Model Building and Scaled Testing of 5MW and 10MW Semi-Submersible Floating Wind Turbines

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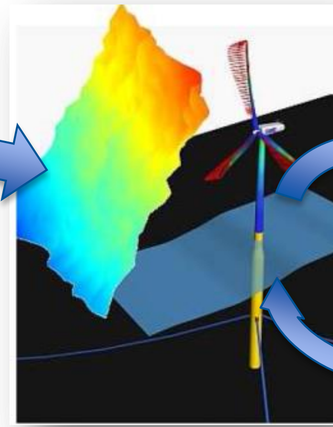
The research leading to these results has received funding from the European Community's Seventh Framework Programme under grant agreement No. 308974 (INNWIND.EU).

Motivation for INNWIND.EU model test

Large OWT



Simulation models

Scaled testing

- Software validation: Coupled models with varying fidelity
- Investigation of methods to incorporate aerodynamics
- Comparison to other experiments
- Public set of experimental data with generic model
- Experience for further model test in INNWIND.EU

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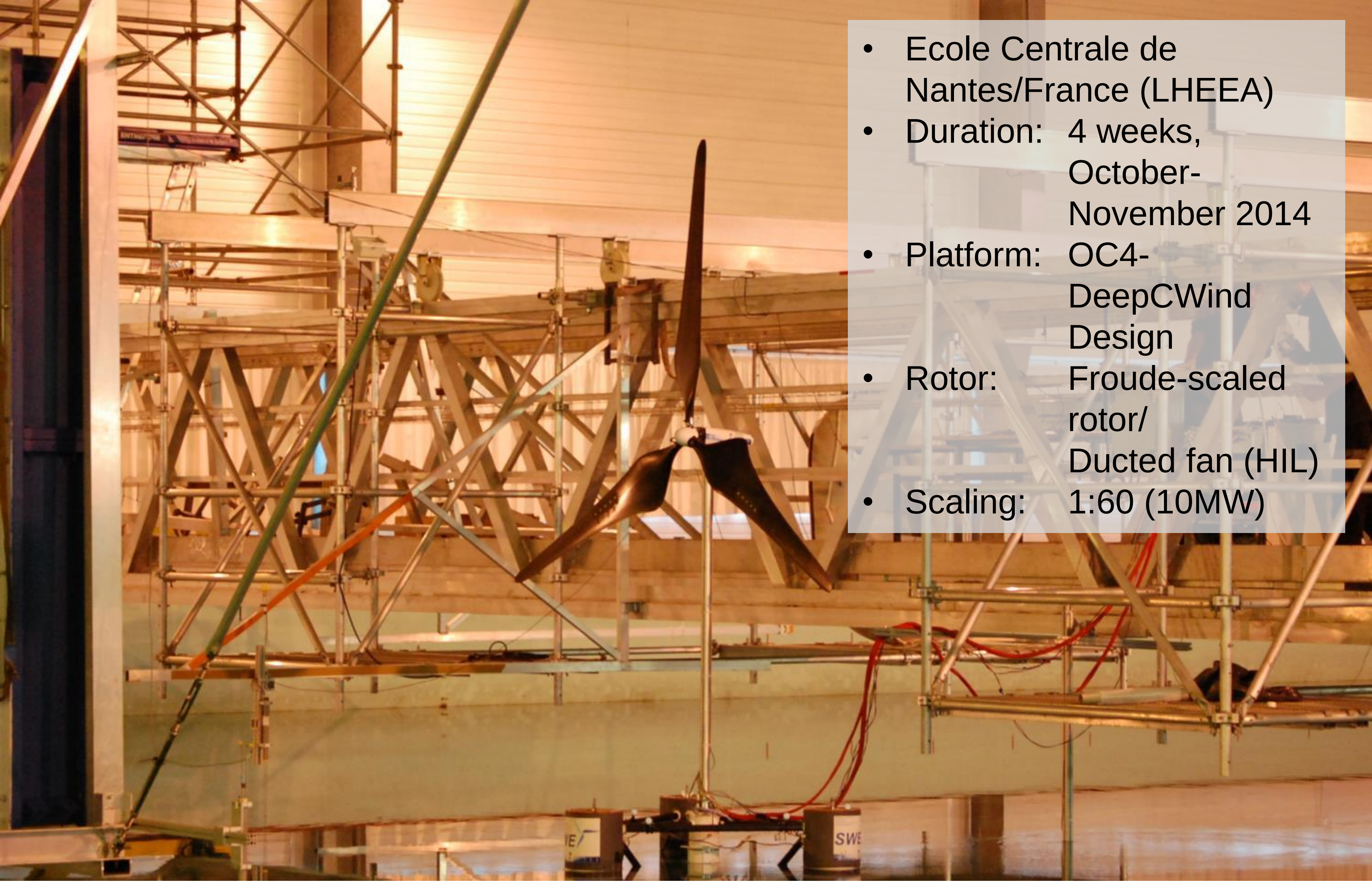
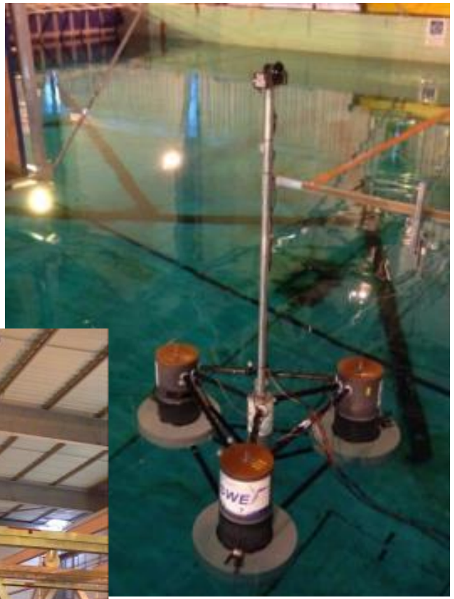


- Ecole Centrale de Nantes/France (LHEEA)
- Duration: 4 weeks, October-November 2014
- Platform: OC4-DeepCWind Design
- Rotor: Froude-scaled rotor/ Ducted fan (HIL)
- Scaling: 1:60 (10MW)

Presentation Outline

1. Aerodynamic scaling
   – Experimental scales
   – Froude-scaled rotor
   – Ducted fan (HIL)
2. Platform model:
   – Manufacturing
   – Mass distribution
3. Mooring system adaptation
4. Sensor systems
5. Wave tank
6. Test cases
7. Conclusion



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Aerodynamic Scaling

1. Correct Froude-scaling of
   - Rated rotor speed Ω
   - Wind speed v_0
   - Thrust force F_{thrst}
2. Set thrust coefficient c_T through blade pitch angle θ s.t.

