DeepWind-An Innovative Offshore Wind Turbine Concept

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Innovative Concepts and new Technologies

Uwe Schmidt Paulsen*

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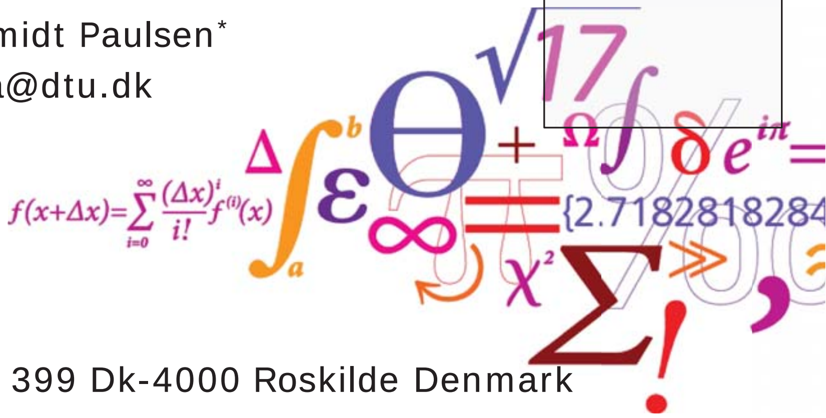

EU FP7+ DeepWind Consortium

www.deepwind.eu

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DTU Wind Energy

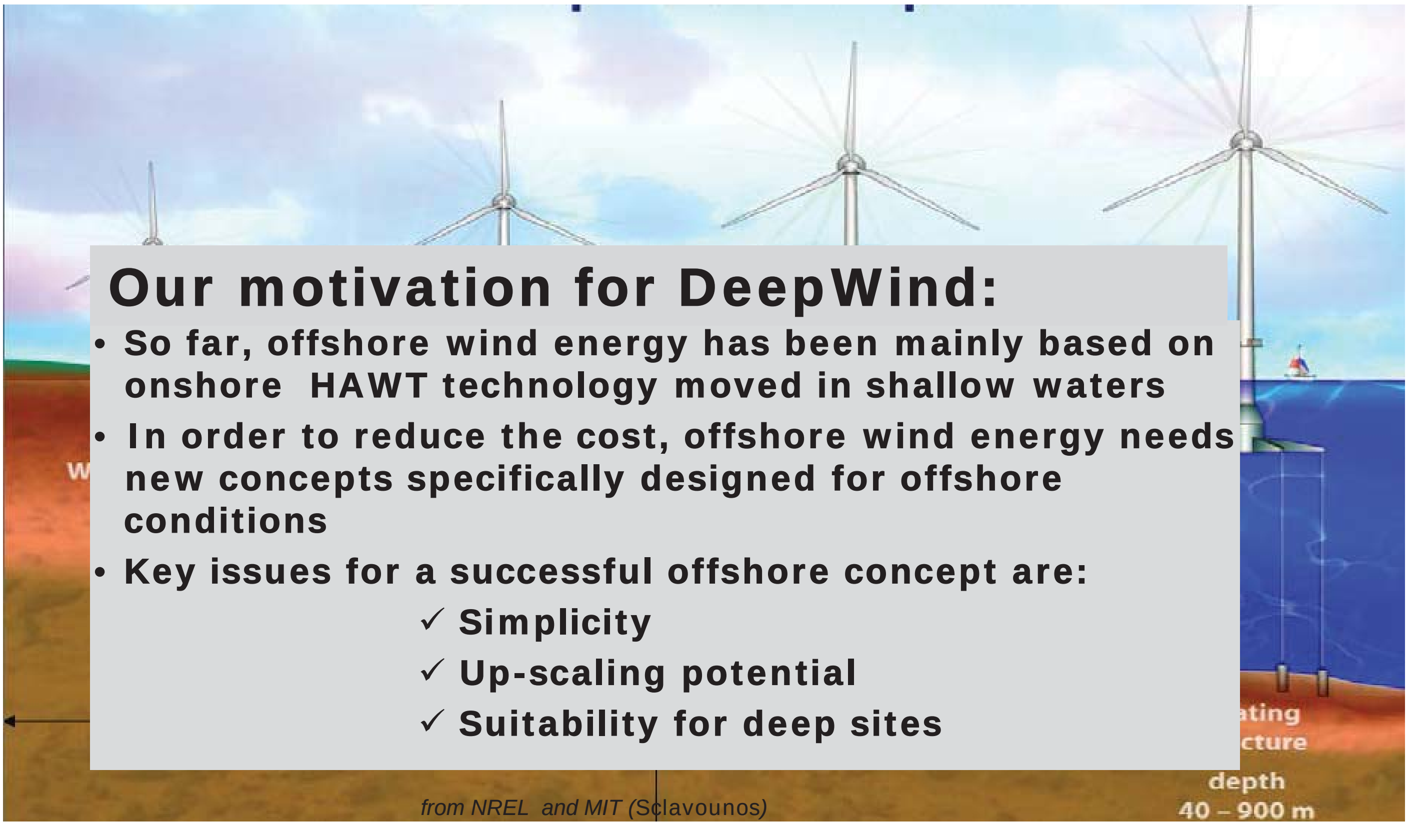
Department of Wind Energy

DeepWind

Contents

- DeepWind Concept
- DeepWind instruments and goals
- Results in the project
- Conclusion

Concept From shore to deep sea



Our motivation for DeepWind:

- So far, offshore wind energy has been mainly based on onshore HAWT technology moved in shallow waters
- In order to reduce the cost, offshore wind energy needs new concepts specifically designed for offshore conditions
- Key issues for a successful offshore concept are:
  - ✓ Simplicity
  - ✓ Up-scaling potential
  - ✓ Suitability for deep sites

from NREL and MIT (Sclavounos)

DeepWind

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DeepWind Concept

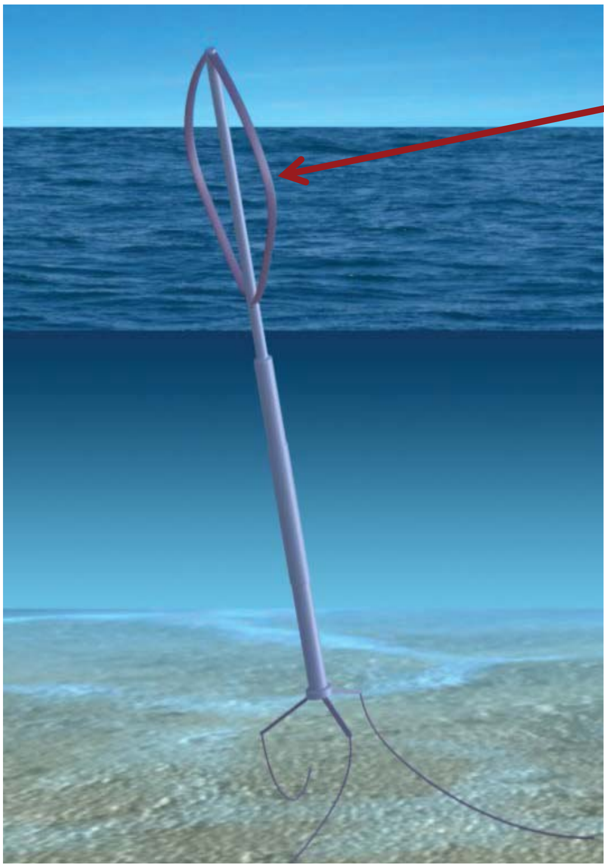
- Genuine offshore concept
  - Simple
  - Scalable
  - For deep sea sites
- Floating offshore based on VAWT technology
- Cost difference allows room for design space
- A priori: Tech Range 100-1000 m depth
- So far
  - demonstrator
  - exhibition model
  - paper work results
- Contributions to reduce risk(selected list):

- Vita L, Paulsen US, Pedersen TF, Madsen HA, Rasmussen F *A Novel Floating Offshore Wind Turbine Concept* in Proceedings of the European Wind Energy Conference (EWEC), Marseille, France,2009.
- Vita L, Zhale F, Paulsen US Pedersen TF, Madsen HA, Rasmussen F. *Novel Concept For Floating Offshore Wind Turbines: Concept Description And Investigation Of Lift, Drag And Friction Acting On The Rotating Foundation* in Proceedings of the ASME 2010 29th International Conference on Ocean, Offshore and Arctic Engineering, June 6 Shanghai 2010 OMAE2010-20357
- Vita L *Offshore floating vertical axis wind turbines with rotating platform* Risø DTU, Roskilde, Denmark, PhD dissertation PhD 80, 2011
- Stefan Carstensen1 Xerxes Mandviwalla, Luca Vita and Uwe Schmidt Paulsen *Lift of a Rotating Circular Cylinder in Unsteady Flows* ISOPE June2012

