HAWC2
– offshore wind turbine simulations

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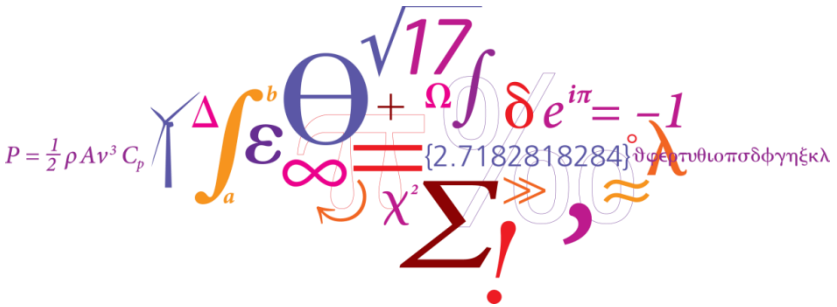
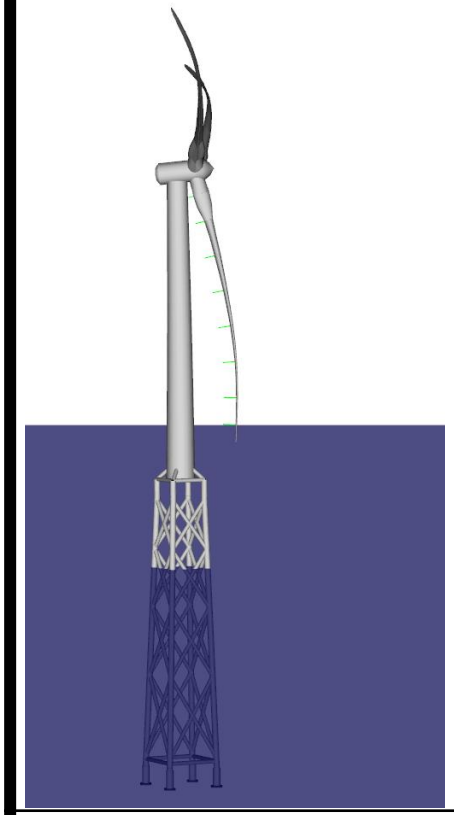
DTU Wind Energy
Department of Wind Energy



HAWC2 overview

Purpose: Enable accurate load simulations for research purposes
- However it should also be robust and suited for industrial application!

HAWC2 module overview



Envir.	Load	Structure	Externals
Wind and wakes	Rotor(s) Aerodynamics Aerodrag	Beams Bodies Substructures Constraints	Control Generator Servo Custom user
Water	Hydrodynamics Boyancy Ice Soil		Wamit coupling Dynamic mooring lines Superelement DOF reduction

Extras: (constraint) Turbulence, Visualization, Load setup and execution, Post processing

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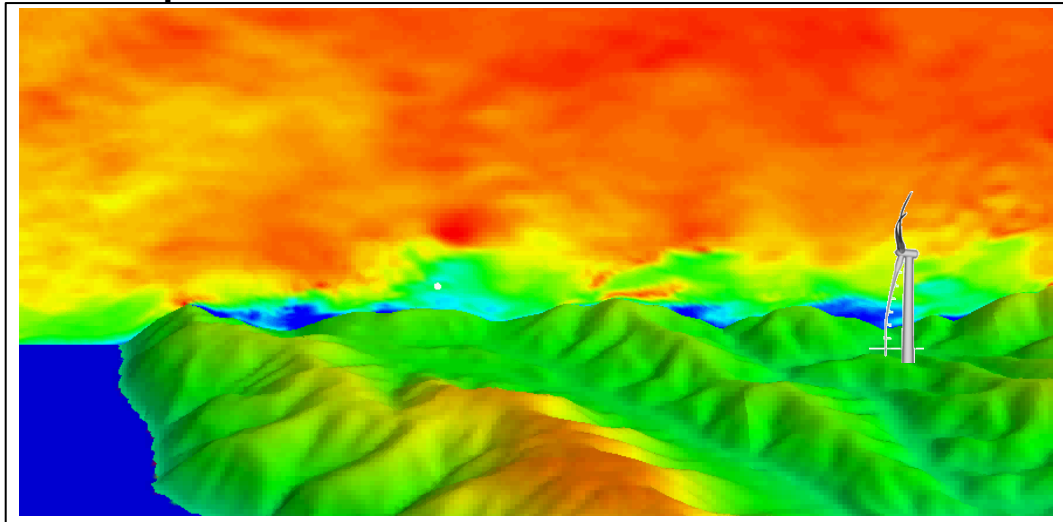
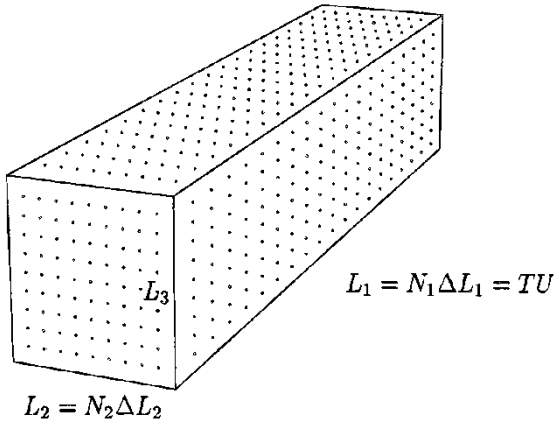
on!