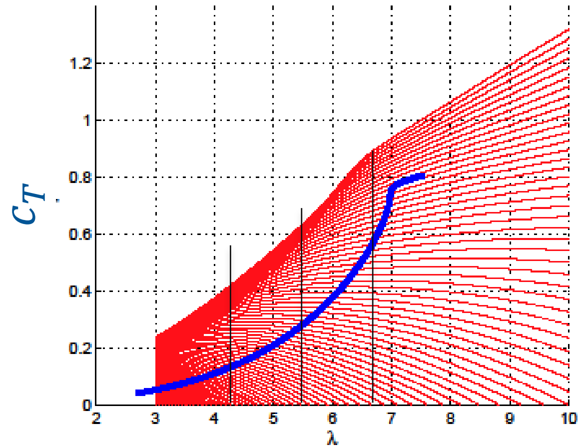
$$F_{thrst} = \frac{1}{2}\rho\pi R^2 c_T\left(\frac{\Omega R}{v_0}, \theta\right) v_0^2$$

for the given rotor radius R.

➢ Assessment of different scales possible.

Froude-scaling:

Property	Scaling Factor
Length	λ
Mass	$\lambda^3 \frac{\rho_{fresh}}{\rho_{salt}}$
Velocity	$\sqrt{\lambda}$
Force	$\lambda^3 \frac{\rho_{fresh}}{\rho_{salt}}$



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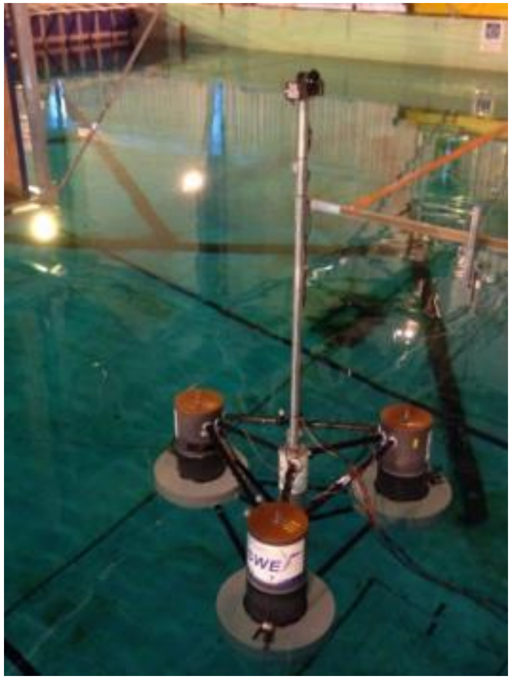
Aerodynamic Scaling

- Froude-scaled rotor
- Constant rpm

- Ducted fan
- Real-time controlled (HIL)
- No wind generator necessary



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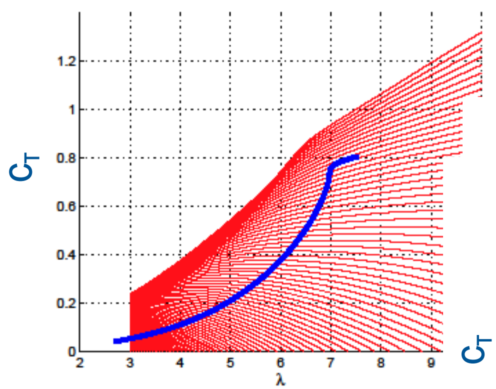
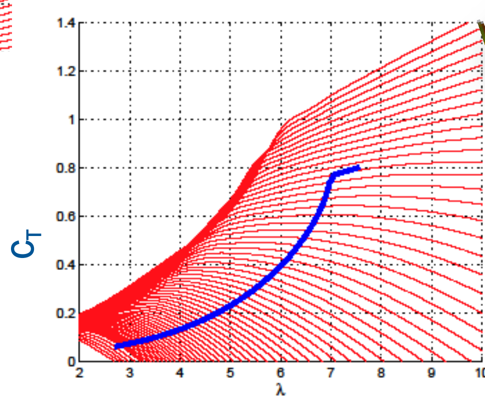
Froude-scaled Rotor

- **Froude-scaling**: High Reynolds mismatch
- **How to get realistic rotor performance:** Higher rotor solidity (increase blade chord, i.e. airfoils Reynolds)

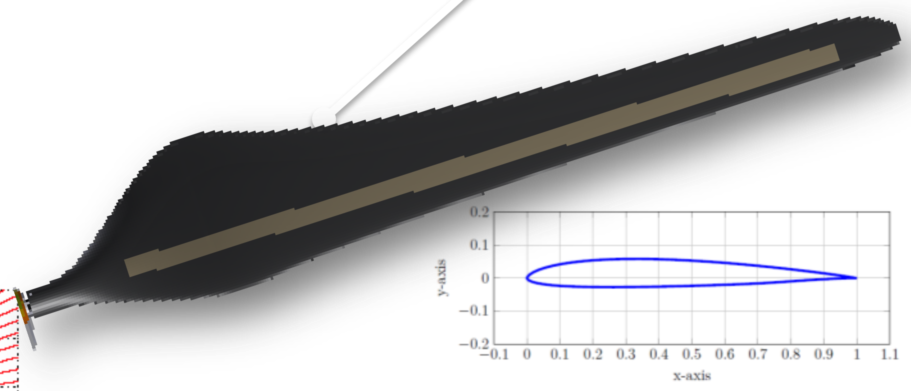


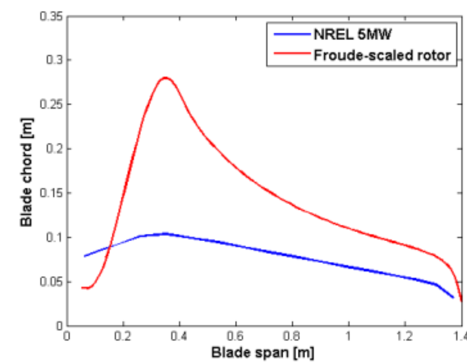
Model ►

◄ Full-Scale



Low Reynolds, low cambered RG-14 airfoil





➢ Scaled thrust can be obtained.

