference technical committee

Publications:

Content of the presentation

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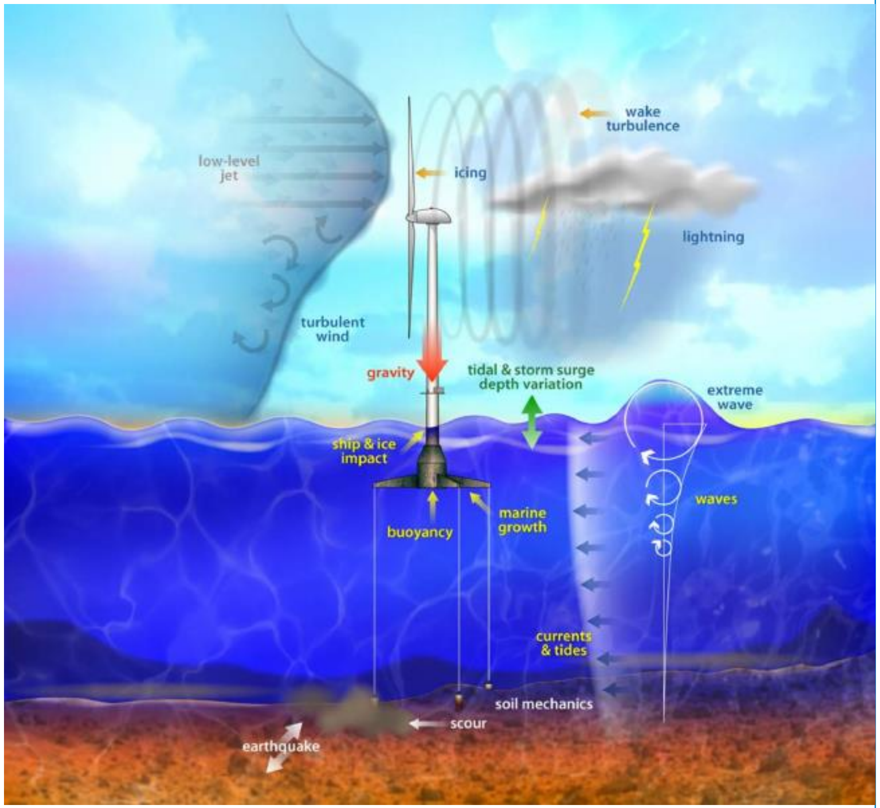
- Motivation
- Introduction & wording
- State of the Art: Selected examples
- Current research and development topics
  - scaling effects for combined wind and wave tests
  - servo-hydro-aero-elastic coupled calculation
- Conclusion



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Motivation

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MOTIVATION - Floating offshore wind vision

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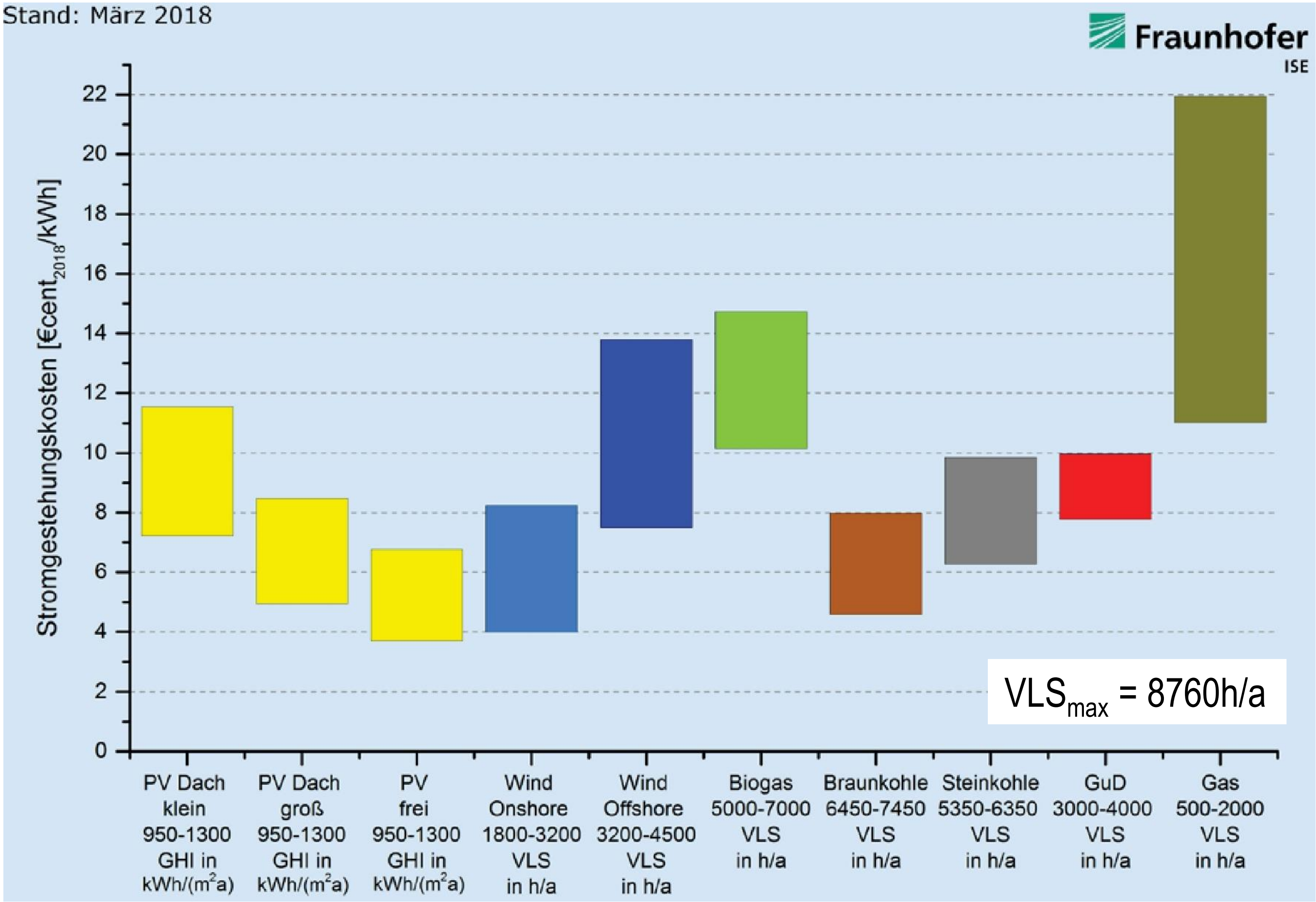
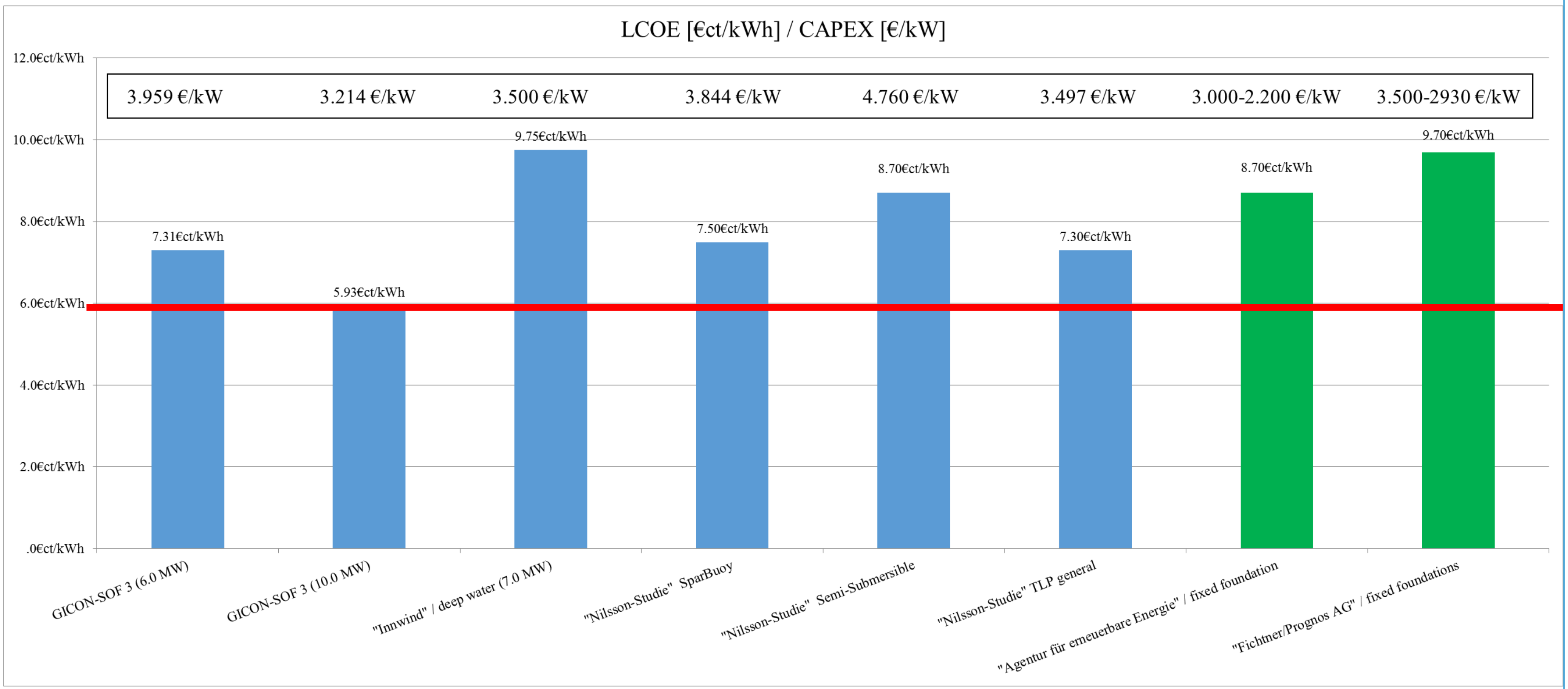
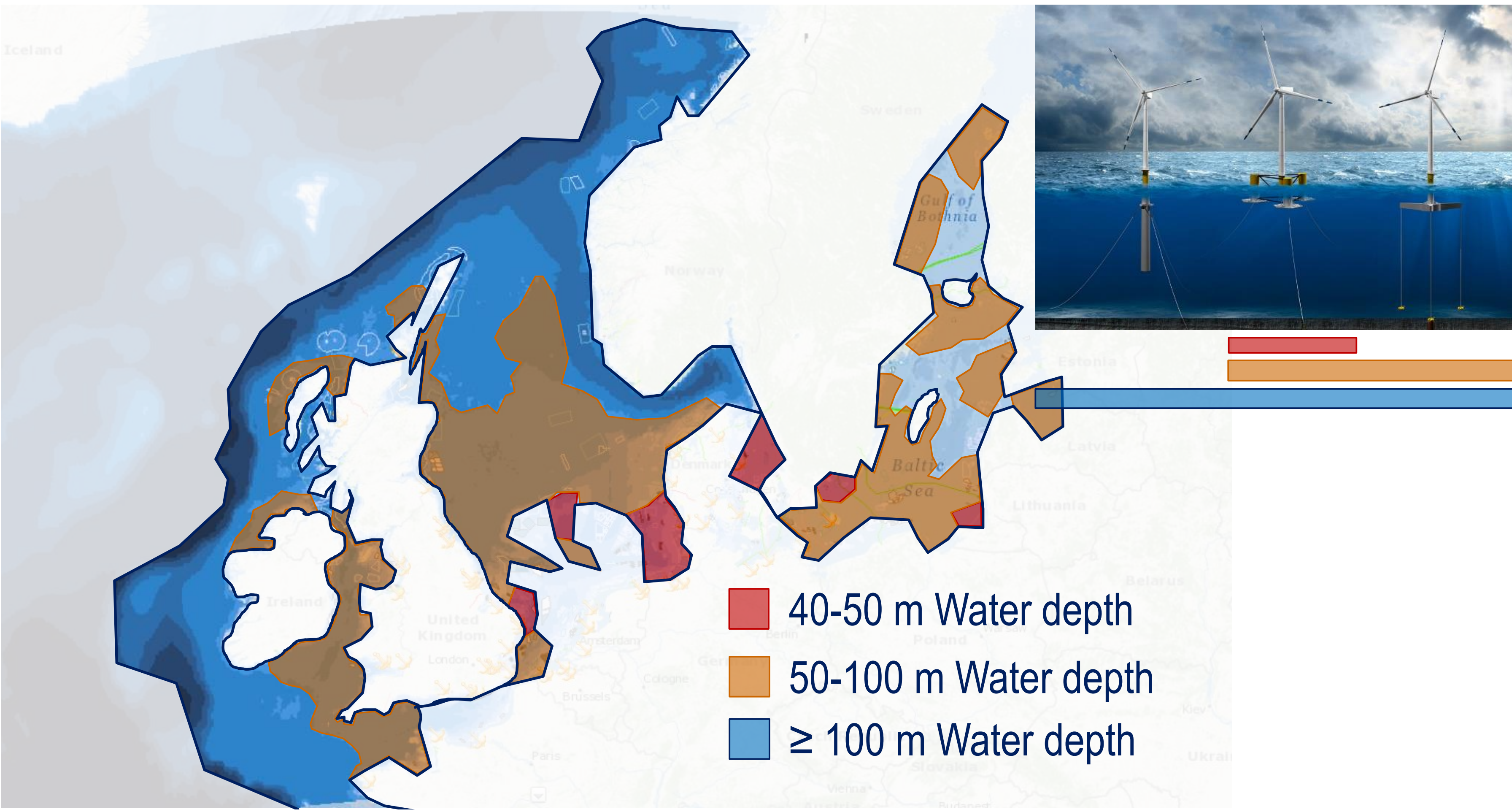
Motivation - LCOE