DeepWind

The Concept

- No pitch, no yaw system

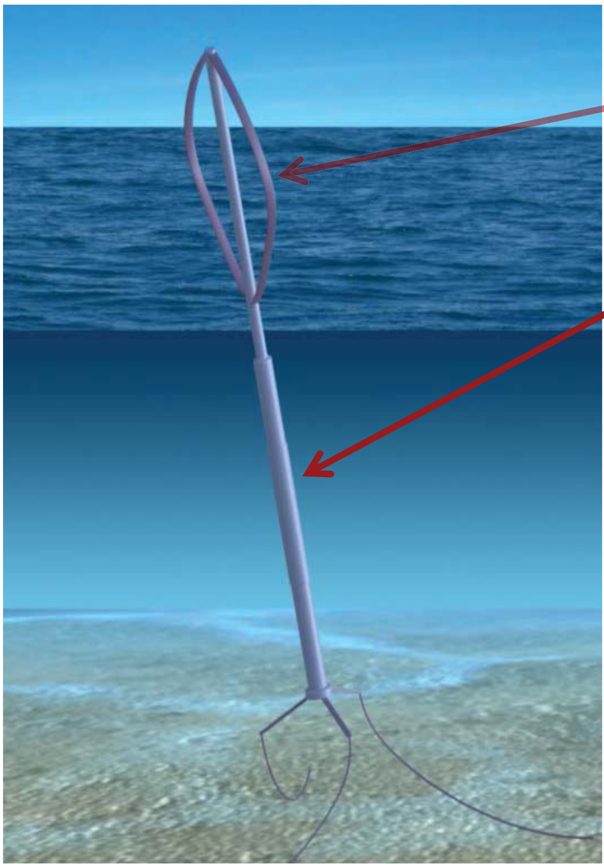


- Light weight rotor with pultruded blades

DeepWind

The Concept

- No pitch, no yaw system
- Floating and rotating tube as a spar buoy

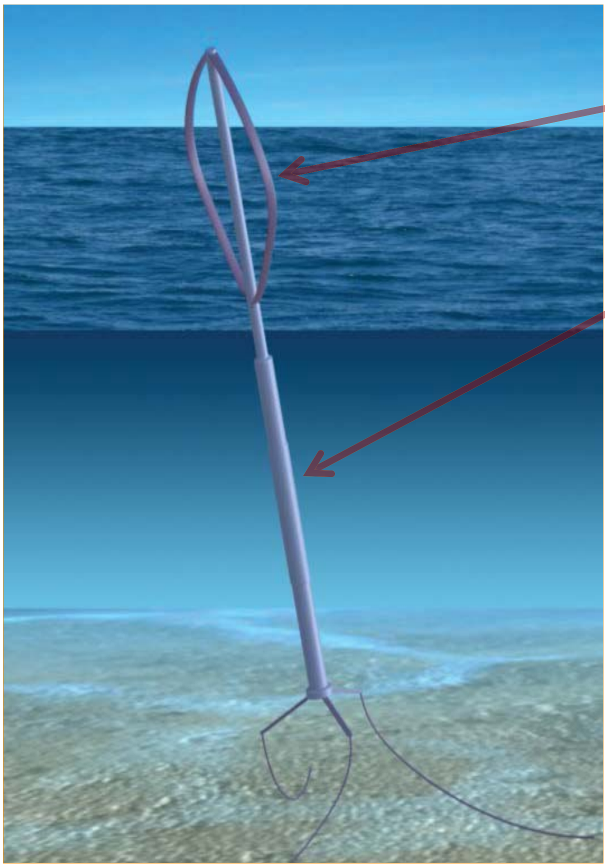


- Light weight rotor with pultruded blades
- Long slender and rotating underwater tube with little friction

DTU

DeepWind
The Concept

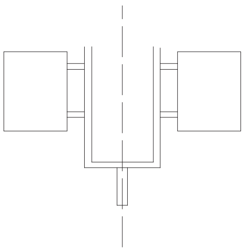
- No pitch, no yaw system
- Floating and rotating tube as a spar buoy
- C.O.G. very low – counter weight at bottom of tube

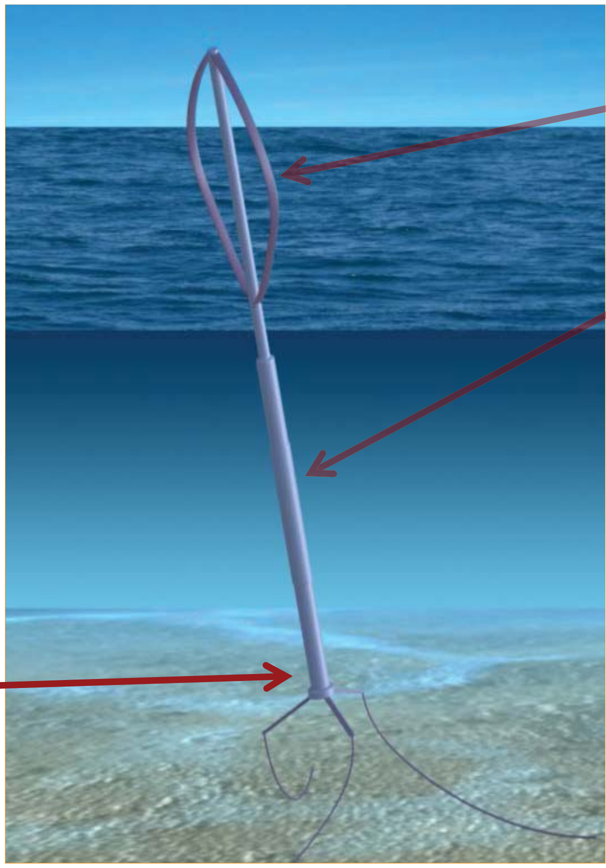


- Light weight rotor with pultruded blades
- Long slender and rotating underwater tube with little friction with little friction

DeepWind
The Concept

- No pitch, no yaw system
- Floating and rotating tube as a spar buoy
- C.O.G. very low – counter weight at bottom of tube
- Safety system





- Light weight rotor with pultruded blades
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DeepWind

The Concept

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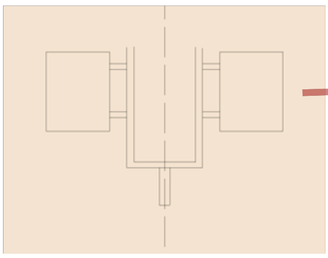
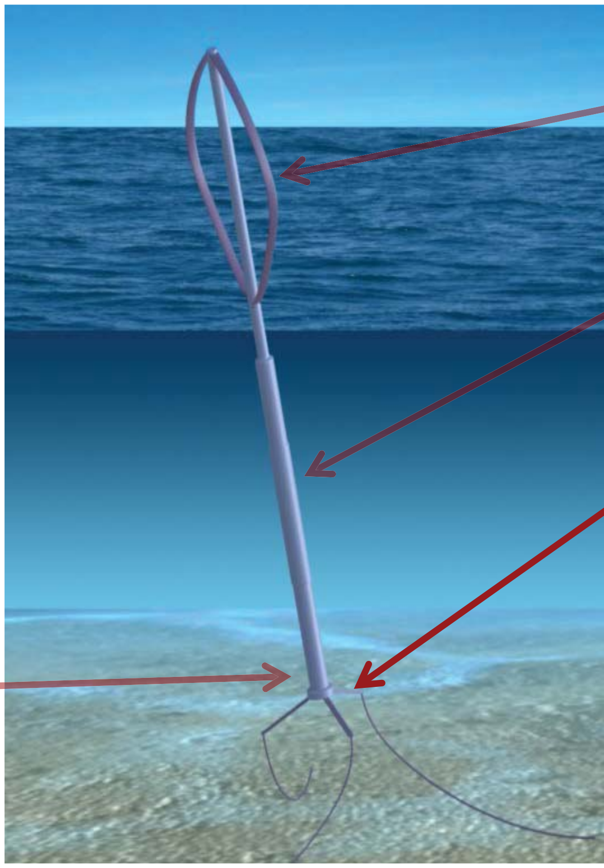
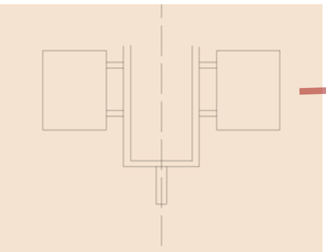