Turbulence from
- Mann (default)
- Mann (w. boyancy)
- Veers

	Externals
ures	Control Generator Servo
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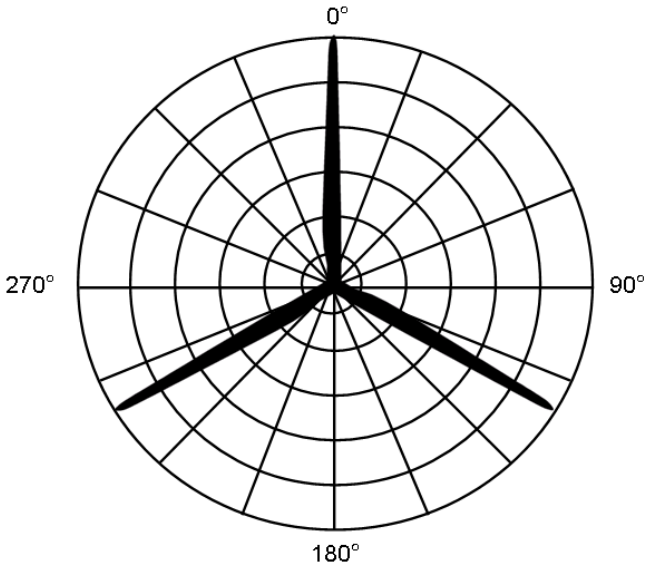

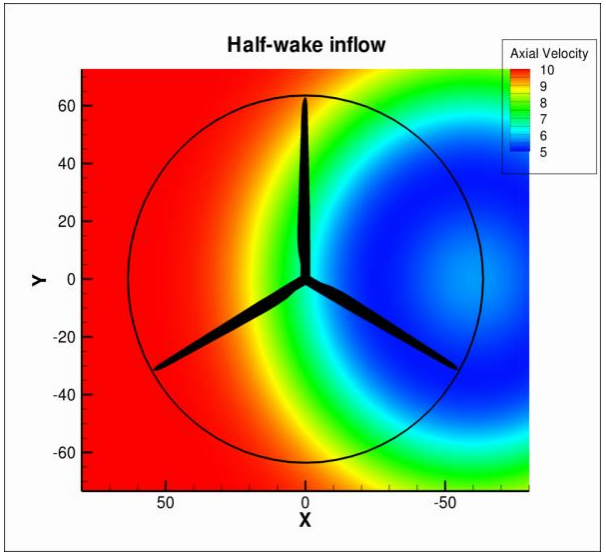

- **Azimuthally divided BEM with lowpass filtered induced velocities, yaw correction Beddoes-Leishman dyn. stall (default)**
- **Nearwake model**
- **HAWC2-Ellipsys, a special 3D CFD coupled version**

Extras: (constraint) Turbulence, Visualization, Load setup and execution, Post processing

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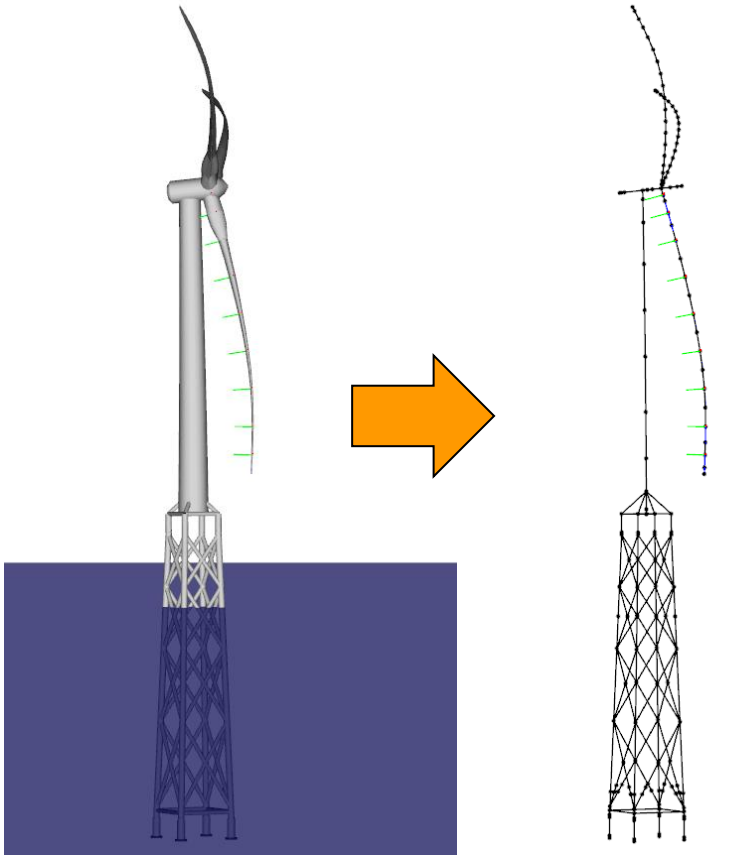