Motivation - Reduced LCOE

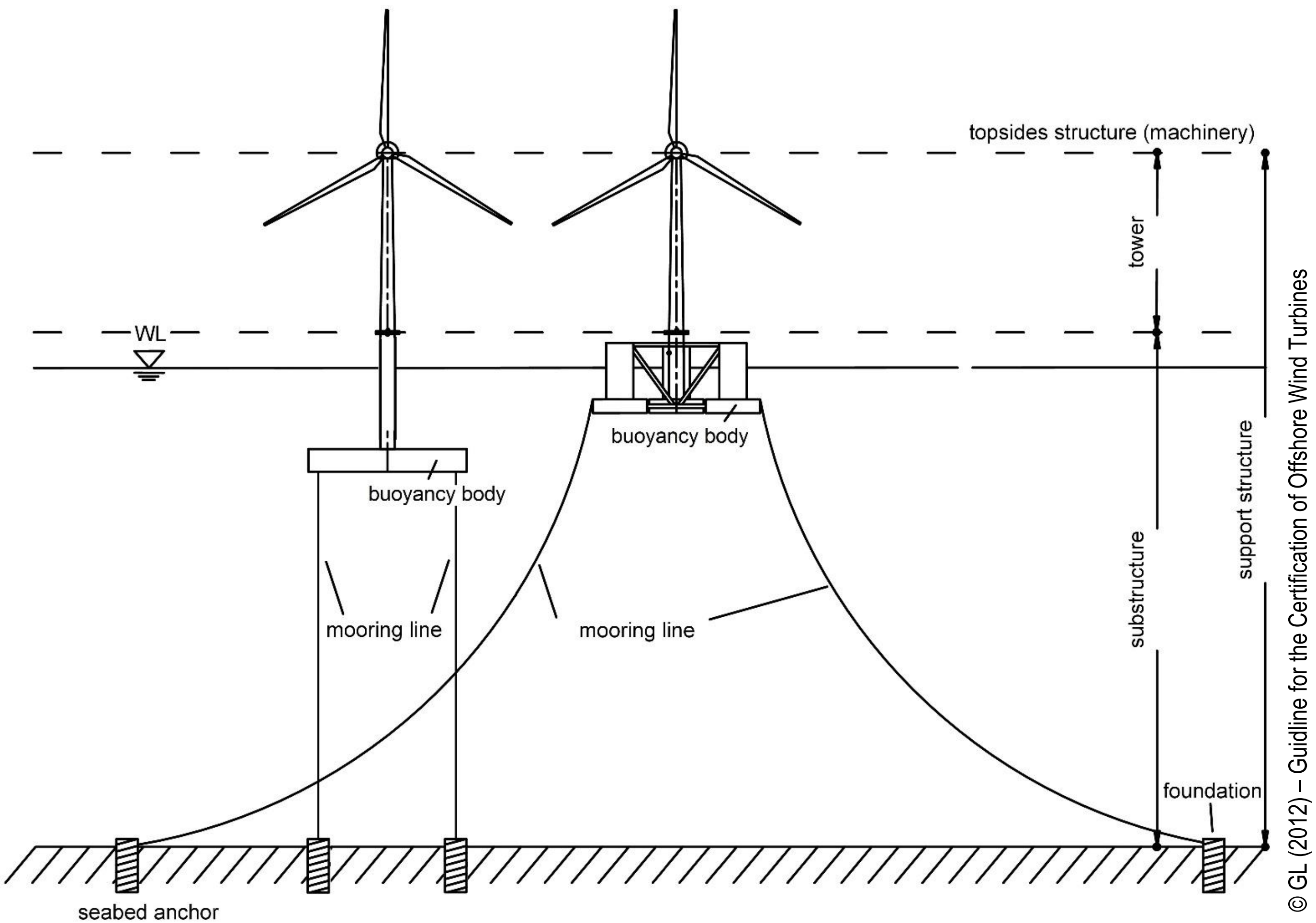


Motivation - Bathymetry north sea



Introduction & wording

Introduction - Definition



Introduction - Substructures

	Fixed	Floating
Water depth	0 – 50 m Design depending on the water depth	50 – x m Design independent from the water depth
Installation	Hugh and expensive transport & installation vessels needed	Transport & installation with the wind turbine on top; only small tug boats needed
Certification	Each support-structure need it´s own certification	Type certification is possible
Costs	Cost competitive for specific boundary conditions (water depth, distance to shore)	On the way to be cost competitive
Environmental impact	Noisy pile driving, decommissioning issues	No pile driving and nearly fully decommission

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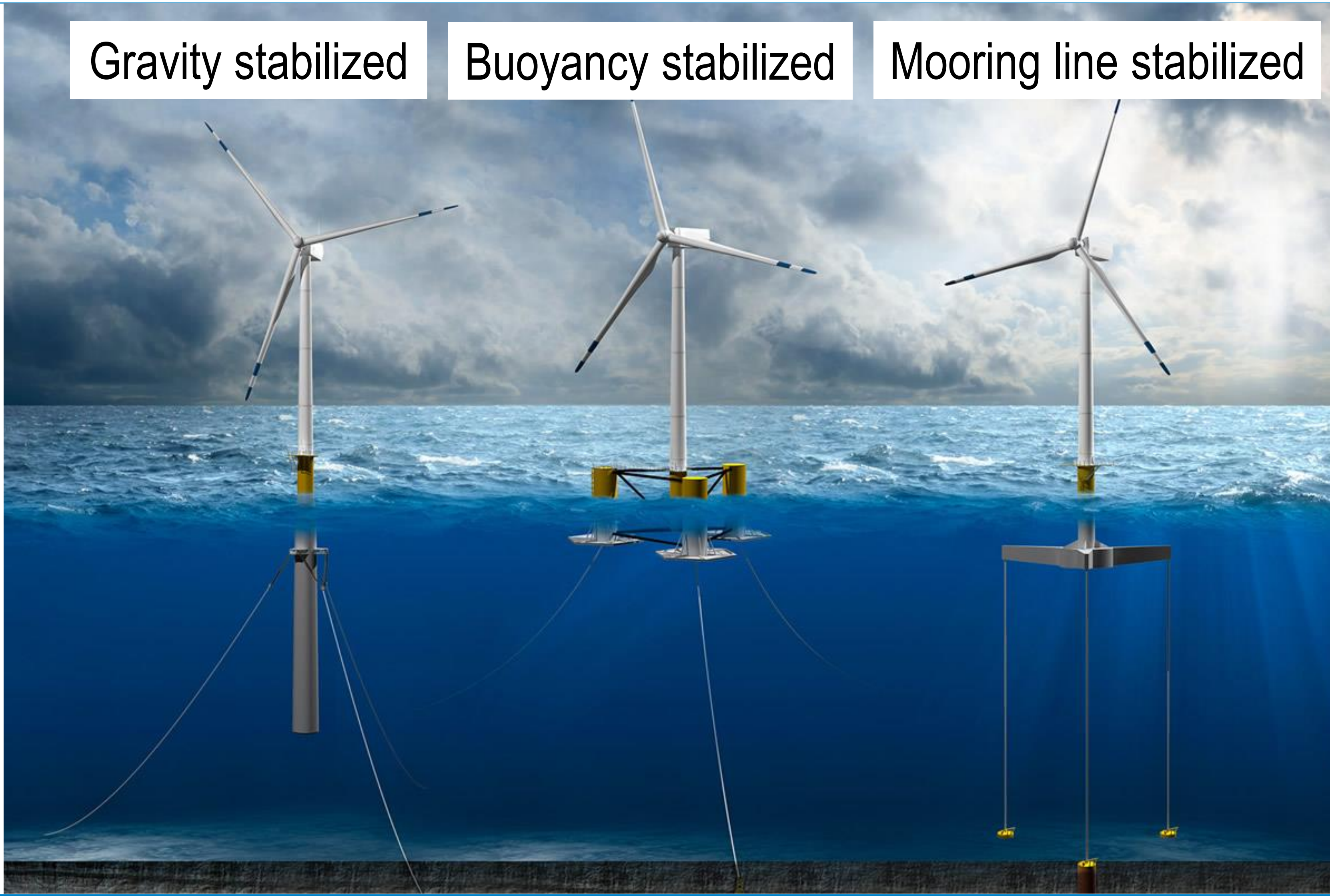
Introduction - Kind of floating solutions



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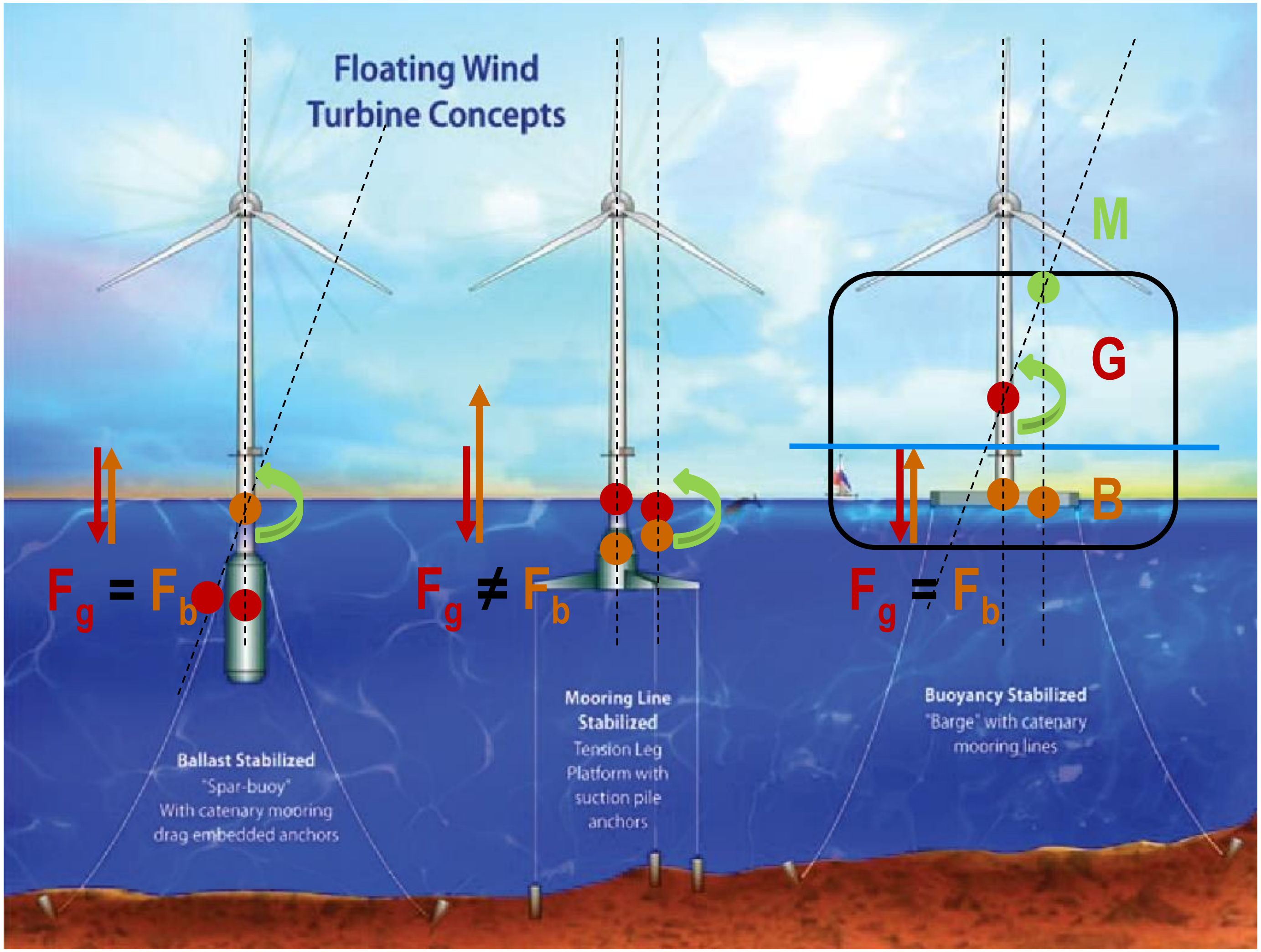
Introduction - Floating stability



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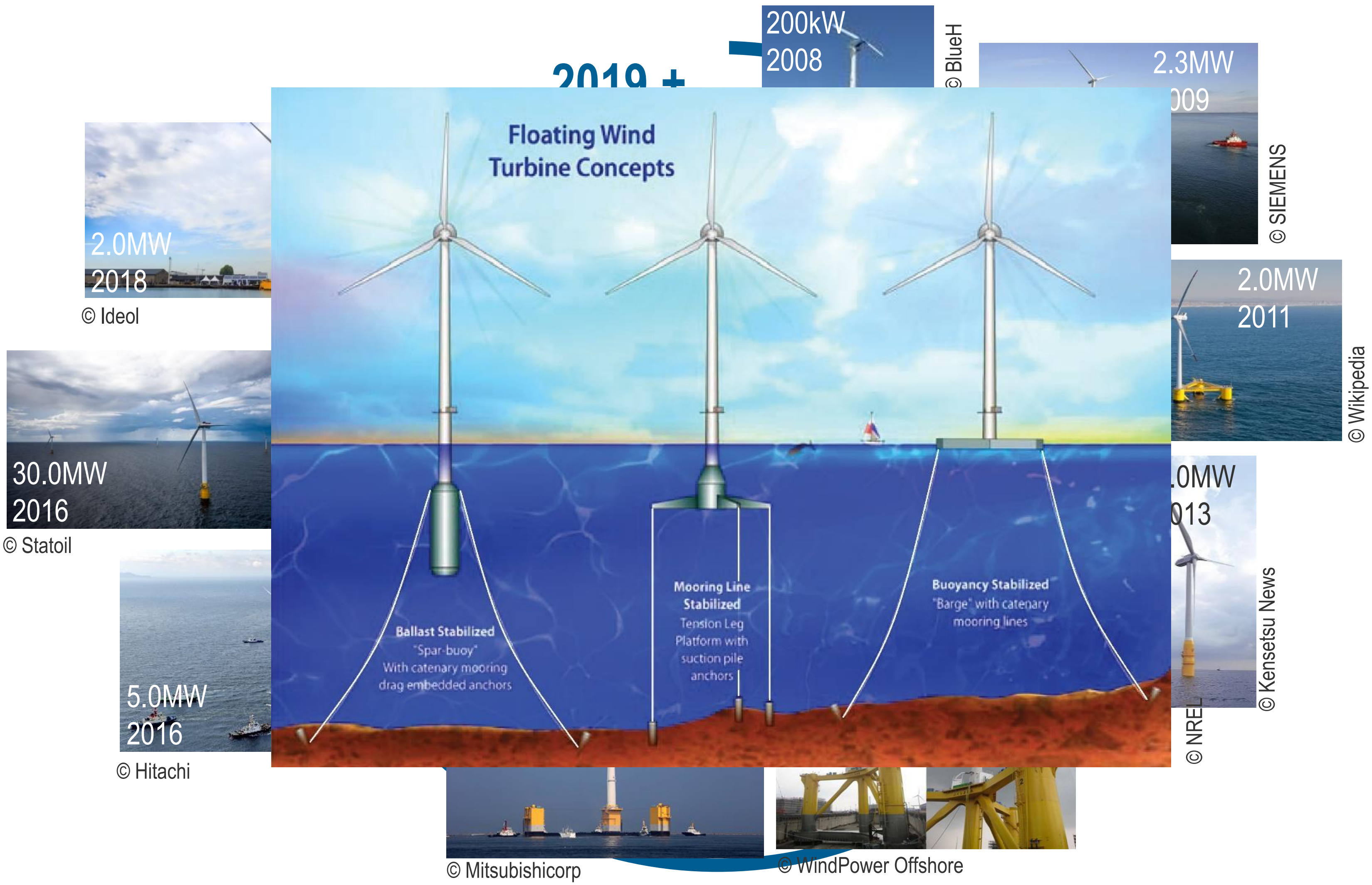
Introduction - Floating solutions pilot plants



