Experimental study of the DTU 10 MW wind turbine on a TLP floater in waves and wind

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Experimental study of the DTU 10 MW wind turbine on a TLP floater in waves and wind

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Part of the INNWIND.EU project

DTU Wind Energy
Department of Wind Energy
Preliminary results
Extreme environment

Setup and validation
Floater design

Scaling principles
Aerodynamic design
Scaling principles for floating wind turbine tests I

Define a length scale ratio

\[ \lambda = \frac{L_p}{L_m} \]

Gravity is dominant!
Ratio of force to gravity is preserved

\[ \frac{M_p a_p}{M_p g} = \frac{M_m a_m}{M_m g} \quad \Rightarrow \quad a_p = a_m \]

Hereby time scale ratio is locked:

\[ \frac{T_p}{T_m} = \sqrt{\lambda} \quad \Leftarrow \quad \frac{L_p}{T_p^2} = \frac{L_m}{T_m^2} \]

Preserve ratio of structural and fluid mass

\[ \frac{M_p}{\rho_{wp} \text{Vol}_p} = \frac{M_m}{\rho_{wm} \text{Vol}_m} \quad \Rightarrow \quad \frac{M_p}{M_m} = \frac{\rho_{wp}}{\rho_{wm}} \lambda^3 \]

Classical Froude scaling of mass, length and time. Well known for wave tank tests.
Scaling of rotor properties

Froude scaling of hydrodynamics: \[ \lambda = \frac{L_p}{L_m} \]
\[ \frac{T_p}{T_m} = \sqrt{\lambda} \]
\[ \frac{M_p}{M_m} = \frac{\rho_w p}{\rho_{wm}} \chi^3 \]

Keep overall geometry

Keep consistent scaling of rotational frequency

Preserve tip speed ratio

\[ R_{\text{rotor},m} = R_{\text{rotor},p} / \lambda \]
\[ \omega_m = \omega_p / \sqrt{\lambda} \]
\[ \frac{\text{TSR}_p}{\text{TSR}_m} = \frac{\omega_p R_p}{\omega_m R_m} = 1 \]
\[ \Rightarrow \quad u_{a,m} = u_{a,p} / \sqrt{\lambda} \]

Thrust force and thrust coefficient

\[ F_T = \rho_a C_T A u_a^2 \sim \rho_w \chi^3 \]
\[ \Rightarrow \quad \frac{C_{T_p}}{C_{T_m}} = \frac{\rho_{wp}}{\rho_{wm}} \]
Air velocities (model scale) $\sim 1.5 \text{ m/s}$

Re (proto scale) $\sim 10M$

Re (model scale): $\sim 25k$

Not likely to scale correctly!
Scaling principles

Air velocities (model scale) $\sim 1.5 \text{ m/s}$

Re (proto scale) $\sim 10M$

Re (model scale): $\sim 25k$

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Aerodynamic design
Aerodynamic design
Low-Re airfoils and 2D wind tunnel measurements

Figure 5: Applied airfoils for spanwise sections.

Figure 3: Measured airfoil characteristics for SD7003 at Reynolds number 30k, 40k, 50k, 60, 100k, 200k. Selig data applied for 100k and 200k.
Mold for blades

Figure 10 Model scale wind turbine blade (left) and negative mold (right)
Wind generator and hub

6 units, 4x4m, max speed of 1.7 m/s

rpm control, collective blade pitch
Scaling principles

Air velocities (model scale) ~ 1.5 m/s
Re (proto scale) ~ 10M
Re (model scale): ~ 25k

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Compact, cost efficient

TLP was chosen – Bachynski (2014) gives input on design considerations

Designed with static model and a WAMIT based dynamic model

Figure 2.4: Floater geometry loaded into WAMIT.
Environmental conditions

Johannesen et al (2002); Bachynski (2014)

Design requirements

- max tendon angle with vertical: 10 deg
- max tension: $1.8 \times T_0$
- min tension: $0.2 \times T_0$
The floater
Preliminary results

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Air velocities
(model scale) ~ 1.5 m/s
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Floater design
Wind field in rotor plane

(a) Mean wind speed.

(b) Turbulence intensity.
Rotor thrust

Figure 5.13: Thrust curves for the wind turbine model
Wave climates and RAOs

(a) Sea states 101 - 104
(b) Sea states 105 - 108

(a) Acceleration measured in nacelle and decaying amplitude of linear response.
(b) Power spectrum of acceleration signal.
Scaling principles

Air velocities
(model scale) \( \sim 1.5 \text{ m/s} \)
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Aerodynamic design

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Preliminary results

Regular, gentle waves
Preliminary results

Irregular waves close to rated wind speed with and without wind
Preliminary results

Irregular waves at close to rated wind speed

Figure 7.26: Tower acceleration - Seastate 5 - Wind
Preliminary results

Extreme environment

Scaling principles

Air velocities (model scale) $\sim 1.5 \, \text{m/s}$

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Aerodynamic design

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Response to extreme focused wave

Figure 7.37: Response of structure 1 to focused wave number 8 without wind (S1F08).
Preliminary results

Response to extreme focused wave
Tendon tension

Figure 7.38: Tendon tensions of structure 1 when subjected to focused wave number 8 without wind (S1F08).
Conclusions

Preliminary results
Extreme environment

- Focused waves
- Response in platform motion
- Spectral analysis

Preliminary results
Gentle environment

- Wind effects and rotor effects clearly detectable
- Damping effects and RAOs investigated

Setup and validation
Wind field measured in sweeps at 12 levels.
TI ~ 6%

Floater design
TLP Ø18m, height 25m, draft 37m

Static and dynamic design considerations

Scaling principles
Froude-scaling of water and global aerodynamic loads

Low Re leads to re-designed rotor with larger chord

Aerodynamic design

10 MW rotor scaled to 1:60.
Collective pitch and rpm control

2D wind tunnel test at Re down to 30k incorporated in design

Wind generator 4x4 meter max speed of 1.7 m/s
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