1st DeepWind 5 MW baseline design

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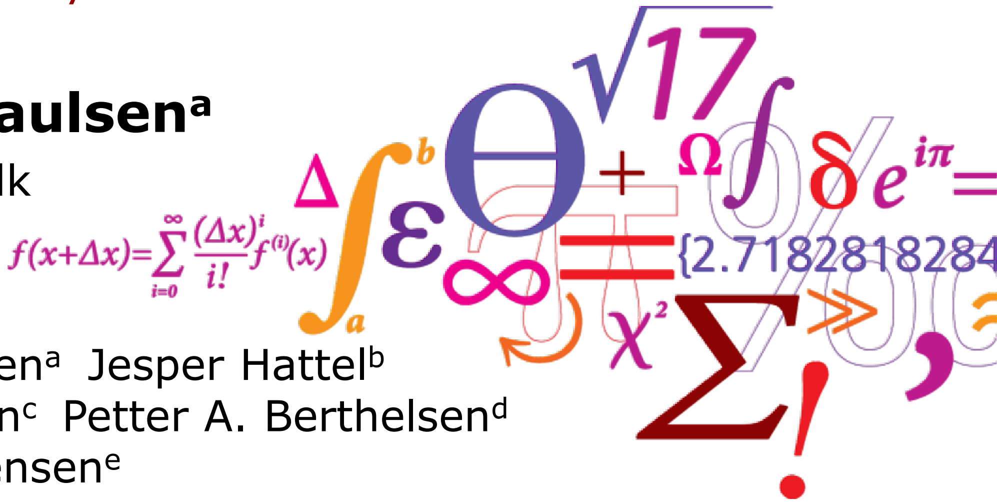

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Agenda

- Introduction
- Rotor and Blades Design
- Floating Platform
- Subsea Generator technology
- Design evaluation
- Conclusions