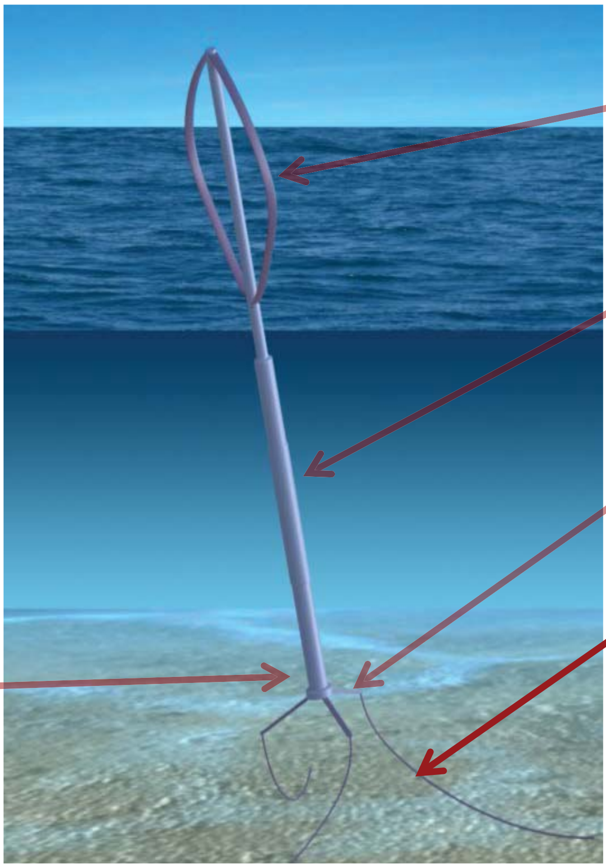


- Light weight rotor with pultruded blades
- Long slender and rotating underwater tube with little friction
- Torque absorption system

DeepWind
The Concept

- No pitch, no yaw system
- Floating and rotating tube as a spar buoy
- C.O.G. very low – counter weight at bottom of tube
- Safety system





- Light weight rotor with pultruded blades
- Long slender and rotating underwater tube with little friction
- Torque absorption system
- Mooring system

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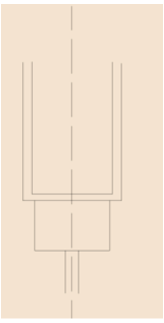
The Concept- Generator configurations

- The Generator is at the bottom end of the tube; several configuration are possible to convert the energy

- Three selected to be investigated first:
  1. Generator fixed on the torque arms, shaft rotating with the tower
  2. Generator inside the structure and rotating with the tower. Shaft fixed to the torque arms
  3. Generator fixed on the sea bed and tower. The tower is fixed on the bottom (not floating).

1



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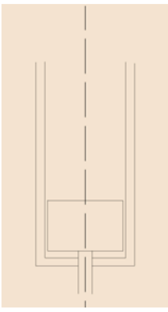
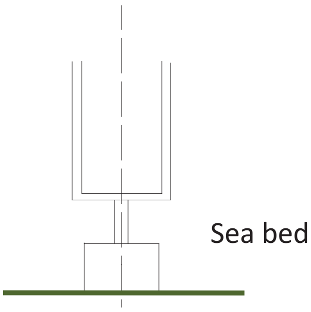
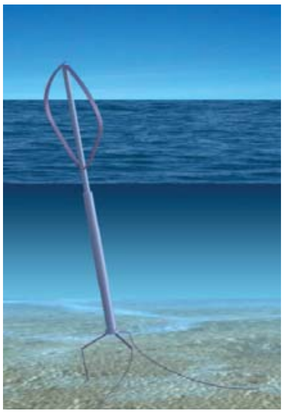


3





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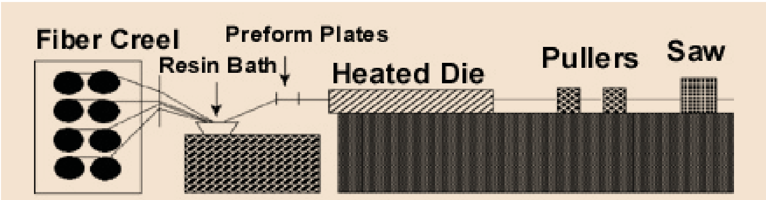
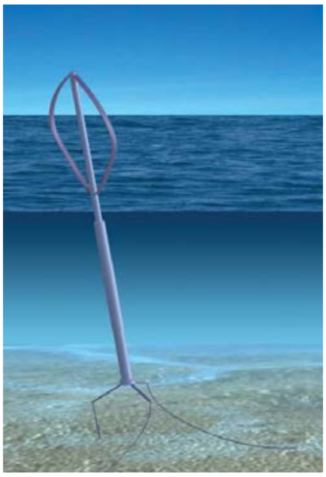
The Concept- Blades technology

- The blade geometry is constant along the blade length
- The blades can be produces in GRP or similar
- Pultrusion technology:
  - Presently block up to approx 1 m units
  - outlook- 11 m chord several 100 m long blade length





- Pultrusion technology could be performed on a ship at site
- Blades can be produced in modules

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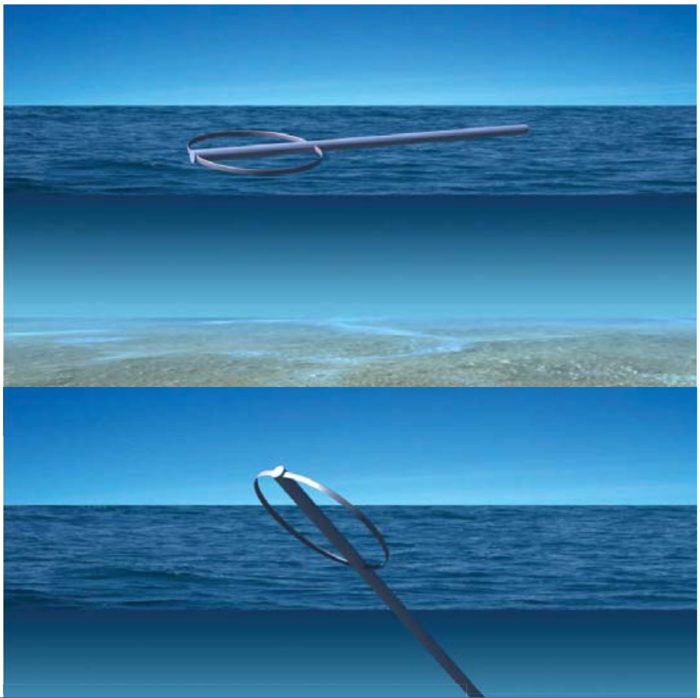
The Concept- Installation, Operation & Maintenance

- INSTALLATION
  - ✓ Using a two bladed rotor, the turbine and the rotor can be towed to the site by a ship. The structure, without counterweight, can float horizontally in the water. Ballast can be gradually added to tilt up the turbine.
- O&M
  - ✓ Moving the counterweight in the bottom of the foundation is possible to tilt up the submerged part for service.
  - ✓ It is possible to place a lift inside the tubular structure.



❑A new basis for cost cutoff in installation procedures

❑Redistributing the costs

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The Concept Upscaling

- Pultrusion technology allows for very long and fail-free manufactured blades
- Concept simplicity
- Few components with less down time failures

- Cost-effective different materials for large structure
- Specific requirements to maintain the underwater components

DeepWind-an Innovative Floating Offshore Wind Turbine concept

DeepWind

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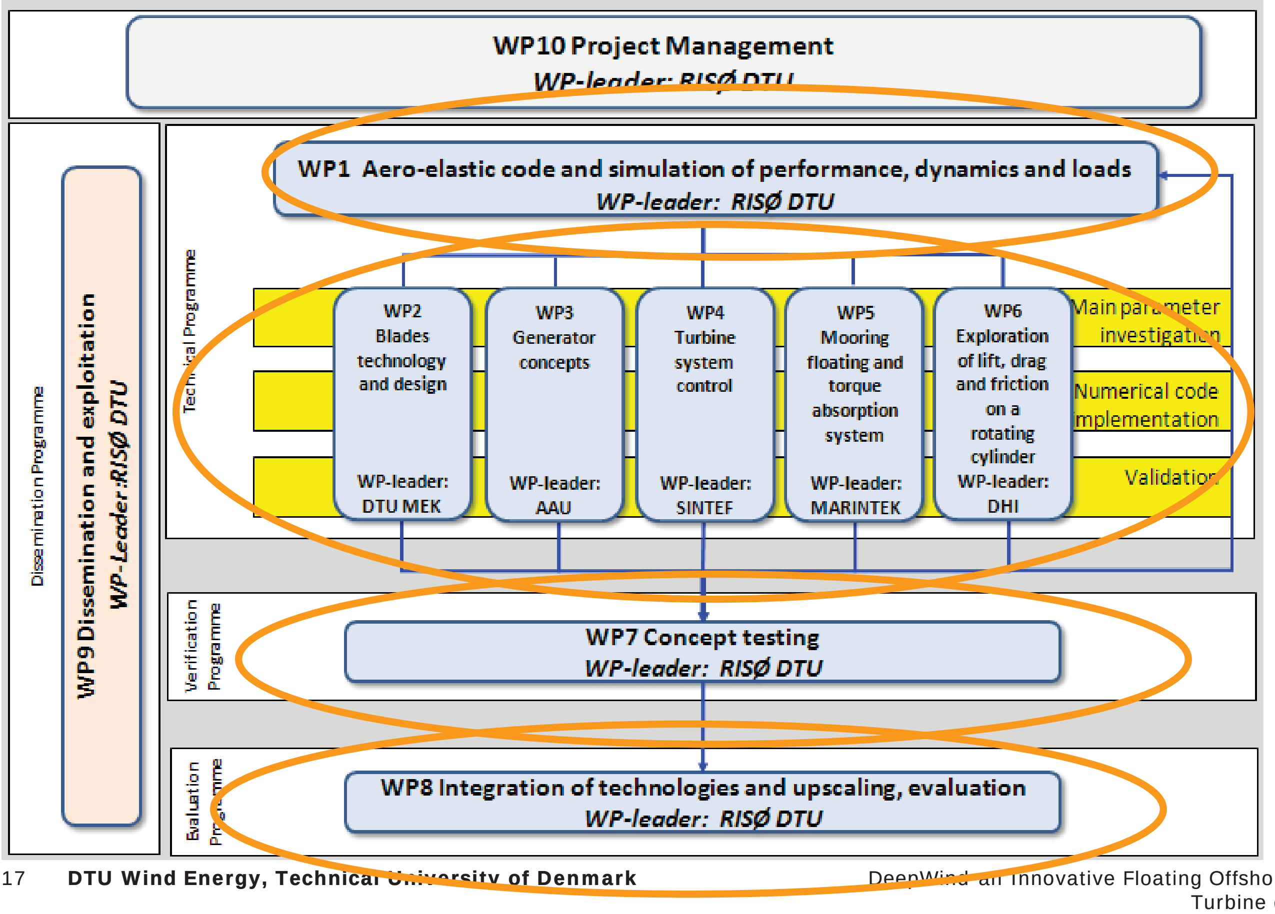
Instruments and goals