State of the Art: Selected examples

- WindFloat
- Hywind
- IDEOL

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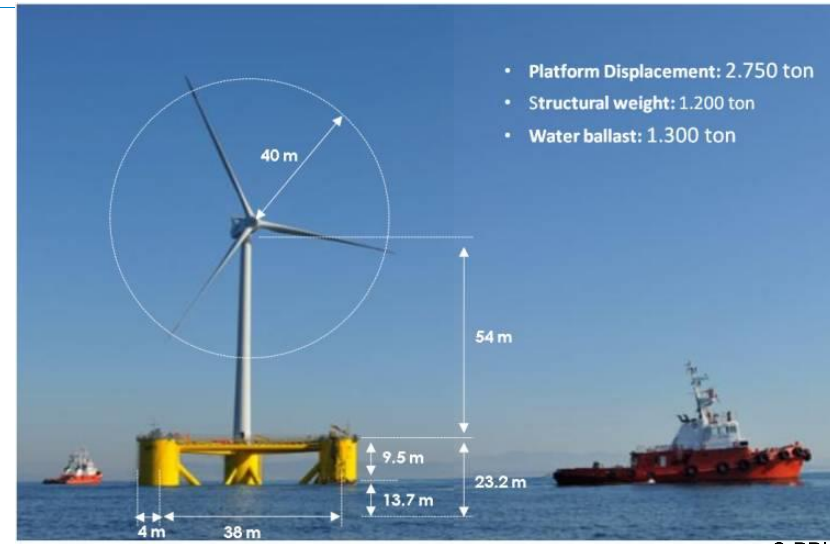
Principle Powers´s buoyancy stabilized system

- Steel structure
- 2011 - 2015 operated in Portugal | 2.0MW
- Since 2018 under operation in Scotland | 2.0MW
- Buoyancy stabilized system
- Active ballasting system by pumping water into the buoyancy bodies
- Drag anchors (pre - installed)
- Heave plates to damp the motion



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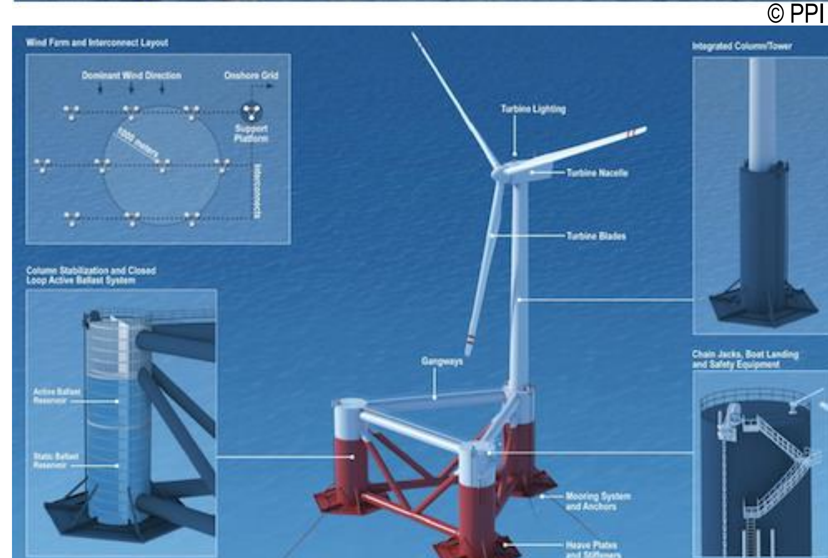
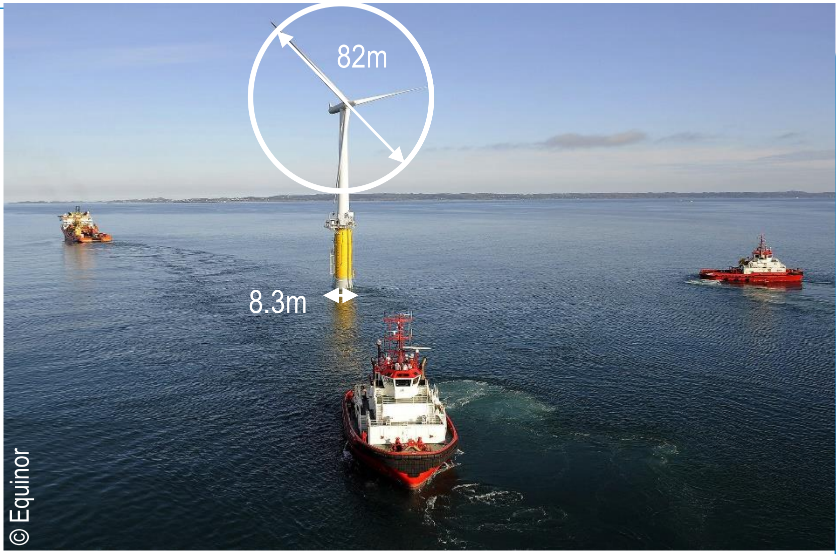
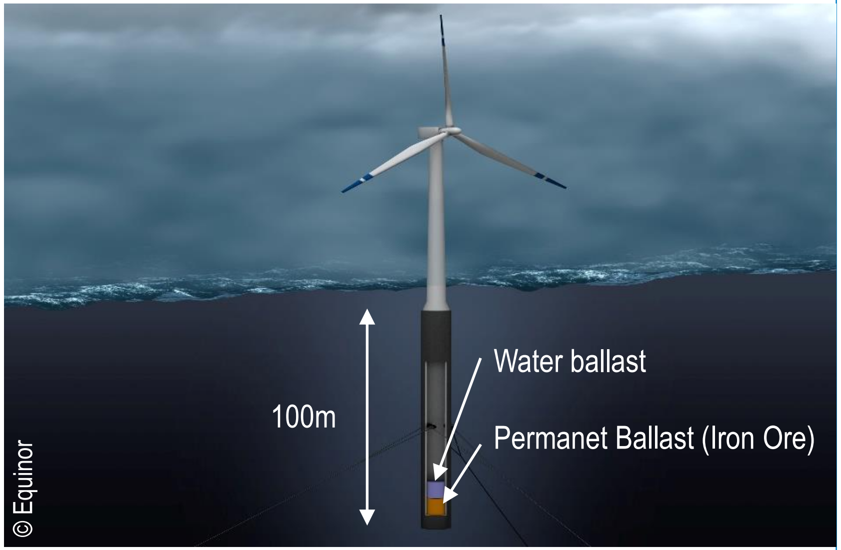


Statoils´s gravity stabilized system

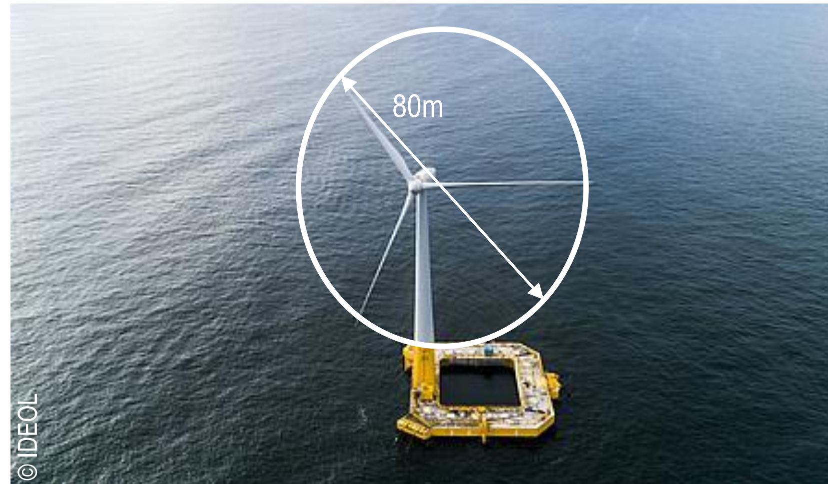
- Steel structure
- Since 2009 under operation in Norway | 2.3MW
- Since 2018 under operation in Scotland | 5 x 6.0MW
- Gravity stabilized system
- Semi-Active water ballasting system
- Drag anchors (pre - installed)
- Pitch controller to damp the motion via aero-dynamic damping

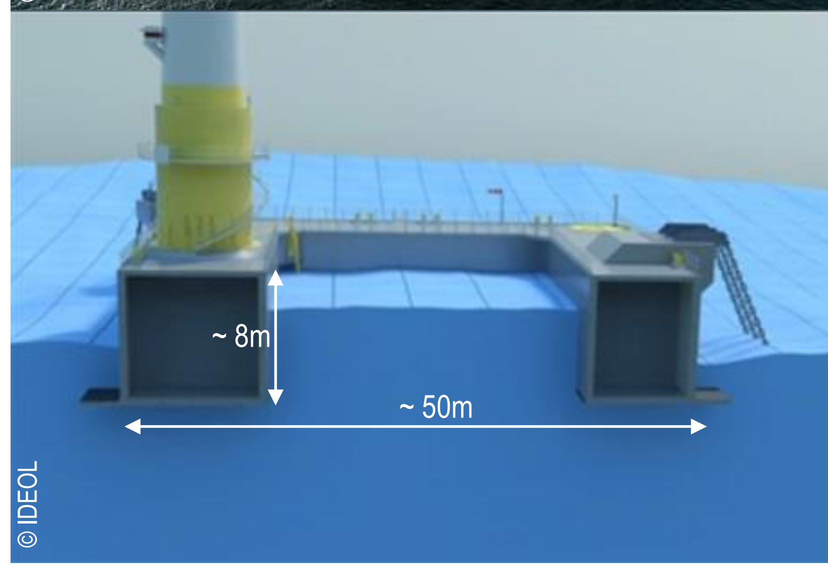




IDEOL´s Powers´s buoyancy stabilized system

- Concrete / Steel structure
- Since 2018 under operation in France | 2.0MW
- Since 2018 under operation in Japan | 3.0MW (two blade system)
- Buoyancy stabilized system
- Semi-Active system by using the damping-pool
- Drag anchors (pre - installed)
- Heave plates to damp the motion

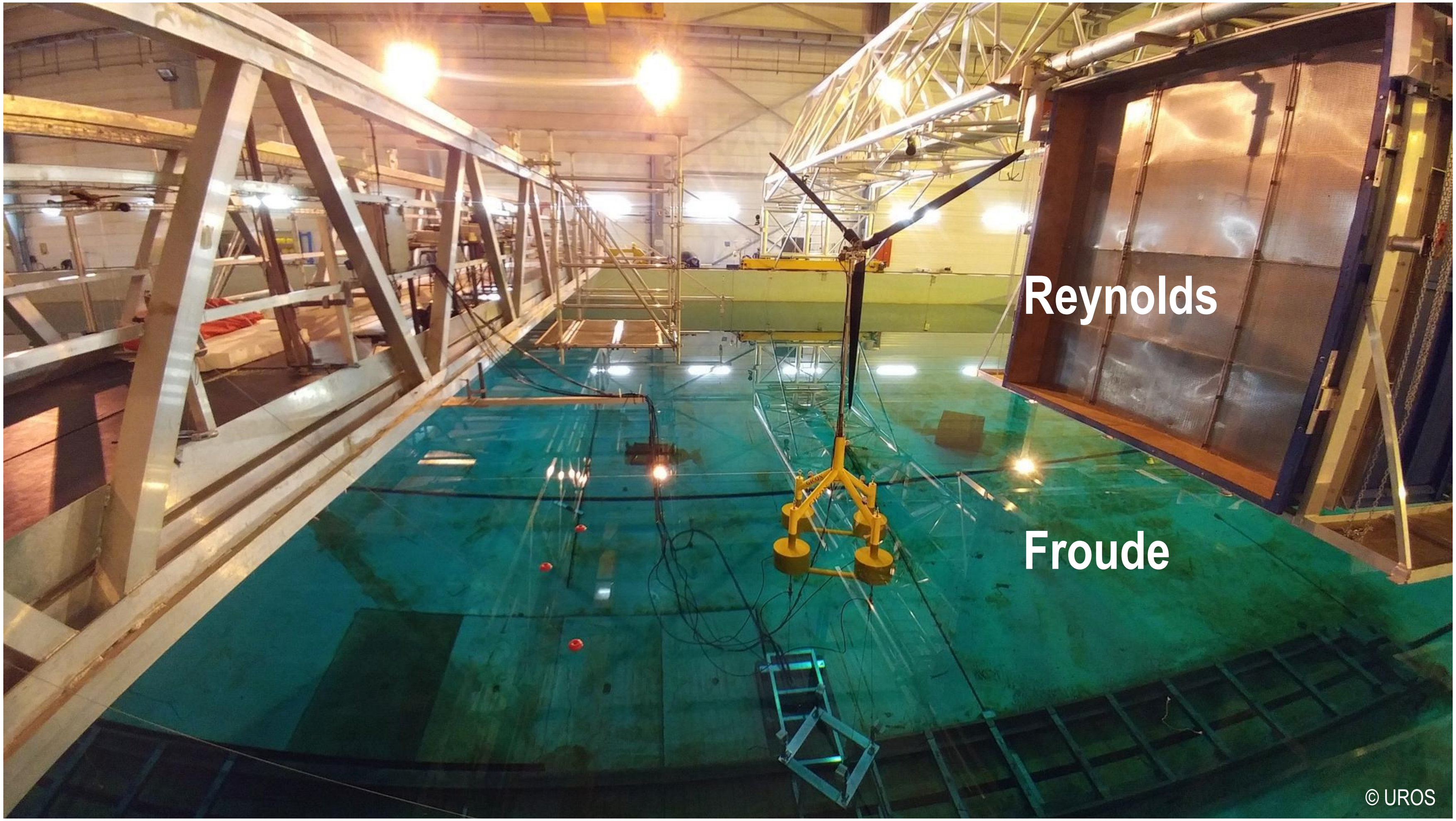




Current research and development topics

- scaling effects for combined wind and wave tests
- servo-hydro-aero-elastic coupled calculation