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- **Introduction**
  - **Design Constraints**
  - **Environmental Loads**
  - **1st Design Assumptions**
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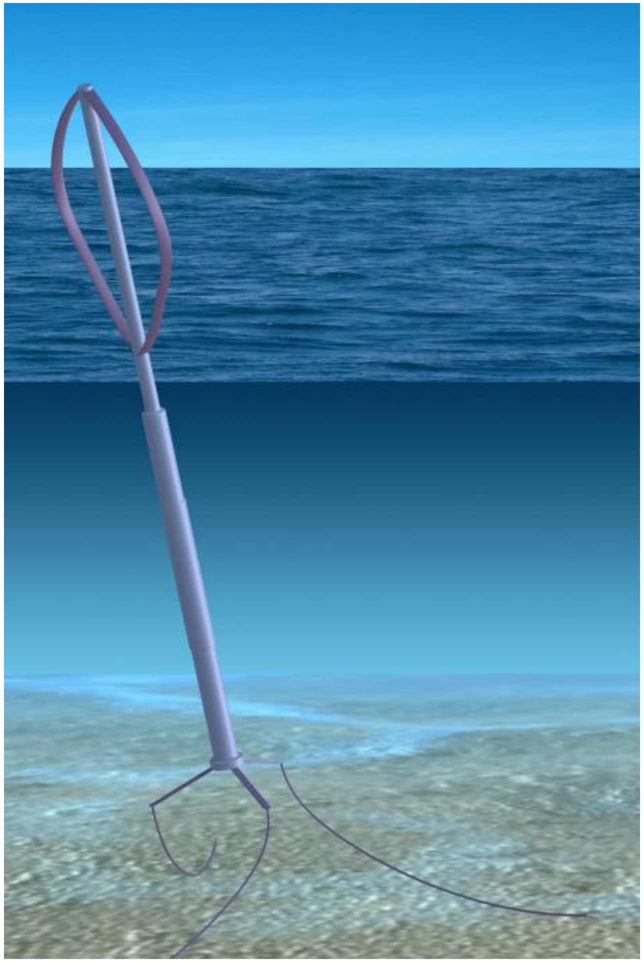
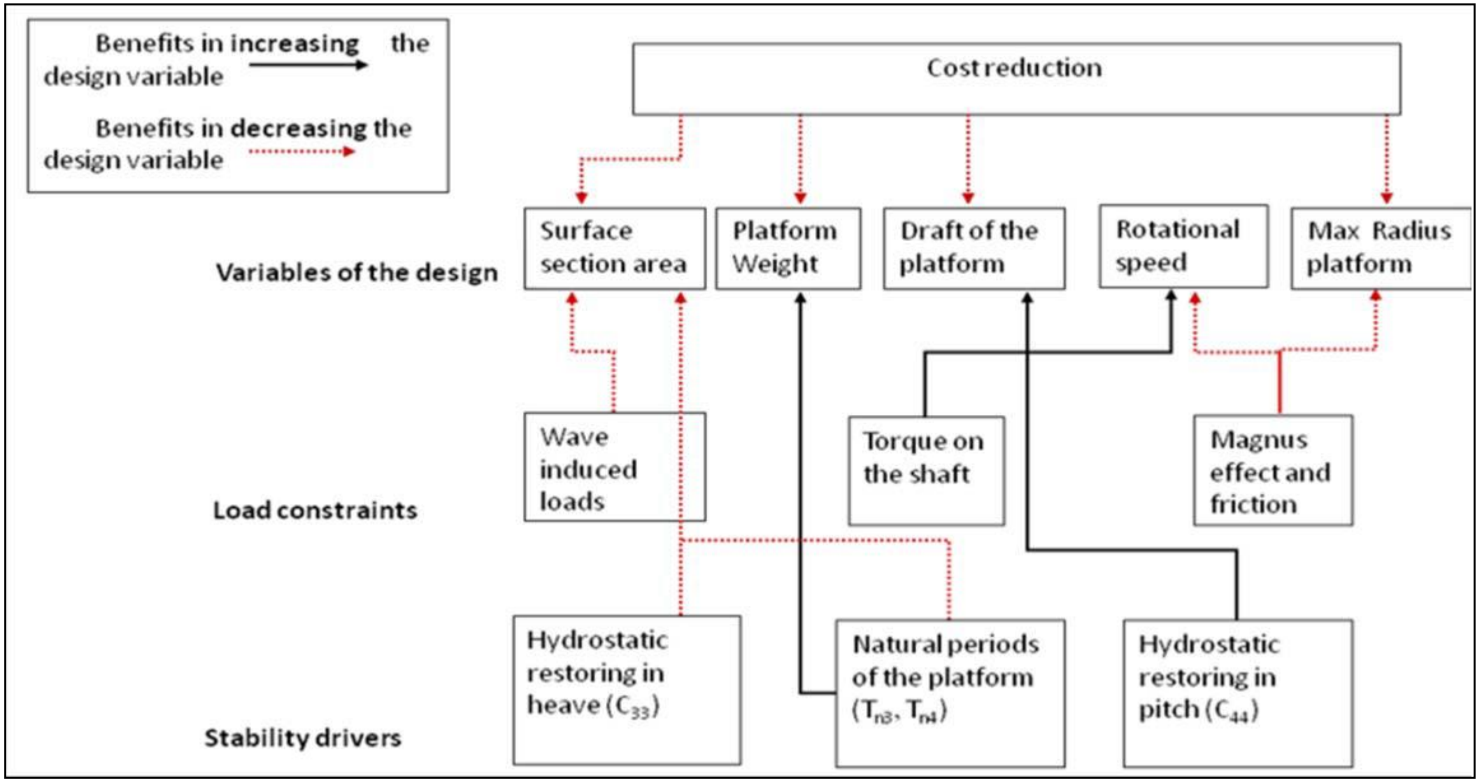
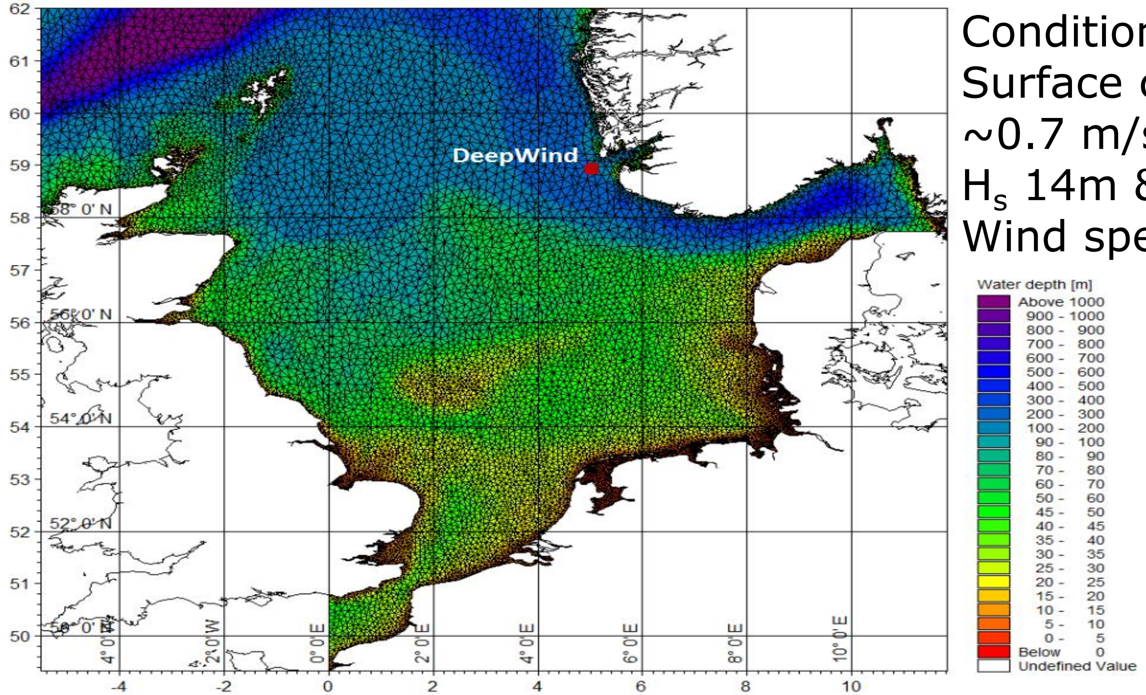