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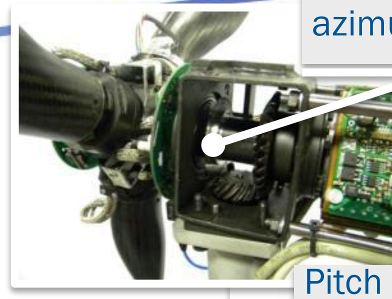
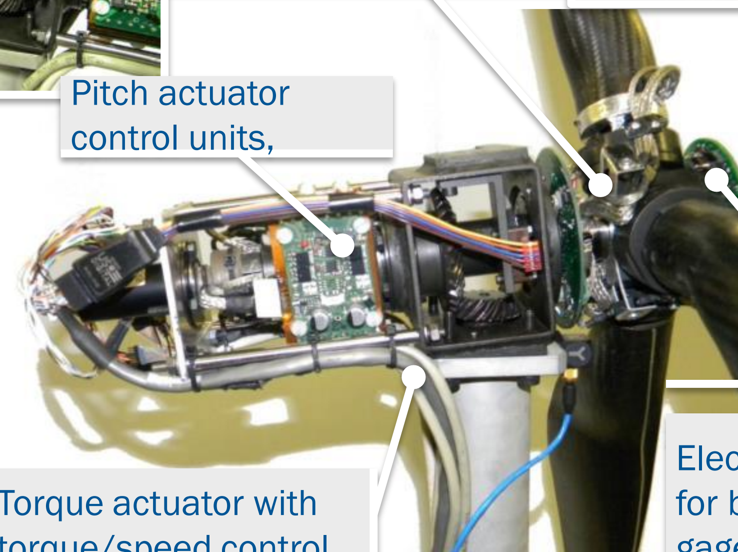
Froude-scaled Rotor



Optical encoder for azimuth readings

Shaft strain gages



Pitch actuator control units,

- Pitch demand
- Torque or speed demand

Pitch actuator

Torque actuator with torque/speed control

Electronics board for blade strain gages signal conditioning

Control hardware:
- Supervisory control
- pitch-torque control law

Remote Control Unit:
- Management of experiment
- Data logging and visualization

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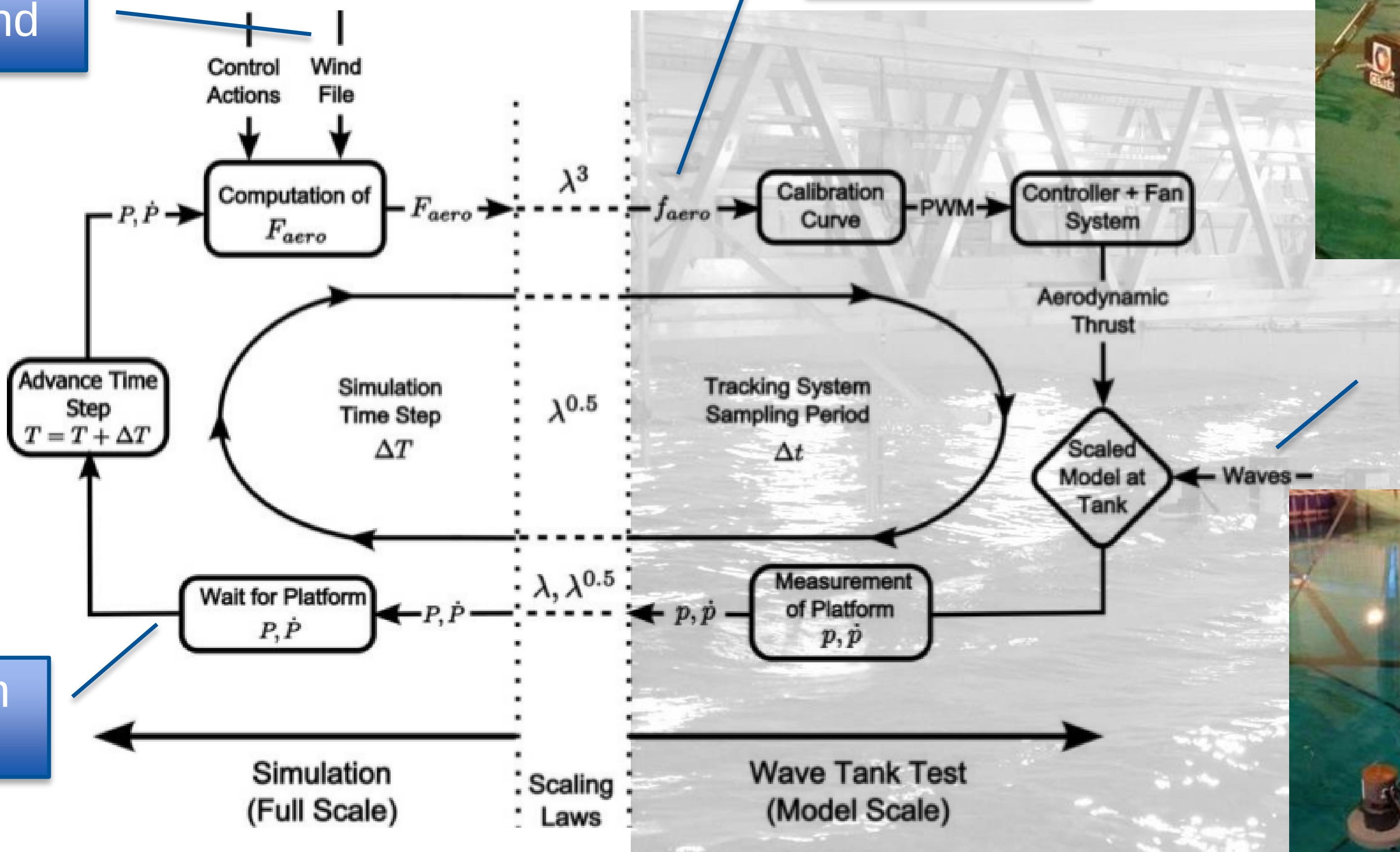
Ducted Fan