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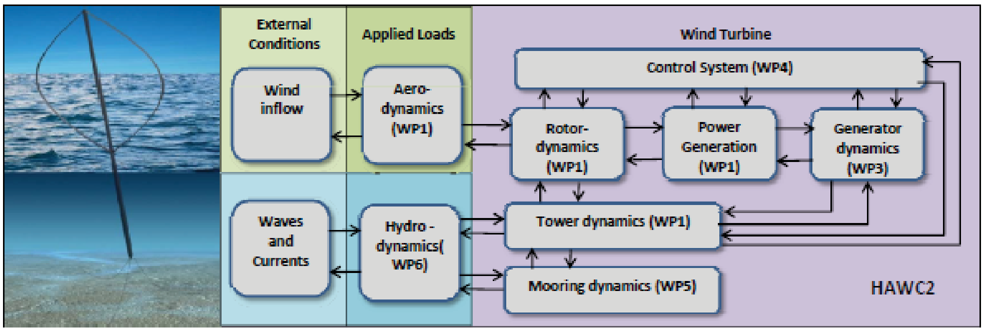
Results 1st Design Assumptions



- Dynamic stall neglected
- Atmospheric turbulence not considered
- Evaluation of loads with 3 DOF
- No mooring

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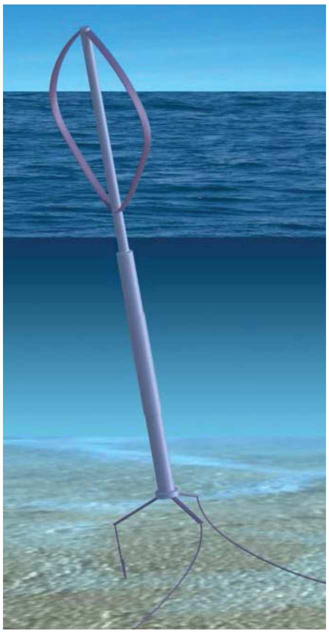
Results 2MW VAWT vs HAWT



	Deep Wind	HyWind*
Power	2 MW	2.3 MW (+15%)
Rotor Diameter	67 m	82.4 m (+23%)
Rotor Height	75 m	65.0 m (-13%)
Chord (blades number)	3.2 m (2)	N/A (3)
Rotational speed at rated conditions	15.0 rpm	16 .0 rpm (+7%)
Radius of the rotor tower	2.0 m	3.0 m (+50%)
Maximum radius of the submerged part	3.5 m	4.15 m (+19%)
Total tower length (underwater part)	183 m (93m)	165 (100)
Displacement	3000 tons	5300 tons (+77%)

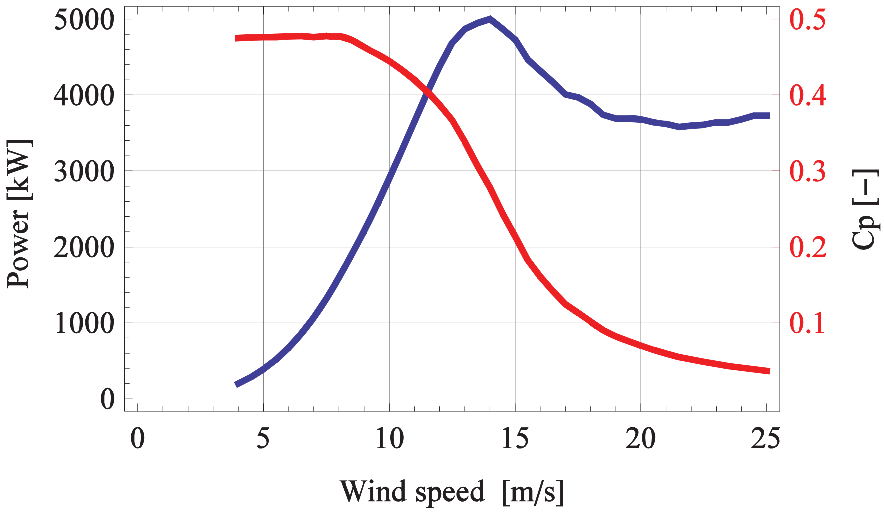
*"*HYWIND, Concept, challenges and opportunities* ", Statoil

Uwe Schmidt Paulsen *Prospects of Large Floating Vertical Axis Wind Turbines* Proceedings in Deep Sea Offshore R&D Conference Trondhjem(NO) 2011

Results 1 st BaseLine 5 MW Rotor Design

Paulsen US , Vita L, Madsen HA, Hattel J, Ritchie E, Leban KM, Berthelsen PA, Carstensen S *1st DeepWind 5 MW baseline design Energy Procedia 00 (2011) 000–000*

Geometry			Performance		
Rotor radius (R)	[m]	63.74	Rated power	[kW]	5000
Rotor height (H)	[m]	129.56	Rated rotational speed	[rpm]	5.26
Chord (c)	[m]	7.45	Rated wind speed	[m/s]	14
Solidity (σ =Nc/R)	[-]	0.23	Cut in wind speed	[m/s]	5
Swept Area	[m²]	10743	Cut out wind speed	[m/s]	25



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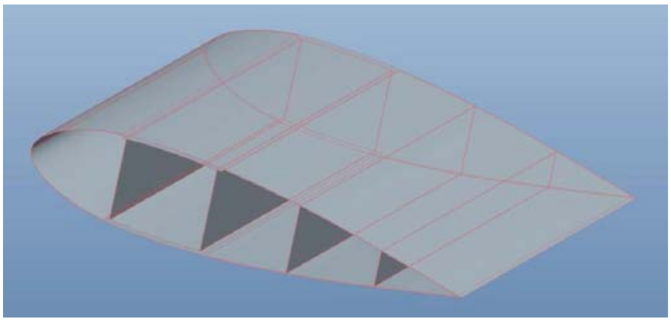
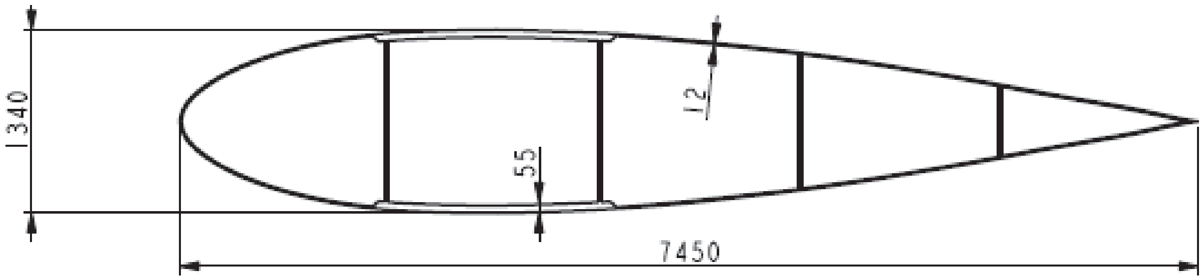
Results 1 st BaseLine 5 MW Design Blades

- blade weight 154 Ton
- blade length 187 m
- Blade chord 7.45 m, constant over length
- All GRP
- NACA 0018 profile





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Results 1 st BaseLine 5 MW Design Generator