Scaling effects



Thrust Force F_T

- According to Blade-Element-Momentum-Theory (BEMT):

$$F_T = F_L \cdot cos(\alpha) + F_D \cdot sin(\alpha)$$

$$F_L = 0.5 \cdot c_L(Re, \alpha) \cdot \rho \cdot c \cdot v_{rel}^2 \qquad F_D = 0.5 \cdot c_D(Re, \alpha) \cdot \rho \cdot c \cdot v_{rel}^2$$

- Fixed Parameters: Air density ρ, Wind speed v_{rel}
- Design Parameters: Chord length c, Aerodynamic Coefficients c_L, c_D, Angle of Attack α

F_L . . . Lift force	F_D . . . Drag Force	α . . . Angle of Attack
c_L . . . Lift coefficient	c_D . . . Drag coefficient	Re . . . Reynolds number
ρ . . . Air density	c . . . Chord length	v_{rel} . . . Wind speed at blade element

Thrust Force F_T

- According to Blade-Element-Momentum-Theory (BEMT):

$$F_T = F_L \cdot cos(\alpha) + F_D \cdot sin(\alpha)$$

$(F_T = T)$

$$F_L = 0.5 \cdot c_L(Re, \alpha) \cdot \rho \cdot c \cdot v_{rel}^2$$

$$F_D = 0.5 \cdot c_D(Re, \alpha) \cdot \rho \cdot c \cdot v_{rel}^2$$

$$C_T = \frac{T}{\frac{1}{2}\rho A V^2}$$

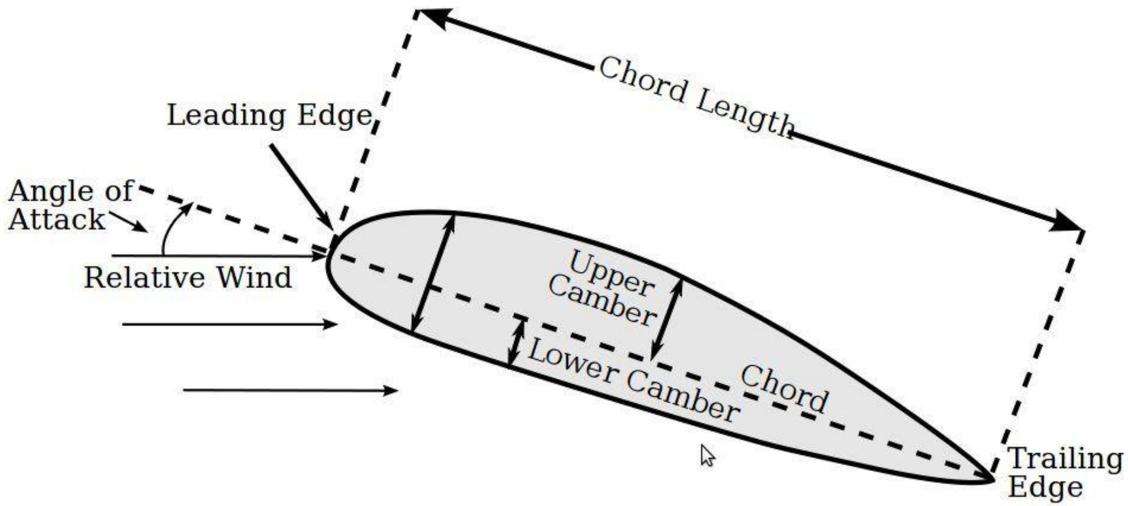
$$C_P = \frac{P}{\frac{1}{2}\rho A V^3}$$

Step 1: Increasing the chord length c

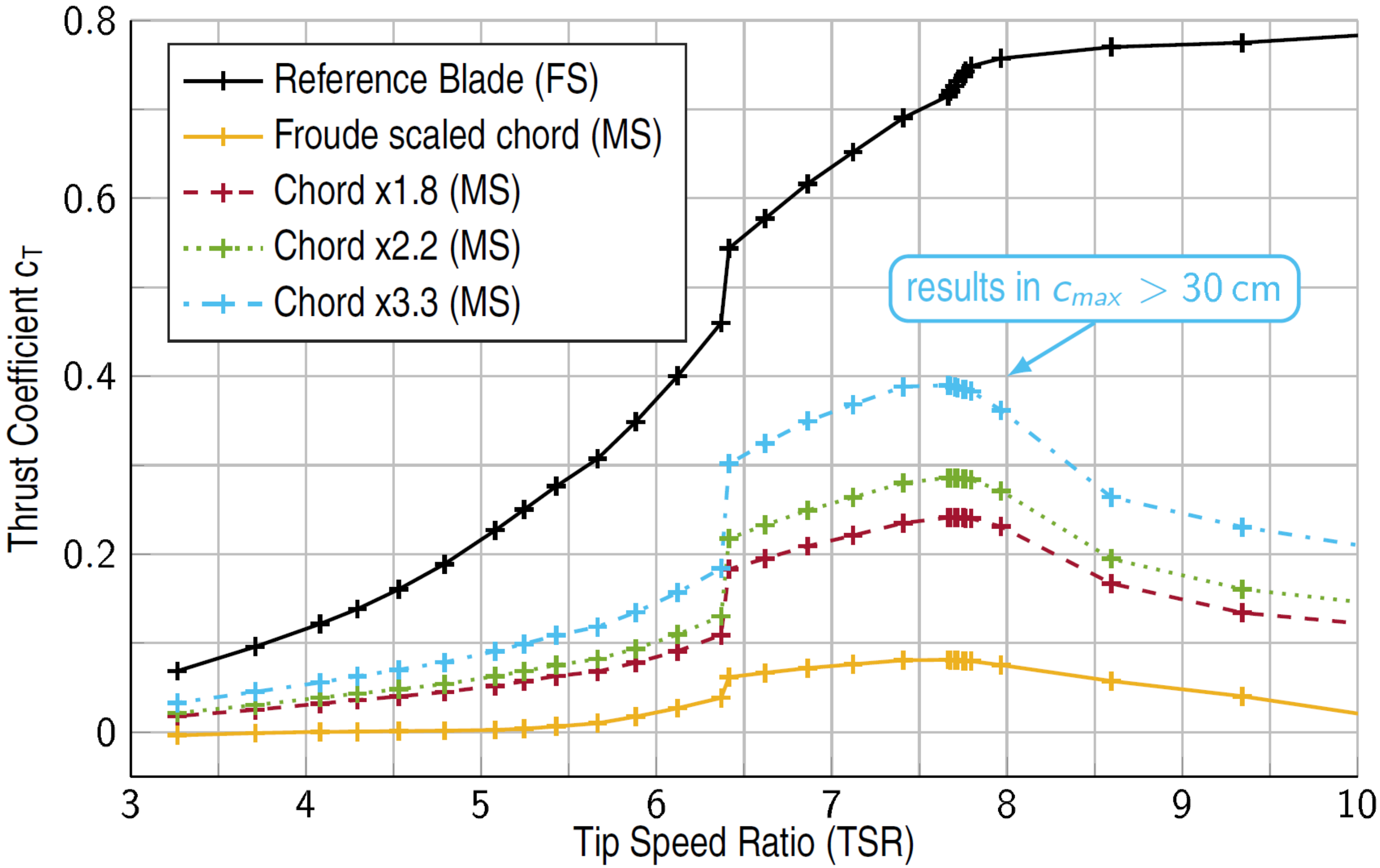
- According to Blade-Element-Momentum-Theory (BEMT):

$$F_T = F_L \cdot cos(\alpha) + F_D \cdot sin(\alpha)$$

$$F_L = 0.5 \cdot c_L(Re, \alpha) \cdot \rho \cdot c \cdot v_{rel}^2 \qquad F_D = 0.5 \cdot c_D(Re, \alpha) \cdot \rho \cdot c \cdot v_{rel}^2$$



Step 1: Increasing the chord length c



Step 2: Adjusting lift and drag coefficients c_L, c_D

- According to Blade-Element-Momentum-Theory (BEMT):