Design Constraints



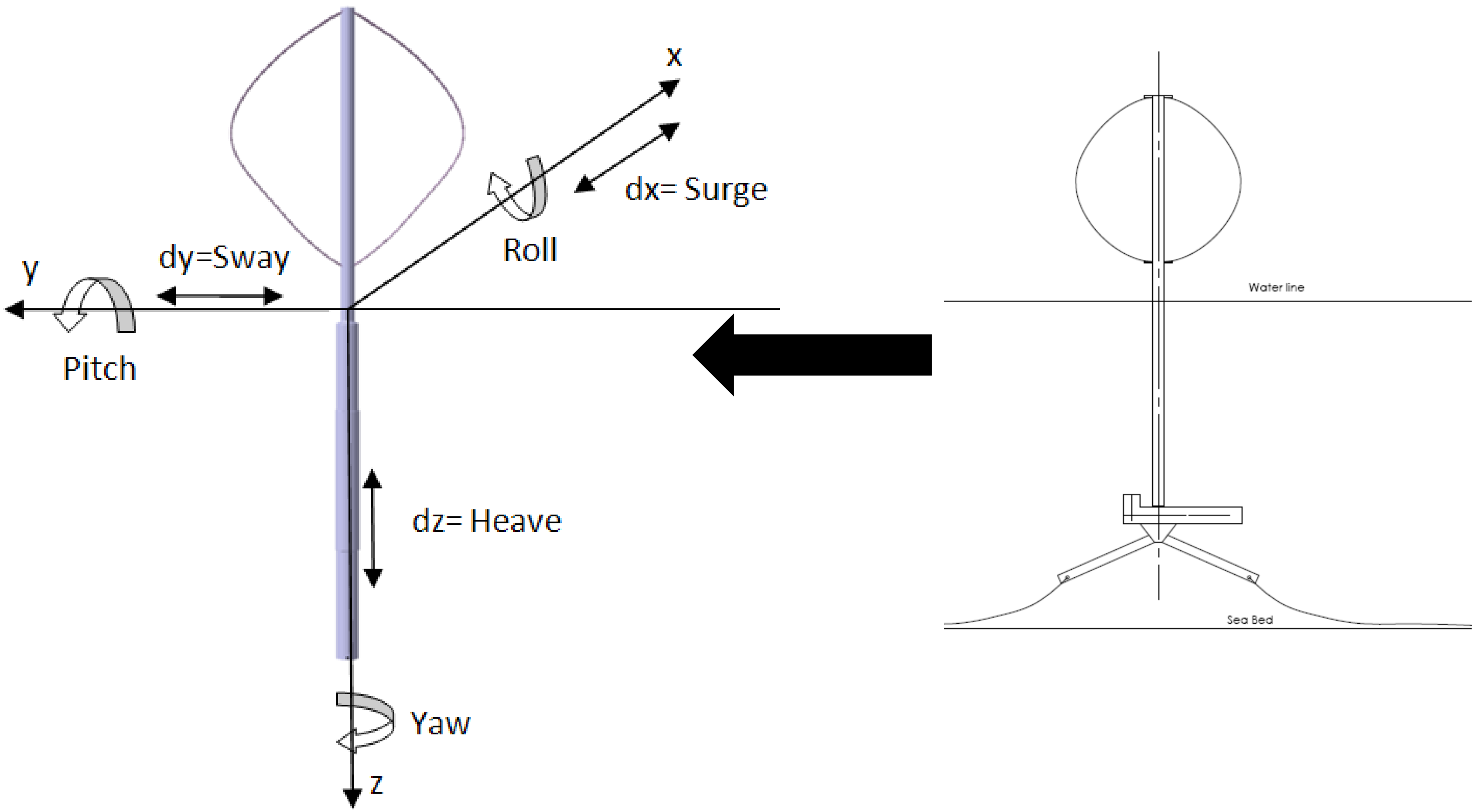
Environmental Conditions Loads

- Current Force	Magnus force
- Wave Loads	Morrison formulation
- Wind Loads	Wind shear
- 3 sea states define the environment at Hywind site
- Evaluation of loads



Conditions as per NORSOK:
Surface current(Wind and Waves): ~0.7 m/s
H_s 14m & T_P 16s {3h|Prob ~10^{-2}}
Wind speed <25 m/s