- 5 MW mechanical power at estimated 5.26 rpm and 9.1 MNm shaft torque renders a 400 pole 17.53 Hz design with a pole pitch of around 7.85cm
  - This corresponds to an air-gap diameter of around 10 m outer diameter of around 10.5 m, with a core length of around 1.4 m.
  - Mass of Copper, Iron and permanent magnet materials of around 90 metric tons
  - Design fits reasonable with the platform design

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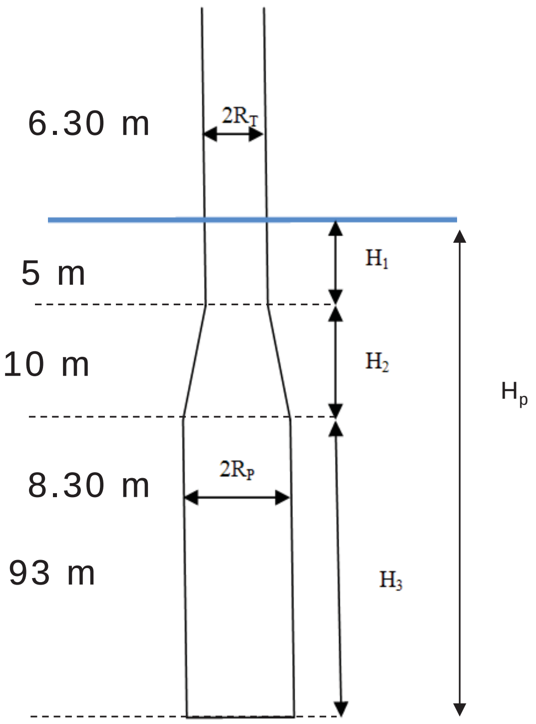
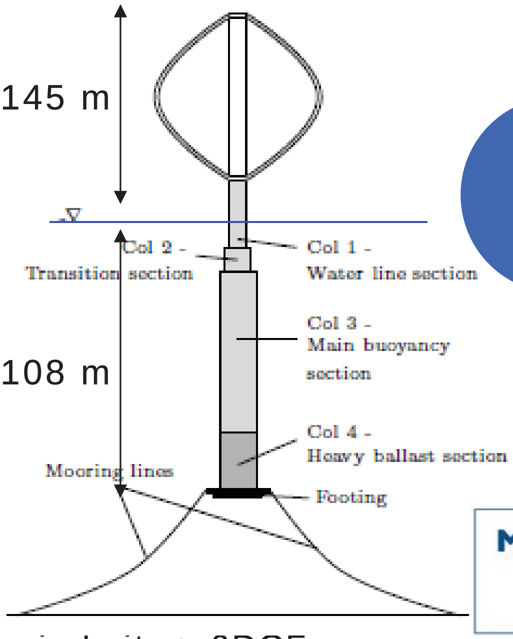
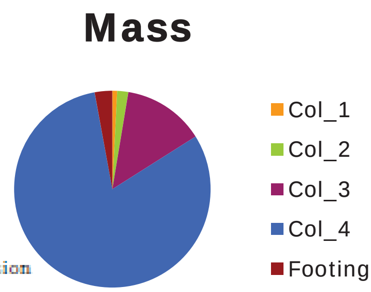
Results 1 st BaseLine 5 MW Design Floater







Hywind site+ 6DOF:
~4900 tons mass 0.9k€/ton
~ 35/60 sec natural periods in yaw/surge

❑Petter Andreas Berthelsen, Ivar Fylling, Luca Vita, Uwe Schmidt Paulsen CONCEPTUAL DESIGN OF A FLOATING SUPPORT STRUCTURE AND MOORING SYSTEM FOR A VERTICAL AXIS WIND TURBINE Proceedings of the ASME 2012 31st International Conference on Ocean, Offshore and Arctic Engineering OMAE2012 June 10–15, 2012, Rio de Janeiro, Brazil

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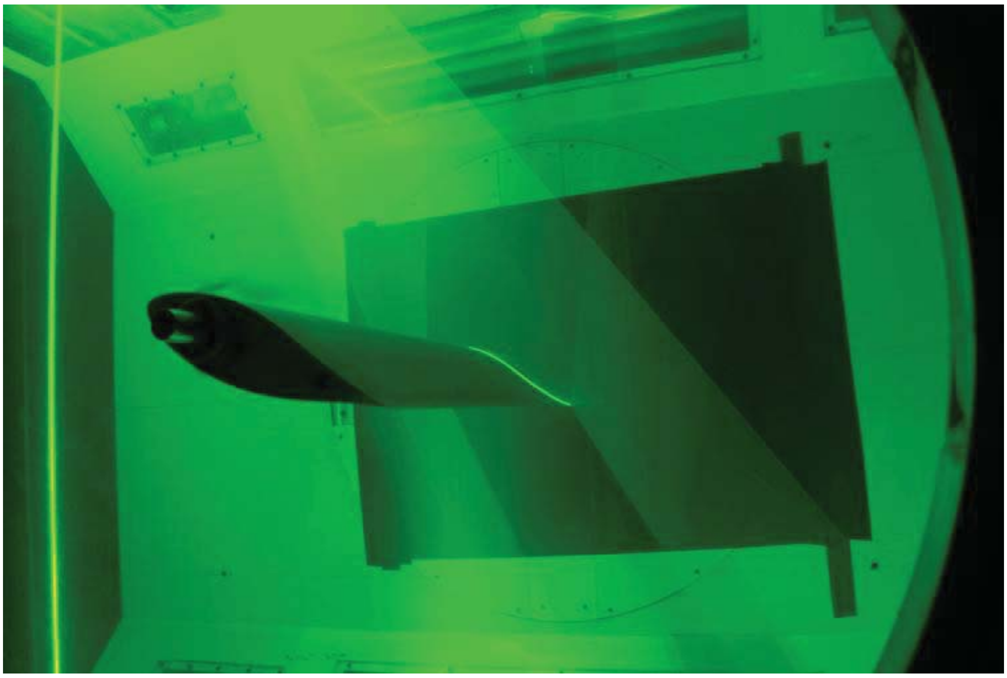
Results LTT Windtunnel tests (July 2012)



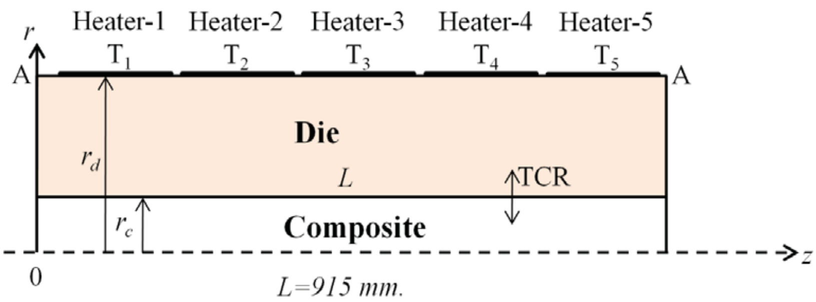
Analysis of advanced airfoils developed for VAWTs

DeepWind

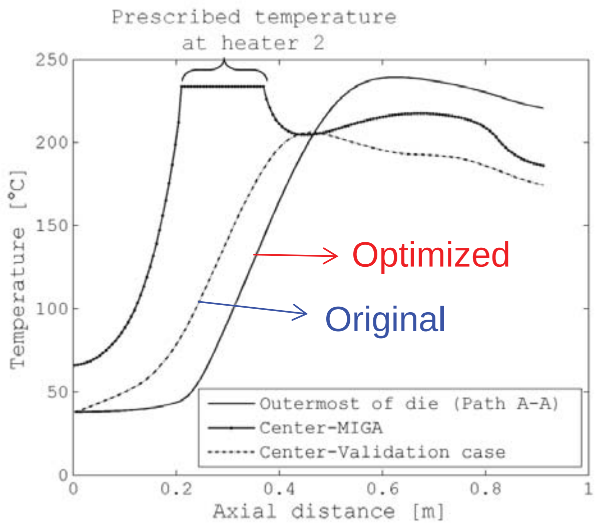
Results Modelling of Pultrusion Process

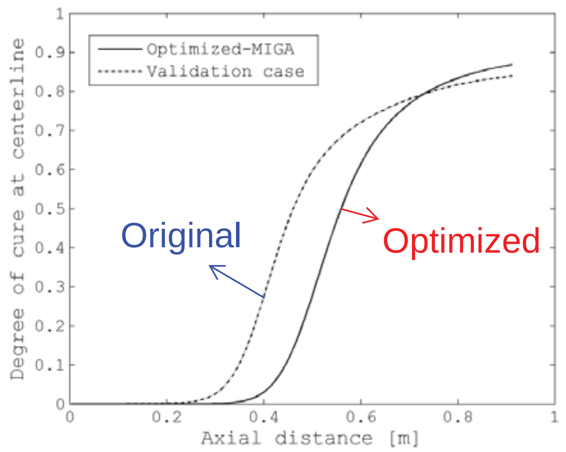
Studies already done:

- ❑ Process optimization studies by using gradient based and/or genetic algorithms
  - -Optimal heater configuration
  - -Increase productivity i.e. increase pulling speed while satisfying the desired cure degree



Baran I, Tutum CC, Hattel JH. *App Compos Mat*. 2012.
DOI: 10.1007/s10443-012-9278-3.