$$F_T = F_L \cdot cos(\alpha) + F_D \cdot sin(\alpha)$$

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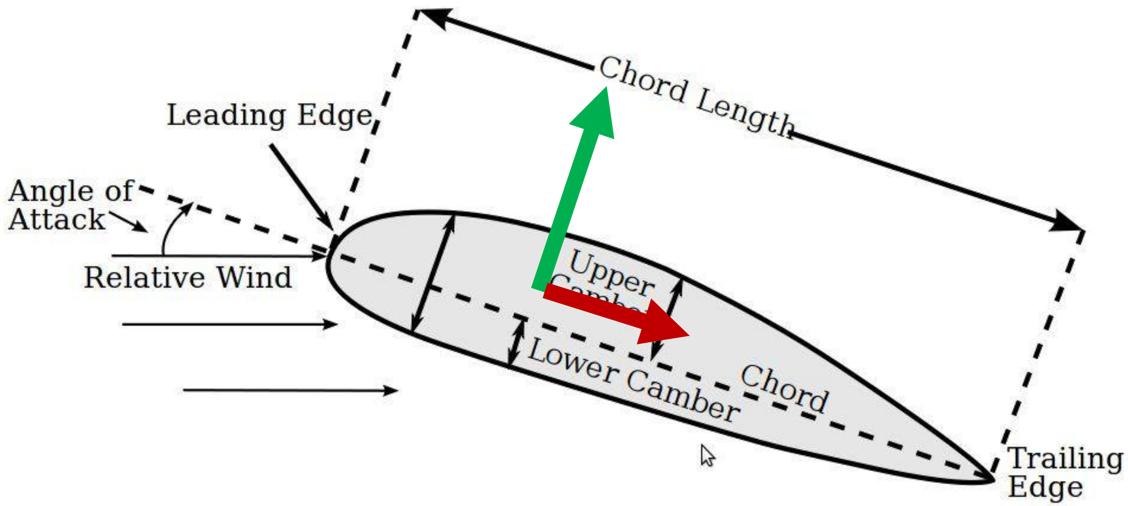
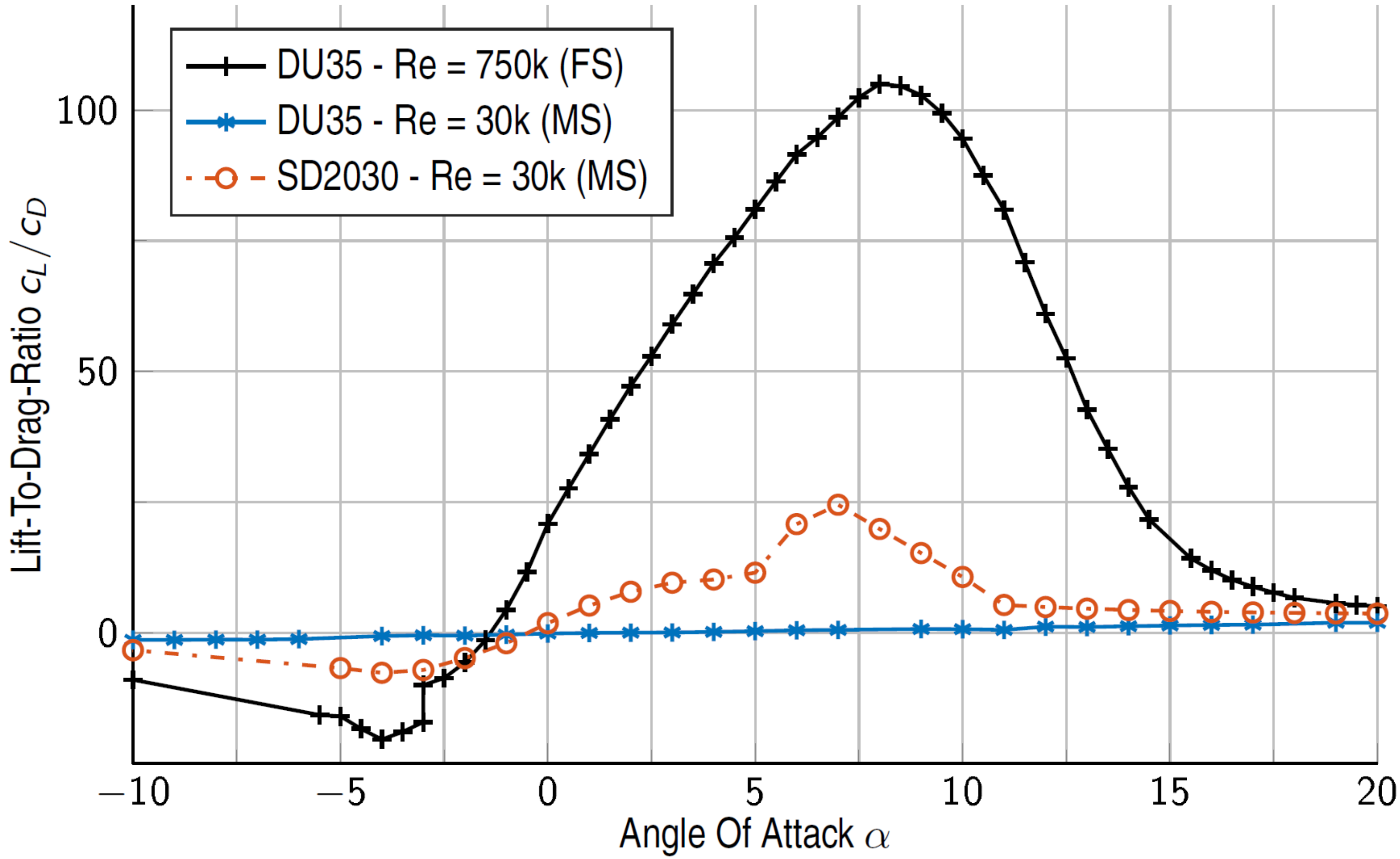
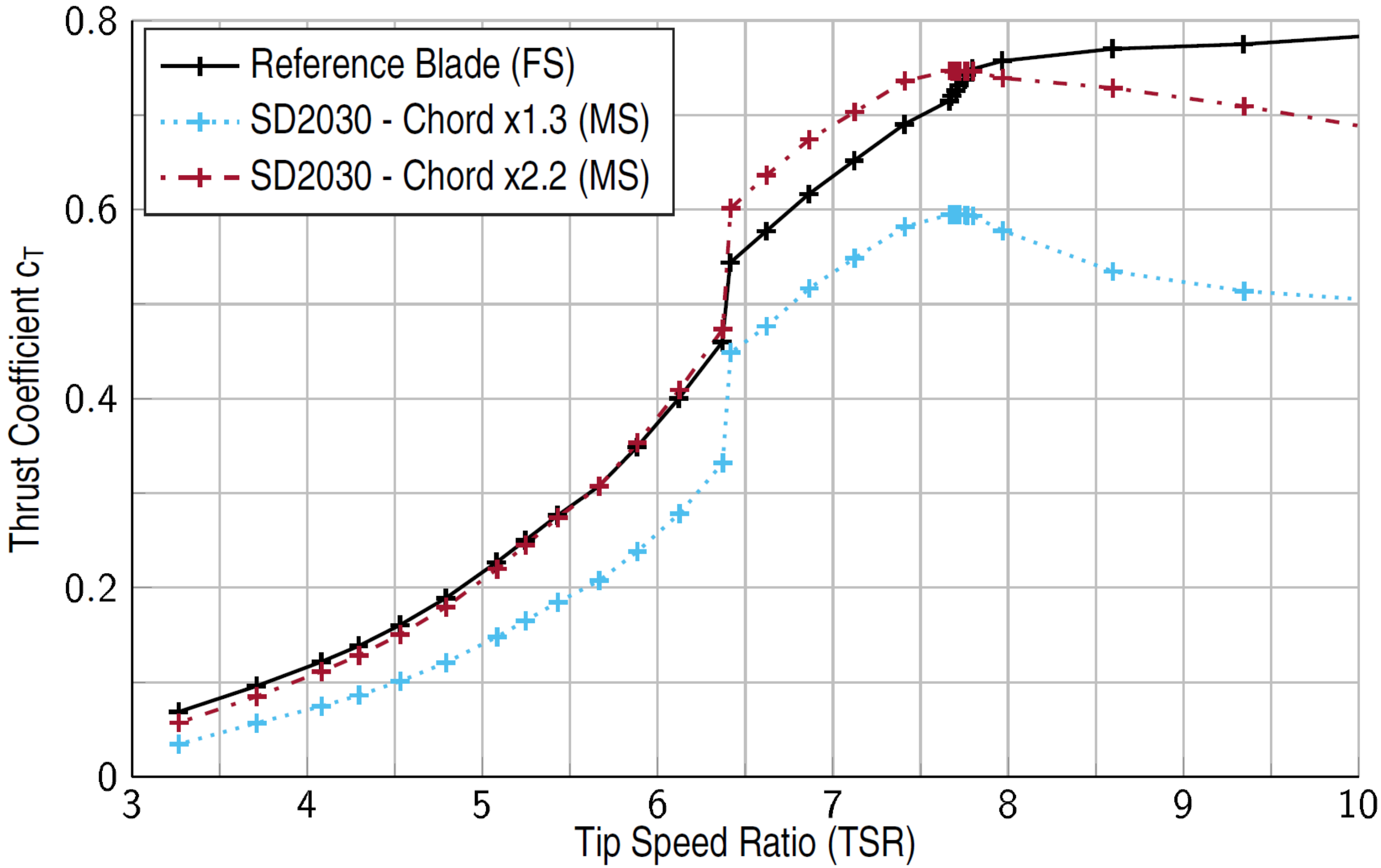


Scaling effects

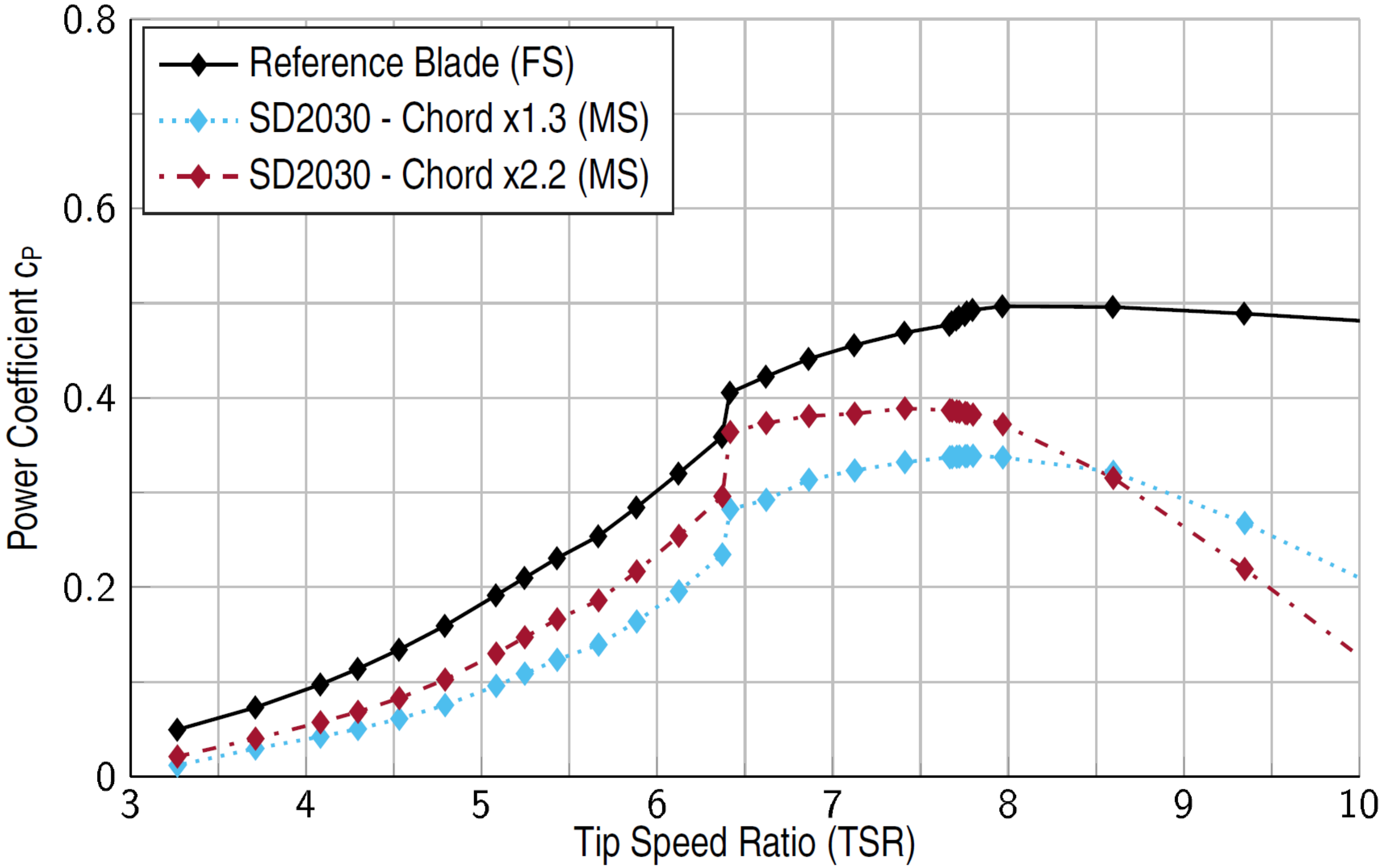
Step 2: Adjusting lift and drag coefficients c_L, c_D



Step 2: Adjusting lift and drag coefficients c_L, c_D



Step 2: Adjusting lift and drag coefficients c_L, c_D

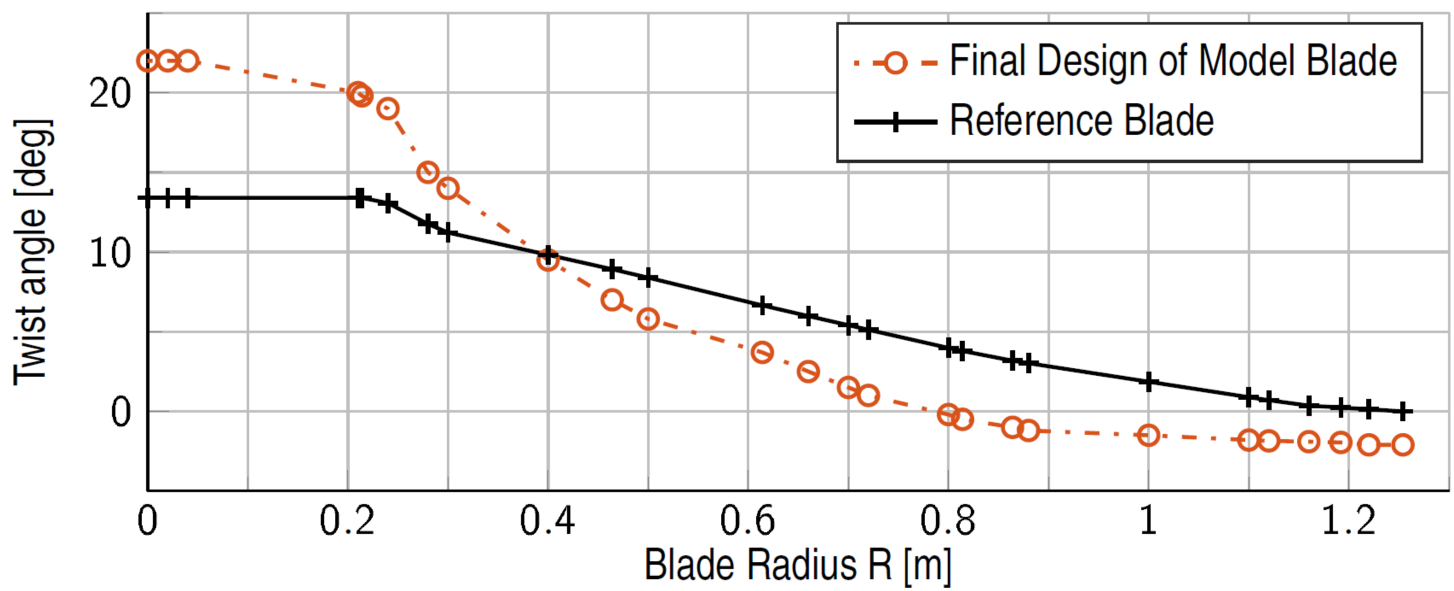


Step 3: Adjusting Angle of Attack α

- According to Blade-Element-Momentum-Theory (BEMT):

$$F_T = F_L \cdot cos(\alpha) + F_D \cdot sin(\alpha)$$

$$F_L = 0.5 \cdot c_L(Re, \alpha) \cdot \rho \cdot c \cdot v_{rel}^2 \qquad F_D = 0.5 \cdot c_D(Re, \alpha) \cdot \rho \cdot c \cdot v_{rel}^2$$