- **Structure discretized into nodes and elements**
- **Elements grouped into bodies**
- **Contraint equations couple bodies together**
- **Bodies grouped into substructures**

- **Substructures can be DOF reduced into superelements**
- **Superelements can be imported from ANSYS (new feature)**

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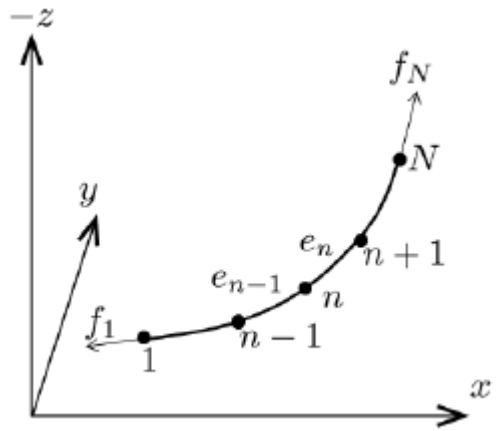
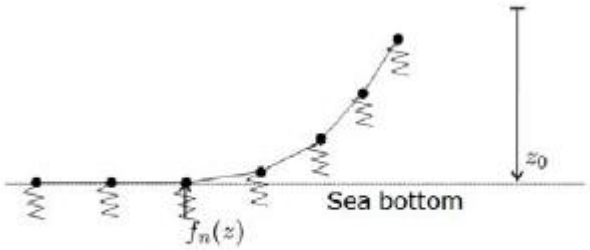
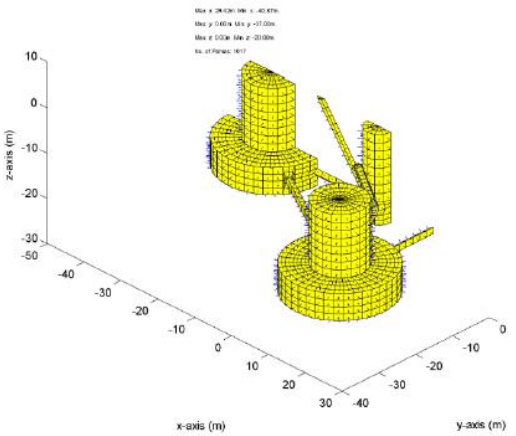
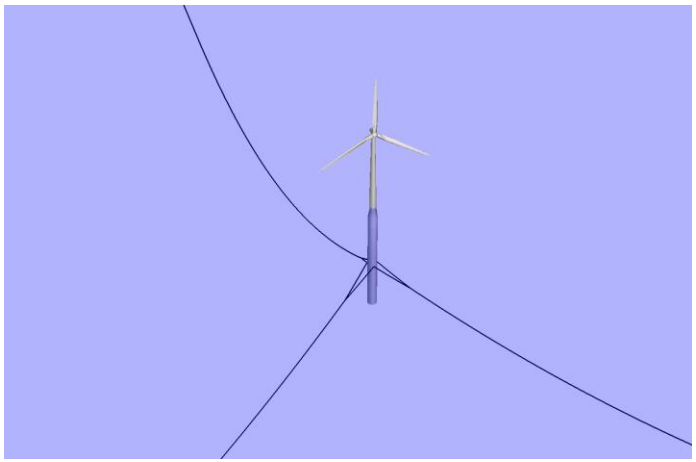




$$f_n(z) = \begin{cases} 0 & \text{if } z < z_0 \\ K\left((z-z_0)^2 + (z-z_0)\right) & \text{if } z \geq z_0 \end{cases}$$