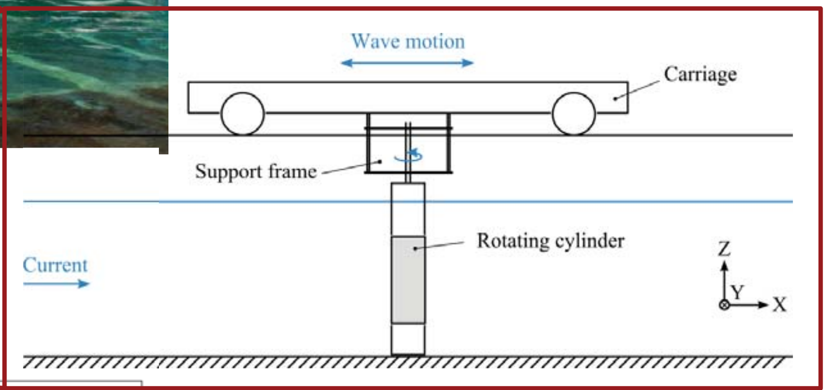
DeepWind

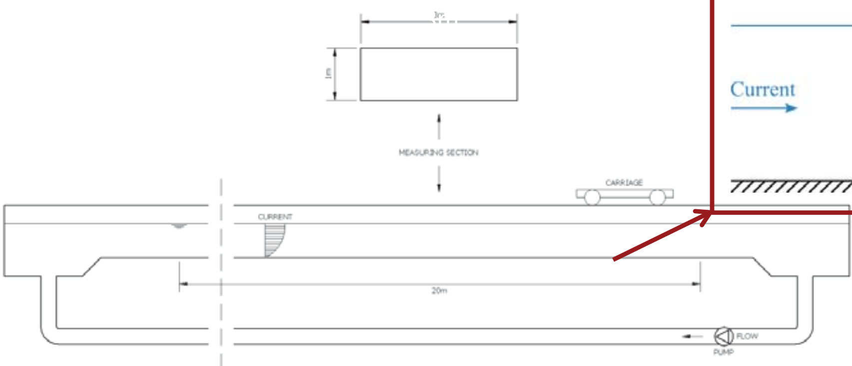
Results Physical Model Experiments

Picture

Carstensen et al *Lift of a Rotating Circular Cylinder in Unsteady Flows ISOPE june2012*

Close-up (sketch)





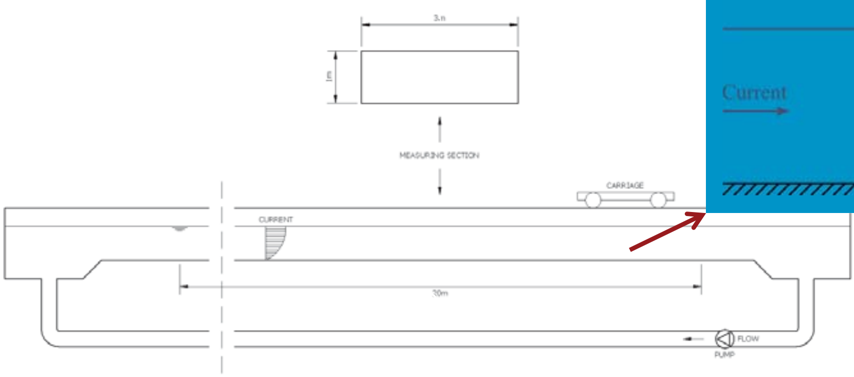
Sketch

DeepWind
Results Physical Model Experiments

Picture

$$U = U_m \sin(2\pi f t + \varphi) + U_c$$

Carstensen et al *Lift of a Rotating Circular Cylinder in Unsteady Flows ISOPE june2012*



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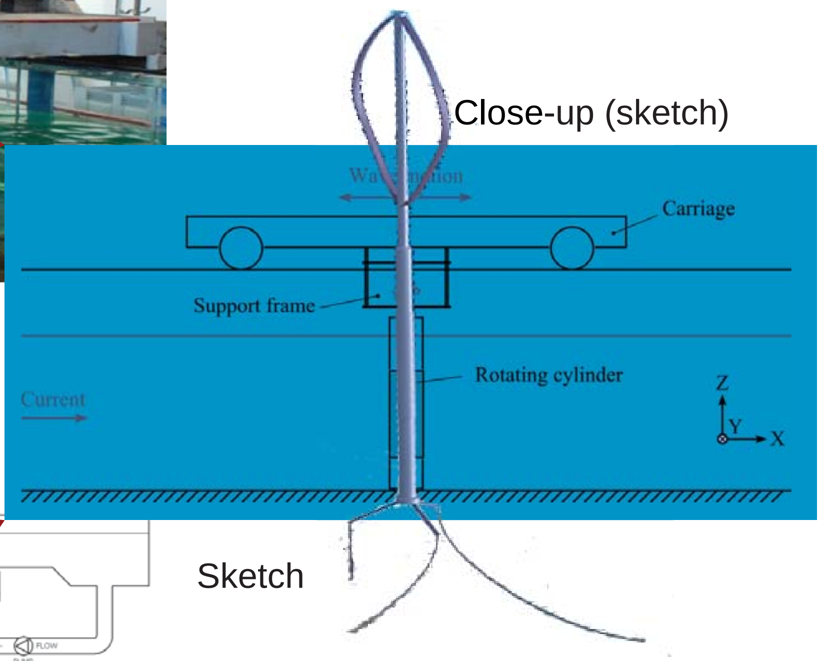

Sketch

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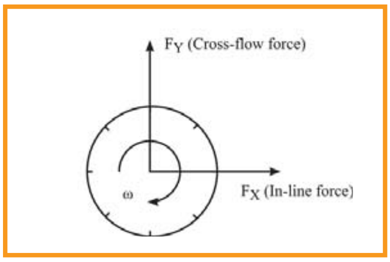
Results Physical Model Experiments Forces

(a) Morison formulation, waves and current:

$$F_X = \frac{1}{2}\rho C_D D U|U| + \rho C_m A \frac{dU}{dt} \qquad F_Y = 0$$

Sketch



(b) Cylinder rotating in steady current:

$$F_X = \frac{1}{2}\rho C_D D U|U| \qquad F_Y = \frac{1}{2}\rho C_L D U|U|$$

(c) Cylinder rotating in unsteady flow (Ideal Fluid):

$$F_X = \rho C_m A \frac{dU}{dt} \qquad F_Y = \rho \Gamma U = \rho 2 A \omega U = \rho C_\Gamma A \omega U$$

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Results Physical Model Experiments Oscillatory Lift Force

KC small: (1 < KC < 8)

$$F_Y = \rho C_\Gamma A\omega U + \rho C_{mY} A\frac{dU}{dt}$$

$$KC = \frac{2\pi a}{D} = \frac{U_m T}{D}$$

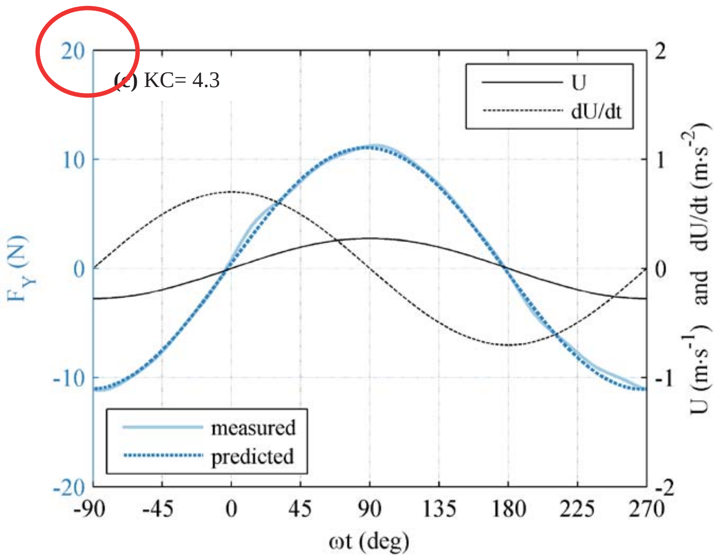
$$Re = \frac{aU_m}{\nu} = \frac{TU_m^2}{2\pi\nu}$$