1st Design Assumptions



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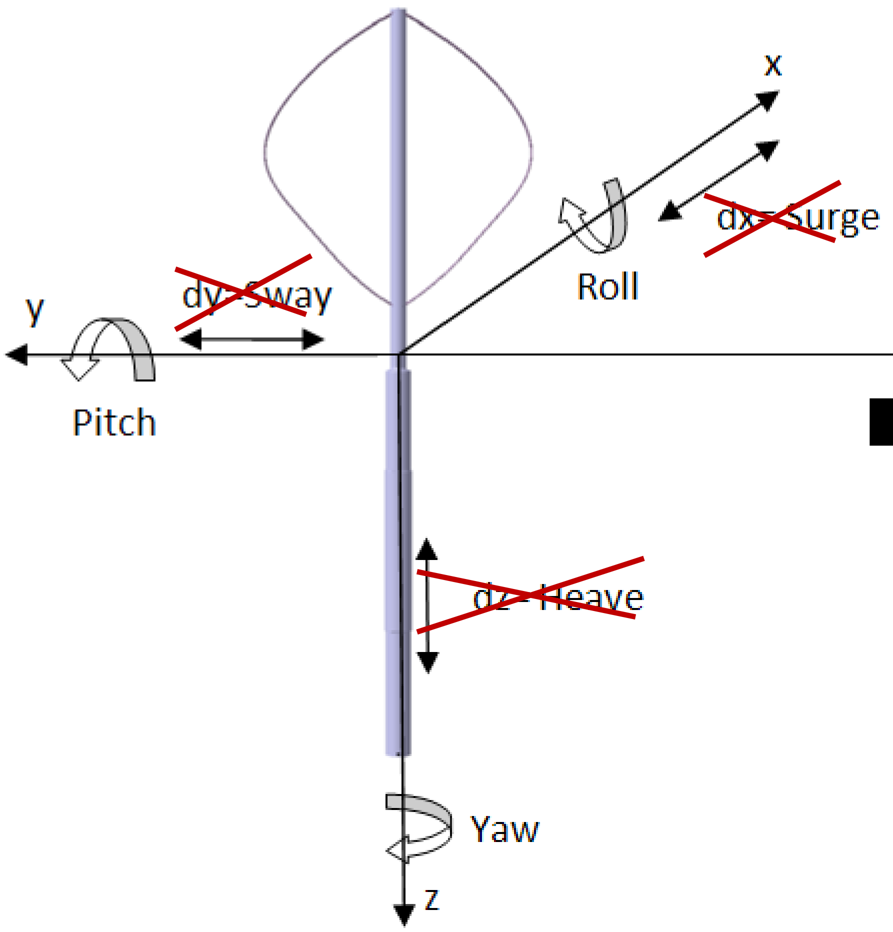

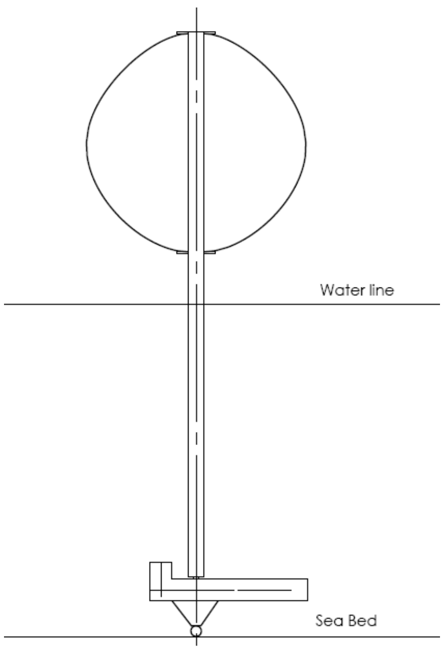

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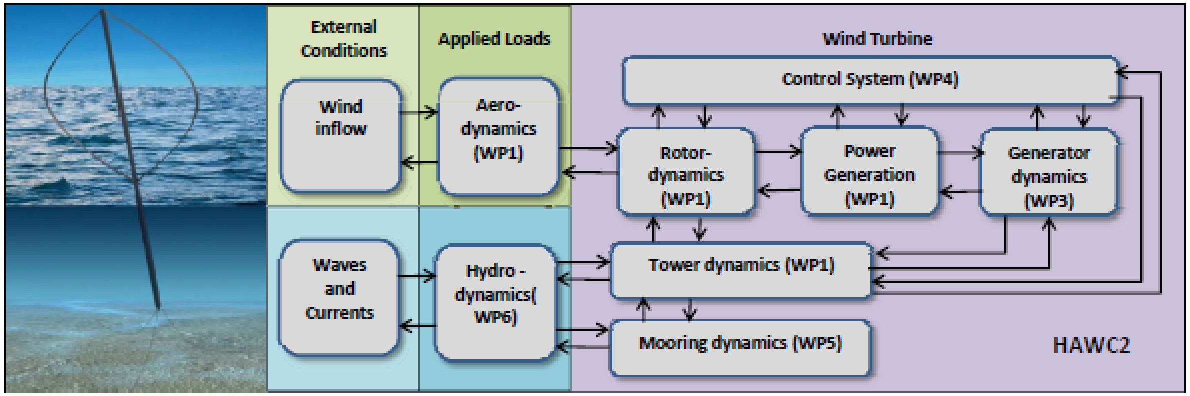