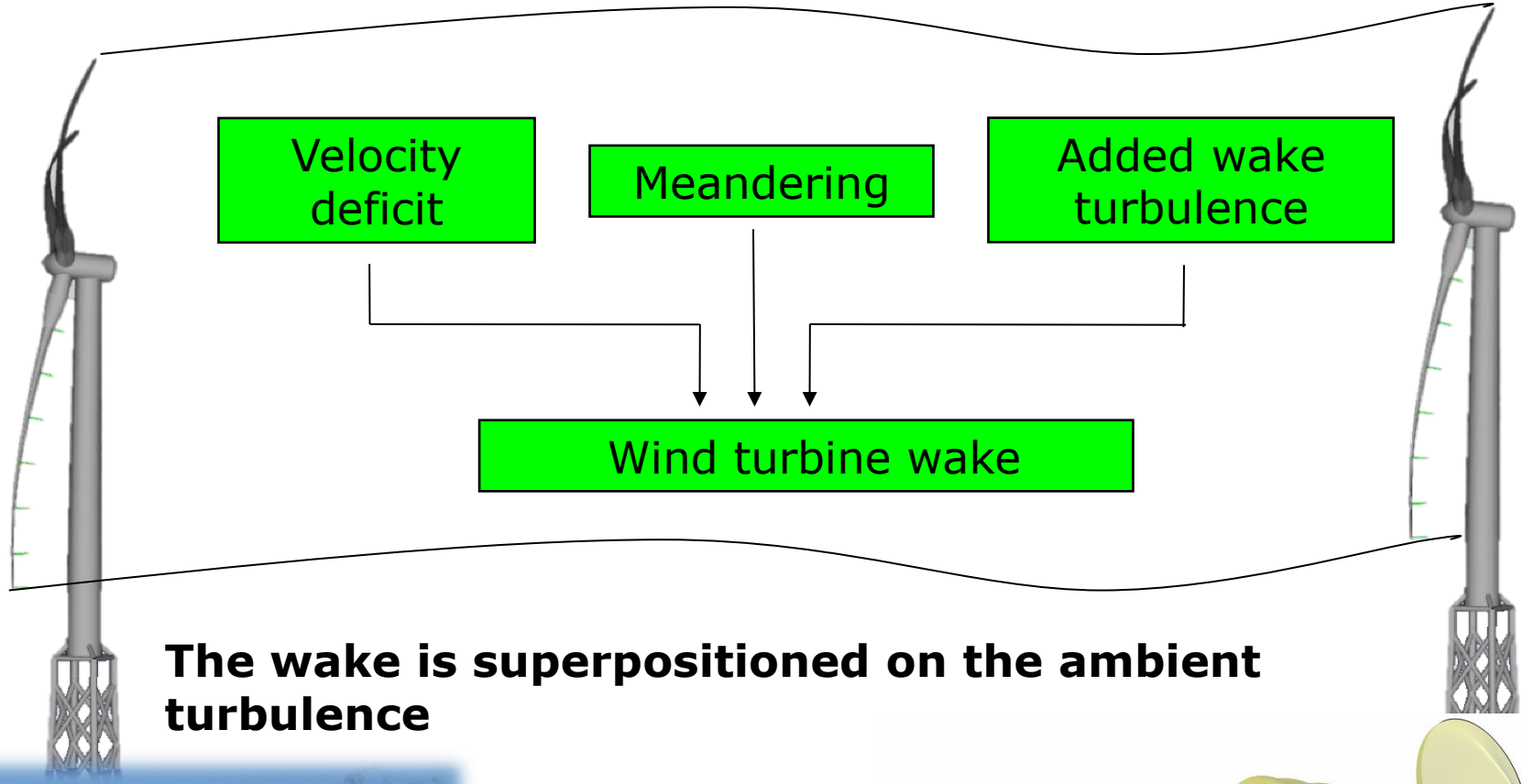




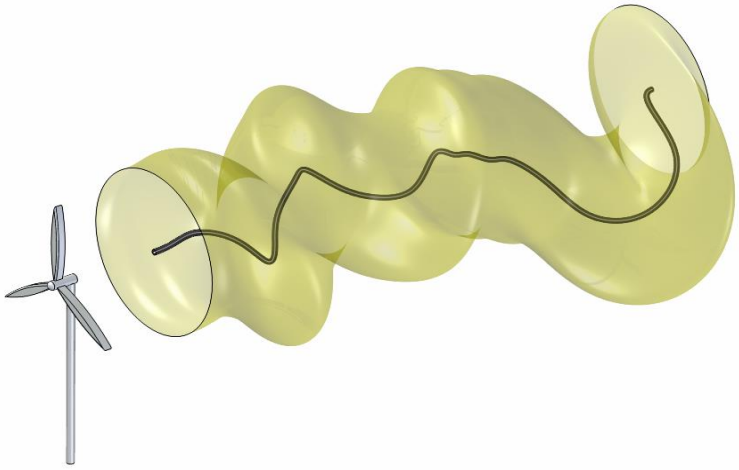
What about wake effects?