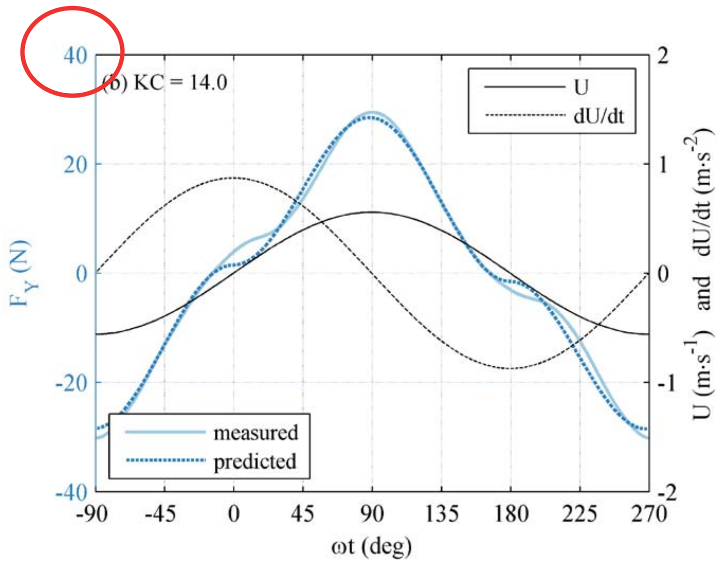
$$T \cong C\sqrt{\frac{H}{g}} = C\sqrt{2ae^{-2\pi z/L}}$$

KC large: (12 < KC < 24)

$$F_Y = \frac{1}{2}\rho C_L DU|U| + \rho C_{mY} A\frac{dU}{dt}$$

Carstensen et al *Lift of a Rotating Circular Cylinder in Unsteady Flows ISOPE june2012*





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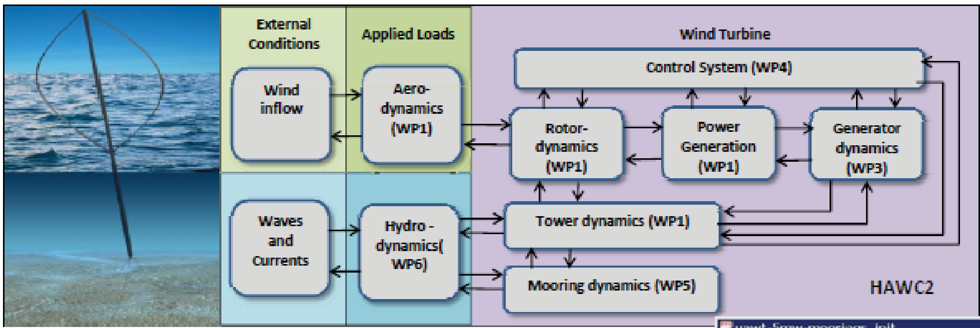
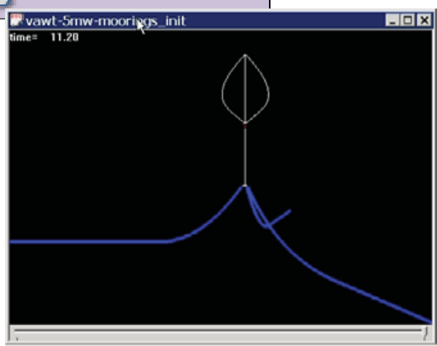
Results 2nd Design Assumptions



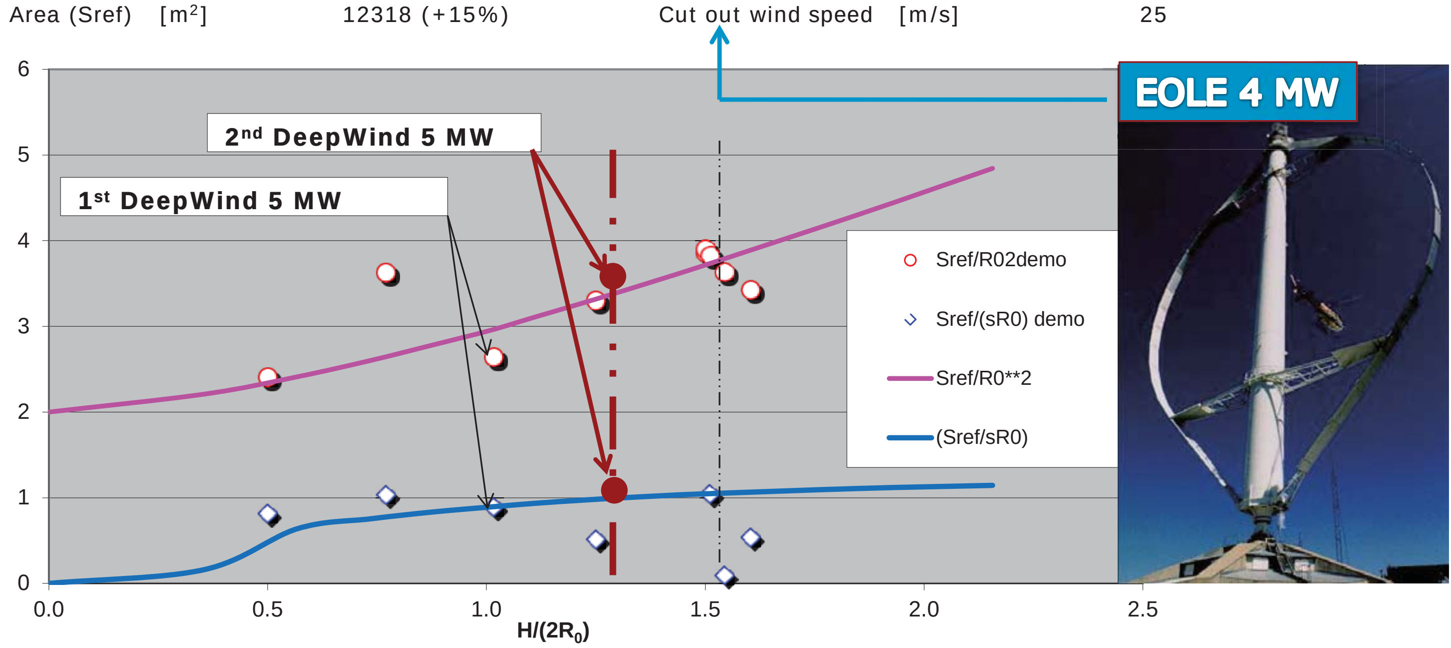


- ✓ Actuator cylinder model*
- ✓ Dynamic stall
- ✓ Atmospheric turbulence
- ✓ Evaluation of loads 6 DOF
- ✓ Mooring system

*Madsen HA, Larsen T, Paulsen US *Adoption of the aeroelastic code HAWC2 for vertical axis turbines using the actuator cylinder flow model* 51st AIAA conference Dallas Texas(USA) Jan 2013

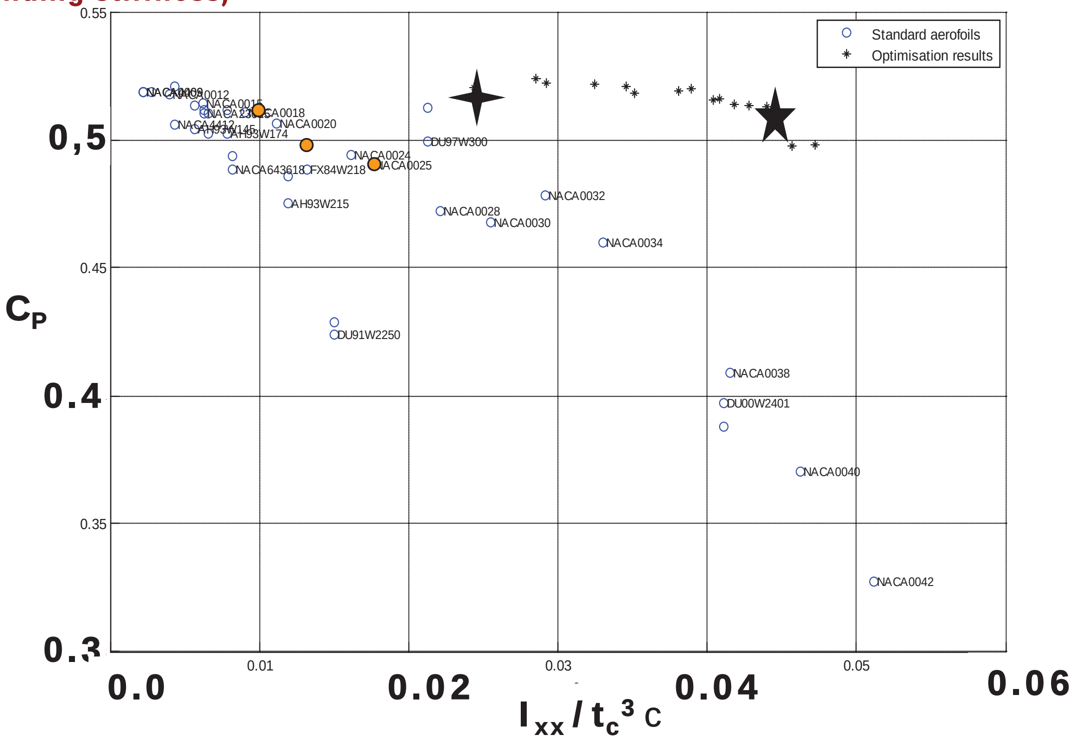
DeepWind
Results 2 nd iteration 5 MW Design Rotor