- Dynamic stall neglected
- Atmospheric turbulence not considered
- Evaluation of loads with 3 DOF
- No mooring

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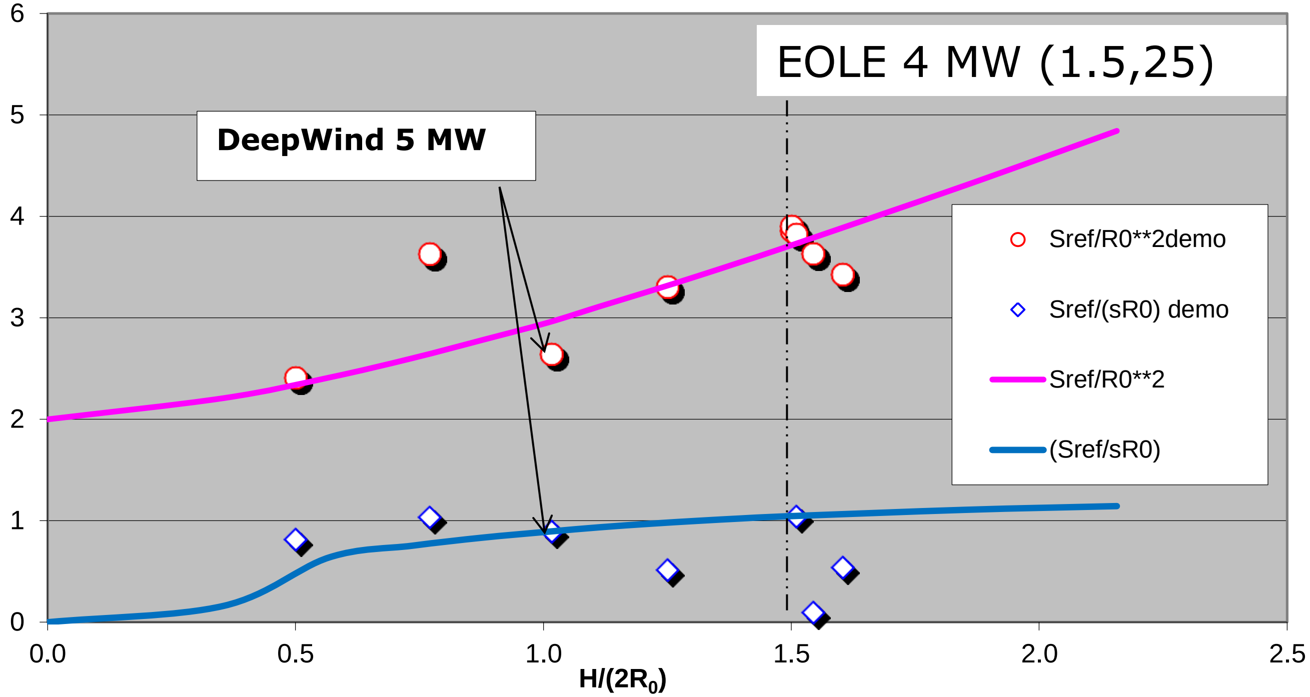
Rotor Design

Geometry

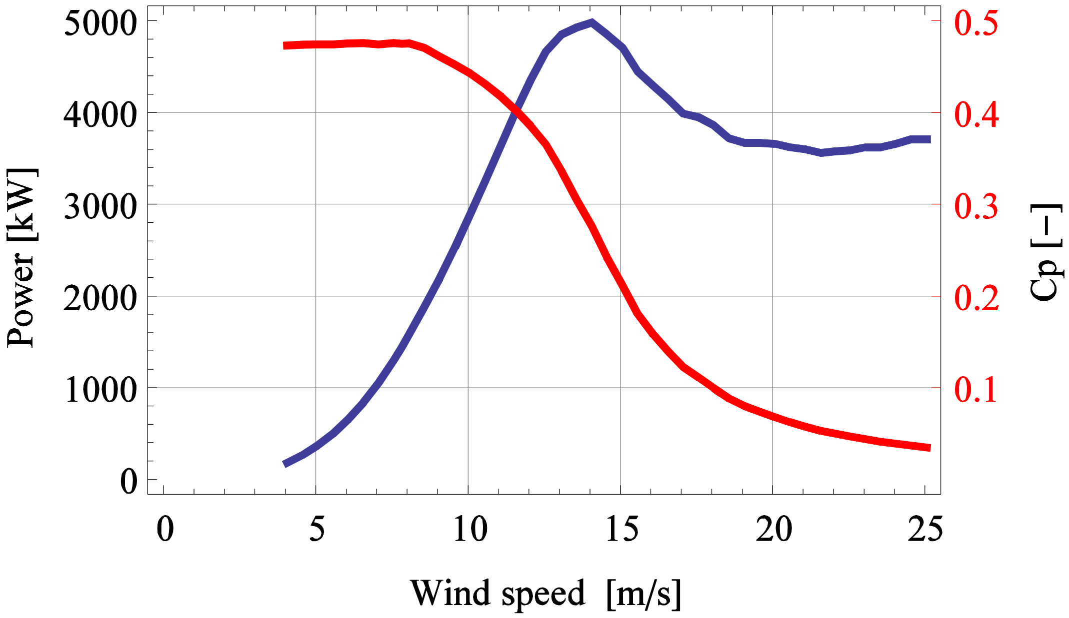
Rotor radius (R_0)	[m]	63.74
$H/(2R_0)$	[-]	1.016
Solidity ($\sigma = Nc/R_0$)	[-]	0.23
Swept Area	[m²]	10743