Step 3: Adjusting Angle of Attack α

- According to Blade-Element-Momentum-Theory (BEMT):

$$F_T = F_L \cdot cos(\ \alpha\ ) + F_D \cdot sin(\ \alpha\ )$$

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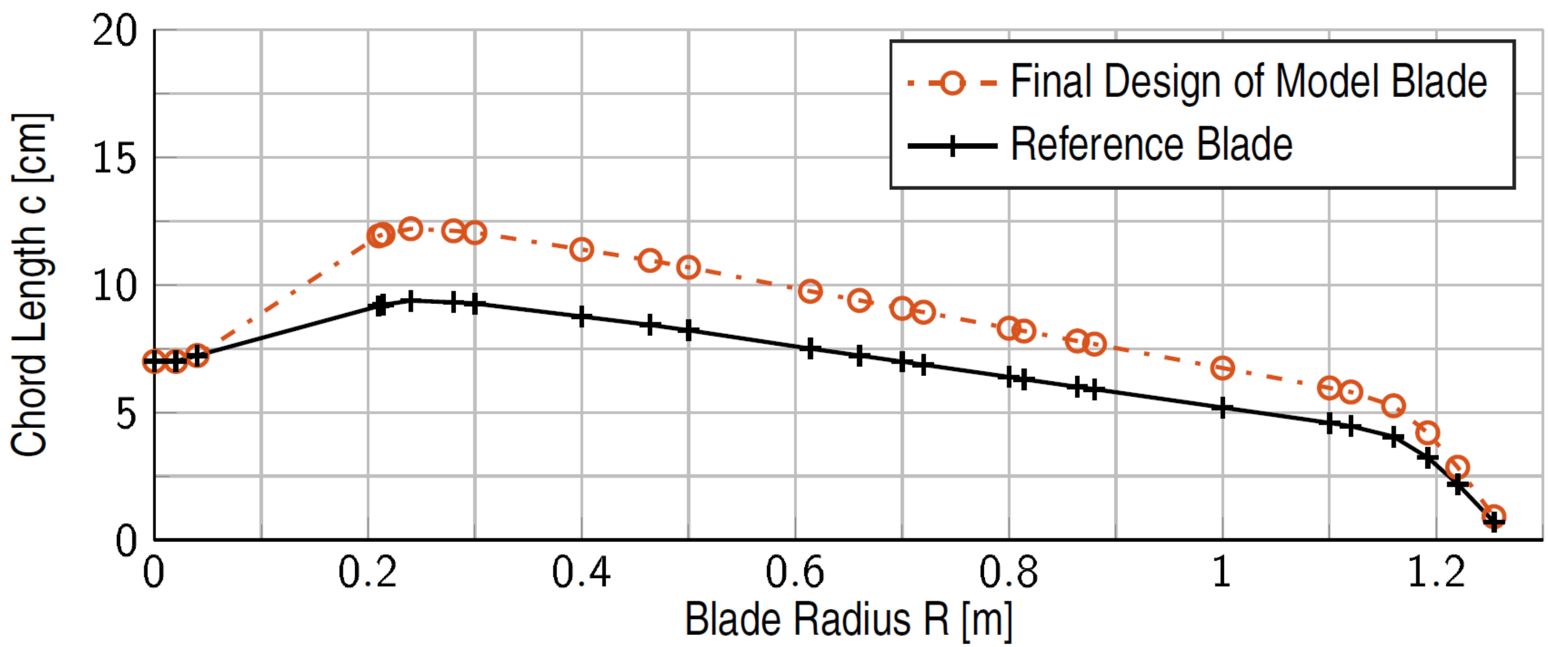

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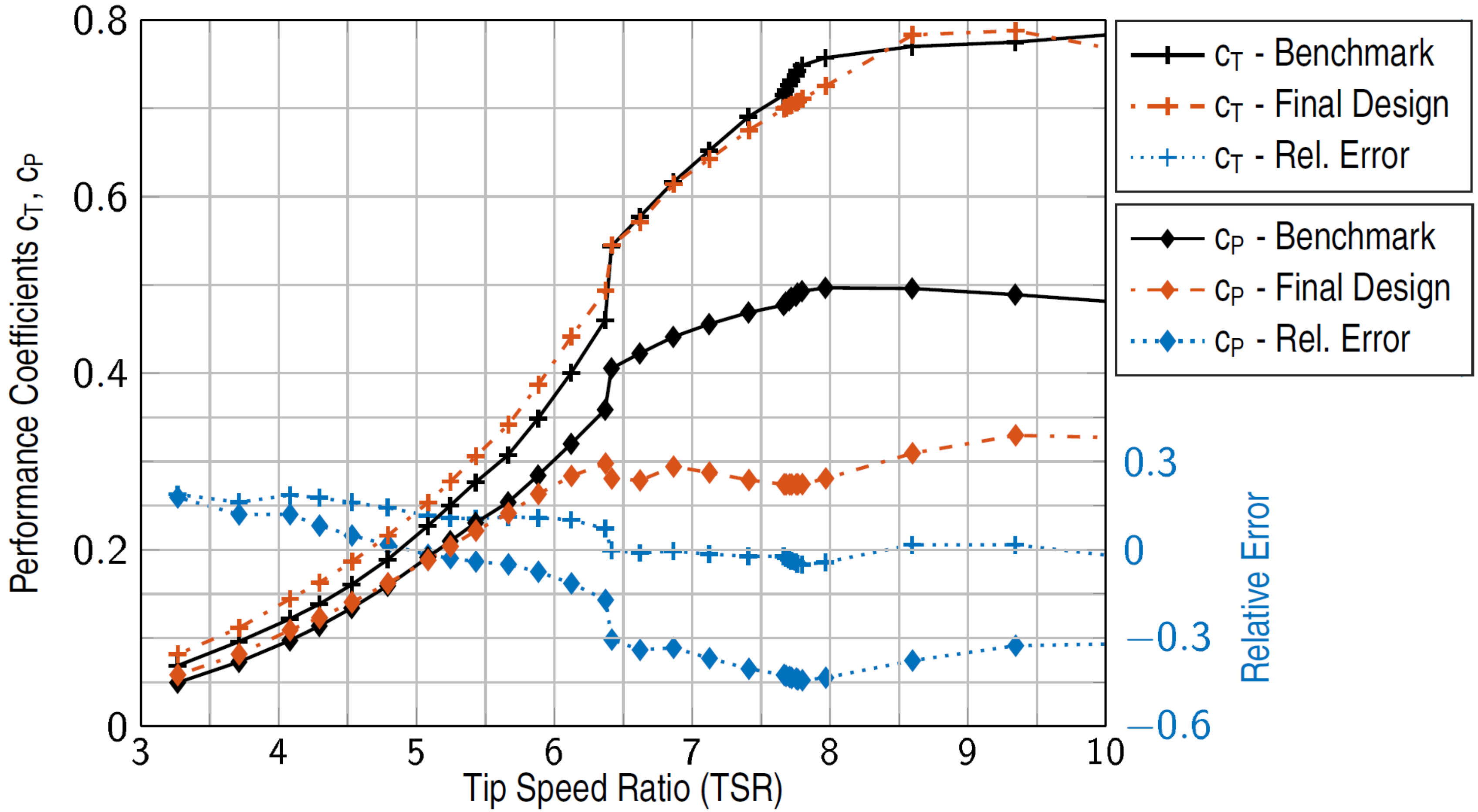
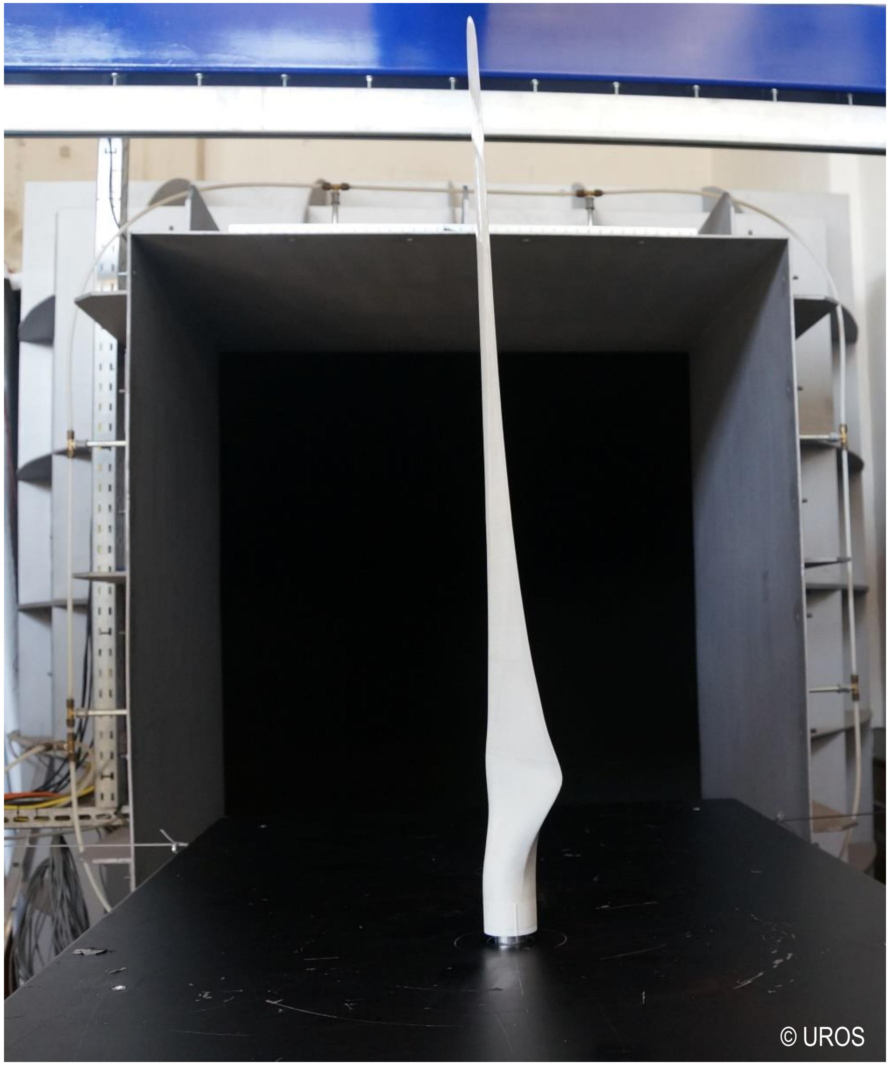
Scaling effects

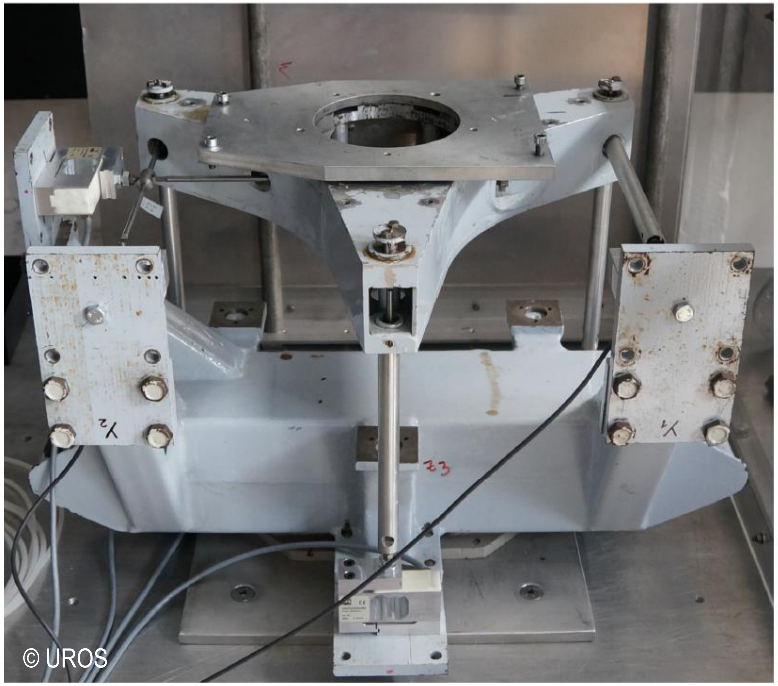
Performance of the new scaled model rotor