Wind

Demanded thrust



Waves

Platform states

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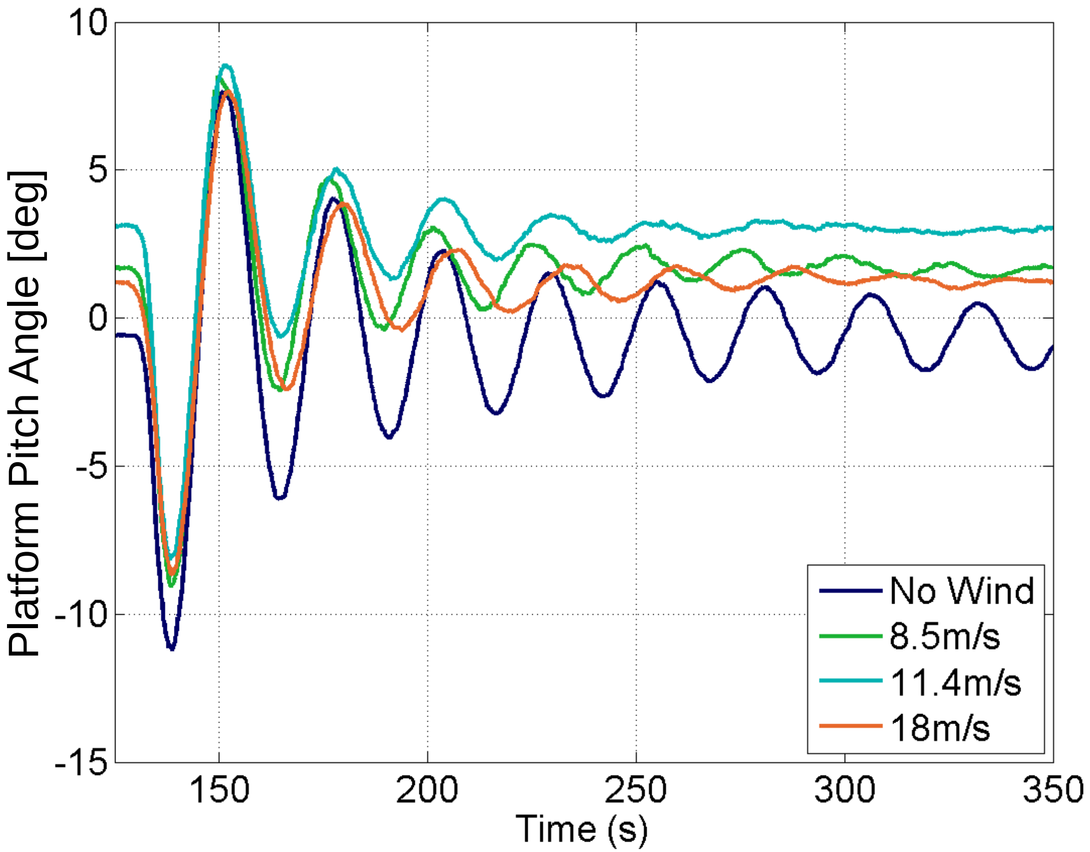
Ducted Fan



- Aerodynamic damping

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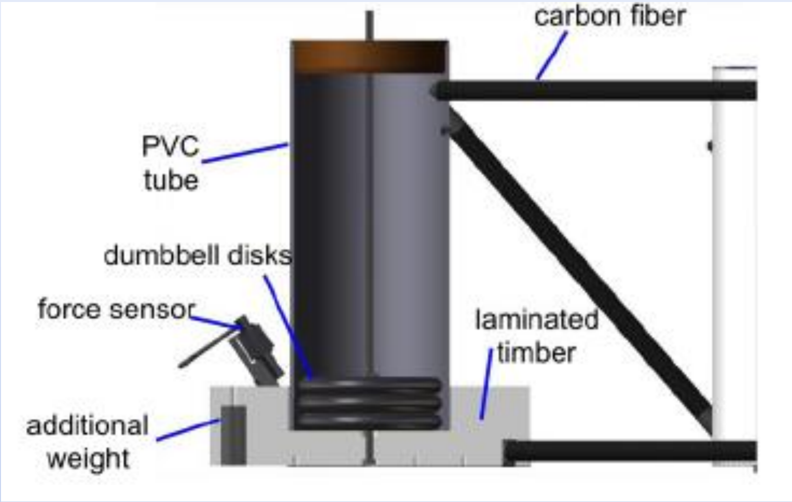
Platform model

Fabrication:

- Struts: carbon fibre
- Lower columns: wood
- Upper columns: PVC
- Central column: Carbon fibre-reinforced PVC
- Ballast: dumbbell disks
- Assembly: Inserted threads & srewed connections



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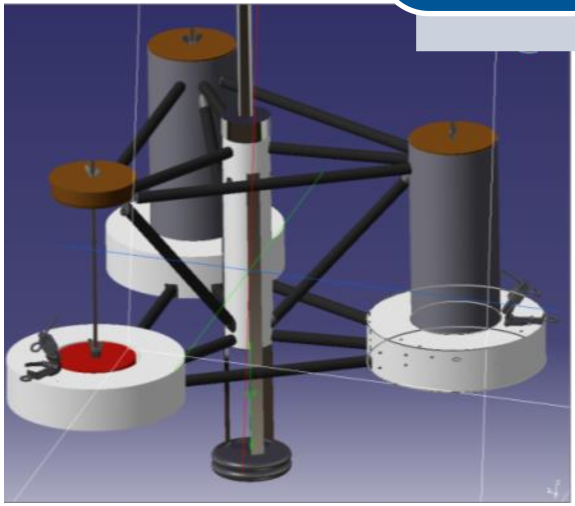
Platform model

Mass distribution:

CAD model

Verification through pendulum tests

Tuning with ballast



$$T = 2\pi\sqrt{\frac{I}{mgL}}$$

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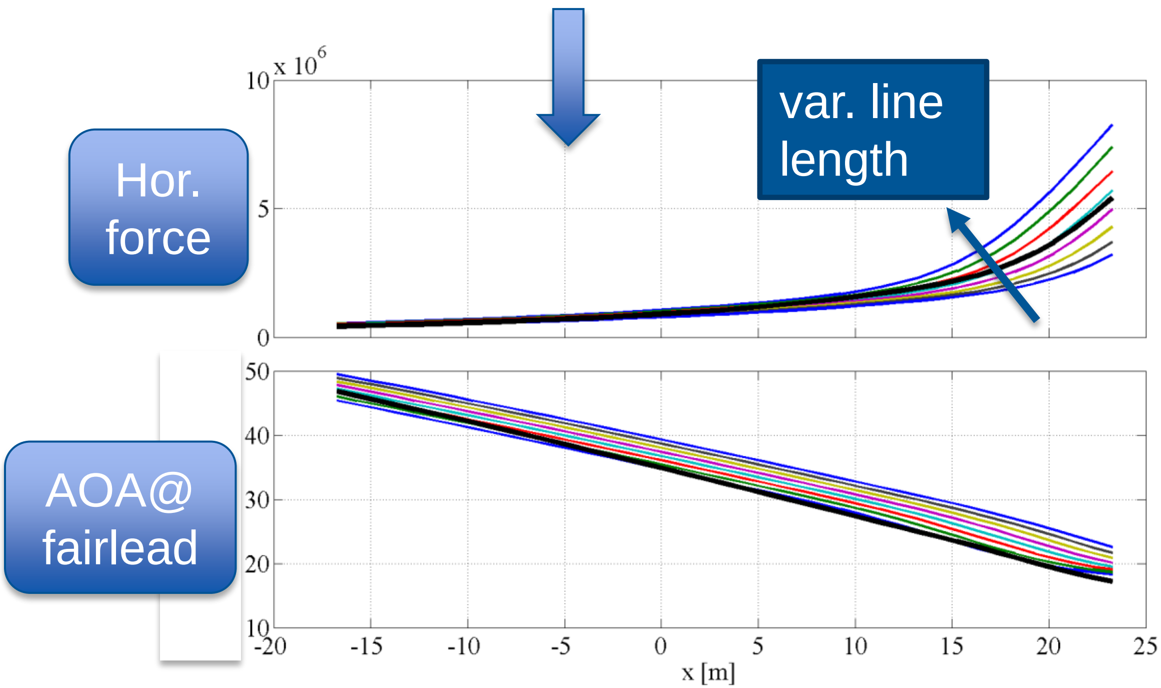
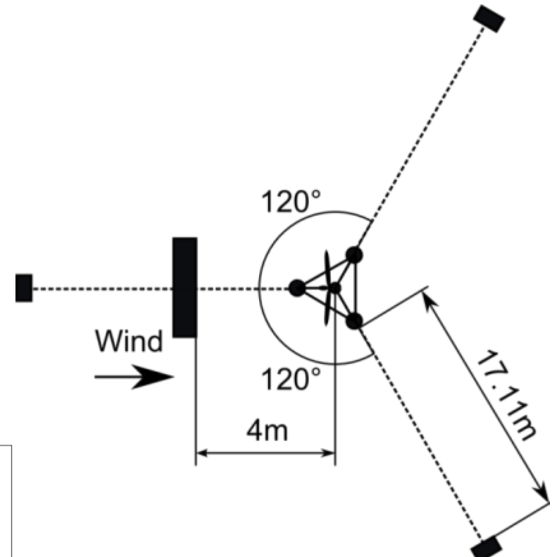
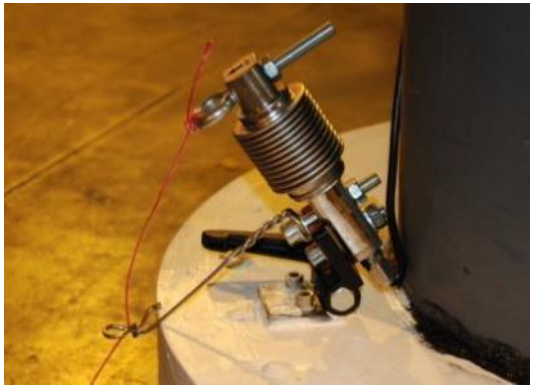
Mooring System

- OC4 lines had to be **shortened** by 1.5m due to wave tank dimensions
- Depth of basin 0.5m **deeper** than scaled depth







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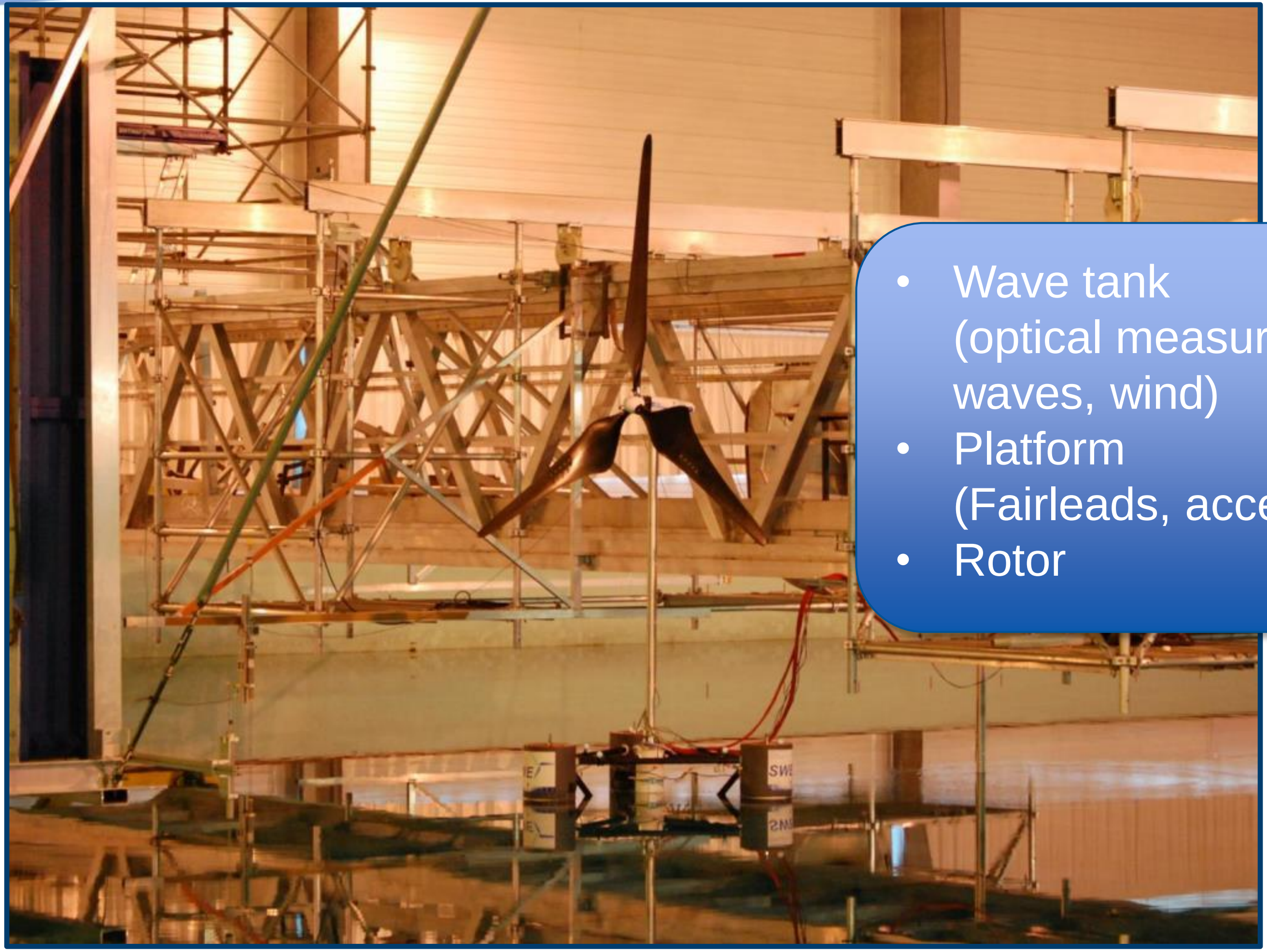
Sensors