Rotor and Blades Design

Rotor Design

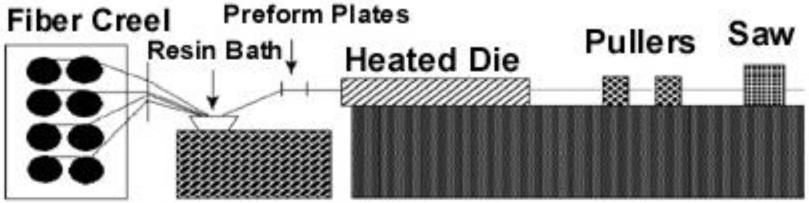
Performance		
Rated power	**[kW]**	**5000**
Rated rotational speed	**[rpm]**	**5.26**
Rated wind speed	**[m/s]**	**14**
Cut in wind speed	**[m/s]**	**5**
Cut out wind speed	**[m/s]**	**25**



Rotor and Blades Design

Blade Design

Pultrusion:

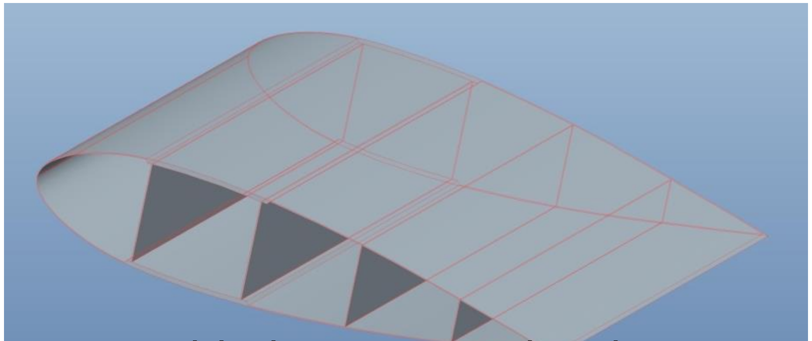


Constant chord over length

Low manufacturing cost +

Structural strength for thin profiles -

.:. Structural stiffeners to improve strength in blade cross section

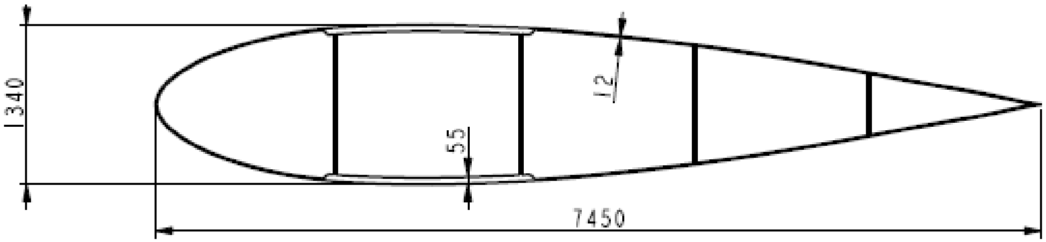

5 MW blade section, chord 7.45 m

Rotor shape:

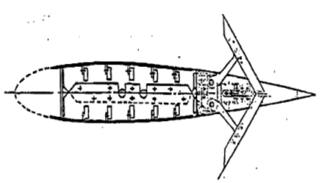
Gravity and centrifugal loads are important for VAWT rotor blade shape design
Pultrusion for Troposkien design over/under dimension the blade at different sections along the blade path
Present design not fully shape optimized due to less rigidity at low blade weight
Change of loads for taking into account for gravity over centrifugal loading