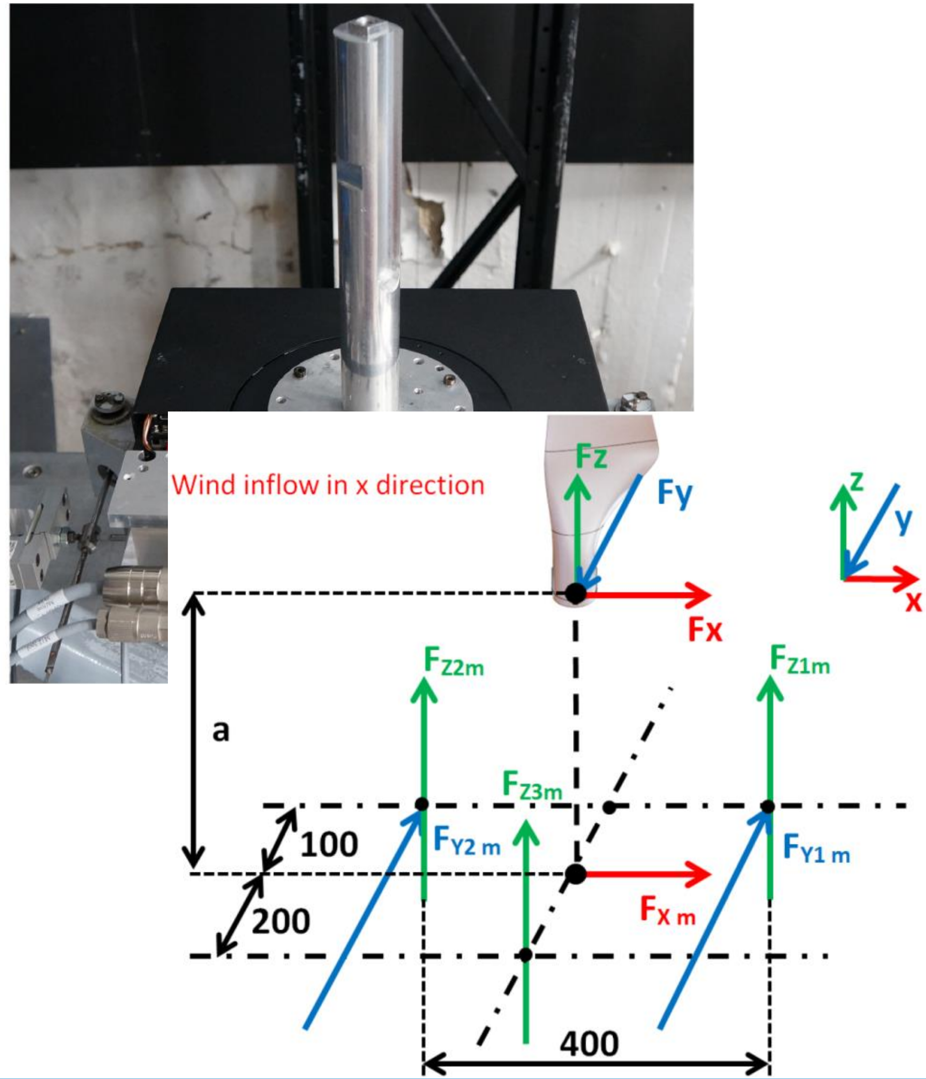


Scaling effects



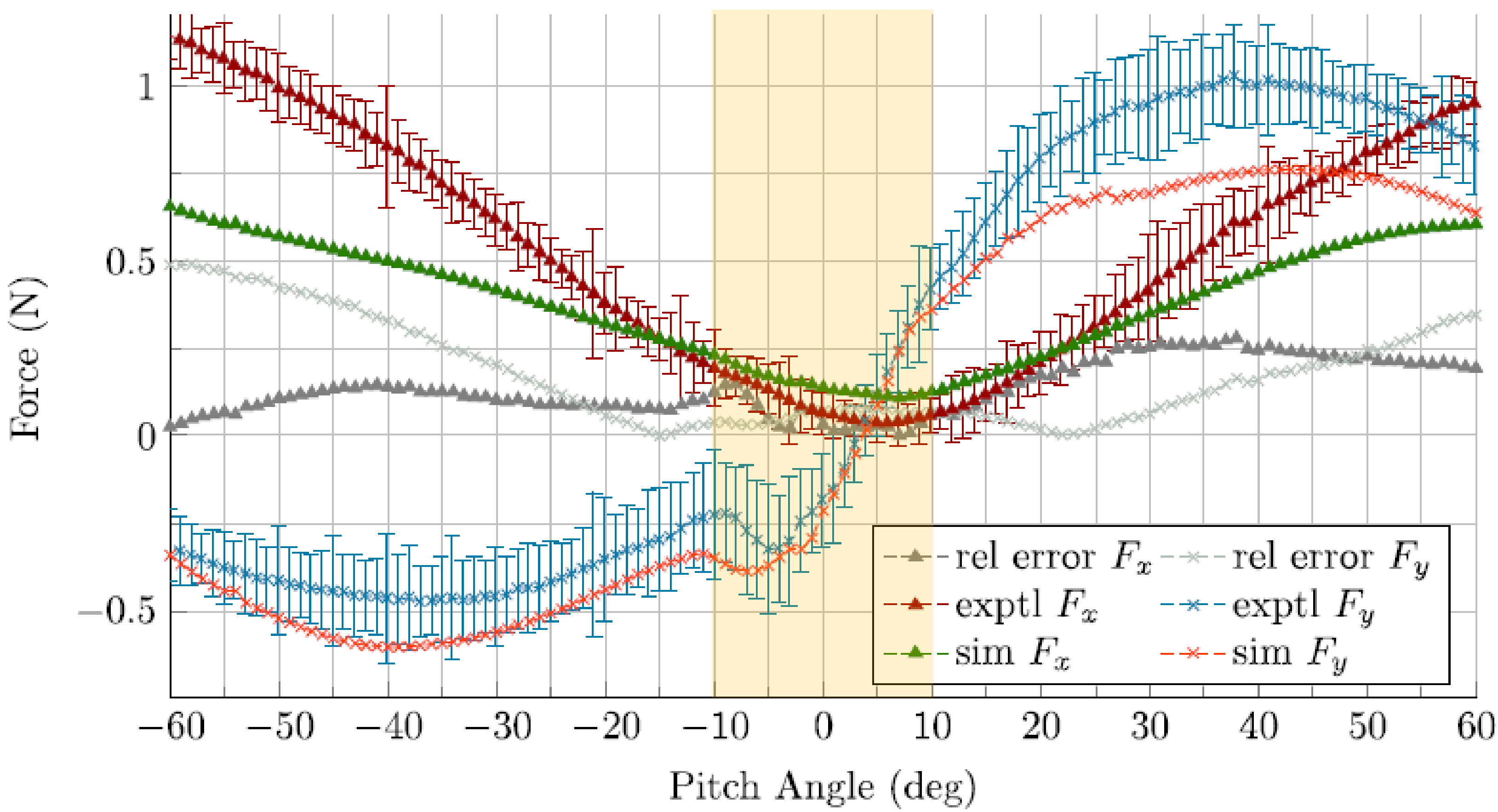
Scaling effects





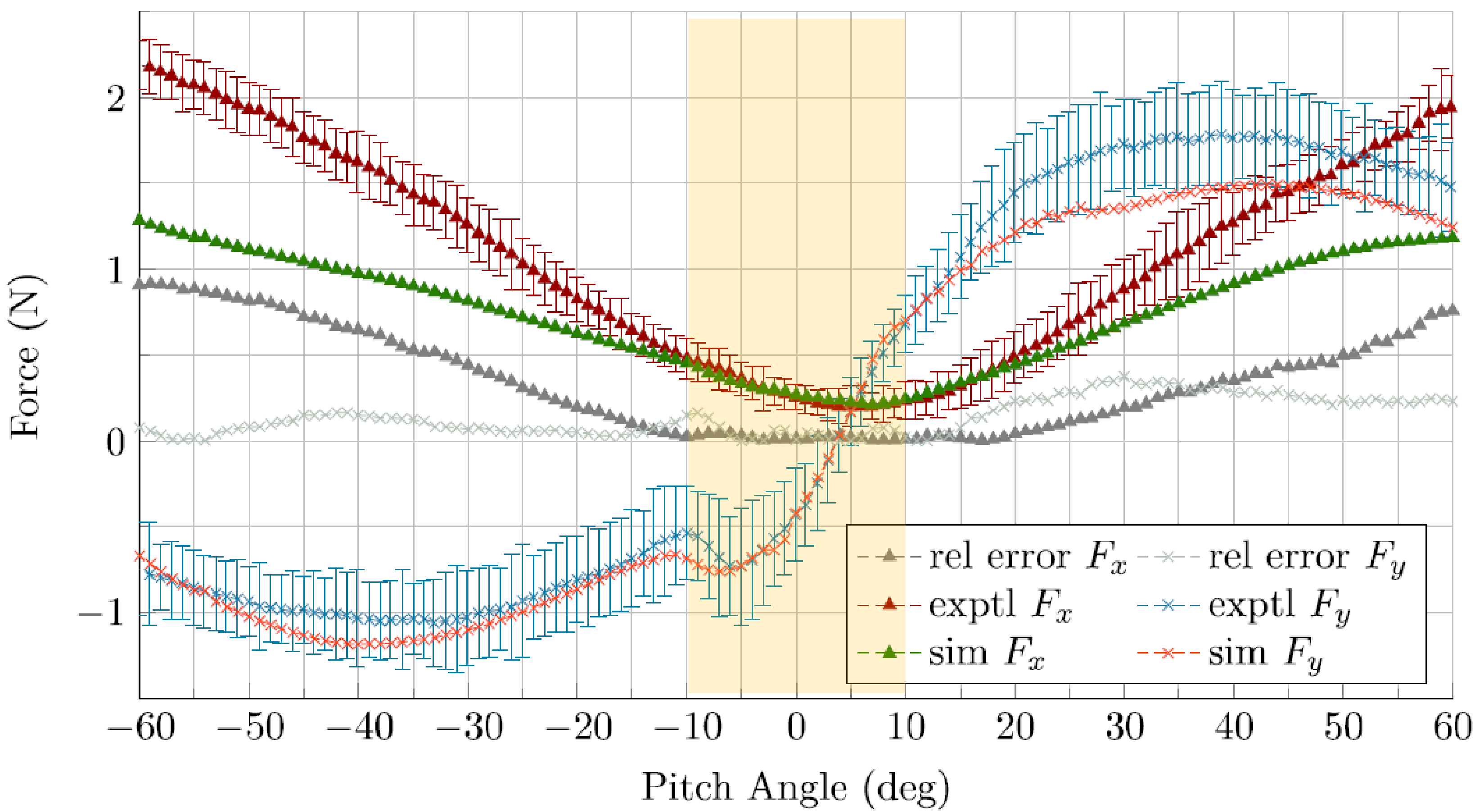
Scaling effects

5 mps



Scaling effects

7 mps

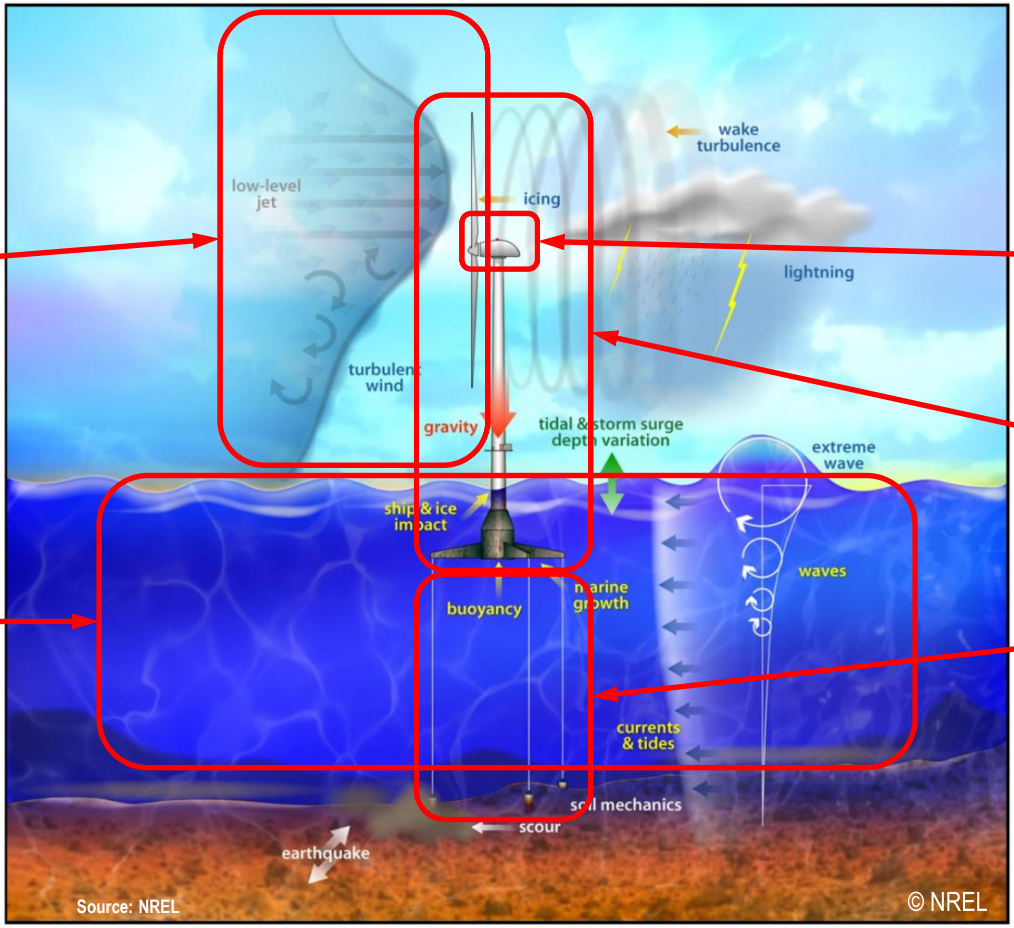


Servo-hydro-aero-elastic coupled calculation

Coupled calculation

Aerodynamics (incl. wind inflow)

Hydrodynamics

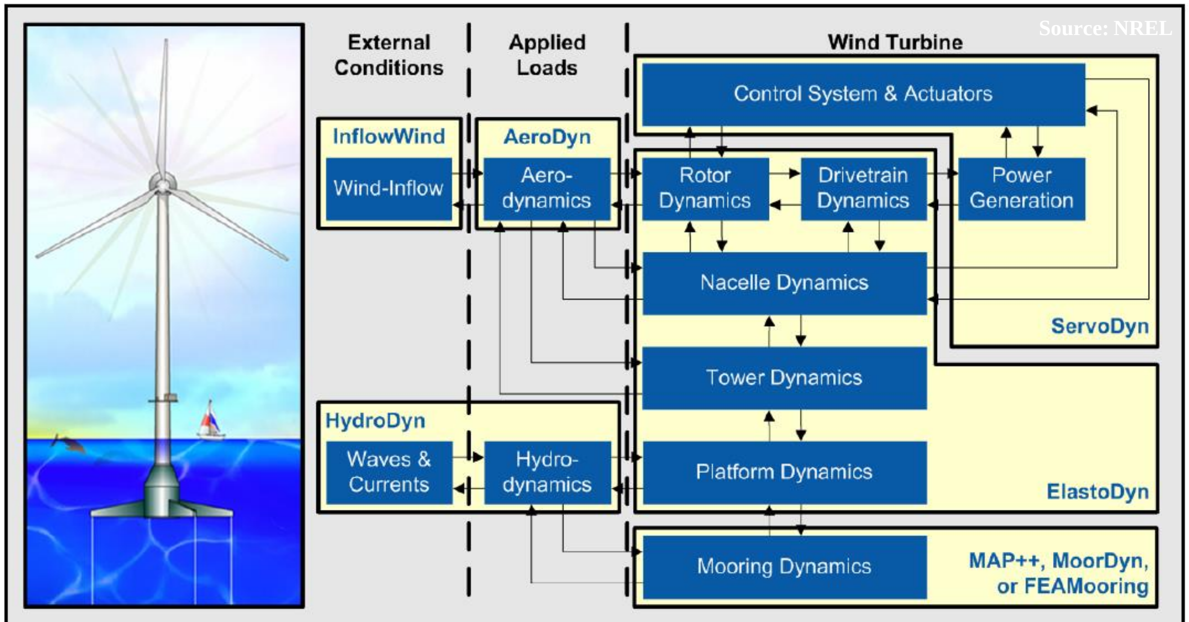


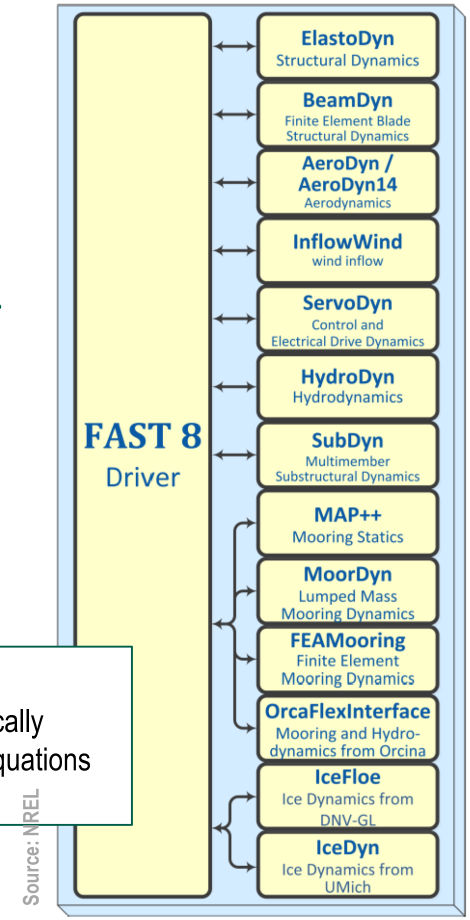
Controller/ Actuators

Structural Dynamics

Mooring Dynamics

Coupled calculation





Driver („Glue Code“)