- Wave tank (optical measurement, waves, wind)
- Platform (Fairleads, accelerations)
- Rotor

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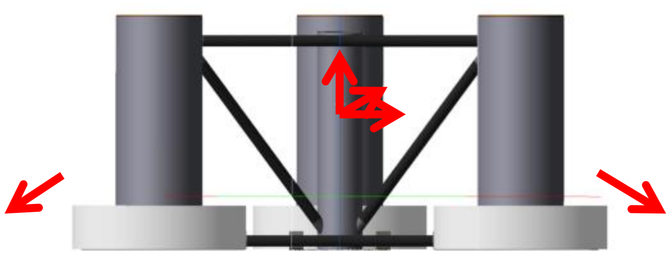
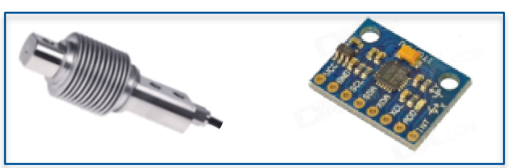
Sensors: Onboard

Platform

- Sampling rate 100Hz, 16bit res.
- Accelerometer & gyroscope
- Fairleads force transducers
- Onboard storage and wireless transmission





Wind turbine

- Sampling rate 250Hz
- Tower base force transducer
- Shaft torque-meter
- Blade strain gages
- Rotor speed and azimuth
- Blade pitch angle

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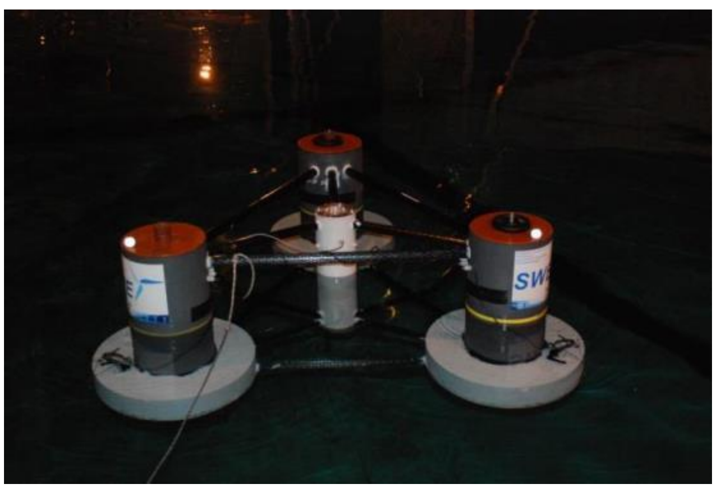
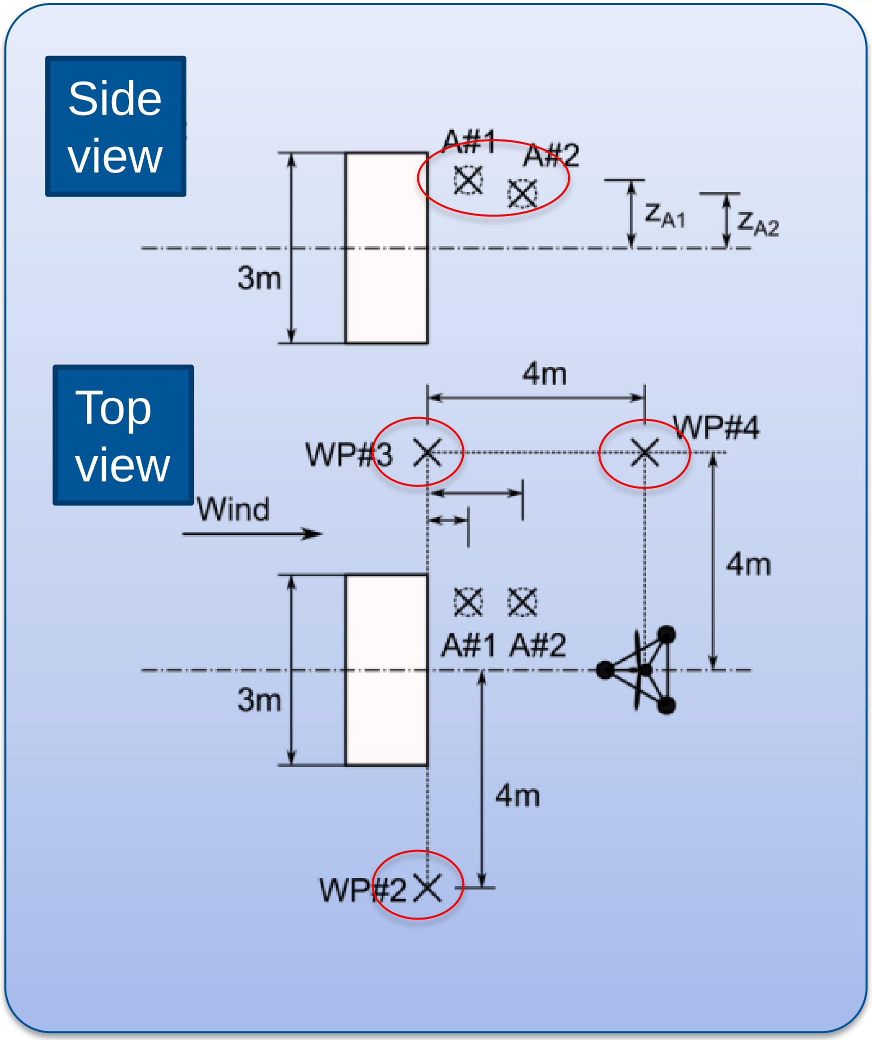
Sensors: Wave Tank