- Influence on both loads and production

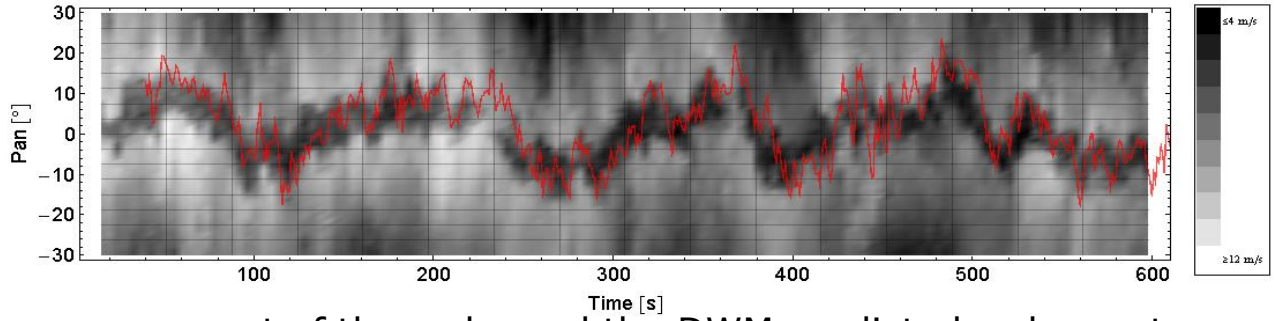
Principle of Dynamic Wake Meandering



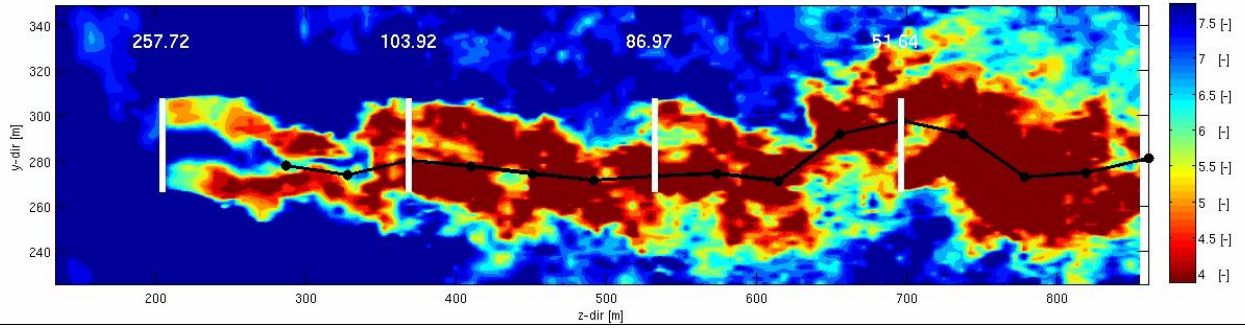
The wake is superpositioned on the ambient turbulence



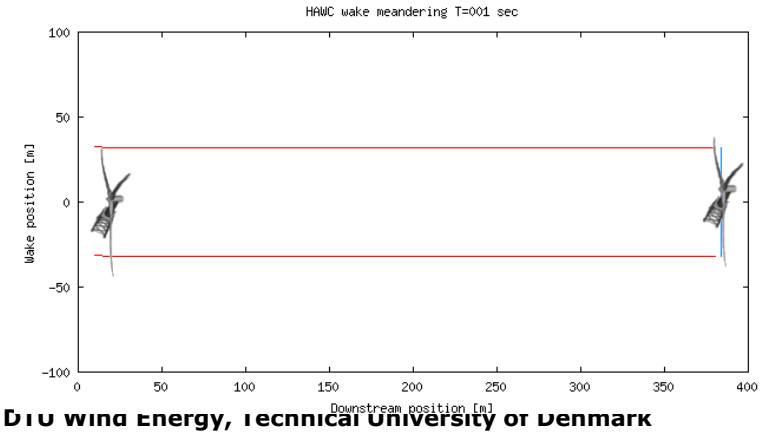
Wake modelling – important for loads and power