Rotor and Blades Design

Blade Design



DeepWind 5 MW 1st design, 7.45 m chord
All GRP



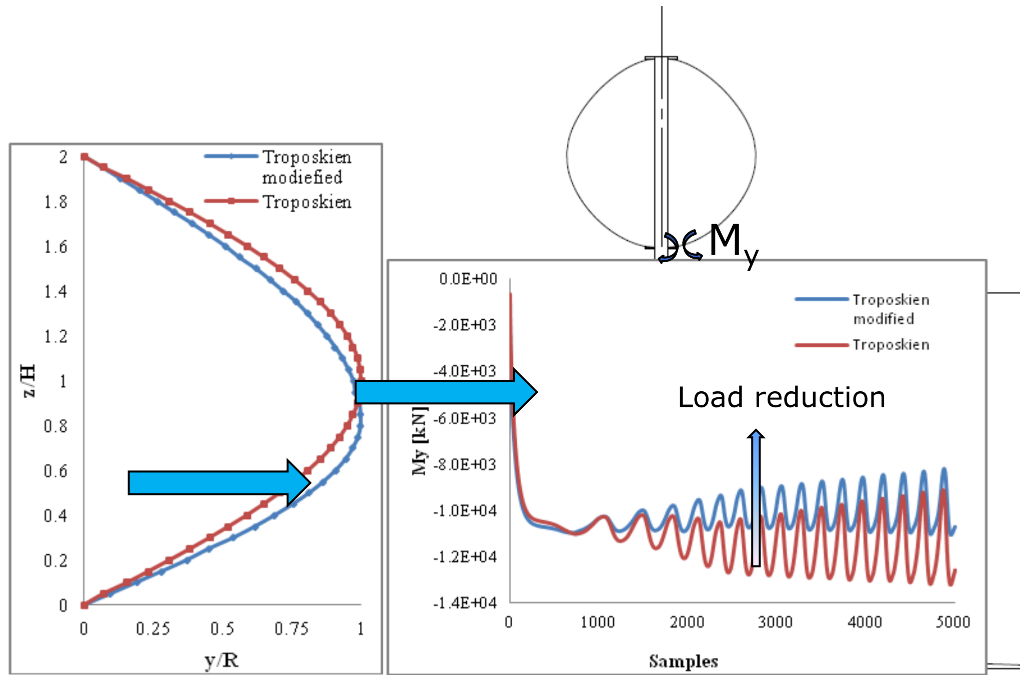
EOLE 4MW , 2.4 m chord
GRP and Steel

Rotor and Blades Design

Blade Design

Blade length: 189m
Blade weight: 154tons
Blade thickness: 18%

Rotor blade loads prediction:
taking high gravity load into account



Next design iteration:

.:. Change to slightly increased rpm results in a lighter rotor
.:. Sectionalize into blade with different thickness and chord lengths

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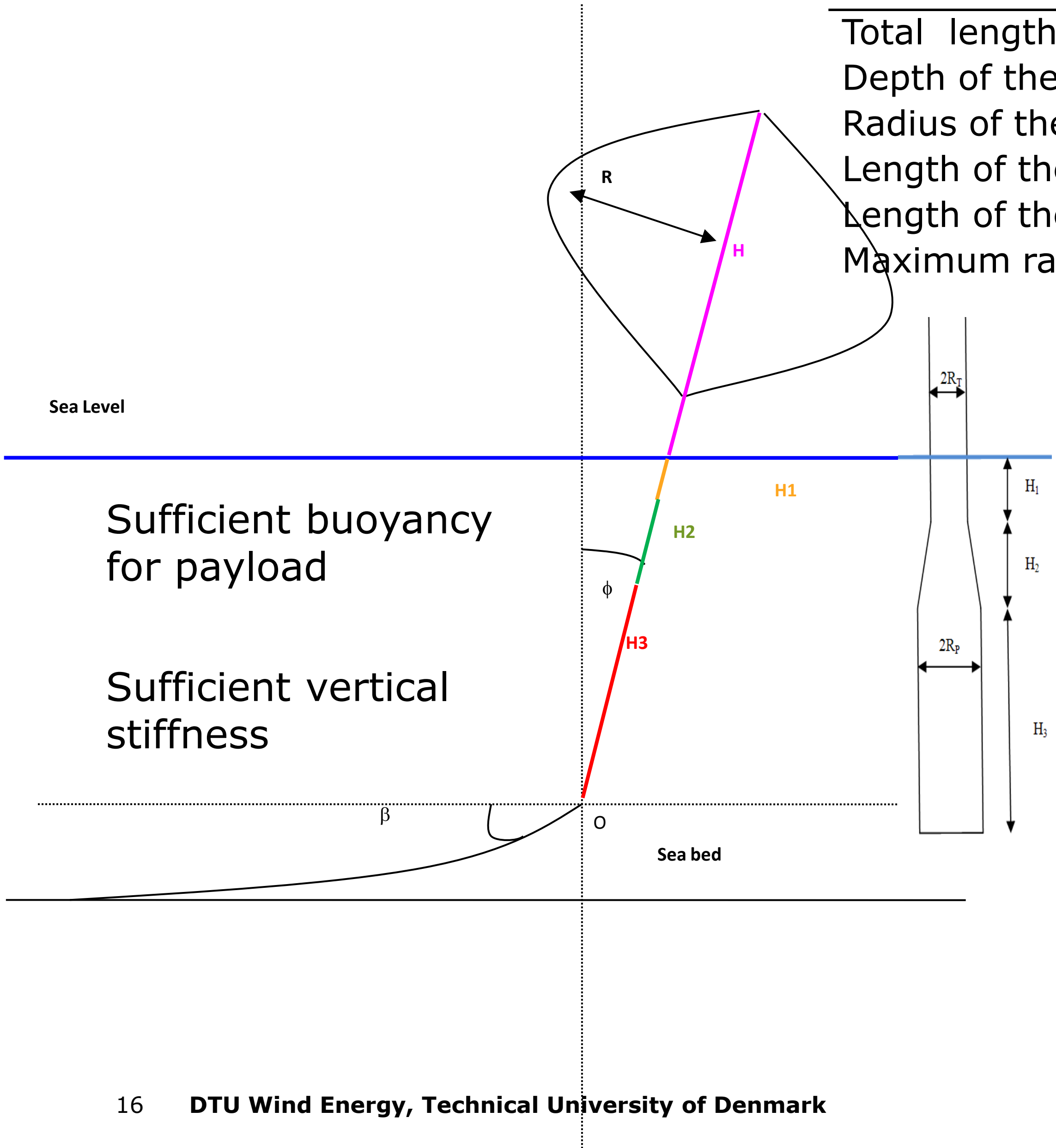
Floating Platform