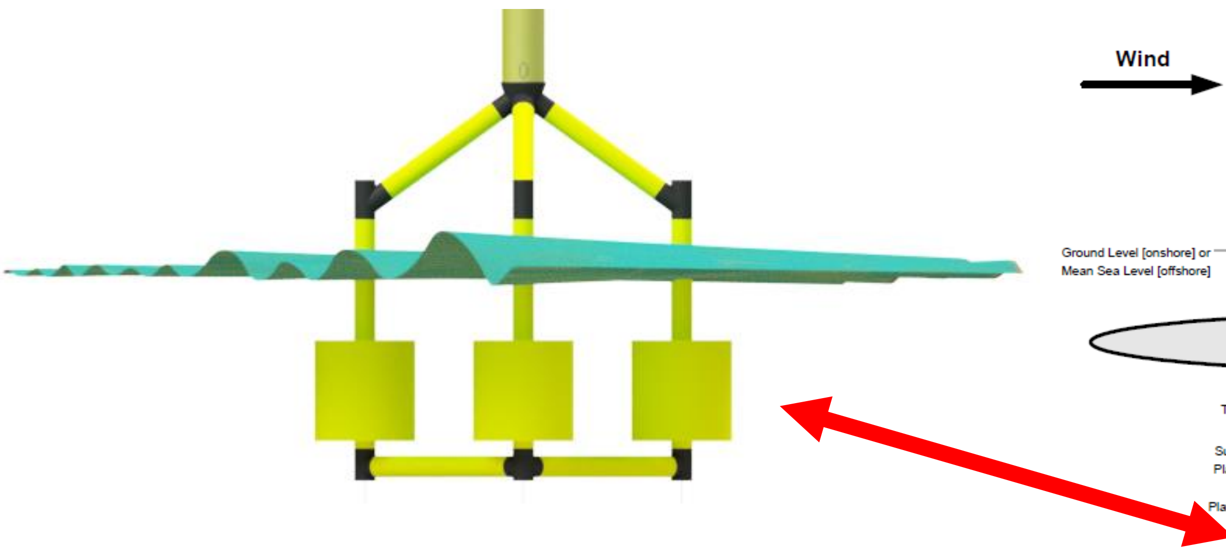
- Drives time-domain solution forward
- Calls individual modules
- Derives module inputs from outputs
  - including mesh-to-mesh mapping
  - including interpolation/extrapolation in time

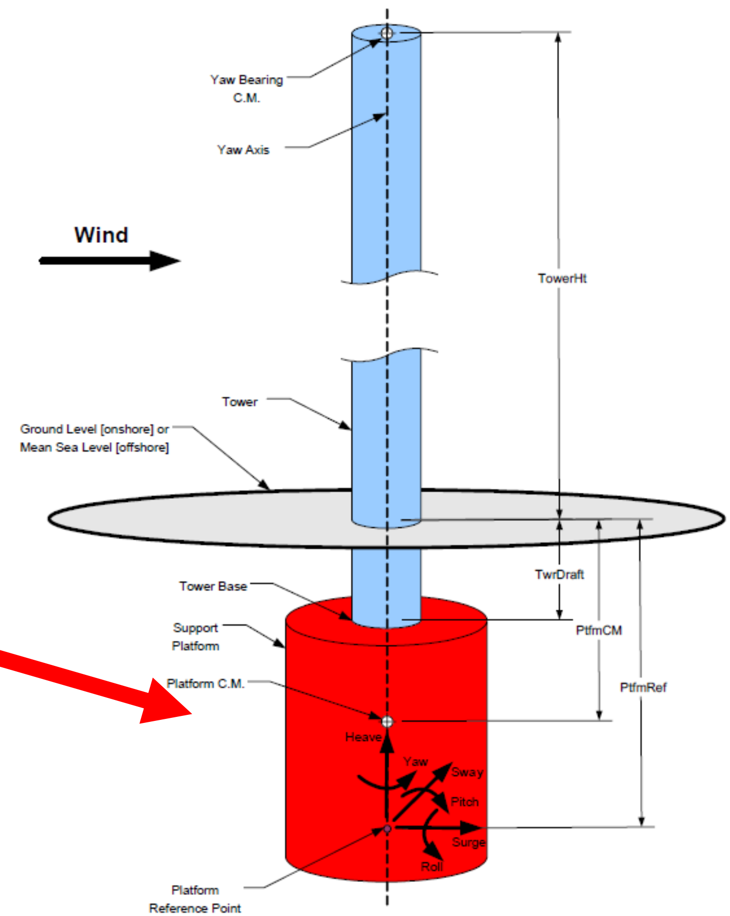
Modules

- Derive module outputs by numerically integrating the modules system equations (ODE or DAE)

Coupled calculation

- ElastoDyn – Substructure Model
  - 6-DOF rigid body





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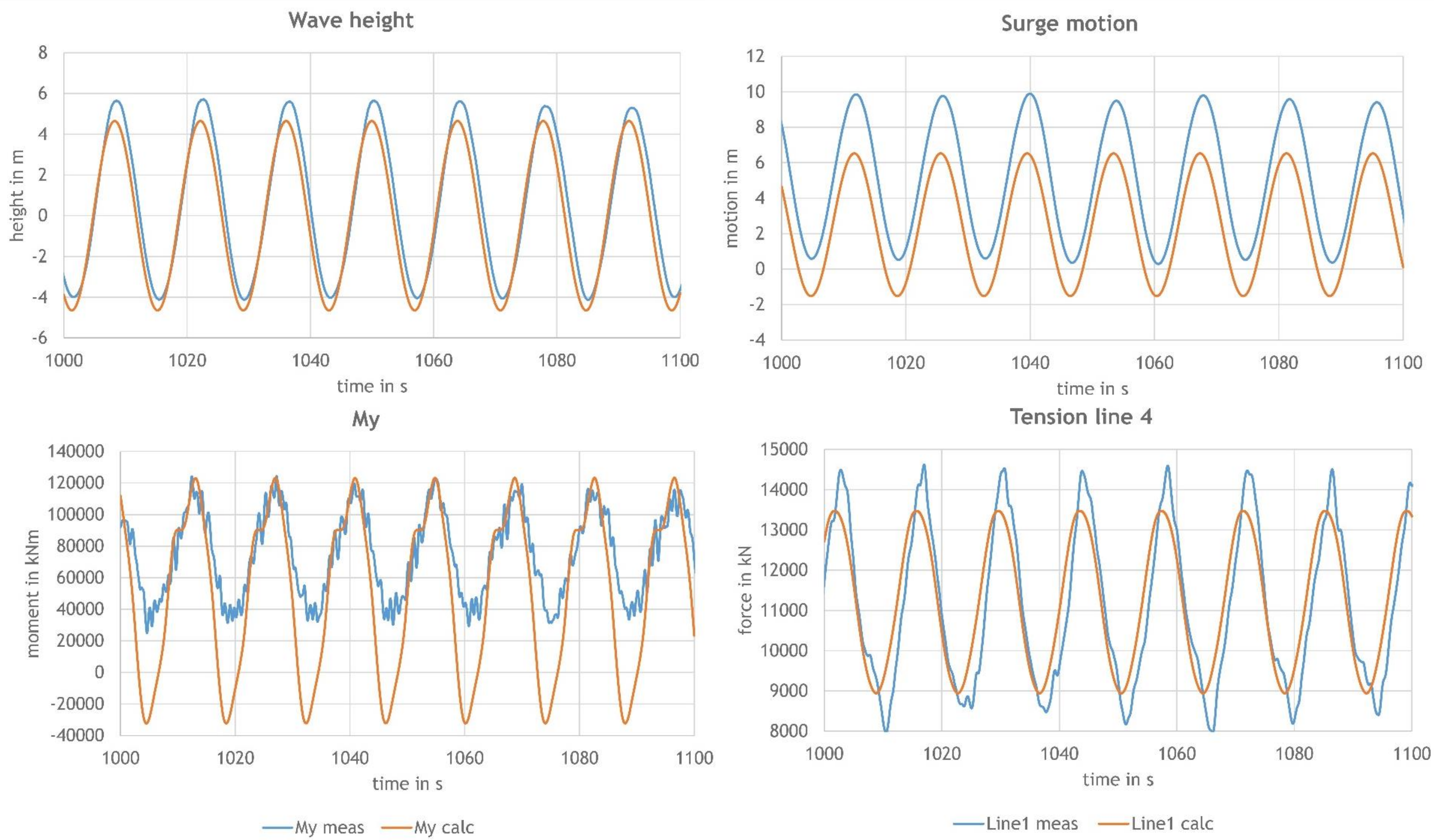
Coupled calculation

Regular Waves



Conclusion

- Floating offshore wind could be the future in offshore wind
- R&D work needed within the field of coupled simulations
- R&D work needed within the field of scaled testing - change the profile (define a own profile)

Prepared by:

Project TEAM Floating Offshore Foundation

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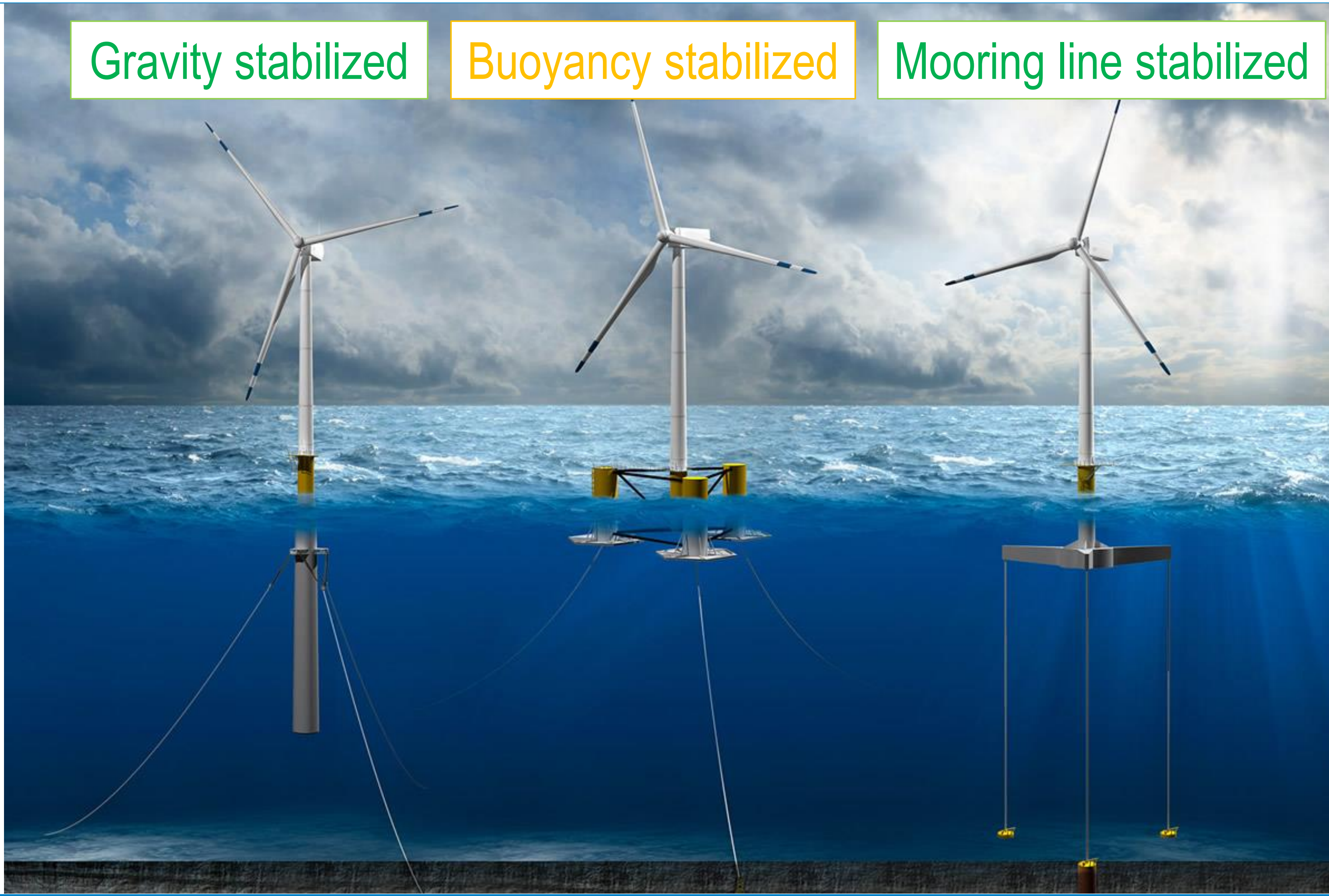
R&D work at the Chair with regard to floating wind



R&D work at the Chair with regard to floating wind

Gravity stabilized	Buoyancy stabilized	Mooring line stabilized
• Structural basis design • Active controlled Spar-Buoy concept • Transport and Installation process design etc. • Reduce costs for fabrication via a structural optimization tool • Tank tests & validation	• Code comparison (OC5&OC6) • Simulation Code Verification	• Structural basis & detail design • One-Step installation process • Using composite materials • Modularity design to get a flexible supply chain • Reduce costs for fabrication via a structural optimization tool and flexible supply chain • Tank tests & validation

- Design of inter array cableing for floating offshore wind farms
- Floating O&M platforms for offshore wind
- In collaboration with Windrad Engineering – wind turbine design