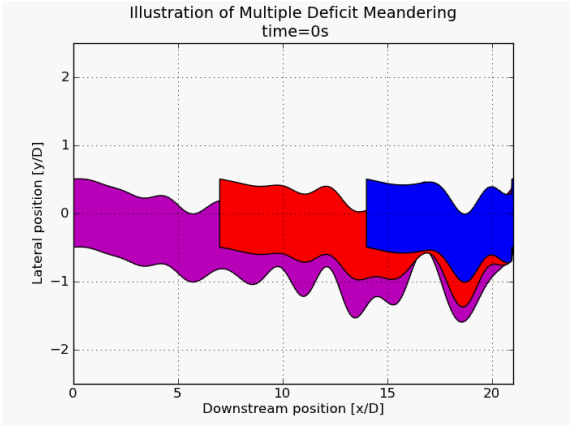


Lidar measurement of the wake and the DWM predicted wake center position



LES CFD

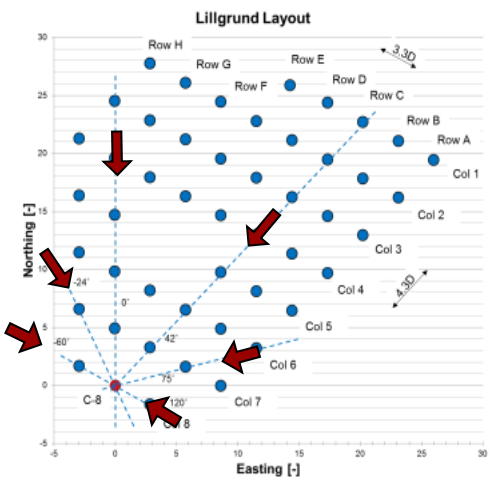




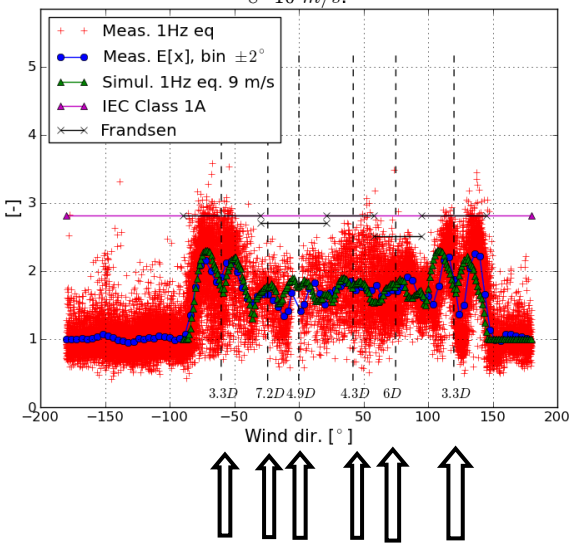
DWM

Results from Lillgrund

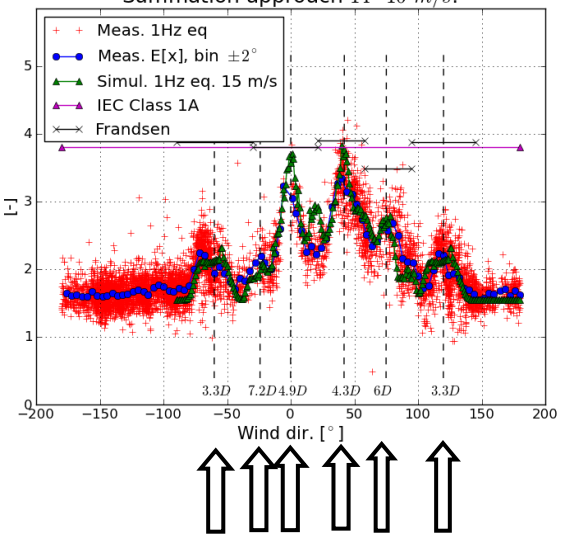
3-7D spacing, single and multiple wake situations



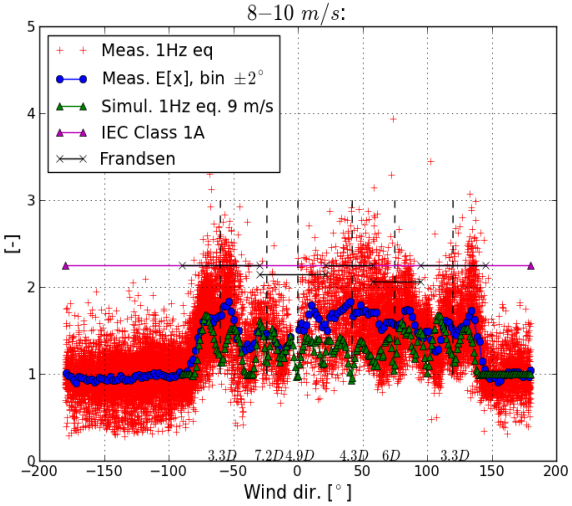
Lillgrund measurement blade root flap m=10
$8-10\ m/s$:



Lillgrund measurement blade root flap m=10
Summation approach $14-16\ m/s$:



Lillgrund measurement tower bend. m=5
$8-10\ m/s$:



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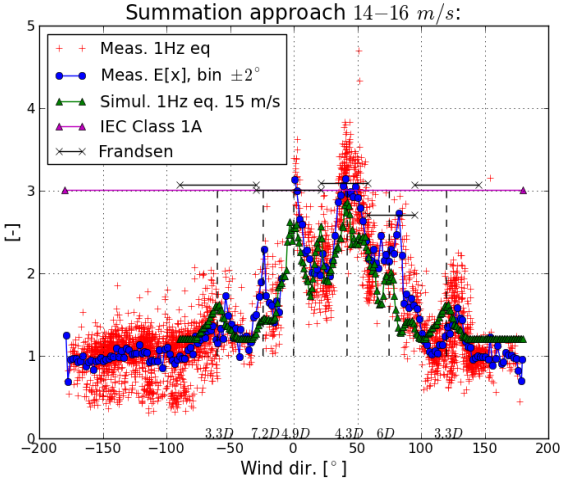

Wake effects may cause significantly increased loads at high wind speeds, even though a single wind turbine here is "aerodynamic transparent"

Larsen TJ, Larsen GC, Aagaard Madsen H, Petersen SM. 2015. Wake effects above rated wind speed. An overlooked contributor to high loads in wind farms. In Scientific Proceedings. EWEA Annual Conference and Exhibition 2015 . European Wind Energy Association (EWEA). pp. 95-99.

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Further turbines simulated with HAWC2 during research projects:

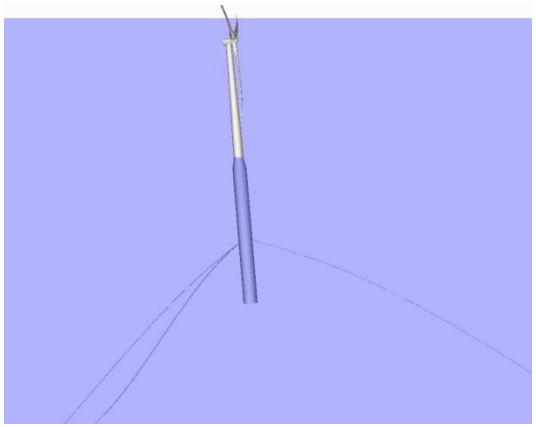
What are the needs?