Total length ($H_P=H_1+H_2+H_3$)	[m]	108
Depth of the slender part (H_1)	[m]	5
Radius of the slender part (R_T)	[m]	3.15
Length of the tapered part (H_2)	[m]	10
Length of the bottom part (H_3)	[m]	93
Maximum radius of the platform (R_P)	[m]	4.15



Sufficient buoyancy for payload

Sufficient vertical stiffness

6-DOF

$T_{heave}, T_{pitch}, T_{roll} > T_{wave}$ (5-25 s)

Sufficient stiffness in roll and pitch
Acceleration should be limited

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  - **Generator state of the art**
  - **Design approach**
  - **First iteration dimensions of 5 MW direct drive generator**
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Generator state of the art

- possible solutions
  - SCIG - Squirrel Cage Induction Generator (Radial Flux RF)
  - DFIG – Doubly Fed Induction Generator(Radial Flux RF)
  - EESG - Electrically Excited Synchronous Generator (Radial Flux RF)
  - PMSG - PM Synchronous Generator(Radial Flux RF)
  - TFPM - Transverse Flux PM Generator
  - AFPM – Axial Flux PM Generator
- Advantages and disadvantages of candidates were investigated

- SWOT analysis was performed to filter the list down to:
  - ❑Synchronous PM (radial flux)
  - ❑Synchronous Electrically excited (radial flux)
  - ❑Transverse flux PM

Subsea Generator technology

Generator state of the art

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Subsea Generator technology

DeepWind Generator design approach

- Design algorithms for the machines was implemented in code language
  - Usual design rules for power station generators were applied(also subsea environment)
  - Output from design approach:
    - » Dimensions of generator
    - » Mass of active and inactive materials
    - » Losses
- For given output, the $R_P \sim RPM^{-1}$
- For lower RPM, number of poles increases, so the leakage field (thereby decreasing efficiency). This effect will be minimized by optimization measures of the magnetic field.
- Though cooling conditions are unknown, thermal effects for each candidate are simulated for design rules.
- Power electronic converter features multi kilovolt connection
- Control of shaft speed for control of power flow

Subsea Generator technology

First Iteration Dimension for 5 MW Direct Drive Generator

- 5 MW mechanical power at estimated 5.26 rpm and 9.1 MNm shaft torque render a 400 pole 17.53 Hz transverse flux generator 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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Design evaluation

- Design of floating turbine and platform system evaluated with HAWC2
  - Combinations of different direction of waves and currents with respect to wind direction for analysis of loads

- Main results:
  - Platform stability shows that the large inertia of the rotor affects the pitch and the roll mode towards a large natural period
  - Rotor inclination less than 12º in combinations of wave and currents relative to wind direction and inclination less than 6º in still water
  - The tower section at sea water level displaces for the most critical situation about 2 tube diameters both along and perpendicular to wind direction, for still water 1.7 and 0.1 tube diameters, respectively
  - Maximum loads calculated occur at the larger values of the wave height (most critical sea state). SF of 2
  - Mean loads are depending on currents direction. SF of 4.

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Conclusions

- A first iteration design of the 5 MW DeepWind baseline design for Darrieus type floating wind turbine
- Water depths of minimum 150 m is needed to operate the turbine
- The design specifications are circulated amongst the partners of the DeepWind consortium for further iteration in the work packages and for referencing improvements on sub-components level against the baseline design
- Results from the evaluation show that design space issues are still open for improvements

Next steps in DeepWind project

- To carry out next iterations with reference to baseline design
- To integrate results in the code
  - model testing of currents and wave loads on a rotating cylinder
  - Turbulence effects
  - Dynamic stall
  - Mooring
- To establish a 1 kW demo turbine to be launched in Roskilde fjord by March 2012
- To conduct testing
- To show the turbine/videos during the EWEC 2012 CPH conference

Thanks to
DeepWind consortium
EU

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