Geometry			Performance		
Rotor radius (R0)	[m]	58.5 (-8%)	Rated power	[kW]	6200 (+24%)
Rotor Height (H)	[m]	143 (+10.4%)	Rated rotational speed	[rpm]	5.63 (+ 7%)
H/(2R0)	[-]	1.222 (+22%)	Rated wind speed	[m/s]	14
Solidity (σ =Nc/R0)	[-]	0.15 (-33%)	Cut in wind speed	[m/s]	5
Swept Area (Sref)	[m²]	12318 (+15%)	Cut out wind speed	[m/s]	25



Results C_P vs dimensionless flapwise Inertia

(bending stiffness)



©DeepWind,TUDelft

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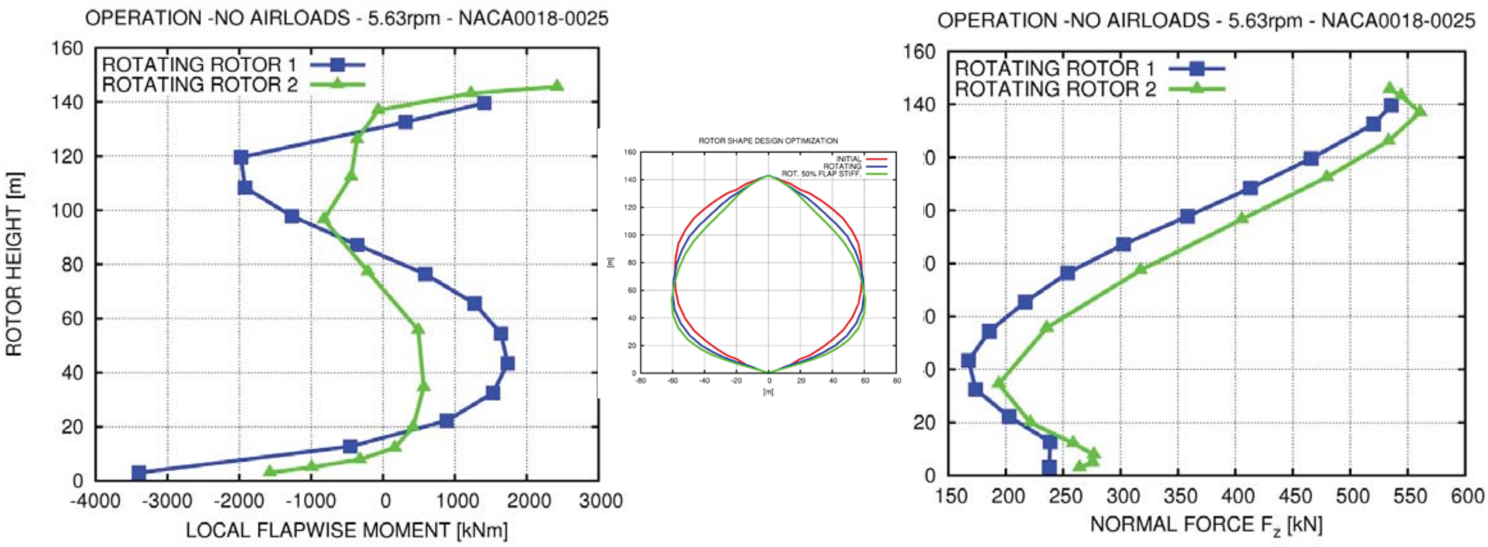
Results case-2+ 1iteration



- Uwe Schmidt Paulsen, Helge Aagård Madsen ,Ismet Baran, Per Nielsen, Jesper Hattel *Design Optimization of a 5 MW Floating Offshore Vertical Axis Wind Turbine* presented at the Deep Sea Offshore Conference Trondheim (NO) 2013

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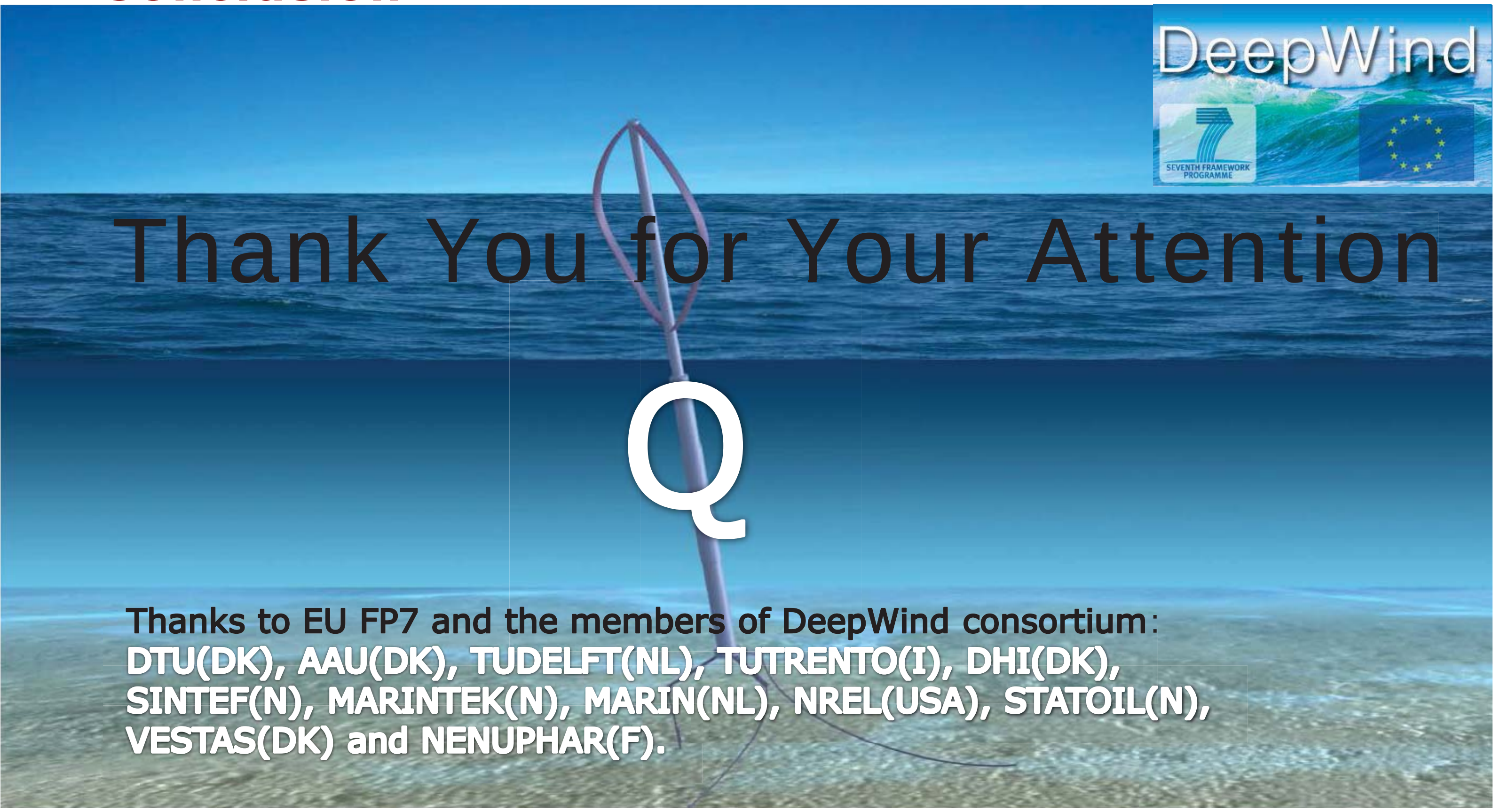
Conclusion

- ✓ Established a full design tool and verification code integrating VAWT concept
- ✓ Established a full model for blade pultrusion and preparation of advanced thick airfoils of laminar flow family with smaller CD_0 and good C_P
- ✓ Design tool for PMG subsea generators; 1st design of a 5 MW generator
- ✓ Design tool and verification tool for VAWT controls
- ✓ 1st Floater for 5 MW design
- ✓ Verified Fluid dynamics for rotating cylinders
- ✓ Iteration from a 1st 5 MW floating concept to a 2nd iteration towards a light weight 5MW rotor with low bending moment

- Continuation of iterations for improved design and for Cost analysis
- 1st campaign of Demonstrator tests conducted
- Next tests to be carried out in Ocean lab

Conclusion


DeepWind
SEVENTH FRAMEWORK PROGRAMME
Thank You for Your Attention
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