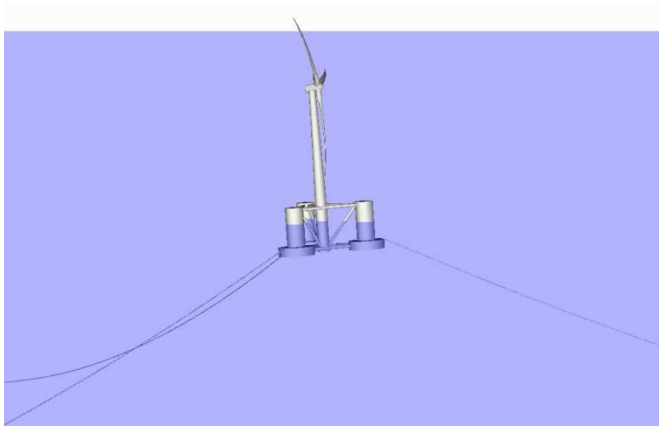
- As simple as possible – as complex as necessary!
- The complex models are used to validate and calibrate simpler engineering models where experiments are not available.
- If several levels are possible within the same code a lot of uncertainty is removed.

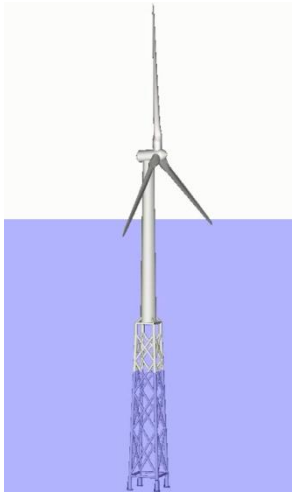
- Ensure stable turbine response – geometric nonlinear effects and blade torsion important for large turbines.
- Ensure correct dynamics up to ~5Hz
- In case of near-resonant operation aero-servo-structural couplings are of key importance (DAMPING, DAMPING, DAMPING!)
- Linear wave loading may not always be sufficient and embedded SF waves are not the answer if fatigue is affected.

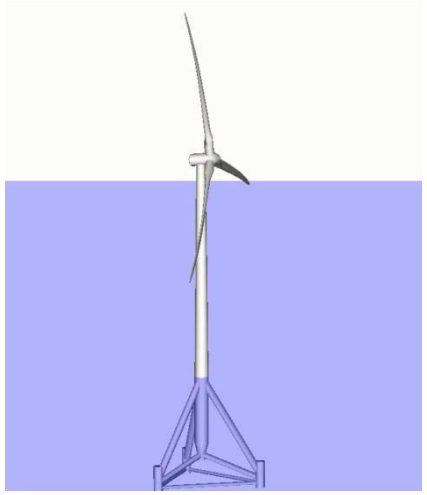
- Simulation speed is always an issue and 10min simulations may be too short for large and especially floating turbines.
- Improved simulation of the installation process may be needed
- Atmospheric stability to be included in site-specific designs

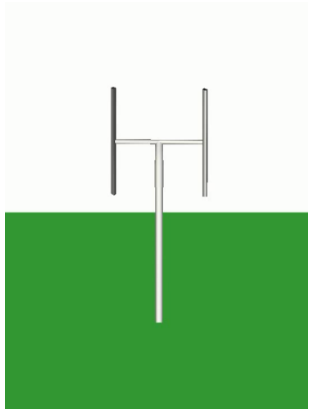
Different concepts investigated with HAWC2

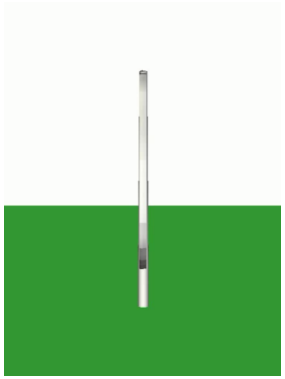






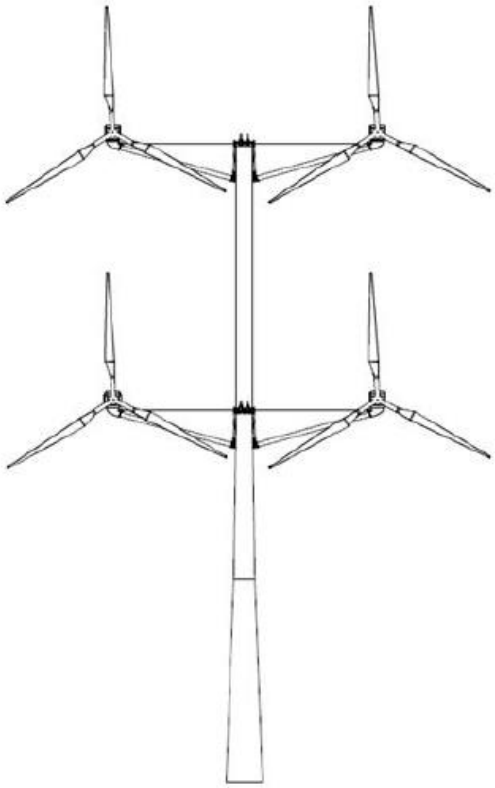






And what about this multi-rotor?