Wave tank

- 2 anemometers
- 3 wave probes
- Video motion capture





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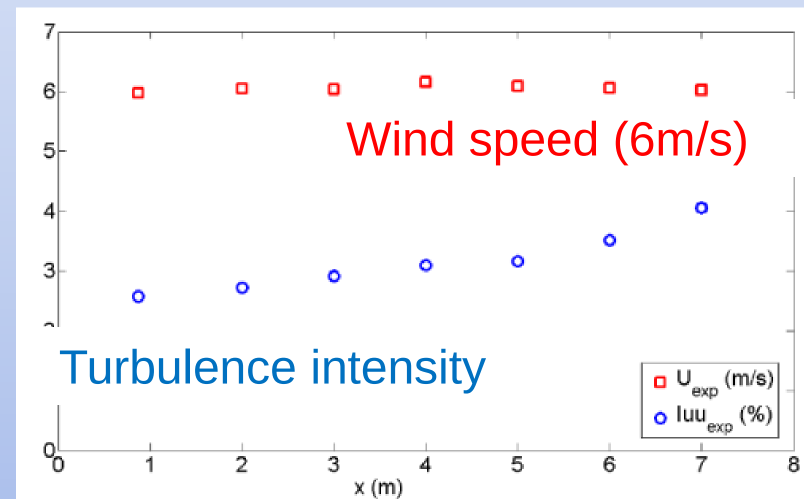
Wind & Wave Tank

Wind

- Outlet of 3x3m
- Adjustable position
- Mean Turbulent Intensity below 5%
- Wind speeds 0.5…15m/s

Waves

- 50x30x5m
- Reg./irreg. waves, adjustable wave dir.



Axial distance from outlet

[Courbois, A. (2013)]

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Test Cases

- System ID (free decay, static mooring displacement)
- Regular waves, irregular waves
  - w/ wind
  - w/o wind
- Extreme wave conditions
- Sensitivity tests (wind speed, mooring lines)

	$\lambda = 45$			$\lambda = 60$		
	Hs (m)	Tp (s)	Wind (m/s)	Hs (m)	Tp (s)	Wind (m/s)
Sea State #1	0,052	0,820	1,043	0,039	0,710	0,9
Sea State #2	0,073	0,969	1,267	0,055	0,839	1,1
Sea State #3	0,092	1,088	1,699	0,069	0,942	1,5
Sea State #4	0,137	1,327	2,683	0,103	1,149	2,3

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Conclusions

- Generic OC4 model with two methods for aerodynamics successfully tested
- Adjustable mass distribution
- Two scales tested
- Partly wireless data transmission
- Complete set of test data will be published on WWW.INNWIND.EU
- Tool validation is ongoing

Recommendations:

- Identify rotor properties in open jet w/o recirculation, perform comparison cases with closed wind tunnel
- Perform „sensitivity“ tests on model properties
- CAD „supervision“ advisable

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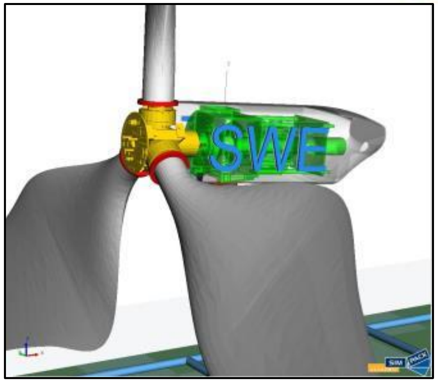
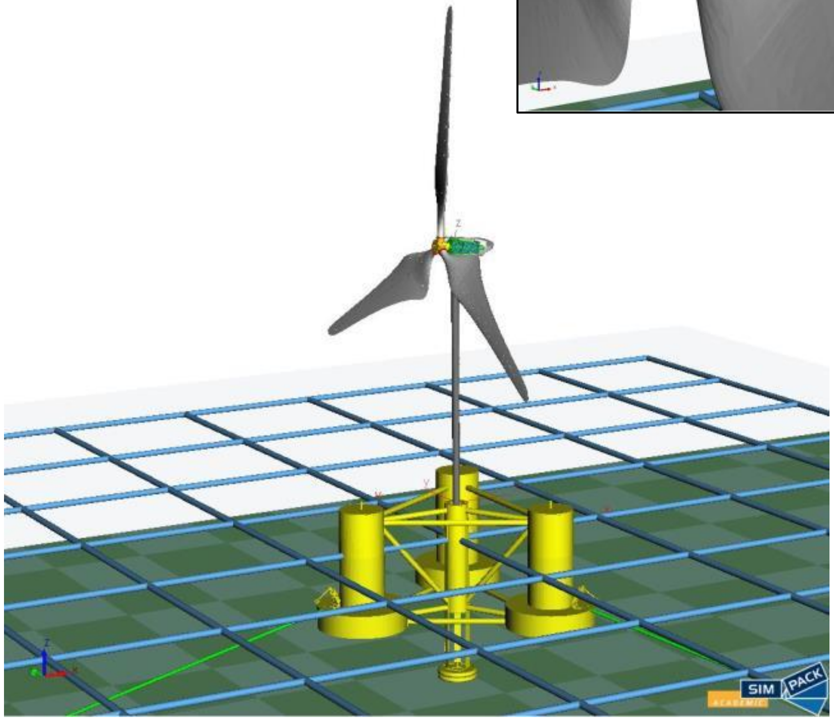
Outlook: Scaled Simulation Model

Small-scale model:

- Hydrodynamic coefficients scaled
- Blade polars for small-scale rotor
- Valid position of reference wind speed measurement in open jet
- Reconstruction of irregular wave field





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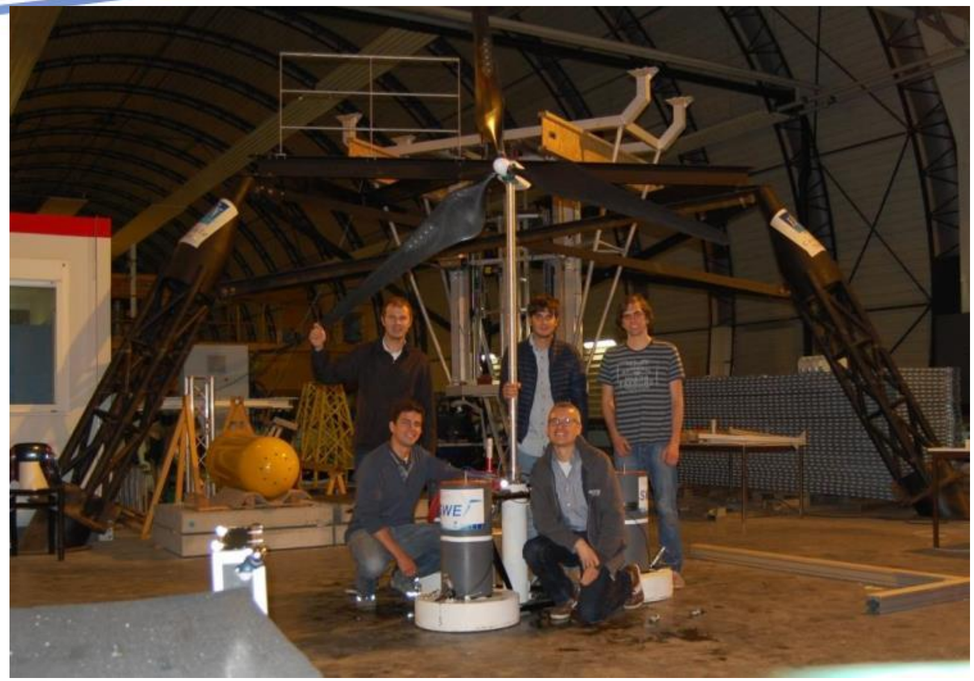
Thank you!



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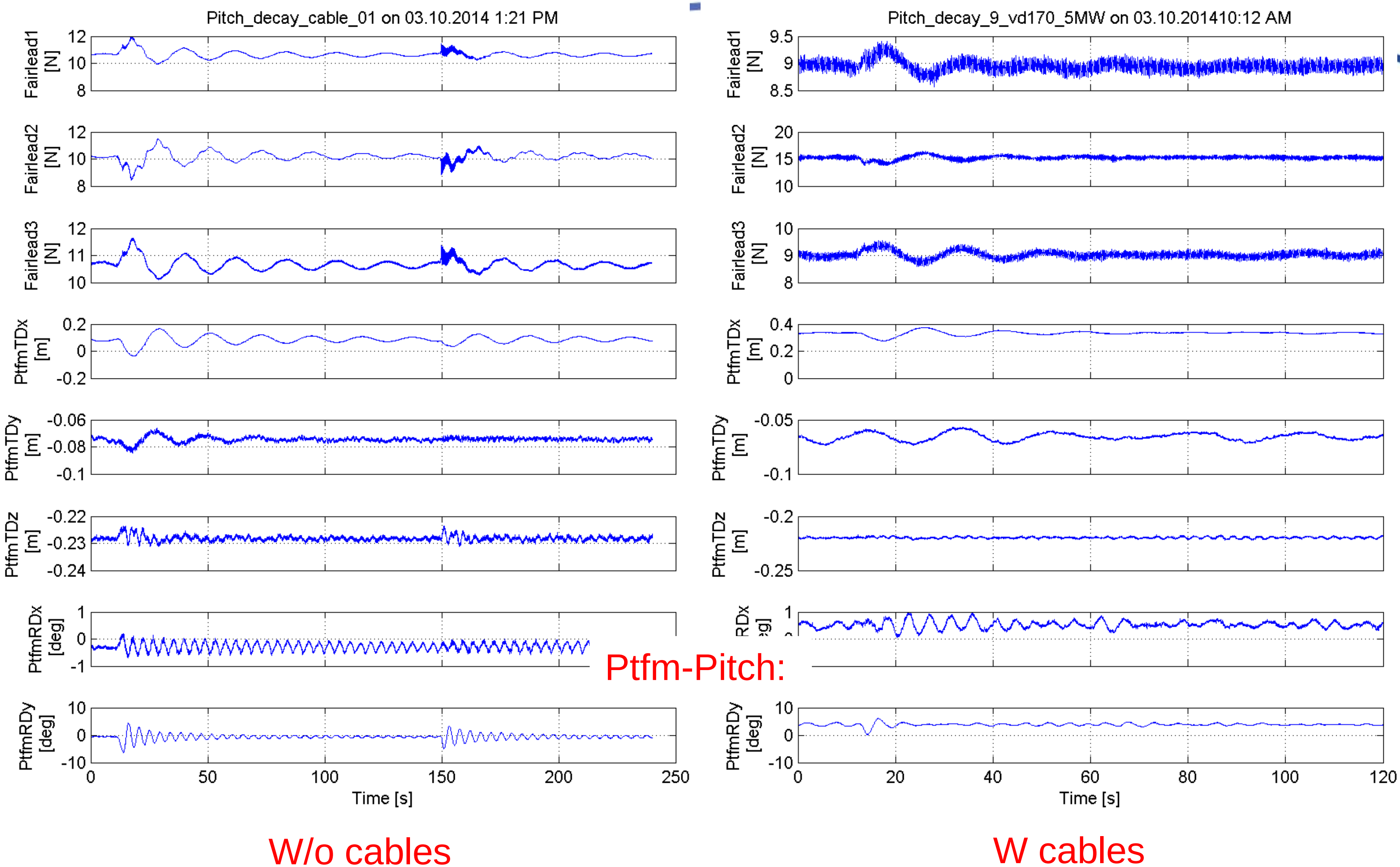
University of Stuttgart
Germany

Results: Free-decay



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