Vestas latest test concept – installed at Risø – Fully simulated with HAWC2



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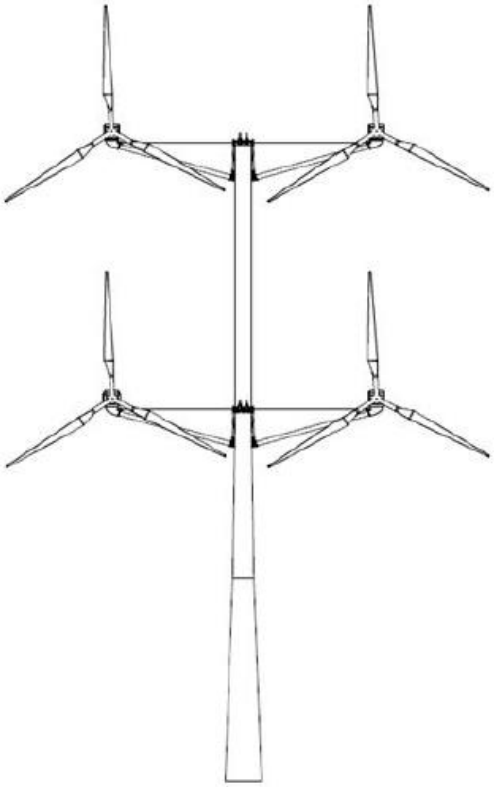

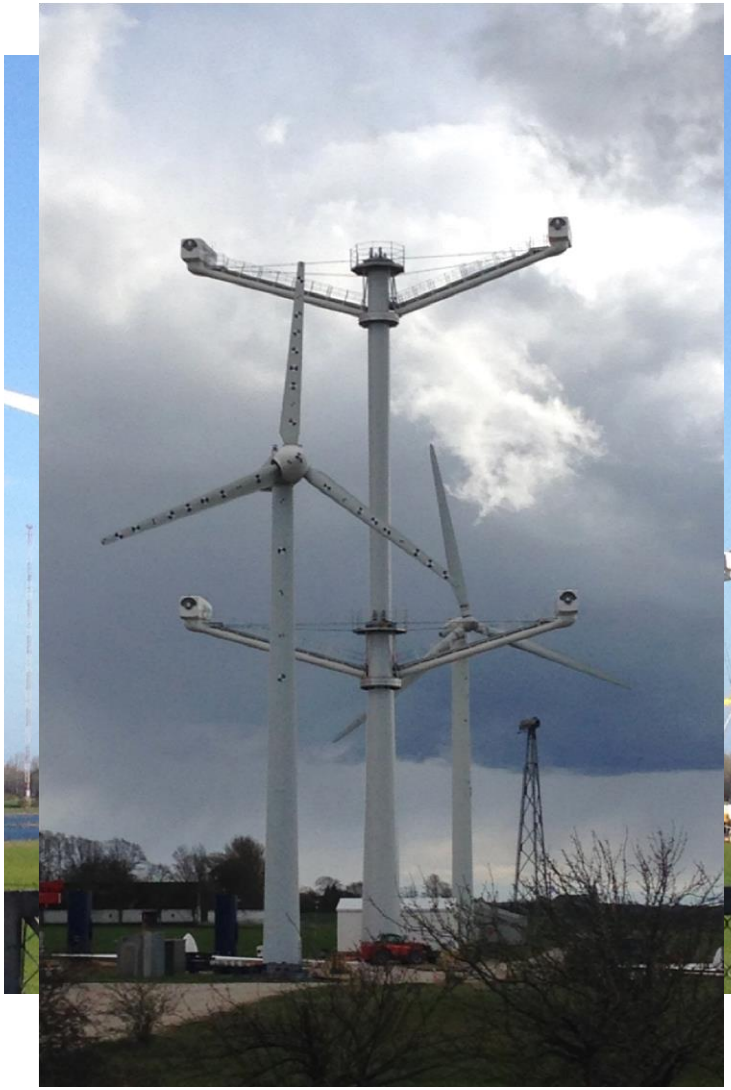

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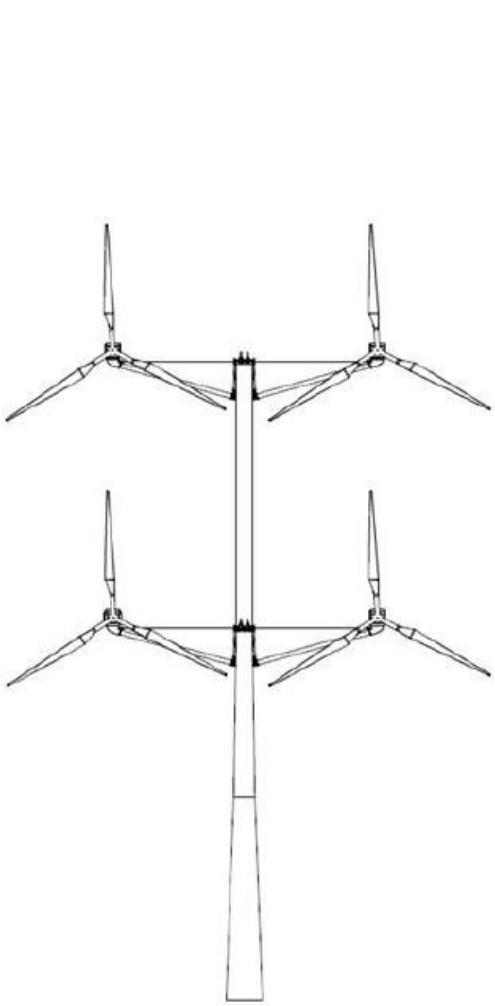

HAWC2 simulation of the Vestas MR